Telecom Australia

Telecom Information Kit No. 4

LINKING A NATION

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LINKING A NATION

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The Magic Chain

SHEET 1

On November 23, 1872, a grand celebratory banquet was held in Sydney to mark the successful opening of telegraphic communication with Europe. The Governor of New South Wales, Sir Hercules Robinson, said in a speech at that banquet: "The Earth has been girdled, as it were, with a magic chain..."

Yet the new link in that "magic chain" was quite unremarkable to look at. A single strand of iron wire, suspended on porcelain insulators on top of a series of roughly-hewn wooden posts, the Overland Telegraph Line would have seemed hardly likely to bring about the beginnings of a communications revolution for Australians. Yet that is what it did.

Unremarkable as a short stretch of it might have seemed to a casual observer, the Overland Telegraph Line was indeed remarkable in many ways. For one thing, that single strand of wire stretched out, not for tens of kilometres, not for hundreds, but for more than three thousand kilometres right across the arid centre of Australia, from Adelaide to Darwin, across country that had barely been explored. At Darwin it met with an undersea cable that had been extended from Java, where it connected with a line going on to Europe and England.

It was remarkable also in its effects, because for the first time in Australia's history it allowed communication to take place with England in a matter of hours. Before the Overland Telegraph Line was completed, news and letters from England took a minimum of 60 days to reach Australia, by the fastest clipper ships then at sea.

The actual building of the Line is a story full of heroic endeavour, of clashing personalities, of impossible conditions, and of deadlines missed. But this is not the place to tell that story, which is described more fully in a Telecom booklet called "The Overland Telegraph Line", and in great detail in a book called "An End to Silence" by Peter Taylor. The purpose of this sheet is rather to look at how the Line worked, as the purpose of this kit as a whole is to look at the development of the technology of long-distance telecommunications.

So, how did that single strand of iron wire cause such a communications revolution?

The line was operated using the principles of Morse telegraphy. Samuel Morse set up his first commercial telegraph line in 1844, between Baltimore and Washington in the United States. Messages were sent using a code of his own invention, consisting of dots and dashes.* These were transmitted as short or long pulses of electricity along a conducting wire.

On the Overland Telegraph Line, the electricity was supplied by banks of large batteries enclosed in glass containers, each over 25 cm high and 10 cm in diameter. About eighty of these batteries were needed at each repeater station to provide the necessary voltage for sending telegraph messages on to the next station. They contained zinc and lead electrodes and solutions of copper sulphate and magnesium sulphate, and each produced about 1½ volts of electricity.

Pulses of electricity were sent by closing a Morse key, or sender. Such keys are still used by ham radio operators. Basically, the key was a spring-loaded switch, which when pressed down by the operator's hand closed a set of contacts and allowed current to flow along the line. By keeping the key down for shorter or longer periods of time, pulses of differing lengths could be sent.

In any electrical circuit, there must be a continuous loop so that current can return to the battery. Yet we have said that the Overland Telegraph Line (in common with all other telegraph lines at that time) consisted of only a single strand of iron wire. How did the current return to the battery? The answer is that the return path was through the Earth itself. One terminal of the set of batteries was always carefully grounded to allow this to happen, as of course was one terminal of the receiving equipment. (See diagram 1).

This use of a ground return had advantages and disadvantages. It certainly made the erection of a line very easy, as just one wire needed to be erected on a simple pole. And apart from the porcelain insulators on each pole, the wire itself could be left bare and uninsulated. Techniques for wrapping or coating wires with an insulating substance all along their length were then at a very primitive stage, and would have increased the cost enormously.

One major disadvantage, however, was that it was vital to prevent the bare wire from becoming 'earthed', that is, from coming into electrical contact with the ground, because this would 'short-circuit' the wire and prevent the electrical current reaching the next repeating station. This, of course, was the reason the wire had to be erected on poles, away from contact with the ground. But in wet conditions the branch of a tree touching the wire could create a conducting path to the earth; so trees had to be cleared on either side of the line. Indeed, in rainy conditions, the insulator and pole themselves could become coated with water and so allow current to leak to the earth. Over a long route these small leakages could badly affect the circuit. It was also necessary to put lightning conductors on every second pole, so that lightning would strike the conductor rather than the wire, which otherwise might be broken. Of course, it was vital to prevent the conductor (which ran down into the ground) from coming into contact with the insulator or the wire, else it would provide a tailor-made short-circuit.

Because the wire was elevated, it was also rather vulnerable. Breaks were common, for a variety of reasons. In one reasonably typical period between 1887 and 1892, the line failed a total of 36 times, interrupting communications for periods ranging from 3 hours to 63 hours in length. Of these interruptions, ten were caused by lightning breaking insulators, despite the lightning conductors; three by storms; two by poles falling over; two by men deliberately cutting the wire in order to obtain assistance from the lineman who would ride out to the break; one by Aboriginals stealing wire (they apparently used it for fishhooks); one by a train pulling down a quarter of a mile of wire; one by a flood; one by a bushfire; and four by short circuits of various kinds, of which by far the most interesting was caused by a frog becoming jammed between the wire and an iron pole! The other breaks were caused by unknown factors.

Still, these interruptions represented less than 2% of the operational time of the line during this period, so the breaks, though irritating, did not suffice to really hold up communication. It is important to realise, too, the length of the line, and its remoteness, so that in fact the record was remarkably good. Much credit for this should go to the linemen who rode out on horseback (or in later years, on a bicycle) along the line, looking for the break.

We have mentioned repeater stations several times so far without explaining what they were. Repeater stations were

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*See Telecom Information Kit No. 1, "From Dots to Data"

The Magic Chain

needed because the pulses of electricity sent out along the line by the Morse equipment would eventually weaken and be distorted so that they could no longer be read. It was essential, therefore, to set up repeater stations at regular intervals where the Morse signals could be read, and then sent on again with renewed strength. On the Overland Telegraph Line, there were eleven repeater stations between Port Augusta and Darwin, at an average separation of about 240 kilometres from each other.

Buildings for the repeater stations were constructed during the erection of the Line. They were of solid construction, of wood or stone, with a number of necessary outbuildings. Most stations in the interior kept a small herd of bullocks to provide fresh meat, as well as about twenty horses, so in effect each station had to act also as a small farm. Six men worked at each station.

At the stations, in addition to the primary electrical circuit and batteries which sent signals along the line, there was a secondary circuit and a second set of batteries used to power the Morse sounder and other equipment. When a pulse of electricity came down the line (representing a dot or a dash), the by now weak current operated an electromagnet in a piece of equipment called the line relay. An electromagnet works just like an ordinary magnet except that it only attracts while electricity is passing through its coil.

When a signal came in, the electromagnet attracted a piece of metal called an armature. The movement of the armature was enough for it to act as a switch and to allow current from the secondary (local) circuit to flow. In this way, a weak current in the primary circuit could allow a much stronger current to flow in the secondary circuit (see Diagram 2).

The strong current in the local circuit was used to operate the sounder. This was basically just a large electromagnet which could pull down a spring-loaded armature with such force that it made a loud sound when it hit a stop, and again when it was released when the current stopped. By listening to the sounder skilled operators could pick out the Morse code and write down the letters as they heard them. Occasionally a paper-tape register was used instead, which automatically marked down the dots and dashes onto a continuous strip of paper tape; but skilled telegraphists scorned its use.

DIAGRAM 1

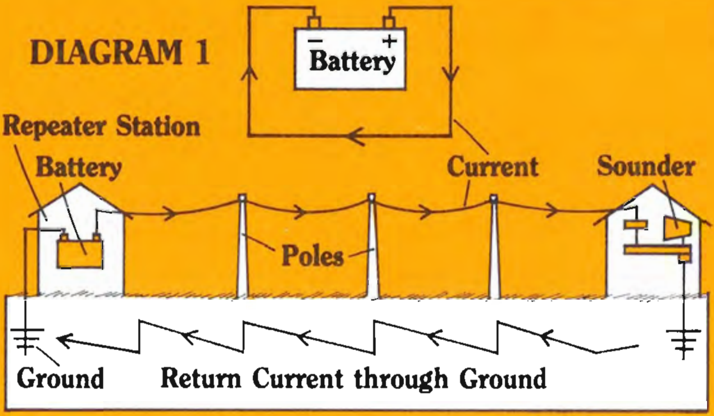
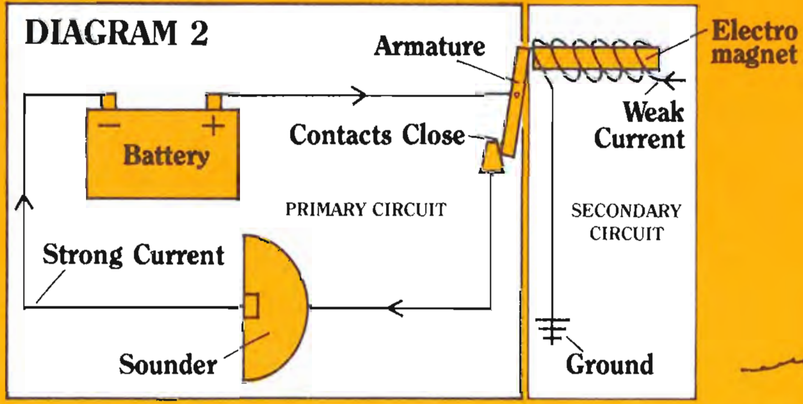


DIAGRAM 2



Once the message was written out (and any obvious errors corrected), the operator would use the Morse key to send the message on again to the next station down the line. So the telegram passed from station to station, not just along the Overland Telegraph Line, but through stations across Asia and Europe, perhaps finally reaching England within hours of it leaving Australia.

The technology of telegraph transmission remained basically the same for many years, though improvements were made, such as automatic transmitters which worked from a pre-punched paper tape. More details of these developments can be found in Telecom Information Kit No. 1, "From Dots to Data".

The single strand of iron wire across Australia's arid centre remained a vital link for decades. A second wire was added in 1898, this time of copper (a much better conductor of electricity). Morse code continued to be transmitted on the line until after the Second World War, though by then telephone conversations were also carried on the line, and Australia had many other links to the outside world.

Today, telecommunications traffic still follows part of the same route as the old Overland Telegraph Line, but using a technology incomparably more sophisticated, and capable of carrying more information in a minute than the Overland Telegraph Line could have in a hundred days!

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Overcoming the Problems of Long Lines

SHEET 2

Manual telegraph operators on the Overland Telegraph Line could key messages at rates of up to 30 words per minute. Later, automatic transmitters working from punched tape could transmit at hundreds of words per minute. Yet, in the early days at least, when messages from Adelaide reached Darwin and had to be repeated for transmission over the undersea cable to Java, they could often only be sent at the rate of about three words per minute. Why was there this difference? The answer relates to the particular difficulties found in operating telegraph cables beneath the sea or beneath the ground.

The most immediate and obvious difficulty, of course, was that of insulation. Sea water is a good conductor of electricity, and from what we said on the last sheet about the importance of keeping the telegraph wire insulated from electrical contact with the earth, it will be clear that submarine telegraphy could only be possible if the submerged wire could be kept completely from contact with water. Even for a cable buried underground, the exclusion of moisture was an absolute essential, and almost as difficult.

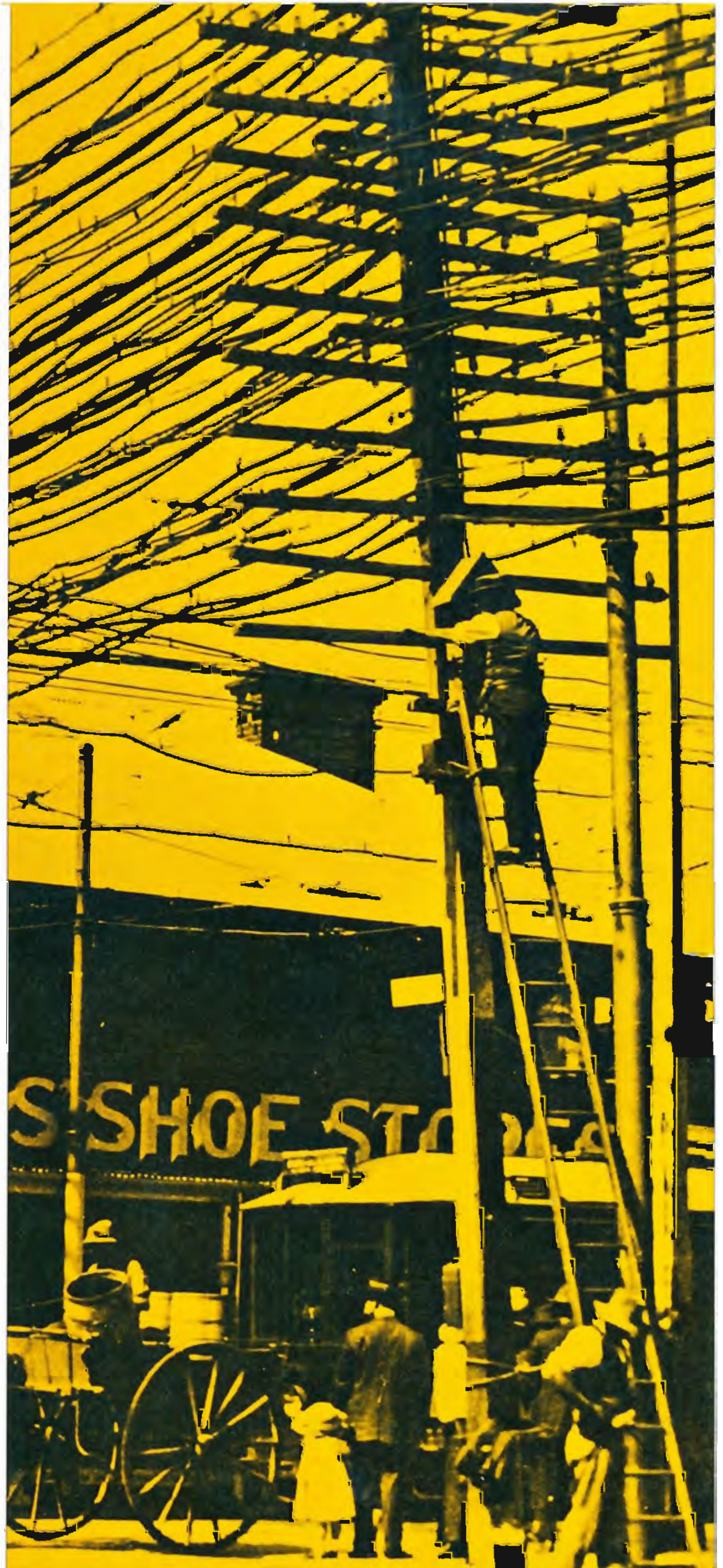
There were a number of early optimistic attempts to carry out telegraphy across stretches of water by cladding wires with rubber or with gutta-percha, a gum-like material obtained from certain trees. Samuel Morse attempted to operate a rubber-coated cable across New York Harbour in 1842, but the line went dead even before the official opening ceremony. In 1850, an even more ambitious venture was attempted when a small tug, the *Goliath*, was used to lay a copper wire embedded in a half-centimetre coating of gutta-percha across the English Channel, a distance of forty kilometres. But when attempts were made to send messages, all that was received was a meaningless jumble of characters. By the next morning, this cable, too, was dead. The amount of money lost in early attempts to lay submarine cables such as these was heartbreaking.

It is curious that in both the case of the Morse cable and the Channel cable, the ultimate failure of the wire was blamed on irate fishermen dragging up the cable in their nets (or with their anchor), and cutting it. It seems likely that these stories are untrue. The most likely cause of the complete failure of these cables is that the insulation broke down, allowing water to come into contact with the wire. Even a small pinprick in the insulating material would be enough to set up a conducting path, so rendering the cable useless. The manufacturing techniques for cables in these early days were not sufficiently sophisticated to eliminate such small breaks in the insulating material. Also, breaks could be created by handling or laying of the cable.

However, these problems could be overcome; and in fact the first successful undersea cable was laid across the English Channel in 1851, and within a decade a number of shorter distance undersea cables were laid quite successfully. In 1859, a cable was laid across Bass Strait to link Tasmania with the mainland, but it failed, and it was not until 1869 that the first successful Bass Strait cable was laid.

But the longer the distance, the greater the problems. The Atlantic Ocean was the graveyard of many dreams of uniting England and the United States by telegraphy. After many unsuccessful attempts marked by broken cables and electrical faults, a transatlantic cable was laid completely between the two countries in 1858. Messages of congratulation were exchanged between the President of the United States and Queen Victoria (though at the agonisingly slow rate of one-and-a-half words a minute!). But, a month after the cable was landed, it too failed, and was never more to work.

It was not until 1866 that a transatlantic cable was to prove successful. The huge paddle-steamer, the *Great Eastern*, the largest ever built, was used to carry and lay the tonnes of cable,



thicker and more strongly reinforced than any previous cable, across the sea-bottom. This cable operated successfully for five years before any maintenance was necessary, and proved a financial and commercial success.

One hazard of submarine cables, especially in tropical waters, was the teredo worm, which took a liking to the insulation of cables, and was the cause of many failures to cables before they began to be bound with solid steel wire.

But although submarine cables could now be successfully laid, the speed of transmission over long lengths of submerged cable was still painfully slow. The reason that signals had to be sent so slowly was because of an electrical phenomenon known as capacitance. To explain this, it will be useful to imagine an analogy.

Imagine that some hydraulically-minded inventor had devised a new communication system using water pipes. A water pipe is laid between the two people who wish to communicate. When the first person wishes to send a signal to the second person, he turns on a tap letting water into the pipe. The second person receives a signal when water starts coming out of his end of the pipe. This is certainly an extremely unlikely way to communicate, but it lets us consider some of the principles involved in a real cable. For example, in our pipe system, the water (representing the signal) will take a finite time to move from one end of the pipe to the other. But more importantly than that, the capacity of the pipe will affect how quickly a second signal can be sent after the first: before that can happen, the water filling the pipe because of the first signal must drain away. You can see that, with a short pipe, this draining-away process will not take very much time, so that a second signal can be sent quite quickly after the first. But the longer the pipe, the more water it can hold (it has a greater capacity), so the draining-away process will take much longer, and so signals will need to be sent at much longer intervals.

Although this is only a very crude analogy to what happens with a metal cable and electricity, something similar is going on. In certain circumstances a piece of metal can store a quantity of electrical charge almost as though it were a container storing a quantity of liquid. This phenomenon is known as capacitance. Without going into the details of how this occurs, it is sufficient to say that, if two plates of metal are made into a kind of sandwich with a layer of insulating material between them, and if each plate is then connected to one terminal of a battery, then the plates will quickly fill up with electrical charge and will store the charge (if the insulation is perfect) indefinitely. The point to note is that the plates would take a definite time to charge up or to have the charge drained away.

Now, a long telegraph cable covered in insulation and lying on the sea-bed is very similar to the two plates of metal we have just discussed. The metal wire forms one 'plate', the gutta-percha the insulating layer, and the electrically conducting sea-water (and thus the earth) the other 'plate'. So that when an electrical voltage is applied to one end of the wire (to send a telegraph signal), the cable charges up with electricity (like the pipe filling with water), and before the next signal is sent this charge must drain away, otherwise the signals will overlap and become confused. The longer the cable, the greater the capacity, and the more the problem.

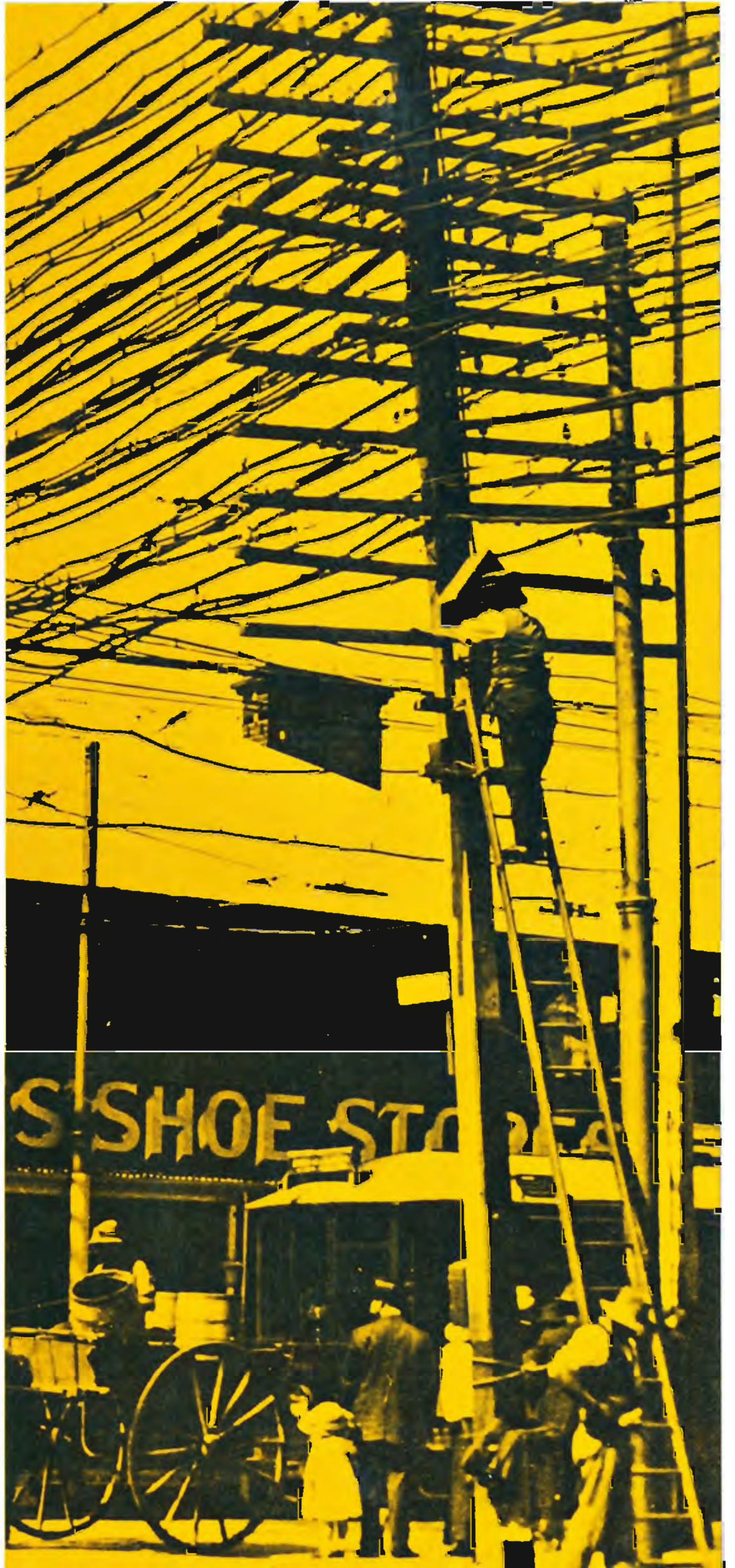
One way of reducing the problem was to increase the thickness of the insulating layer, as this reduces the electrical capacitance. But it was not for many years, after the invention of a communications medium far more sensitive than telegraphy, that the problem was completely overcome.

That new communications medium, of course, was the telephone. Invented by Alexander Graham Bell in 1876, the telephone transmitted, not the crude on-or-off pulses of electricity used in telegraphy, but a complex, smoothly-changing electrical signal which varied in strength exactly like the variations in air pressure caused by the sound of a human voice. The telephone receiver was extremely sensitive to these variations of current, and reproduced from them a good copy of the original sound.

Early telephone experiments were carried out over the existing telegraph wires, because these were by this time very extensive. This meant, of course, that these early telephone circuits employed a ground return. Even when telephone companies were erecting their own lines, these were basically identical to telegraph lines, a single aerial wire with a ground return. However, with such circuits, and particularly when using telegraph lines in busy areas, an at first interesting, but eventually annoying, phenomenon was noted. Telephone users could hear the clicks of telegraph traffic going on in neighbouring wires. Experienced telegraphists, listening on the telephone, could read out the messages they heard in this way. On telephone lines passing through extremely busy groups of telegraph wires, the telegraph traffic could be heard as a continuous static, like the sound of frying.

Later, it was noticed that telephone lines in close proximity similarly affected each other so that the speakers on one line could hear the conversation going on the other line. The name given to this phenomenon was induction.

Induction arises because of the linked nature of electricity and magnetism. In 1819 Hans Oersted of Denmark had shown that when an electrical current was passing through a wire, it produced a small magnetic field, sufficient to deflect a compass



Overcoming the Problems of Long Lines

needle (which was normally affected by the Earth's magnetic field alone). This is the principle of the electromagnet, which by coiling the electrical wire, directs and increases the magnetic effect, which only operates when electricity is passing through the coil. Later, it was found that a changing magnetic field similarly produces an electrical current in a piece of wire within the field.

In the phenomenon of induction, both of these effects are operating. Take two wires, laid parallel to each other. If in the first wire there is a changing electrical current (as caused, for example, by a telephone conversation), then this will produce a correspondingly changing magnetic field. If the second wire is close enough to the first, then this changing magnetic field will cause (or induce) an electrical current in it which will match the changing current in the first wire, thus in a sense transferring a ghost image of the telephone conversation into the second wire. This is called "crosstalk". The closer the wires, and the longer the distance they remain parallel, the stronger the effect. Crosstalk on telephone wires was found worst where telephone lines ran over long distances on the same poles.

Bad as this problem was with aerial wires, it very nearly rendered the practical development of underground telephone cables beyond reach.

In the 1880s, there was increasing pressure for telephone lines to be laid underground. The rapid popularity of the telephone meant that in many cities, particularly close to telephone exchanges, the number of overhead wires was growing so much that poles were overburdened, and were extremely unsightly and dangerous. The obvious solution was to put these wires underground, at least in congested city areas. But obvious solutions are not always practical ones. Apart from the expense of digging trenches to take the cables, there were then great difficulties in maintaining adequate insulation against moisture. Putting the wires in such close proximity threatened severe crosstalk problems from the effects of induction, and of course there was the problem, with long cables, of electrical capacitance.

Fortunately, in time all of these problems were overcome. The money could be found to dig the trenches, or underground ducts could be shared with gas and water mains. From the experience obtained in making submarine cables, water-tight coverage could be devised for underground cables, although these had a number of significant differences. And a solution was found to the problem of induction, though at some cost.

The best way to reduce or eliminate induction, it was found, was to provide a complete metallic circuit for the telephone conversation. In other words, instead of providing a single wire with the return path for the electricity through the earth, two wires were provided to give a return path along the wires. The advantage of this was that, if the two wires of a particular circuit were close to each other (though of course insulated from each other), then an external induction effect should induce currents in both wires simultaneously; and the effects in the return wire would cancel out the effect in the first. The result would be no crosstalk.

However, in practice, there was usually some resultant inductive effect between neighbouring pairs. This was because one of the wires of a pair could be physically closer to an adjoining pair than the other and therefore have a stronger inductive effect. To overcome this, in the case of wires on poles, the wires of pairs were crossed over or transposed at specific intervals: these transpositions, as they were called, had the effect of balancing out the relative closeness of each wire of a pair to the wires of neighbouring pairs and therefore helping to cancel out the inductive effects. The same principle was used to reduce the effects of induction in the tightly packed pairs in underground cables. However, instead of transposing the wires at specific intervals as for open wires on poles, the wires of cable pairs were continuously twisted about each other so that each wire of a pair had about the same overall closeness to the wires of neighbouring pairs over the length of the cable. The same method continues to be used today.

Problems with electrical capacity were far greater for telephone transmission than for telegraph transmission, because, to give acceptable speech quality, the electrical signals on the telephone line had to be able to alter roughly eight thousand times a second! Compare this rate with the snail's pace of three words a minute over long submarine telephone cables, and you will begin to see the size of the problem. Of course, for relatively short underground telephone cables, the problem was reduced, but even over only a few kilometres, the capacitance of the cable tended to distort speech.

The provision of metallic circuits reduced this problem somewhat. But the real breakthrough was when it was found that the lowest capacitance occurred in cables which were *not* filled solidly with an insulator, as was traditional, but which were left dry, or filled only with air, with the wires insulated from each other by being wrapped in paper or cotton.

The development of dry-core cable, using twisted metallic pairs, occurred over a number of years, but was completed by about 1890. From that time, the overburdened telephone poles began to disappear from inner city areas, as they were replaced by underground cables.

Dry-core cable reduced the problem of capacitance sufficiently for relatively-short-distance telephone cables to be used, but over long distances, and particularly for submerged cables, the problem remained for many years. They were eventually overcome by the invention of loading coils. In 1899, an American professor of mathematics, Michael Pupin, showed that by inserting special coils into a long submarine cable, the phenomenon of capacitance could be cancelled out by a kind of self-induction. If the coils were placed in the cable at the right intervals, the two effects completely cancelled each other out.

Pupin's discovery made long-distance cable telephony possible as well as enormously increasing the rate at which telegraph messages could be sent over submarine cables. Even so, when in 1936 a submarine telephone cable was laid between Tasmania and the mainland of Australia, it was the then longest in the world, while the first trans-Atlantic telephone cable was not laid until 1956, using specially-developed submersible repeaters. By then, far more sophisticated telecommunications transmission methods had been developed for use on land.

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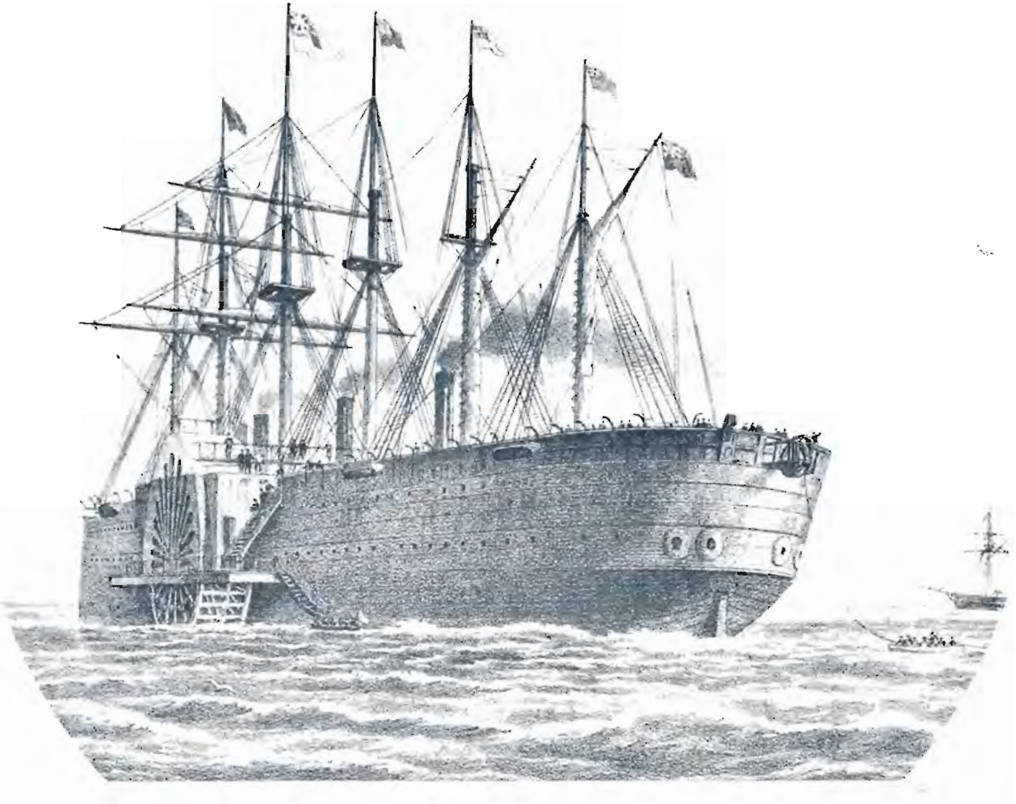

The Great Eastern laying the transatlantic cable in 1876.

The telegraph cable from Java comes ashore at Darwin in 1871.

SHEET 3

Australia's Telecommunications Network

COAXIAL CABLE		RADIO
═	EXISTING SYSTEM	—
═ ═ ═	PROPOSED SYSTEM	— — — —

◉	EXISTING TV STATION WITH BROADBAND RELAY.
◎	PROPOSED TV STATION WITH BROADBAND RELAY.
△	SATELLITE EARTH STATION
●	TERMINATING OR BRANCHING STATION FOR TELEPHONE CIRCUITS.
•	RADIO REPEATER STATION.
═	TELEVISION RELAY ONLY.

Australia's Telecommunications Network

Imagine, if you will, that a series of maps has been made showing the extent of Australia's telecommunications links as they were at the end of each year from 1854 to the present. If we were to flash photographs of these maps up on a projection screen, one after the other in quick succession, it would be like watching a movie film of the growth and development of Australia's telecommunications network. It would look to us like a living thing, as though a manic spider was at work spinning a lopsided web over the map of Australia.

Tentatively at first, with a few scattered strands representing the first short telegraph lines in each colony, the web would suddenly strike out over long distances in the late 1850s, linking the capitals of the eastern States, at the same time as it became more tightly interwoven around those capitals. We would see a sudden strand leap out in 1872 to cross the continent from south to north: the Overland Telegraph Line. A little later a strand would appear across the Nullarbor, linking east and west. Bound closely to the coast at first, the network would be seen to encroach further and further inland as the 1880s were reached.

At this point a new degree of complexity would become evident, if the detail on the maps was fine enough: as the telephone is introduced and becomes popular, complex meshes of telephone links spring up around cities and towns. By the 1900s, telephone trunk links begin to extend between cities.

And so the web would grow, always reaching out to more and more remote areas, always filling in existing gaps, with existing links always becoming thicker as duplicate and triplicate lines are added to service increasing traffic loads.

As we draw nearer to the present day, by the 1960s, new links of far greater capacity than any before suddenly begin to appear and rapidly stretch out, replacing existing routes: broadband telecommunications links in the form of coaxial cables or microwave links.

And so we would reach the present day, with a vast and complex telecommunications network stretching out across Australia. The last few maps flashed up on the screen would show broadband links almost encircling the continent.

Perhaps this is rather a fanciful way to descibe the growth of telecommunications in Australia; but this description does emphasise that the network is a dynamic, growing thing. It is still growing, becoming yet more complex, reaching out to more and more Australians. And not only is it growing, but it is constantly alive with telecommunications traffic, every minute of every day.

Telephone calls, telex messages, computer data, even television and radio relays; all of these and more flood continually along our telecommunications links.

It is vital to realise, too, that the network is not a mere passive collection of wires, cables and microwave beams. Its most vital attribute is that it is a *switched* network. At the junctions of the web are switching points: telephone and telex exchanges at various levels, or specialised computers which act as exchanges for computer date transmission. These switching points allow traffic to be directed through the network so as to connect together any two terminal points: two telephones, so that people can talk to each other across the continent; two telex machines, so that telex messages can be typed on one machine and printed out on the other; two facsimile machines; two computers, or a computer and a data terminal and so on.

The switching points also direct communications traffic along differing routes to reach the same destination, depending on how busy certain links are at that time. If a particular route is busy, traffic is diverted along a less busy route.

The map on this sheet shows you the present state of Australia's broadband telecommunications links. It does not show the myriad of smaller-capacity links, which would be impossible to depict on a map of this scale. Indeed, there are more than 37 million kilometres of wire, coaxial tubes and microwave links in the present Australian network – enough to reach, if they could be placed end to end, to the Moon and back nearly 50 times!

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SHEET 4

Microwave Radio – Beams through the Air

In 1959, the first broadband telecommunications link in Australia was opened for traffic. It was a microwave radio link between Melbourne and Bendigo in Victoria, and it was the beginning of a quiet revolution in Australian telecommunications. A revolution which saw the replacement of over-burdened aerial wire and pole routes with much greater capacity microwave or coaxial cable links; a revolution which is today substantially complete, leaving Australia with a modern high-quality, widespread broadband telecommunications network.

Microwave and coaxial cable systems are called broadband links because they carry a very large volume of communications using a much broader range (or band) of frequencies compared to earlier systems. A single broadband bearer can carry hundreds or even thousands of telephone calls simultaneously by using a principle called frequency-division multiplexing.

Frequency-division multiplexing means that many telephone calls can be transmitted at the same time over the same bearer and yet be distinguished from each other at the receiving end because they are each carried at a different frequency. In a way, this is rather like how broadcast radio works. There are many different radio stations transmitting in the radio band, but they can be easily distinguished by your receiver because they are transmitted at different carrier frequencies to which the receiver can be tuned. Two radio stations must transmit at frequencies far enough apart so that they do not interfere with each other. This need to prevent overlap limits the number of stations that can transmit within a particular band of frequencies.

Similarly, in frequency-division multiplexing of telecommunications, the number of channels that can be transmitted at the same time depends on the width of the band of frequencies that can be transmitted on that medium. A broadband system carries traffic over a very wide range of frequencies, and so can carry a great many channels.

In a microwave radio system, telecommunications traffic is transmitted in the form of directed beams of microwaves. Microwaves are a kind of electromagnetic radiation like light or like the radio waves used in ordinary broadcasting, but of a frequency intermediate between these. (See Telecom Information Kit No. 2, "This Busy Ray", for more information about frequencies and electromagnetic radiation).

Like light, microwaves normally travel in a straight line. For this reason, it is necessary to set up microwave repeating stations within line-of-sight of each other. And because you can see further the higher you are, microwave transmitting and receiving antennas are set on tall towers.

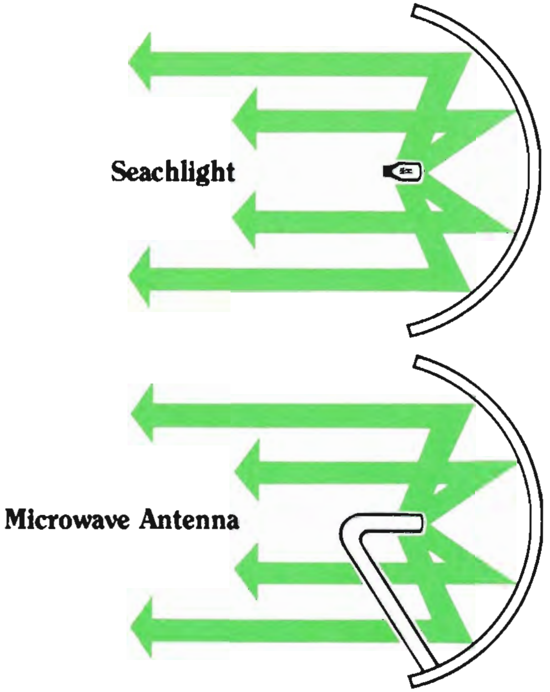
These antennas are usually parabolic dishes, which are the same sort of shape as the mirrors in powerful searchlights, and for the same reason. A light placed at the focal point of such a mirror will be reflected by it into a parallel beam (see diagram 1). Similarly, a microwave source placed at the focus of a dish of such a shape will be reflected into a tight parallel beam. In the reverse direction a parallel beam coming in to a parabolic dish will be focused together at one point. On microwave antennas, there is a hook-shaped hollow tube at the focus of the dish which emits or receives the microwaves.

Along a microwave route, a series of towers are set up at reasonably regular intervals, usually about every forty kilometres, but depending on the terrain. Each tower must be within sight of the top of the towers on either side of it, and there must be no intervening obstacles.

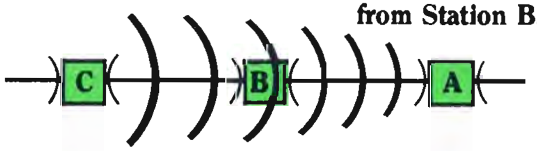
Microwaves received by an antenna on one of the towers are guided by the hollow metal tube (called a waveguide) from its focus down the tower and into equipment which is usually housed in either a prefabricated building at the base, or at the new solar-powered repeater stations, in an underground concrete container. The function of this equipment is to boost the incoming microwave signal and retransmit it. The re-strengthened signals are led up another waveguide and to an antenna on the other side of the tower and transmitted on to the next tower along the route. And so the microwave signals pass up the chain of towers to their destination, all in the barest fraction of a second.

It is important to note that actually, each antenna is

Microwave Radio – Beams through the Air



Station A may interfere with signals received by Station C from Station B.



Signals passing beyond Station B from Station A cannot be received by Station C.

continuously involved in two-way traffic, accepting incoming microwaves and transmitting outgoing microwaves simultaneously.

The route for the towers has to be chosen very carefully. Radio propagation tests are carried out along the proposed path for the microwave link, to see whether there will be any effects which could interfere with the reception of radio signals. For example, when the East-West microwave system across the Nullarbor was built in the late 1960s, a survey team found that the enormous flat surface of the Nullarbor reflected microwaves, and as a result, could cause serious fading of signals. Another problem was that the rapid heating up of the desert surface during the day, and its equally rapid cooling at night, tended to cause serious bending of the microwave beam. Similarly, problems can be caused by reflections of microwave beams off water and other objects.

The route is carefully surveyed, and the height of the towers must be calculated carefully by studying a profile of the terrain in between one tower and the next. The curvature of the Earth must be taken into account. So must the height of trees or other vegetation on the route, and allowance made for future growth. The aim is of course to keep the height of the towers to a minimum at the same time as keeping the distance between towers to a maximum.

The final route of towers is never an exactly straight line, even over such flat areas like the Nullarbor, but a very shallow zig-zag. This is deliberate, and is done to avoid the possibility that signals from one tower might "overshoot" its neighbour and interfere with signals being received at the tower beyond that (see diagram 2).

The equipment at each repeater station must be kept going by some source of electrical power, of course, and Telecom Australia has come up with some innovative solutions to the problems of providing this power in remote areas. In less remote regions if suitable mains power is unavailable, electrical power is usually supplied by a generator driven by a diesel motor, but the need to supply diesel fuel and maintenance make this uneconomic in more remote areas. So Telecom has pioneered the use of alternative energy sources.

One such source is wind power. When the East-West microwave link was built, most of the repeater stations in the remote parts of the link had small windmills installed which kept charged a bank of batteries at each station, which supplied power for the operation of the equipment. However, if the wind was insufficient, a diesel powered generator cut in to keep the batteries charged.

A much more recent installation of wind powered telecommunications equipment was on King Island, in Bass Strait.

Solar power has now been used extensively to power microwave repeaters. The first major telecommunications route in the world to be powered exclusively by solar energy was opened between Alice Springs and Tennant Creek in October 1979. A much longer solar-powered route – indeed, the longest in the world – is presently under construction between Port Hedland and Kununurra in Western Australia, and should be completed by mid-1983.

Yet another unusual energy source is being used along the more than 1000 kilometre route of the gas pipeline from Moomba gasfield in South Australia to the coastal regions of New South Wales. A microwave system runs all along the length of the pipeline, and it is powered by generators using some of the gas from the pipeline itself.

One unusual kind of microwave system is in limited use in Australia. This system is called tropospheric scatter, or "tropo". The troposphere is the lowest level of the atmosphere, extending upwards about eleven kilometres. Tropospheric scatter systems in effect bounce microwaves off layers of air in this region to receivers which are over the horizon, and so out of line of sight. Such systems require much more power than ordinary microwave links, and are subject to various kinds of fading. Such links provide communications at present between Darwin and Gove in the Northern Territory, for example.

Telecom Australia

Coaxial Cable – the Underground Connection

SHEET 5

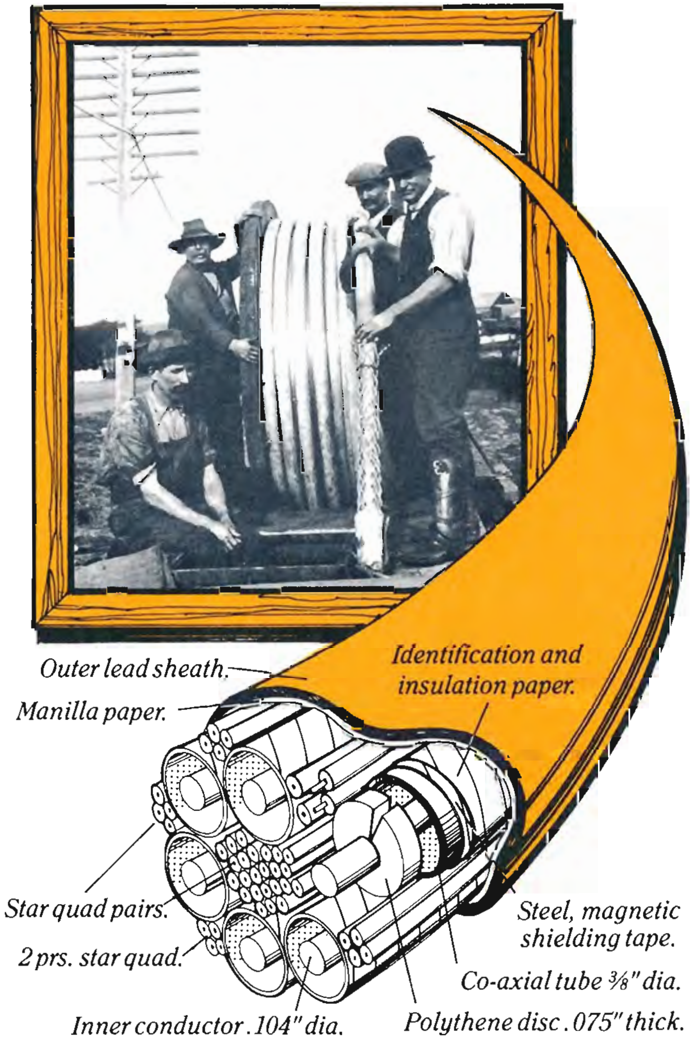
The first major installation in Australia of coaxial cable was in the early 1960s, when the first broadband link joining Sydney, Canberra and Melbourne was constructed. The link opened for traffic in April 1962.

The cable laid between these centres contained six coaxial tubes and 32 pairs of other wires, and had a potential capacity of thousands of simultaneous telephone calls, in addition to being able to relay television programs.

A coaxial tube consists of an outer conductor which is a hollow metal tube, usually copper, about a centimetre in diameter, with an inner conductor, usually a solid wire a few millimeters in diameter, running along inside it. The inner wire is kept centred in the outer tube by means of polythene discs spaced at regular intervals throughout the tube. Apart from the polythene discs, the inner conductor is kept insulated from the outer tube simply by air. Such tubes are called coaxial because the two conductors share the same centre, or axis. (See diagram 1.)

Such a tube can be used to carry electrical signals in exactly the same way as an ordinary pair of wires, with equal but opposite currents flowing in the two conductors. The great advantage of coaxial construction in such a situation, however, is that the outer conductor shields the inner conductor to contain inductance effects. This both means that coaxial tubes can be packed closely together without fear of mutual interference, and that (particularly at high frequencies), there is very little attenuation or loss of signal strength over distance, as energy is not lost readily from the tube because of this shielding effect.

Prior to 1934, coaxial type construction had been used only for submarine cables. These used solid insulating material in order to withstand the great pressures encountered on the ocean floor and had a relatively narrow broadwidth transmission capability. At this time however, research at the Bell Telephone Laboratories showed that air insulated coaxial cables were capable of transmitting a much greater bandwidth such that hundreds of telephone channels could be carried over a single pair of coaxial tubes using frequency division multiplexing.



The construction, manufacture and laying of underground cables has made great strides since these early days.

Modern six tube co-axial cable.

In coaxial systems using frequency-division multiplexing, a pair of tubes is required to provide a complete "go and return" circuit, the equivalent of a group of four ordinary wires in a conventional system.

Many tubes can be packed together within one coaxial cable (up to 22 such tubes in some very large systems used overseas), but within Australia, four or six tubes are the most common, with limited use of twelve-tube cables. In the gaps between these tubes can be packed a number of simple wire conductors which can be used to provide communications to smaller towns along the route of the cable, or for control information.

Like a microwave system, a coaxial cable must have repeaters placed at certain intervals along its route to boost the signal strength. These repeaters must be spaced much more closely than those of microwave systems. In the 1960s, the equipment to pick up the weakened signal from the coaxial cable and boost it before retransmission was valve-operated and located in small buildings along the route. But in the 1970s, the decreasing size and increasing reliability of electronic components following the invention of transistors enabled most of this equipment to be placed in small underground containers, accessible through a manhole.

In metropolitan areas, coaxial cables are installed in underground ducts. However, in country areas, and over long-distance routes, the cable is buried about a metre deep along its route. The path for the cable is first cleared, to allow access for machinery, and then the earth is broken up by digging equipment, or sometimes by blasting. Large boulders and rocks which could damage the cable are removed.

Care must be taken not to bend the cable too much, or the coaxial tubes could be distorted or pinched. Large bulldozers have been adapted to feed the cable from huge drums down into the trench as it is being ploughed open.

Rather larger excavations have to be made for the underground housings for the repeater equipment, into which the cable is led and jointed. However, some repeaters are still housed in small buildings and any communication lines that have to be split off from the main cable to service towns along the route are separated at such points.

Once the cable is laid, the coaxial tubes are pressurised, so that any hole or break in the tubes causes an escape of air. This both keeps out dust and allows the break to be detected a long distance away, due to the drop in pressure, which can be detected

Coaxial Cable – the Underground Connection

by special instruments.

Lengths of cable are usually planned so that the end of a length will fall at the point where a repeater has to be installed. But lengths still have to be spliced together in the field, and this is a slow, careful process. The exclusion of dust is a high priority, and the joint must be carefully tested.

Once the cable has been laid and buried, the ground along the path of the cable is smoothed over, and conditions returned as closely as possible to the way they were before. Once grass grows back, it is often very difficult to tell where the cable goes.

You will see from the broadband map on Sheet 3 that the extent of coaxial cable routes in Australia is less than the extent of microwave systems. Why is one kind of broadband system chosen over another? There are many factors which come into this decision.

More land has to be acquired for a coaxial cable route, though once work on laying the cable has been completed, land can often be returned to its original use; often cable can be laid alongside highways, on Crown land. However, terrain is an important factor in laying coaxial cable: it is difficult to lay cable over hilly or rough ground, whereas radio repeaters can take advantage of hills, and skip over difficult terrain. Coaxial cable is also vunerable to being cut by digging or farm machinery.

These factors, and many others, are taken into consideration when planning a new broadband link. Generally speaking, coaxial cable is provided where terrain is not a problem and where a high-capacity link, with frequent "drop-offs" to service intervening towns, is needed. Radio links are used where long distances must be covered with few intervening drop-off points. Of course, all other factors being equal, the relative costs of the systems is the determining factor.

Again, looking at the broadband map on Sheet 3, you will notice that there is often the possibility of sending traffic over two alternative paths between two places. For example, between Adelaide and Melbourne via Mildura or via Bordertown; between Tasmania and the mainland via King island or via Flinders Island. There are many other examples.

This ability to route traffic over alternative geographical routes is a key factor in maintaining network security. For example, if the coaxial cable between Melbourne and Sydney was completely broken (perhaps by a bulldozer excavating a dam) then a lot of Melbourne-Sydney circuits and also circuits to Canberra, depending on the location of the break, would be lost. However, communications would still be able to be maintained, despite some likely congestion, because traffic would be routed over the microwave radio system.

Apart from Perth and Darwin, there are alternative broadband routes between all other capital cities and also to most regional centres in the eastern States. Alternative routing will be possible to Perth and Darwin after the completion of a proposed microwave radio system between Kununurra and Katherine by about 1987.

Telecom Australia

Modern coaxial cable laying machine.

SHEET 6

Telecom's Plans and Developments in Long-Distance Telecommunications Transmission

The future holds many exciting developments in transmission technology. Telecom Australia is presently examining several new techniques which show great promise for long-distance telecommunications, particularly in the very remote areas of Australia.

One of these new developments is in the use of hair-thin strands of glass to carry telecommunications traffic in the form of flashes of laser light. The development of these optical fibres, as they are called, and the promise they hold, are described fully in Telecom Information Kit No. 2, "This Busy Ray". Current field trials in Australia are over relatively short distances, but overseas, trials have been made with a somewhat different kind of fibre which indicate that it has the potential to carry very large volumes of traffic over long distances before repeaters are needed. It is expected that optical fibres will start to be used for interstate links in Australia by about 1990.

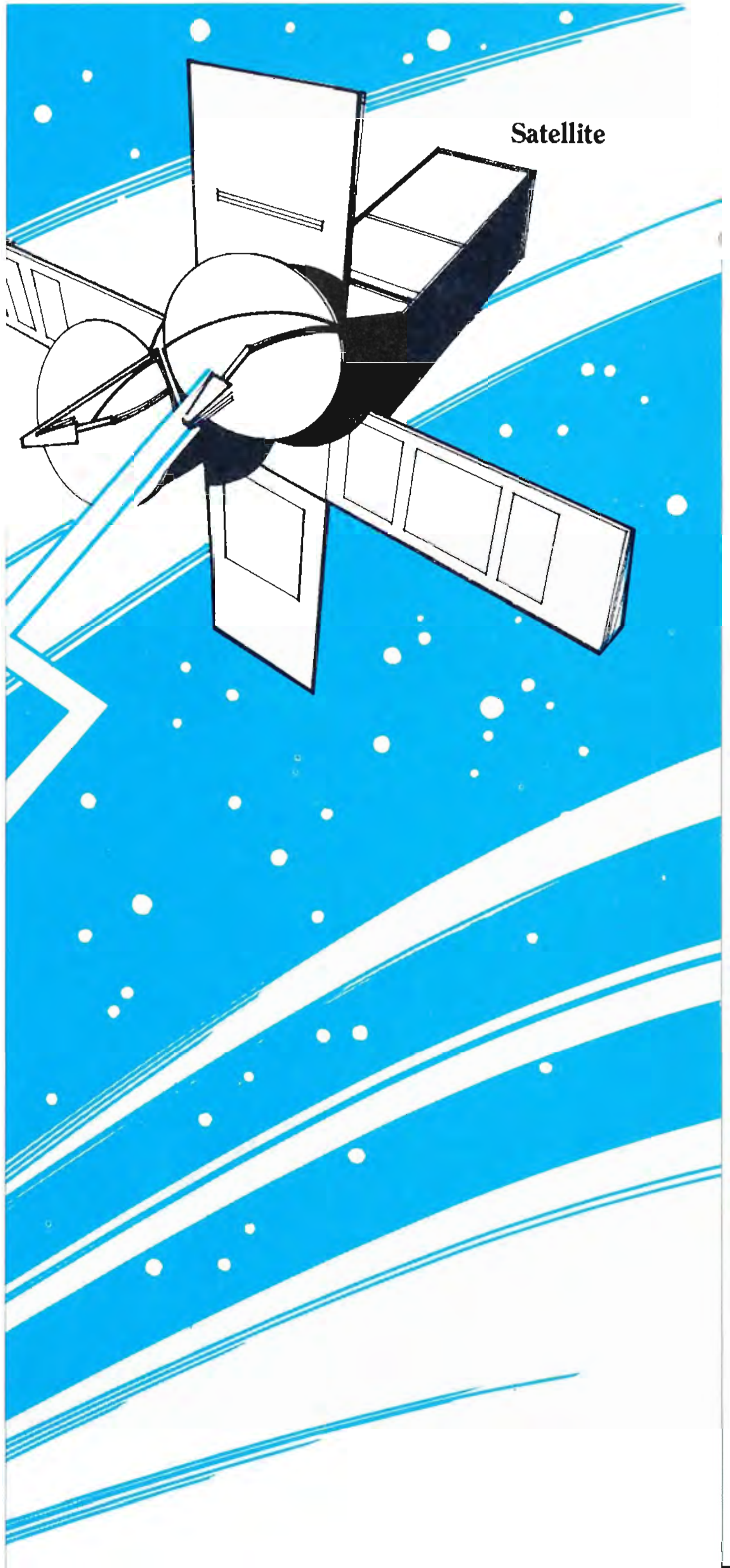
The way in which optical fibres carry telecommunications traffic exemplifies an important trend in transmission methods both in Australia and around the world. This is the trend towards using digital methods rather than the traditional analogue methods of transmission.

The distinction between digital and analogue and the benefits of digital transmission methods are explained much more fully in Telecom Information Kit No. 1, "From Dots to Data". Here it will suffice to say that digital methods involve transmitting information (whether it be the human voice, a telex message, or computer data) as a series of numbers or digits, each of which is represented by a pattern of on-or-off pulses - in an optical fibre, as a series of on-or-off flashes of light. Traditional analogue methods transmit information as a smoothly-varying signal which matches the smoothly-varying changes in the sound level of a voice.

Digital systems are being introduced in a number of areas of the Telecom network at present, and they will become much more common - indeed, it is likely that eventually, all telecommunications traffic will be carried in this form.

One major step towards this goal has been the recent development of microwave radio systems which use digital transmission methods. The first such system in service in Australia will open between Melbourne and Sydney in 1984, followed by links between Adelaide and Melbourne and between Sydney and Brisbane the following year.

But it is the very remote and isolated areas of Australia that have always been the most difficult to provide with the kind of high-quality telecommunications that those living in the more densely settled areas of the continent take for granted. Some 40,000 people at present live in areas with either poor quality telecommunications or hardly any at all. Some of these people rely on single strands of wire on wooden poles to connect them to the rest of the network - lines they have erected themselves. These lines provide a very poor quality of service. Others can



communicate only through the radio system of the Royal Flying Doctor Service.

The major problems in providing telecommunications to such areas are their remoteness from the existing high-quality network, and the fact that settlements in these areas, often consisting of only a few people, are isolated at quite large distances from their neighbours; in other words, the density of population is extremely low. Obviously, laying cables or even erecting wires on poles to all of these settlements would be a very daunting and expensive task.

Fortunately, there are other ways to reach these people. One method which has been give a great deal of publicity in Australia recently, is by means of a satellite system. The Federal Government has decided to authorise the building and launching of a domestic communications satellite for Australia, to be run by a part-government owned company, Aussat. The satellite, to be launched by the American Space Shuttle in 1985, will be placed in geostationary orbit. The geostationary orbit is a circle in space at a height of 36,000 km above the equator.

Any satellite placed in orbit above the Earth completes a loop about the globe in a period of time depending on its average height. The further away from the Earth a satellite is placed, the slower will be its orbit. Very low satellites can complete an orbit in less than two hours, but the Moon, which is the Earth's only natural satellite, takes one month to complete its orbit. Between these two extremes, there must logically be a height at which a satellite will complete its orbit in exactly 24 hours. Such a satellite will circle at exactly the rate that the Earth is turning on its axis, and so, to an observer on the ground, will appear to be motionless in the sky.

The great advantage of communications satellites being placed in this orbit is that radio receiving and transmitting dishes can be set up pointing permanently at the satellite, without needing to track its movement. And, of course, the satellite never sets below the observer's horizon, and is therefore always available.

The major use of the Australian domestic satellite will be to bring radio and television broadcasts to rural areas of Australia. For this purpose users on the ground can set up quite small dish antennas (less than two metres in diameter) to receive the relatively high-power signal being beamed down by the satellite.

However, a telecommunications service would need to use one of the lower-powered transmitters on the satellite, and this would mean that users would need to have much larger antennas, about four to five metres in diameter.

Telecom plans to provide telecommunications via the domestic satellite as a premium service - that is, the service will be necessarily more expensive than an ordinary telephone service. In the initial stage, it is expected that some 250 services will be provided in this way, using 60 "earth stations" - controlling centres on the ground equipped with large antennas. Such

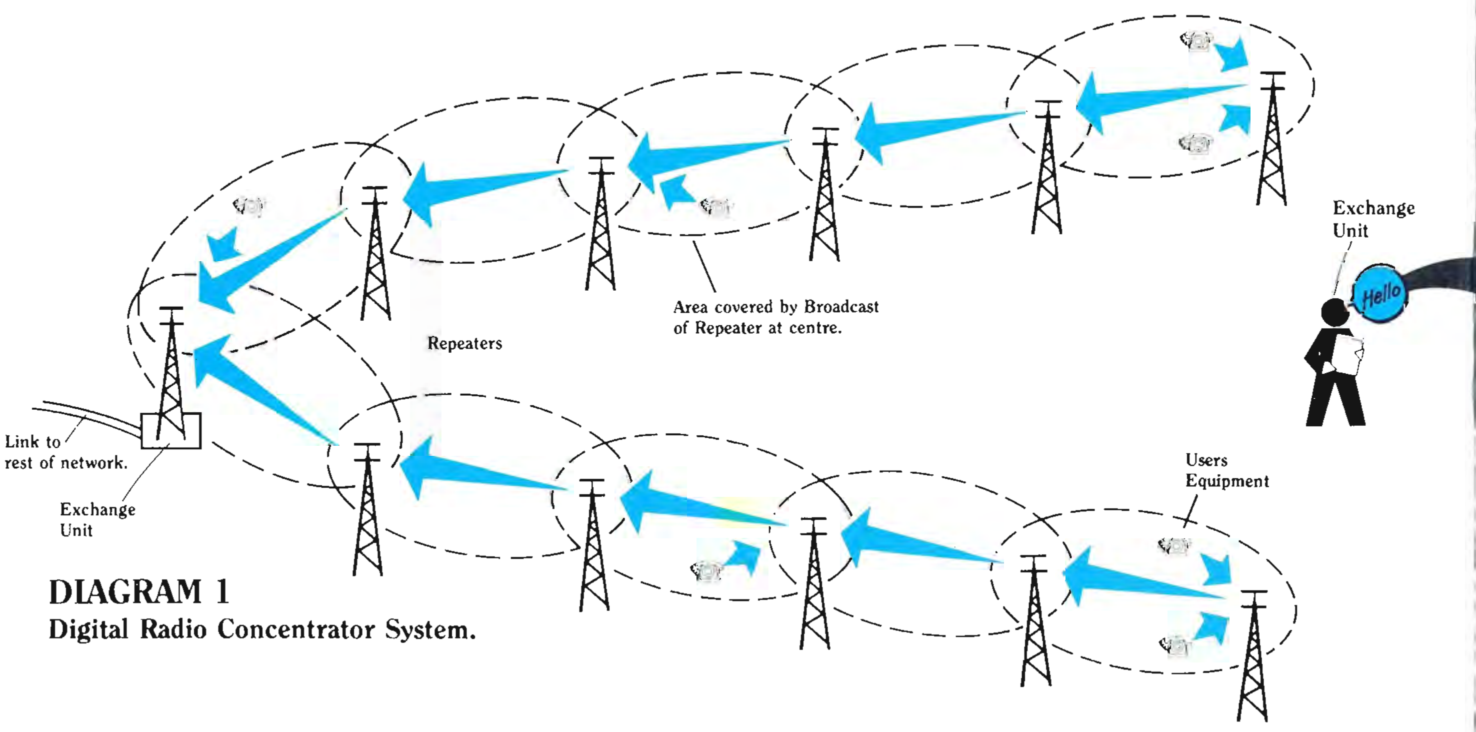


DIAGRAM 1
Digital Radio Concentrator System.

services are likely to be of greatest value in the most remote parts of the continent. One possible use will be for mining companies working in near-desert areas.

The satellite service would work in the following manner. When a user lifts his or her telephone receiver and dials a number, signals are transmitted by equipment at that location, via the satellite, to the associated earth station. The earth station acts very much like an ordinary telephone exchange in deciding where the call is to be connected. If the call is to another user of the satellite service, the earth station sends signals to the equipment at the location of both the caller an the called person, advising both sets of equipment to transmit and receive on a particular radio frequency which is at that time unused by any other users of the system. The call then proceeds between the two people directly via the satellite. When the call is over, the earth station can reallocate the frequency to other users.

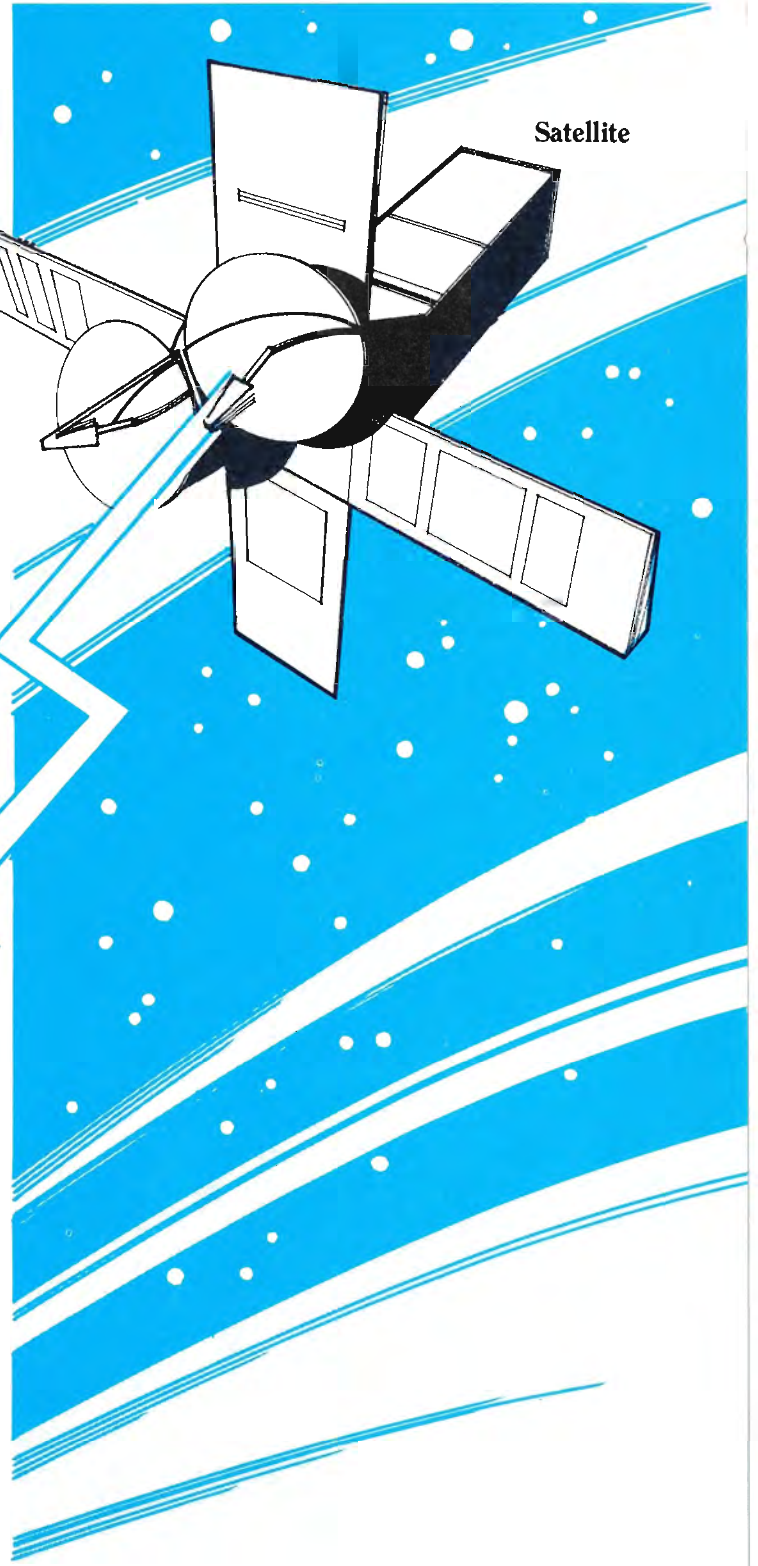
The situation where the called person is connected to the ordinary ground-based network is slightly different. A particular free frequency is still allocated to the caller, but communication is via an earth station connected to the network. A similar situation occurs in reverse when a caller from the ground-based network wishes to speak to someone connected to the satellite-based system.

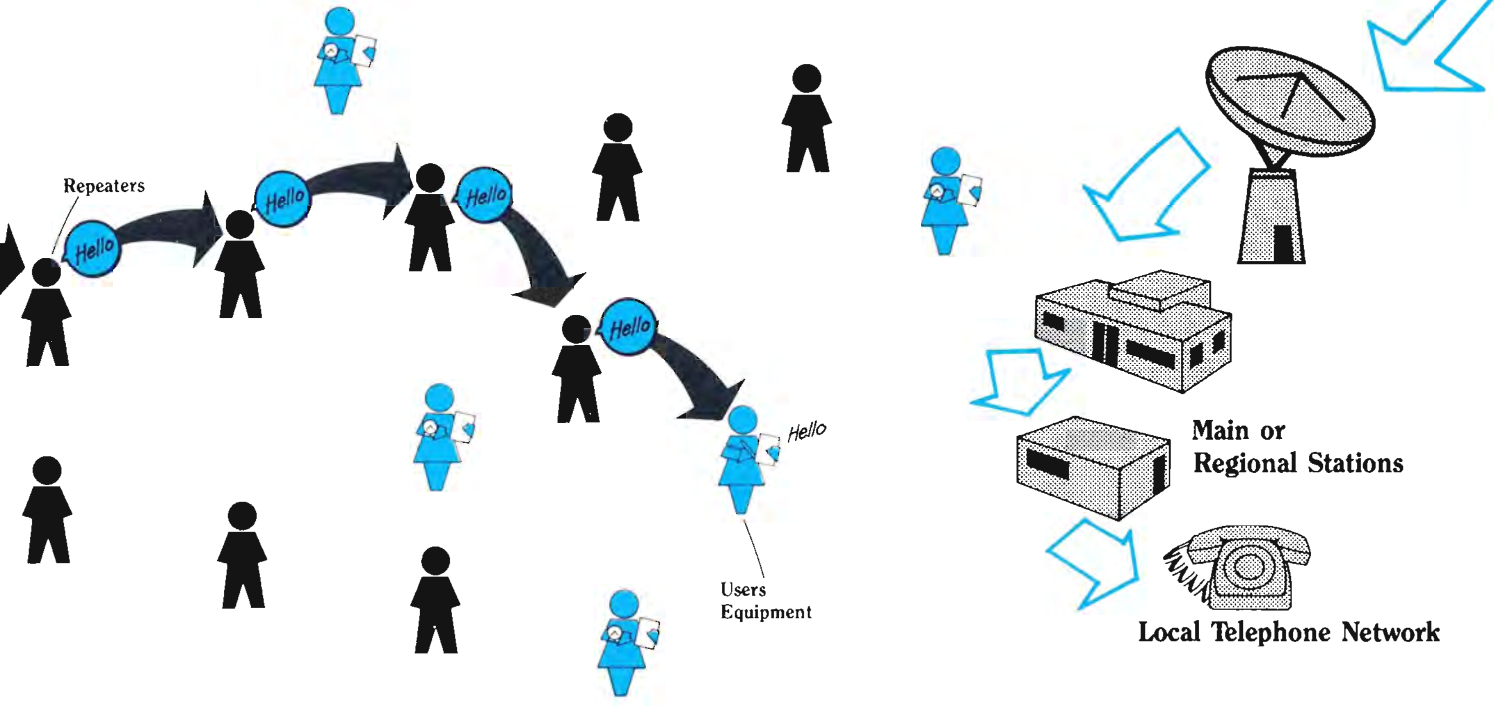
However, Telecom has developed a remarkable new concept over the last few years which is likely in the long run to have a far more important impact on remote area communications than the satellite. This is the Digital Radio Concentrator System (DRCS), and it will be entirely ground-based.

The great advantage of the DRCS for telecommunications in the remote areas we have been discussing is that it allows telecommunications channels to be extended to isolated users without degrading the quality of transmission, by means of a chain of relatively cheap radio repeaters which require little power and so can be solar-powered.

Such users can be located at distances up to 450 km away from the exchange unit associated with their system, and yet can be provided with high-quality STD telephony, telex, facsimile or data services. At this extreme range, a chain of nine repeaters or less would be needed to provide these services.

One great benefit of digital methods over analogue methods is that the information contained in a digital signal can be regenerated perfectly despite quite high levels of noise (any unwanted signal). In the particular example we are discussing, the Digital Radio Concentrator System, this means that signals can be passed down a long chain of repeaters to the exchange unit without being degraded by accumulated noise. Using analogue methods, noise would build up as each repeater passed on the signal, to the extent that, after only a couple of steps, the signal could begin to be swamped by noise. In practical terms, this would mean that a telephone conversation would be so full of hiss





Telecom's Plans and Developments in Long-Distance Telecommunications Transmission

and static that it would be impossible to hear. On the other hand, by using digital methods, noise is not allowed to build up, and the result is a high-quality service over very long distances.

The repeaters used in the DRCS are not at all the same as those we have talked about in microwave systems, which use large dishes to direct beams of microwaves. The DRCS repeaters are much more like conventional radio masts which might be used to broadcast signals to taxis or to police cars in the city. They are of modest power, and so broadcast signals within a circle of perhaps 30 km radius. Within this distance will be located the repeaters on either side in the chain, and probably a number of telecommunications users' stations. (See diagram 1.)

Each user's station has an antenna through which it transmits signals to the nearest repeater, and through which it receives signals from the repeater. The repeater picks up signals from the users within its area of coverage, as well as signals from the next repeater in the chain, and retransmits those signals on a slightly different frequency (so that there is no confusion between the signals it broadcasts and those of another repeater). And so the signals are passed up or down the chain.

You may be asking how the signals from various users are kept separated from each other as they are passed along. This is achieved by the use of time-division multiplexing. We have already discussed frequency-division multiplexing on Sheet 4, by which means different signals on the same bearer are kept separate by being transmitted at different frequencies. In time-division multiplexing, signals are kept separate by being transmitted (in digital form, as a series of numbers representing sound levels or other information) in different time slots.

In the DRCS, each interval of four milliseconds (a millisecond is one thousandth of a second) is divided into 16 time slots.

The first of these very brief intervals of time is allocated to control and synchronisation information. The other 15 intervals are allocated among the currently active users of the system. Together, these intervals plus the first time slot are called a "frame".

Let's see if we can make the operation of the DRCS simpler to understand by means of a model based on the more everyday world. Let's say that a class of schoolchildren have set out to create such a model on the school oval. The teacher will act as the exchange unit, some of the boys as repeater stations, and some of the girls as individual users. Each person taking part in the model has a watch which has been synchronised with all of the others. They have agreed that, in their model, each time slot will last exactly one minute (rather than the approximately one quarter of a millisecond in the real system!). Also, for the purpose of simplicity, they are ignoring the role of the control time slot.

Each of the girls acting as users is given a slip of paper indicating her time slot - a number between one and fifteen. The teacher has a series of messages he wishes to pass to the various users, which he will transmit one word at a time.

Let's say the time is 10.00am, and this has been agreed as the start of the first time frame. At 10.01, the teacher (acting as the exchange unit) reads out the first word fo his first message. All of the boys (acting as repeaters) who are within hearing distance of the teacher repeat the word loudly. In turn, boys within hearing distance of them pass on the word. Eventually, all of the girls on the oval can hear the nearest boy to them repeating the word that the teacher originally read out. However, only *one* of the girls pays any attention to the word - the girl who holds the slip of paper reading "1" (acting as the user who has been allocated time slot 1). She writes it down. At 10.02, the teacher reads out the first word of his second message. Only the girl holding the slip of paper marked "2" writes down the word after it has been repeated by the boys. And so it continues, until at 10.15am, the teacher reads the first word of the last message. At 10.16am, he reads the second word of the first message, and again this is recorded only by the girl allocated time slot 1. The process continues until all of the messages have been read out in full, and at the end, each girl holds a separate message. While the process is continuing, each girl knows that she only need pay attention at certain times, to the words being spoken by the boys. The girl holding the piece of paper marked "3", for example, knows she need only listen and write at 10.03, 10.18, 10.33, and so on, and she looks carefully at her watch waiting for these times.

In the same way, separate messages can be passed back to the teacher by each girl reading one word of her message only at the specified times for her, this word then being heard and passed on by the boy nearest to her, and so on down the line to the teacher. By keeping all watches synchronised, and allocating time slots uniquely to particular users, all of the information transmitted is kept separate.

This school oval model is lacking in a number of ways, of course, but it should give you at least some idea of how the DRCS operates. In the real situation, each time frame lasts only 4 milliseconds. Information is transmitted not as separate words, but as binary numbers representing the level of sound (or other information) at that moment. In the real DRCS, too, the distances over which the signals are transmitted are such that the finite speed of radio signals must be taken into account in maintaining synchronisation. The particular time slot allocated to a user is not permanently fixed, but a free slot is allocated each time a user picks up the telephone receiver, or is called by another user (whether connected to the DRCS or to the conventional network).

The concept of the DRCS was developed by Telecom engineers in 1978, but contracts were let to NEC, a Japanese company, for the development and building of the equiment to be used. Field tests of the system have been going on in Queensland, South Australia and the Northern Territory since November 1982.

There seems little doubt that the Digital Radio Concentrator System will have a profound impact on the availability and quality of telecommunications services for the remote and rural population of Australia over the next decade, and indeed, into the future. An Australian concept, it has attracted widespread interest from around the world, and many countries with similar problems to ours are likely to find an important use for the system.

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LINKING A NATION

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