PERANCANGAN DAN PEMBUATAN SISTEM PENGENDALI PERSIGNALAN DAN INTERLOCKING JALUR KERETA API DENGAN MENGGUNAKAN PLC SIEMENS S7-200 DI STASIUN KERETA API BLIMBING - MALANG

SKRIPSI

Disusun oleh :

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03.17.093

KOSENTRASI TEKNIK ELEKTRONIKA
JURUSAN TEKNIK ELEKTRO S-I
FAKULTAS TEKNOLOGI INDUSTRI
INSTITUT TEKNOLOGI NASIONAL MALANG

2008

LEMBAR PERSETUJUAN

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SKRIPSI

Disusun dan diajukan sebagai salah satu syarat untuk memperoleh gelar Sarjana Teknik Elektronika Strata Satu (S-1)

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Masa Bimbingan : 9 Mei 2008 s/d 9 November 2008

Judul Skripsi : Perancangan Dan Pembuatan Sistem Pengendali Persignalan Dan Interlocking Jalur Kereta Api Dengan Menggunakan PLC Siemens S7-200 Di Stasiun Kereta Api Blimbing - Malang

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KATA PENGANTAR

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Malang, Oktober 2008

Penulis

ABSTRAKSI

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Kata Kunci : **Reed switch, interlock, motor weisel, palang signal, dan PLC**

Aplikasi ilmu elektro telah merambah hampir semua ruang lingkup kehidupan manusia yang terindikasi dengan maraknya barang-barang dengan sistem otomatisasi modern. Salah satunya adalah penerapan pada jalur rel kereta api. Sering kita jumpai masih banyak jalur rel kereta api yang terdapat di Indonesia masih menggunakan mechanical interlock yang digunakan untuk mengubah jalur rel kereta api. Selain itu, mechanical interlocknya masih dilakukan oleh operator. Berangkat dari masalah inilah, penulis ingin merancang dan membuat suatu alat yang dapat mendeteksi obyek yang berupa kereta api, dimana alat tersebut akan memberikan referensi data untuk tujuan perancangan jalur kereta api yang aman dan berkualitas.

Alat ini menggunakan detektor berupa reed switch. Reed switch tersebut setiap saat akan mendeteksi apakah ada obyek kereta api yang lewat. Kemudian data yang telah diperoleh akan dimasukkan sebagai inputan bagi PLC (Programmable Logic Control).Setelah data inputan tersebut diproses oleh PLC selanjutnya digunakan untuk menggerakkan motor weisel sebagai interlocknya dan palang signal sebagai outputan dari PLC. Adapun error yang terjadi adalah dimana magnet kurang dekat dengan reed switch sehingga reed switch tidak bekerja dengan maksimal, sedangkan error pada motor weasel dan motor palang signal adalah jalur kereta api dan palang signal yang digerakkan tidak dapat kembali ke kondisi awal.

DAFTAR ISI

DAFTAR GAMBAR

DAFTAR TABEL

بسم الله الرحمن الرحيم

" In The Greatest Name of Allah,

the Majesty of All, the Most Merciful, and Source of world "

1st, me wish to say praise maximum thanks to **Allah SWT** which have given blessing and its it him so that this skripsi can be finished. We thank you for prosperity and health during doing this skripsi. Thank which its. Amieen...

This skripsi is I dedicate special to both my old fellow which during the time have take care of, guiding, & love me so that I can like this time. To all prayer and effort which during this time don't desist him passed to me which I cannot reciprocate besides finished of this skripsi. I thanks you for anything and for my brother, thank you for prayer and its support during the time. I hope you is not naughty again & will become one who proud & super to old fellow.

For special someone (*Riev Piopio Ndut*) beside my which during this time there no its fatigue in supporting, his attention and affection, which have cooked delicious food, thank you for everything euphoria beautiful memory & experience during the time, thanks a lot darling. Me cannot reciprocate you what have give besides progressively love & love you honey.

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♦♥♣♠ END ♠♣♥♦

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BAB I

PENDAHULUAN

1.1. Latar Belakang

Perkembangan teknologi khususnya dibidang industri dewasa ini telah membawa perubahan dan kemajuan bagi peradaban kehidupan manusia, dimana perkembangan teknologi tersebut telah mendorong manusia untuk membuat inovasi baru. Salah satu perkembangan teknologi yang bisa kita temukan yaitu dibidang industri. Perkembangan teknologi industri yang berkembang saat ini adalah peralatan yang mampu beroperasi secara otomatis dengan kinerja yang maksimal. Didalam industri, sangat dibutuhkan sistem kontrol yang baik untuk dapat menunjang proses berjalannya industri tersebut dan untuk meningkatkan efesiensi dalam proses produksi.

Dalam system kontrol dikenal pula istilah PLC (*Programmable Logic Control*). PLC yaitu kendali logika terprogram merupakan suatu piranti elektronik yang dirancang untuk dapat beroperasi secara digital dengan menggunakan memori sebagai media penyimpanan instruksi-instruksi internal untuk menjalankan fungsi-fungsi logika, seperti fungsi pencacah, fungsi urutan proses, fungsi pewaktu, fungsi aritmatika, dan fungsi yang lainnya dengan cara memprogramnya.

Pembuatan program dapat menggunakan komputer sehingga dapat mempercepat hasil pekerjaan. Fungsi lain dari PLC yaitu dapat digunakan untuk memonitor jalannya proses pengendalian yang sedang berlangsung, sehingga dapat dengan mudah dikenali urutan kerja (*work sequence*) proses pengendalian yang terjadi pada saat itu.Pada saat sekarang ini pemanfaatan teknologi canggih sudah merupakan kebutuhan yang utama di semua bidang. Hal ini dimaksudkan untuk mencapai suatu hasil yang lebih baik dengan efesiensi yang lebih tinggi. Adapun pengaplikasian teknologi adalah sebagai suatu sistem pengontrolan pada suatu bidang yang menggunakan teknologi.

Salah satu contoh pengaplikasiannya adalah pada bidang perkereta apian. Dimana PLC dapat digunakan untuk mengatur interlocking pada jalur kereta api. Dengan adanya pengontrollan yang menggunakan PLC maka akan membuat efesiensi dan terotomasisasi sistemnya dibandingkan dengan menggunakan mechanical interlocking.

Karenanya penulis bermaksud ingin membuat suatu sistem interlocking dengan PLC pada jalur kereta api. Hal ini dikarenakan pada saat sekarang ini masih banyak stasiun-stasiun yang masih menggunakan mechanical interlocking, terutama pada stasiun-stasiun kecil yang tersebar pada daerah kota besar. Dimana hal ini nantinya dapat meningkatkan mutu dari perkereta apian yang ada saat ini. Dan juga dapat mempermudah untuk memahami dari suatu sistem yang ada pada perkereta apian tersebut.

1.2. Perumusan Masalah

Berdasarkan hal tersebut diatas maka dalam hal ini yang terpenting adalah bagaimana membuat desain sebuah sistem yang dapat bekerja dengan handal pada saat normal ataupun ada gangguan. Oleh karena itu penggunaan PLC atau peran dari PLC sendiri akan berpengaruh besar sebagai pengontrol untuk menjalankan proses interlocking pada jalur kereta api ini. Berdasarkan permasalahan tersebut, maka skripsi ini diberi judul :

"PERANCANGAN DAN PEMBUATAN

SISTEM PENGENDALI PERSIGNALAN DAN INTERLOCKING

JALUR REL KERETA API DENGAN MENGGUNAKAN

PLC SIEMENS S7-200

DI STASIUN KERETA API BLIMBING- MALANG"

1.3. Tujuan

Adapun tujuan yang ingin dicapai dalam perancangan dan pembutan alat ini adalah sebagai berikut :

- Merancang suatu sistem unit electrical interlocking baik hadware maupun software dalam bentuk prototype

1.4. Batasan Masalah

Untuk mencapai tujuannya secara maksimal, maka diperlukan batasan masalah yang diharapkan agar permasalahan tidak meluas dan tetap terfokus pada tujuan utama. Adapun batasan-batasan masalah pada skripsi ini yaitu :

- o Skripsi ini membahas cara kerja dari pengendali persignalan dan interlocking pada jalur kereta api
- o Hanya membahas pengubah jalur dan palang signal kereta api
- o Tidak membahas mengenai kecepatan dan jadwal kereta api
- o Tidak membahas desain perangkat keras PLC (Programmable Logic Control)

- Tidak membahas catu daya yang digunakan
- PLC yang digunakan SIEMENS type S-7200
- Perangkat lunak yang digunakan Micro Win V3.2

1.5. Metodologi Pembahasan

Dalam melaksanakan penulisan skripsi ini metodologi sebagai berikut :

a. Studi literatur

Mempelajari teori-teori yang terkait melalui literatur yang telah ada, yang berhubungan dengan pembahasan masalah.

b. Perencanaan dan pembuatan alat

Membuat digram blok rangkaian yang sesuai dengan rencana kerja, yang kemudian direalisasikan dengan masalah perencanaan dan pembuatan berdasarkan diagram blok rangkaian yang telah disusun.

c. Studi analisa alat

Dimaksudkan untuk melakukan analisa dan pengujian alat yang telah dirancang apakah sesuai antara fungsi dengan kerja yang diharapkan.

d. Pengambilan Kesimpulan

Dilakukan setelah mendapatkan hasil dari perancangan dan pengujian alat. Jika hasil yang diperoleh telah sesuai dengan sfesifikasi yang ditentukan saat dilakukan perancangan, berarti alat tersebut telah dianggap selesai dan sesuai dengan harapan.

e. Penyusunan buku laporan

Bertujuan untuk menyusun data laporan yang berpedoman pada alat yang telah selesai dibuat beserta kesimpulan dan cara kerja alat.

1.6. Sistemaika Penulisan

Pembahasan dalam Skripsi ini akan diuraikan dalam lima bab, yang penjabarannya adalah sebagai berikut :

Bab I : PENDAHULUAN

Membahas tentang latar belakang, rumusan masalah, tujuan, metodologi pembahasan dan sistematika pembahasan yang akan dipaparkan dalam skripsi ini.

Bab II : LANDASAN TEORI

Membahas tentang berbagai macam teori yang mendukung dalam pengendalian persignalan dan interlocking jalur kereta api sebagai objek yang akan dikendalikan dengan menggunakan PLC.

Bab III : PERENCANAAN DAN PEMBUATAN ALAT

Membahas tentang proses kerja pengendalian persignalan dan interlocking jalur kereta api yang digunakan untuk mendeteksi suatu objek dengan menggunakan PLC.

Bab IV : PENGUJIAN SISTEM

Membahas tentang pengujian terhadap pengendali persignalan dan interlocking jalur kereta api setelah diimplementasikan PLC didalamnya.

Bab V : PENUTUP

Merupakan bagian akhir dari laporan yang terdiri dari kesimpulan dan saran.

BAB II

LANDASAN TEORI

Dalam merancang dan menganalisa suatu rangkaian elektronika diperlukan pemahaman tentang teori-teori dasar yang menunjang sebagai bahan acuan dalam merencanakan suatu sistem. Bab ini menjelaskan tentang pembahasan komponen penunjang yang harus dipahami untuk pembahasan selanjutnya.

2.1. Pengenalan PLC

Pada awalnya, sistem kontrol industri menggunakan cara konvensional yaitu dengan sistem sambungan menggunakan beberapa komponen seperti timer, relay, counter dan kontaktor.

Generasi selanjutnya, sistem kontrol industri sudah menggunakan mikroprocessor dengan bahasa pemrograman assembler.

PLC pertama kali digunakan pada tahun 1968-an, yaitu pada saat tuntutan automatisasi industri semakin besar. Perusahaan yang pertama kali merealisasikan kriteria rancangan PLC adalah General Motors (GM), meskipun hanya berupa sekuensial kontrol, tidak seperti PLC yang dikenal sekarang, mampu untuk menangani pengendalian proses – proses yang kompleks, seperti temperatur, posisi, tekanan, aliran. Bahkan modul – modul dengan kemampuan yang telah dikembangkan lebih lanjut.

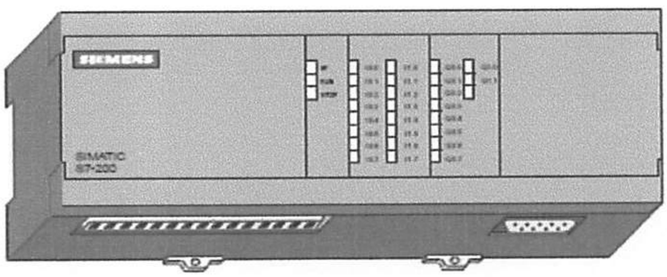
Secara definisi, Programmable Logic Controller (PLC) adalah suatu rangkaian micro controller yang terdiri dari beberapa bagian, yaitu CPU, Memory, Data Register, Internal relay, Input / Output Counter dan Timer yang terintegrasi dalam satu perangkat.

2.1.1. Beberapa manfaat dalam penggunaan PLC dalam industri :

- Penghematan komponen seperti timer, relay dan counter.
- Tidak memerlukan pekerjaan wiring kabel yang rumit.
- Kecepatan respon yang tinggi dan efisinesi.
- Mudah untuk modifikasi system.
- Dapat digunakan untuk system yang kompleks (MMI atau HMI) dan dapat di komunikasikan antar PLC.

2.1.2. Bentuk dan Spesifikasi dari PLC Siemens Tipe S7-200 CPU 214 yaitu :

a. Bentuk



Gambar 2.1 : Bentuk dari PLC Siemens S7-200 CPU 214

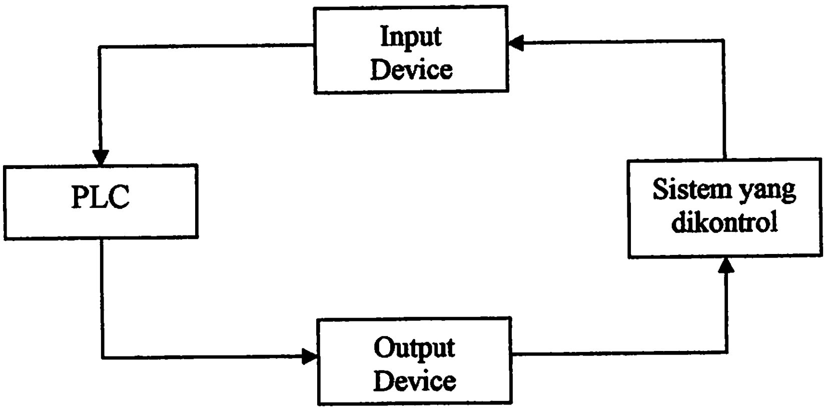
b. Spesifikasi dari PLC Siemens S7-200 CPU 212, CPU 214, CPU 215, CPU 216, adalah sebagai berikut:

Feature	CPU 212	CPU 214	CPU 215	CPU 216
Physical Size of Unit	160 mm x 80 mm x 62 mm	197 mm x 80 mm x 62 mm	218 mm x 80 mm x 62 mm	218 mm x 80 mm x 62 mm
Memory				
Program (EEPROM)	512 words	2 Kwords	4 Kwords	4 Kwords
User data	512 words	2 Kwords	2.5 Kwords	2.5 Kwords
Internal memory bits	128	256	256	256
Memory cartridge	None	Yes (EEPROM)	Yes (EEPROM)	Yes (EEPROM)
Optional battery cartridge	None	200 days typical	200 days typical	200 days typical
Backup (super capacitor)	50 hours typical	190 hours typical	190 hours typical	190 hours typical
Inputs/Outputs (I/O)				
Local I/O	8 DI / 6 DQ	14 DI / 10 DQ	14 DI / 10 DQ	24 DI / 16 DQ
Expansion modules (max.)	2 modules	7 modules	7 modules	7 modules
Process-image I/O register	64 DI / 64 DQ	64 DI / 64 DQ	64 DI / 64 DQ	64 DI / 64 DQ
Analog I/O (expansion)	16 AI / 16 AQ	16 AI / 16 AQ	16 AI / 16 AQ	16 AI / 16 AQ
Selectable input filters	No	Yes	Yes	Yes
Instructions				
Boolean execution speed	1.2 µs/instruction	0.8 µs/instruction	0.8 µs/instruction	0.8 µs/instruction
Counters / timers	64/64	128/128	256/256	256/256
For / next loops	No	Yes	Yes	Yes
Integer math	Yes	Yes	Yes	Yes
Real math	No	Yes	Yes	Yes
PID	No	No	Yes	Yes
Additional Features				
High-speed counter	1 S/W	1 S/W, 2 H/W	1 S/W, 2 H/W	1 S/W, 2 H/W
Analog adjustments	1	2	2	2
Pulse outputs	None	2	2	2
Communication interrupt events	1 transmit/ 1 receive	1 transmit/1 receive	1 transmit/2 receive	2 transmit/4 receive
Timed interrupts	1	2	2	2
Hardware input interrupts	1	4	4	4
Real time clock	None	Yes	Yes	Yes
Communications				
Number of comm ports:	1 (RS-485)	1 (RS-485)	2 (RS-485)	2 (RS-485)
Protocols supported Port 0: Port 1:	PPI, Freeport N/A	PPI, Freeport N/A	PPI, Freeport, MPI DP, MPI	PPI, Freeport, MPI PPI, Freeport, MPI
Peer-to-peer	Slave only	Yes	Yes	Yes

Tabel 2.1 : Spesifikasi PLC Siemens Tipe S7-200

2.1.3. Prinsip kerja PLC :

Prinsip kerja PLC secara singkat dapat ditunjukkan seperti pada gambar berikut :



Gambar 2.2 : Diagram Blok Prinsip Kerja PLC [12]

PLC dapat menerima data berupa sinyal analog dan digital dari komponen input device. Sinyal dari sinyal input device dapat berupa saklar-saklar, tombol-tombol tekan, peralatan pengindera dan peralatan sejenisnya.

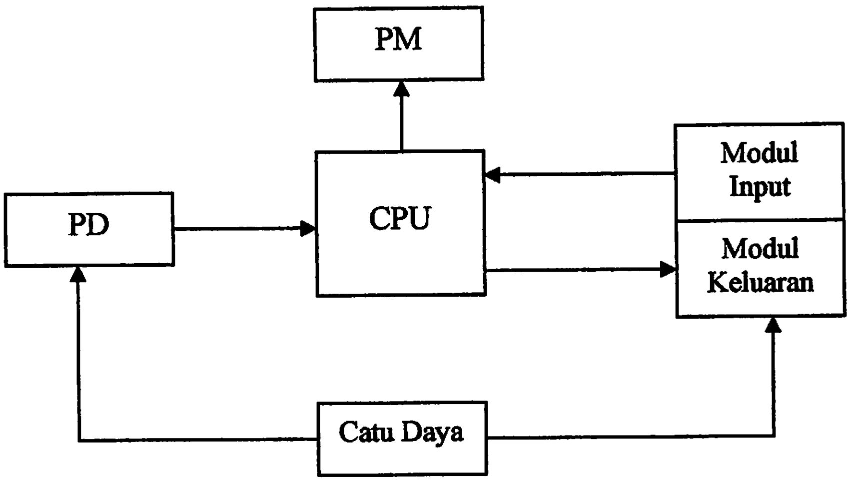
PLC juga dapat menerima sinyal analog dan input device yang berupa potensiometer, putaran motor dan peralatan sejenisnya. Sinyal analog ini oleh modul masukan dirubah menjadi sinyal digital.

Central Processing Unit (CPU) mengolah sinyal digital yang masuk sesuai dengan program yang telah dimasukkan. Selanjutnya CPU mengambil keputusan-keputusan yang berupa sinyal dengan logika High (1) dan Low (0). Sinyal keluaran ini dapat langsung dihubungkan ke peralatan yang akan dikontrol atau dengan bantuan kontaktor untuk mengaktifkan peralatan yang akan dikontrol.

2.1.4. Bagian-bagian dari PLC

Pada prinsipnya, bagian-bagian dari PLC terdiri dari CPU (Central Processing Unit), PM (Programming Memory), PD (Programming Device), modul masukan keluaran (I / O) dan Catu Daya..

♦ **Diagram Blok Koordinasi Bagian-Bagian PLC :**



Gambar 2.3 : Diagram Blok Koordinasi Bagian PLC

Fungsi masing-masing adalah sebagai berikut :

1. **Central Processing Unit (CPU)**

CPU berfungsi untuk mengambil instruksi dari memory, mendekadekannya dan kemudian mengeksekusi instruksi tersebut. Selama proses tersebut CPU akan menghasilkan sinyal kendali, mengalihkan data ke bagian masukan atau keluaran dan sebaliknya, melakukan fungsi aritmatika dan logika juga mendeteksi sinyal luar CPU.

2. **Programming Memory (PM)**

PM adalah bagian yang berfungsi untuk menyimpan instruksi, program dan data. Program pada PLC ini dapat dilakukan dengan cara mengetik pada papan ketik (keyboard) yang sesuai dengan masing-masing PLC. Papan ketik ini sering juga disebut dengan Programming Device.

3. **Programming Device**

PD disebut juga Programming Device Terminal (PDT), adalah suatu perangkat yang digunakan untuk mengedit, masukkan, memodifikasi dan memantau program yang ada didalam memori PLC. Bagian-bagian dari PDT adalah monitor dan papan ketik (keyboard).

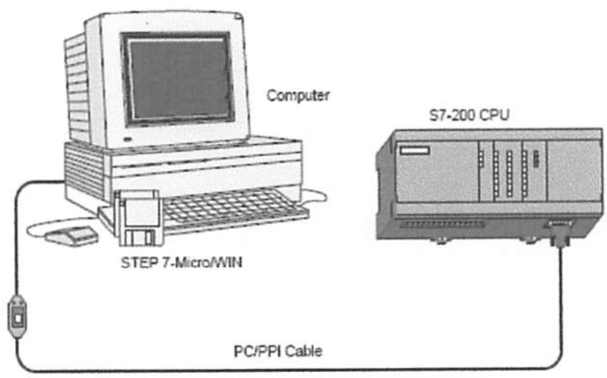
Dalam PLC ada tiga jenis Programming Device yaitu :

a. Special Purpose adalah perangkat Programming Device sejenis dengan computer yang khusus digunakan untuk pemrograman PLC.
b. Keypad adalah peralatan sejenis dengan kalkulator yang khusus digunakan untuk pemrograman PLC.
c. Personal Computer (PC) adalah perangkat Programming Device yang digunakan dalam pemrograman PLC dengan menggunakan computer peribadi.

4. Modul Input / Output

Modul masukan atau keluaran adalah suatu peralatan atau perangkat elektronika yang berfungsi sebagai perantara atau penghubung (Interface) antara CPU dengan peralatan masukan / keluaran luar.Modul ini terpasang secara tidak permanen atau mudah untuk dilepas dan dipasang kembali.

- Contoh gambar dari PLC yang dihubungkan ke PC :

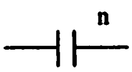


Gambar 2.4 : PLC yang dihubungkan ke PC

2.1.5. Cara memprogram PLC :

PLC dapat diprogram dengan dua cara yaitu dengan menggunakan Handy Programmer atau dengan menggunakan Personal Computer melalui software khusus. Metoda programnya menggunakan program yang berbentuk Ladder atau Statement List. Dimana didalamnya terdapat instruksi-instruksi sebagai berikut :

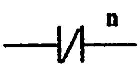
- *Normally Open contact*

  Symbol : 

  Operand : n (bit) = I, Q, M, SM, S, T, C, V

  Deskripsi : Kontak normally open akan tertutup apabila terbacanya nilai bit yang tersimpan di alamat n adalah "1". Power akan mengalir melalui kontak normally open ketika tertutup (sedang aktif).

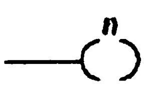
- *Normally Closed contact*

  Symbol : 

  Operand : n (bit) = I, Q, M, SM, S, T, C, V

  Deskripsi : Kontak normally closed akan tertutup apabila terbacanya nilai bit yang tersimpan di alamat n adalah "0". Power akan mengalir melalui kontak normally closed ketika tertutup (sedang aktif).

- *Output Coils*

  Symbol : 

  Operand : n (bit) = I, Q, M, SM, S, T, C, V

Deskripsi : Output coils akan menyala (aktive) dan bit yang disimpan pada alamat n akan di set ke "1" ketika aliran power menuju ke coils.

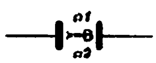
- *Invert Power Flow contact*

Symbol : NOT —|NOT|—

Operand : tidak mempunyai operand

Deskripsi : Kontak NOT (pembalik aliran power) mengubah keadaan aliran power. Jika aliran power mencapai kontak NOT, aliran power akan berhenti. Jika aliran power tidak mencapai kontak NOT, akan menjadikan sumber aliran power.

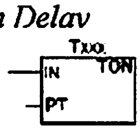
- *Comparator Byte ">=" contact*

Symbol : 

Operand : n1, n2 (unsigned byte) : VB, IB, QB, MB, SMB, SB, AC, Constant, *VD, *AC

Deskripsi : Kontak Komparator Byte ">=" akan tertutup apabila nilai byte yang tersimpan di alamat n1 lebih besar atau sama dengan nilai byte yang tersimpan dialamat n2. Dan power akan mengalir melalui kontak letika tertutup.

- *Timer – On Delav*

Symbol : 

Operand : Txxx word = CPU 212 : 32 – 63

CPU 214 : 32 – 63 ; 96 -127

CPUs 215. 216 : 32 – 63 : 96 – 255

PT (word) = VW, IW, QW, MW, SW, SMW, LW, AIW, AQC, Constant, *VD, *LD, *AC

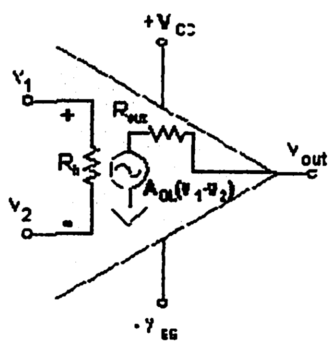
Deskripsi : Kontak ON – Delay Timer (TON) akan menghitung maik ke nilai maksimum ketika input (IN) aktif (menyala). Ketika nilai Txx lebih besar atau sama dengan (>=) Preset Time (PT), bit timer akan aktif (on). Dan akan reset apabila input (IN) mati (off). Timer akan berhenti apabila mencapai nilai maksimum.

2.2. OPERASIONAL AMPLIFIER (OP-AMP)

2.2.1. Teori

- **Penguat Diferensial Sebagai Dasar Penguat Operasional**

Adapun simbol dari penguat differensial itu sendiri, dapat dilihat seperti pada gambar berikut :

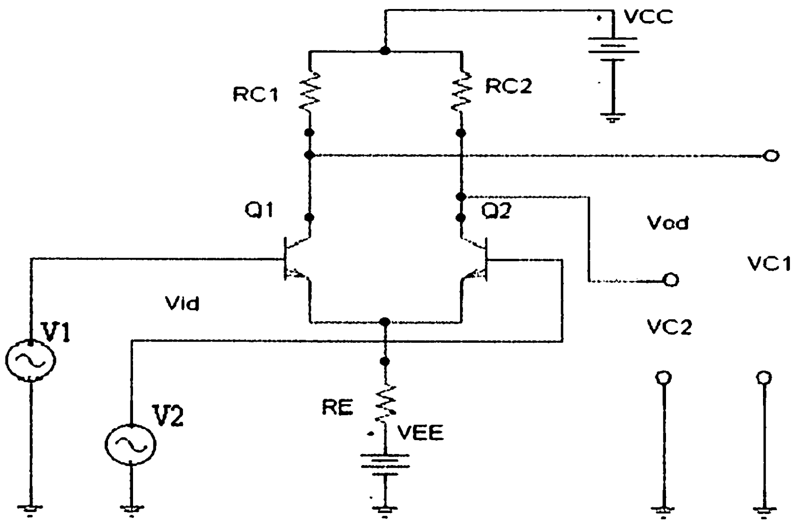


Gambar 2.5 : Simbol dari Op-Amp

Simbol op-amp pada gambar diatas dengan 2 input, *non-inverting* (+) dan input *inverting* (-). Umumnya op-amp bekerja dengan *dual supply* (+V_{cc} dan –V_{ee})

namun banyak juga op-amp dibuat dengan *single supply* (V_{cc} – *ground*). Simbol rangkaian di dalam op-amp pada gambar diatas adalah parameter umum dari sebuah op-amp. R_{in} adalah resitansi input yang nilai idealnya infinit (tak terhingga). R_{out} adalah resistansi output dan besar resistansi idealnya 0 (nol). Sedangkan A_{OL} adalah nilai penguatan open loop dan nilai idealnya tak terhingga.

Penguat diferensial adalah suatu penguat yang bekerja dengan memperkuat sinyal yang merupakan selisih dari kedua masukannya. Berikut ini adalah gambar skema dari penguat diferensial sederhana:



Gambar 2.6 : Penguat diferensial sederhana

hal ini disebabkan karena :

$$I_{B1} = I_{B2} \quad (2.2\text{-}1)$$

sehingga : $I_{C1} = I_{C2}$ dan $I_{E1} = I_{E2}$, karena itu tegangan keluaran $V_{C1} = V_{C2}$ (harganya sama), sehingga $V_{od} = 0$.

Apabila terdapat perbedaan antara sinyal V_1 dan V_2, maka :

$$V_{id} = V_1 - V_2 \qquad \text{(2.2-2)}$$

Hal ini akan menyebabkan terjadinya perbedaan antara I_{B1} dan I_{B2}. Dengan begitu harga I_{C1} berbeda dengan I_{C2}, sehingga harga V_{od} meningkat sesuai sesuai dengan besar penguatan Transistor.

Untuk memperbesar penguatan dapat digunakan dua tingkat penguat diferensial (*cascade*). Keluaran penguat diferensial dihubungkan dengan masukan penguat diferensial tingkatan berikutnya. Dengan begitu besar penguatan total (A_d) adalah hasil kali antara penguatan penguat diferensial pertama (V_{d1}) dan penguatan penguat diferensial kedua (V_{d2}).

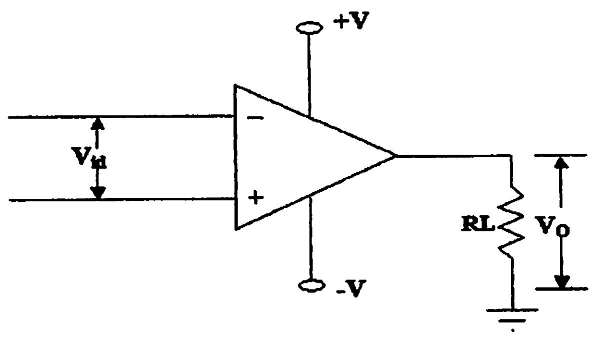
Dalam penerapannya, penguat diferensial lebih disukai apabila hanya memiliki satu keluaran. Jadi yang digunakan adalah tegangan antara satu keluaran dan bumi (*ground*). Untuk dapat menghasilkan satu keluaran yang tegangannya terhadap bumi (*ground*) sama dengan tegangan antara dua keluaran (Vod), maka salah satu keluaran dari penguat diferensial tingkat kedua di hubungkan dengan suatu pengikut emitor (*emitter follower*).

Untuk memperoleh kinerja yang lebih baik, maka keluaran dari pengikut emiter dihubungkan dengan suatu konfigurasi yang disebut dengan *totem-pole*. Dengan menggunakan konfigurasi ini, maka tegangan keluaran X dapat berayun secara positif hingga mendekati harga VCC dan dapat berayun secara negatif hingga mendekati harga VEE.

Apabila seluruh rangkaian telah dihubungkan, maka rengkaian tersebut sudah dapat dikatakan sebagai penguat operasional (*Operational Amplifier* (Op Amp)).

Penguat Operasional

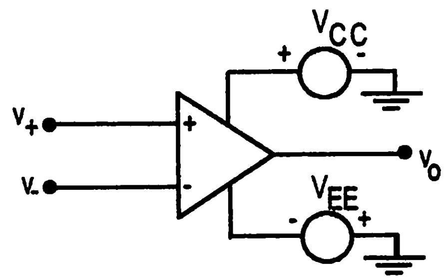
Penguat operasional (Op Amp) adalah suatu rangkaian terintegrasi yang berisi beberapa tingkat dan konfigurasi penguat diferensial yang telah dijelaskan di atas. Penguat operasional memilki dua masukan dan satu keluaran serta memiliki penguatan DC yang tinggi. Untuk dapat bekerja dengan baik, penguat operasional memerlukan tegangan catu yang simetris yaitu tegangan yang berharga positif $(+V)$ dan tegangan yang berharga negatif $(-V)$ terhadap tanah (*ground*). Berikut ini adalah simbol dari penguat operasional :



Gambar 2.7 : Simbol penguat Operasional

Dasar-dasar Penguat Operasional

Penguat operasional (opamp) adalah suatu blok penguat yang mempunyai dua masukan dan satu keluaran. Opamp biasa terdapat di pasaran berupa rangkaian terpadu (*integrated circuit*- IC).



Gambar 2.8 : Rangkaian Dasar Penguat Operasional

Gambar 2.8 menunjukkan sebuah blok opamp yang mempunyai berbagai tipe dalam bentuk IC. Dalam bentuk paket praktis IC seperti tipe 324 hanya berharga beberapa ribu rupiah. Seperti terlihat pada gambar 2.8 , opamp memiliki masukan tak membalik *v+* (*non-inverting*), masukan membalik *v-* (*inverting*) dan keluaran *vo*. Jika isyarat masukan dihubungkan dengan masukan membalik (*v-*), maka pada daerah frekuensi tengah isyarat keluaran akan "berlawanan fase" (berlawanan tanda dengan isyarat masukan). Sebaliknya jika isyarat masukan dihubungkan dengan masukan tak membalik (*v+*), maka isyarat keluaran akan "sefase". Sebuah opamp biasanya memerlukan catu daya ± 15 V. Dalam menggambarkan rangkaian hubungan catu daya ini biasanya dihilangkan. Data keadaan ideal opamp dan kinerja IC LM 324 seperti terlihat pada tabel 2.2.

Idealnya, jika kedua masukan besarnya sama, maka keluarannya akan berharga nol dan tidak tergantung adanya prubahan sumber daya, yaitu :

$$v_o = A(v_+ - v_-) \qquad \text{.........(2.2-3)}$$

dimana *A* berharga sangat besar dan tidak tergantung besarnya beban luar yang terpasang.

Tabel 2.2. Sifat Ideal Dan Data Yang Sebenarnya Dari Opamp IC LM 324

Parameter	D a t a	Harga Ideal
tegangan ofset masukan, V_{io}	2 mV	0
arus ofset masukan, I_{io}	20 nA	0
arus panjar masukan, I_B	80 nA	0
nisbah penolakan modus bersama (CMRR), ρ	90 dB	ω
pergeseran dari I_{io}	1 nA/°C	0
pergeseran dari V_{io}	25 μV/°C	0
frekuensi penguatan-tunggal (*unity-gain frequency*)	1 MHz	∞
bandwidth daya-penuh	10 kHz	∞
penguatan diferensial lingkar terbuka, A	105 dB	∞
hambatan keluaran lingkar terbuka, R_o	75 Ω	0
hambatan keluaran lingkar tertutup, R_i	2 M	∞

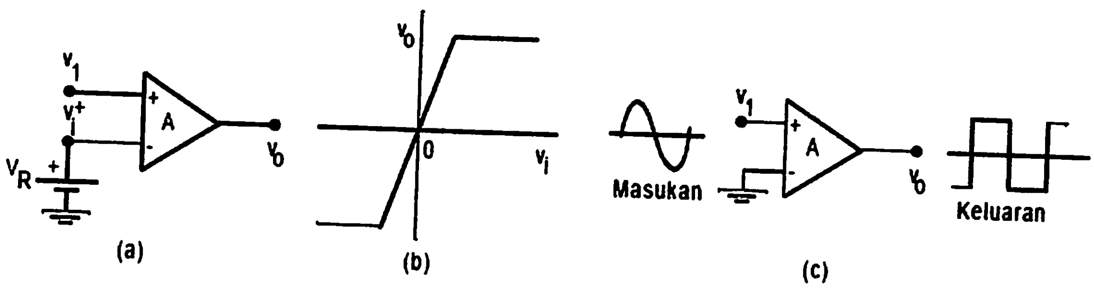
Keterangan :

* Tegangan ofset masukan (*input offset voltage*) Vio menyatakan seberapa jauh *v*+ dan *v*- terpisah untuk mendapatkan keluaran 0 volt.
* Arus offset masukan (*input offset current*) menyatakan kemungkinan seberapa berbeda kedua arus masukan.
* Arus panjar masukan (*input bias current*) memberi ukuran besarnya arus basis (masukan).
* Harga CMRR menjamin bahwa output hanya tergantung pada (*v*+) - (*v*-), walaupun *v*+ dan *v*- masing-masing berharga cukup tinggi.

Untuk menghindari keluaran yang berosilasi, maka frekuensi harus dibatasi, *unity gain frequency* memberi gambaran dari data tanggapan frekuensi. Ini hanya berlaku untuk isyarat-kecil saja karena untuk isyarat yang besar penguat mempunyai keterbatasan nilai dv_0/dt sehingga keluaran bentuk-penuh hanya dihasilkan pada frekuensi yang relatif rendah.

- **Komparator (*Comparator*)**

Pada gambar 2.9a, jika tegangan masukan 1 *v* lebih besar dari tegangan referensi *R V* , tegangan keluaran *o v* akan berharga positif. Karena harga penguatan sangat besar maka perbedaan tegangan yang relatif kecil akan membawa penguat pada "daerah jenuh". Karakteristik transfer menunjukkan bahwa sedikit penurunan pada v_i (milivolt) akan membawa opamp dari jenuh positif ke jenuh negatif (lihat gambar 2.9b). Jika $V_R = 0$ volt, ini akan menjadi *zero-crossing comparator*. Komparator jenis ini dapat digunakan untuk mengubah isyarat AC menjadi gelombang kotak dengan operasi pemotongan (*clipper*) seperti terlihat pada gambar 2.9c.



Gambar 2.9 : Aplikasi Nonlinier Opamp :

a) Komparator b) Karakteristik Transfer Dan c) Operasi Pemotongan (*Clipper*).

2.3.Resistor

Pada umumnya resistor adalah komponen elektronika yang dapat menghambat gerak lajunya arus listrik. Resistor dapat disingkat dengan huruf "R" dengan satuan ohm. Kemampuan resistor untuk menghambat disebut juga resistansi atau hambatan listrik. Suatu resistor dikatakan memiliki hambatan 1 Ohm apabila resistor tersebut menjembatani beda tegangan sebesar 1 Volt dan arus listrik yang timbul akibat tegangan tersebut adalah sebesar 1 ampere, atau sama dengan sebanyak 6.241506×10^{18} elektron per detik mengalir menghadap arah yang berlawanan dari arus.Hubungan antara hambatan, tegangan, dan arus, dapat disimpulkan melalui hukum berikut ini, yang terkenal sebagai hukum Ohm:

$$R = \frac{V}{I}$$

di mana V adalah beda potensial antara kedua ujung benda penghambat, I adalah besar arus yang melalui benda penghambat, dan R adalah besarnya hambatan benda penghambat tersebut.

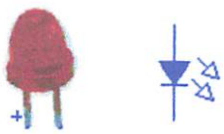
♣ **Berdasarkan penggunaanya, resistor dapat dibagi menjadi 4**:

1. **Resistor Biasa** (tetap nilainya), ialah sebuah resistor penghambat gerak arus, yang nilainya tidak dapat berubah, jadi selalu tetap (konstan). Resistor ini biasanya dibuat dari nikelin atau karbon.
2. **Resistor Berubah** (*variable*), ialah sebuah resistor yang nilainya dapat berubah-ubah dengan jalan menggeser atau memutar *toggle* pada alat tersebut. Sehingga nilai resistor dapat kita tetapkan sesuai dengan kebutuhan. Berdasarkan jenis ini kita bagi menjadi dua, **Potensiometer**, rheostat dan **Trimpot** (*Trimmer Potensiometer*) yang biasanya menempel pada papan rangkaian (*Printed Circuit Board*, PCB).

3. **Resistor NTC** dan **PTS**, NTC (*Negative Temperature Coefficient*), ialah Resistor yang nilainya akan bertambah kecil bila terkena suhu panas. Sedangkan PTS (*Positife Temperature Coefficient*), ialah Resistor yang nilainya akan bertambah besar bila temperaturnya menjadi dingin.
4. **LDR** (*Light Dependent Resistor*), ialah jenis Resistor yang berubah hambatannya karena pengaruh cahaya. Bila cahaya gelap nilai tahanannya semakin besar, sedangkan cahayanya terang nilainya menjadi semakin kecil.

2.4. Light Emmiting Dioda (LED)

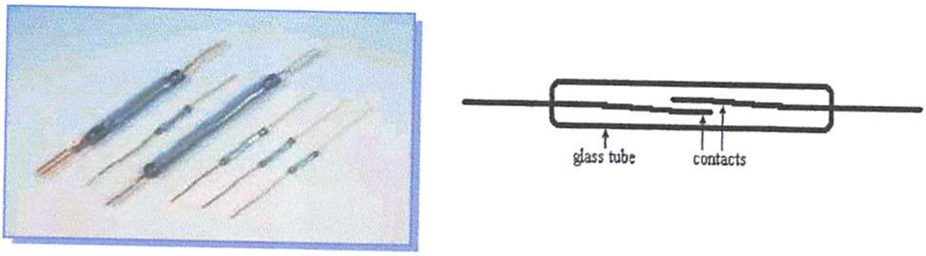
LED ini digunakan sebagai tampilan deteksi, yang mana akan dipasang bersebelahan dengan jalur yang terdapat reed switch. LED ini akan bercahaya bila ada obyek yang sedang melalui reed switch dan kemudian diteruskan ke LED, sehingga dapat menampilkan jalur yang dilalui oleh obyek.



Gambar 2.10 : Simbol LED

2.5. Reed Switch

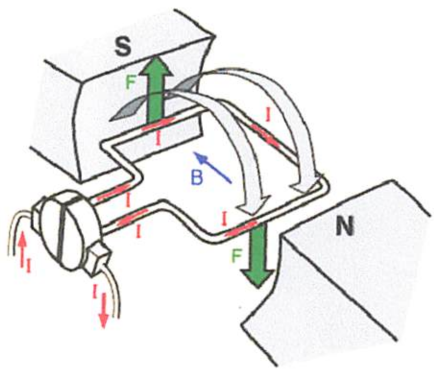
Reed Switch ini digunakan sebagai pendeteksi, yang mana akan dipasang dibeberapa titik pada jalur kereta api. Reed Switch ini akan memberi input bila ada obyek yang melewatinya dengan berupa sinyal magnetik, sehingga mampu mendeteksi obyek tersebut.



Gambar 2.11 : Reed Switch

2.6. Motor DC

Motor DC adalah peralatan elektromekanis yang mengubah daya listrik menjadi daya mekanis dengan arus searah sebagai suplai energi listriknya. Motor DC terdiri dari dua bagian dasar yaitu stator dan rotor. Stator merupakan bagian dari motor DC yang tidak bergerak sedangkan rotor merupakan bagian yang bergerak. Pada skripsi ini motor DC yang digunakan adalah 12 V, yang mana motor DC ini akan berfungsi sebagai penggerak motor signal.



Gambar 2.12

Interaksi Antara Medan Magnet Dan Penghantar Yang Dialiri Arus

Sumber: www.HyperPhysics.com

Gaya yang dihasilkan sebesar: *(Cathey, 2001:50)*

$$F = B.I.l \quad \text{...} \quad (2.6\text{-}1)$$

Gaya itu menimbulkan torsi sebesar:

$$T = F.r \qquad (2.6\text{-}2)$$

$$T = B.I.l.r \qquad (2.6\text{-}3)$$

dengan:

F = Gaya (N).

B = Rapat fluks (T).

I = Arus yang mengalir pada penghantar (A).

l = Panjang penghantar (m).

r = Jari-jari inti jangkar (m).

T = Torsi (Nm).

Jangkar memiliki jumlah penghantar dan cabang paralel penghantar sehingga dari Persamaan *(2.6-2)* dan *(2.6-3)* didapatkan:

$$T = \frac{Z}{a} B.I_a.l.r \qquad (2.6\text{-}4)$$

dengan:

Z = Jumlah penghantar jangkar.

a = Jumlah cabang paralel penghantar jangkar yang berada di antara sikat.

I_a = Arus jangkar (A).

Rapat fluks yang dihasilkan sebesar:

$$B = \frac{\phi.p}{2\pi.r.l} \qquad (2.6\text{-}5)$$

Jika Persamaan *(2.6-5)* diberikan ke Persamaan *(2.6-4)* didapatkan:

$$T = \frac{z}{a} B.I_a.l.r = \frac{z}{a} \frac{\phi.p}{2\pi.r.l} B.I_a.l.r$$

maka akan didapatkan nilai T sebesar :

$$T = \frac{p.Z}{2\pi.a}.\phi.I_a \quad \text{.......}(2.6\text{-}6)$$

Dimana telah diketahui bahwa besarnya nilai K pada motor DC sebagai berikut :

$$K = \frac{p.z}{2\pi.a}$$

Sehingga persamaan *(2.6)* dapat ditulis juga sebagai berikut :

$$T = K.\phi.I_a \quad \text{.......}(2.6\text{-}7)$$

dengan:

p = Jumlah kutub stator.

ϕ = Fluks tiap kutub stator (Wb).

K = Konstanta mesin.

2.7. Variabel Resistor (Potensiometer)

Variable Resistor adalah resistor yang nilai resistansinya dapat diubah-ubah pada batasan tertentu, variable resistor juga biasa dikenal dengan potensiometer. Potensiometer biasanya memiliki knop atau tombol yang dapat diputar / digeser untuk mengubah nilai resistansinya. Hal ini berguna untuk berbagai kebutuhan misalnya untuk mengatur volume. Nilai yang tercantum pada potensiometer menandakan nilai resistansi maksimal yang dimilikinya, misal potensiometer 50 kΩ berarti bisa memiliki nilai resistansi antara 0 sampai 50 kΩ.

2.8. Transistor

Transistor adalah alat semikonduktor yang dipakai sebagai penguat, pemotong (switching), stabilisasi tegangan, modulasi sinyal atau fungsi lainnya. Transistor dapat berfungsi semacam kran listrik, dimana berdasarkan arus inputnya (BJT) atau tegangan inputnya (FET), memungkinkan pengaliran listrik yang sangat akurat dari sirkuit sumber listriknya.

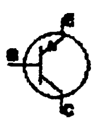
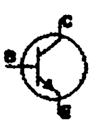
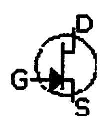
Pada umumnya, transistor memiliki 3 terminal. Tegangan atau arus yang dipasang di satu terminalnya mengatur arus yang lebih besar yang melalui 2 terminal lainnya. Transistor adalah komponen yang sangat penting dalam dunia elektronik modern. Dalam rangkaian analog, transistor digunakan dalam amplifier (penguat). Rangkaian analog melingkupi pengeras suara, sumber listrik stabil, dan penguat sinyal radio. Dalam rangkaian-rangkaian digital, transistor digunakan sebagai saklar berkecepatan tinggi. Beberapa transistor juga dapat dirangkai sedemikian rupa sehingga berfungsi sebagai **logic gate**, memori, dan komponen-komponen lainnya.

2.8.1. Cara Kerja Transistor

Dari banyak tipe-tipe transistor modern, pada awalnya ada dua tipe dasar transistor, bipolar junction transistor (BJT atau transistor bipolar) dan field-effect transistor (FET), yang masing-masing bekerja secara berbeda.Transistor bipolar dinamakan demikian karena kanal konduksi utamanya menggunakan dua polaritas pembawa muatan: elektron dan lubang, untuk membawa arus listrik. Dalam BJT, arus listrik utama harus melewati satu daerah/lapisan pembatas dinamakan depletion zone, dan ketebalan lapisan ini dapat diatur dengan kecepatan tinggi dengan tujuan untuk mengatur aliran arus utama tersebut.

FET (juga dinamakan transistor unipolar) hanya menggunakan satu jenis pembawa muatan (elektron atau hole, tergantung dari tipe FET). Dalam FET, arus listrik utama mengalir dalam satu kanal konduksi sempit dengan depletion zone di kedua sisinya (dibandingkan dengan transistor bipolar dimana daerah Basis memotong arah arus listrik utama). Dan ketebalan dari daerah perbatasan ini dapat dirubah dengan perubahan tegangan yang diberikan, untuk mengubah ketebalan kanal konduksi tersebut. Lihat artikel untuk masing-masing tipe untuk penjelasan yang lebih lanjut.

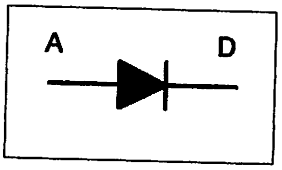
2.8.2. Adapun Jenis Transistor

	PNP		P-channel
	NPN		N-channel

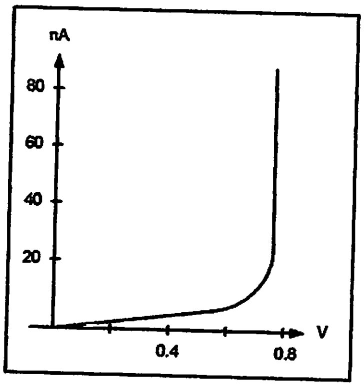
Gambar 2.13. Jenis Transistor PNP dan NPN

2.9. Dioda Penyearah

Dioda penyearah digunakan untuk mengubah arus bolak-balik (alternaty current) menjadi arus searah (direct current). Pada prinsipnya, dioda penyearah ini akan melewatkan arus pada suatu arah saja dengan memotong gelombang negatif sehingga pada output dioda hanya ada gelombang positif saja. Dioda ini paling banyak diaplikasikan pada rangkaian catu daya dan tersedia dalam berbagai jenis dan kemampuannya dalam hal mengendalikan atau melewatkan arus.



Gambar 2.14. Dioda Simbol Dioda Penyearah



Gambar 2.15. Karakteristik Dioda

(Sumber : Eduard Rusdianto ST,2002, Penerapan Konsep dasar Listrik dan Elektronika, hal. 17.)

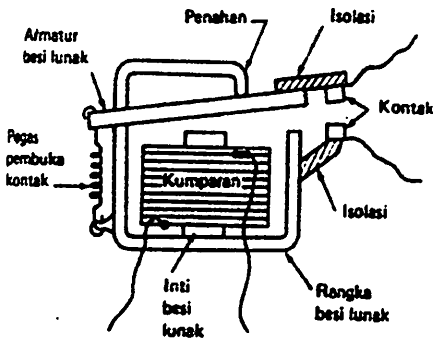
Jika kaki anoda dioda diberi tegangan input maka arus akan mengalir dari anoda ke katoda atau disebut dengan rangkaian tertutup dan hal ini disebut dengan hubungan bias maju (forward bias), sebaliknya bila kaki katoda diberi tegangan input maka arus tidak dapat mengalir sehingga hal ini disebut dioda dbias mundur (*forward reverse*).

2.10 Relai

Relai merupakan suatu alat untuk menghubungkan atau memutuskan arus Relai dapat terdiri dari sebuah kumparan atau solenoida, sebuah inti feromagnetik dan sebuah armatur yang dapat bergerak yang merupakan tempat dipasangnya kontak yang berfungsi sebagai penyambung dan pemutus arus Relai berdasarkan arusnya digolongkan menjadi :

1) Relai arus DC
2) Relai arus AC

Relai ini menggunakan prinsip magnet listrik dalam mengoperasikan kontak kontak tersebut. Diipasaran banyak sekali jenis jenis relai yang dijual dan yang paling banyak digunakan adalah relai jenis elektromagnetis, yang bekerja berdasrkan elektromagnetis. Susunan relai yang paling sederhana adaah terdiri dari kumparan kawat penghantar yang dililitkan pada sebuah inti Bila kumparan ini dilairi oleh arus listrik baik DC maupun AC, maka akan terjadi suatu medan magnet. Medan magnet inilah yang berfungsi memindahkan posisi hubung kontak yang ada dalam relai. Perlu diketahui kontak tersebut terbuat dari bahan logam yang dapat bereaksi terhadap magnet. Ada beberapa susunan kontak relai dimana semuanya terisolasi terhadap arus listrik yang ada pada kumparan



Gambar 2.16. Konstruksi Relai

(Sumber : Komunikasi Elektronika Robert L Sharder ,Hal 64)

.Jenis susunan kontak relai tersebut adalah sebagai berikut

- Normally Open

  Yaitu pada keadaan normal kontak kontak dalam keadaan terbuka, dan akan menutup jika relai dialiri tegangan tertentu.

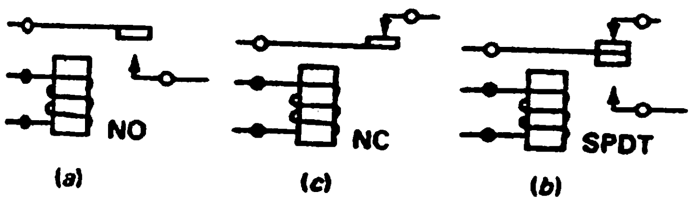
- Normally Close

  Yaitu pada keadaan normal kontak kontak dalam keadaaan tertutup,dan akan terbuka jika relai dialiri teganngan tertentu.

- SPDT (SPST)

  Relai yang mempunyai kontak tengah yang dalam keadaan normalnya tertutup ,namun melepaskan diri dari posisi semula dan membentuk kontak tengah terhubung dengan kontak lainnya.

Keuntungan dari penggunaan relai adalah dapat menghubungkan daya ysng besar dengan memberi daya yang kecil..



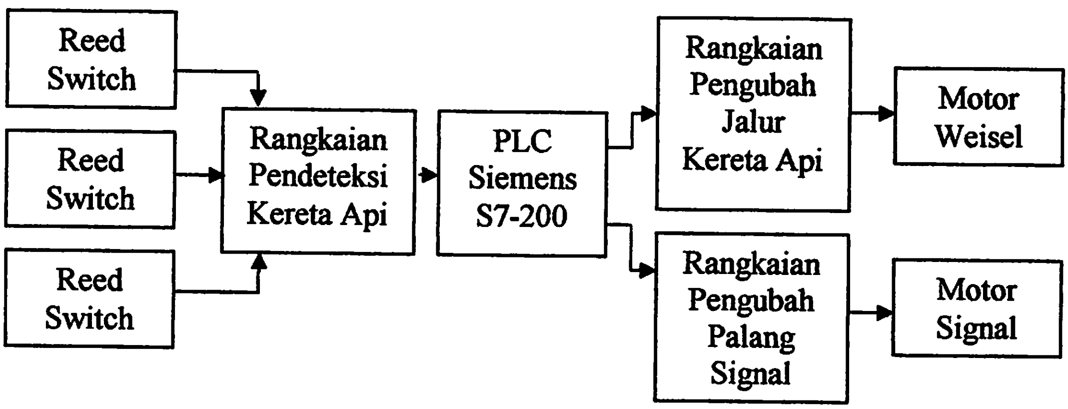
Gambar 2.17 Simbol Skematik Relai

(Sumber : Komunikasi Elektronika Robert L Sharder ,Hal 64)

BAB III

PERANCANGAN DAN PEMBUATAN ALAT

Perencanaan skripsi ini terdiri dari dua bagian, yaitu : perancangan perangkat keras (Hardware) dan perangkat lunak (Software). Pembahasan dalam bab ini akan dilakukan perblok, dari diagram keseluruhan seperti ditunjukkan pada gambar 3.1 di bawah ini :



Gambar 3.1 : Blok Diagram Pengendali Persignalan Dan Interlocking

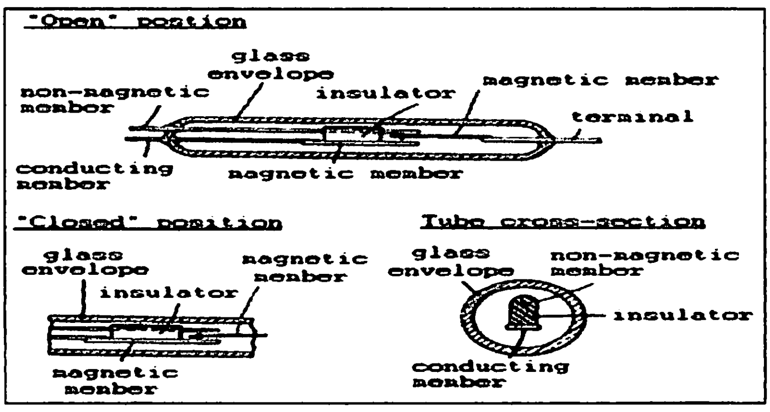
Fungsi dari tiap-tiap blok diagram dijelaskan sebagai berikut :

1. Unit sistem PLC Siemens S7-200 merupakan unit pengolah data.
2. Unit Rangkaian Pendeteksi Kereta Api berfungsi untuk memberikan inputan ke PLC apakah terdapat obyek kereta api / tidak.
3. Unit Rangkaian Pengubah Jalur Kereta Api berfungsi untuk mengubah jalur sesuai outputan dari PLC.

4. Unit Rangkaian Pengubah Palang Signal Kereta Api berfungsi untuk mengubah palang signal sesuai outputan dari PLC.
5. Unit reed switch berfungsi untuk mendeteksi kereta api pada jalur kereta api.
6. Unit motor weisel berfungsi untuk mengubah jalur kereta api.
7. Unit motor palang signal berfungsi untuk menggerakkan palang signal.

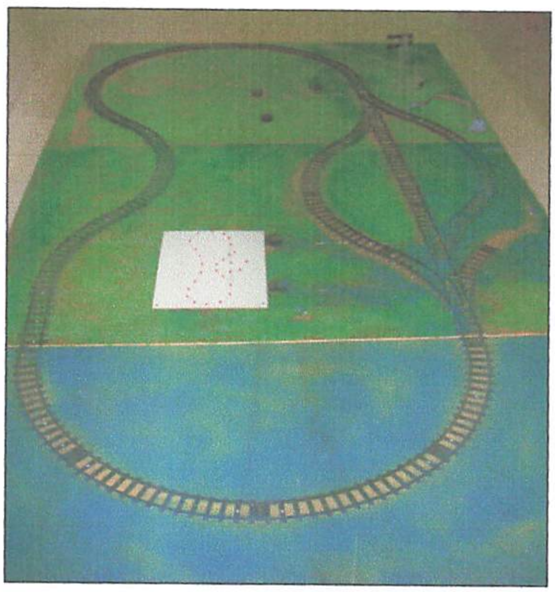
Prinsip Kerja

Seperti terlihat pada blok diagram diatas prinsip kerja dari alat ini secara garis besar adalah pada saat starting awal, obyek yang berupa kereta api dan jalur yang digunakan terlebih dahulu diseleksi oleh station dengan cara mendeteksi dari obyek yang ada. Station ini terdiri dari 12 buah reed switch yang dipasang pada jalur kereta api di stasiun kereta api. Pada saat kereta api berjalan menuju stasiun, obyek tersebut akan diseleksi oleh reed switch yang terdapat sebelum masuk jalur percabangan rel kereta api, reed switch ini berfungsi sebagai pendeteksi apakah ada tidaknya obyek yang akan melalui jalur kereta api.



Gambar 3.2 : Reed Switch

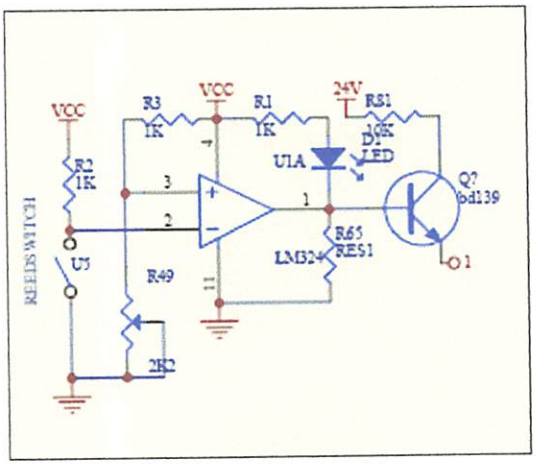
Apabila ada obyek yang berjalan melalui jalur kereta api dan ketika melalui posisi reed switch maka reed switch akan memberikan inputan sinyal bagi PLC. PLC memproses inputan yang didapat dengan memproses jalur kereta api yang akan dilalui oleh obyek. PLC akan memproses dengan melihat jalur mana yang kosong yang didapat dari reed switch yang dipasang pada jalur kereta api yang terdapat di stasiun, apabila sudah sesuai dengan jalur yang diinginkan maka PLC akan mengeluarkan output untuk menggerakkan motor weisel yang berfungsi sebagai pengubah jalur kereta api dan motor signal untuk palang signal yang berfungsi sebagai tanda bagi masinis kereta api.



Gambar 3.3: Unit station pengendali persignalan dan interlocking

3.1 Perencanaan Perangkat Keras

3.1.1. Perencanaan rangkaian pendeteksi jalur kereta api



Gambar 3.4 : Rangkaian Pendeteksi Keberadaan Barang

3.1.1.1. Prinsip kerja dari rangkaian pendeteksi kereta api :

Pada dasarnya prinsip kerja rangkaian pendeteksi kereta api adalah dimana saat reed switch memberi sinyal kepada rangkaian, bila reed switch aktif maka akan memberikan inputan kepada rangkaian.

Komponen-komponen yang digunakan adalah sebagai berikut;

- Reed Switch

  Rumus dasar :

  $V = I . R$ -- (3.1)

  $$Ireed = \frac{Vreed}{Rreed}$$

  $$= \frac{5}{1}$$

  $= 5$ mA

❖ Komparator

- Potensiometer = 2K2 Ω
- IC LM 324
- VCC = 5 ; Ground ; -5

Rumus dasar :

$$V_{Ref} = \frac{R_{Var}}{R_{Var} + R_3} \times V_{CC} \text{ --- (3.2)}$$

$$V_{Ref} = \frac{2K2}{2K2 + 1K} \times 5$$

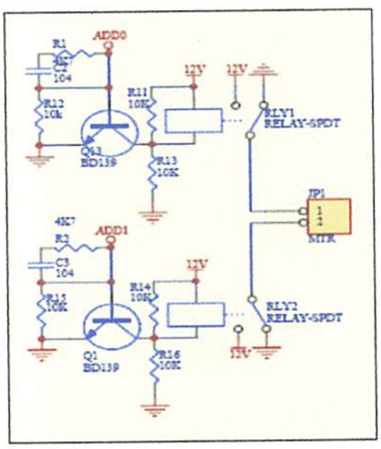
= 3,44 Volt

$$V_O = V_{Ref} - V_{In} \text{ -- (3.3)}$$

$= 3{,}44 - 5$

= -1,56 Volt

3.1.2. Perencanaan rangkaian pengubah jalur kereta api



Gambar 3.5 : Rangkaian pengubah jalur rel kereta api

3.1.2.1. Cara kerja dari rangkaian pengubah jalur kereta api

Data yang diproses didalam PLC akan dikirimkan ke rangkaian pengubah jalur rel kereta api. Dimana output dari PLC tersebut akan berlogika 0 (low) bila jalur tidak dirubah (motor weisel non aktif), dan jika jalur berubah (motor weisel aktif) maka akan berlogika 1 (high).

Pada rangkaian ini relay bergerak dengan diatur oleh transistor, dimana relay akan aktif bila ada arus yang masuk melalui kumparan relay yang diatur oleh transistor yang mendapatkan bias dari kaki basis sehingga bila basis mendapat bias maka akan terjadi aliran antara kaki kolektor dan emitor sehingga tegangan diantara kaki keduanya akan minimal (saturasi), dan bila sebaliknya maka pada kolektor dan emitor akan open circuit (Cut off).

Pada perencanaan rangkaian ini, relay dipakai sebagai kontaktor dan pembalik arah putaran motor. Transistor yang digunakan sejumlah dua buah transistor jenis NPN (BD139) dengan arus maksimum 300 mA yang mampu untuk menghidupkan dan mematikan relai yang bertegangan 12V dengan resistansi sekitar 350Ω (dari pengukuran) sehingga dapat dihitung besarnya arus relay yaitu :

$$I_{relay} = \frac{V_{CC}}{R_{relay}}$$

$$I_{relay} = \frac{12V}{350\Omega} = 34{,}3mA$$

Sedangkan untuk menentukan nilai hambatan pada resistor dapat ditenrukan melalui perhitungan sebagai berikut :

Dimana dari data sheet Transistor diketahui :

- $h_{FE} = 40$
- $V_{BE} = 1$ V
- $V_{CE} = 0,5$ V

Maka = $I_c = \frac{V_{cc} - V_{ce}}{R_{relay}}$

$$I_C = \frac{12 - 0,5}{350} = 32,85\,mA$$

$$I_B = \frac{I_C}{h_{FE}}$$

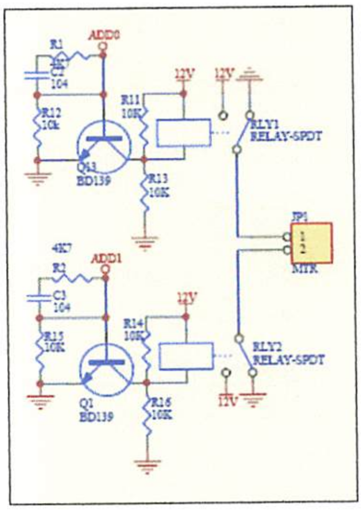
$$I_B = \frac{32,85x10^{-3}}{40} = 0,82\,mA$$

$$R_B = \frac{V_{BB} - V_{ce}}{I_B}$$

$$R_B = \frac{5 - 1}{0,82x10^{-3}} = 4,8K\Omega$$

Karena nilai resistor 4,8 KΩ tidak ada di pasaran maka digunakan resistor dengan nilai 4K7Ω.

3.1.3. Perencanaan rangkaian palang signal



Gambar 3.6 : Rangkaian palang signal

3.1.2.1. Cara kerja dari rangkaian palang signal

Data yang diproses didalam PLC akan dikirimkan ke rangkaian palang signal. Rangkaian ini sama seperti pada rangkaian pengubah jalur rel kereta api. Dimana output dari PLC tersebut akan berlogika 0 (low) bila jalur tidak dirubah (motor signal non aktif), dan jika jalur berubah (motor signal aktif) maka akan berlogika 1 (high).

Pada rangkaian ini prinsipnya sama dengan rangkaian pengubah jalur rel kereta api, dimana relay akan aktif bila ada arus yang masuk melalui kumparan relay yang diatur oleh transistor yang mendapatkan bias dari kaki basis sehingga bila basis mendapat bias maka akan terjadi aliran antara kaki kolektor dan emitor sehingga tegangan diantara kaki keduanya akan minimal (saturasi), dan bila sebaliknya maka pada kolektor dan emitor akan open circuit (Cut off).

Pada perencanaan rangkaian ini, relay dipakai sebagai kontaktor dan pembalik arah putaran motot. Transistor yang digunakan sejumlah dua buah transistor jenis NPN (BD139) dengan arus maksimum 300 mA yang mampu untuk menghidupkan dan mematikan relai yang bertegangan 12V dengan resistansi sekitar 350Ω (dari pengukuran) sehingga dapat dihitung besarnya arus relay yaitu :

$$I_{relay} = \frac{V_{CC}}{R_{relay}}$$

$$I_{relay} = \frac{12V}{350\Omega} = 34,3mA$$

Sedangkan untuk menentukan nilai hambatan pada resistor dapat ditenrukan melalui perhitungan sebagai berikut :

Dimana dari data sheet Transistor diketahui :

- $h_{FE} = 40$
- $V_{BE} = 1$ V
- $V_{CE} = 0,5$ V

Maka = $I_c = \frac{V_{cc} - V_{ce}}{R_{relay}}$

$$I_C = \frac{12 - 0,5}{350} = 32,85 mA$$

$$I_B = \frac{I_C}{h_{FE}}$$

$$I_B = \frac{32,85x10^{-3}}{40} = 0,82 mA$$

$$R_B = \frac{V_{BB} - V_{ce}}{I_B}$$

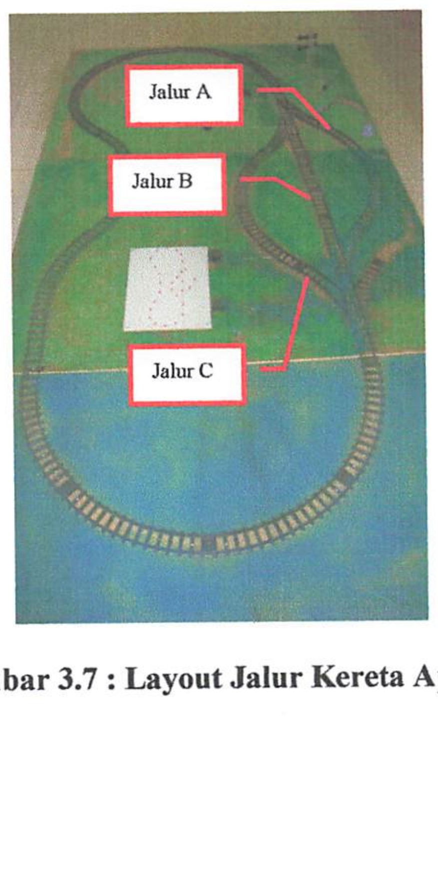
$$R_B = \frac{5-1}{0{,}82x10^{-3}} = 4{,}8K\Omega$$

Karena nilai resistor 4,8 KΩ tidak ada di pasaran maka digunakan resistor dengan nilai 4K7Ω.

3.1.4. Ukuran Mekanik

Untuk mendapatkan kerja yang optimal, ukuran-ukuran mekanik juga sangat diperlukan dan diperhatikan agar pada saat alat bekerja atau beroperasi tidak terjadi kekeliruan.

Adapun ukuran-ukuran mekanik tersebut seperti yang bisa kita lihat pada beberapa gambar berikut :

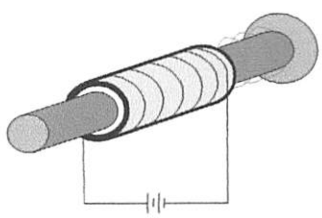


Gambar 3.7 : Layout Jalur Kereta Api

Secara garis besar alat ini memiliki panjang dan lebar ± 2,8 x 1,2 meter. Apabila dilihat dari gambar diatas, jalur kereta api terdapat 3 jalur yang digunakan antara lain jalur luar, tengah dan dalam. Adapun untuk lebih jelasnya adalah sebagai berikut :

- Jalur A = Jalur Luar
- Jalur B = Jalur Tengah
- Jalur C = Jalur Dalam

3.1.5. Selenoid



Gambar 3.8 : Selenoid

3.1.5.1.Cara kerja dari selenoid

Saklar solenoid bekerja pada tegangan sebesar 12 volt. Saklar solenoid central lock mendapat sinyal dari PLC, jika sinyal tersebut bernilai 1 (high) maka central lock akan bekerja dan apabila tidak mendapat sinyal dari PLC maka central lock akan bernilai 0 (low). Central lock ini akan bekerja bila jalur kereta api sudah sesuai dengan yang diinginkan, sehingga akan merubah jalur kereta api pada persimpangan jalur kereta api.

3.2. Perangkat lunak

Program kerja yang dilaksanakan dengan rangkaian "Ladder" untuk memproses yang sederhana seringkali tidak memerlukan (mempresentasikan) tahapan perancangan yang benar. Namun demikian program yang ada tidak sulit untuk dimengerti. Untuk suatu kasus, strategi atau metodologi perancangan program dan system sangat diperlukan. Dalam pemrograman logic, seperti pemrograman pada PLC terdapat dua tipe rangkaian program kerja yang dapat merupakan dasar, yaitu :

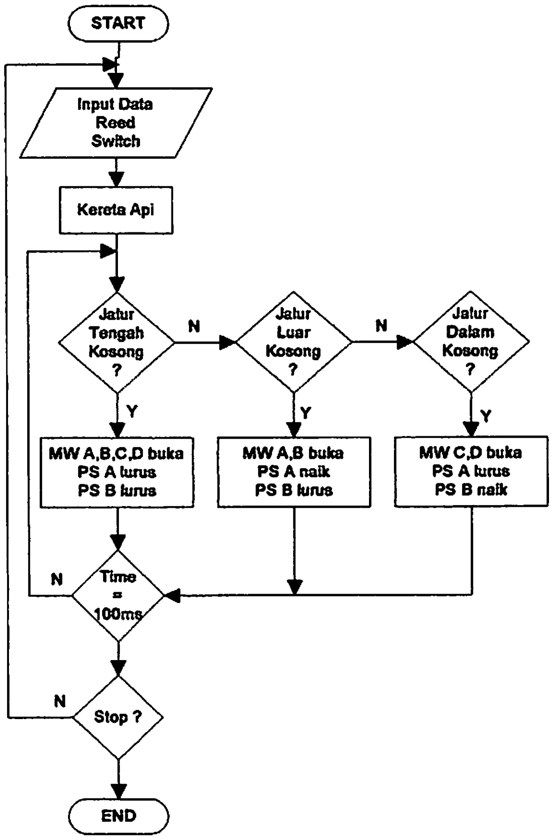
a. Interlock atau Combinational Logic
b. Rangkaian sequensial

Pada system interlock atau rangkaian kombinasi (Combinational Logic), output rangkaian logic pada suatu saat semata ditentukan oleh kombinasi dan dari sejumlah input pada saat itu pula. Sedangkan pada system sequensial kondisi output bergantung pula pada kondisi atau status input dan atau output sebelumnya.

Perancangan software disini digunakan untuk mengkompile file yang telah kita buat agar dapat didownload kedalam PLC Siemens S7-200. Software ini akan memegang peranan penting, karena apabila tidak ada software ini maka tidak akan ada yang mengatur aliran data inputan ataupun outputan dari PLC.

Berikut ini akan diberikan penjelasan mengenai program yang dibutuhkan untuk PLC dalam bentuk diagram alir atau flowchart dan ladder diagram :

3.2.1 Flowchart



Gambar 3.9 : Flowchart dari pengendali persignalan dan interlocking

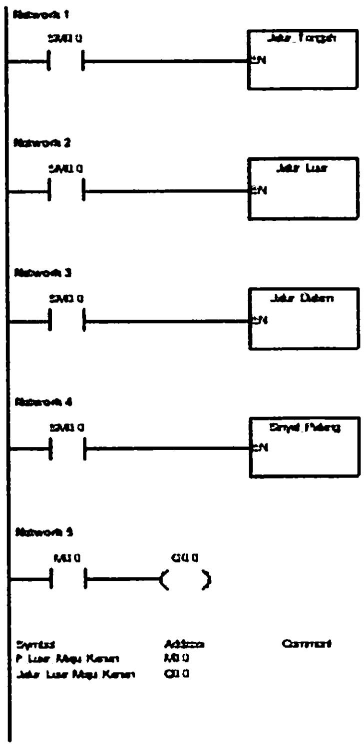
Ket: • MW = Motor Weisel

• PS A = Palang Signal A (Palang Signal Jalur Luar)

• PS B = Palang Signal B (Palang Signal Jalur Dalam)

3.2.2 Ladder Diagram

Untuk ladder diagramnya dapat dilihat seperti di bawah ini :



Gambar 3.10 : Ladder Diagram PLC

BAB IV

PENGUJIAN DAN ANALISA DATA

Dalam pembuatan alat pasti tidak terlepas dari suatu kesalahan, demikian juga pada pembuatan alat pengendali persignalan dan interlocking dengan menggunakan PLC Siemens S7-200 ini. Untuk menghindari dari suatu kesalahan maka perlu dilakukan pengujian dan pengukuran pada masing-masing blok diagram yang telah direncanakan, sehingga didapatkan hasil yang sesuai dengan perencana.

Rangkaian yang diuji dan dianalisa adalah sebagai berikut :

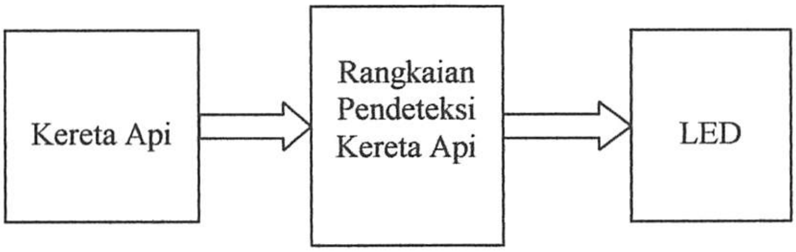
1. Rangkaian Pendeteksi Pendeteksi Kereta Api
2. Rangkaian Pengubah Jalur Kereta Api
3. Rangkaian Palang Signal

4.1. Pengujian Rangkaian Pendeteksi Kereta Api

4.1.1. Tujuan

Dalam pengujian rangkaian pendeteksi kedatangan kereta api ini memiliki tujuan untuk mengetahui apakah rangkaian tersebut dapat bekerja dengan baik apabila ada obyek / kereta api yang terdeteksi, sehingga rangkaian tersebut akan memberikan inputan kepada PLC.

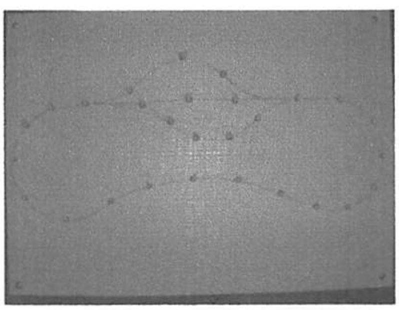
4.1.2. Diagram Blok Pengujian Rangkaian Pendeteksi Kereta Api



Gambar 4.1 : Diagram Blok Pengujian Rangkaian Pendeteksi Kereta Api

4.1.3. Hasil Pengujian dan Analisa

Dalam pengujian rangkaian pendeteksi barang ini terlihat bahwa rangkaian pendeteksi kereta api dapat mendeteksi dengan baik. Hal ini dapat terlihat pada gambar dibawah ini :



Gambar 4.2 : Pengujian Rangkaian Pendeteksi Kereta Api

Nama	Keterangan	
	Tidak Ada Kereta Api	Ada Kereta Api
Reed Switch Detektor (RD) 1	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 2	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 3	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 4	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 5	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 6	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 7	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 8	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 9	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 10	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 11	LED kondisi ON	LED kondisi OFF
Reed Switch Detektor (RD) 12	LED kondisi ON	LED kondisi OFF

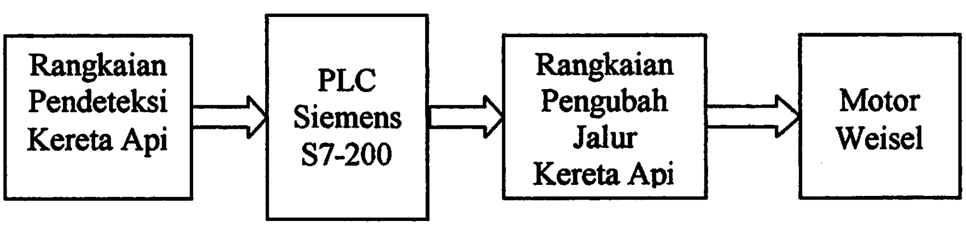
Tabel 4.1 : Kondisi Reed Switch Pada Jalur Kereta Api

4.2. Pengujian Rangkaian Pengubah Jalur Kereta Api

4.2.1. Tujuan

Dalam pengujian rangkaian pengubah jalur kereta api ini memiliki tujuan yaitu untuk mengubah jalur sesuai jalur mana yang digunakan untuk dilewati kereta api. Dimana jalur yang berubah digerakkan oleh motor weisel berdasarkan output dari PLC.

4.2.2. Diagram Blok Pengujian Rangkaian Pengubah Jalur Kereta Api

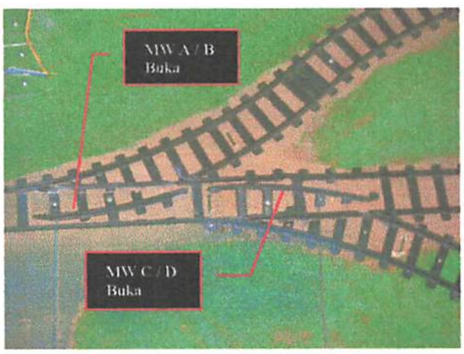


Gambar 4.3 : Diagram Blok Pengujian Rangkaian Pengubah Jalur Kereta Api

4.2.3. Hasil Pengujian Dan Analisa

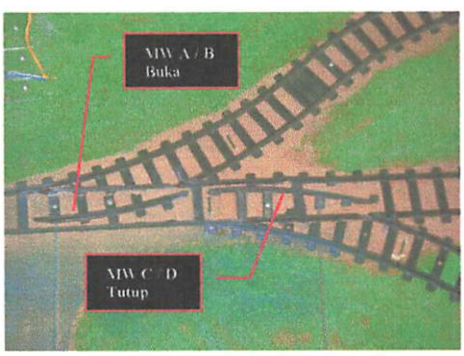
Dari hasil pengujian dapat dilihat bahwa rangkaian pengubah jalur kereta api mendapatkan output dari PLC (*Programmable Logic Control*) setelah memproses data yang didapat dari rangkaian sebelumnya dengan mengubah jalur kereta api sesuai dengan jalur mana yang akan digunakan, dengan demikian maka dapat dikatakan bahwa rangkaian pengubah jalur kereta api dapat bekerja dengan baik. Adapun hasil yang didapatkan dari pengujian tersebut seperti berikut :

- Motor Weisel A, B, C dan D yang terdapat pada jalur kereta bagian tengah akan membuka



Gambar 4.4 : Kondisi Motor Weisel Saat Kondisi Lajur Tengah

- Motor Weisel A dan B yang terdapat pada jalur kereta bagian luar akan membuka



Gambar 4.5 : Kondisi Motor Weisel Saat Kondisi Lajur Luar

- Motor Weisel C dan D yang terdapat pada jalur kereta bagian dalam akan membuka

Gambar 4.6 : Kondisi Motor Weisel Saat Kondisi Lajur Dalam

Untuk mengetahui apakah motor weisel bergerak, maka kita perlu melakukan pengukuran. Dibawah ini kita bisa lihat hasil pengukuran seperti berikut :

NO	Motor Weisel	Vout (VOLT)
1	Aktif	11,25
2	Non aktif	0,00

Tabel 4.2 : Hasil Pengukuran Rangkaian Pengubah Jalur Rel Kereta Api

Setelah melakukan pengujian selama 10 kali, maka hasil yang didapat adalah sebagai berikut :

No.	Pengujian	Hasil Pengujian	Keterangan
1.	Pengujian ke I	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error

2.	Pengujian ke II	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error
3.	Pengujian ke III	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error
4.	Pengujian ke IV	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error
5.	Pengujian ke V	Motor weisel tidak bekerja secara maksimal, dikarenakan jalur kereta api tidak kembali ke posisi semula	Terjadi error
6.	Pengujian ke VI	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error
7.	Pengujian ke VII	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error
8.	Pengujian ke VIII	Motor weisel tidak bekerja secara maksimal, dikarenakan jalur kereta api tidak kembali ke posisi semula	Terjadi error
9.	Pengujian ke IX	Motor weisel tidak bekerja secara maksimal, dikarenakan jalur kereta api tidak kembali ke posisi semula	Terjadi error
10.	Pengujian ke X	Semua rangkaian pada pengubah jalur kereta api ini bekerja dengan baik	Tidak terjadi error

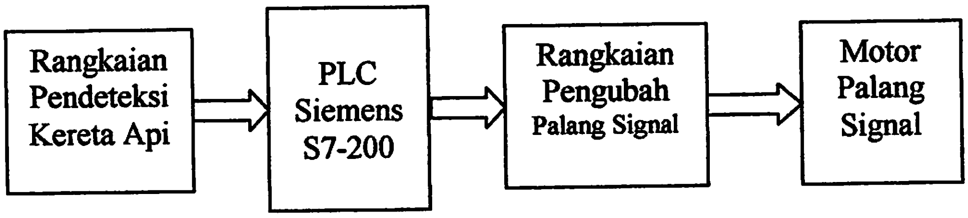
Tabel 4.3 : Hasil Pengujian Rangkaian Motor Weisel

4.3. Pengujian Rangkaian Palang Signal

4.3.1. Tujuan

Dalam pengujian rangkaian palang signal ini memiliki tujuan yaitu untuk menggerakkan palang persignalan yang berfungsi sebagai tanda bagi masinis kereta api apakah sesuai dengan perubahan jalur kereta api atau tidak. Apabila jalur kereta api dirubah ke jalur luar, maka motor palang signal akan bekerja dengan menaikkan atau menurunkan palang signal, dan apabila jalur kereta api tersebut tidak berubah jalur maka palang signal akan dalam keadaan diam (lurus).

4.3.2. Diagram Blok Pengujian Rangkaian Palang Signal

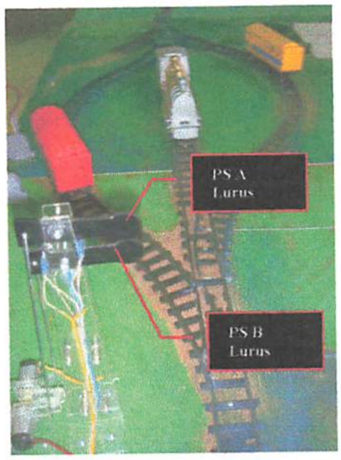


Gambar 4.7 : Diagram Blok Pengujian Rangkaian Palang Signal

4.3.3. Hasil Pengujian Dan Analisa

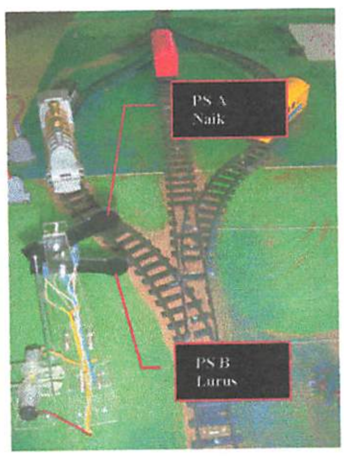
Dari hasil pengujian dapat dilihat bahwa rangkaian pengubah palang signal dapat bekerja berdasarakan data dari PLC (*Programmable Logic Control*) yang telah diproses dengan menggerakkan palang signal berdasar pada saat perubahan jalur kereta api dilakukan, dengan demikian maka dapat dikatakan bahwa rangkaian pengubah palang signal dapat bekerja dengan baik. Adapun hasil yang didapatkan dari pengujian tersebut seperti berikut :

- Jalur Tengah yang digunakan bila Palang Signal dalam kondisi palang signal A dan B sama-sama dalam keadaan lurus



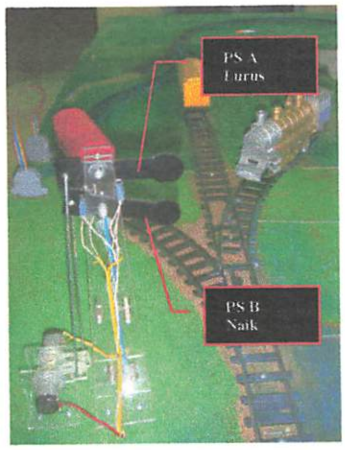
Gambar 4.8 : Kondisi Palang Signal Saat Kondisi Jalur Tengah

- Jalur Luar yang digunakan bila Palang Signal dalam kondisi palang signal A dalam keadaan naik dan palang signal B dalam kondisi lurus



Gambar 4.9 : Kondisi Palang Signal Saat Kondisi Jalur Luar

- Jalur Dalam yang digunakan bila Palang Signal kondisi palang signal B dalam keadaan naik dan palang signal A dalam kondisi lurus



Gambar 4.10 : Kondisi Palang Signal Saat Kondisi Jalur Dalam

Keterangan :

- Palang signal A adalah palang signal untuk Jalur Luar
- Palang signal B adalah palang signal untuk Jalur Dalam

Untuk mengetahui apakah motor signal bergerak, maka kita perlu melakukan pengukuran. Dibawah ini kita bisa lihat hasil pengukuran seperti berikut :

NO	Motor Weisel	Vout (VOLT)
1	Aktif	11,18
2	Non aktif	0,00

Tabel 4.4 : Hasil Pengukuran Rangkaian Palang Signal

Setelah melakukan pengujian selama 10 kali, maka hasil yang didapat adalah sebagai berikut :

No.	Pengujian	Hasil Pengujian	Keterangan
1.	Pengujian ke I	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
2.	Pengujian ke II	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
3.	Pengujian ke III	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
4.	Pengujian ke IV	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
5.	Pengujian ke V	Motor signal tidak bekerja secara maksimal, dikarenakan palang signal tidak kembali ke posisi semula	Terjadi error
6.	Pengujian ke VI	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
7.	Pengujian ke VII	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error
8.	Pengujian ke VIII	Motor signal tidak bekerja secara maksimal, dikarenakan palang signal tidak kembali ke posisi semula	Terjadi error
9.	Pengujian ke IX	Motor signal tidak bekerja secara maksimal, dikarenakan palang signal tidak kembali ke posisi semula	Terjadi error
10.	Pengujian ke X	Semua rangkaian pada palang signal ini bekerja dengan baik	Tidak terjadi error

Tabel 4.5 : Hasil Pengujian Rangkaian Palang Signal

4.4. Pengujian Rangkaian PLC *(Programmable Logic Control)*

4.4.1. Tujuan

Untuk mengetahui apakah minimum sistem yang dibuat sudah sesuai dengan yang direncanakan.

4.4.2. Alat yang digunakan

1. Catu daya
2. PLC
3. Rangkaian

4.4.3. Langkah Pengujian

1. Menyusun rangkaian seperti blok dibawah ini :

Gambar 4.11 : Skema Pengujian

2. Menyiapkan perangkat keras dari PLC Siemens S7-200
3. Menghubungkan catu daya
4. Memasukkan program software ke hardware

4.4.4. Hasil Pengujian

Input	Output (Led)	Hasil
ON	Nyala	Berfungsi
OFF	Mati	Tidak berfungsi

Tabel 4.6 : Hasil Pengujian Rangkaian Pada PLC

4.4.5. Analisa hasil pengujian

Dari hasil pengujian maka dapat disimpulkan sebagai berikut :

♫ Input High (1) Indikator led nyala

Hal ini menandakan led yang terdapat pada rangkaian dalam keadaan nyala atau high, maka rangkaian telah bekerja dengan baik.

♫ Input Low (0) Indikator led mati

Hal ini menandakan led yang terdapat pada rangkaian dalam keadaan mati atau low, maka rangkaian tersebut tidak bekerja.

Ini membuktikan bahwa rangkaian PLC dapat bekerja dengan baik sesuai dengan struktur program yang telah di program.

BAB V

PENUTUP

5.1. Kesimpulan

Dari perencanaan dan pembuatan alat sorting warna ini dapat disimpulkan :

1. Detektor pada rel kereta api bekerja sesuai dengan system kerja pada switch, dimana pada saat kereta api lewat saklar akan menutup sehingga terjadi logika "0" atau "low" dan tegangannya 0,00 Volt, sebaliknya pada saat tidak ada kereta api yang lewat maka saklar akan terbuka sehingga berlogika "1" atau "high" dan tegangannya 23,8 Volt.
2. Jalur pada rel kereta api akan bergerak sesuai dari hasil *output* dari PLC sebagaimana berikut :
    a. Motor Weisel A, B, C dan D yang terdapat pada jalur kereta bagian tengah akan membuka
    b. Motor Weisel A dan B yang terdapat pada jalur kereta bagian luar akan membuka
    c. Motor Weisel C dan D yang terdapat pada jalur kereta bagian dalam akan membuka
3. Palang signal jalur dalam naik bila kereta api melewati jalur dalamPada saat jalur rel kereta api pada percabangan jalur berubah maka palang signal akan ikut berubah sebagaimana berikut :
    a. Palang signal jalur luar dan dalam sama-sama lurus bila kereta api melewati jalur tengah

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www.railwayengineering.com

LAMPIRAN

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NIM	: 0317093
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Konsentrasi	: Teknik Elektronika S-1
Hari/ Tanggal	: Rabu / 24 September 2008

NO	MATERI PERBAIKAN	PARAF
1.	Teori Dasar PLC Bab II	
2.	Perancangan Bab III	
3.	Blok Diagram Bab III	
4.	Hasil Pengujian Rangkaian Komparator	
5.	Ladder Diagram Teori dan persilangan	

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Mengetahui,

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PEMBIMBING II

Ir. Eko Nurcahyo
NIP. Y. 1028700172

PERKUMPULAN PENGELOLA PENDIDIKAN UMUM DAN TEKNOLOGI NASIONAL MALANG

INSTITUT TEKNOLOGI NASIONAL MALANG

FAKULTAS TEKNOLOGI INDUSTRI
FAKULTAS TEKNIK SIPIL DAN PERENCANAAN
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Malang, 04 Juni 2008

Nomor : ITN-020/7/TA /2008
Lampiran :
Perihal : *Bimbingan Skripsi*

Kepada :Yth. Sdr. Ir. WIDODO PUDJI M, MT *)
Dosen Pembimbing
Jurusan Teknik Elektro S-1
di
Malang

Dengan hormat,
Sesuai dengan permohonan dan persetujuan dalam proposal skipsi untuk mahasiswa:

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Nim	: 0317093
Fakultas	: Teknologi Industri
Jurusan	: Teknik Elektro S-1
Konsentrasi	: Teknik Elektronika S-I

Maka dengan ini pembimbingan tersebut kami serahkan sepenuhnya kepada Saudara/i selama masa waktu 6 (enam) bulan, terhitung mulai tanggal:

09 MEI 2008 S/D 09 NOVEMBER 2008

Adapun tugas tersebut merupakan salah satu syarat untuk memperoleh gelar Sarjana Teknik. Jurusan Elektro apabila lewat dari batas waktu tsb. Maka, skripsinya akan digugurkan.
Demikian atas perhatian serta kerjasama yang baik kami ucapkan terima kasih

Ketua Jurusan
Teknik Elektro S-1

Ir. F. Yudi Limpraptono,MT
NIP. Y. 1039500274

Tindasan:
3. *)Perpanjangan
4. Mahasiswa yang Bersangkutan
5. Arsip

INSTITUT TEKNOLOGI NASIONAL MALANG
FAKULTAS TEKNOLOGI INDUSTRI
JURUSAN TEKNIK ELEKTRO

FORMULIR BIMBINGAN SKRIPSI

Nama : BAGUS BUDI PRASETYO WINDARTO
Nim : 03.17.093
Masa Bimbingan : 09 MEI 2008 s/d 09 NOVEMBER 2008
Judul Skripsi : PERANCANGAN DAN PEMBUATAN SISTEM PENGENDALI PERSIGNALAN DAN INTERLOCKING JALUR KERETA API DENGAN MENGGUNAKAN PLC SIEMENS S7-200 DI STASIUN KERETA API BLIMBING-MALANG

No.	Tanggal	Uraian	Paraf Pembimbing
1.	20-8-08	Revisi Bab 1, Bab 2, dan Bab 3	[paraf]
2.	25-8-08	Acc Bab 1, Bab 2, dan Bab 3	[paraf]
3.	30-8-08	Revisi Bab 4, Bab 5, dan Foto alat	[paraf]
4.	4-9-08	Revisi Bab 4	[paraf]
5.	9-9-08	Acc Bab 5	[paraf]
6.	11-9-08	Acc maju seminar hasil	[paraf]
7.	16-9-08	Acc maju ujian skripsi	[paraf]
8.			
9.			
10.			

Malang,
Dosen Pembimbing I,

[tanda tangan]

Ir. Widodo Pudji Muljanto, MT.
Nip. Y. 102 870 0171

Form.S-4b

PERKUMPULAN PENGELOLA PENDIDIKAN UMUM DAN TEKNOLOGI NASIONAL MALANG

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FAKULTAS TEKNIK SIPIL DAN PERENCANAAN
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Malang, 04 Juni 2008

Nomor : ITN-021/7/TA /2008
Lampiran :
Perihal : *Bimbingan Skripsi*

Kepada :Yth. Sdr. Ir. EKO NURCAHYO *)
Dosen Pembimbing
Jurusan Teknik Elektro S-1
di
Malang

Dengan hormat,
Sesuai dengan permohonan dan persetujuan dalam proposal skipsi untuk mahasiswa:

Nama	: BAGUS BUDI PRASETYO WINDARTO
Nim	: 0317093
Fakultas	: Teknologi Industri
Jurusan	: Teknik Elektro S-1
Konsentrasi	: Teknik Elektronika S-I

Maka dengan ini pembimbingan tersebut kami serahkan sepenuhnya kepada Saudara/i selama masa waktu 6 (enam) bulan, terhitung mulai tanggal:

09 MEI 2008 S/D 09 NOVEMBER 2008

Adapun tugas tersebut merupakan salah satu syarat untuk memperoleh gelar Sarjana Teknik, Jurusan Elektro apabila lewat dari batas waktu tsb. Maka, skripsinya akan digugurkan.
Demikian atas perhatian serta kerjasama yang baik kami ucapkan terima kasih

Ketua Jurusan
Teknik Elektro S-1

Ir. F. Yudi Limpraptono,MT
NIP. Y. 1039500274

Tindasan:
3. *)Perpanjangan
4. Mahasiswa yang Bersangkutan
5. Arsip

INSTITUT TEKNOLOGI NASIONAL
FAKULTAS TEKNOLOGI INDUSTRI
JURUSAN TEKNIK ELEKTRO

FORMULIR BIMBINGAN SKRIPSI

Nama : **BAGUS BUDI PRASETYO WINDARTO**
Nim : **03.17.093**
Masa Bimbingan : **09-Mei-2008 s/d 09-November-2008**
Judul Skripsi : **PERENCANAAN DAN PEMBUATAN SISTEM PENGENDALI PERSIGNALAN DAN INTERLOCKING JALUR REL KERETA API DENGAN MENGGUNAKAN PLC SIEMENS S7-200 DI STASIUN KERETA API BLIMBING-MALANG**

No	Tanggal	Uraian	Paraf Pembimbing
1	22-8-08	Revisi Bab 1, Bab 2, dan Bab 3	
2	29-8-08	Acc Bab 1, Bab 2, dan Bab 3	
3	3-9-08	Revisi Bab 4, dan Foto Alat	
4	6-9-08	Acc Bab 4	
5	10-9-08	Revisi Bab 5	
6	12-9-08	Acc Bab 5	
7	13-9-08	Acc maju seminar hasil	
8	19-9-08	Acc maju ujian skripsi	
9			
10			

Malang, 22- Sept 2008
Dosen pembimbing II

Ir. Eko Nurcahyo
NIP. Y .1028700172

Form S-4a

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Formulir Perbaikan Ujian Skripsi

Dalam pelaksanaan Ujian Skripsi Janjang Strata 1 Jurusan Teknik Elektro Konsentrasi T. Energi Listrik / T. Elektronika / T.Infokom, maka perlu adanya perbaikan skripsi untuk mahasiswa :

NAMA : BAGUS UMAR PRASETYO W

N I M : 03.17 073.

Perbaikan meliputi :

1. Rancangan Bab III di bendahin semua!
2. Teori Dasar PLC Bab II

Malang, 200

( )

INSTITUT TEKNOLOGI NASIONAL MALANG
FAKULTAS TEKNOLOGI INDUSTRI
JURUSAN TEKNIK ELEKTRO

Formulir Perbaikan Ujian Skripsi

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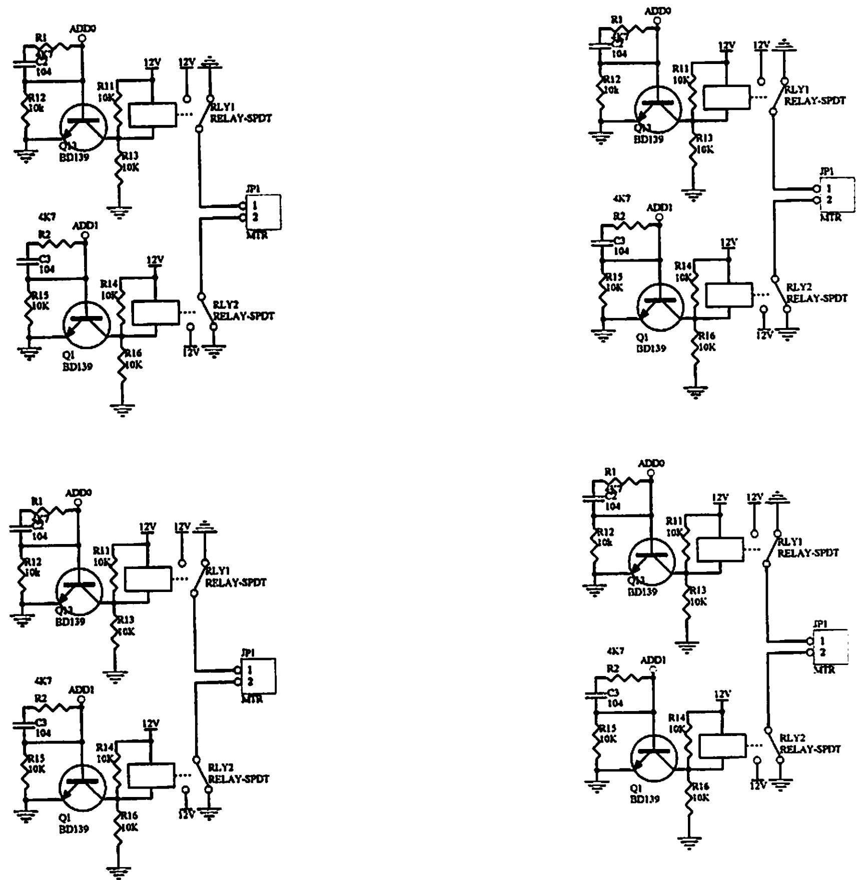
NAMA : Bagus Budi Prasetyo
N I M : 0317093
Perbaikan meliputi :

Pengujian komparator
Blok Diagram diperbaiki
Ladder diagram teori dan perencanaan.

Malang, 24 Sept 2008

(M. Ibrahim Ashari, ST, MT)



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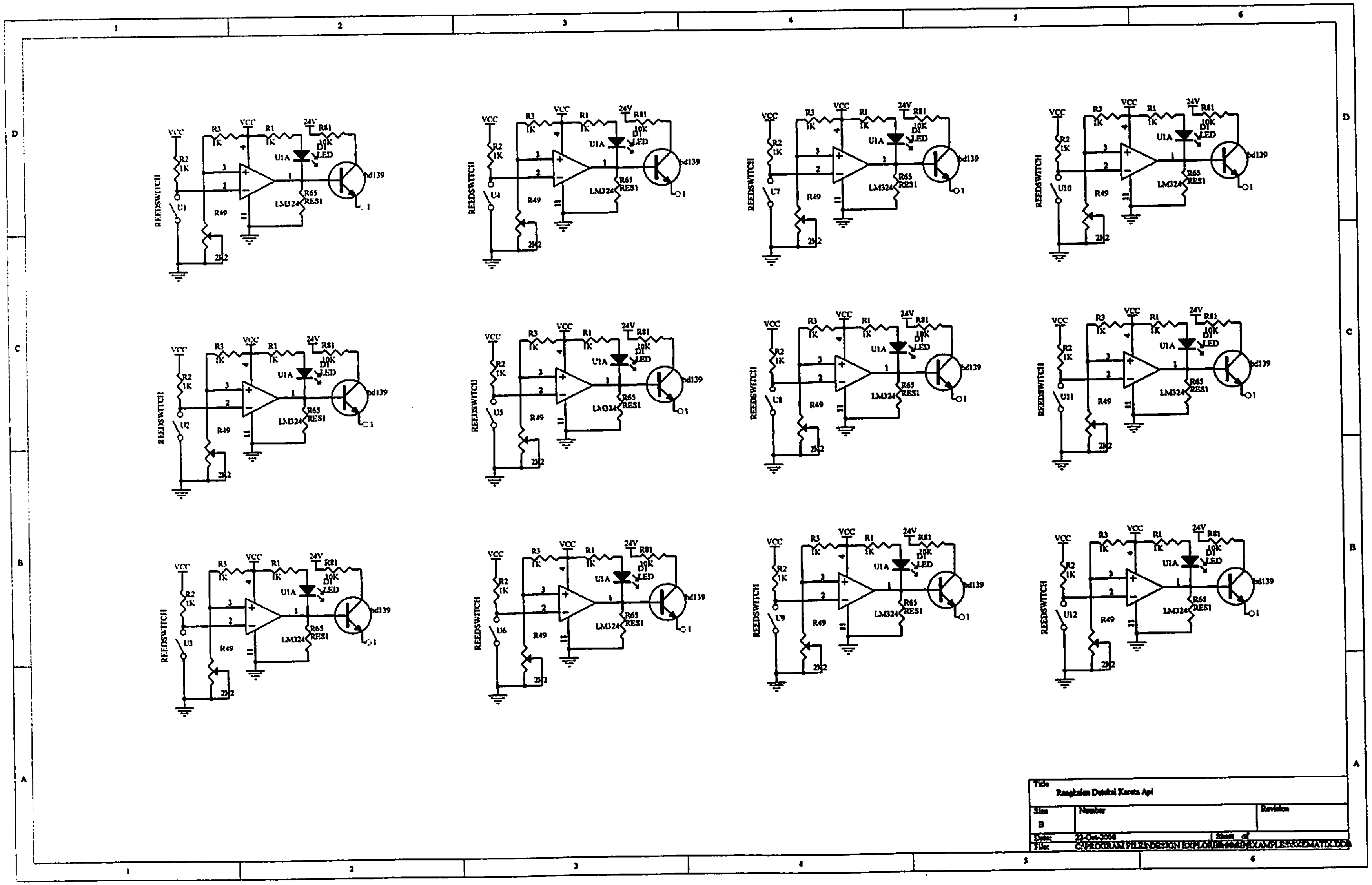
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VCC
R2
1K
R3
R1
U1A
D1
LED
24V
R81
10K
R65
RES1
LM324
R49
2K2
bd139
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
U11
U12
Title
Rangkaian Deteksi Kereta Api
Size
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Definitions[2]

Train Control—the process by which the movement of rail rapid transit vehicles is regulated for the purposes of safety and efficiency. The system that accomplishes train control performs four types of functions:

Train Protection-assurance that trains maintain a safe following distance, that overspeed is prevented, and that conflicting movements at junctions, crossings, and switches are precluded;

Train Operation--control of train movements—specifically regulating speed, stopping at stations, and opening and closing doors;

Train Supervision-assignment of routes, dispatch of trains, and maintaining or adjusting schedule;

Communication—interchange of command and status information among trains, wayside elements, stations, and central control.

Automatic Train Control (ATC)—the use of machines to perform all or most of the functions of train control in the normal mode of operation. Human involvement in ATC systems consists mainly of monitoring and back-up. The acronyms ATP (automatic train protection), ATO (automatic train operation), and ATS (automatic train supervision) denote particular groups of automated functions.

Rail Rapid Transit-an electrified rail system operating in urban areas on exclusive rights-of-way. Rail rapid transit is considered here to exclude commuter railroad systems and light rail systems, although the technology of train control is similar for all three.

---

[2] A glossary of train control terms is presented in Appendix D. Explanation of the fundamentals of train control and descriptions of typical train control equipment are contained in Chapter 3.

INTRODUCTION

In requesting this assessment, the Senate Committee on Appropriations posed four major questions concerning automatic train control technology:

1. What is the state of ATC technology?
2. What application is made of ATC technology in existing and planned rail rapid transit systems?
3. Are the testing programs and methods for ATC systems adequate?
4. How is the level of automation selected, and what tradeoffs are considered?

These questions served initially as the basic framework for organizing and directing the assessment. As the study progressed, it became apparent that each issue raised by the requesting committee had many ramifications and that there were corollary questions that had to be addressed. Therefore, the study was expanded in scope and detail to consider not just the matters enumerated in the letter of request but, more generally, the entire field of automation technology in train control systems. The findings of this broader investigation dealing with policy, planning, and operational concerns are summarized below. Supporting data and discussion are presented in chapters 5, 6, and 7. At the conclusion of this chapter is a brief interpretation of the findings that responds directly and specifically to the issues raised by the Senate Committee on Appropriations.

POLICY AND INSTITUTIONAL FACTORS

The development of rail rapid transit systems is influenced by three major pieces of Federal legislation: the Urban Mass Transportation Act of 1964, the Department of Transportation Act of 1966, and the National Mass Transportation Assistance Act of 1974. Transit system planning, development, and (since 1975) operation are supported by these acts and the annual appropriations that flow from them. The administrative agency for Federal support of transit development programs is the Urban Mass Transportation Administration (UMTA). Neither the existing legislation nor the administrative programs of UMTA deal specifically with ATC systems as such. Research in train control technology and development of individual ATC systems are carried on within a more general program of activities relating to rail rapid transit as a whole.

Findings pertaining to policy and institutional considerations are as follows:

Regulation

At the Federal level, regulation of rail rapid transit (and ATC specifically) is of recent origin, Regulation is vested in two agencies—UMTA and the Federal Railway Administration (FRA), whose respective areas of responsibility are not clearly defined, It is not surprising, therefore, that so far neither agency has done much to regulate or standardize ATC systems. However, FRA has recently indicated the intention to start rulemaking procedures concerning ATP and the safety aspects of door operation.

The National Transportation Safety Board (NTSB) is charged with overseeing rail rapid transit safety and with accident investigation. Implementation of NTSB recommendations is left to either FRA or UMTA or is handled as a matter of voluntary compliance by transit agencies.

Most regulation of rail rapid transit (and ATC specifically) is carried out either by State public utility commissions or by the transit agencies themselves as self-regulating bodies. The concern of State regulatory bodies is primarily safety, Little attention is given to operational concerns, such as reliability, maintainability, level of service, efficiency, and economics.

Advantages in increased Federal regulation, particularly in the areas of safety assurance and equipment standardization, must be weighed carefully against the disadvantages of preempting State and local authority and raising possible barriers to innovation.

Institutions

Decisions relating to ATC design and development are influenced by several nongovernmental institutions or groups. The strongest influence is that of the local planning or operating authorities, which rely heavily on engineering and technical consultants employed to assist in planning and development activities,

Other institutions and groups acting to shape the course of ATC design and development are equip-

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ment manufacturers, industry associations, and organized labor. Except in isolated cases, only the equipment manufacturers exercise any significant influence during the ATC design and development process The influence of labor is usually brought to bear only as a new system is being readied for operation and a contract with the union local is being negotiated.

Community planners, public-interest groups, and the public at large play only a small role in the design and development of ATC systems. There is some evidence that these groups may be assuming more influence, not in technical concerns, but in the area of establishing priorities and general service characteristics.

Policy Impacts

Federal policy from 1964 to 1974 may have tended to encourage the development of new, technologically advanced transit systems employing highly automated forms of train control. In part, this policy appears to have stemmed from the expectation that automation would lead to increased productivity-a benefit that, in the case of ATC, has not been substantiated. This policy may be in the process of change as a result of the National Mass Transportation Assistance Act of 1974.[1]

Transit agencies, when planning new systems, have also been inclined to favor technological advancement partly as a reflection of how they perceived Federal Government policy and partly because they or their consultants believed advanced technology was necessary to win public support for development and patronage of the system.

This situation has created a tendency for system designers to turn to highly automated forms of train control as a means of offering improved performance and service. The superiority of automated over manual methods of train control is not certain, however, except in the area of train protection (ATP).

The public appears to attach greater importance to dependability of service and personal security than to ATC system performance characteristics. The cost of automatic train control has negligible influence on the public primarily because it is small in relation to the total cost of the system (typically between 2 and 5 percent). A question on train control system automation, as a specific issue, has never been submitted to the public for decision by referendum.

THE PLANNING, DEVELOPMENT, AND TESTING PROCESS

The evolution of a rail rapid transit system from concept to start of revenue service may span 10 to 20 years. The process has three major phases: planning, engineering development, and testing, Research and development to support design are conducted throughout but tend to be concentrated in the middle phase, where detail design and development takes place. The design and engineering of the train control system, while generally concurrent with the development cycle of the whole transit system, is usually neither the pacing item nor a dominant technical concern.

Findings concerning the planning, development, and testing process for ATC systems are as follows:

Planning

Formulation of the ATC design concept and determination of the extent to which the system will be automated are greatly influenced by nontechnical factors, notably social and political concerns, the prevailing attitude of decisionmakers and system designers toward technological innovation, and reaction to the recent experience of other transit agencies.

Cost-benefit analyses conducted during the system design process seldom, if ever, include evaluation of alternative ATC concepts and different levels of automation, perhaps because ATC represents only 2 to 5 percent of total system cost and benefits are not easily quantified.

The comparative operational costs of alternative levels of ATC are given very little consideration.

Engineering Development

ATC procurement specifications vary greatly in terms of approach and level of detail; but the trend in newer systems is toward a more quantitative form of specification, particularly for reliability, maintainability, and availability requirements.

[1]The OTA study, An Assessment of Community *Planning for* Urban Mass Transit, February 1976 (Report Nos. OTA–T–16 through OTA–T–27), deals extensively with the history and current trends of planning and public policy in mass transit.

There is a recognized need in the transit industry for improvement in the writing of specifications and in setting realistic requirements for reliability, maintainability, and availability.

In new transit systems, the ATC equipment is procured as a package through a single contractor. In existing transit systems, ATC equipment is often acquired piecemeal as additions or improvements to equipment already in operation.

In most instances, contractor selection is based on low bid from technically qualified competitors. This procedure is usually required by State law or local ordinance. Noncompetitive procurement is seldom used, except for a follow-on to an earlier contract.

Testing

Testing is conducted at several points in the development process, generally for one of three purposes: qualification and validation of component and subsystem design, assurance of conformity to specification, and demonstration of total system performance prior to final acceptance and start of revenue service.

Performance verification and acceptance testing of train control systems, coming near the end of the development cycle, may be slighted because of pressure to open the system for service. The preoperational test program may be either abbreviated or deferred until after the start of revenue service and often extends into the first year of operation or longer.

The quality and extent of assurance and acceptance testing vary greatly among transit systems, largely as a function of the qualifications and experience of the organization managing the development of the system. There is a need for more detailed and comprehensive test plans, more clearly defined criteria and methods of measurement, more rigorous procedures for conducting tests, and more complete documentation of test findings.

Research and Development

There are no test tracks and experimental facilities for carrying out R&D activities related to train control, except at individual transit systems or at a manufacturer's plant as part of a product development program. The Pueblo facility does not permit detailed study of ATC design and engineering problems in a realistic operational setting.

The state of ATC technology is such that the greatest R&D need is refinement of existing designs and not development of innovative or more advanced technology. Yet, relatively little R&D effort is concentrated on presently known operational problems, such as reliability, maintainability, and availability, performance testing methods and standards, and development of a uniform data base on ATC system performance.

OPERATIONAL EXPERIENCE

No rail rapid transit system now operating or under development in the United States has a train control system that is completely automatic. All employ some mixture of manual and automatic control, and all have at least one person on board the train to carry out some control functions. Only two rail rapid transit systems operating in the United States at the end of 1975—BART in San Francisco and the PATCO Lindenwold Line in Philadelphia and suburban New Jersey-are automated to the extent that the trainman has little or no direct part in operating the train. In all other U.S. rail rapid transit systems, trains are operated manually, with automation employed only for train protection and some supervisory functions. New transit systems being planned and developed in Washington, Baltimore, and Atlanta show the influence of BART and PATCO with respect to both the level of automation and the use of advanced ATC technology.

A survey of the operational experience with ATC leads to the following findings:

Safety

Automatic Train Protection (ATP) systems are superior to manual methods of preventing collisions and derailments, principally because ATP safeguards against human error and inattention. The use of ATP is becoming universal in the U.S. transit industry.

Automatic Train Operation (ATO) offers no clear safety advantages over manual modes of operation.

Automatic Train Supervision (ATS) does not produce additional safety benefits beyond those attainable with traditional manual or machine-aided forms of supervision carried out by dispatchers, towermen, and line supervisors.

In conjunction with increased automation, the size of the train crew is often reduced to one. One-man operation does not appear to have an adverse effect on passenger security from crime or on protection of equipment from vandalism.

Performance

Under normal operating conditions, the ride quality provided by ATO is comparable to that of manually operated trains. The principal advantage of ATO is that it eliminates variation due to the individual operator's skill and provides a ride of more uniform quality. Manual operation is considered to be the more effective mode of control under certain unfavorable weather and track conditions.

Systems with ATC have experienced problems of schedule adherence during the start-up period, but it is not certain how much of this is a result of train control automation and how much is due to other factors such as the complexity and reliability of other new items of transit system equipment.

Reliability of ATC equipment has been a major operational problem. Failure rates for both wayside and carborne components have been higher than anticipated, but not greater than those of other transit system components of comparable complexity and sophistication (e.g., communications equipment, propulsion motors, electrical systems, air-conditioning equipment, and door-operating mechanisms).

Maintenance of ATC equipment, like other items of new technology, has been troublesome because of longer repair time, more complicated troubleshooting procedures, higher levels of skill required of maintenance personnel, and the lack of people with these skills. A shortage of spare parts has also hindered maintenance efforts.

On the whole, however, ATC equipment contributes proportionally no more to vehicle downtime or service interruptions than other transit system components. The problem is that ATC, like any other new element added to a transit system, has an effect that is cumulative and tends to lower the general reliability of the system.

Costs

ATC typically accounts for 2 to 5 percent of the capital cost of rail rapid transit; the variation is almost directly proportional to the level of automation,

Because of the reduction in train crew that often accompanies ATO and because of the centralization and consolidation of train supervisors brought about by ATS, automated systems are somewhat cheaper to operate than manual systems. These savings are offset, however, by the increased labor costs of maintaining ATC equipment. In comparison with manual systems, the maintenance force for ATC systems is larger, skill requirements and the corresponding salary levels are higher, training of technicians must be more extensive and hence costly, and repairs are more frequent and take longer. The combined operation and maintenance costs of automated systems are about the same as those of manual systems, There is no evidence that ATC systems lead to more efficient train operation or to any significant change in energy consumption. Vehicle weight, route layout, and propulsion system characteristics are far more dominant factors in energy use than automated or manual operation.

Human Factors

Monotony and light responsibility make it difficult for operators of highly automated systems to maintain vigilance. There has also been a tendency for ATC system designers, notably in BART, to make insufficient use of the human operator to back up or enhance automatic system performance. The designers of systems now under development are seeking to integrate the operator more effectively into the ATC system, to give man a more meaningful set of responsibilities, and to make automatic equipment more amenable to human intervention.

For maintenance employees and train supervision personnel, ATC systems impose new and higher skill qualifications and more demanding performance requirements.

The effect of automation on passengers is negligible, except insofar as it maybe more difficult for them to obtain information with fewer transit system employees on the train.

ASSESSMENT OF ATC TECHNOLOGY

The following is an analysis and interpretation of the findings in light of the concerns expressed in the letter of request from the Senate Committee on Appropriations.[4]

[4]This letter and related correspondence are contained in appendix I.

The State of ATC Technology

ATC technology is a mature technology insofar as train protection (ATP) and train operation (ATO) functions are concerned. The major difficulties encountered in these areas have arisen from the application of new, unproven techniques that represent departures from conventional train control system engineering. Train supervision (ATS), except for certain well-established dispatching and routing techniques, is the least advanced area of ATC technology. Research and development efforts are now underway to devise computer programs and control techniques to permit comprehensive, real-time supervision and direction of train movement by automated methods.

Operational experience indicates that automatic train protection (ATP) enhances the safety of a transit system because it safeguards against collisions and derailments more effectively than manual and procedural methods. Performance and service characteristics of ATC systems are as good as, and perhaps better than, manual systems once the somewhat lengthier period of debugging and system shakedown has passed. Reliability and maintenance continue to be serious problems for systems using higher levels of ATC and probably account for an increase in operating costs that outweighs any manpower savings achieved through automation.

Application of ATC Technology in New Systems

In assessing the application of technology in new transit systems, a distinction must be made between train protection (ATP) and train operation and supervision (ATO and ATS). All systems-old, new, and planned—rely on automatic devices to accomplish train protection functions. Two forms of technology are employed. One uses wayside signals with trip stops, the other uses cab signals. The trend in the transit industry today is toward cab signaling, which is the newer technology, because it offers somewhat more flexible protection than wayside signaling, and because it provides an evolutionary path to partially or fully automated train operation. The new systems in Washington, Atlanta, and Baltimore and the recent extensions to existing systems (e.g., the CTA Dan Ryan extension and the MBTA Red Line) all employ cab signaling and the more automated forms of operation derived from it.

With regard to ATO and ATS, the new systems under development and those in the planning stages will employ more advanced technology and higher levels of automation than those built and put in operation before 1969. With some exceptions, such as door closure or train starting, train operation in the new systems will be entirely automatic, but supervised by an on-board operator who will intervene in case of emergency or unusual conditions. Central control functions (ATS) will be assisted, or in some cases accomplished entirely, by automatic devices. Thus, train operation and supervision in new systems will resemble those of PATCO and BART, and the general trend is toward extensive use of ATO and ATS.

There is almost no research and development now in progress to produce new ATC technology for rail rapid transit. The development work currently underway is devoted primarily to refinement of existing techniques and their application in particular localities. The transit industry has watched closely the experience of BART and PATCO. The results of the PATCO approach, which made use of conventional technology, have been compared to those of BART, where innovative technology and more extensive automation were employed. The designers of the Washington, Atlanta, and Baltimore systems have generally opted for a middle ground with regard to automation and have followed a cautious approach to new technology, inclining more toward PATCO than BART. Particular care has been given to the role of the human operator in backing up or augmenting the performance of ATO. and ATS equipment. The experience of BART and PATCO has also led the newer systems to give careful attention to the reliability and maintainability of ATC equipment and to developing strategies for assuring system performance in adverse conditions or degraded modes of operation. It is certain that WMATA, the next of the new systems to be put in operation, will be scrutinized by the transit industry for other lessons to be learned.

The Testing Process

As train control systems have grown more complex, the testing process has been burdened in two ways: there are more elements that must be tested from prototype through final installation, and there are more interrelationships that must be checked out before the system can be placed in revenue service. The problem of testing is especially difficult in a new transit system, where all the equipment is new and untried and where all the parts need to be tested before initiating passenger operations.

The experience of BART has underscored both the basic need for testing and the importance of giving careful attention to test methods, procedures, and documentation of results. The application of new technology on a large scale in a transit system involves more than just development and installation of equipment; it also involves the application of management techniques to integrate the parts of the system and to test and evaluate the performance of these parts, singly and in the system as a whole. Perhaps the greatest shortcoming in the area of testing in the transit industry today is the lack of a satisfactory method for comprehensive evaluation of transit system performance, under realistic conditions, in the preoperational period, This is often compounded by political, social, and economic pressures to open the system for revenue service as soon as possible, with the result that the test program may be truncated or deferred until after opening day and the full certification of the system may not come until months or years later.

The managers of the new systems under development appear to be mindful of these problems. Improved testing methods and procedures are being devised. More complete programs of preoperational testing, even at the expense of postponing revenue service, are being planned. An incremental approach to testing and full system operation has been adopted, with each step building on the results of earlier phases and with testing timed to the pace of system growth. Methods of testing in revenue service, both in regular hours of operation and during nighttime periods, are being explored. More attention is being given to documentation of test plans and results.

Selecting the Level of Automation

There is no single procedure for selecting the type of train control system and the level of automation. Individual transit authorities follow rules of their own devising. Some rely on the advice of consultants; others draw upon the experience of their own technical staff, Only a few generalizations can be made about the nature of this process.

The decisionmaking process does not appear to be deeply analytical. Criteria of choice are not often defined, the rules of choice are not made explicit, and the analysis of alternatives is not documented except in a fragmentary fashion by internal memoranda and working papers.

Established transit systems, where extensions or new lines are being planned, give considerable attention to the engineering characteristics of the proposed train control system, primarily to assure that new ATC equipment can be successfully integrated with other parts of the existing system, In this case, engineering criteria serve primarily as constraints upon the type of ATC equipment that can be used or upon the level of automation to be selected. The established rules and procedures of the transit system act in much the same way to limit the choice of design alternatives. But there is no evidence to indicate that the planning and design process includes studies directed specifically at determining an optimum train control system or at balancing train control system design features against the service and operating characteristics of other equipment or of the transit system as a whole.

In new transit systems, the process for selecting a train control system is governed even less by system engineering and trade-off studies. The level of automation appears to be selected, more or less arbitrarily, early in the system development cycle. It is treated more as a postulate or a design goal than as a point for analysis and trade-off. It also appears that characteristics of the proposed ATC system are derived more from general, nontechnical decisions about the nature of the whole system and its desired service features (speed, headways, station spacing, etc.) than from technical considerations of control system design or automation technology.

During the planning process, the development and acquisition costs of ATC equipment are considered, but formal cost-benefit studies specific to the ATC system are usually not conducted. ATC costs-and, to a lesser extent, benefits—are sometimes factored into cost-benefit studies for the transit system as a whole; but the objective of these studies is to analyze other aspects of the system or to justify a more general choice regarding transit mode, system size, or route structure. The operational costs of ATC are seldom included in system cost-benefit studies, and they are not subjected to separate analysis to determine their potential influence on the life-cycle costs of the transit system,

RAIL RAPID TRANSIT

Rail rapid transits is an old and established part of the national transportation system. It carries large numbers of people at high speeds within central business districts and to and from outlying areas. The patronage in Chicago, for example, is over half a million people on a typical weekday; in New York City as many as 3-1/2 million riders are carried daily. Nationwide, rail rapid transit serves about 2 billion passengers per year. In the newer systems, top speeds of 70–80 miles per hour are attained, with average speeds of 30–40 miles per hour for an entire trip. In cities where there is an existing rail rapid transit system, it is difficult to conceive how they could function properly, or at all, without this mode of transportation.

Most rail rapid transit systems in this country were built over 30 years ago. The New York, Boston, and Chicago systems date from the turn of the century. In recent years, other major cities have turned to rail rapid transit as a solution to the problems of urban transportation and automobile traffic congestion. The Lindenwold Line (PATCO) in New Jersey and BART in San Francisco were built within the last 10 years, and rail rapid transit systems are planned or under construction in Atlanta, Baltimore. and Washington, D.C. The major cities with existing systems (New York, Chicago, Boston, Philadelphia, and Cleveland) have undertaken programs to extend and improve their service.

Along with the new attention to rail rapid transit has come an increased concern with technology. The basic technology of rail rapid transit, which derives largely from railway engineering, is quite old. Propulsion and braking systems, for example, are products of the late nineteenth century. The electric track circuit, used to detect the presence of trains and to assure safe separation of trains, was developed over 100 years ago. The cam controller (a mechanism for controlling the application of power to d.c. propulsion motors) was first used in the Chicago subway system in 1914. Cab signaling systems. functionally similar to those of today, were in use in the 1930's. While this technology has been refined and improved over years of operational experience, many transit system planners and engineers believe that new and more sophisticated forms of technology need to be applied in order to achieve systems of higher safety, performance, and efficiency,

Generally, two avenues of technological innovation are proposed for rail rapid transit: substitution of electronic for electromechanical components and more extensive use of automation, One such application of new technology is in the area of train control, where the replacement of men with electronic monitoring and control mechanisms is thought to offer several advantages--greater consistency of performance, safeguarding against human error, more extensive and precise control of train operations, and reduced labor costs in operating the system. However, some transit engineers have misgivings about the ability of the newer automatic train control systems to perform as safely and efficiently as manual systems, There is also some doubt about the cost-benefit of automation. Automated control systems are more expensive to design and produce, and their complexity may make them less reliable and more costly to maintain. Automatic train control is, thus, a controversial matter in rail rapid transit, especially as a result of the difficulties encountered by the BART system in San Francisco. BART is the newest and most technologically advanced transit system in the United States, but it has not yet lived up to the levels of performance and service predicted during its planning and development, or even to the standards set by older and technologically less advanced transit systems now in operation. Some critics contend that problems of BART stem from its extensive use of unproven innovative technology for train operation and control,

A part of the controversy over automation may stem from a common misconception that it is synonymous with computers. Electronic data processing is certainly one way to achieve automatic operation, but there are others. The track circuit, the electromechanical relay, the emergency air brake, the trip stop, and recorded passenger information announcements are all automatic devices; and none involves a computer in the usual sense of the term. Another misconception is that automation is something new, a product of aerospace technology. While it is true that automated equipment has been employed extensively in advanced aviation and space systems, the birthplace was certainly not there. Automation has been with us since the beginning of the industrial revolution. All of the

*Rail rapid transit is an electrified rail system operating in urban areas on exclusive rights-of-way, Rail rapid transit is considered here to exclude commuter railroad systems and light rail systems, although the technology of train control is similar for all three.

automatic devices mentioned above have been in use in rail rapid transit for many years.

Thus, the issue is not whether automation should be applied in rail rapid transit train control. Automatic train control devices of various types have been used in rail rapid transit for many years. The real concerns are where should automation be applied, how far should the train control process be automated, and what technology should be used. As phrased by the OTA staff in planning this assessment of automatic train control in rail rapid transit, the central question is: "What degree of system automation is technically feasible, economically justifiable, or otherwise appropriate for rail rapid transit?" The answer, which entails examination of safety, performance, and cost, is crucial to the future development of rail rapid transit and its value as a public transportation system.

OBJECTIVES

This study was undertaken with the following objectives:

1. to examine the design characteristics of automatic train control systems and evaluate the state of automatic train control technology;
2. to assess the operating experience and performance of transit systems which employ various forms of automatic train control;
3. to analyze the process by which automatic train control systems are planned, developed, and tested;
4. to examine the policy and institutional factors that influence the application of automatic train control technology in rail rapid transit.

Thus, the emphasis of this report is not on technology as such. While there is considerable attention given to technical matters in the early chapters, it is intended as background for subsequent examination of the results and implications that ensue from the application of automation in rail rapid transit systems. The bulk of this report is devoted to an assessment of the practical results of ATC in operating transit systems and to the practical results of ATC in operating transit systems and to an evaluation of the planning and development process by which ATC systems evolve in the context of public institutions and government policy.

SCOPE

The scope of this report is limited to automatic train control technology in rail rapid transit systems. No attempt has been made to deal either with rail rapid transit technology as a whole or with the application of ATC to small-vehicle fixed-guideway systems.[6] The parts of this report that deal with the planning and development process are confined to matters relating to the evolution of the train control system. It is recognized that ATC design and development does not occur in isolation, but as a part of the larger process by which the entire transit system is planned and built. A more general assessment of mass transit planning is the subject of a separately published report.[7]

Five operating rail rapid transit systems are examined in this report:

- Bay Area Rapid Transit System (BART) in the San Francisco area,
- Chicago Transit Authority (CTA),
- Massachusetts Bay Transportation Authority (MBTA) in the Boston area,
- New York City Transit Authority (NYCTA),
- Port Authority Transit Corporation (PATCO), the Lindenwold Line, in Philadelphia and suburban New Jersey.

These systems were selected for study because they embrace a broad range of system characteristics. They vary from a simple one-line system (PATCO) to complex and dense transit networks (CTA and NYCTA). They represent a range of automation, from predominantly manual (NYCTA and CTA) to highly automated (BART). They differ greatly with respect to age--NYCTA, MBTA, and CTA being the oldest and PATCO and BART the newest. They also employ several forms of train control technology--conventional (CTA, MBTA, NYCTA), advanced (PATCO), and innovative (BART).

[6] An assessment of the technology of transit systems employing automatically operated small vehicles on fixed guideways was issued by OTA in June 1975 under the title, Automated Guideway Transit (Report No. OTA-T-8).

[7] An Assessment of Community Planning for Mass Transit, Office of Technology Assessment, February 1976 (Report Nos. OTA-T-16 through OTA-T-27).

In addition to these five operating systems, others in the planning and development stage are considered in the parts of the report that deal with the process by which transit systems are conceived, designed, and built. The principal rail rapid transit systems under development are:

Metropolitan Atlanta Rapid Transit Authority (MARTA)

Mass Transit Administration (MTA) in Baltimore

Washington Metropolitan Area Transit Authority (WMATA)

STUDY METHOD

This assessment was a joint undertaking by the OTA Transportation Program Staff and the Urban Mass Transit Advisory Panel, an 11-member group made up of representatives of the transit industry, State department of transportation, planning consultants, organized labor, and public-interest groups. Battelle Columbus Laboratories acted as technical consultants and provided major assistance in collecting data and conducting interviews with transit system officials, planning organizations, and equipment manufacturers. The OTA staff also carried out an independent program of visits to interview transit system officials at five sites and to collect data on their operational experience with ATC equipment. The findings of the Battelle investigation were presented to the panel in a series of background and technical documents. This material was combined with the results of the OTA staff effort to form the basis for this technology assessment.

ORGANIZATION

This report is organized to accommodate readers of different interests and technical backgrounds. The next two chapters, entitled "Automatic Train Control" and "Transit System Descriptions," are intended to acquaint the reader with basic train control technology and the operational characteristics of the rail rapid transit systems selected for study. These chapters are written with a minimum of technical detail and provide a general background for the subsequent examination of operational, planning, and policy issues. Those already familiar with train control technology and transit operations may wish to skim this material or to pass on directly to chapters 5, 6, and 7, which deal with operational experience, planning and development, and policy issues relating to automatic train control technology. As an accommodation to differing reader interests, these chapters are organized in three levels of detail. The first level is a summary of the major issues at the beginning of each chapter. Next is a presentation of the individual issues, each headed by a capsule statement and a synopsis of the principal findings and conclusions. The third level consists of supporting detail and discussion of the implications for each issue. Thus, the reader can pursue each topic to whatever depth desired.

At the end of the report are various technical appendices, intended primarily for those who wish more specific information on train control technology and system engineering features. Appendix D—Glossary of Terms, and Appendix E—Chronology of Train Control Development, may also be of interest to the general reader.

Train control is the process by which the movement of rail rapid transit vehicles is regulated for the purposes of safety and efficiency. The process is carried out by a combination of elements-some men, some machines—located on the train, along the track, in stations, and at remote central facilities. These elements interact to form a command and control system with four major functions:

. Train Protection	prevention of collisions and derailments,
. Train Operation	control of train movement and stopping at stations,
● Train Supervision	direction of train movement in relation to schedule,
. Communication	interchange of information among the elements of the system.

The train control system is analogous to the sensory organs and central nervous system of the human body. It senses and processes information, makes decisions, and transmits commands. Also as in the human body, the execution of commands is not a function of the train control system but of other parts specialized for that purpose. For example, the train control system may sense train speed, determine that it should be increased, provide an appropriate command signal to the motors, and monitor to see that the desired result is achieved. The means by which a speed change is effected, however, are not part of the train control system. All the equipment for getting electric power to the wayside, bringing it into the train, converting it to mechanical energy, and providing tractive effort is external to the train control system. Similarly, the equipment to select a route for a particular train and transmit commands to aline switches accordingly are within the train control system, but the parts of the trackwork that actually moye (the switch points) are not elements of the train control system.

TRAIN CONTROL SYSTEM FUNCTIONS

Presented below is a description of the specific functions performed by a train control system and of the way in which functional elements interact. These functional relationships are also illustrated by the diagram in figure 1. Since the purpose is only to provide the reader with a general background for understanding the nature of train control, the definitions presented here are brief and nontechnical.[9]

Train Protection

Train protection is a family of functions whose purpose is to assure the safety of train movement by preventing collisions and derailments. Train protection functions and requirements override all other control system functions either through equipment design or, in a completely manual mode, by rules and procedures. The functions that make up train protection are:

Train detection—monitoring of the track to determine the presence and location of trains;

Train separation-assuring that trains on the same track maintain a safe following distance to prevent collisions;

Route interlocking—preventing trains on crossing, merging, or branching routes from making conflicting (unsafe) moves that would cause a collision or derailment;

Overspeed protection—assuring that train speed remains at or below the commanded or posted civil speed limit[10] as to prevent collisions resulting from going too fast to stop within the available distance and to prevent derailments due to excessive speed on curves or through switches;

Train and track surveillance-observing conditions on and in the vicinity of the track ahead of the train and monitoring safety-related conditions on board the train.

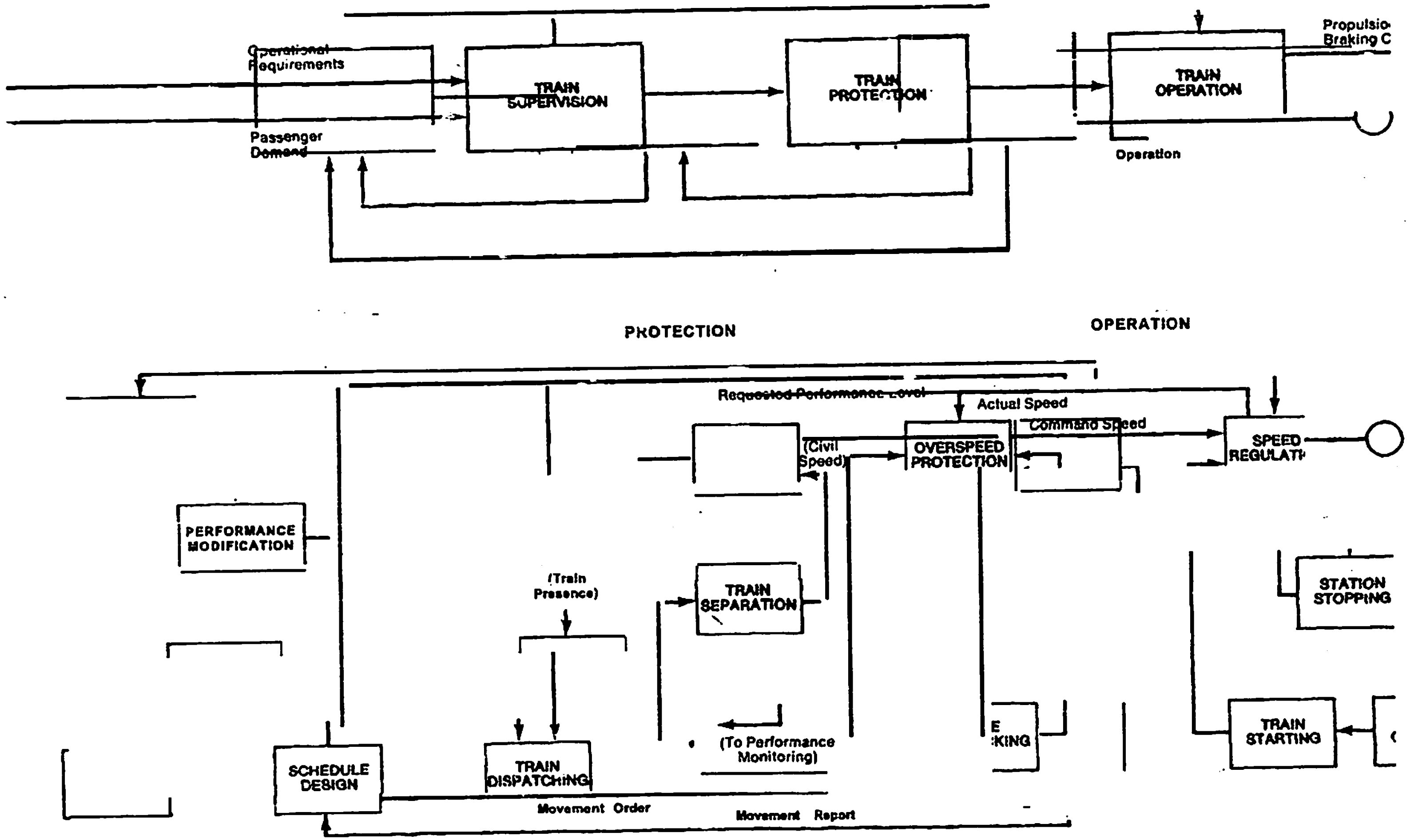
Train Operation

Train operation consists of those functions necessary to move the train and to stop it at stations

F. For more detailed technical descriptions of train control system functions and technology, see appendices A and B.

[9]There is no universally accepted terminology and scheme of definitions for train control system functions within the transit industry. The terms and classification employed here are based on several sources and represent the best of current usage.

[10]A glossary of train control and rail rapid transit terms is provided in appendix D.



* To simplify the diagram, the functions of Alarming and Recordkeeping are not shown

FIGURE 1.—Train

to board and discharge passengers. Train movement, as controlled by train operation functions, is under the direction of train supervisory functions and always within the constraints of train protection functions. Train operation involves the following:

- Speed regulation-controlling train speed, within the constraints of overspeed protection, to make the run according to schedule;[11]
- Station stopping—bringing the train to a stop within some specified area in a station;
- Door control--opening of doors in stations to permit passengers to enter or leave the train and closing of doors when the train is ready to start;[12]
- Train starting—initiating train departure from a station after the doors are closed (and provided the train protection system permits it),[13]

Train Supervision

Train supervision involves monitoring the movement of individual trains in relation to schedule and route assignments and overseeing the general disposition of vehicles and flow of traffic for the system as a whole. The train supervision system may thus be thought of as making strategic decisions which the train operation system carries out tactically, In addition, train supervision includes certain information processing and recording activities not directly concerned with train safety and movement but necessary to the general scheme of operations. Train supervision functions are:

- Schedule design and implementation—preparing a plan of service in light of expected demand, available equipment, and environmental conditions and issuing a schedule to implement the plan;
- Route assignment and control--selecting and assigning routes to be followed by trains (and rerouting as necessary);
- Train dispatching-controlling train departures from terminals or waypoints in accordance with the schedule;
- Performance monitoring—following the progress of trains against the schedule by obtaining periodic updates of train identity, location, and destination;
- Performance modification—adjusting movement commands and revising the schedule in response to train, traffic, and environmental conditions.
- Alarms and malfunction recording-alerting to malfunctions, breakdowns, or problems, and recording their time, location, and nature;
- Recordkeeping —maintaining operational logs and records for business and payroll purposes, for scheduling maintenance, for ordering supplies and equipment, and for computing technical statistics.

Communication

The communication system is the means by which the information needed to carry out all other train control functions is transmitted and exchanged.[14] This information may take any of several forms-voice, visual, auditory, and digital

[11] Speed regulation involves more than matching actual to command speed. It also includes control of acceleration, jerk limiting (controlling the rate of change of acceleration), slip-slide control (correction of wheel spinning during acceleration and skidding during braking), and flare-out (gradual relaxation of braking effort as the train comes to a stop). Flare-out is considered by some transit engineers to be a subsidiary function of speed regulation, and hence part of the train control system. Acceleration control, jerk limiting, and slip-slide control are regarded by transit engineers to be propulsion and braking system functions, but they are mentioned here because of their relationship to the train control functions of speed regulation and station stopping.

[12] The mechanisms that actually open and close doors are not part of the train control system, but the signals to actuate these mechanisms and the interlocks to assure that doors are closed before starting and that they remain closed while the train is in motion are generated within the train control system. Because of the safety implications of door control, some transit engineers consider it to be a part of train protection.

[13] Train starting is sometimes classified as part of the door control function. It is separated here for two reasons: (1) in some automated systems, door control is automatic while train starting is retained as a manual function; (2) in manual systems, the door control and train starting functions are often assigned to different persons.

[14] On the function diagram in figure 1, communication functions are indicated by the lines connecting the boxes which represent train protection, operation, and supervision functions.

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or analog electrical signals.[15] Unlike other train control functions, which involve information processing and decisionmaking, communication is largely a facilitative process-serving to convey information but without producing any unique functional outcomes of and by itself. For this reason, the categorization given below indicates not functions as such but major classes of information that must flow throughout the system in order for other train control functions to take place:

Train protection—information necessary to locate individual trains, to assure their safe separation, to prevent overspeed, and to control movement at route interlockings;[16]

Command and status—information on the operational state of the system, command signals to control train and switch movement, and feedback to determine the response of system elements to command inputs;[16]

Emergency—information on the nature and location of emergency events and summons for help to elements within the transit system or to outside agencies (e.g., fire, police, medical, and rescue);

Passenger service—information relating to train service and system operation for the purpose of assisting passengers using transit facilities;

Maintenance—information needed to plan or conduct preventive and corrective maintenance;

Business operations--operational information used to maintain a record of (and to plan for) work force allocation, vehicle utilization, procurement of supplies and equipment, operating expenses, and system patronage.

[15]Some transit engineers limit the definition of communication to verbal or visual communication (radio, telephone, TV, and the like). Machine-to-machine communications, since they tend to be very specialized, are considered part of the function which they serve. This seems to be unnecessarily restrictive and makes an artificial distinction between information exchange by human operators and other forms of information exchange involved in operating the system (i.e., man to machine or machine to machine). The definition offered here is generic and embraces all types of information flow, regardless of how effected.

[16]Customarily, this part of the communication system is completely separate from the network used for other types of information and is considered to be an integral part of the train protection system.

AUTOMATION

At one time or another, all of the train control functions listed above have been performed by human operators, and many still are, even in the most technologically advanced transit systems. Theoretically, any of these functions could also be performed by automatic devices, and more and more have, in fact, been assigned to machines over the years, Before examining the technology by which train control automation has been achieved, it is first necessary to consider what is meant by automation and to clarify the terminology used in this report.

Figure 2 is a generalized diagram of the process by which any train control function is accomplished. It involves receiving information about some operational state of the system and some desired state. This information must then be interpreted—for example, by comparing the two states and deriving a quantitative expression of the difference, Next, an appropriate control response to null the difference must be selected, and some specific command message to the controlled element must be formulated and transmitted. A final, and all-important, step is monitoring the results of the control action to ascertain that the desired system state or condition has been achieved. This last step, called feedback, provides an input signal to start the process all over again, thereby creating a loop that permits the control process to be continuous and adaptive.[17]

If all of the steps in the general sequence shown in Figure 2 are performed by a human operator, the process is called manual, even though manual action in the strict sense may not be involved. Thus, manual denotes a process that may include visual, auditory, and other forms of sensory perception as well as purely cognitive activities such as interpretation, weighing alternatives, and decisionmaking. The command output might be accomplished by some manual activity such as pressing a button or moving a control lever, or it might take the form of a voice command or simply a nod of the head. The essential feature of a manual process, as the term is used here, is that all the basic control steps to accomplish a function are human activities.

[17]This description overlooks the difference between closed- and open-loop control systems. For a discussion of the application of each in train control technology, see appendix B.

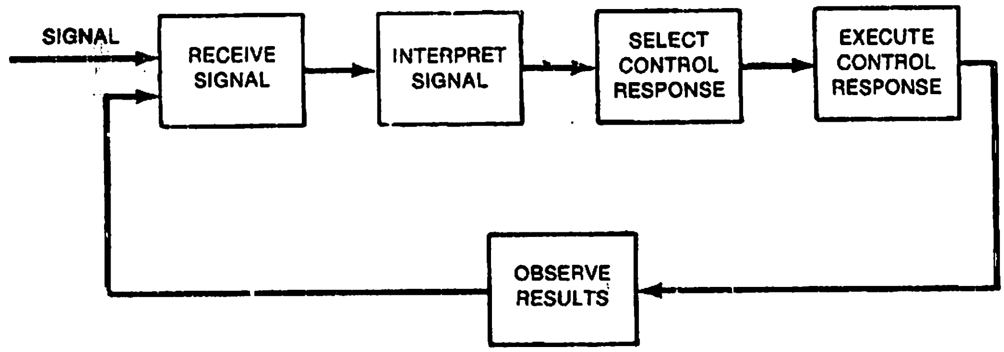


FIGURE 2.—Generalized Control Process

It is also possible for all of the steps in the control loop to be accomplished by some mechanical or electrical device. If so, the process is called automated. The device need not necessarily be complicated, nor is a computer required in order for the apparatus to process information and make a "decision." A simple junction box with a two-state logic circuit (ON or OFF) would satisfy the definition of an automated control device, provided no human actions were required to receive and interpret input signals, select and order a response, and monitor the result.

Between the extremes of purely manual control and fully automatic control, there are numerous combinations of mixed man-machine control loops. These are called semi-automated or partially automated—the terms are used synonymously to denote a process (or a system) in which there are both manual and automatic elements. Thus, automation is not to be taken in an absolute, all-or-nothing sense. The machine can be introduced by degrees into a system to perform specific functions or parts of functions. When comparing parts of a train control system or when comparing one system with another, it is therefore possible to speak of automation in comparative terms and to say that one is more or less automated than another, depending on how many specific functions are performed by machines.

For brevity, acronyms are used to describe certain areas where automation is applied in train control. ATC (automatic train control) refers generally to the use of machines to accomplish train control functions. It does not necessarily suggest a completely automated system. It can be applied to a system where certain functions or groups of functions are performed automatically while others are performed manually. ATP (automatic train protection), ATO (automatic train operation), and ATS (automatic train supervision) are used to designate major groups of functions that may be automated. For example, if a system is said to have ATP, it means that train protection is accomplished (either completely or mostly) by automatic devices without direct human involvement. If a system is described as having ATC consisting of ATP and some ATS, this indicates that train protection is assured by automatic devices and that train supervision is a mixture of manual and automatic elements. By implication, train operation in such a system would be manual.

While automation involves the substitution of machine for human control, this does not mean that the human operator is removed from the system altogether. An automated system is not always an unmanned system, even though all functions are routinely performed by machines. For instance, train protection and train operation may be completely automatic in a given transit system, but there could still be an operator or attendant on board the train to oversee equipment operation and, most importantly, to intervene in the event of failure or malfunction. This emergency and backup role is, in fact, a major type of human involvement in even the most automated train control systems, In all rail rapid transit train control systems now in operation or under development, automation is utilized only for normal modes of operation, with manual backup as the alternative for unusual conditions, breakdowns, and emergencies.

In passing, it should also be noted that automation is not synonymous with remote control, even though the two may at times go hand in hand. In train supervision, for example, many functions are accomplished manually by controllers who are physically far removed from the train and wayside. In central control facilities, the operators may never actually see the vehicles or track and yet perform all or most of the functions necessary to set up routes, dispatch trains, and monitor traffic. Conversely, automated functions are often performed locally, i.e., by devices on board the train or at a station or switch. In general, the location of the controlling element in relation to the controlled element is independent of how the functions are accomplished. However, it is also true that automation does facilitate the process of remote control, and systems with a high level of ATC tend also to employ more centralized forms of train control, especially for supervisory functions.

AUTOMATIC TRAIN CONTROL TECHNOLOGY

The automatic equipment that accomplishes train control functions is often of complex design, but the basic technology is quite simple. The purpose of this section is to provide an acquaintance with the fundamental elements of an ATC system—track circuits, signaling apparatus, train operating devices, interlocking controls, and supervisory equipment, The details of this technology and the design features of ATC equipment now in use in rail rapid transit systems are omitted here but are provided in appendices B and C.

Track Circuits

For safety and efficient operation of a transit system, it is imperative to know the locations of trains at all times. The sensing device providing this information is the track circuit, which was invented over 100 years ago and has remained essentially unchanged in principle even though extensively refined and modified in its engineering details.

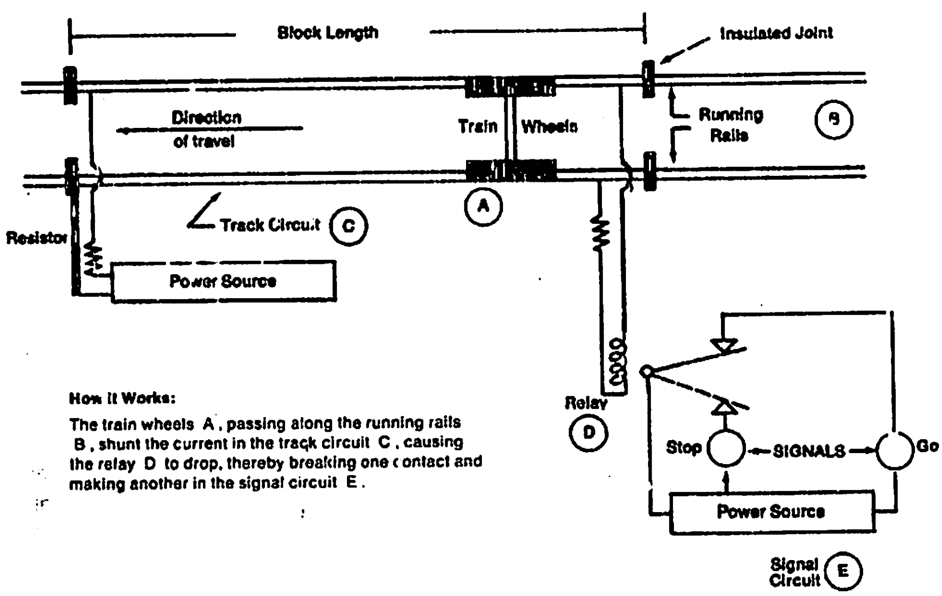


FIGURE 3.—Simple D.C. Track Circuit

The track circuit is an electrical circuit consisting of a power source, the running rails, and a signal receiver (relay).[1] The track is divided into electrically isolated segments (called blocks) by insulated joints placed at intervals in the running rails.[2] This forms a circuit with a power source connected to the rails at one end of the block and a relay at the other. The relay, in turn, forms part of a second electrical circuit which has its own independent power supply (commonly a battery) and includes a signaling device such as wayside colored lights,

When no train occupies the block, the relay is energized by the track circuit battery, causing the relay to "pick up, " i.e., a movable element (armature) is moved to and held electromagnetically in a position opposed to the force of gravity. This closes an electrical contact in the secondary signal circuit. When a train enters the block, the wheels and axles conduct electricity between the running rails, thereby short circuiting (shunting) the track circuit and reducing the current to the relay. This weakens the electromagnetic force holding up the armature, allowing it to drop under the force of gravity. This action opens the contact that was previously closed and closes a different contact in the signal circuit. The relay, therefore, acts as a switch in the secondary signal circuit and creates one electrical path when it picks up and another when it drops.

Thus, the basic principle of the track circuit is the shunting phenomenon produced by the train wheels passing along the electrically energized running rails. The presence of the train is detected in the track circuit as a reduction of electrical current, which-by means of the relay—is used to control the secondary signal circuit and operate various types of track occupancy indicators.

The track circuit is designed according to the fail-safe principle. In order for a clear (unoccupied block) indication to be given, the track circuit must be in proper working order. If one of the rails were to break, the relay would receive no current; and the armature would drop just as if a train were present. A broken electrical connection, a failure of the power source, or a burned-out relay coil would also have the same effect.

Wayside Signals

One of the earliest types of signal devices employed to control train movement, and one still widely used, is the automatic wayside block signal, It consists of a color-light signal, in appearance much like the traffic signal on city streets, located beside the track at the entrance to each block, This signal is controlled by the track circuit relay, as described above. The signal directs train movement by displaying red, yellow, or green lights (aspects) to indicate track circuit occupancy ahead,

Since it would be impractical for the train to creep ahead block by block, waiting to be sure each block is clear before entering, the wayside signals are arranged to give the operator advanced indication of speed and stopping commands. Figure 4 is an illustration of a three-block, three-aspect wayside signal system, This signaling arrangement tells the train operator the occupancy of the track three blocks ahead of the train and conveys three different movement commands (indications)—green (proceed), yellow (proceed prepared to stop at the next signal), red (stop).

In the illustration, Train A is stopped in Block 4 and Train B is approaching from the rear. Since there is a separation of at least three blocks between them, Train B receives a green aspect at the entrance to Block 1, allowing it to proceed at the maximum allowable speed. At the entrance to Block z, however, Train B receives a yellow aspect, indicating that the train operator should be prepared to stop at the next signal because there may be a train ahead. At the entrance to Block 3, Train B is commanded to stop by a red signal aspect. When Train A leaves Block 4 and moves on to Blocks 5 and 6, the signal at the entrance to Block 3 changes to yellow and then green, allowing Train B to proceed.

The wayside signaling system is made fail-safe through design and by operating rules. Dual, or sometimes triple, lamps are used to illuminate each signal aspect. Redundant power sources are sometimes provided. The ultimate safeguard, however, is

[1]Track circuits may utilize one or both running rails, may operate on direct or alternating current, and may have electromechanical relays or solid-state electronic receivers. The type described here is a double-rail dc track circuit with a relay. The other types are similar in principle and operation.

[2]Block length in rail rapid transit systems varies considerably as a function of track and traffic conditions and signal system design. Some are as short as 40 feet; others are over half a mile long,

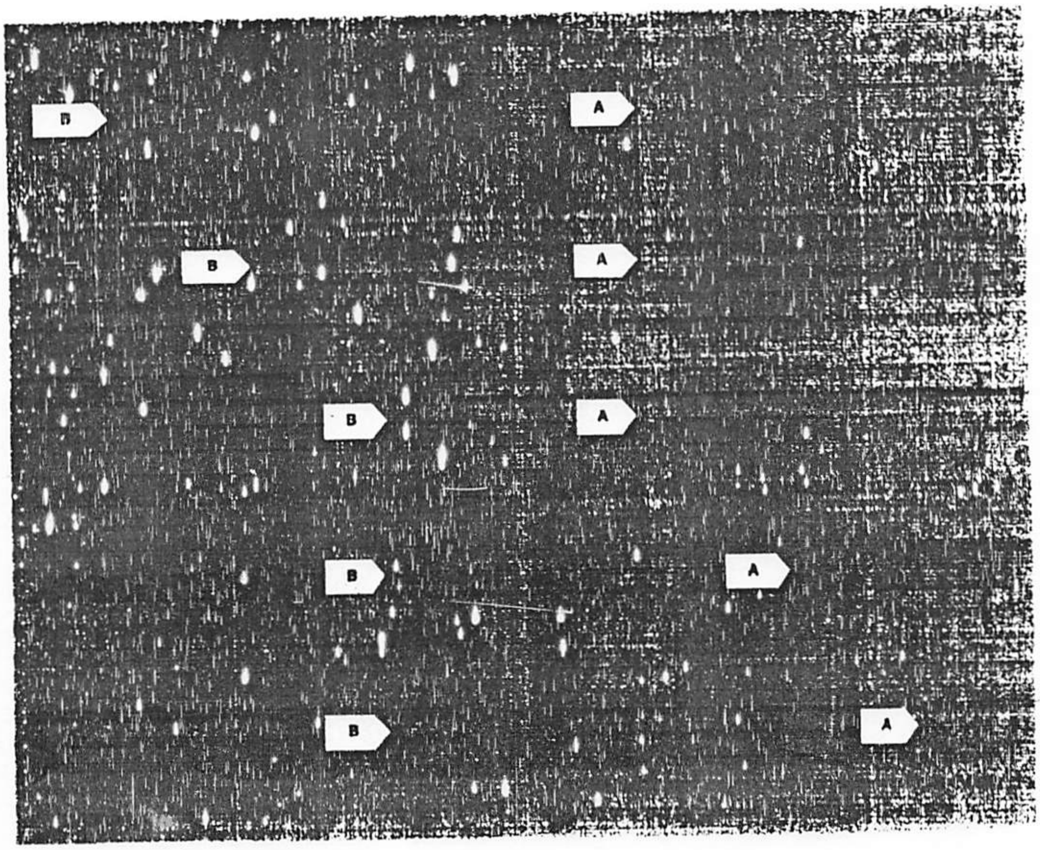


FIGURE 4.—Three-Block, Three-Aspect Wayside Signal System

procedural. A complete failure of the signal lamps or a loss of power would result in a dark (unlighted) signal, which standard operating rules require the train operator to observe as if it were a red signal.

Trip Stops

In the wayside signal system described above, safe train movement depends solely on the compliance of the operator with signal indications. To guard against error, inattention, or incapacitation of the train operator, wayside signals can be supplemented with an automatic stop-enforcing mechanism, called a trip stop.

The trip stop is a device located beside the track at each wayside signal. The type commonly used in the United States consists of a mechanical arm that is raised or lowered in response to the track occupancy detected by the track circuit. When the arm is in the raised position, it engages a triggering device on the train and actuates (trips) the emergency brake.[20] A train entering a block in violation of the wayside signal indication would thus be brought to a complete stop before colliding with the train in the next block regardless of what action the train operator took, or failed to take.

In addition to protecting against rear-end collisions, trip stops can also be used in conjunction with the track circuits and other signal appliances to provide automatic protection against overspeed. For this application, a timing device is added to the circuit controlling the trip stop. When a train enters a

[20] An alternative system employing inductive train stops is used on main-line railroads in the United States and on rail rapid transit systems abroad. The device is somewhat more complex than the mechanical trip stop, but it avoids mechanical contact between a stationary wayside element and a moving train and is less vulnerable to blockage by snow or debris. Both trip stops and inductive train stops have the inherent disadvantage of requiring strict alinement of wayside devices. Further, if either type of device is removed, the system will operate in a mode that is not fail-safe.

block, the trip stop at the entrance to the next block is in the raised position but will be lowered after a time interval corresponding to the minimum time (the maximum speed) permitted for a train to traverse the block. This arrangement is commonly used on curves, downgrades, and other such sections of track where excessive speed could cause a derailment. A variation of this scheme is commonly used at stations to allow a following train to close in on a leading train, provided the follower moves at appropriately diminishing speed as it approaches its leader

Like track circuits and signals, the trip stop is designed to operate in a fail-safe manner The trip is raised to the stopping position by gravity or a heavy spring and lowered by a pneumatic or electric mechanism. Thus, failure of the trip stop actuating mechanism or its source of energy will result in the trip stop being raised to the stop position.

Cab Signals

Automatic block signal systems with wayside signals and trip stops, while offering effective train protection, have certain operational disadvantages. Sometimes the signals are obscured by fog, rain, or snow. In such cases, operating rules require that the operator consider the signal as displaying its most restrictive aspect and operate the train accordingly. If the signal is actually displaying a more permissive indication, time is lost unnecessarily. A second disadvantage is that wayside signals convey commands only at the entrance to a block. The train operator must reduce speed to the maximum permitted by the signal and maintain that speed until reaching the next signal. If conditions change immediately after the train enters the block and it becomes safe to proceed at a greater speed, the train operator has no way of knowing this since the signal is behind him. Again, time is lost. With wayside block signals there is also the possibility that the operator will fail to observe the signal correctly, read the wrong signal in multiple-track territory, or forget the indication of the last signal passed. If there are trip stops, these kinds of human failure do not result in an unsafe condition, but the efficiency of train operation can be adversely affected.

One way to overcome these disadvantages is to provide signal displays within the cab of the train, This is called cab signaling, A display unit, mounted in the cab within the train operator's forward field of view, shows indicator lights similar to those of wayside signals, e.g., red, yellow, and green aspects. Cab signals can thus convey the same movement commands as wayside signals, but they do so continuously in response to the instantaneous condition of the track ahead. They can also convey precise speed commands instead of just stop-and-go information, thus providing more flexible operation and paving the way to ATO. The cab signal unit has an audible warning that sounds whenever the signal aspect becomes more restrictive and continues to sound until the operator silences it by an acknowledging device. Figure 5 is an illustration of a typical cab signal.

Transferring the display of information from the wayside to the cab involves an alternate type of track circuit technology. To operate cab signals, the current passing through the track circuit (usually a.c. is not steady, as for conventional wayside signals, but is pulsed (turned on and off) at several different repetition rates in response to track occupancy. Each pulse rate is a code to indicate allowable train speed. This pulsed d.c. energy is passed through the rails, picked up inductively by a receiver (antenna) on the train, and decoded to retrieve speed command information, This information is used to actuate the appropriate cab signal display. Because the train is continuously receiving pulses of energy, a change in the pulse rate of the coded track circuits indicating a change of conditions ahead of the train is instantaneously received by carborne equipment and displayed by cab signals regardless of where the train happens to be within a block.

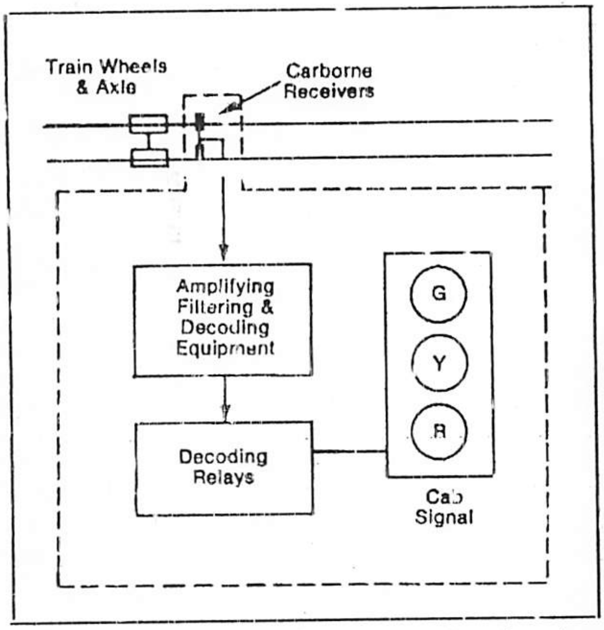
Figure 6 illustrates how cab signals control a train in a three-block, three-aspect signaling system. In this example, the code rates transmitted through the rails (expressed as pulses per minute) correspond to the following signal aspects:

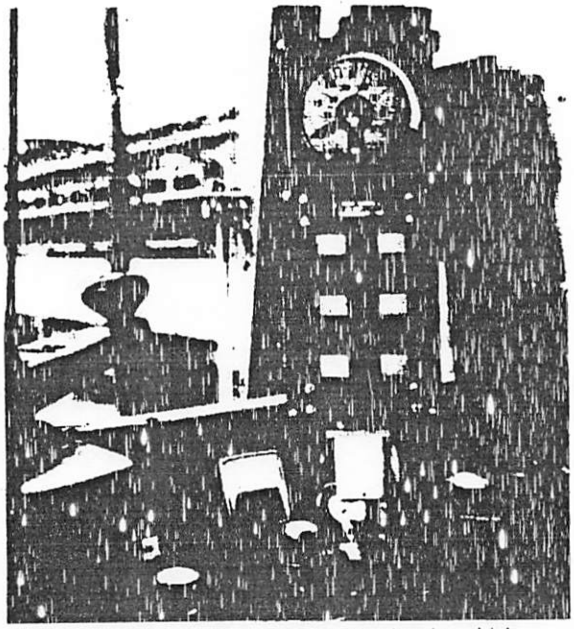
180 Green (Proceed)

75 Yellow (Proceed at medium speed prepared to stop)

O Red (stop)[11]

[11]Note that o code-the absence of a code—is the most restrictive, Thus, any failure of the track circuit or the carborne receiver is a fail-safe condition since it is interpreted by the cab signal equipment as a command to stop.





HOW IT WORKS: Receiver coils, mounted on the train near the rails, receive pulse-coded track signals, which are decoded and used to pick up relays that energize the cab signal lamp indicating track conditions ahead.

FIGURE 5.-Cab Signals

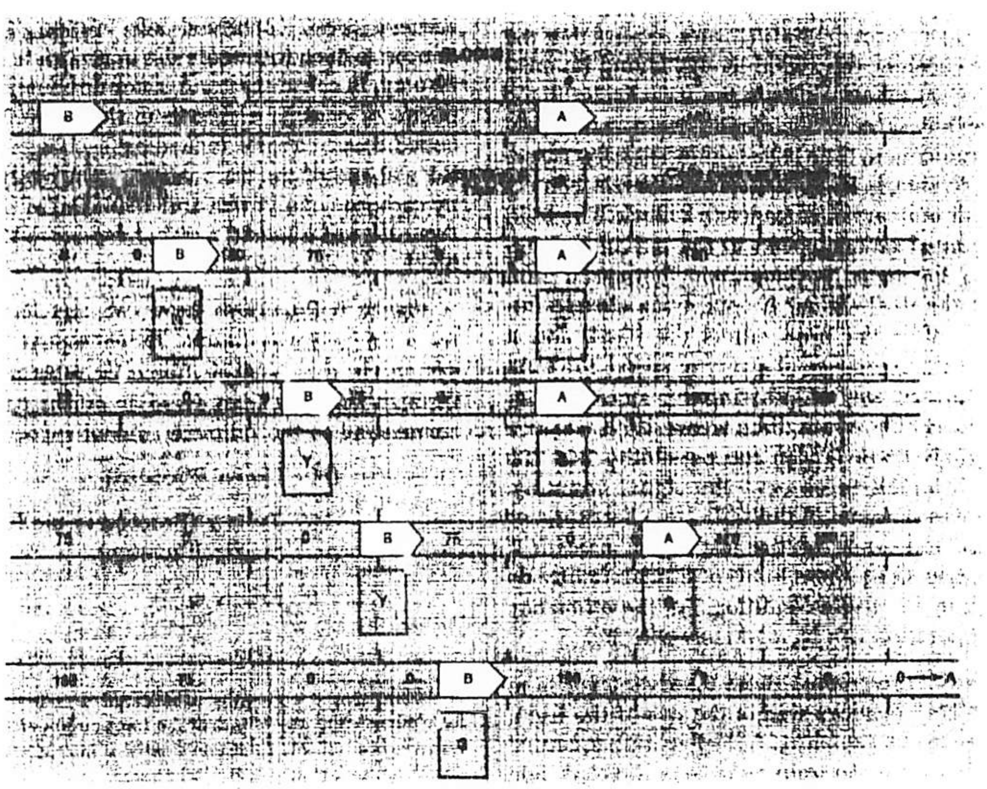


FIGURE 6.—Three-Block, Three-Aspect Cab Signal System

The situation depicted here is the same as in the illustration of wayside signals (figure 4). Train B is approaching Train A, which is completely stopped. Note that the moment Train A starts to move and clears the block, Train B receives a green signal immediately—not at the entrance to the next block, as it would with wayside signals. Note also that a O code appears in the part of the block immediately behind Train B as it moves along the track and that Train B can approach closer to Train A before being required to stop.

Speed Control

With the addition of speed sensing and brake control mechanisms, cab signals can also be used to provide automatic overspeed protection. Figure 7 is a schematic diagram of such a system. It is the same as the schematic shown in figure 5, except for the addition of speed and code rate comparison equipment and the direct connections to the propulsion and braking systems.

This arrangement allows the train operator to control speed so long as it does not exceed the commanded speed shown on the cab signal unit. If the commanded speed is exceeded or if the block speed changes to a lower value because of another train ahead, the operator receives an audible warning. The operator has a fixed time (typically 2 to 3 seconds) to initiate the required braking manually. If this is done, the brakes can be released when the commanded lower speed is reached. If not, the brakes are applied automatically and irrevocably by the ATC system, and the train is brought to a full stop before the operator can resume control. This is analogous to the overspeed control provided by wayside signals with trip stops, except that braking can be initiated anywhere within a block not just at the entrance. Another difference is that trip stops act to stop the train after an overspeed condition has occurred over a measured course, usually several hundred feet in length. Cab signals do the same, but instantaneously, thus eliminating the delay inherent in the preliminary measured course and per-

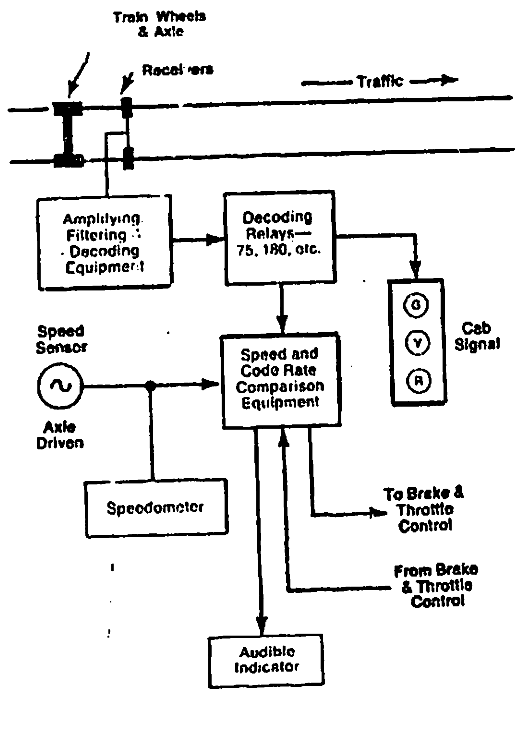


FIGURE 7.—Cab Signal System With Automatic Overspeed Protection

mit trains to follow one another more closely for a given block length.

Automatic Train Operation

Basically cab signaling provides carborne automatic train protection in the form of collision prevention. With the addition of on-board equipment for sensing and comparing command (allowable) and actual speed, cab signaling makes it possible to expand the train protection function to permit speed regulation. This, in turn, forms the basis for extending automation into the area of train operation.

Several forms of automatic train operation (ATO) are possible, but all have two basic features-automatic speed regulation and station stopping.

Automatic speed regulation (ASR), as the name implies, is basically a comparator circuit for matching actual speed to command speed. Speed comands received from coded track circuits are picked up by a carborne receiver, decoded, and compared to actual train speed sensed by a tachometer in the drive mechanism. Up to this point, an automatic speed regulation system is like cab signaling. The difference arises in how this comparison is used. With cab signals, the comparison is used to actuate a penalty brake application to stop the train when actual speed exceeds command speed. With ASR, the comparison is used to control the motors and brakes in an effort to minimize the difference between actual and command speed. An advisory display of speed commands and train speed may be provided for the operator. In effect, ASR removes the human operator from the control loop for running the train and provides for an essentially instantaneous and invariant response by propulsion and braking systems, without the delay of human reaction time and without the variability and possibility for misinterpretation inherent in manual train operation.

The other basic element of ATO is station stopping, which involves bringing the train to stop automatically at a predetermined location in each station. This is accomplished by special wayside control units working in cooperation with position receivers, logic circuits, and automatic speed regulation equipment on the train. One method uses wayside "triggers" spaced some distance from the station as reference points for programed stopping. The first trigger, farthest from the station, transmits a command signal that generates, on board the train, a velocity-distance profile which the train is to follow to a stop. Additional triggers, nearer the station platform, correct the generated velocity-distance profile for the effects of wheel slip and slide. The ASR system monitors the velocity-distance profile and controls the braking effort to bring the train to a stop at a predetermined point. Another method of programed stopping makes use of long wayside antenna to provide a series of position signals to a carborne control system as the train passes along its length. The carborne control system determines train position and combines this with speed and deceleration information (sensed on board the train), to produce an appropriate propulsion or braking command for the traction control system.

To this basic ATO system, other automated features may be added. Doors can be opened automatically after the train is brought to a stop in a station, This requires a circuit to actuate door opening mechanisms and appropriate safety interlocks to assure that the train is in fact stopped and at a station. Door closure may also be automated by adding a timing circuit to measure how long the doors have been open and to initiate a door closure signal automatically after a predetermined dwell time has elapsed. Train departure can also be initiated automatically by introducing another control circuit to apply propulsion power after receipt of a signal confirming that doors are closed and locked.

For each of these levels of ATO, the train operator may be provided with an advisory display to show what commands are being received and what response is being made by automatic mechanisms. The operator may also be provided with manual override controls to inhibit automatic functions or to vary automatic system operation. For example, the operator may intervene manually to adjust the stopping point, to prevent some or all doors from opening, to vary station dwell time, or to initiate or prevent departure. Figure 8 shows a functional diagram of a typical ATO system and a picture of the train operator's console.

Interlocking

An interlocking is an arrangement of signals and signal appliances so interconnected that functions must succeed each other in a predetermined sequence, thus permitting safe train movements along a selected route without collision or derailment. An

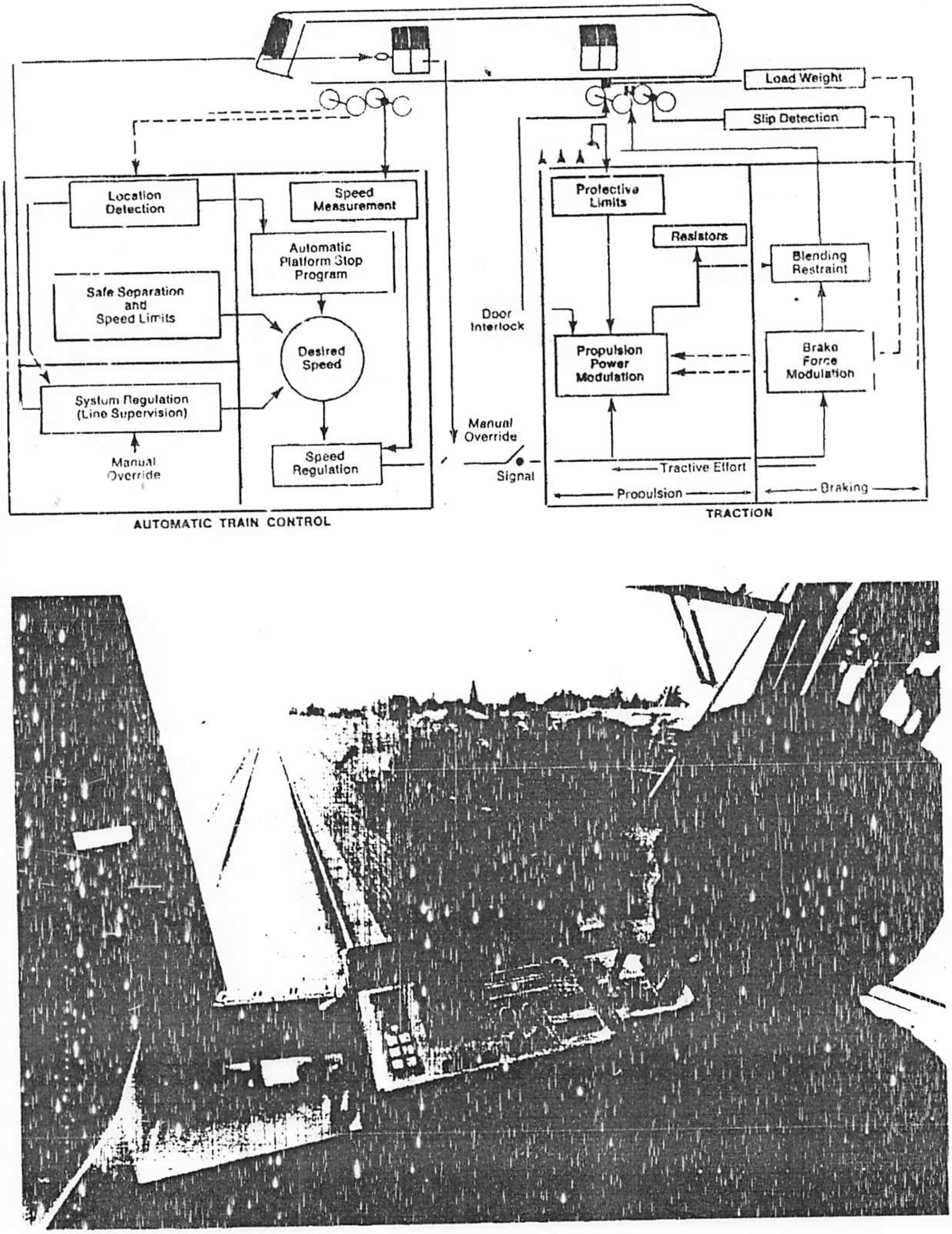


FIGURE 8.—Automatic Train Operation System

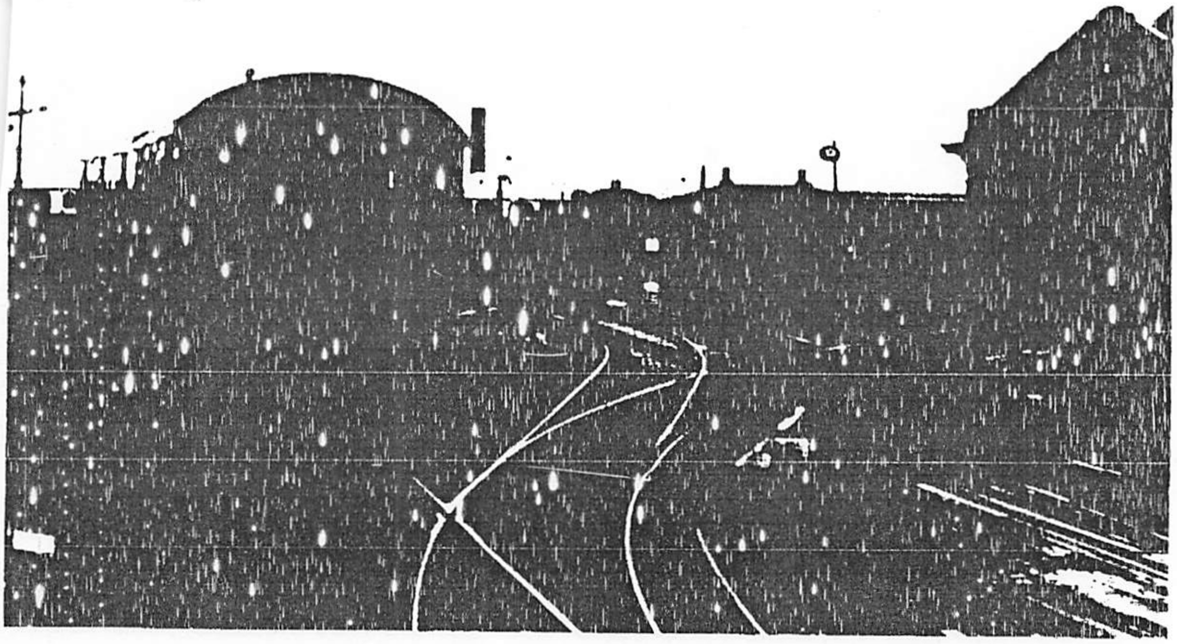


FIGURE 9.—Typical Interlocking Location

interlocking thus consists of more than just switches to allow trains to move along crossing, merging or branching routes; it is also made up of signals and control devices that automatically prevent conflicting or improper movements. Interlocking may be manually controlled or equipped with automatic devices that sort trains through branches and junctions according to desired destinations,

Several forms of automatic interlocking are in use. One of the oldest and simplest is an arrangement of hand-operated switches, each of which controls an individual signal or track turnout. The switches are mechanically or electrically interconnected such that once a particular route is selected, the switch points locked in place, and the signals cleared, no other route for a potentially conflicting move can be established until the train bound for the cleared route has safely passed, This arrangement represents a semiautomated form of movement control, Manual operation is required to select a route and move the control levers, but all else follows automatically, including inhibition of further switch movement until the train has traversed the limits of the interlocking.

A more advanced, but still not completely automated, type of interlocking is a system that permits a towerman or central supervisor to select the entrance and exit points for a train to pass through an interlocking, with the switches and signals for the appropriate route then being set up automatically by an arrangement of electrical relays, Figure 10 shows such a control panel for a system called entrance-exit route interlocking, The tower operator moves the control knobs to designate a desired route. Internal logic circuits automatically select the best available nonconflicting route, aline and lock switches, and activate the appropriate wayside signals to allowing train movement while holding other signals at stop to prevent conflicting moves. This level of automation may be characterized as automatic execution in response to manual inputs,

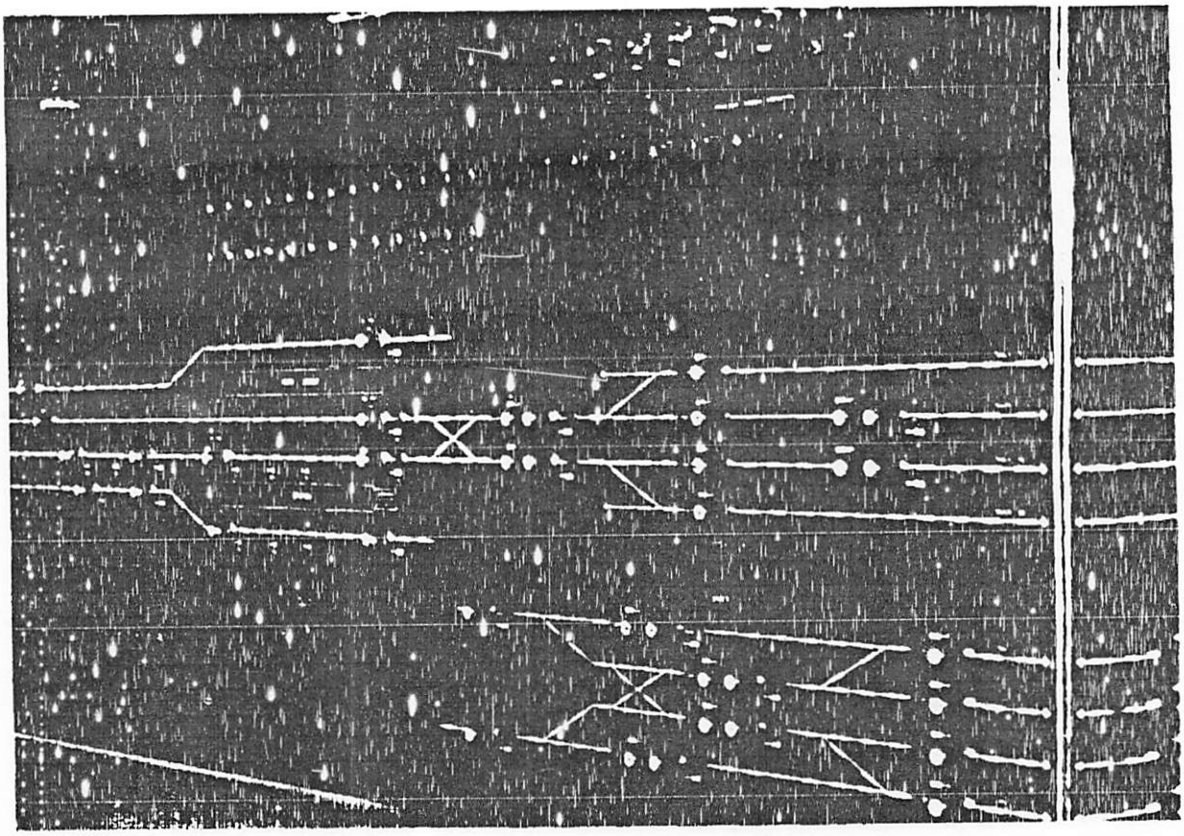


FIGURE 10.—Entrance-Exit Interlocking Control Panel

Fully automatic interlocking are also in use. In addition to track circuits, switch operation, and signal control elements, the automatic interlocking must have some device for identifying a specific train in order to create the necessary input to the logic circuits.[23] One method to identify trains is by means of wayside optical device that scans a panel on the lead car which gives destination, route, and other needed information. Another method makes use of a carborne transponder that is interrogated by a wayside device. With either technique, however, train identity becomes the substitute for manual inputs that allows trains to be sent along predetermined routes without human involvement.

[23]A rudimentary form of automatic interlocking is one that uses a simple in-out logic circuit to switch trains from one track to another. This device is commonly used at terminals and operates to switch each entering train from the inbound to the outbound track and thus does not require train identity information.

Train Supervision Equipment

Train supervision embraces a wide variety of functions. The special-purpose equipment that has been developed to perform these functions is equally varied. In a general survey of train control technology it is not possible to describe all types of automatic and semiautomatic devices that are in use. The following, therefore, is a brief catalog of some of the more important systems.

Train dispatching is concerned with the timing of train departures from terminals in accordance with the schedule of operations. In conventional transit systems this function is accomplished by preprogrammed dispatching machines that automatically ring a bell or flash a light as a signal to the train operator that it is time to leave a terminal or intermediate waypoint. In some systems, the dispatch function may be assigned to a central train control computer that transmits electric starting signals to the train in accordance with a master schedule stored in the computer memory.

Route assignment and control is a train supervisory function that is allied to the train protection function of route interlocking. Route control is a strategic function, consisting of selecting routes for trains and transmitting the orders to wayside points, where the orders are implemented tactically by interlocking equipment. In conventional transit systems, route assignment and control is performed locally, either manually or automatically. With remotely controlled route interlocking, however, it becomes operationally practical to place the strategic and tactical management of routing in a computer. The programing to accomplish this is relatively simple and straightforward, and a computer is ideally suited to handle what is an essentially repetitious task with a limited number of alternative courses of action. The safety aspects of route interlocking are assured not by central computer control, but locally by conventional interlocking equipment at the wayside,

Performance monitoring involves comparing the overall movement of traffic with the schedule and taking action to smooth out irregularities of traffic flow. In most transit systems this function is carried out by central control personnel aided by automatic display devices. One such device is a pen recorder that marks a moving paper graph to record the passage of trains past check points, Each spike on the graph indicates the presence of a train, as detected by the track circuits, at some time and place along the route. A train supervisor, by checking this graph against the schedule, can monitor the progress of all trains operating on line and detect delays or queuing up of trains, (Figure 18, page 36 shows such a device,)

Another form of performance monitoring aid is the model board (figure 11), which is a schematic representation of the track plan of the transit system with indicator lights to denote track circuit occupancy and, hence, the position of each train on the line, This is the functional equivalent of the pengraph recorder, but in a more pictorial form of display. Another type of model board used in newer transit systems has, in addition to the master track plan, small cathode ray tube displays that permit individual supervisors to obtain more detailed or expanded views of selected track sections or to call up special-purpose presentations of data,

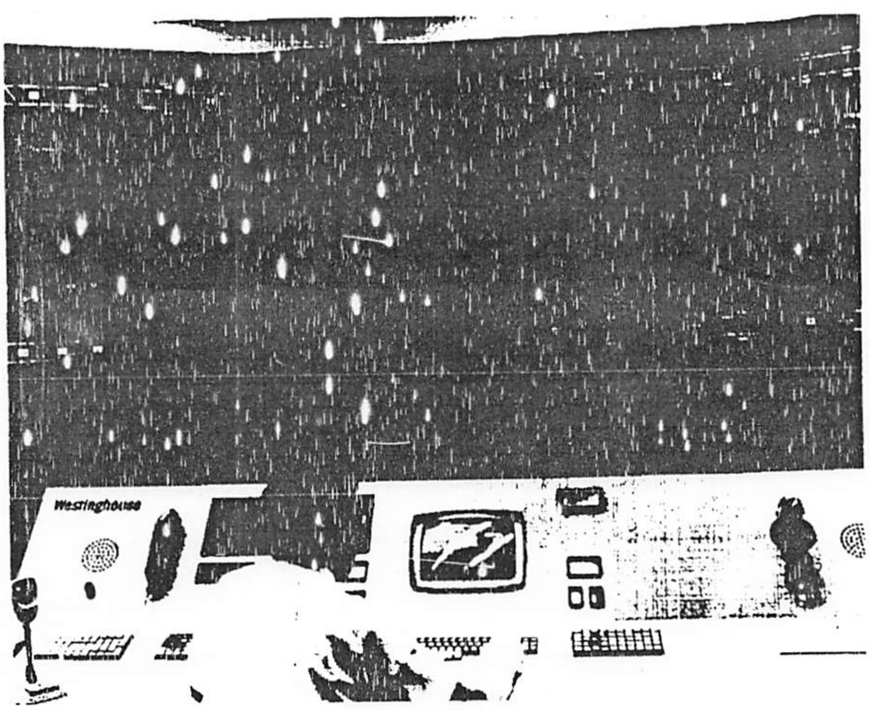


FIGURE 11.—Model Board and Train Control Console

Pengraphs, model boards, and the like are not fully automatic supervisory devices. The human operator is still needed to interpret the display and to formulate orders to individual trains. In the most advanced systems routine performance monitoring is assigned to computers, which keep a continuous watch on traffic movement and automatically calculate and transmit performance commands to trains. Man, in this circumstance, acts in a completely different supervisory capacity. He does not monitor and regulate traffic. Instead, he supervises machines which, in turn, monitor and regulate traffic.

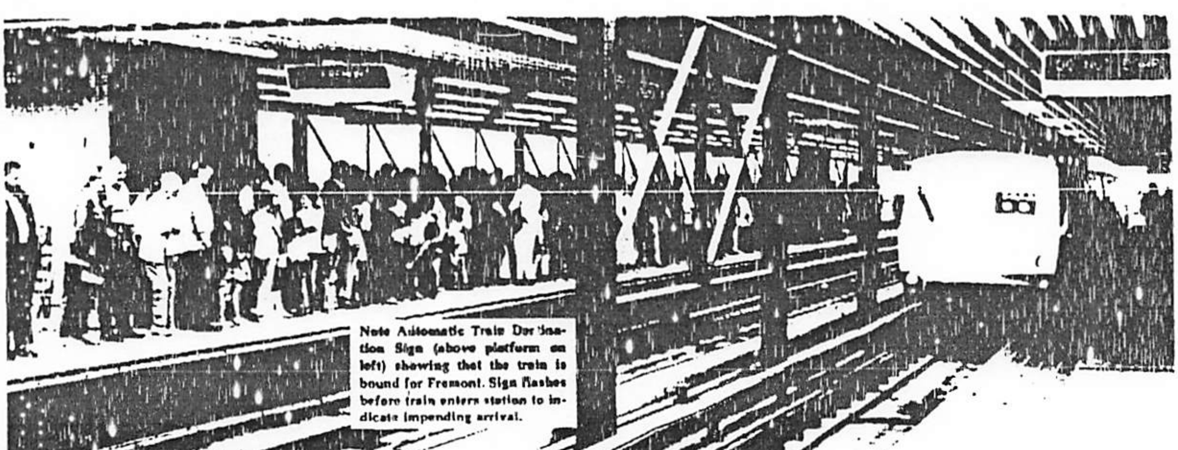
There are two general types of action that can be taken to smooth out irregularities in traffic flow. Both are accomplished in response to commands from central control. One is to hold a train in a station for a time longer or shorter than the scheduled dwell time or, in extreme cases, to direct a train to bypass a station in order to close up a gap. The other method is to alter the speed of the train between stations. This latter method is called performance level modification and takes the form of a proportional reduction of train speed below the speed normally allowed in each block. In systems supervised by a central computer and with automatic train operation, performance level modification is accomplished without human intervention. The required reduction is calculated by the central computer and automatically transmitted to stations or other critical locations, where the signals are picked up by carborne ATC equipment that modifies the response to the normal speed commands transmitted by the coded track circuits. These systems may also include provisions for manual inputs and displays at central control or on the train, but the normal mode of operation is automatic.

A WALK THROUGH A TRANSIT SYSTEM

To place ATC in perspective, it maybe helpful to make a brief tour of the facilities of a transit system, pointing out the type and location of the equipment that carries out train control functions.

Station

The passenger's first point of contact with a transit system is the station. The most prominent features-vending and fare collection facilities (possibly automated), escalators and elevators, heating and air conditioning, and platform amenities—have nothing to do with train control. There may also be public address systems and video or audio surveillance equipment for fare collection and platforms. These are not, strictly speaking, part of the train control facility even though they maybe connected to the central control facility and monitored by central supervisory personnel, About the only direct manifestations of ATC are the automated train departure and destination signs or loudspeakers found in some transit systems. These public announcement devices are connected to the ATC system and use information inputs derived from track circuits and train identification equipment, There may be an ATC equipment room in the station, but it is out of sight and locked. Its presence is usually unknown to passengers.



Note Automatic Train Destination Sign (above platform on left) showing that the train is bound for Fremont. Sign flashes before train enters station to indicate impending arrival.

FIGURE 12.—General View of Rail Rapid Transit Station

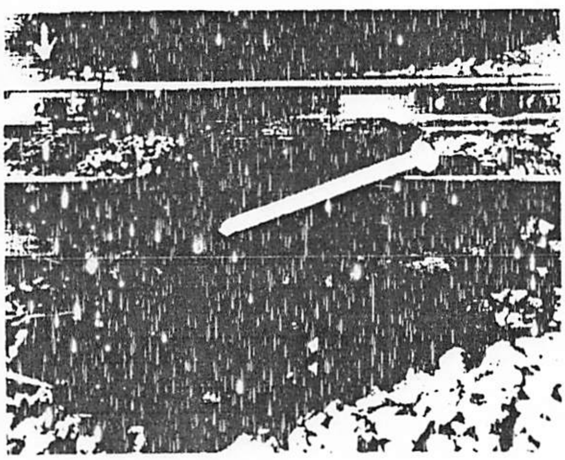


FIGURE 13.—Trip Stop

Wayside

An observant passenger might notice two wayside features that can be seen from the station platform. Looking down the tracks in the direction of train movement, there are wayside signal lights that change aspect from time to time. Often, just beyond the downstream end of the platform and alongside the rail, there is a trip stop which can be seen to raise behind a train that has just left the station and later lower as the train recedes.

Moving out along the tracks, other wayside elements can be found. The track circuits themselves are not plainly visible since they are largely in wayside housings. However, at intervals there are small flat equipment cases situated between the rails and connected to them by electrical wiring. These are the impedance bonds that isolate the track into blocks. At the ends of the blocks, there are small boxes, containing relays, with electrical connections from the track circuits to the signaling apparatus,

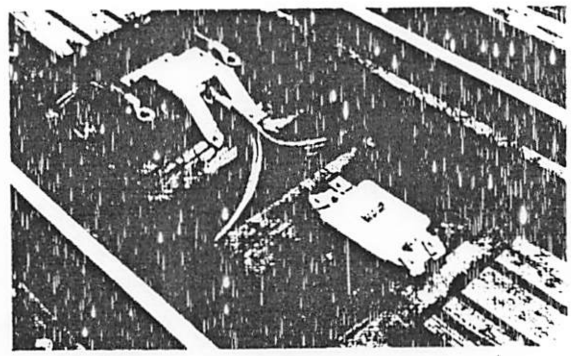


FIGURE 14,—Track Circuit Wiring

Other signal equipment is contained in small cases placed at intervals along the right-of-way. There are also telephones or other communication equipment and antennas or transmitters used for precision station stopping, train identification, or performance level modification, In certain locations, ATC apparatus and other trackside equipment may be housed in small sheds to protect the equipment from the weather and to facilitate maintenance by wayside workers.

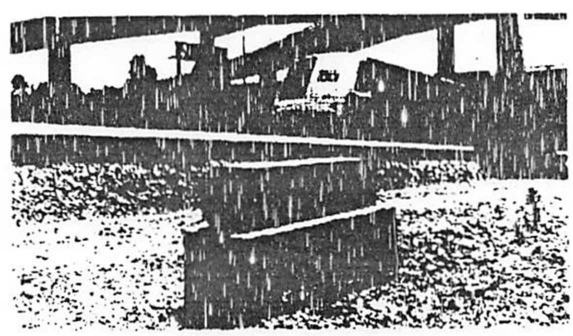


FIGURE 15.—Wayside Equipment Case (contains multiplex equipment for transmittin, information between trains and station control rooms)

At junctions and crossovers there is switch apparatus, the most visible parts of which are the switch points, frogs, levers, and motive equipment, This is the wayside equipment, known as a switch machine, that performs the function of interlocking for train protection,

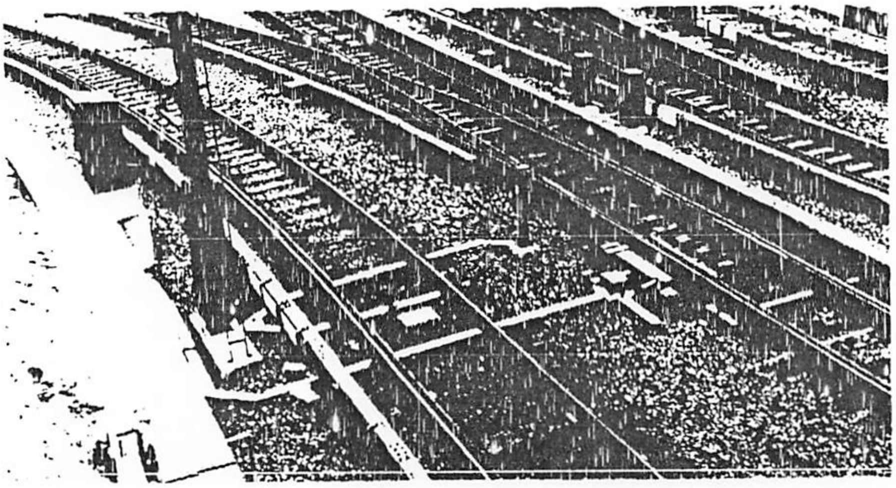


FIGURE 16.—Track Apparatus at an Interlocking

By far the largest part of the equipment, facilities, and structures along the right-of-way—trackage, tunnels, bridges, the third rail, and power distribution equipment-are not related to train control. Nevertheless, the wayside is where the bulk of the ATC equipment in a transit system is located. The proportion varies as a function of the level of automation, but generally about 80 percent or more of all train control equipment is not on the train but along the wayside and in central control facilities.

Central Control

Supervisory control of the system may be exercised in a central control room equipped with model boards, communication, equipment, system monitoring apparatus, and individual supervisor's

FIGURE 17.-Central Train Control Facility

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FIGURE 18.—Two Views of a Central Control Facility with Electromechanical Equipment

left-a clock-driven paper tape device for dispatching trains

above-pengraph device for monitoring train movement

consoles. If the system has ATS, the computers and other data processing equipment are also located in the central control building, which often houses administrative and training facilities as well.

Not all transit systems have a single centralized control facility. Some disperse control and supervision to outlying towers, situated at major interlocking along the routes. Figure 19 is a photograph of such a local control tower.

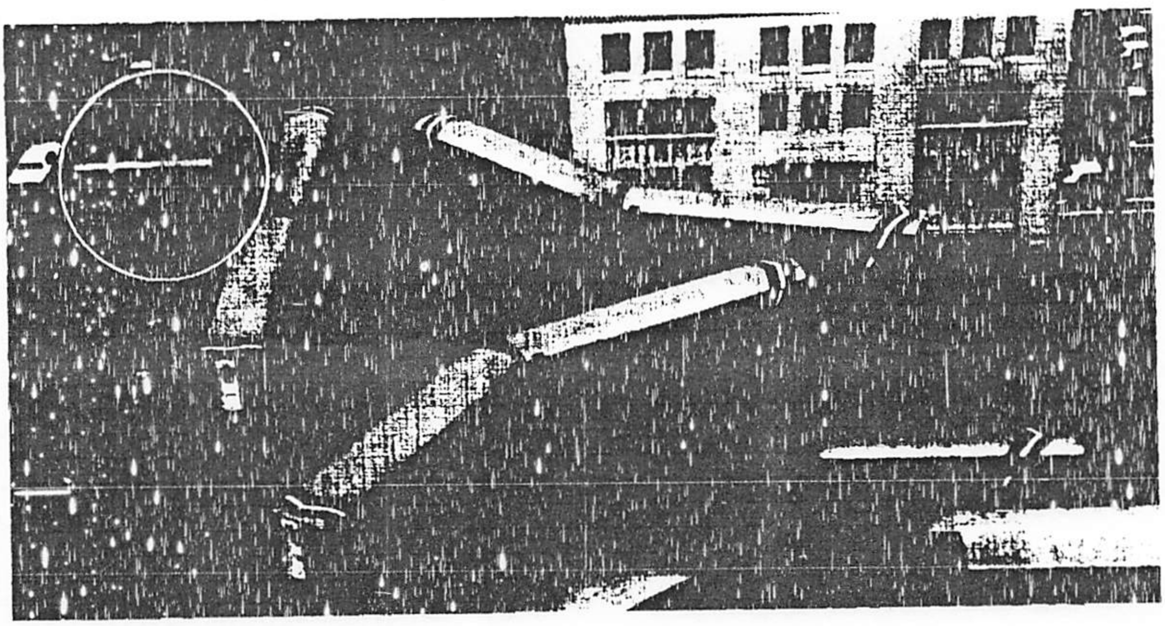

FIGURE 19.—Tower for Local Control of Interlocking

Vehicles

Most of the ATC equipment on transit vehicles is carried in equipment cases under the body or in the train operator's cab. About the only features distinguishable from outside the train are a receiver coil mounted on the lead car to pick up coded track circuit signals (figure 20) and—for systems with optical scanners-small identification panels mounted on the side of each car.

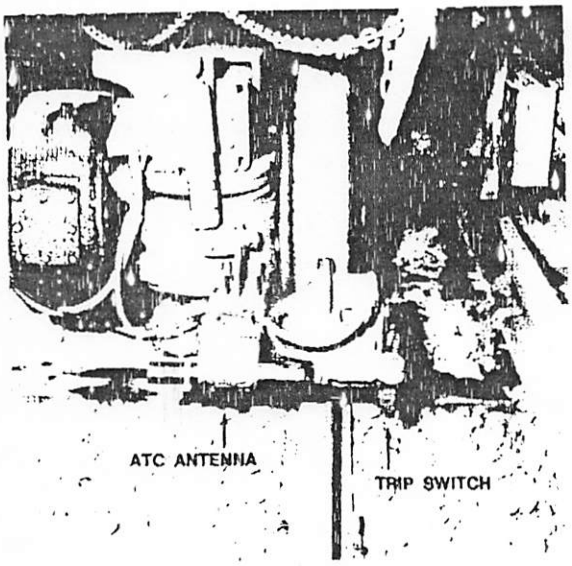

FIGURE 20.—Carborne Receiver Coil for Coded Track Circuit Signals

The operator's cab contains the displays and controls necessary to operate the train or to monitor the functions of ATC equipment. The amount and sophistication of this equipment varies greatly—ranging from very simple and utilitarian apparatus in manually operated systems to highly complex consoles in the newest and most automated systems. The console typically includes propulsion and brake controls, a speedometer and command speed indicator, lighted placards indicating the operating state of automatic elements, warning lights, pushbuttons or control knobs to make data inputs or to select various operating modes, a train phone or radio for communicating with central supervisors, a passenger address microphone, and a deadman control to prevent the train from operating in case the operator is inattentive or incapacitated.

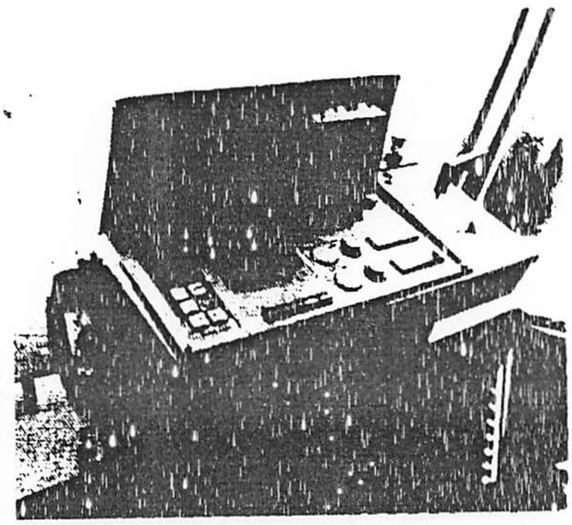

FIGURE 21.—Train Operator's Console for System with ATO

Yards and Shops

A large part of the important activity of a transit system does not occur in revenue service on the main lines, but in the yards and shops, These facilities, though seldom seen by the riding public, contribute greatly to the quality and level of service that the transit system offers.

The yards are usually located near terminals and consist of a vast complex of tracks for storing vehicles and making up trains to be operated on the lines. Even in systems with the most advanced levels of automation, train operation in yards is under manual control. Train sorting and classification is also an essentially manual operation, although some systems have a limited amount of automatic switching in the yards, principally to and from revenue tracks.

Car shops and maintenance facilities are usually located within the yard complex. The shops contain facilities for light and heavy maintenance, component repair, car washing, and checkout of vehicles before they are dispatched back into service,

The maintenance facility may also include a test track and special test equipment to qualify vehicles and components for acceptance or to carry out trials of equipment modifications.

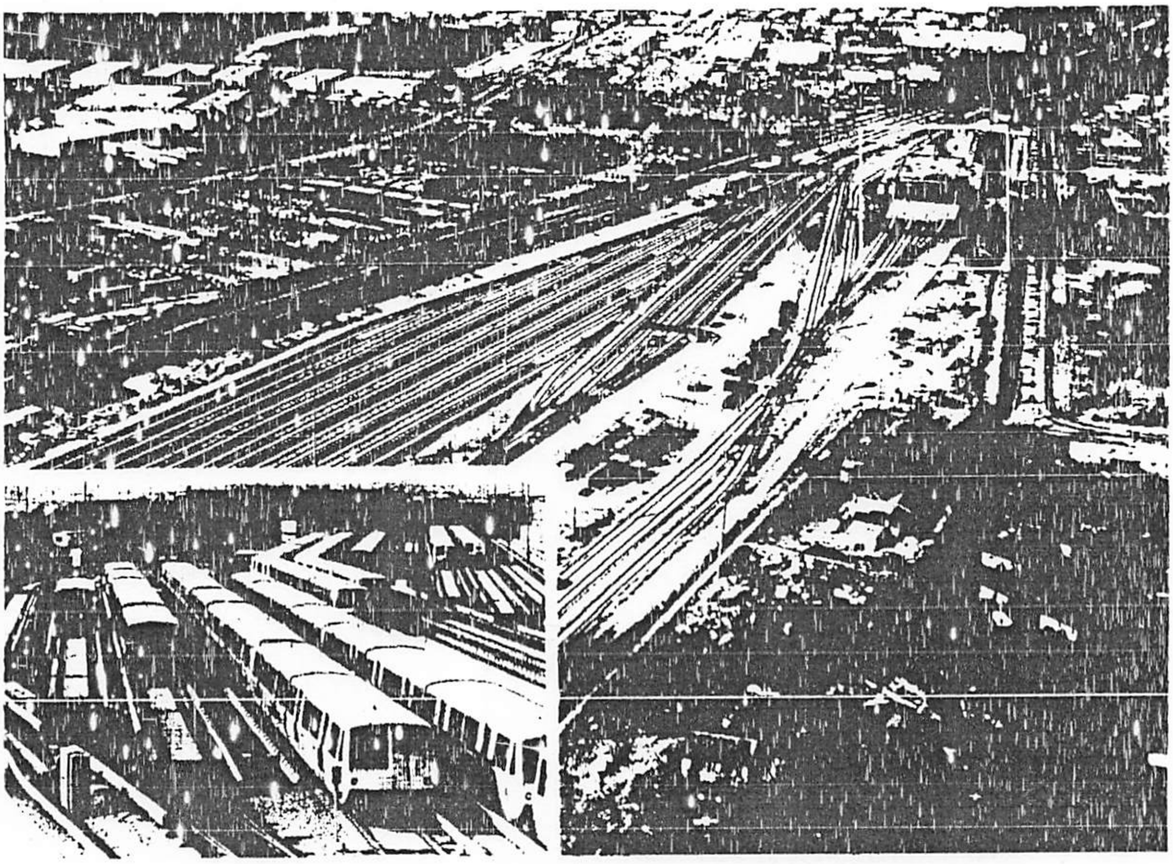

FIGURE 22.—Aerial View of Rail Rapid Transit Yard and Maintenance Facility

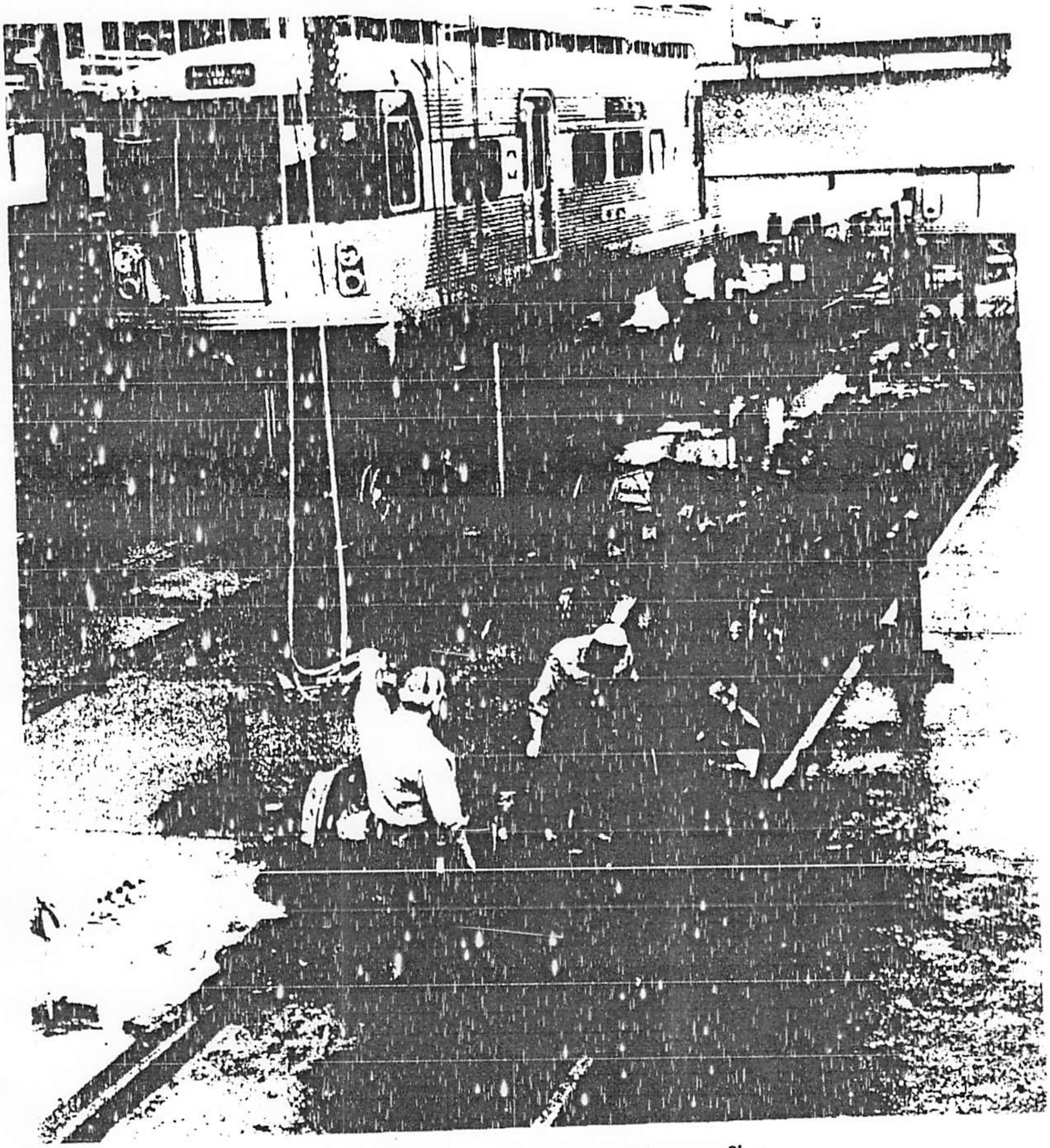

FIGURE 23.—Rail Rapid Transit Car Maintenance Shop

Essentially Manual

At this level, train protection, operation, and supervision are carried out by train operators and towermen or central supervisors with little or no aid from automatic equipment. Trains are protected and operated either by rules and procedures alone or with the aid of advisory wayside signals. There are no automatic stop-enforcing mechanisms either on the wayside or on board the train. Train dispatching is carried out by personnel at terminals or at control towers along the routes, using either a written schedule or timing devices that act as prompters to signal train departure. Route assignment and interlocking control are accomplished by manually activated equipment that may have some automatic safety features but are entirely controlled by human operators. Communications are by means of visual signals (lights, hand signals, posted civil speed., etc.) or by telephone from stations and towers to central control.

Many of the older transit systems in this country began operation at the manual level, but they have since advanced to more automated forms of train control. One of the last vestiges of a purely manual system is on the Ravenswood and Evanston lines of the Chicago Transit Authority, which as late as 1975 operated without any automatic block signal protection,

Wayside Train Protection

Wayside signals with trip stops form the basis for automatic train protection, by assuring separation of following trains and preventing conflicting moves at interlocking. Incorporation of timing devices with the trip stops also provides equipment-enforced overspeed prevention. While train protection thus becomes automatic, train operation is still completely manual. Train supervision also remains an essentially manual activity, although track circuits and signals used primarily for train protection do permit some automation of route interlocking and dispatching—usually in the form of semi-automatic devices (i. e., manually activated but automatically operating).

All transit systems in the United States have at least this level of automation. The most notable example of an entire system with enforced wayside signaling is the New York City Transit Authority. Portions of the Chicago, Boston, and Cleveland systems and all of the Philadelphia (SEPTA) system also employ this form of automatic train protection.

Carborne Train Protection

Cab signaling, using coded track circuits and automatic carborne stopping and speed limit enforcement, represents the same level of ATP as wayside signals with trip stops. To this extent, this level of automation is equivalent to the preceding. Generally, however, cab signaling is considered a higher level of automation since it also provides some automatic aids to train operation—principally automatic and continuous display of speed informa- tion to assist the operator in running the train and stopping at stations. Other aspects of train operation are still essentially manual. Cab signaling does not necessarily lead to any increase in the automation of supervisory function nor is it accompanied by any change in the communications systems.

This level and form of automation is generally regarded as the minimum for a new transit system, and most of the older transit systems either have converted or plan to convert to cab-signaled ATP.

Automatic Train Operation

The major advantage of cab signaling over wayside signaling is that bringing the speed command on board the train also permits evolution to automatic train operation. All of the information needed to operate the train automatically is either inherent in the cab signal system or readily available through modular additions. At this level, the human is removed from the speed control, station stopping, door control, or starting loops--or any combination of them. The human no longer functions as an operator but as an overseer of carborne control systems.

Along with ATO, there is often (but not necessarily) an increase in the level of automation of train supervisory functions. ATS functions that are sometimes considered operationally desirable to implement at the time ATO is installed include automatic dispatching, route assignment, and performance level modification.

The two newest transit systems in this country—Bay Area Rapid Transit and the Port Authority Transit Corporation—both have ATO. The new systems under development in Washington, Atlanta, and Baltimore will also have it.

ne experiences on Formal specification of Railway Interlocking Systems using Statecharts

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Abstract

he introduction on the market of computerized Railway rlocking Systems has pushed an increasing interest in use of Formal Methods, due to their ability to precisely ify the logical rules that guarantee the safe establish-t of routes and equipments for trains through a railway l Recently, a trend has emerged about the use of the hical language statecharts as a standard formalism to luce precise specifications of these systems.

paper resumes our experiences in modeling railway rlocking systems using this formal language. Our stud-ave addressed the design problem from different points iew: we have modeled the specifications using two dif-nt approaches that we call functional description and graphical description. The names indicate that the first roach is focused on the modeling of the logical function he Interlocking Systems, while the latter focuses on the graphical distributions of the element of the controlled ion or yard.

geographical approach has also inspired a proposal for istributed interlocking system, where the logical rules embedd. d into distributed equipments communicating neans of safe buses.

Introduction

The case for Formal Methods in the development of RISs ilway Interlocking Systems) has stimulated a consider-e literature about formalization of interlocking systems (see, for example, [3, 5, 17]). And indeed European guidelines and standardization groups recommend the use of formal methods in the development of safety critical computer-controlled systems for railways applications [8, 9, 10].

Some European railway companies have constituted a consortium to define a standard interlocking system at a European level: the Eurointerlocking project. Inside this project a trend has developed towards the use of statecharts for modeling interlocking rules [15]. Statecharts have been considered suitable to express the sequences of checks and actions typical of an interlocking system.

In this paper we resume our experiences in modeling RISs using statecharts, following two different approaches to the formalization of Interlocking we have investigated: the functional approach and the geographical one.

The functional approach, discussed in section 3 faces the design of a RIS using logical objects not related to physical objects to the layout. Examples of logical objects are the reservation and the setting of a safe route through the controlled yard. On the other side a switch (or *point*) is a physical yard object, so defining a logical object associated to a switch can be considered as a geographical association. In section 4 is proposed a geographical style of formal description, in which the model is obtained by the composition of objects modeling the physical entities, following the geography of the controlled yard. We have then studied the impact of this style on the possibility of incremental validation.

Furthermore, the same approach has then inspired a proposal for developing a distributed RIS (see section 5), whose safety validation is strongly based on formal veriion and simulation of the formal description.

Introducing formal specification in computer-based interlocking

A Railway Interlocking System (RIS) is a complex in-ation for the safe establishment of routes for trains ugh a railway yard. Electronic signalling systems have iced (and actually are still replacing) old mechanical in-cking systems due to their advantages in terms of:

- less dependency on operators failures;
- self-diagnostic system checks to improve reliability;
- possibility of integrated and centralized systems.

cally, a RIS receives a route request; the answer to this est has to go through a series of checks and actions of ind:

- a route can not be locked if a track section element is occupied;
- a route is available if no part of the route is already locked;
- if the route is available it will be locked;
- locking a route implies that all its track elements become locked;
- when a route is locked signals for the route can be switched to green, and then the original route request is positively acknowledged.

The aim of these checks and actions is to guarantee that no train can be driven into a route occupied by another train. In the case of RIS, the principle schemata, a sort of ladder-like, relay based language, widely known by railway engineers, constituted the common reference language by which to describe interlocking systems, since the times interlockings were relay based [11]. In the introduction of computer-based RIS some industries had defined their own approach to produce computer based interlockings, more or less formalized, often based on some logic formalism or language, but they were anyway constrained to relate their own development/specification method/language to principle schemata, understood by the national company signalling engineers.

The main activity of the RIS, which is an embedded system, is to ensure the safe operation of the devices in a railway station. Such a system controls an arrangement of equipments (signals, switches, track circuits, automatic blocks) so interconnected that their functions shall be performed in proper sequence and for which interlocking rules are defined in order to guarantee safe operations.
A simple (the simplest) example of RIS, that we have used in our experiences as a case study, refers to the layout shown in the figure 1, and is based on a real Italian Interlocking System [6]. Line segments represent track segments in the station; some of them have track circuits, that is, sensors of the presence of a train, which are numbered inside circles, joints between segments represent switches. Lollypop-like drawings represent signals of various type. Numbered labels are attached to each important part of a route. This example (a single track line station) is constituted by eight allowed routes, two switches, eight signals, six track circuits and two automatic blocks.
Interlocking rules are obviously the core of the system, so their correctness is the main objective to be addressed by a formal specification. The rules aim at allowing only the safe combinations of switches positions, signals and trains in a station in order to avoid collisions. The signal indications, handled by the interlocking system, govern the correct use of the routes, authorizing the movement of trains. The rules usually enforce a predefined sequence of actions: issuing a route request command usually first triggers a check that all the track elements involved in the route are free; in the case, commands are issued for the positioning of switches for that route and for locking the track elements. This phase may be followed by a global centralized control over the correct state of the commanded elements, after which the route is locked and signal indications for the route are set. A route

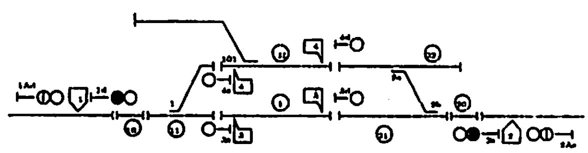

Figure 1. The simplest railway yard layout.

can be set free only if all switches on the route are being in the correct position, and no train is present. The signals can be set to green only if the route in front is set to free. These sentences express two examples of generic principles that hold for every interlocking systems. Actually, the precise and complete set of such rules depends on the kind of station or railway yard, and also on national policies traditionally established by railway companies or regulatory boards.
Obviously, a RIS being a safety-critical system, the formalization of such rules is a top requirement, and this is the reason of the wide interest generated by RISs in the formal method community. Note however that the generic rules expressed above need to be conjugated on every specific layout; for instance, the rules should be set for the route 1-3 in

ure 1 taking into account switch 1, track circuit 10, 11, I, l so on.

the traditional process adopted by many railway companies to develop relay based interlocking system since sevl decades, the generic principles were encoded into relay cuit templates.

ıen a new interlocking plant had to be installed these genl principles had only to be adapted to the particular lay- of the station in use. The adaptation process was also ded by some more or less formalized rules. At the end the process there was a diagram containing the command l control circuits for each logical or physical object of the tion.

An example of this kind of diagram is shown in figure 2; s diagram, taken from an Italian interlocking, represents a cuit, for the route 1-3, which is generated basing on temtes supplied to help the engineers in the design of new tions. In this example, the permission to set the route 1-3 free is given by the relay CD1_3, which is energized folving the shown combination of various (normally-open d normally-closed) contacts activated by other relays, iere command rules are given in other schemata. The nplate will be associated to layout objects and replicated each object. In this circuit template there are all the con-ts needed to manage that kind of object; the only action perform on it is the substitution of these generic contacts th the ones dictated by the layout. The structure of all di-

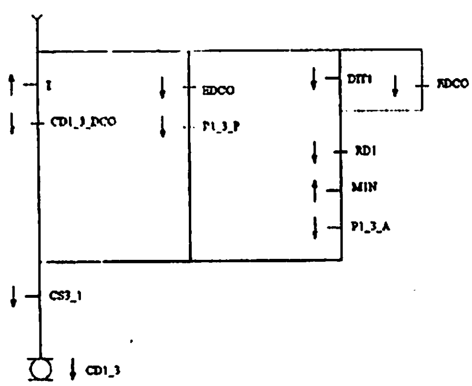

Figure 2. An instantiated relay schema referred to route 1-3

agrams related to routes is always the same but the number and the name of some contacts (serial or parallel) is different from a route to another.

In the example (figure 2) the suffix of the variables are generated using the layout data, but furthermore the contacts (in this route there is only one) MIN, which are related to the switches used by the route, could be more then one (in series): this series of contacts means that in order to enable this route all the switches used by it have to be in the correct position.

The safety of old times, relay based, interlocking systems was based on single fail-safe concepts exploiting the intrinsic characteristics of relay technology. The introduction of computer in the control and command chain has subverted this approach to safety, since failure modes of computer controlled equipment may be much more diverse and difficult to predict.

The first approach followed by some railway companies was to maintain the traditional and well-established relay-based principle diagram as the trusted source of information for computer-based interlocking developers, looking for conformance of the installed systems to such source, by means of costly and tedious, but possibly not exhaustive, testing.

This approach has put on manufacturers' shoulders the burden of conceiving a family of interlocking products, together with means to instantiate the generic product by taking into account some proprietary, formalized version of principle diagrams suitable to be (more or less automatically) interpreted or compiled into running code, that has to be shown conformant to the trusted source. Actual approaches have varied from manufacturer to manufacturer (see [4, 11]).

But computer technology permits more flexibility: new features are very interesting but require an innovative approach and a complete formalization of the whole system [8]. Domain specific languages have been proposed for the formalization of RISs [13], the most prominent one being EURIS [3, 7].

More recently, the possibility of using commercial support tools has pushed the use of "general-purpose" languages [10], and a recent trend has indicated Statecharts as a means for defining a standard formalization [15]. In our experiences described in the following, we have adopted the Statemate statecharts style [18].

3 Functional approach to RIS specification

Most of computer based interlocking systems use (in their implementation and/or formal specification) some form of centralized data base where the rules of the interlocking logic are stored. The main feature of this approach consists in generating the rules by adopting a design methodology focused on functions, such as the switch points checking function, the routes setting function or the routes verification [11]. This is why we call this approach functional. These functions are designed basing on a *control table*, which indicates all of the conditions that have e satisfied before a signal can be switched from red to n to admit a train into the track section beyond [14]. placement of the yard equipments is ignored in this de- methodology, it does not exist a direct correlation be- n the geographical position on the yard of a device and function that controls it implemented in the RIS. For reason it is a hard task to identify the parts of the sys- stimulated by external events.

ecification or implementation following this approach nelting pot of functionalities not easy to separate. The raphic information of the yard is not available any more the RIS functional description. An example of func- l approach, implemented by relay technology, is shown gure 2. We can define by statecharts the behavior of relay circuits. This kind of description is very apre- d by railway company in fact relay technology is well olidated and then safety engineers are more confident is kind of technology instead a different one where re- chema are not direct referred.

approach is similar to a translation of relay circuits to charts. It may be a starting point to introduce new for- sms into specification activity and then pass to more erful kind of models.

he yard shown in figure 1 has been modeled using func- al approach (both related to relay schemata and not), ific modules have been dedicated to record commanded es; these modules have been given the responsibility of king the occupancy of the interested track circuits, fol- ing what prescribed by the *control table* given as input.

The approach of geographical specification

4.1 A geographical approach

A different approach can consider distributing the knowledge of the interlocking rules to objects modeling the geographical placement of physical elements, in order to develop the specification of a particular interlocking prod- uct by simply composing objects, following the geography of the controlled yard. An example of geographical spec- fication is the EURIS language (EUropean Railway Inter- locking Specification), which is a visual and graphical spec- fication language for railway control systems [3, 7]. Us- ing this language it is possible to build in a component- based way the control system from the layout of the sta- tion to model. The EURIS specification language, proposed in 1992 and used at Siemens, is used to specify different railway yards using the same generical specification com- ponents. Actually it consists of a set of standardized rail- way control components [7], which should be composed to- gether easily, increasing the speed of development and per- mitting the reuse of components. Each element includes a set of rules inside it, which are able to adjust to different layout configurations. Because EURIS is a graphical lan- guage another advantage is that specifications are easy to read, since they immediately represent the physical position of elements in the yard.

The EURIS language inspired our study on this direc- tion but differently to it we have not used a domain specific language but a general purpose.

4.2 Statecharts geographical model

We have suggested a way to design an interlocking sys- tem starting from its layout and ending in its operational specification. In the work we focused on a methodology that does not use any sort of global summarizing variables, which is usual instead for a functional approach.

With the term *summarizing variable* we mean a variable whose values depend from the values of a set of other sin- gle variables, each related to a physical entity of the layout. As an example we can consider a variable associated to a route, that is true if and only if at least one of the variables recording the occupancy of the track circuits belonging to the route is set to true, as has been shown in section 3 about the functional approach. The use of summarizing variables, though useful for abstracting certain global aspects of the system, makes the model more distant from the physical topology.

The geographical experience, differently that the pre- vious analysis of functional approach, shows how each module is dedicated to the management of each track circuit that has the responsibility to check its compatibility with commanded routes. In the same way, all the activities performed by functional objects have been distributed to these geographical objects. Hence, the control for example of the correct position of a particular switch point is performed from all the interested elements and not by a single object dedicated to the management of all the switch points. Each object of the model implements the rules that

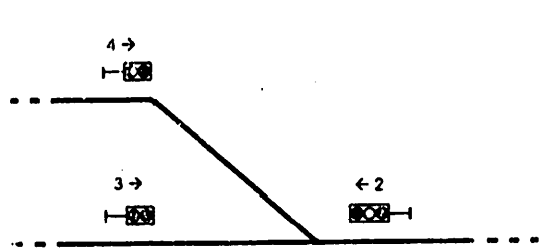

Figure 3. An example of routing.

interest only that object. If, for example, we consider the three signals of Figure 3, the model will include an object each semaphore. The object related to the semaphore which permits the movement of a train in the right ection, should control that the red lights of semaphores ight and 2 left are fired and also that the green lights are itched off. This control is done not looking at a global nmarizing variable which in the example would show t the route is free, but communicating with the objects t control the other semaphores and devices.

In this way, we obtain a model whose structure reflects layout of the railway yard. This has positive effects on readability of the model, and on the possibility of isolat- in the model only those objects that are interested by a ngc in the physical layout.

On the other hand, we loose on generality: in the func- al approach the module handling all switch points can generic, and it is the control table that embeds the knowl- ;e about the specific rules for the railway yard. Our ob- ts have not a generic behavior usable in any different ge- aphical layout (like EURIS): we have to redesign them any different station, though following expected patterns h predetermined rules.

The consequences of this approach are:

- The structure of the model should reflect the geographical topology of the yard.
- The elements of the model should replicate the behavior of the physical components of the yard.
- The elements of the model should embed all the logical rules interesting the corresponding physical components (in order to avoid the usage of summarizing variables).

This kind of model is able to minimize the interdependency between objects.

Objects cannot be completely independent; in fact an interlocking system is by definition a system that have to control the interrelations between the objects. However, a geographical model maximizes independency: where there is independency in the yard, we want that it is reflected in the model.

4.2.1 Structure of the layered model

The model is built following a layered architecture for the RIS, which consists of three layers: *Command (human) layer*, *Logical layer* and *Physical layer* (Figure 4). The first layer (Command) is dedicated to the interaction with operators or other systems, which send commands to the RIS.

At the lowest level (Physical), there are the yard devices and equipments, which have to be commanded and controlled by the RIS. This level is constituted of the actual device interfaces, with actual variables used to control the

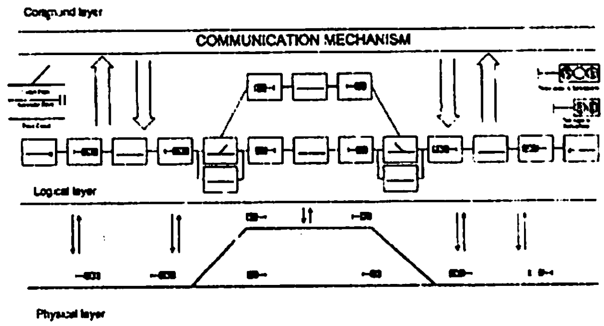

Figure 4. Illustration of the layered interlocking architecture.

yard.

The middle level is the core of the RIS, where the interlocking rules are specified. It is formed by a separate object for each physical device.

Figure 5 shows how the objects are interconnected with the command and the physical layer. The state of any object is one to one related with the actual state of physical device.

Every object related to a particular route is able to receive the command requesting that route, in which case it performs the proper checks about the physical layer and the other objects of the logical layer. When a route reservation command is sent by an external system (also human), this message is sent to all the objects related to that route. Then all the objects evaluate their rules interacting each other to confirm the received command.

Inside each object it is therefore distributed the logic that is

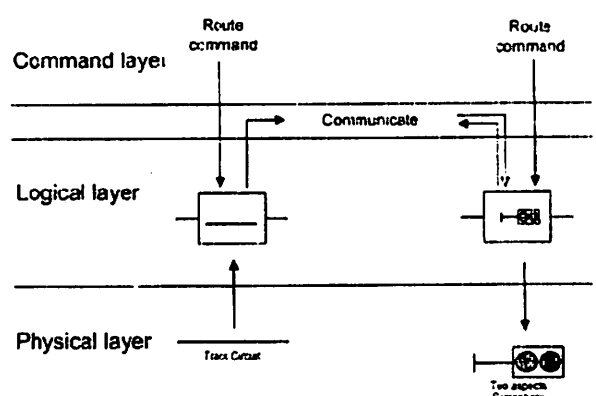

Figure 5. Illustration of inter-object communication.

ally centralized in a classical functional approach: there sts no coordinator object.

.2 The statecharts model

e system is specified combining the geographical elements as it is illustrated in figure 4 and 5. Each geographical element is defined by an activity chart specified using Statemate statechart formalism.

As shown in Figure 6, the top level of the model consists an activity chart, composed by several activities, which strictly related to physical objects placed on the yard. a lower level each block is formed with a set of nested activities and statecharts that implement the interlocking s. We can note that the topology of this level is exactly responding to the geographical layout of the yard (refer Figure 1).

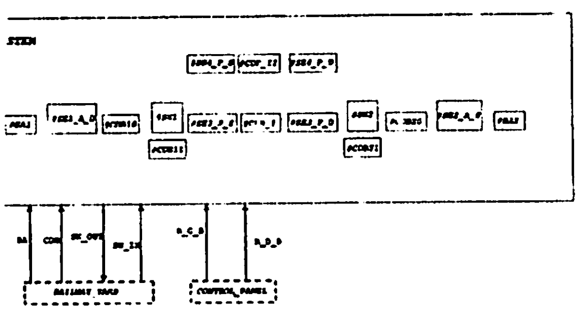

Figure 6. The first level of the statechart model and the distribution of the internal activity charts.

The interaction between activities can occur by signalling an event (including variables value changes), either by direct addressing, i.e. the target is specified, or by broadcasting. In our model, every element (variables, events and so on) has a scope in which it is visible. The scope of an element can be explicitly defined by the user: every change in the value of an element is broadcast to all activities and statecharts in the element's scope, and is thus seen by all the charts within the scope.

Shared variables are therefore used to implement the communication between objects: every block checks which is the state of other nearby objects sniffing some of their state variables.

An example of the statechart describing the behavior of an activity (control activity chart) is shown in Figure 7 where a green light manager is illustrated: the figure shows the use of a logical state such as that used to reserve the object. These local states are needed because we do not have any global object that records which elements are in use, so the control logic has been decentralized. We can note that the chart communicates with plenty of other objects, such as track circuits and other distinct track circuits, by looking at shared variables. Indeed, it is evident how the interlocking rules are distributed over the conditions for the transitions in each activity chart.

Figure 7 represents the statechart controlling a green light: when an operator (either human or system) gives a command, this statechart and all the other statecharts controls that the track circuits related to it are reserved and the track circuits incompatible with it are free. Also this example makes evident the large usage of shared variables. Though each chart works in parallel with the others, they are strictly interrelated by this massive usage of shared variables.

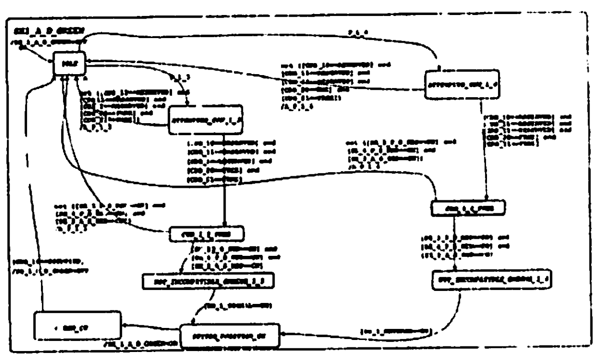

Figure 7. The statechart controlling the green light of a semaphore.

4.3 Revalidation

At first sight it could seem that the layout of a railway yard is fixed and cannot be changed. Actually, the layout can be changed during construction works to enable partial operation of the yard, or after for maintenance works, or for extensions. This may happen several times in the lifetime of an interlocking system, which anyway spans several decades. Computer based RIS have the obvious advantage over relay-based ones that any change can be addressed by a change in the software. However, the strict guidelines followed in the development of this piece of safety critical software require a costly validation activity: any change to the software requires a revalidation activity as well.

The adoption of methods and techniques that can reduce such efforts and costs is therefore an important industrial ecti·/e.

Tne main question is: "Do we have to revalidate the olc system? Or there is the possibility to understand at is actually changed, so to limit the revalidation effort?"

The geographical approach appears interesting in the re- :tion of revalidation effort as well. In fact we can assume t software modification related to a geographical object :cts only a closed set of other objects, so reducing the ded revalidation effort of the whole system.
ng the geographical approach, in case of a change to ıc parts of the interlocking system there may be some dules that do not need to be changed because they are affected by the modification done. Since each object forms its controls independently and the system does use global summarizing variables, we can think that se objects do not have to be revalidated. The objects ected by the modification need instead to be revalidated. . using new test scenarios or modifying the already ex- ng ones. More detailed information about the reduction revalidation effort using a geographical approach can be ınd in [1].

A proposal for a Distributed Interlocking System (DRIS)

1 The Distributed System Architecture

We have observed that the geographic approach used to model the RIS keeps the original topology of the system, and this fact has inspired our proposal to physically distribute the control by deploying each activity in a separate controller embedded to the controlled entity [2]. The

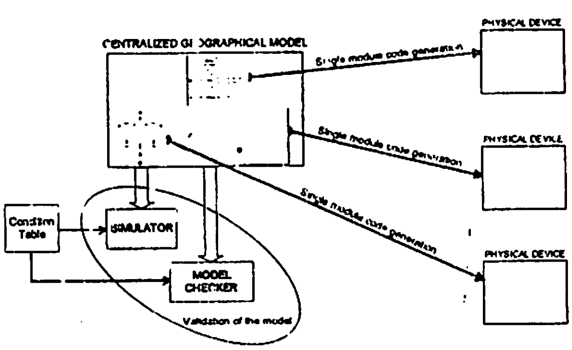

Figure 8. Development cycle.

distribution consists in generating slices of the geographic model, described in section 4, as is illustrated by the Figure 8. An obstacle to physical code distribution is however represented by the shared variables used in the model for communication between the separate activities. The semantics of Statecharts requires that every activity is able to read and write shared variables at any step. In a distributed implementation, variables need either to be associated to an activity, which should provide for safe reading and writing by other activities, or to be replicated among the interested activities, and in this case consistency of the replicas should be guaranteed.

The synchronous nature of the operation of Statecharts considers variables values to be read at the beginning of a step. Only when the evaluation of variables has dictated the live transitions that can be fired, one of them is fired and the associated actions, including writing on variables, are performed. It is possible to perform automatically checks that guarantee that no conflict is raised about simultaneously writing of a variable by two activities, in order to avoid race conditions.
This operational semantics allows to consider a distributed implementation based on the adoption of a field bus, by which variable values are broadcasted at the beginning of a new operation step, and by which writing commands issued by (one and only one) activity are conveyed to the owner of the variable at the end of the step.
Indeed, our idea is based on the rapid development of safe field bus area: we think that the market is now mature to accept this kind of approach in the railway area as well, given the large number of applications of field buses in different safety-concerned industrial areas: from factory automation to fly-by-wire and drive-by-wire, in avionics and automotive areas respectively.

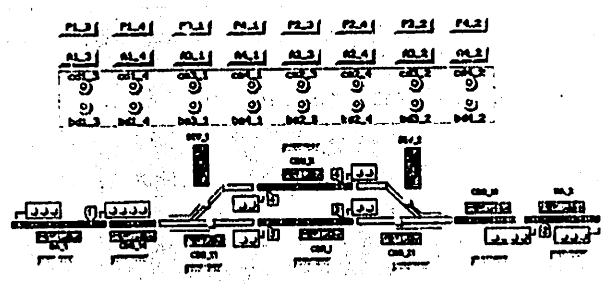

Figure 9. The control panel.

Due to the synchronous operation typical of Statecharts, a good candidate to act as the basic platform on which our approach is based is the architecture named TTA (Time Triggered Architecture) [16].

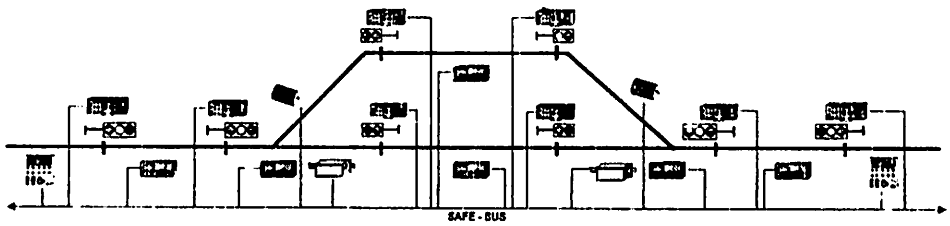

Figure 10. The network devices deployment.

This architecture has been created for the implementation of dependable distributed embedded systems, and permits to decompose a large real-time application into nodes: obviously the main critical feature consists of the communication mechanism and the synchronization one. In the TTA, the system maintains a fault tolerant global time at every node. This global time permits to reduce the communication complexity allowing the use of shared variables for communication purposes; events that happens in the distributed system at different nodes at the same global clock-tick have to be considered simultaneous. The TTP (Time Triggered Protocol) is in charge of guaranteeing the consistency of different views of the same variable at any given clock tick.

Another issue that should be taken into account is given by the safety requirements in case of a fault. In our proposals, faults can occur in any distributed controller. The basic safety requirements, to be achieved both by exploiting the fault tolerant features of the bus protocol, and by properly designing the distributed components, are that:

- any failure of a component is reduced to a crash of the component itself, so that a failsilent policy is enforced;
- the presence of a silent component does not undermine the safe operation of the interlocking; that is, no route for which the failed component is needed can be set and acknowledged.

For increased availability, we can add the requirement:

- any failed (fail-silent) component does not affect the correct setting of a route which is totally (geographically) independent from the component interested by the failure.

Note that the distributed system is formed from redundant controls, which are located at every devices (Figure 10). The redundancy of the controls exhibited by the geographic approach can be considered as a positive safety measure: a decision about the establishing of a route is taken only if all the controls have been successful; the controls are redundant, but diverse and independent, hence they constitute a safeguard against software faults. Note that this safety measure is not due to the exploitation of the TTA architecture (or of any other suitably fault tolerant bus), but is intrinsic in the model.
The system architecture is completed by a monitoring computer (or more than one computer) attached to the bus, able to read the variables values that are exchanged on the field bus, which uses such data for diagnostics, for displaying to the humans the state of the yard and of the interlocking system, and for logging data about the system. The monitoring computer can also be used as an added safety measures by taking in charge the forcing of the system in a safe state in case it detects anomalous variable values.

5.2 Development cycle

What is needed to implement a distributed RIS can be summarized in the following development cycle, which includes validation activities as well, and is fully supported by the functionalities of the Ilogix Statemate tool:

1. Control table:
   This table is taken as the contractual input for the process, and fully describes the interlocking rules according to the given yard topology.
2. Statechart design using geographic approach:
   As described in section 4, a geographic model using activity and statecharts is developed. Furthermore, in order to verify the correctness of the geographical model a functional model, using a parallel design, should be developed as well.
3. Validation of distributed design:
   The geographic model is validated by means of two different alternative methods (which actually should be both applied for increased safety):
   (a) tests played by simulation:
   We are able to simulate the whole model with the

Statemate simulator tool, that permits to interact directly by using a panel appropriately created as well (Figure 9). Extensive tests should be carried on defining suitable test scenarios, on the basis of the information given by the control table.
An interesting way to achieve even more confidence is parallel co-simulation of the same scenarios applied both to the geographical model and to the functional model; this also because functional modeling is more consolidated in railway companies' practice.

(b) Control table based safety properties proved by model checking:
Safety properties described by the control table should be defined so that they cover the overall safety requirements. Typically, properties of the kind: "two conflicting routes can never be set simultaneously" should be expressed and verified by the Statemate model checker. Model checking is able to guarantee that such properties are always satisfied by the model, while simulation may leave some dangerous execution paths unexploited.

4. Fault injection:
Extensive verification, again by simulation and/or model checking, should be done in order to validate the fail-safe behaviour of the model. Typically, faults should be injected in the model (e.g. by forcing a fail silent behaviour of some objects) in order to test the overall safety of the system in presence of faults.

5. Automatic code generation

(a) Statemate code generation:
From the statechart geographic centralized model it is also possible to generate C or ADA code by using the automatic code generator tool, which is part of the Statemate tool, for every single device. Because of the detailed nature of the model, the code generated is immediately usable without need of any other translation into lower level languages, except for the communication interface which is not part of the requirements specification. The resulting code shares with the geographic model the correspondence between software modules and yard devices. For this reason there is the possibility to generate code for each module, to be targeted and deployed on a local controller.

(b) Shared variables implemented through field bus protocol: The variables which are shared between the obtained software components should instead be implemented basing on the safe protocol established to this purpose over the adopted field bus.

6. Physical deployment and integration:
Deployment of the various modules over the distributed controllers connected to the field bus is now possible.

7. System in field testing:
Though the extensive validation effort carried on the model and the automatic generation of code are enough to guarantee the safety of the system, in field testing is necessary to guarantee that any possible interference from the physical world does not undermine the safety and functionality of the system.

The parallel co-simulation of the geographical and functional models is aimed to achieve a sufficient confidence on the absence of errors in the final DRIS. Even more convincing would be a proof of equivalence of the two models. This is a challenging task, due to the current unavailability of tools, and also to the inherent complexity of this approach, which is left as a subject for our future work.

6 Conclusions

This paper resumes our experiences in modeling railway interlocking systems using this formal language. Our studies have addressed the design problem from different points of view: we have modeled the specifications using two different approaches that we call functional description and geographical description.

All the experiences have been applied to some simple Italian interlocking examples.

In the experience made on developing a geographical approach aimed at developing a distributed RIS we have pushed to the point that the interlocking logic can be entirely distributed on "in the field" local controllers, following a trend consolidated in automotive and avionics applications, based on the use of robust field-buses. We have argued that in this approach formal verification gets the role of the primary method to asses the safety of the system. All the steps of the proposed developed cycle need to be carefully experimented and assessed on real designs.

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Signalling Systems for Safe Railway Transport

Tetsuo Takashige

Introduction

ains could not run safely without gnalling devices. This article looks at ur tools that ensure railway safety in pan: block systems, train control systems, ain traffic control systems, and wireless ommunications devices.

Block Systems

utomatic block system

raking distance—the distance needed to ome to a complete halt after brakes are applied—is longer for trains than it is for road vehicles. Consequently, only one train can occupy a specific section of track at one time. Such a section of track is called a block. Track circuits are used to determine whether a train is in a specific block.

Figure 1 shows how the rails form part of an electric circuit (track circuit). When the train's wheels pass a certain point, they cause a short circuit, preventing electric current from proceeding further. This makes it possible to detect a train in a block.

An automatic block system uses the track circuit to automatically detect trains in blocks and to control the signals for each block. All double-tracked sections in Japan use the automatic block system. As Figure 2a shows, there are basically three signal aspects: red, meaning stop immediately before entering the next track section occupied by an ahead train; yellow, meaning proceed with caution at a speed no greater than 45 km/h (55 km/h or faster is permitted on some sections) as far as the signal, and green, meaning the next track section is clear and the train can enter that section at the maximum speed. In heavily used sections, two other signal aspects are also used (Fig. 2b): two yellow lights (restricted speed), and one yellow and one green light (reduced speed).

Other block systems

In addition to the automatic block system, a number of other block systems are used on single tracks. In many cases, a track circuit system or an electronic block system (electronic coding verification system) is used. Both are semi-automatic block systems.

The track circuit system controls train movement in the blocks between stations, and involves interlocking signal levers at

Figure 1 General Principles of Track Circuit

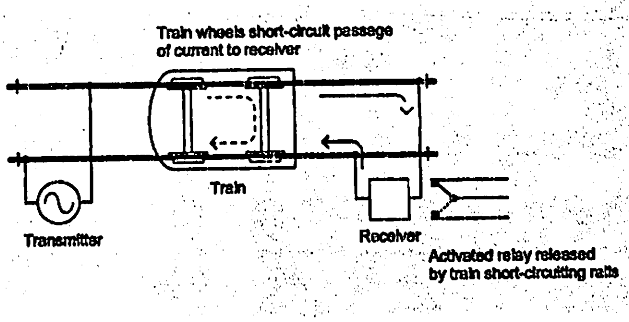


Figure 2 Automatic Block Signalling System

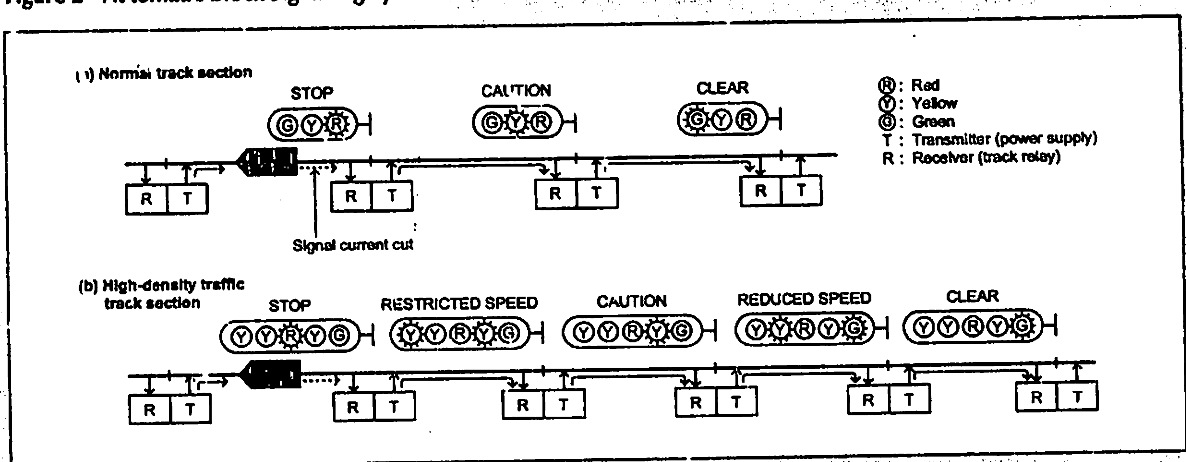
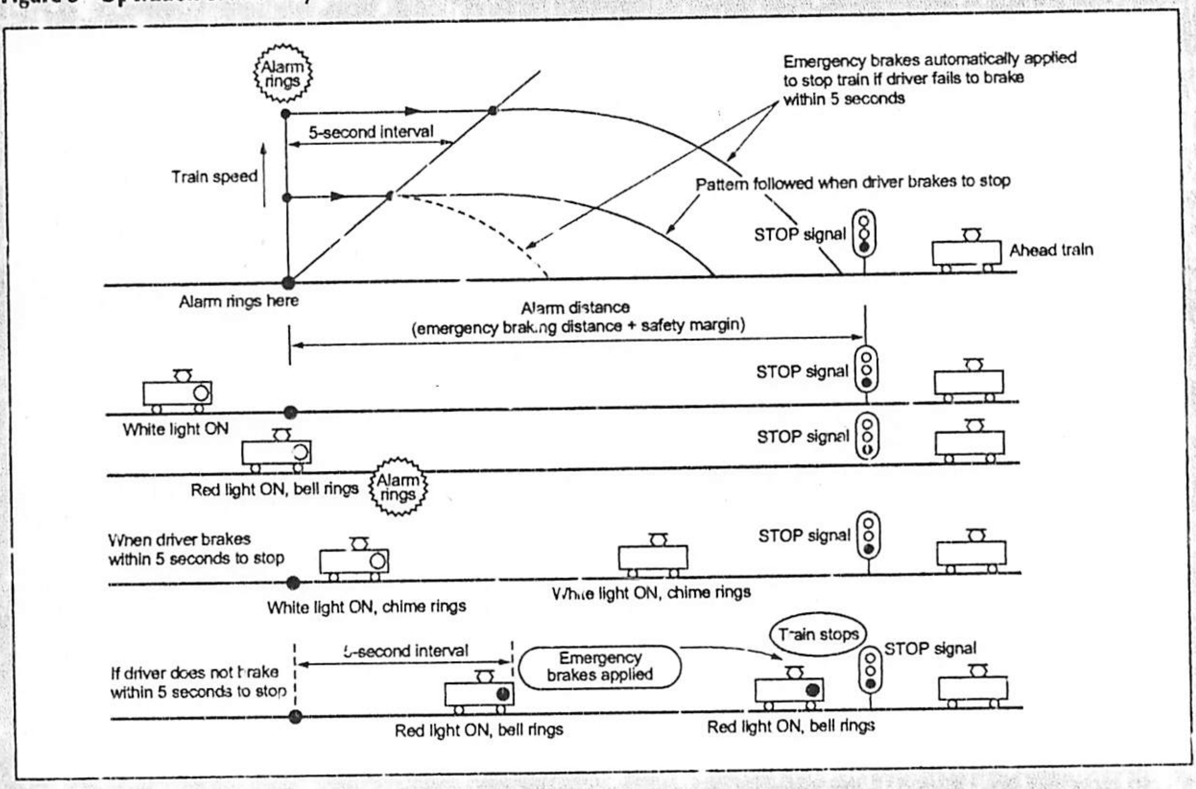


Figure 3 Operation of ATS-S System



the two stations that a train is travelling between. The train's departure and arrival are detected by the track circuits at the station entrance and exit.

In the electronic block system, each train has a radio communications device that transmits the train's ID. When the driver is ready to leave a station, he presses a button and the signal changes automatically to green. When the train arrives at the next station, the train's ID is transmitted to a receiver, clearing the block. This type of electronic block system requires fewer staff because the driver basically controls the block.

Train Control Systems

Automatic Train Stop (ATS)

The driver must always obey the signal, but the possibility of human error can cause serious accidents. Two rail accidents with serious loss of life in the early 1960s resulted in the installation of the so-called Automatic Train Stop (ATS) system throughout Japan. In the ATS system, an alarm sounds in the cab when the train approaches a stop signal, warning the driver to stop. If he fails to apply the brakes, the ATS stops the train automatically. (Figure 3 shows the operation of the ATS-S system used by the JRs.)

The ATS system uses ground coils installed on the track some distance before signals. If a train passes a coil when the signal aspect is stop, an alarm is sent immediately to the driver, regardless of the train speed. If the driver does not stop within 5 seconds after the alarm is received, the emergency brakes are applied automatically to stop the train. In other words, the emergency brakes are not applied if the driver applies the brakes and presses the Acknowledge button. However, this means that if the driver stops at the ground coil, the train can still proceed under his control through a stop signal. So-called 'absolute stop' ground coils that do not depend on driver ackowledgement are installed in stations and at start signals to prevent any possibility of an accident occurring due to the driver moving ahead by mistake.

A new ATS-P type of system that does not depend on driver acknowledgement has been installed recently, mostly in the Tokyo and Osaka regions. Ground coils communicate between the ground and the trains (Fig. 4) and train braking patterns are monitored by the ground coils to ensure that the trains stop before a stop signal. If a train exceeds the speed permitted by the braking pattern, the service brakes are applied automatically to stop the train. The train can then proceed again, but only in accordance with instructions received from the next coil. This system offers higher safety levels, because it does not depend on driver acknowledgement.

Private railways in Japan have installed an improved version of the ATS-S system throughout most of their networks. This system offers on-board speed verification capability and, since it can apply train brakes automatically, does not depend on driver acknowledgement.

In an intermittent control system using coils, no information is received before the train passes the coil, meaning that signal changes in heavily used sections do not provide a suitable level of compliance. To alleviate this problem, the railways have installed a continuous control ATS system for some track sections. This system uses an audio-frequency (AF) current to transmit ATS-related information along the track circuit, making it possible to receive information on board the train at any time. This system offers similar advantages to the ATC system described below.

Automatic Train Control (ATC)

The Automatic Train Control (ATC) system was developed for high-speed trains like the shinkansen, which travel so fast that the driver has almost no time to acknowledge trackside signals. The ATC system sends AF signals carrying information about the speed limit for the specific track section along the track circuit (Fig. 5). When these signals are received on board, the train's current speed is compared with the speed limit and the brakes are applied automatically if the train is travelling too fast. The brakes are released as soon as the train slows below the speed limit. This system offers a higher degree of safety, preventing collisions that might be caused by driver error, so it has also been installed in heavily used lines, such as Tokyo's Yamanote Line and some subway lines.

Although the ATC applies the brakes automatically when the train speed exceeds the speed limit, it cannot control the motor power or train stop position when pulling into stations. However, the Automatic Train Operation (ATO) system can automatically control departure from stations, the speed between stations, and the stop position in stations. It has been installed in some subways.

Digital ATC

The ATC system has been used to control all sections of shinkansen tracks ever since the first shinkansen in 1964 and there has never been a collision. However, ATC has three disadvantages. First, the headway cannot be reduced due to the idle running time between releasing the brakes at one speed limit and applying the brakes at the next slower speed limit. Second, the brakes are applied when the train achieves maximum speed, meaning reduced ride comfort. Third, if the operator wants to run faster trains on the line, all the related relevant wayside and on-board equipment must be changed first.

The digital ATC system uses the track circuits to detect the presence of a train in the section and then transmits digital data from wayside equipment to the train on

Figure 4 Operation of ATS-P System

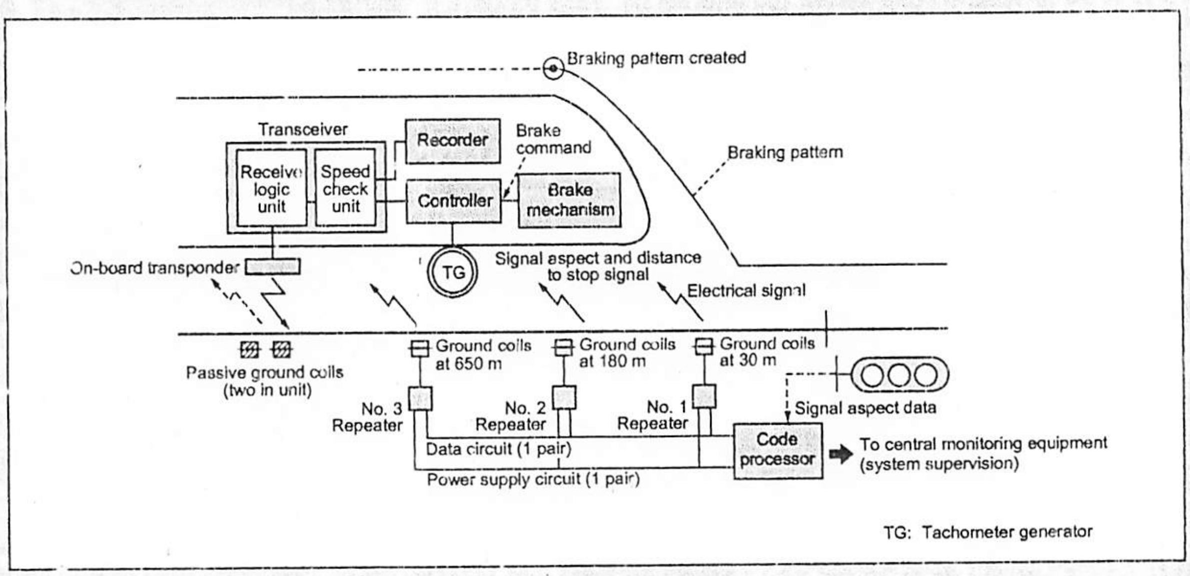


Figure 5 ATC Train Running Pattern

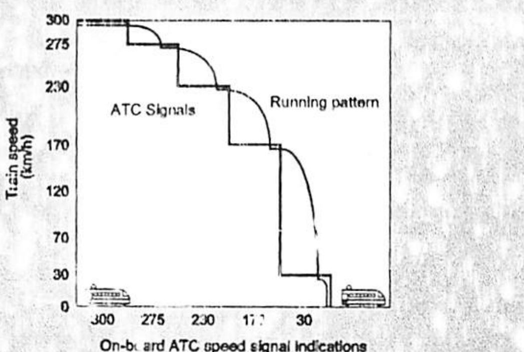
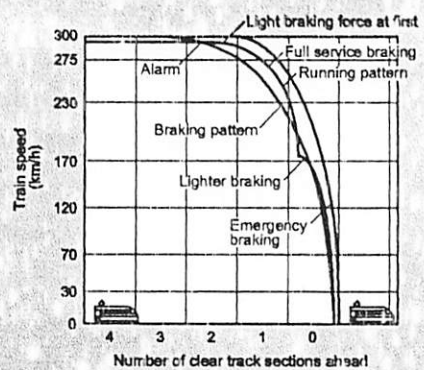


Figure 6 Digital ATC Train Running Pattern



the track circuit numbers, the number of clear sections (track circuits) to the next train ahead, and the platform that the train will arrive at. The received data is compared with data about track circuit numbers saved in the train on-board memory and the distance to the next train ahead is computed. The on-board memory also saves data on track gradients, and speed limits over curves and points. All this data forms the basis for ATC decisions when controlling the service brakes and stopping the train.

Figure 6 shows a running pattern generated by the digital ATC system. The created pattern determines the braking curve to stop the train before it enters the next track section ahead occupied by another train. An alarm sounds when the train approaches the braking pattern and the brakes are applied when the braking pattern is exceeded. The brakes are applied lightly first to ensure better ride comfort, and then more strongly until the optimum deceleration is attained. The brakes are applied more lightly when the train speed drops to a set speed below the speed limit. Regulating the braking force in this way permits the train to decelerate in accordance with the braking pattern, while ensuring ride comfort.

There is also an emergency braking pattern outside the normal braking pattern and the ATC system applies the emergency brakes if the train speed exceeds this emergency braking pattern.

The digital ATC system has a number of advantages: (1) Use of one-step brake control permits high-density operations because there is no idle running time due to operation delay between brake release at the intermediate speed limit stage. (2) Trains can run at the optimum speed with no need to start early deceleration because braking patterns can be created for any type of rolling stock based on data from wayside equipment indicating the distance to the next train ahead. This makes mixed operation of express, local, and freight trains on the same track possible at the optimum speed. (3) There is no need to change the wayside ATC equipment when running faster trains in the future.

The Railway Technical Research Institute (RTRI) is currently conducting basic research into an improved and innovative ATC for Tokyo's Yamanote Line and the shinkansen lines.

CARAT and ATACS

Use of track circuits to detect trains in blocks and to send transmissions from the ground to the train requires a lot of wayside equipment. A Computer And Radio Aided Train control system (CARAT) is being developed to reduce the equipment amount and permit on-board detection of train locations without using track circuits. CARAT will control train traffic by transmitting information between the ground and trains. The system is similar to the digital ATC system in the sense that wayside equipment will transmit information on the distance to the next train ahead, and braking patterns will be created on board. However, CARAT will be able to obtain accurate information on train locations, and transmission of information from the trains to the wayside equipment will make it possible to create moving blocks. As Figure 7 shows, CARAT will be a comprehensive train control system capable of transmitting commands from trains to station points and level crossings. RTRI has already conducted CARAT verification experiments on JR's Joetsu Shinkansen. JR East has conducted subsequent performance tests on its Senseki Line, to test the Advanced Train Administration and Communications System (ATACS), which uses radio telecommunications. One purpose of these tests was to verify that the system is safe for track maintenance personnel. Development of these systems is continuing, with every reason to believe that they will soon come into service.

Figure 7 CARAT System

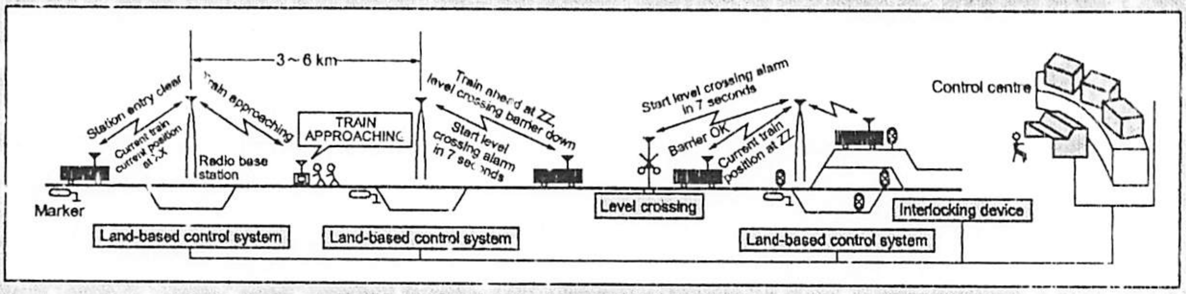
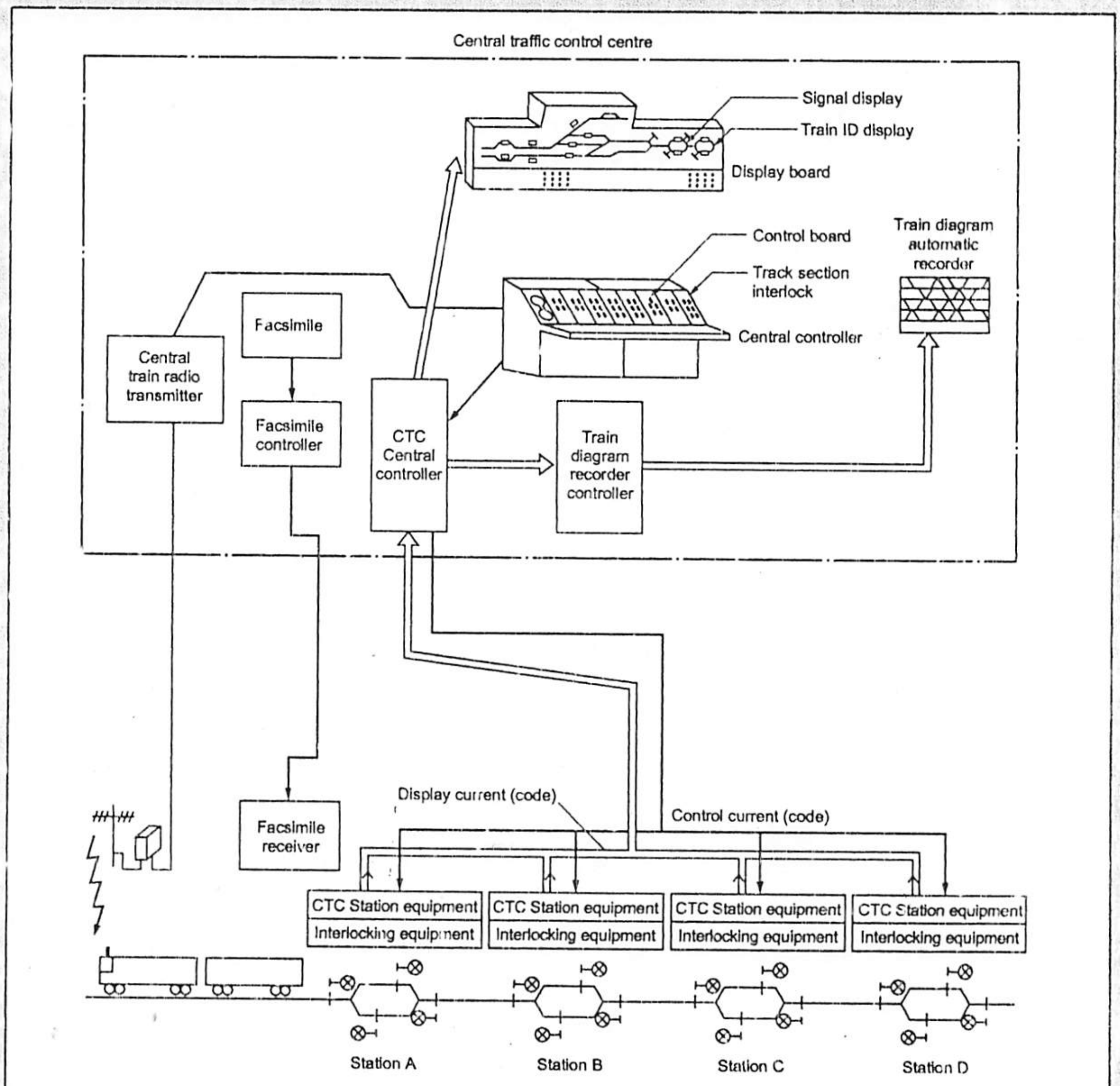


Figure 8 CTC System



;ain Traffic Control Systems

'C and PRC Train traffic control stems

ain traffic control requires full and ntinuous knowledge of the train operations. a conventional traffic control system, tions use telephone communications to ablish a route, but this process is too w and inefficient for modern rail traffic lumes.

ntralized Traffic Control (CTC) provides traffic control centre with information the situation of all trains in all track ctions and permits the centre to ntrol train routes directly (Fig. 8). The art of the centre is a number of ntralized display and control panels, nnected to stations and trains by various es of equipment: radio equipment, mmand telephones, train schedule orders, train number display units, etc. ien the CTC system was first introduced, in routing was controlled directly by ntre personnel. However, the increasing mber of trains overwhelmed the tem, prompting development of the mputerized Programmed Route ntrol (PRC) system.

C was used for the first shinkansen erations in 1964, but routing decisions re automated in 1972. The shinkansen Mputer aided TRAffic Control system OMTRAC) has a number of advanced ctions, including route control, traffic ordination, rolling stock management, d passenger information services. MTRAC is an extremely efficient traffic ntrol system, so it is used for some non-nkansen services as well. The JRs and vate railways have installed or are alling it on most track sections with h-density or high-priority operations.

)SMOS and ATOS

East improved the COMTRAC system 1998 when it opened the Hokuriku nkansen. This system is called COSMOS (COmputerized Safety Maintenance and Operation Systems for Shinkansen) and integrates existing COMTRAC functions with traffic planning, traffic administration, maintenance equipment control, and rolling stock control. Route control is not under centralized control. Instead, routing responsibility is shared with individual stations so that if the system fails at one or several stations or at the Control Centre, the effect on the system as a whole will be minimized and some traffic will continue to flow.

The Autonomous decentralized Transport Operation System (ATOS), a new and very powerful traffic control system is being implemented for the Tokyo region to control 17 track sections, 390 stations (140 interlocked), and 6200 daily train operations. The system first entered service in 1996 on JR East's Chuo Line.

ATOS and COSMOS are very similar—ATOS began first, but efforts were focused on COSMOS as the shinkansen control system. ATOS is far bigger than COSMOS, so the latter was put into service sooner.

Wireless Communications Devices

Narrow-gauge train radio communications

Train safety would be far lower without radio communications between train crews and control centre staff. Before the introduction of train radio, a crew member would have to use a trackside railway telephone to call the control centre if an accident occurred outside a station. Today, the train crew can communicate immediately with the control centre using the train radio.

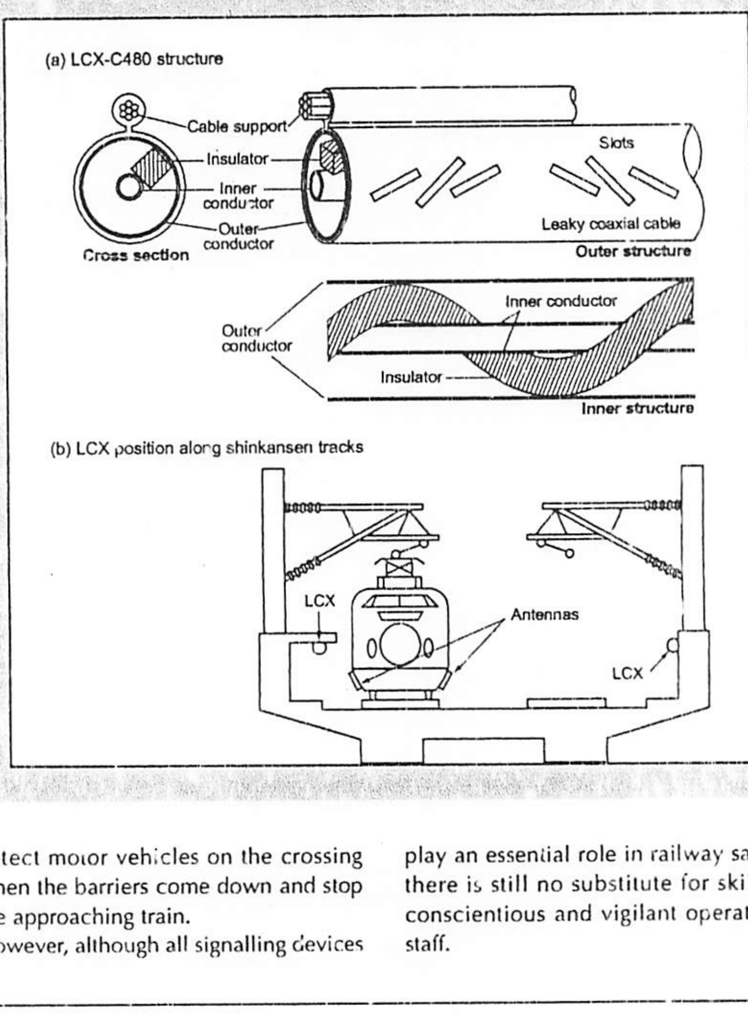
Railways use duplex, semi-duplex and simplex radio telecommunications for non-shinkansen lines. Duplex is used on sections with heavy traffic, semi-duplex is used on high-priority sections with less dense traffic, and simplex is used on other track sections. The simplex system is actually an extension of the existing system that drivers and train crew already used to communicate with each other. Semi-duplex and simplex systems are also used for communication between train crews. Japan's private railways also use train radio communications. The type depends

COSMOS Shinkansen command centre *(JR East)* on the specific track sections. Private trains also have limited-range (1 km) radio equipment that broadcasts an accident warning signal directly to approaching trains in order to prevent a second accident.

Shinkansen radio communications

Shinkansen trains have used radio communications since the very first services in 1964 but Japan's mountainous topography makes radio communications very difficult in some locations. Another problem of the early shinkansen days was the small number of available radio channels. To ensure better reliability and to increase the number of communications channels, leaky coaxial (LCX) cables were laid first along the full length of both the Tohoku Shinkansen and Joetsu Shinkansen to transmit data and messages to and from command and track telephones, and on-board public telephones. LCX cables were subsequently laid along the Tokaido Shinkansen as well. Figure 9 shows the installation details; the supported LCX cable is run along the noise-control barrier beside the track, with suitable-size slots cut into the cable to allow the signal to leak out.

Figure 9 Installation of Leaky Coaxial Cable along Shinkansen Tracks



Conclusion

This article has described some signalling equipment used by Japanese railways to ensure safe railway operations. Other devices, such as interlocked signals and points in stations are used as well. Most of the many thousands of interlocks are either relay or solid-state electronic interlocks and there are about 1000 of the latter now in service.

In addition, almost all level crossings in Japan are controlled by automatic devices that detect an approaching train and lower the barriers automatically. Some level crossings on very busy roads have extra obstruction warning devices to detect motor vehicles on the crossing when the barriers come down and stop the approaching train.

However, although all signalling devices play an essential role in railway safety, there is still no substitute for skilled, conscientious and vigilant operations staff. ■

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Tetsuo Takashige

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Reed Switch Operational Characteristics

Introduction

The Reed Switch was first invented by Bell Labs in the late 1930s. However, it was not until the 1940s when it began to find application widely as a sensor and a Reed Relay. Here it was used in an assortment of stepping/switching applications, early electronic equipment and test equipment. In the late 1940s Western Electric began using Reed Relays in their central office telephone switching stations, where they are still used in some areas today. The Reed Switch greatly contributed to the development of telecommunications technology.

Over the years several manufacturers have come and gone, some staying longer than they should have, tainting the marketplace with poor quality, and poor reliability. However, most of the manufacturers of Reed Switches today produce very high quality and very reliable switches. This has given rise to unprecedented growth.

Today Reed Switch technology is used in all market segments including: test and measurement equipment, medical electronics, Telecom, automotive, security, appliances, general purpose, etc. Its growth rate is stronger than ever, where the world output can not stay abreast with demand.

As a technology, the Reed Switch is unique. Being hermetically sealed, it can exist or be used in almost any environment. Very simple in its structure, it crosses many technologies in its manufacture. Critical to its quality and reliability is its glass to metal, hermetic seal, where the glass and metal used must have exact linear thermal coefficients of expansion. Otherwise, cracking and poor seals will result. Whether sputtered or plated, the process of applying the contact material, usually Rhodium or Ruthenium, must be carried out precisely in ultra clean environments similar to semiconductor technology. Like semiconductors, any foreign particles present in the manufacture will give rise to losses, quality and reliability problems.

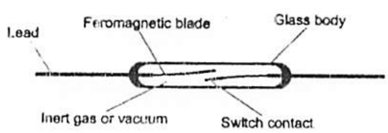
Over the years, the Reed Switch has shrunk in size from approximately 50 mm (2 inches) to 6 mm (0.24 inches). These smaller sizes have opened up many more applications particularly in RF and fast time domain requirements.

Reed Switch Features

1. Ability to switch up to 10,000 Volts
2. Ability to switch currents up to 5 Amps
3. Ability to switch or carry as low as 10 nanoVolts without signal loss
4. Ability to switch or carry as low as 1 femptoAmp without signal loss
5. Ability to switch or carry up to 7 GigaHertz with minimal signal loss
6. Isolation across the contacts up to 1015 W
7. Contact resistance (on resistance) typical 50 milliOhms (mW)
8. In its off state it requires no power or circuitry
9. Ability to offer a latching feature
10. Operate time in the 100 ms to 300 ms range
11. Ability to operate over extreme temperature ranges from –55 oC to 200 oC
12. Ability to operate in all types of environments including air, water, vacuum, oil, fuels, and dust laden atmospheres
13. Ability to withstand shocks up to 200 Gs
14. Ability to withstand vibration environments of 50 Hz to 2000 Hz at up to 30 Gs
15. Long life. With no wearing parts, load switching under 5 Volts at 10 mA, will operate well into the billions of operations

The Basic Reed Switch

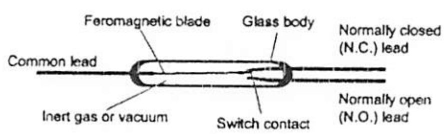
Shown below Figure #1



(Figure #1. The basic hermetically sealed Form 1A (normally open) Reed Switch and its component makeup.)

A Reed Switch consists of two ferromagnetic blades (generally composed of iron and nickel) hermetically sealed in a glass capsule. The blades overlap internally in the glass capsule with a gap between them, and make contact with each other when in the presence of a suitable magnetic field. The contact area on both blades is plated or sputtered with a very hard metal, usually Rhodium or Ruthenium. These very hard metals give rise to the potential of very long life times if the contacts are not switched with heavy loads. The gas in the capsule usually consists of Nitrogen or some equivalent inert gas. Some Reed Switches, to increase their ability to switch and standoff high voltages, have an internal vacuum. The reed blades act as magnetic flux conductors when exposed to an external magnetic field from either a permanent magnet or an electromagnetic coil. Poles of opposite polarity are created and the contacts close when the magnetic force exceeds the spring force of the reed blades. As the external magnetic field is reduced so that the force between the reeds is less than the restoring force of the reed blades, the contacts open.

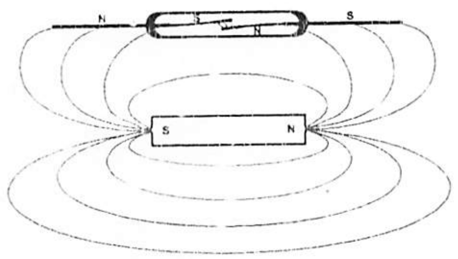
The Reed Switch described above is a 1 Form A (normally open (N.O.) or Single Pole Single Throw (SPST)) Reed Switch. Multiple switch usage in a given configuration is described as 2 Form A (two normally open switches or Double Pole Single Throw (DPST)), 3 Form A (three normally open switches), etc. A normally closed (N.C.) switch is described as a 1 Form B. A switch with a common blade, a normally open blade and a normally closed blade (see Figure # 2) is described as a 1 Form C (single pole double throw (SPDT)).



(Figure #2. The 1 Form C (single pole double throw) three leaded Reed Switch and its component makeup.)

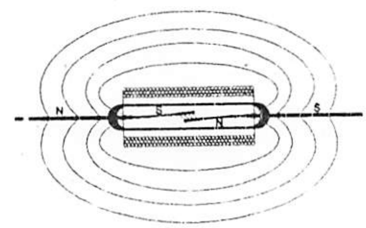
The common blade (or armature blade), the only moving reed blade, is connected to the normally closed blade in the absence of a magnetic field. When a magnetic field of sufficient strength is present, the common blade swings over to the normally open blade. The normally open and normally closed blades always remain stationary. All three reed blades are ferromagnetic; however, the contact area of the normally closed contact is a non-magnetic metal which has been welded to the ferromagnetic blade. When exposed to a magnetic field, both the fixed reeds assume the same polarity, which is opposite that of the armature. The non-magnetic metal interrupts the magnetic flux on the normally closed blade so that the armature sees an un-interrupted flux path to the normally open blade, and it is that which it seeks. Here the attractive force is of sufficient magnitude between the normally open and armature that the contacts close.

To close Reed Switch contacts, two approaches are generally used. 1. The use of a permanent magnet (see Figure #3);



(Figure #3. The basic operation of a Reed Switch under the influence of the magnetic field of a permanent magnet. The polarization of the reed blades occurs in such a manner to offer an attractive force at the reed contacts.)

or 2. The use of a coil wound with copper insulated wire (see Figure #4).



(Figure #4. A Reed Switch sitting in a solenoid where the magnetic field is strongest in its center. Here the reed blades become polarized and an attractive force exists across the contacts.)

When a permanent magnet, as shown, is brought into the proximity of a Reed Switch the individual reeds become magnetized with the attractive magnetic polarity as shown. When the external magnetic field becomes strong enough the magnetic force of attraction closes the blades. The reed blades are annealed and processed to remove any magnetic retentivity. When the magnetic field is withdrawn the magnetic field on the reed blades also dissipates. If any residual magnetism existed on the reed blades, the Reed Switch characteristics would be altered. Proper processing and proper annealing clearly are important steps in their manufacturing.

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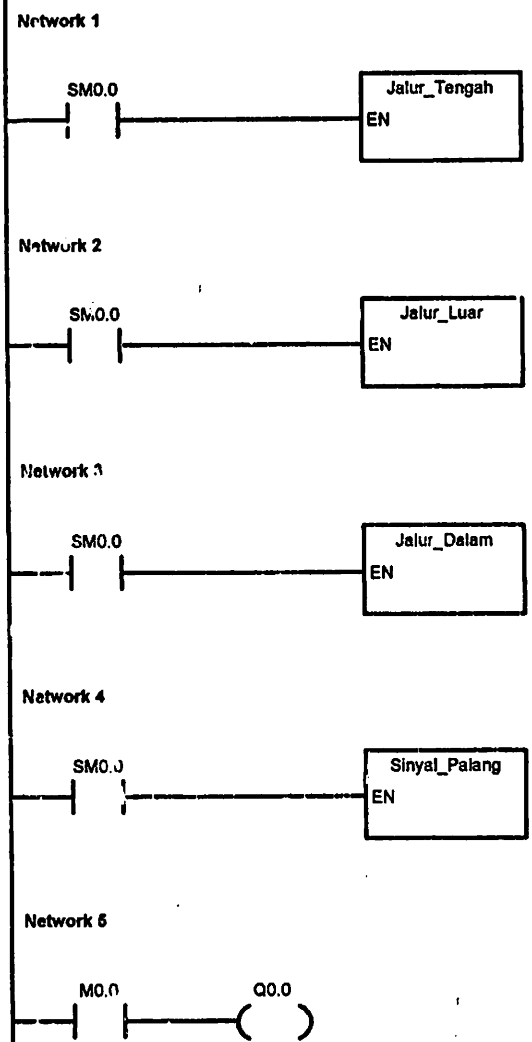

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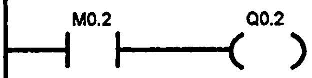

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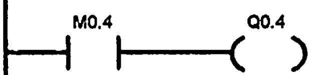

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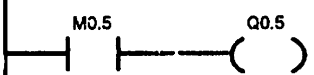

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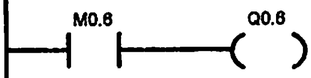

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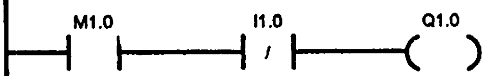

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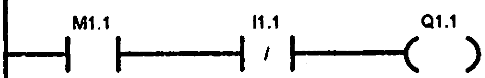

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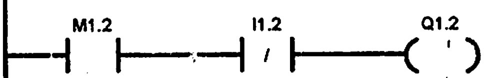

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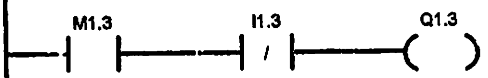

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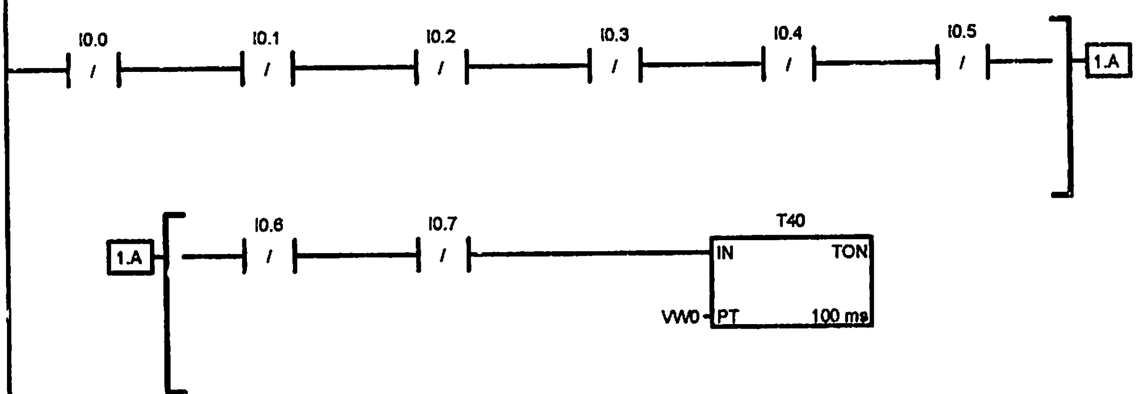

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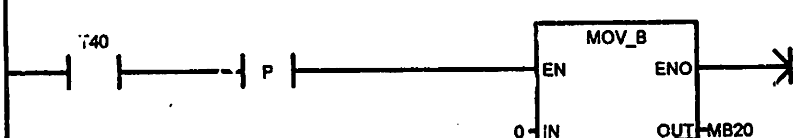

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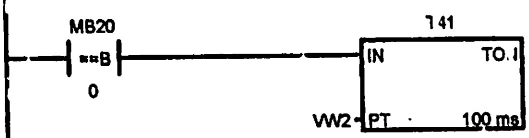

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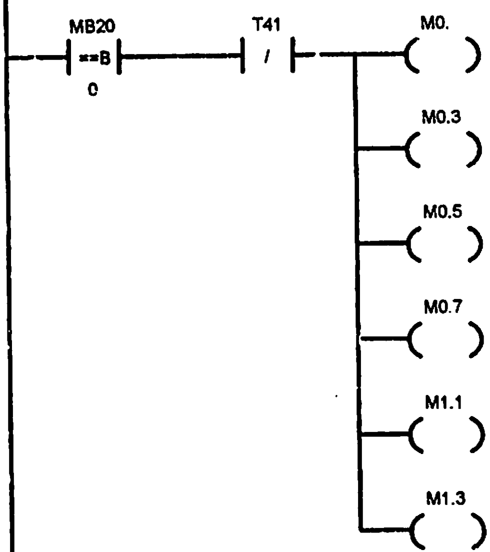

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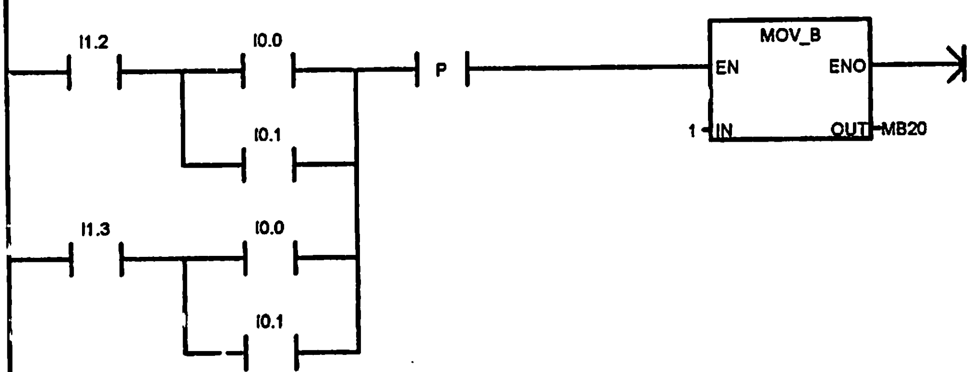

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Network 2

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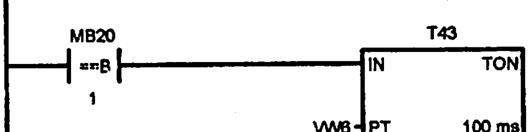

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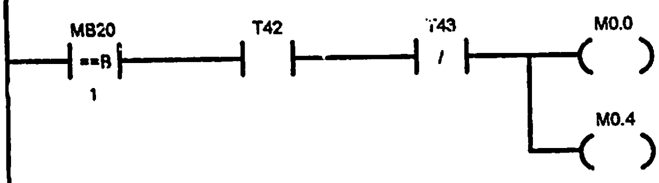

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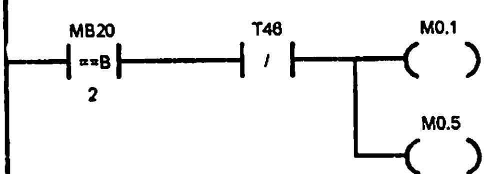

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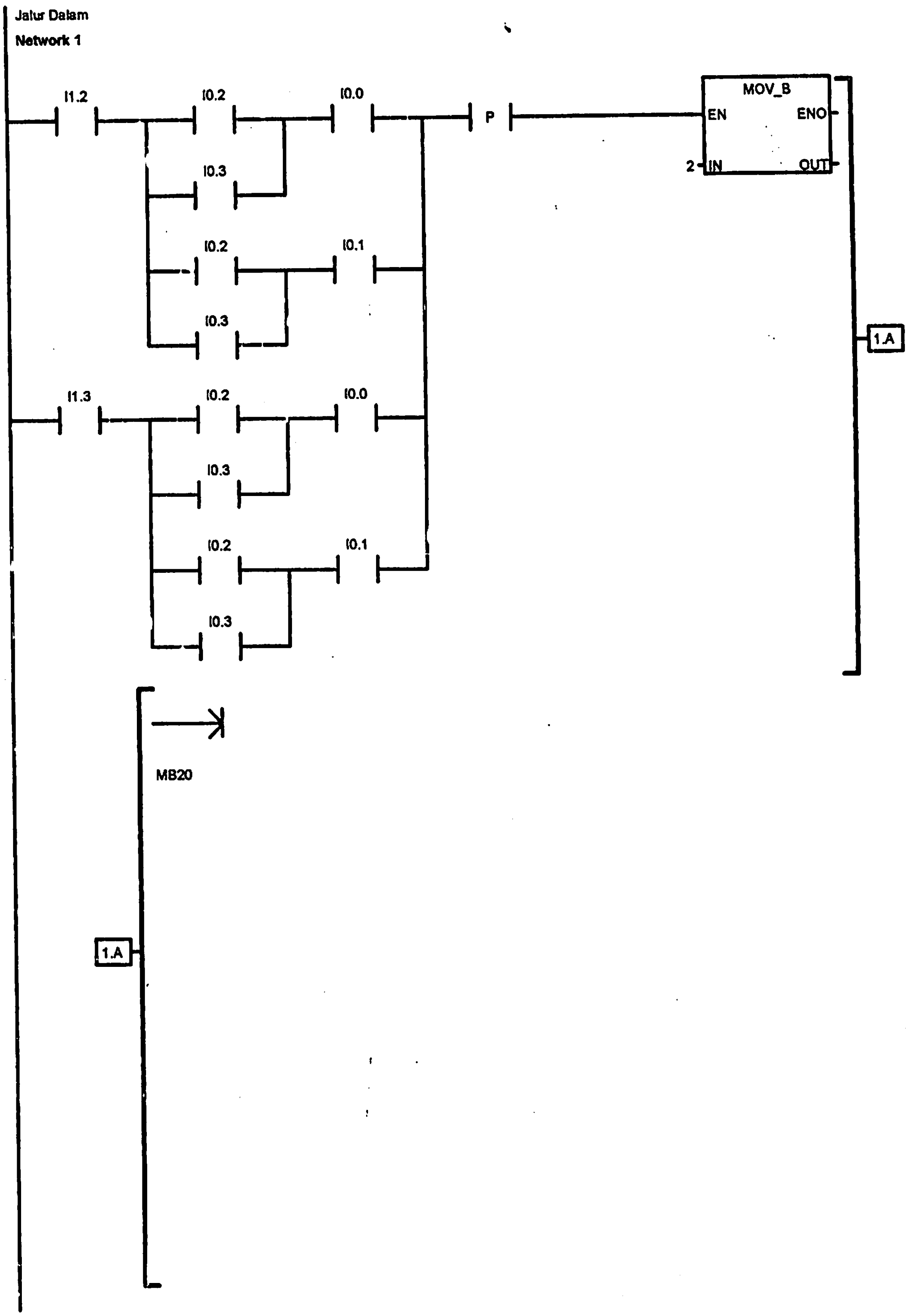

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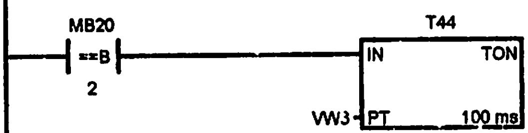
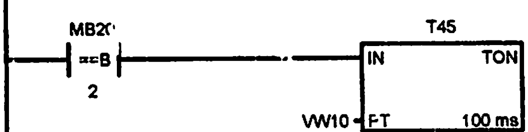
Jalur_Tengah_2	I0.1	

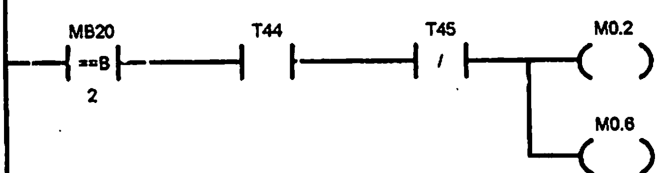
Network 2



Network 3



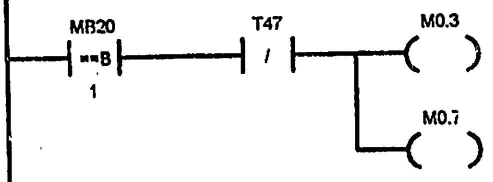
Network 4



Symbol	Address	Comment
F_Dalam_Maju_Kanan	M0.2	
F_Dalam_Maju_Kiri	M0.6	

Network 5

Network 6



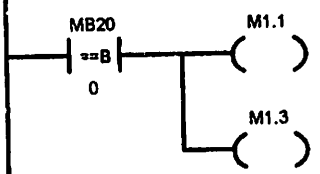
Symbol	Address	Comment
F_Dalam_Mundur_Kanan	M0.3	
F_Dalam_Mundur_kiri	M0.7	

Block: Sinyal_Palang
Author [redacted]
Created: 08/29/2008 03:55:24 pm
Last Modified: 08/29/2008 05:15:29 pm

Symbol	Var Type	Data Type	Comment
EN	IN	BOOL	
	IN		
	IN_OUT		
	OUT		
	TEMP		

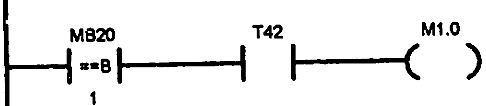
Sinyal Palang

Network 1 Sinyal Luar & Dalam Turun



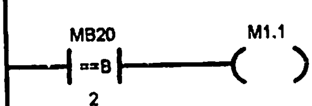
Symbol	Address	Comment
F_Sinyal_Dalam_Turun	M1.3	
F_Sinyal_Luar_Turun	M1.1	

Network 2 Sinyal Luar Naik



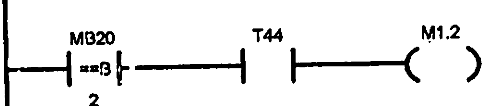
Symbol	Address	Comment
F_Sinyal_Luar_Naik	M1.0	

Network 3 Sinyal Luar Turun



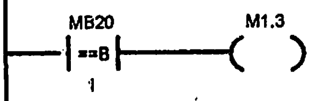
Symbol	Address	Comment
F_Sinyal_Luar_Turun	M1.1	

Network 4 Sinyal Dalam Naik



Symbol	Address	Comment
F_Sinyal_Dalam_Naik	M1.2	

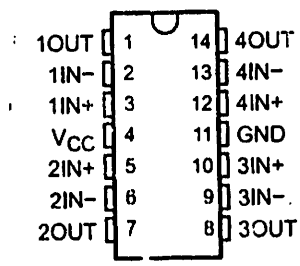
Network 5 Sinyal Dalam Turun



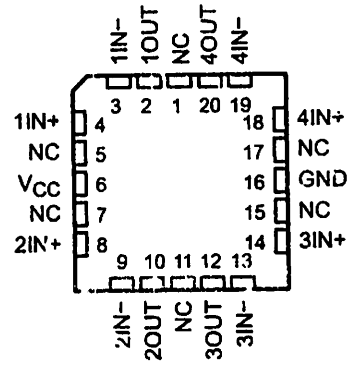
Symbol	Address	Comment
F_Sinyal_Dalam_Turun	M1.3	

- **2-kV ESD Protection for:**
  - **LM224K, LM224KA**
  - **LM324K, LM324KA**
  - **LM2902K, LM2902KV, LM2902KAV**
- **Wide Supply Ranges**
  - **Single Supply . . . 3 V to 32 V (26 V for LM2902)**
  - **Dual Supplies . . . ±1.5 V to ±16 V (±13 V for LM2902)**
- **Low Supply-Current Drain Independent of Supply Voltage . . . 0.8 mA Typ**
- **Common-Mode Input Voltage Range Includes Ground, Allowing Direct Sensing Near Ground**
- **Low Input Bias and Offset Parameters**
  - **Input Offset Voltage . . . 3 mV Typ**
    A Versions . . . 2 mV Typ
  - **Input Offset Current . . . 2 nA Typ**
  - **Input Bias Current . . . 20 nA Typ**
    A Versions . . . 15 nA Typ
- **Differential Input Voltage Range Equal to Maximum-Rated Supply Voltage . . . 32 V (26 V for LM2902)**
- **Open-Loop Differential Voltage Amplification . . . 100 V/mV Typ**
- **Internal Frequency Compensation**

LM124 . . . D, J, OR W PACKAGE
LM124A . . . J OR W PACKAGE
LM224, LM224A, LM224K, LM224KA . . . D OR N PACKAGE
LM324, LM324K . . . D, N, NS, OR PW PACKAGE
LM324A . . . D, DB, N, NS, OR PW PACKAGE
LM324KA . . . D, DB, N, NS, OR PW PACKAGE
LM2902 . . . D, N, NS, OR PW PACKAGE
LM2902K . . . D, DB, N, NS, OR PW PACKAGE
LM2902KV, LM2902KAV . . . D OR PW PACKAGE
(TOP VIEW)



LM124, LM124A . . . FK PACKAGE
(TOP VIEW)



NC – No internal connection

description/ordering information

These devices consist of four independent high-gain frequency-compensated operational amplifiers that are designed specifically to operate from a single supply over a wide range of voltages. Operation from split supplies also is possible if the difference between the two supplies is 3 V to 32 V (3 V to 26 V for the LM2902), and V_{CC} is at least 1.5 V more positive than the input common-mode voltage. The low supply-current drain is independent of the magnitude of the supply voltage.

Applications include transducer amplifiers, dc amplification blocks, and all the conventional operational-amplifier circuits that now can be more easily implemented in single-supply-voltage systems. For example, the LM124 can be operated directly from the standard 5-V supply that is used in digital systems and provides the required interface electronics, without requiring additional ±15-V supplies.

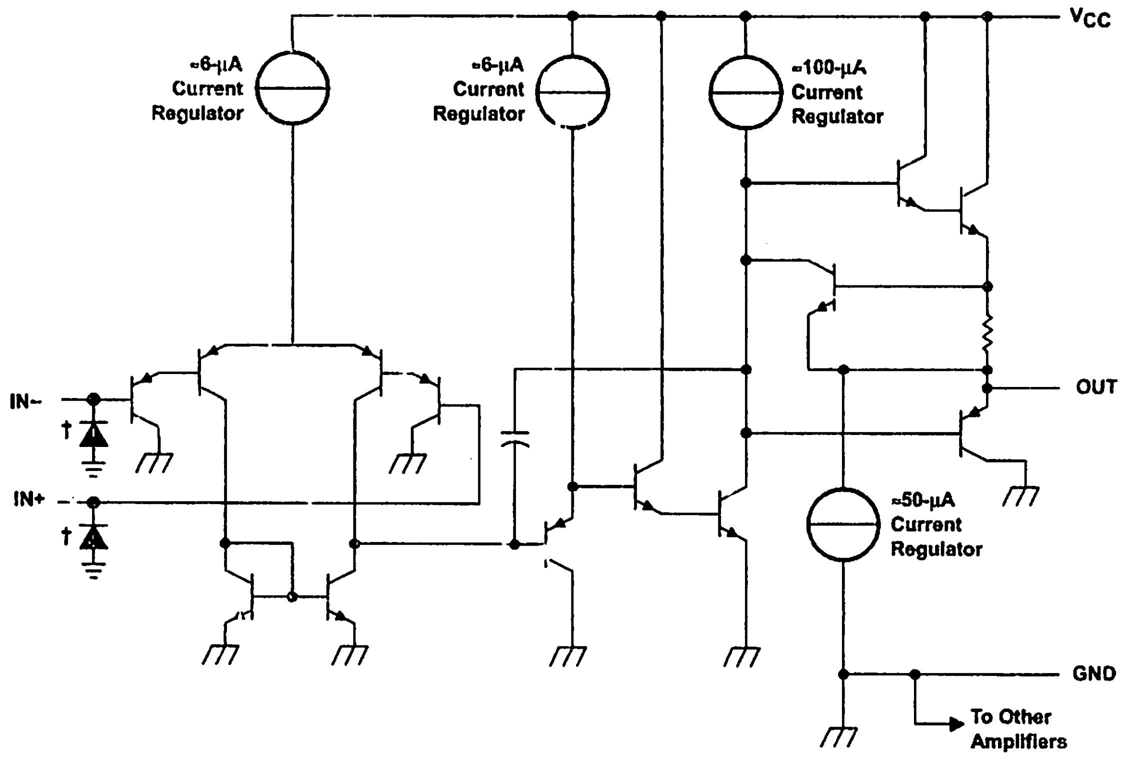
escription/ordering information (continued)

ORDERING INFORMATION

T_A	V_{IO}max AT 25°C	MAX TESTED V_{CC}	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	7 mV	30 V	PDIP (N)	Tube of 25	LM324N	LM324N
					LM324KN	LM324KN
			SOIC (D)	Tube of 50	LM324D	LM324
				Reel of 2500	LM324DR	
				Tube of 50	LM324KD	LM324K
				Reel of 2500	LM324KDR	
			SOP (NS)	Reel of 2000	LM324NSR	LM324
				Tube of 50	LM324KNS	LM324K
				Reel of 2000	LM324KNSR	
			TSSOP (PW)	Tube of 90	LM324PW	L324
				Reel of 2000	LM324PWR	
				Tube of 90	LM324KPW	L324K
				Reel of 2000	LM324KPWR	
	3 mV	30 V	PDIP (N)	Tube of 25	LM324AN	LM324AN
				Tube of 25	LM324KAN	LM324KAN
			SOIC (D)	Tube of 50	LM324AD	LM324A
				Reel of 2500	LM324ADR	
				Tube of 50	LM324KAD	LM324KA
				Reel of 2500	LM324KADR	
			SOP (NS)	Reel of 2000	LM324ANSR	LM324A
				Tube of 50	LM324KANS	LM324KA
				Reel of 2000	LM324KANSR	
			SSOP (DB)	Reel of 2000	LM324ADBR	LM324A
			TSSOP (PW)	Tube of 90	LM324APW	L324A
				Reel of 2000	LM324APWR	
				Tube of 90	LM324KAPW	L324KA
				Reel of 2000	LM324KAPWR	
–25°C to 85°C	5 mV	30 V	PDIP (N)	Tube of 25	LM224N	LM224N
					LM224KN	LM224KN
			SOIC (D)	Tube of 50	LM224D	LM224
				Reel of 2500	LM224DR	
				Tube of 50	LM224KD	LM224K
				Reel of 2500	LM224KDR	
	3 mV	30 V	PDIP (N)	Tube of 25	LM224AN	LM224AN
				Tube of 25	LM224KAN	LM224KAN
			SOIC (D)	Tube of 50	LM224AD	LM224A
				Reel of 2500	LM224ADR	
				Tube of 50	LM224KAD	LM224KA
				Reel of 2500	LM224KADR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

chematic (each amplifier)



COMPONENT COUNT (total device)	
Epi-FET	1
Transistors	95
Diodes	4
Resistors	11
Capacitors	4

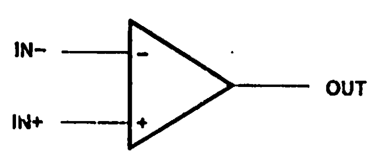
† ESD protection cells - available on LM324K and LM324KA only

ORDERING INFORMATION (CONTINUED)

T_A	V_{IO}max AT 25°C	MAX TESTED V_{CC}	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
−40°C to 125°C	7 mV	26 V	PDIP (N)	Tube of 25	LM2902N	LM2902N
				Tube of 25	LM2902KN	LM2902KN
			SOIC (D)	Tube of 50	LM2902D	LM2902
				Reel of 2500	LM2902DR	
				Tube of 50	LM2902KD	LM2902K
				Reel of 2500	LM2902KDR	
			SOP (NS)	Reel of 2000	LM2902NSR	LM2902
				Tube of 50	LM2902KNS	LM2902K
				Reel of 2000	LM2902KNSR	
			SSOP (DB)	Tube of 80	LM2902KDB	L2902K
				Reel of 2000	LM2902KDBR	
			TSSOP (PW)	Tube of 90	LM2902PW	L2902
				Reel of 2000	LM2902PWR	
				Tube of 90	LM2902KPW	L2902K
				Reel of 2000	LM2902KPWR	
		32 V	SOIC (D)	Reel of 2500	LM2902KVQDR	L2902KV
			TSSOP (PW)	Reel of 2000	LM2902KVQPWR	L2902KV
	2 mV	32 V	SOIC (D)	Reel of 2500	LM2902KAVQDR	L2902KA
			TSSOP (PW)	Reel of 2000	LM2902KAVQPWR	L2902KA
−55°C to 125°C	5 mV	30 V	CDIP (J)	Tube of 25	LM124J	LM124J
			CFP (W)	Tube of 25	LM124W	LM124W
			LCCC (FK)	Tube of 55	LM124FK	LM124FK
			SOIC (D)	Tube of 50	LM124D	LM124
				Reel of 2500	LM124DR	
	2 mV	30 V	CDIP (J)	Tube of 25	LM124AJ	LM124AJ
			CFP (W)	Tube of 25	LM124AW	LM124AW
			LCCC (FK)	Tube of 55	LM124AFK	LM124AFK

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

symbol (each amplifier)



ectrical characteristics at specified free-air temperature, V_{CC} = 5 V (unless otherwise noted)

PARAMETER		TEST CONDITIONS†		T_A‡	LM124, LM224			LM324, LM324K			UNIT
					MIN	TYP§	MAX	MIN	TYP§	MAX	
V_{IO}	Input offset voltage	V_{CC} = 5 V to MAX, V_{IC} = V_{ICR}min, V_O = 1.4 V		25°C		3	5		3	7	mV
				Full range			7			9	
I_{IO}	Input offset current	V_O = 1.4 V		25°C		2	30		2	50	nA
				Full range			100			150	
I_{IB}	Input bias current	V_O = 1.4 V		25°C		−20	−150		−20	−250	nA
				Full range			−300			−500	
V_{ICR}	Common-mode input voltage range	V_{CC} = 5 V to MAX		25°C	0 to V_{CC} − 1.5			0 to V_{CC} − 1.5			V
				Full range	0 to V_{CC} − 2			0 to V_{CC} − 2			
V_{OH}	High-level output voltage	R_L = 2 kΩ		25°C	V_{CC} − 1.5			V_{CC} − 1.5			V
		R_L = 10 kΩ		25°C							
		V_{CC} = MAX	R_L = 2 kΩ	Full range	26			26			
			R_L ≥ 10 kΩ	Full range	27	28		27	28		
V_{OL}	Low-level output voltage	R_L ≤ 10 kΩ		Full range		5	20		5	20	mV
A_{VD}	Large-signal differential voltage amplification	V_{CC} = 15 V, V_O = 1 V to 11 V, R_L ≥ 2 kΩ		25°C	50	100		25	100		V/mV
				Full range	25			15			
CMRR	Common-mode rejection ratio	V_{IC} = V_{ICR}min		25°C	70	80		65	80		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC}/\Delta V_{IO}$)			25°C	65	100		65	100		dB
V_{O1}/V_{O2}	Crosstalk attenuation	f = 1 kHz to 20 kHz		25°C		120			120		dB
I_O	Output current	V_{CC} = 15 V, V_{ID} = 1 V, V_O = 0	Source	25°C	−20	−30	−60	−20	−30	−60	mA
				Full range	−10			−10			
		V_{CC} = 15 V, V_{ID} = −1 V, V_O = 15 V	Sink	25°C	10	20		10	20		
				Full range	5			5			
		V_{ID} = −1 V,	V_O = 200 mV	25°C	12	30		12	30		μA
I_{OS}	Short-circuit output current	V_{CC} at 5 V, GND at −5 V	V_O = 0,	25°C		±40	±60		±40	±60	mA
I_{CC}	Supply current (four amplifiers)	V_O = 2.5 V,	No load	Full range		0.7	1.2		0.7	1.2	mA
		V_{CC} = MAX, V_O = 0.5 V_{CC},	No load	Full range		1.4	3		1.4	3	

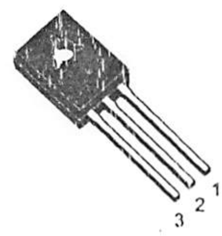
† All characteristics are measured under open-loop conditions, with zero common-mode input voltage, unless otherwise specified. MAX V_{CC} for testing purposes is 26 V for LM2902 and 30 V for the others.
‡ Full range is −55°C to 125°C for LM124, −25°C to 85°C for LM224, and 0°C to 70°C for LM324.
§ All typical values are at T_A = 25°C.

BD135
BD139

NPN SILICON TRANSISTORS

Type	Marking
BD135	BD135
BD135-10	BD135-10
BD135-16	BD135-16
BD139	BD139
BD139-10	BD139-10
BD139-16	BD139-16

- STMicroelectronics PREFERRED SALESTYPES



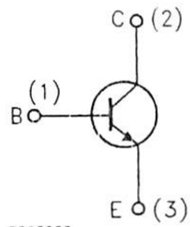
SOT-32

DESCRIPTION

The BD135 and BD139 are silicon Epitaxial Planar NPN transistors mounted in Jedec SOT-32 plastic package, designed for audio amplifiers and drivers utilizing complementary or quasi-complementary circuits.

The complementary PNP types are BD136 and BD140 respectively.

INTERNAL SCHEMATIC DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value		Unit
		BD135	BD139	
V_{CBO}	Collector-Base Voltage ($I_E = 0$)	45	80	V
V_{CEO}	Collector-Emitter Voltage ($I_B = 0$)	45	80	V
V_{EBO}	Emitter-Base Voltage ($I_C = 0$)	5		V
I_C	Collector Current	1.5		A
I_{CM}	Collector Peak Current	3		A
I_B	Base Current	0.5		A
P_{tot}	Total Dissipation at $T_c \leq 25\ ^oC$	12.5		W
P_{tot}	Total Dissipation at $T_{amb} \leq 25\ ^oC$	1.25		W
T_{stg}	Storage Temperature	-65 to 150		^oC
T_j	Max. Operating Junction Temperature	150		^oC

THERMAL DATA

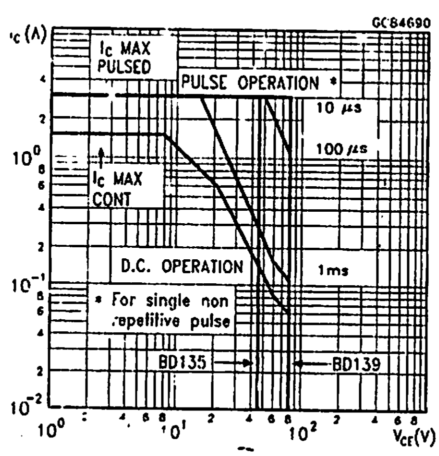
$R_{thj-case}$	Thermal Resistance Junction-case	Max	10	°C/W

ELECTRICAL CHARACTERISTICS (T_{case} = 25 °C unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit
I_{CBO}	Collector Cut-off Current (I_E = 0)	V_{CB} = 30 V V_{CB} = 30 V T_C = 125 °C			0.1 10	µA µA
I_{EBO}	Emitter Cut-off Current (I_C = 0)	V_{EB} = 5 V			10	µA
$V_{CEO(sus)}$*	Collector-Emitter Sustaining Voltage (I_B = 0)	I_C = 30 mA for **BD135** for **BD139**	45 80			V V
$V_{CE(sat)}$*	Collector-Emitter Saturation Voltage	I_C = 0.5 A I_B = 0.05 A			0.5	V
V_{BE}*	Base-Emitter Voltage	I_C = 0.5 A V_{CE} = 2 V			1	V
h_{FE}*	DC Current Gain	I_C = 5 mA V_{CE} = 2 V I_C = 150 mA V_{CE} = 2 V I_C = 0.5 A V_{CE} = 2 V	25 40 25		 250 	
h_{FE}	h_{FE} Groups	I_C = 150 mA V_{CE} = 2 V for **BD135/BD139** group-10 for **BD135/BD139** group-16	63 100		160 250	

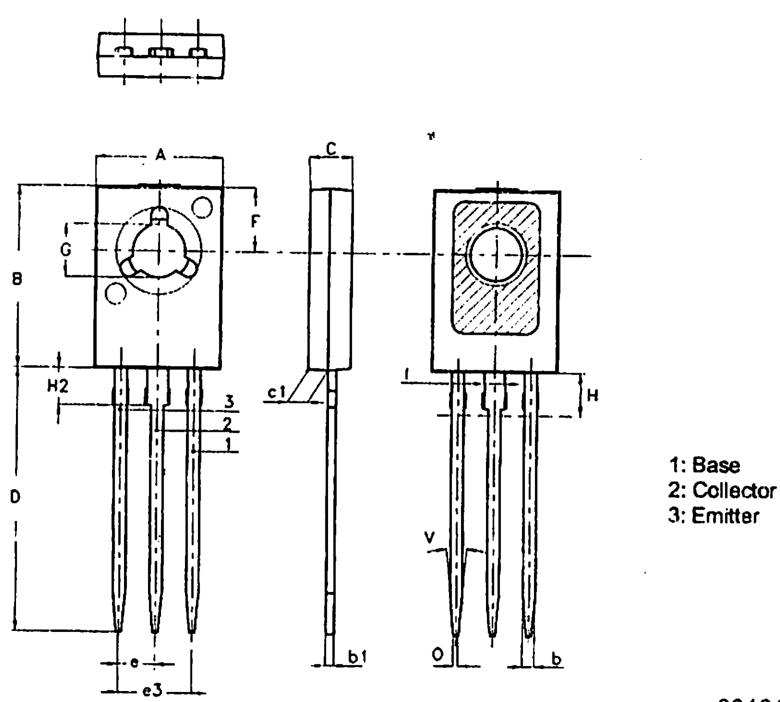
* Pulsed: Pulse duration = 300 µs, duty cycle 1.5 %

Safe Operating Area



SOT-32 (TO-126) MECHANICAL DATA

DIM.	mm			inch		
	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.
A	7.4		7.8	0.291		0.307
B	10.5		10.8	0.413		0.425
b	0.7		0.9	0.028		0.035
b1	0.40		0.65	0.015		0.025
C	2.4		2.7	0.094		0.106
c1	1.0		1.3	0.039		0.051
D	15.4		16.0	0.606		0.630
e		2.2			0.087	
e3		4.4			0.173	
F		3.8			0.150	
G	3		3.2	0.118		0.126
H			2.54			0.100
H2		2.15			0.084	
I		1.27			0.05	
O		0.3			0.011	
V		10°			10°	



0016114/B

PCB Relays

JZC-20F(4088)

Features:

Superminiature, low coil power consumption.

Switching capacity up to 15A.

PC board mounting.

Suitable for household electrical appliance, automation system, instrument and meter.

Detail Parameter

Outline Dimensions	22.5 ¡Á 16.5 ¡Á 23.5 mm
Contact Arrangement	
(China)	1A 1D 1Z
(International)	1A 1B 1C
Contact Rating	5A,10A,15A/120VAC,28VDC; 5A,7A,10A/220VAC
Contact Resistance	<=100 m¦¸
Max. Switching Power	280W,1200VAC
Max. Switching Voltage	110Vdc 380Vac
Max. Switching Current	10A
Mechanical Operation life	1×10^7
Electrical Operation life	1×10^5
Coil resistance	0.36W 0.45W
Coil Rated Voltage	3, 6, 9, 12, 18, 24, 48 Vdc
Pickup voltage VDC(max)	75% rated voltage
Release voltageVDC(min)	10% rated voltage
Operate Time	<=10ms
Release Time	<=5ms
Coil Maximan Voltage VDC	130% rated voltage
Insulation Resistance	100 M¦¸(at 500V)
Dielectric Strength	
(Between contacts)	50Hz, 750V
(Between contact and coil)	50Hz, 1500V
Shock Resistance	10G 11ms
Vibration resistance	10 ~ 55Hz amplitude 0.35mm
Ambient Temperature	-40 ~ 70¡ãC
Relative Humidity	85% (at 40¡ãC)
Mass	13g
Cross Reference	

Mounting payout (Bottom View)mm Wiring Diagram