FROM TELETYPE TO MEGABYTE
150 YEARS OF RAILWAY COMMUNICATIONS

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SUMMARY

In October 1877 Bell published construction details of his telephone invention. A NSW Railway engineer, Mr Cracknell built a copy and transmitted words and music by telephone over the telegraph wire from West Maitland to Sydney in December 1877. It was an era of excitement and delight in engineering. Morse code had become a mature technology, voice systems were spreading and soon de Forest's vacuum tube triode was to make amplification possible. Transmission systems were no longer limited in distance and the engineers had visions of linking the continent by telegraph and telephone.

The visions were gradually realised, though not without difficulty and dedication. The work practices of those days would not be considered now[1]. New engineering problems were found, analysed and solved, as communication systems grew in complexity and expanse. Some of the problems were unique to railways and a few were unique to Australia (at that stage). From these beginnings railway communications have embraced analogue carrier telephony, radio, optical fibre and digital carrier systems for radio and cable. Mobile radio has been implemented for train control, security, maintenance and administration. Some of these developments are described and discussed in this paper.

1 INTRODUCTION

The founders of our railways were engineers with vision and determination. They were, perhaps the trendsetters in a nation that rapidly embraced new technology. One characteristic of these engineers was an interest in technology and a willingness to share their knowledge and experiences.

Signal engineers who were keen to learn and to share knowledge formed the IRSE. At the inauguration of the Australian Division of IRSE in 1948[2], the Chairman, Mr Barton noted:

> *"It appears a matter of regret that some of our Communication Engineers – men specialising in modern communication systems – have not joined up with us, and I express the hope that we can get them interested in the near future."*

That hope was realised. Over the last fifty years there have been around one hundred Australian IRSE papers on communications systems, developments and ideas. There is scope for more!

This paper draws on some of those published in the past to present some snapshots of communications history. This is not a comprehensive history as many areas (such as telemetry, telephony, closed circuit television and passenger information systems) have not been included for want of space. Other areas have been treated in greater depth. The bias is the author's.

We commence with that simple but revolutionary invention, the electric telegraph.

2 ELECTRIC TELEGRAPH[3]

2.1 Dramatic Changes in Technology

The first electric telegraph in Australia was installed between Melbourne and Williamstown, opening on 1 March 1854. Following this a system was installed between Port Adelaide and Adelaide.

During these colonial times, such new fangled ideas were certainly not welcome in New South Wales. The Governor in Chief expressed his opposition to the introduction of the of telegraph (July 1855):

> *"in the present state of the colony there does not appear to be any such demand for the adoption of these rapid means of conveying intelligence, as would justify an application to the council for its sanction to the large outlay which would be required for the establishment of an electric telegraph on the most economical principle".*

Despite such clear opposition, the first electric telegraph was installed in Sydney within two years. It connected between South Head Lighthouse, the Sydney Post Office, the Royal Exchange and the Redfern railway terminus.

The person responsible for its installation was Captain Martindale who was the Undersecretary for Public Works, Commissioner for Main Roads, Commissioner for Railways and Superintendent of Electric Telegraphs. He reported to the Legislative Assembly on 27 May 1857 that:

> *"The advantage to the railway department in meeting the wants, and ensuring the safety, of the public using the rail will be very great, and the more so as single lines extend. Indeed it is barely safe to operate a single line of the railway without a telegraph."*

The telegraph was extended rapidly, one branch reaching Liverpool by October of that year. The NSW Government decided that the line should be open to the general public and on 26 January 1858 made the following proclamation:

RAILWAY DEPARTMENT SYDNEY

OPENING OF THE ELECTRIC TELEGRAPH

Notice is hereby given that on and after the 26th instant, the line of electric telegraph between Sydney and Liverpool, and Sydney and South Head, will by order of the Government be open to the public for the transmission of messages...

B H Martindale, Superintendent, 26 January 1858

During the next year the telegraph was extended, and NSW, Victoria and South Australia were connected. The extension of the Northern line to Brisbane in 1861 completed the connection of the Eastern capitals.

2.2 Communications Carriers

Many telegraph offices were established on railway stations and the telegraph was a joint service shared by the railways and the public, the Post Office being a separate entity. A NSW Government statement in 1859 prescribes some commercial arrangements:

> *"On the railway lines an arrangement has been made that so far as the [telegraph] line extends along the railways, accommodation shall be provided for the telegraph clerks on the railway stations and all messages for the department on railway business shall be sent free. The telegraph department however taking all receipts for public telegrams sent by railway wire".*

So the public communications infrastructure became a railway responsibility. The operators of the service were employed by another department but were accommodated on railway property and provided an outsourced facility for the railway.

These telegraph operations continued in NSW until around 1876 when the NSW Post Office absorbed the NSW Electric Telegraph. There was a complicated transition and the railways and post office have continued to lease each other's wires for over a century.

The commercial arrangements changed over the years, as did the relative proportions of the leased services. By 1932 there were 3,823 miles of NSW railway wire on PMG[4] poles and only 2,316 miles of PMG wire on railway pole lines.

The railway administration was very conscious of the costs involved and by 1947 had reversed the imbalance to 1,006 miles on PMG poles, while the PMG had 2,953 miles on railway poles.

The telegraph system reached its peak in the 1920's. In the month of December 1929 a total of four millions words were handled by the NSW telegraph system. The traffic gradually decreased over the following decade, the NSW traffic falling to three million words in December 1940.

2.3 The Telephone

The telephone came into being in 1876. Alexander Graham Bell published construction details of his telephone in October 1877. The NSW railway's Mr Cracknell was obviously a reader of Scientific American, where the details were published, as he built a copy and successfully tested it in December 1877. Mr Cracknell transmitted words and music by telephone over the telegraph wire from West Maitland to Sydney.

Telephone circuits soon came into use in the railways, taking advantage of the telegraph wires. It was possible to operate both a telegraph and a telephone on the one pair of wires (with suitable filtering).

Telegraph lines had been built along the railway lines, with train running information and other administrative information transmitted from a central location and received at all stations on the line. This was so convenient and efficient that an "omnibus" or multiple party telephone circuit was also used. Each station on the omnibus circuit was given a call sign consisting of long and short rings, very often the first letter of the call sign that the station had on the Morse circuit. If all stations were to be notified, one very long ring was given and all stations answered in turn, the most remote answering first.

Most of these omnibus circuits were eventually extended to a switchboard, generally in a telegraph office attached to the district office. By 1926 NSW had 143 omnibus circuits with a total of 1,180 locations.

2.4 Train Control

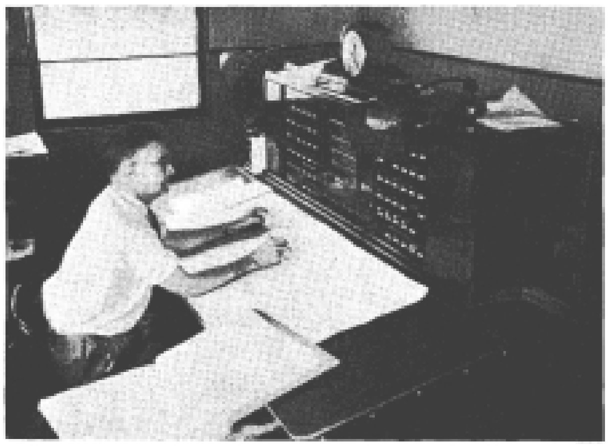

Figure 1 - Train Control Desk in Sydney, 1948

The train control desk of Figure 1 gave long and distinguished service. Desks of this style have only recently been withdrawn from service and replaced by computerised workstations. The desk shown was ergonomic in its design and used some of the latest technology.

The concept of "Train Controllers" was introduced around 1935. Responsibility for the regulation and supervision of traffic and loading of goods trains was taken out of the hands of the staff at the various railway stations and centred in the hands of the train controllers. These men were each responsible for a section of line about 100 miles long and had an office and desk equipped with telephone facilities to give access to all places of importance on his district and the neighbouring districts.

Usually one pair of wires was provided throughout the section and all telephone connections were in parallel across the wires. At the Train Controller's desk there was an amplifier and loudspeaker, a foot-switch and a number of keys labelled with wayside telephone locations. These keys enabled the train controller to call any wanted party without ringing the bells at other places. The keys did not switch circuits but interfaced to a Western Electric 3.5 Hz selector, which worked with remote decoding equipment to ring the appropriate bell. This equipment is still in use in 2005.

Any wayside telephone wishing to speak to the controller had only to lift the receiver, listen for other traffic and then announce the identity of the caller. The train controller heard the voice over the loudspeaker.

Mr Henry noted in 1948[5] "by means of this control system trains are speeded up, delays at crossings are avoided, trucks are not left empty at unattended sidings, and emergency arrangements are quickly put in hand".

2.5 Automatic Telephony

The railway continued to be at the forefront of communication development, with the second automatic telephone exchange in Australia being installed in a NSW railway office in 1913. (The first was a Strowger exchange that was installed in Geelong the previous year.) Many more automatic exchanges were installed in railway offices and the railways applied the developments that were being made in other areas. The public communications networks were jealously guarded by the PMG and interconnection to the public network was subject to strict regulations that were developed and enforced by the PMG.

For many years the railway networks had provided railway users with direct access to the public network (dial "0" for an outside line). The reverse was not the case. PMG engineers took the view that they could not guarantee a good grade of transmission to their customer once the call entered railway equipment that was not under PMG control. The PMG did not approve the installation of railway direct indial facilities until 1947 (after much high level negotiation).

3 TRANSMISSION SYSTEMS

3.1 The Pole Line – Simple & Sophisticated

The pole line consists of wooden, steel or concrete posts supporting wires on insulators. It seems very simple. But like most engineering designs, sophisticated analysis and design underlie the implementation.

Figure 2: Toodyay – Kalgoorlie Steel Pole[6]

Resistive loss in the wire was the first problem. This was countered by using heavy wire, which also increased the mechanical strength. of the lines.

Direct lines used copper wire weighing up to 200 pounds per mile (approximately 3 mm diameter) to counter the attenuation of telephone signals. With wire of this diameter a telephone circuit could extend about 160 km. This could then be extended by another direct trunk of similar length, but with weak transmission. As each pair of wires could accommodate only one conversation, the pole lines had many wires and were heavily loaded.

The technology was enduring. A recently dismantled section (2004) from Toodyay to Kalgoorlie in Western Australia had four pairs of 200 pound per mile hard drawn copper wires. This wire was attached to ceramic insulators mounted on timber cross arms, supported on wooden poles or steel poles constructed from rail[7].

Impedance vs Resistance

Resistance was not the only factor affecting transmission. Long parallel wires have intrinsic inductance and there is capacitance between the wires. Careful selection of the spacing between the wires in each pair balanced the wire inductance and capacitance, so that the impedance of the pair of wires became essentially resistive. The 160 km circuits had no amplification and demonstrate the effectiveness of these techniques.

However, solving the impedance balance revealed a new problem – cross talk between the telephone circuits. Not only was there capacitance between the parallel wires in each pair; there was also capacitance between the wires of one pair and the adjacent pairs. Trunk routes had many pairs of wire and potential for cross talk between each. A solution had to be found.

3.2 Extending Transmission – Transposition

Figure 3: Transposition (nearer pair, lower cross arm)

The solution was (at first glance) simple. The wires in each pair were transposed at intervals. The transposition physically reversed the position of the wires on the cross arm (See Figure 3). The effect was to twist the wires so that equal and opposite currents were induced in alternate transposition sections. The end points were terminated in balanced circuits and cross talk was minimised. However, if the identical transpositions were used on all wires on the route, the effect of the transposition was negated. Complicated transposition schemes were developed to ensure that cross-talk was minimised. There were books of these schemes and the transposition plan was an essential part of any aerial route.

Transposition on aerial routes can only practically take place at poles. The coarseness of the transposition intervals is a fundamental limitation on the transmission capacity of aerial lines[8].

Cables

Insulated cables offer greater flexibility. The transposition is achieved by twisting the wires together. If all the wires were twisted at the same pitch (twist length), adjacent pairs would have little benefit from the transposition. This is countered by using different twist lengths for pairs that are in close proximity. An example is the familiar Cat 5 LAN cable – this cable is suitable for operation at over 100 Mb/s with twisted wires. Different twist lengths are used for the pairs in Cat 5 cables to minimise crosstalk.

3.3 Increased capacity – Carrier Systems

At the beginning of the twentieth century Lee de Forest developed the vacuum tube. This device permitted amplification of small electrical signals. A vacuum tube amplifier could be fitted to a wire line to compensate for the attenuation of the transmission line. This revolutionised transmission technology and permitted the development of "carrier" circuits. Physical circuits transmitted voice signals exactly as they were received.

Mr AG Henry described carrier technology in a comprehensive paper on Communications in the New South Wales Railways (1948)[9].

"Carrier telephony is coming more and more into use owing to the high grade of circuits obtainable and economy in the use of line wires. Already 2700 miles of carrier channels have been installed on these [NSW] railways and 750 miles are in the process of installation. The principle of the carrier telephone is based on knowledge that the voice can be transmitted by alternating currents of frequency lying between about 300 and 3,000 cycles per second. The carrier telephone equipment acts as a frequency transformer and enables a number of simultaneous conversations to take place over one pair of wires by, for example, leaving a first speaker's voice frequencies untransformed, while another may be transformed in frequency above the first and a third speaker's voice above the second and so on. Then, after sending over the line, selective devices called filters can individually direct these conversations into appropriate separate paths and then transform them back again to the original

frequencies where they can be made audible and intelligible."

A "carrier" frequency was used to transform each conversation, hence the name "carrier systems". The technique is otherwise known as Frequency Division Multiplex.

Aerial wire routes using carrier channels were still under construction in the 1980's. These routes were either twelve or fifteen channel systems. In most cases there was a three-channel carrier system and a twelve-channel carrier stacked above the three channels. The three-channel system had usually been installed earlier and then expanded with the twelve-channel group.

Carrier techniques were applied with great success to insulated cables. Cables had more precisely controlled characteristics and could carry much higher frequencies. The number of frequency divided channels on each pair increased substantially and 120 channel carrier systems were used on specially designed two-pair cables (single quad carrier).

3.4 Coaxial Cable

Coaxial cables were employed for all major routes by the PMG and then Telecom Australia. A coaxial cable network was built to link the capital cities and larger country centres. Coaxial cable was the only practical method (apart from microwave radio) for television signal distribution in the 1950's and continued to be used for television until optical fibre became practical. Coaxial cable technology largely bypassed the railways in Australia, an exception being a coaxial cable installed in the 1970's on the North Coast line in NSW. This cable was exceptional as it had a single coaxial tube for both the sending and receiving directions. The Telecom cables of the time all had pairs of tubes and were of a different diameter from the railway orphan.

3.5 PCM – More Conversations on Copper

The next step was to move to digital techniques. Pulse Code Modulation was used on Queensland Rail's copper circuits between Central to Ipswich in the mid 1970's as a part of the communications upgrade for the Brisbane electrification. Digital modulation techniques offered great flexibility and reduced signal impairment. Not only that, but much more capacity could be achieved on a transmission system. Transmission capacity was now measured in Megabits per second rather than the number of 3.1 kHz voice channels per system.

3.6 Optical Fibre

Optical fibre was used on the QR mainline electrification project around 1983. This was probably the first use of optical fibre in railway systems. It was followed by NSW for the Illawarra line electrification and then by a multitude of systems. A snapshot of the technology at the time of the electrification was provided at an IRSE conference in 1986[10]. Trunk services between Sydney and Port Kembla had been provided by a twelve-channel open wire link. A composite three-fibre and copper cable, together with other copper cables, replaced the open wire circuits. An 8 Mb/s PCM system was installed on the optical fibre.

Australian National contracted with Telecom Australia for construction of an optical fibre route across the Nullarbor, the railway having access to some fibres in the carrier's cable.

Queensland Rail, NSW railways and Westrail installed optical fibre in conjunction with most of their electrification projects. There are now extensive optical fibre networks. WestNet Rail has recently converted the route, from Kalgoorlie to Perth to optical fibre transmission.

Optical fibre is used for closed circuit television distribution in most of the metropolitan networks, as well as telephone and data traffic.

3.7 Microwave Radio

The Commonwealth constitution of 1901 gave the Post Master General a monopoly over all communications systems in Australia, but granted specific exemption to State railways, in the interests of train safety[11]. Railways were permitted to install and maintain their own communications, but only on railway property.

Microwaves travel directly from the site to site, not along the railway line. This meant that although the transmission might commence and terminate on railway property, the transmission is not confined to the property. Microwave repeaters are usually not on railway property as they are located for line-of-sight transmission.

Railway use of microwave systems displeased the Post Master General (PMG)[4]. In his view they encroached on the domain of the PMG. Only after much legal wrangling did NSW gain permission to construct the first railway microwave link[12] from Sydney to Orange in 1971. The PMG had control of radio frequency licensing, as well as being the monopoly telecommunications supplier. The PMG delayed approval of the railway system from 1964 to 1967, insisting that leased PMG circuits be used for the link. The technical specifications for the route were subject to approval by the PMG.

The Sydney – Orange link was expanded to the north and south and a 48-channel microwave system was built from Sydney to Grafton in 1978 for CTC backup communication.

Queensland Rail built extensive networks during the mainline electrification period. Microwave radio provided a backup network for the optical fibre on the main lines. The microwave radio sites also provided convenient locations for train radio equipment.

In the early 1980s a channel UHF radio link was built between Tarcoola and Alice Springs. The impetus for this link was the new standard gauge railway line to Alice Springs. The arid and desolate terrain for this route influenced the designers to use microwave radio rather than an aerial cable. The system had adequate capacity for train order and telephone traffic along the railway route and at the stations. There was a bonus as Telecom leased a sixty-channel supergroup from the railway between Tarcoola and Alice Springs[13]. Solar power and the solid-state electronics avoided the use of diesel generators at the repeater locations on this route, with substantial savings in maintenance costs, as fuel transport was not required.

The situation has reversed with the construction of the Alice Springs to Darwin railway. The microwave system has been abandoned and circuits are now leased from the carriers. Satellite telephones are used for communication with trains.

Figure 4 : Jumperkine Loop and Radio Link

Westrail has used microwave radio extensively and has microwave systems in Perth, along the southern route and through the Avon Valley. The Avon Valley route has recently been augmented by optical fibre.

3.8 ISDN

As digital technology expanded the industry moved to an Integrated Services Digital Network (ISDN). This was seen at the time to be the way of all future networks but is itself being displaced by Internet technology. In the mid 1980's Metrail (Melbourne metropolitan railways) converted its telephone systems to ISDN[14]. A fifty-year-old telephone exchange at Spencer Street was replaced, along with some more modern exchanges. The changes that have occurred in the twenty years since then can be seen from the feature list of the ISDN PABX equipment installed by Metrail. Features as data switching, text mail, local area network, packet switching and protocol conversion are no longer performed through PABX equipment.

3.9 PRETZELS AND PUDDLES

One might wonder why railway systems were so small in capacity and why equipment was retained long after public carriers had moved to further generations. The reason is fundamental. Railway lines are skinny, pretzel like structures with little bumps at intervals. Staff are based at these lumps, leaving the majority of the line empty for most of the time. The railway communication networks inevitably take on a similar topology.

In contrast, public telecommunications serve large "puddles" of people, with short distances between most of the puddles. Indeed, the puddles often connect to form a big pond. A high capacity network and a grid of connections is a much more satisfactory arrangement. It is interesting to consider the Tarcoola to Alice Springs system where the public carrier was not equipped to deliver a pretzel-like system. The railway network provided a solution.

4 TELEPRINTERS, TELEX AND DATA

4.1 Teleprinters

There had been several experimental teleprinter installations in NSW prior to 1950 but only one attempt to directly replace Morse[15]. In 1935 a printer was installed on an open-wire physical line between Sydney and Goulburn. The transient currents induced into the open wire repeatedly caused mutilations to transmitted characters. The operators were quick to point out the consequences of undetected errors in figures transmitted in the message and the trial was abandoned.

Over the next ten years teleprinters were operated successfully over carrier channels and teleprinter technology was introduced. NSW decided to replace the whole Morse system with teleprinters in 1948. The teleprinter network was initially a star network, with no switching. Messages were sent from a station to a central location and then retyped for transmission to another station. The re-typing was overcome by recording the message onto a paper tape (known as "torn tape") that was read for further transmission.

Strange as it might seem, it was not until 1967 that a torn tape teleprinter replaced the last Morse line between Sydney and Brisbane.

An extensive teleprinter network was developed prior to the distributed use of computer terminals. The teleprinters were eventually connected through special exchanges (telex) so that messages could be sent directly from one machine to another. A national railway telex facility permitted interstate bookings for passenger travel.

The paper tape facility was maintained on teleprinters until the demise of the telex during the 1990's.

4.2 Data

From the 1960's onward, data transmission systems were installed for computer links, mainly associated with seat bookings. Data transmission networks have been established and extended by each administration. As voice and data traffic have merged into digital systems, the data networks have become indistinguishable from voice, signalling and other functions. The measure of link capacity is now the number of megabytes per second that it can carry.

The situation was not so tidy in the 1970's and 1980's. In NSW for example[16], the 1970's saw the introduction of remote terminals that connected to mainframe computers via a data communication network. The computers were bought from Unisys, Hewlett Packard, Tandem, NEC and Prime. Each computer manufacturer had different communication specifications and used different protocols. The data transmission networks developed to link these machines to the users included synchronous data, asynchronous data, packet switched data (X.25 protocol) and dialup links.

Local Area Networks separated by hundreds of kilometres were interconnected with 9,800 bits per second dedicated links. There were proposals to also use the public switched data network.

Personal computers were coming into vogue with 2,400 bits per second connections to remote locations for assistance and file transfer. Message switching was important in this era as the telex traffic was slowly migrating into data systems. Store and forward processing was used and the railway messaging systems were connected between states (eg NSW to QR's QICTEX telex network and the Telecom Telex switch).

Packet Switched data was seen as the panacea to all the problems of proprietary terminals with incompatible protocols and diverse physical interfaces. The packet switch was intended to allow connection from any terminal to multiple hosts with a single network. Data transmission rates of 4,800 to 64,000 bits per second were available on the packet switched network.

In June 1984 Australian National began commissioning a Computer Based Message Switching System. This system was intended to eliminate telegraph offices located at Adelaide, Port Augusta and Peterborough[17].

David Keddie's paper about this system quoted from Telephony, June 1984. The quotation demonstrates the change in meaning of various terms over the years:

"There are various interpretations of the term 'electronic mail' and distinctions are sometimes made between electronic mail and electronic messaging. … electronic mail refers to the transmission electronically of items which could otherwise by sent by physical means: essentially, paper documents which could be sent via facsimile or communicating word processors.

"In some types of system, the item is not necessarily received in the same form in which it was created; in other words, only the textual content of the item is transmitted without information about how the text was originally laid out. A distinction thus can be made between electronic mail services which are intrinsically document-related (teletex, facsimile) and those which are message oriented."

The last ten years have brought massive changes in the way we think about data transmission. Proprietary protocols have withered as internet protocols have grown.

5 SAFETY AND SYSTEM INTEGRITY

5.1 Safety

Safety of train operation has long been cited as a reason for railway communication systems to be directly operated by the railways. In 1901 the Commonwealth Constitution gave the Post Master General a monopoly over all communications in Australia but granted specific exemption to State railway systems in the interests of train safety. Railways were permitted to install and maintain their own communications, but only on railway property.

The simple systems that were employed at the turn of the century relied upon the physical construction of the bearer for their integrity. Track circuits and safeworking systems were directly connected from end to end and identified by circuit. Incorrect connection of different circuits could not readily be detected so there was great emphasis on the responsibility of staff to check and recheck each connection. The concept of having someone from outside the railway making such connections and rearrangements was unthinkable – the consequences of inadvertent error would be too severe.

While pole routes were shared and some railway wires were carried on PMG poles, safeworking circuits were always confined to railway pole routes. Some of the safeworking and signalling systems used voltages that could not be contemplated on telephone networks. (For example, two hundred Volt DC pulses were used on the Western Electric systems for telemetry and signalling functions.)

The limitation to railway-operated circuits was a requirement of the technology available at the time. The system design assumed and indeed required a fixed connection and mapping from one end to the other. The majority of the railway systems used direct current signalling and were vulnerable to changes in polarity and connection of the lines. This situation continues with the electric staff systems that need a direct current connection between pairs of machines.

The development of transmission networks for railway signalling systems has been limited by their reliance on physical connections. Carrier equipment has been in use in railways for communications systems since the 1930s. Its use for signalling systems has been affected by the bandwidth of each carrier channel being restricted to between 300 Hz and 3400 Hz. With no direct current connection, the operation of functions such as polarity reversal and pulsing direct current was made more difficult and signalling systems continued to use physical circuits. (It is interesting that the telephony systems also used DC signalling over carrier systems through the "E&M" facilities, which provided an on/off indication in each direction of transmission. The E&M leads were used for telephone dialling and call signalling in most telephony systems, being superseded only when fully digital carrier systems became available).

Figure 5 : Tunnel coverage survey for train radio

5.2 System Integrity

Railway communications and signalling systems are required to operate reliably and accurately. The operation depends in part on the integrity of the system. In the simpler systems (and even in many of the current systems) this requires a procedural method of ensuring that the end points of the system are correctly and continuously connected.

This type of connection began in 1879, when a Preeces Block instrument for absolute block working was introduced between Sydney and Newtown. In 1888 the first Electric Tablet was introduced between Balmoral and Mittagong and by within four years all single line sections on the NSW Southern line equipped with this system.

Some systems have alarm mechanisms built into them that identify interruptions to the physical circuit. (It is assumed that the circuit that was interrupted could have been corrupted by incorrect re-connection.) Any system that connects through a distribution frame or patch panel is vulnerable to this type of corruption.

Switched circuits cannot be considered if the physical connection is essential to the system integrity. A switched system is not guaranteed to always make the correct connection and continuous connection cannot be guaranteed. This places a severe limitation on the flexibility of service provision. Most railways would only accept a system that is physically located on the railway property and maintained by persons competent with the particular system.

5.3 Alternative Approaches

The alternative is to develop a system that does not rely on any particular physical connection for its integrity and operation. The more sophisticated telemetry systems (and of course the electronic telephony systems) were probably the first railway systems to take this approach. Each device in the system was given an identity code, which it transmitted in every communication with the controlling device or devices. The system integrity could then be checked on every exchange of data and a means had been created to test the system unambiguously at any instant.

Protocols and addressing systems have rapidly developed and are essential elements of systems that we take for granted today – the Local Area Network (LAN) and cellular telephone are examples of such systems. The LAN usually has fixed connections but addresses packets of information to particular devices that may be physically connected anywhere on the network. The cellular telephone has no fixed connection and random location within the network but the protocols identify the terminal and transfer voice and data to the telephone as required.

The operation of communications systems such as the LAN and cellular telephone have been facilitated by the disciplined allocation of protocols and functions to particular layers of a structured transport and communication system.

The Open Systems Interconnection (OSI) seven-layer model[18] is a well-known example of a formally defined approach to system design that separates the functions of physical connection and information transport from the unique functions of the system. If this approach is taken in system design, the system can be made to operate with safety and integrity over a variety of communications systems[19].

6 TRAIN RADIO

6.1 Technology and Funding

It was the advent of the transistor in the 1950's and then the microprocessor in the 1960's that revolutionised mobile radio communication. The transistor permitted drastic size reduction in mobile equipment and made battery powered portable radios practical for railway operations.

Microprocessors made an equally dramatic difference. Data transmission became cost effective, faster and more reliable. Some ingenious signalling systems that had been developed in the 1960's to carry low speed data on various tone frequencies migrated to data modem techniques as microprocessors became available.

Funding for train radio has usually only become available as a part of some other project. One of the early train radio systems in NSW was built in the 1950's to assist in electrification projects[20]. The electrical branch was the sponsor and user of this electrical construction system. It was used for communication between work trains, controllers and flagmen during construction projects. The system was not extended to normal train operations.

Over the next fifteen years, most states had VHF mobile radio systems for maintenance groups and some had train radio systems. Radio was used in many shunting yards for efficiency and safety.

6.2 Victoria – Response to a Disaster

After a fatal head-on collision involving a passenger train, the Victorian coroner directed that radio communication be available between train controllers and train drivers. A Motorola system was purchased with the proprietary MDC600 signalling system. Selective call, emergency call and low speed data are available on this system.

Later, when ASW was introduced, the signalling system was changed to Motorola MDC1200, operating at 1200 bits per second. MDC1200 provides data transmission capability as well as speech. The radio network uses a single pair of frequencies for each railway line or group of lines. The train controller selects the base station that will be used for each conversation.

6.3 Melbourne Metropolitan System

Meanwhile, a new train radio system was required for the metropolitan network. In 1990 a completely different technology was chosen for this network[21]. Rather than have a single channel for each line, this "trunked" radio system has a number of channels at each base station. One of the channels is used for signalling and call setup. The other channels are used for voice or data calls as required. This technology was the forerunner of cellular telephone networks and provides telephone-like operation. The system is based on British standard MPT1327 and equipment is still available from several vendors. The interface to the train controllers was built specially by Westinghouse and is one of the very few token ring local area networks still in operation.

6.3.1 NSW Country

Train radio came into widespread use in NSW when guards' vans were removed from freight trains. The train drivers required radio communication with signallers and with each other to inspect trains and perform brake pipe continuity checks. A single frequency portable radio was introduced for the purpose. It became known as the "without brakevan" or WB radio, a term that has been retained. Various base stations and consoles have been added to what has become an extensive informal radio network.

Comprehensive train radio for country lines was planned during the late 1980's and introduced in the early 1990's. An economical system was required by the new Freight Rail administration, consistent with their orientation to profitable freight operation.

Countrynet train radio was dramatically different from contemporary systems. It was the first application of GPS for routine train location in the world (to our knowledge). Countrynet regularly and automatically reports train position to the train control centre. Another innovation was the use of satellite telephone for lines where base station infrastructure could not be justified. Countrynet has selective calling, broadcast calls and emergency calls and has data transmission capability (though this has never been used).

Figure 6 : Countrynet Train Controller Workstation – train locations (grey squares) are plotted from the GPS data

6.3.2 Sydney Metronet

A rather different approach was taken for the Sydney Metropolitan area. In the interests of standardisation and risk minimisation a British train radio system was adopted. It was then changed substantially. Metronet has a control channel and individual channels for train controllers, signallers and portable radios. It includes an emergency call facility, selective call and short data messages. There is provision for long data messages but this has never been used.

6.3.3 Adelaide

Mr A Mayne gave a very comprehensive paper about the Adelaide train radio system in 1979[22]. The paper is recommended reading. The radio system specified and installed for the Adelaide suburban area was state of the art and the propagation design was based on recent research. The system bought was rather more conservative with tone sequential signalling rather than full data transmission.

Tone sequential signalling is an ingenious development that permits slow speed data transmission over very noisy mobile radio networks. It is available in just about every mobile radio produced and has been applied to many tasks. The signalling system is exceptionally robust as it uses a long tone period, never repeats a tone and has a controlled signalling period. False decodes have not been reported.

Data transmission with modems only came into its own when low cost microprocessors became sufficiently powerful to perform error detection and correction of the transmitted messages. (The Countrynet system (above) uses data transmission with error detection and forward error correction.)

The Adelaide system has recently been upgraded with newer technology. This system was described at a recent IRSE meeting.

6.3.4 Trans Australia

The trans-Australia route, across the Nullarbor, uses an open channel UHF radio for train control, with a second channel for maintenance. Open channel operation is favoured for the verbal train orders that are used on this route.

VHF was originally used for radio communication. Unfortunately, the VHF radio has been retained for train to train and trackside calls. This is the only standard gauge use of VHF in Australia.

6.3.5 Western Australia

Westrail has used VHF radio on country narrow gauge routes for many years. Despite reorganisation and changes of organization, the radio system has continued. The metropolitan area was converted to UHF during the metropolitan electrification and the standard gauge line to Kalgoorlie has also been converted to UHF.

Selective call and vehicle identification is used for the metropolitan area but not for country operations. The selective call system is unusual in that it uses a double set of tone-sequential codes. One set of codes identifies the vehicle – the hardware number and the second set of codes identifies the trip – the run number.

Low traffic levels and restricted budgets have limited the expansion of train radio in country areas. Satellite telephones are fitted to some trains and CDMA is being introduced.

6.3.6 Queensland

Queensland was the first railway to use trunked mobile radio. The first system was designed by Sepac and used tone sequential signalling with expanded tone messages.

Queensland Rail is now using GPS for channel switching and position reporting from trains. The GPS receiver is connected directly to the mobile radio and position messages are sent over the voice channel.

6.4 ASW

The Alternative Safeworking System (ASW) was developed for Victorian medium density country lines in the early 1990's[23]. The development came from the need for a cost effective safeworking system for lines that were perceived to be unsuitable for train orders. Treasury was unwilling to fund a safeworking system as costly as ATCS so an alternative was sought. The system is now in operation on a part of the Adelaide – Melbourne standard gauge route.

The Train Controller has a workstation with a train graph and automated authority generation. Movement authorities are checked and then transmitted to the locomotive on the voice radio network. A modem function is incorporated into the voice radio network and shares the voice radio channel. The authority message is transmitted as text at a raw data rate of 1200 bits per second, with substantial error detection and correction overheads.

Each locomotive is fitted with a Locomotive Display Unit that has two text displays and a keypad area. The upper text display contains the current movement authority. The lower display contains the next authority. Special keys are used to accept and return authorities.

7 COMPLICATIONS – THE REAL WORLD

7.1 Aurora Australis and Summer Storms

Railway communications engineers have learned to respect and design for the real-world complications of electromagnetic interference and lightning.

When the first long pole routes were erected in open country, the engineers found that two types of natural disturbance could completely stop telegraph operations. These were the Aurora Australis and summer storms. Captain Martindale reported an occurrence to the Legislative Assembly in 1859:

The 29th August, upon the evening of which the Aurora Australis was seen, the electric circuit appeared to be deranged in a singular manner.

"The effect of ordinary thunderstorms is to invest the relays with additional magnetic powers, but in the present instance, although an extraordinary current of electricity seemed to be passing along the wires, the magnetic power was apparently neutralised, and this so constantly as to prevent all working, throughout the day. The derangement, lasting from 10 am to 8 pm and occurring frequently, at intervals of half a minute when the Aurora was seen".

One of the earliest Electromagnetic Compatibility (EMC) fixes soon was reported by Mr EG Cracknell, the assistant (and later successor) to Captain Martindale.

Mr Cracknell told the Legislative Assembly that:

The lines in this colony during the summer months appear to be more affected by the lightning than in the neighbouring colonies, and it frequently occurs, that not only the lightning conductors, but the relay coils, are fused by the intensity of the atmospheric charges. To guard against the wholesale destruction, I have arranged a simple cutting-out switch, which completely disconnects the instruments from the line, leaving only the main battery in circuit.

Cracknells' earthing switch continued to be used throughout the Morse era. Whenever a storm approached, the operator used a code word to advise all stations that he was cutting out until the storm had passed.

7.2 Power Coordination

Sydney and Melbourne electrified their railways in the 1920's. Both used direct current and a 1,500 V catenary supply. The traction currents at this voltage are substantial. Since the connection to the train has one wire on the catenary and with an earthed return circuit, stray currents appear around the railway.

The stray currents vary in amplitude as trains move along the track but do not change polarity. The currents will travel along any available path, including water pipes, gas pipes and telephone cables. The direct current is a problem because electrolytic cells are set up in suitable conditions and electrolytic corrosion results.

Telephone and power cables used lead sheathing until plastics became durable and suitable for underground use. The lead sheath was formed onto the cable at manufacture, protecting (in telephone cables) conductors that were insulated by thin paper. The lead barrier was essential to prevent water ingress and joints in the cable were encased in a lead to maintain the continuity of the cable. The cable was then pressurised with dry air so that holes in the cable would have minimal water entry (and leaks could be detected)[24]. All of these protective techniques were good in themselves. However, if stray currents were carried on the outer lead sheath and an electrolytic cell was set up, corrosion would occur. Once the corrosion ate through the lead, the dry air ensured a supply of oxygen, the paper became sodden and the copper wire, lead sheath, electrolytes in the soil, water and electric current combined to eat away the cable. Of course this was a slow process, usually detected by a gas (air) flow alarm at the telephone exchange. Identifying the fault location was more difficult. Time domain reflectometry, a process similar to radar and commonly referred to as Pulse Echo Testing (PET), was often used to identify the fault location[25].

Railway engineers relied mainly on bonding to avoid potential differences in trackside cables. The PMG, gas, water and power cable engineers did not have this luxury. Their cables and pipes were thoroughly earthed at a different location from the railway power source and bonding was generally not an option. A group within each organization was responsible for assessing the risk of stray currents for each cable installation and these groups regularly communicated with the railways. At some locations current was injected into the sheath of the cable or pipe to counter the induced currents and defeat electrolysis.

7.3 Induction – Safety

AC electrification has been used in Brisbane and Perth. The alternating current reduces the problems with electrolysis and the high voltage (25 kV) reduces the problem of induced currents.

Had 1,500 VAC been used, the induction from the very high AC current would have been insurmountable. The problem is worse with at 50 Hz than with the lower frequencies of 16.7 Hz in Europe and 25 Hz in the USA as the induction is directly dependant on frequency.

An AC electrified railway will induce voltages into adjacent cables by a process of both electromagnetic and electrostatic induction[26]. Electrostatic induction is normally overcome by and electrostatic screen on overhead cables and by the earth for underground cables.

Electromagnetic induction is generated by a number of conductors. These include the catenary and contact wire, the rails and the return conductor for the traction system. Since each of these conductors is spaced at some distance from the other and the currents in each are not necessarily balanced, substantial electromagnetic fields are created. Careful analysis and design is essential to ensure that hazardous voltages and currents are not induced into telecommunications circuits beside and near the track. The worst-case condition is usually a short circuit of the traction supply.

Similar precautions are necessary for radiating cables (leaky feeders) used for tunnel radio communication systems. The feeder cables are often run along the top of the tunnel, close to the traction supply. Galvanic isolation has been used for most of these systems to protect against induced voltages and against direct connections should the cable contact the traction wiring.

7.4 Standing Waves

The CTC remote control system between Rockhampton and Gladstone used a combination of open wire line and underground cable[27]. With the transmission line normal, the system operated perfectly. However, if the transmission line was open circuited at Raglan or Bajool, (outside the Rockhampton – Edinda section), controls could be received at Edinda outstation but indications were not transmitted back to Rockhampton.

After many tests it was found that the problem was due to standing waves on the line under these fault conditions. With the line open a Bajool, a null occurred at Edinda at 8.3 kHz. An open circuit at Raglan caused a null at Edinda at 7.6 kHz. The unfortunate coincidence was that these frequencies were used for telemetry transmission from Edinda. Calculation of the line lengths showed that in all cases there was almost an integral number of quarter wavelengths at 8 kHz between the outstations. The solution was to terminate the line under fault conditions, thereby eliminating standing waves.

8 CONCLUSION

Communications are essential for the operation of railways. The technology for communication has been in continual development and expansion over the history of railways. It is likely that the rate of change will increase as new technologies spawn new ideas. Telegraphy, telephony, the thermionic valve and the transistor provided the means to conquer distance.

More recently the microprocessor has lead to more capable and intelligent systems. It is no longer necessary to be a skilled Morse operator to send a text message – the cellular telephone proves that! These developments have improved the efficiency and safety of railways and current radio technology will soon impact on the way we operate trains in Australia.

Since the telegraph, most communications systems have been installed only as a part of some other project. Transmission systems are usually installed as part of an electrification or track upgrade project. It is time for communication engineers to communicate the benefits of technological change effectively.

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[1] An apprentice worked, in some cases, for five months probation without pay.

[2] "The Institution of Railway Signal Engineers", Journal of the Institute of Transport, February 1948.

[3] The historical information in this section is from "*Morse to Micro*", a history of NSW Railways communications by James Dargan. Published by James Dargan in 1988.

[4] The Postmaster General (PMG) was responsible for posts and telegraphs. Until relatively recently, the PMG also had control of radio communications and had a monopoly on data and telephony. The Australian Communications Authority (ACA) is now responsible for communications regulation.

[5] AG Henry, "*Communications in the New South Wales Railways", Journal of the Institute of Transport, August 1948, pp 27 - 32*

[6] Figures 1 and 2 are courtesy of Mr Hank De Jong, WestNet Rail

[7] Steel poles were introduced to counter the effects of bush fire, wind and termites on wooden poles. Used steel rail was an obvious choice of material for the poles and Mr Henry (see footnote 9) records that the telephone lines were typically at a height of 12 to 25 feet above ground, the poles being cut from rails that were 30 or 40 feet in length.

[8] See F Rylands, *"Carrier Telephone Links in the New South Wales Railways",* IRSE Technical Meeting, Sydney, July 1983 for a discussion of transposition spacing and carrier system performance on open wire lines.

[9] AG Henry, "*Communications in the New South Wales Railways", Journal of the Institute of Transport, August 1948, pp 27 - 32*

[10] Meyer, *"Communication in the Illawarra Electrified Areas",* IRSE Convention, March 1986.

[11] J Dargan, op. cit.

[12] H McCamley and L Meyers, *"NSW Railways, Sydney – Orange Microwave Link"*, IRSE Sydney, March 1971.

[13] DJ Both, "*Communications to The Centre. An Introduction – Tarcoola – Alice Springs Railway Microwave System"*. IRSE Technical Meeting, Adelaide, July 1982.

[14] P de Visser: "*Metrail Integrated Services Digital Network (ISDN)"*. IRSE Technical Meeting, Melbourne, November 1986.

[15] J Dargan, op. cit.

[16] J Byron, "*State Rail Data Network*" IRSE Meeting, Sydney.

[17] D Keddie, "*Experience with a Computer Based Message Switching System",* IRSE Technical Meeting, Adelaide, November 1984.

[18] ISO 1983 – International Standard 7498, Information Processing Systems – Open Systems Interconnection – Basic Reference Model (the issue current at the time.)

[19] T Moore, *"Communication Systems for Signalling Systems"*, IRSE Technical Meeting, July 1989.

[20] G Wilson, *"The Communications System of the NSW Railways",* IRSE Sydney, June 1952.

[21] P Guerra and R Leeder, "*Melbourne's Metropolitan Radio System. Equipment & Networking."* IRSE Technical Meeting, Melbourne, March 1992.

[22] A Mayne, "*A Voice and Data Radio System for Adelaide's Suburban Trains", IRSE Meeting, Adelaide, March 1979.*

[23] T Deveney, *"Alternative Safe Working System"*, IRSE Technical Meeting, Moama, November 1990.

[24] For further information, see the comprehensive paper by AH Hambleton: *"The Gas Pressure Concept in Railway Maintenance"*, IRSE Technical Meeting, November 1967

[25] A similar process is routinely used to check optical fibre cable joints. A pulse is sent from one end and reflections from discontinuities in the cable are recorded at the test set. The location of the fault can be determined from the delay between transmitting the pulse and receiving the reflected signal.

[26] A Blakeley-Smith, "*Short Circuit Testing on the new Kuala Lumpur 25 kV Suburban Railway". IRSE Technical Meeting, Brisbane, 1995.*

[27] K Selfe & M Menadue, "*CTC and Power Signalling – Rockhampton – Gladstone, Part 3: Remote Control and Supervisory Equipment", IRSE Meeting, July 1977*