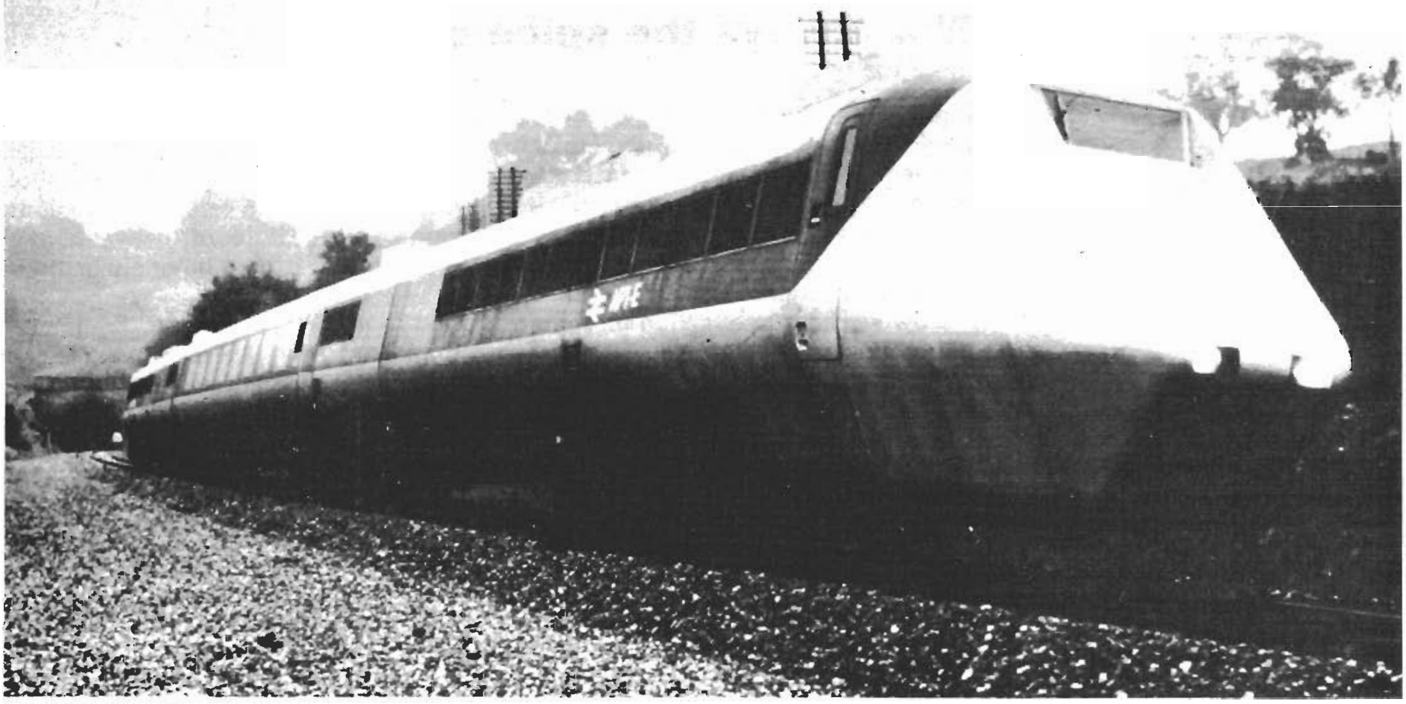
Computers, communication and high speed railways



This article describes how the railways have been making progress in utilization of electronic systems which are now becoming more and more necessary for economy, efficiency and safety as traffic volume and speeds increase. Control and signalling for high speed trains, centralized signal-box operation, a modernized communications system and computer control for the goods fleet are all examined with an eye to the future to determine the benefits that accrue from developments in electronics.

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On September 15, 1830 in the reign of King William IV, the history of railway signalling commenced when the Liverpool to Manchester railway was opened by the Duke of Wellington — a soldier turned politician. The signalling system consisted of railway policemen stationed a mile apart along the track, who indicated to the driver by disciplined hand signals on a time-interval basis whether the line was considered to be clear or obstructed. By night red or white lamps were used. In 1834 the first fixed signal was erected.

From then onwards there has been a steady development in railway signal engineering. It has proceeded from two-aspect to three-aspect time interval and from two-aspect to four-aspect space interval; from flags to semaphore signals; and from upper quadrant signals to multiple-aspect colour lights. Speeds have increased from the 30 m.p.h. of the Liverpool & Manchester Railway to the present day high speed trains where moves towards a 500km per hour train are already evident.

British Railways' 240 km per hour electric advanced passenger train (APT) with its unique body-tilting mechanism, is undergoing main-line trials. The French Societe de l'Aerotrain has designed a 180km per hour electrically linear-motor driven air supported hover-train. They also have the "Orleans" air cushion vehicle capable of 280km per hour. The German Federal Government is completing a test centre at Donauriad as part of its planning for a "desirable transportation system of the future". Krauss-Maffei has already demonstrated a magnetically - supported vehicle, designed for a maximum 320km per hour and its Transrapid system, as it is called, is moving into a new phase with test vehicles reaching 500km per hour on the Donauriad track.

The U.S. Government has allocated massive funds for high speed train research and several corporations are using the Colorado test facility for operational testing of high speed trains with air-cushion or magnetic suspension and utilizing linear propulsion. In 1973 the U.S. signed an agreement with the Soviet Union to co-operate in the field of high speed transport. The Russians have a test facility at Kiev, where linear-motored monorail cars and rolling stock are on trial, as well as air-cushion or magnetic suspension. Japanese National Railways is also experimenting with magnetic levitation and linear motors for suspension and propulsion for its second Tokaido Shinkansen line which will be needed in 1980. Its Tokaido one is already the envy of the world and has been described as the finest operating in any country.

High speed running can be achieved only with suitably designed electrical signalling systems. It has been found, however, that high average speeds on routes with many converging and diverging junctions, carrying mixed traffic, is very difficult to achieve by simply replacing mechanical signalling with electrical equipment controlled from the original signal boxes. The speed of trains and the limited view of overall operations given to each operator provides a disjointed control system and can result in very rapid build-up of delays when mishaps occur. The solution in this country has been found in centralizing control in large signal boxes having very wide areas of track under their control. Operators in these signal boxes are provided with the most modern facilities: control consoles and indicating diagrams depicting each route, track circuit, signal, switch point etc, with convenient means of setting routes; comprehensive train-describer systems which continuously display on the indicating diagram the head-codes of all trains in their correct geographical location; automatic train-identity recording printers etc; teleprinter links to adjacent signal boxes and Traffic Control offices; extensive telephone installations for communications with other signal boxes, Traffic Control Centres, station staff, shunters, train crews etc.

Typical of these new boxes, the work at Feltham represents a further step in the Southern Region's programme of using modern signalling techniques to control large sections of line from a single signal box. Forty-five boxes were replaced when Feltham came into operation at the end of last year and it now controls 351 colour light signals and 112 points in 70 miles of track in the Feltham area. The Feltham signal box is one of the thirteen which will eventually control the whole of British Rail's Southern Region.

The control room houses a five section vertical control panel of the mosaic type. The panel depicts the track layout in a diagrammatic form. Level crossing, signal and points push-button switches and lamp indicators in the line of track provide white and red lights along the track showing "route set" and track "occupied" respectively. The routes are set by the signalman using an entrance/exit operating system. Two push-button switches are operated in a sequential manner and set a route from signal to signal.

The signalling console also houses closed-circuit television monitors, used to observe the road traffic over each crossing. Remote monitoring using this system is used up to distances of 21 miles. Each control panel has a diagram showing a section of the tracks controlled from the box, with push-buttons to operate the points and signals. Trains passing along the lines are shown on the diagram by red lights, while miniature cathode-ray tubes identify each train by a code number. A computer is also used to summarize and record data being continuously fed into the signal box, which is a two-level building, the lower floor containing signalling, train-description and telecommunications equipment rooms together with workshops and stores for the maintenance of that equipment. The upper floor houses the control panel and amenities for the signalmen, traffic regulators and maintenance staff located in the signal box. Information on trains entering or leaving the signalling control area is exchanged automatically between the Feltham and adjacent signal boxes using the telecommunication cable transmission system and is transmitted to the dual computer system situated at Feltham, which controls the operation of a four-digit display on small c.r.ts mounted in the signalling control panel. Progress of the trains is checked with the signal equipment and the descriptions are transferred automatically along the line of route, advance warning of a train's progress being transmitted to adjacent signal boxes. Synchronized station clocks, public address and train departure indicators are being provided on the stations within the control area, the latter two services being controlled from the train describer equipment.

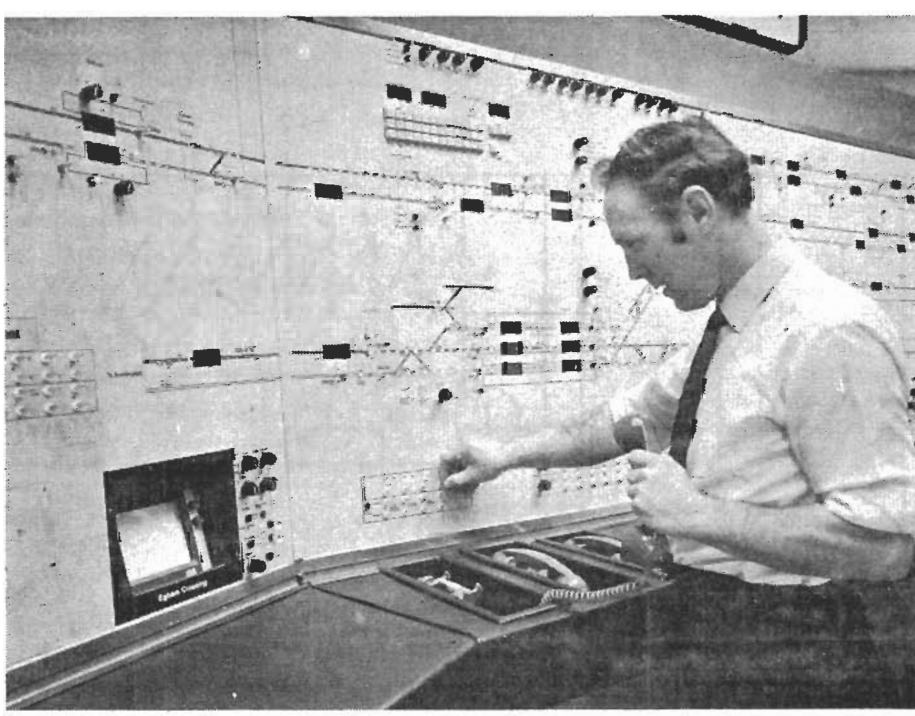
Co-ordination of traffic movements is carried out by the Regulator who sits behind the operators and has a complete view of the whole of the control and indication panel while advance warning of train movements is provided for him on the teleprinter machines on his desk.

From this initial outline of the complexity of British Railways control and signalling systems it becomes clear that the telecommunication system must be wide in its scope of operational practices from providing a general telephone service for administration and control to facilities for data transmission for computer systems. This should enable railway management to achieve a competitive and efficient service for its customers.

Telecommunications

To appreciate the span of the operation in the U.K.[1] it is necessary to delve again into the recent history of railway communication. At the time of nationalization, British Rail inherited four separate telephone systems. These had all been developed independently to provide communication within each railway company, thus offering little scope for expansion into an integrated system. Financial limitations during the early years of nationalization also hampered overall development.

In the middle sixties, the Railways Board began to realize the need for efficient communication and a careful study was made into the various aspects of setting up a satisfactory and economic system that would provide all the facilities required for a modern business organization. In 1969 the Board gave authority for work to proceed in establishing a railway-owned and maintained telecommunications network. The provision of this network is known within the railway organiza-



Interior of Feltham signal box with a close up view showing one of the five track control panels.

tion as the National Telecommunications Plan (NTP). The principal object of the plan is in providing an automatic extension-to-extension trunk-dialling telephone network between all business centres on the railway, as well as a good base for data-transmission services.

The nationwide small-diameter coaxial trunk cable routes consist of surface concrete troughing. The major part of the grid provides for either two or four tubes with a sufficient number of quadded conductors included as may be required for other purposes, the whole comprising a composite cable of the requisite size. The coaxial tubes are engineered to the relevant Post Office specified standard for the particular type of cable. They provide a bandwidth of 4MHz per pair of tubes or 960 high-quality audio circuits, giving a transmission performance to CCITT standards. Consideration is in hand to convert some of the line systems to 12MHz to provide for the ever increasing demand for circuit needs.

To enable compensation to be provided for attenuation loss, transistorized repeaters are inserted in the cable every 4000m and they are housed in buried metal boxes. The repeaters are power fed from the terminal stations and main repeater stations, the power feeding points being a maximum of about 70km apart. Speech channels have an effective bandwidth of 300-3,400Hz, outband signalling provided at a frequency of 3825Hz. The cables are sheathed with lead, aluminium or plastic to suit the particular conditions. They are also gas pressurized to provide additional security.

It is particularly important to reduce impulsive noise to a minimum to avoid any increase in transmission error rate. The methods employed to reduce any induced voltages to the limits specified by the CCITT include the use of special steel-tape armouring, which acts as an electromagnetic screen, in addition to a

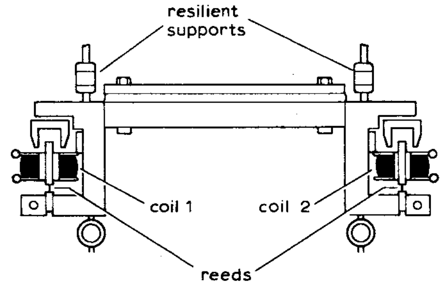


Fig. 1. Arrangement of the tuned double reed unit.

high-conductivity screening sheath of aluminium and the use of booster transformers and return conductors associated with the traction-supply path. The use of pulse code modulation is becoming widespread to provide high-grade circuits over local cables.

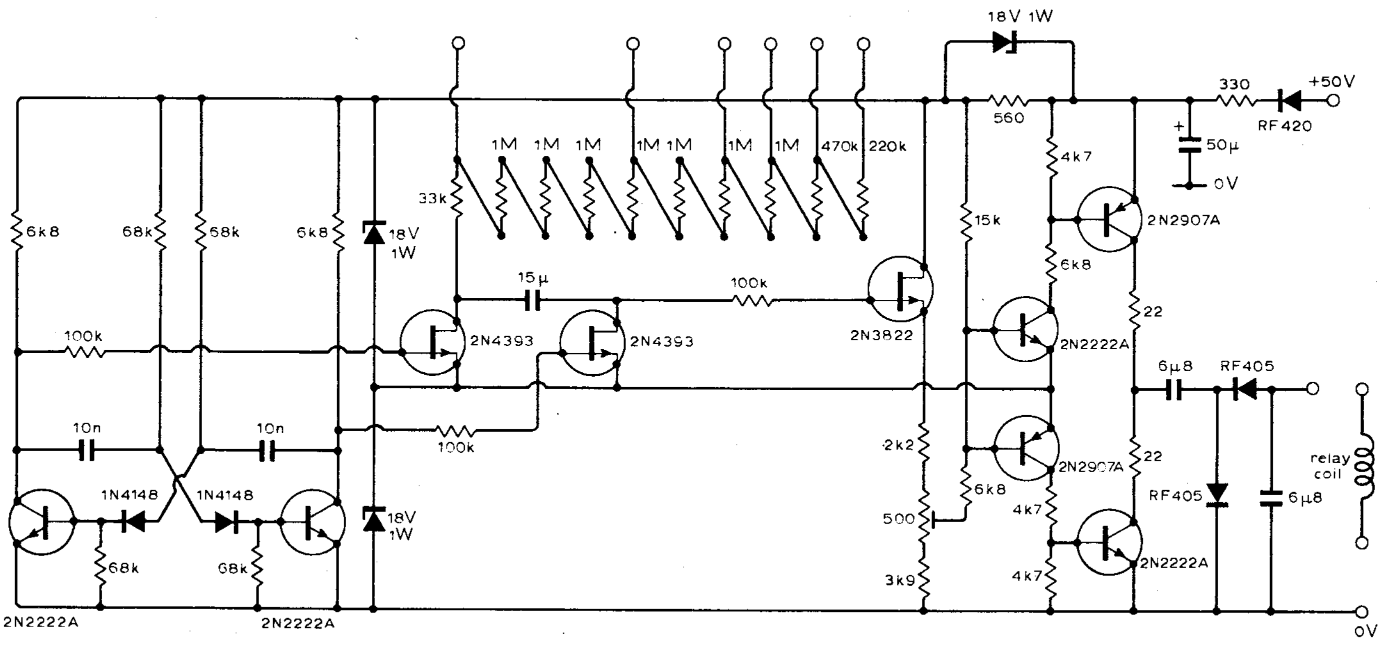
Time division multiplex systems are used only for the transmission of information that cannot affect the safety of trains.[2] Although it is technically possible to design t.d.m. systems that operate on a fail-safe principle, such systems are not economical in cost or efficient in utilization of the carrier-channel bandwidth. An alternative form of multiplexing is the well-known frequency-division method. In this method, a number of generators of frequencies $f_1 \ldots . f_n$ may be connected to a line and at distant points; receivers of $f_1 \ldots . f_n$ may also be connected to the line. The transmission of any of the available frequencies will operate the appropriate receiver. The principle is widely used where on/off data is to be transmitted. The method is not attractive when large quantities of data have to be transmitted between two points; it is most useful where the individual transmitters or receivers are required at different points, for instance along the track.

If the components that determine the operating frequencies of the generator and receiver filter can be guaranteed not to deviate from their normal frequency for any reason whatsoever during the life of the equipment, it is possible to design an f.d.m. system of the necessary high standard of integrity. The remaining problems are concerned with the exclusion of all other sources of interference in the operating frequency band of the system, and a circuit design that cannot result in self oscillation and which continuously proves the correct functioning of all components.

The device chosen for frequency determination in both transmitter and receiver filters is a tuned metal rod that operates on the same principle as a tuning fork. These "reeds" are made of alloys that give them highly stable characteristics. Each reed is about 38mm long and 3mm diameter. A narrow neck is formed near one end, the precise size of which determines the resonant frequency of the reed. Each reed is clamped at the end nearest the neck, with the other end free to move between the poles of a permanent magnet. The reed passes through the centre of a coil and excitation of the coil at the resonant frequency of the reed causes the reed to vibrate, or conversely, vibration of the reed will produce an electrical output at the resonant frequency at the terminals.

In both transmitters and receivers, these reed assemblies are employed in pairs (see Fig 1). Each reed and clamp is mechanically coupled to the clamp of the other of the pair. To use these reeds as receiver filters, the coil of one reed is connected to line and the coil of the

Fig. 2. Basic circuit developed by ML Engineering of a fail safe solid state timer. The timer, which is accurate to better than 5% and will provide up to four minute delays in two second intervals, is protected by ML patents.



other to an amplifier with a transformer/rectifier output driving a safety relay. Both reeds are tuned to the same frequency; when an electrical signal of this frequency appears on the line, the first reed vibrates causing the second to vibrate in sympathy and produce an output on the coil that will be amplified and rectified causing the relay to operate. Consider now the effect of a signal on the line that is just outside the passband of the filter or perhaps a shock to the first coil which overstresses it to the extent of changing the natural frequency of its reed. In both instances, owing to the inefficiency of mechanical coupling, the second reed will not vibrate and the filter will become inoperative.

The passband of these reed filters is between 0.65 and 0.9Hz. The frequency range of the whole system is from approximately 390 to 890Hz. To eliminate the possibility of false operation by induced signals from neighbouring power systems, channel frequencies in the bands covered by the odd harmonics of the supply frequency are not used for safety functions. This still leaves 51 available channels for full safety circuits and the remainder are available for non safety circuits such as indications. Transmitters and receivers can be arranged to transmit in either direction on one pair of wires, giving a full duplex system. Maintenance of reed equipment is simple and consists of interchanging plug-in units. Failure rates of channels are approximately 1.2% per 1000 hours.

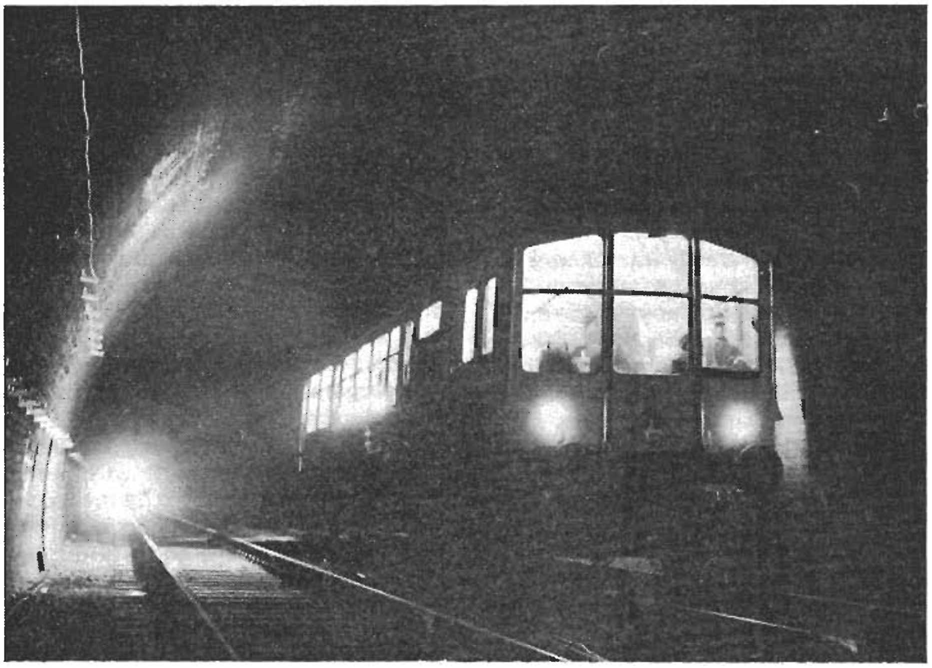
Computers in control

The object of the Total Operations Processing System (TOPS) which started operation in 1973 is to increase the efficiency of handling of the British Rail goods fleet which will be reduced to 175,000 wagons by 1976 while the freight tonnage is estimated to increase from the present 200 million tons to 220 million tons.

International Aeradio's contribution to the programme involved the manufacture and installation of a comprehensive set of data signal processing, switching and monitoring equipment which is situated between dual IBM 370/165 computers installed close to the BR headquarters at Marylebone and remote data terminals which are located at the numerous freight terminals and area headquarters. The complete data communications network (which utilizes the national telecommunications network) is controlled from a monitoring console and enables controllers to monitor the performance of each of the low-speed and medium-speed data paths.

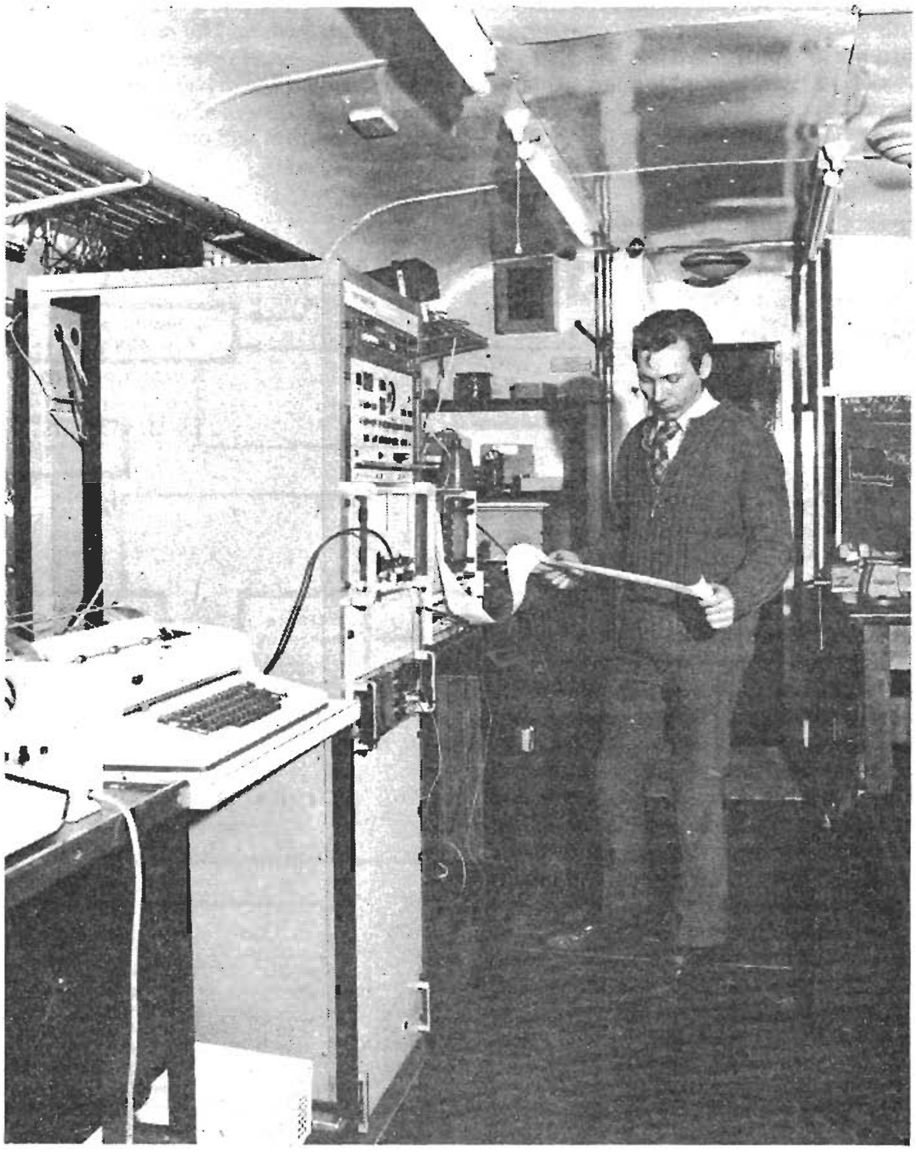
Where circuit degradation occurs, the system enables data path re-routing to be carried out both within the main control centre and at the remote terminals.

The central processing unit requires



British Rail's mobile radio laboratory, test coach Iris, which has been equipped by the Research & Development Division to carry out radio system survey work anywhere on the network. Its first task was to evaluate the performance of a possible system of track-to-train communication which overcomes the loss of signal problems experienced with normal radio links, particularly in tunnels and cuttings.

View of the data processing equipment inside test coach Iris (see text).



to receive messages at the data transfer rate of 188,000 characters per second in a parallel mode. It therefore demands a large number of high-speed bursts of information over a short-distance, wide-band channel. In contrast, the field data terminals operate at a relatively slow speed, 134.5 baud, in a series mode over narrow-band long-distance links. To ensure a steady interchange of data, a series of communication multiplexers are connected between the links and the computer. The multiplexers have a multichannel input with the capability of interconnecting a number of low- and medium-speed circuits with a main wideband output to the computer.

Transmission over the long-line system is frequency division multiplex, the voice frequency signal conversion to binary code being achieved by using modem data sets situated at the ends of the line circuits. The low speed modems are frequency stockable to enable up to eight data channels per audio line to be realized. In addition, facilities are provided at remote transmission centres to combine local data links into their allocated frequency slot in the audio band line.

TOPS is just one of two or three major systems for which there are opportunities for further development with respect to computer control in automatic route setting and train regulation.[3] Another major new project, the production planning system, will be less obvious to the public as it concerns the succession of activities between the specification by the Passenger and Freight Marketing departments of the train services to be provided and the publication of the timetables, working instructions, locomotive programmes, station platform arrangements and the hundred and one other documents necessary for the day to day running of the railway. The application of computers to this process requires a whole series of interlinked systems and the main stages will be as follows: allocation of track capacity; allocation of locomotives; allocation of train crews; and preparation of documents. In the allocation of track capacity, as an example, the computer will calculate the fastest available path within the speed restrictions imposed by the track, the nature of the train and the movements of other trains, and will display this on a v.d.u. screen or graph plotter. The timetabler will then decide whether any train should be switched to an alternative track or held at a signal to allow another to pass and sends a decision message to the computer.

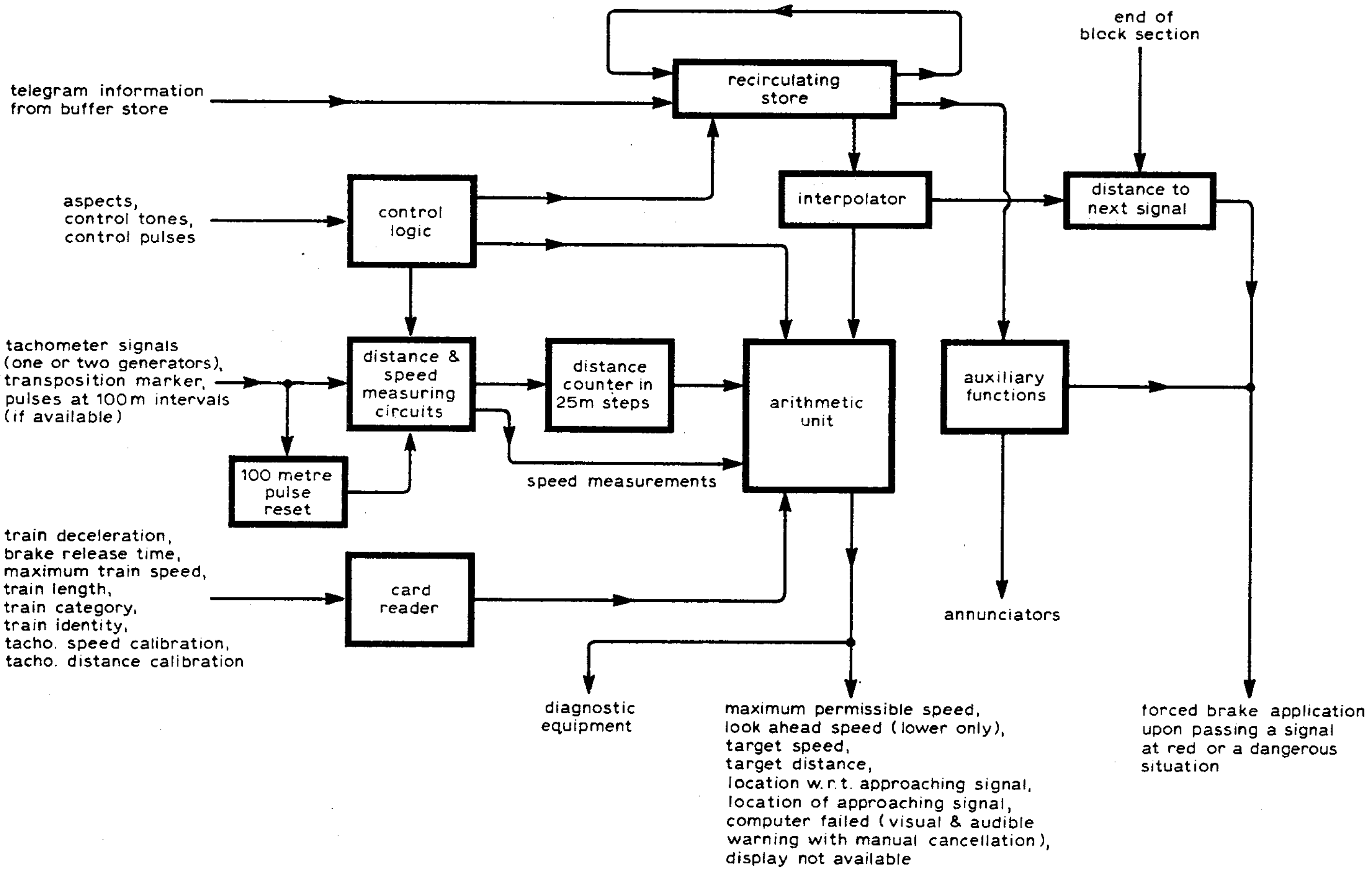
The introduction of a national seat reservation system, heavily reliant on computer processing and information storage is a must for the smooth and efficient operation of high density, high speed passenger services in the future. British Rail seem slow to make progress in this field, but the problems are largely political rather than technical.

The essential reservation system requirements designed to meet future conditions are for equipment and procedures to handle high volumes of information and a capability for providing passengers' requirements quickly up to the latest time practicable prior to train departure. The system would not only provide the best possible customer service, but at times when demand for seats exceeds supply, would ensure that only the requisite number of reservation tickets is issued for a particular service, thus providing the essential measure of control necessary.

A computer reservation system can fulfil the basic requirements of making reservations quickly and once the customer's requirement is established at any sales point equipped with a computer terminal, issue of a reservation ticket can be effected virtually instantaneously.

The design of the proposed computer system will consist of computers at the central site, holding files of fares and inventory information, connected by telecommunication links for data transmission with computer terminals located at sales outlets. Equipment at sales points, mainly BR stations, will consist of: a keyboard, for entering details of the reservation required; a

Fig. 3. Main processor for train-borne equipment in a possible speed supervisory system. The maximum safe speed is calculated from track conditions and the driver warned if he exceeds it. If the warning should be ignored the train will automatically be brought to rest.



ticket printer; and a visual display unit, which provides information to the operator.

Leaky feeders

A possible system of track-to-train communication which overcomes the loss of signal problems experienced with normal radio links, particularly in tunnels and cuttings, is under examination by BR's Research and Development Division. Several leaky coaxial cable types, each with a different braid pattern, are being tested for optimum efficiency at operating frequencies of 46, 86, 138 and 460MHz. For the tests, a 1W signal is fed into a cable strapped to the wall of a tunnel along a stretch of test track. Signals are analyzed by a mobile laboratory, known as test coach Iris, which has been equipped to carry out radio system survey work anywhere on the network.

The sampling rate of an analogue to digital converter which accepts the received signal on board Iris is dependent on wheel-velocity so that the reception bandwidth and accuracy of information received is known and constant. A point worth noting here is that radiation from a leaky feeder is not literally through the holes or imperfections in the outer braid. These imperfections, however, do cause an imbalance in the signal current flowing in inner and outer conductors. The result is therefore a radiated signal. Both data and speech communications can be handled and a single cable can serve a number of parallel tracks.

Two parameters are used to specify the performance of a cable: the longitudinal attenuation per unit length of a cable; and the coupling loss between the cable and antenna. For a complete definition of coupling loss,[4] the arrangement of the cable, and the mobile antenna and its type, together with the distance between the two must be defined, cable attenuation in dBs being approximately proportional to the square root of frequency. For minimum attenuation and hence minimum fixed station equipment per unit length of cable the frequency should be as low as possible. Coupling loss varies with frequency; increasing by about 10 to 20dB from 40 to 500MHz. From this it can be seen that optimum frequencies are in the low v.h.f. region. Frequencies below 30MHz are not really practical except in completely underground systems. Naturally propagated radio signals follow an inverse square law, where a 6dB or four times power increase gives a doubling in distance. Cable systems follow an inverse logarithmic law and a 6dB power increase will give a range increase of only 100 to 300m. Power is therefore not as important a factor as with conventional radio systems. Work has been sponsored partly by the International Union of Railways (European members each contribute to different aspects of research, BR's involvement being with leaky feeder communications) and help has been received from the Coal Board on repeater development.

Another aspect (sic) of work by BR's Research and Development Division at Derby is for a new four-aspect signalling system which could be flexible enough to provide major advances in the field of automatic high-speed train control.

The communication system consists of short stretches of an inductive loop laid between the rails and is based on the tuning-fork tone generation that has been described. The loops at present carry 160mA but this is being reduced to 60mA (remember that a traction rail can carry more than 10,000A).

The driver is supplied with visual information on the particular aspect which he is approaching and must acknowledge by pressing the appropriately lit, appropriately coloured button, otherwise the brakes are automatically applied. A separate colour display in the cab also confirms the aspect after a signal has been passed.

One major problem encountered during development was in deciding whether or not received information was valid or not, depending in which direction the train was travelling. This was overcome by an elegant application of the Poynting vector principle – polarity of the vectors between magnetic and electric fields (which is sensed) depends on the relative position of the power supply.

New signalling developments

An even more advanced system under development can supply the driver with maximum speed information and also any approaching speed restrictions. Failure to comply with speed restrictions, after a short time delay, results in the brakes being automatically applied and the driving system shut down. Another system for collecting trackside information and feeding this to the train driver is by means of transponders fastened to the sleepers. As the train passes over a transponder, it sends an inductive signal to the device which absorbs some of the energy and uses it to "talk" to the train by sending back a coded message. This message can identify the train's exact location and contain other information such as the existence of any speed restrictions which might be coming up. Each transponder requires no maintenance as it uses no internal or external power supply.

Test Coach Mercury has recently been hitching a ride on Inter-City express trains to test such a system between London and Birmingham. Signals at a frequency of 150kHz are transmitted from the coach's underfloor aerial about 18 inches above ground towards the transponders. On receipt of the signal, the transponder uses some of the received energy to generate a 24V d.c. supply to power the solid-state circuitry which generates a coded 75kHz signal which is transmitted back to the train. The code is in the form of binary coded decimal numbers. These numbers are built into the transponder at manufacture and with the availability of 80 bits for coding, the number of combinations is high.

It will be possible to use stored speed supervision information on the train which would be read from store as the train progressed on route. In order to ensure that the store was keeping step with the actual running of the train, uniquely identified transponders would act as position markers. Readings from them being checked against the same information from the store. Speed information would only be displayed to the driver on direct correlation.

Fail safe

Behind all developments and operations to do with railway transport whether mechanical, electrical, organizational or whatever, there is one overriding philosophy, the prime requirement of fail-safe operation.[5] The change in conditions that has occurred with the abolition of so many of the manual and mechanical features and their substitution by automatic electrical or electronic systems is now rapidly approaching the point where little responsibility can be counted upon from the human element and the machine must be capable of accepting full responsibility for safety.

A definition of the term fail safe that has been offered is "a design quality of mechanical and electrical signalling equipment and of the system within which it is used, that under failure conditions will provide safety for traffic." The major contribution made by electronic developments in communications, signalling and computer control, apart from economic control of a system that is making more and more operational demands, is in the reduction of failure-rate within the bounds of the fail safe philosophy and thus providing for Britain a system that can be run with efficiency and safety.

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