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Phil. Trans. R. Soc. Lond. A 1978 **289**, 151-158
doi: 10.1098/rsta.1978.0053

Phil. Trans. R. Soc. Lond. A. **289**, 151–158 (1978) [151]
Printed in Great Britain

Submarine systems

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This paper reviews historical and future growth rates for submerged telephone systems and after consideration of the application of new facilities suggests that the future growth will be largely dependent on the demands for telephone circuits. Future systems to meet the growth rates are considered and are compared on their capability of handling largely telephone traffic and other cost effectiveness. It is concluded that analogue systems on coaxial cables will continue to meet demands until cost effective optical fibre systems become practical and sufficiently reliable.

1. Introduction

Submarine systems present designers with a major problem: how to avoid faults in service. By their very nature – largely installed several miles beneath the sea – such systems are difficult and expensive to repair and are therefore designed for a long trouble free life. Since large numbers of effectively series components are used in their construction the reliability requirements on these components are of necessity very severe, and from their inception submerged systems have become perhaps best known for these aspects and have earned reputations for high reliability and high quality transmission performance. However, the question of design for high reliability on submerged systems has been covered extensively elsewhere and will not form part of the present considerations which will concentrate on the traffic requirements and methods of achieving them.

2. Historic and future growth rates

Historically, submerged telephone systems have experienced a rapid growth rate and this is shown in figure 1, where the cumulative circuits installed are shown for the period 1955–75. The growth is typical of that common to all good communication media where, almost axiomatically, good media lead to high usage and thence to large growth rates. The traffic carried by the installed capacity has, throughout the period, been predominantly telephone traffic although, due to the often major differences in local time and language at the two ends of a system, the use of telex as a percentage of the total circuit usage generally exceeds that on inland networks. In looking forward and attempting to extrapolate to the needs of the future it is necessary to rely very heavily on the economic and general growth factors throughout the world. At this time, a reduction in growth rates has occurred or is occurring due to the general economic situation but continuation of the historical pattern into the 1980s, on an average basis, is very likely and there are no major predictions which do not indicate growth in international telephone and telex traffic at the same rates as hitherto. For the next decade an average growth rate of 16 % per annum is believed likely and there is no reason, other than a major catastrophe, that this should not continue until the end of the century. The additional question to be asked is whether or not the demand for submerged telephone systems will be decreased by an increased use of satellite communication or very much increased by the use of the international network for facilities other than those currently provided.

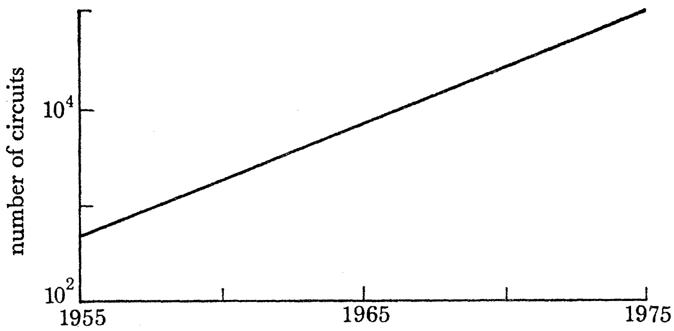

FIGURE 1. Historical survey of submarine systems circuit growth.

On the first point, Merriman's (1976) address to the Institution of Electrical Engineers foresaw that the extrapolation of present growth rates could suggest that, for space communication, the currently available allocations on the 4 and 6 GHz bands, together with the foreseeable demands for orbital positions in the operationally desirable mid Atlantic and mid Pacific oceans, would approach exhaustion in the mid 1980s. In addition, he noted that the further growth of space communication would depend upon the extent to which firm regulatory processes could be internationally determined and the extent to which new frequency allocations in unused segments of the spectrum could be scientifically proven, commercially exploited, and regulated. For these and other reasons Merriman expressed the view that future development in complementary high capacity undersea cable systems must be exploited to meet demands. Certainly, submerged systems have continued to be in demand in parallel with satellite systems, and the total demand, together with the increasing desire for diversity of links on the high density routes, will lead to a natural mixture of space and sea communication links with a continuing high requirement for submerged system capacity.

3. Increased requirements for new facilities

In considering the impact that new facilities may have on the demand for circuits, there are many facilities which are feasible in a technical sense and most of these have been demonstrated as practicable. These have been the subject of many addresses and papers on the future of communication within the community and are shown in figure 2. The variety is large and the assumption is often made that by the wide application of such facilities the growth of traffic on international routes will markedly increase. Certainly, if the facilities can be provided economically, a growth in their use will occur and with such a growth a need will arise to increase the circuit capacity and sophistication of the subscriber networks. However, even taking an optimistic view, the impact on the total international circuit demand will not necessarily be large.

Among the facilities listed the big users of bandwidth are viewphone, confravision, and home newspapers; the remainder will have little impact in terms of total demand on the circuit capacity of trunk or international networks. Home newspapers can be ignored in terms of international links and confravision and viewphone remain. Some need for these facilities on international links may occur but in the period considered this is not expected to be extensive due to the high costs involved. If television, another major user of bandwidth, is to be required this is only likely within a national framework, for example between the Spanish mainland and the Canaries, on a regular basis and the impact of such needs relative to total demands is not expected to be significant.

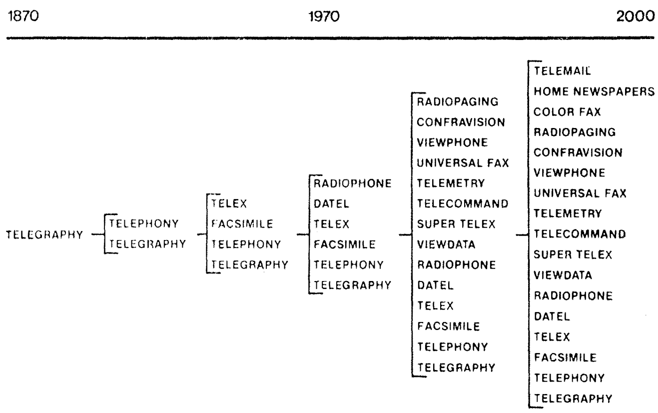

FIGURE 2. Development of telecommunications facilities 1870–2000.

To summarize, the future demand to which submerged systems will need to respond is expected to arise from a growth rate of 16% per annum on traffic which will essentially be telephonic in character.

4. PRESENT SYSTEM TECHNOLOGY AND POSSIBLE FUTURE TECHNOLOGIES

To date the demand has been met by systems which have used analogue, frequency division multiplex, techniques on coaxial cables in which amplifiers or repeaters have been inserted at regular intervals. With the exception of the first of the major submerged systems, Tat-1 and Tat-2, all systems have employed a single coaxial cable to take both directions of transmission. The repeaters of the systems have been powered by a direct current fed down the centre conductor of the coaxial cable from one end of the system to the other. Because the cost of a circuit on such a system decreases as the capacity of the system increases, the bandwidth of systems supplied has increased with demand and the individual circuit costs have reduced. This is shown in figures 3 and 4. Such cost trends have also been found on land line links employing similar techniques and in telecommunications generally individual circuit costs have benefited when the scale of the operation has increased.

In considering the future provision of submerged links they must be judged against the costs of the past and their capability of carrying largely telephone traffic. Essentially, for the future there are several options either currently available or likely to be so before the end of the century. They are:

(*a*) analogue transmission on coaxial cable;
(*b*) digital transmission on coaxial cable;
(*c*) waveguide transmission;
(*d*) optical fibre transmission.

All are electrically feasible. It is unlikely, because of the environment and the practical difficulties of emplacement, that submerged waveguide transmission will occur but the remaining three are mechanically feasible and will be considered further.

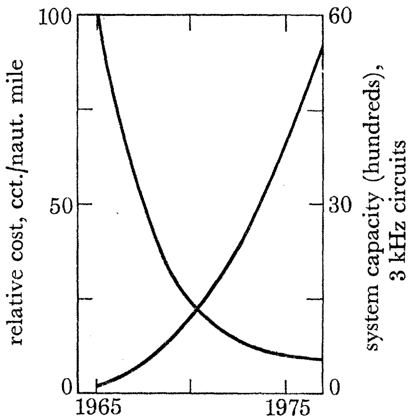

FIGURE 3. Relative cost of submarine systems with time (1 nautical mile ≈ 1.85 km).

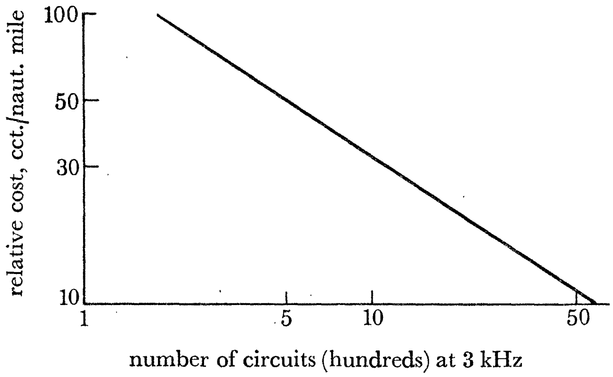

FIGURE 4. Relation between submarine system costs and capacity.

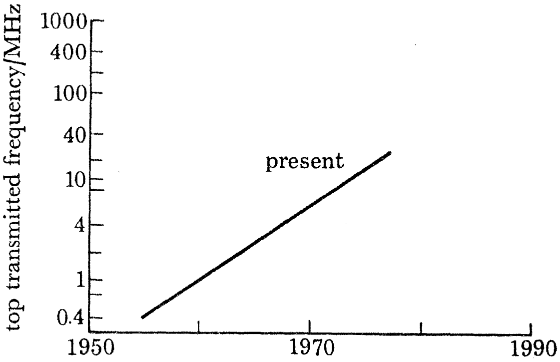

FIGURE 5. System bandwidth plotted against year of introduction.

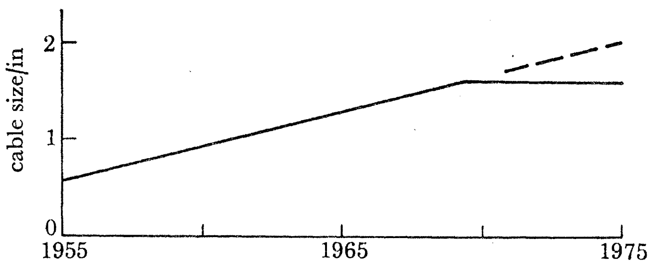

FIGURE 6. Historical survey of submarine systems cable size.

5. Future use of analogue transmission

The point has been reached where circuit capacities of some 5500 extending to a total bandwidth of 45 MHz have been achieved, as shown in figure 5, and these capacities have been paralleled by a growth in coaxial cable diameter as shown in figure 6. The bandwidths of repeaters can certainly be increased over present values and are likely to be of the order of 150–200 MHz for the next generation of systems. It is not so likely that cable diameters will increase greatly over present sizes. This is not due inherently to manufacturing or design difficulties, although the single pass extrusion of large volumes of dielectric is not easy, but rather due to the physical difficulties of handling and laying large diameter cables. A maximum diameter for the outer of the coaxial cable of 2.5 in (6.3 mm) is probable.

With an increase of bandwidth to some 3 or 4 times that of present system values, and very little change in cable diameter, the number of repeaters on a given route will increase. This in turn will lead to an increase in system supply voltage and an increased hazard to the system due to the current surges which will be generated if the cable is accidentally cut. To reduce this hazard repeater designers will be trying to achieve low supply voltages for the repeater amplifiers. Voltages as low as 5 V would be desirable and this in turn will be reflected in the demands placed on transistor designers who will need to produce low voltage, very linear, devices with high power ratings and high reliability.

Efforts will continue to be applied to reduce cable dielectric losses but it is unlikely that for the next generation of analogue systems fundamentally new dielectrics will replace the well established polyethylene. For the larger links, methods of gain control from the shore terminals will become the rule rather than the exception to ease the difficulties of long term system stability caused by large repeater numbers. Increases in repeater numbers will also increase reliability requirements in individual repeaters, and circuits offering the possibility of redundancy, and hence reliability improvement, will receive more attention than previously.

The next step in bandwidth increase, to the 150 MHz region, is feasible using negative feedback amplifiers but circuit realization will be difficult due to the physical lengths of the circuits. This inherent difficulty, and the desire to improve reliability by redundancy techniques could well lead to the application of feedforward circuits in which transistor and circuit specifications in terms of bandwidths are considerably eased and redundancy can be made a feature.

To date, repeater bandwidths up to 36 MHz have been achieved by using a single amplifier to provide gain in both directions of transmission. However, in the future it is more likely that the design problem will be eased by the application of one amplifier to each direction of transmission.

Extension of analogue transmission over a single coaxial cable is very probable up to 150 MHz. The next step to 500 MHz or beyond will almost certainly require feedforward techniques and a reduction in cable attenuation by the use of new materials.

Extension of system bandwidth beyond current values in a reliable manner is not going to be easily achieved. For this reason it is right to consider the likelihood that costs per circuit will continue to decrease. On this matter there are no hard guidelines but in all fields the cost of circuit implementation is being constantly reduced by fuller scale integration and it is difficult to conceive that the cost of provision of the circuitry will cause large perturbations in the current cost curve. However, as noted earlier, cable diameters are not expected to show major increases, and there may well be a reduction in the slope of the cost curve due to this cause. Circuit cost reductions for bandwidths up to 150 MHz should be achievable; beyond this there is a strong possibility that further cost reductions will be small or even impossible. If circuit capacity increase is not associated with circuit cost reduction it will of course mean that system capacity increase by the use of analogue systems will not occur in practice because operators do not want larger capacity systems except as a means of circuit cost reductions.

If system capacity increase is achieved economically, analogue transmission may well be preferred to the end of the century since the needs for systems of 150 MHz are not envisaged to be large before the mid-1980s and those for 450–500 MHz before the mid-1990s.

6. Digital transmission on coaxial cable

On land-line, systems with transmission rates of 140 Mbit/s have reached the stage of field trial and capacities of 4–5 times this bit rate are in development and are certainly feasible. For land line applications such systems on inland trunk routes in the U.K. may make sense for several reasons:

(*a*) digital traffic needs are readily met;

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(*b*) integration of the switching and transmission networks becomes feasible;

(*c*) the costs of signalling are reduced.

However, for a major submerged international route, digital needs may not be large, the state of development in the two terminal countries may not be common or to a common standard, and advantages under (*b*) and (*c*) may not arise. Hence it can be argued that for intercontinental links the cost per circuit for the link alone will remain the ultimate criterion of comparison and it is on this basis that the use of any technology will be judged. In making such a judgement for a digital system on coaxial cable it is assumed that transmission would be undertaken on two cables, one for each direction of transmission. Such an assumption is in line with land-line experience.

Table 1. Possible digital systems on coaxial cable

transmission rate/(Mbit/s)	optimum cable diameter		repeater spacing		telephone channels
	in	cm	naut. mile	km	
20	0.78	1.98	9.7	18.0	280
50	1.00	2.54	7.3	13.5	700
120	1.28	3.25	5.7	10.6	1680
200	1.47	3.73	4.7	8.7	2800
360	1.70	4.32	3.8	7.0	5040
480	1.88	4.78	3.45	6.4	6720

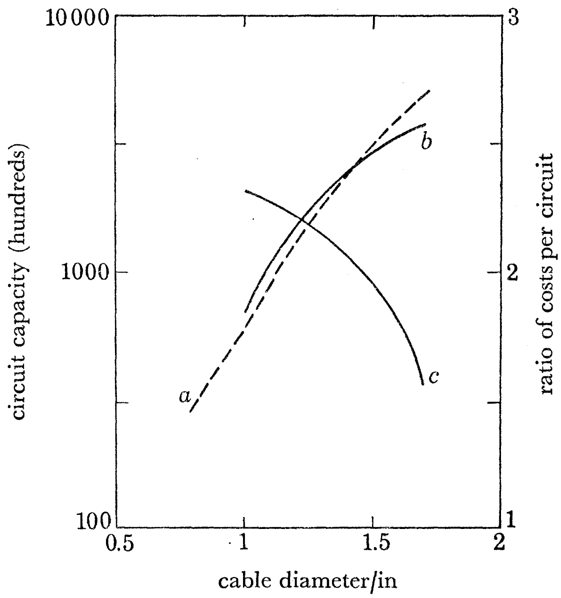

Figure 7. Relative costs of digital and analogue systems: *a*, calculated digital capacities; *b*, extrapolated analogue capacity; *c*, ratio of costs.

For such a system, assuming a 3 level code and no application of a technique for sharing an audio channel between more than one user, table 1 has been derived to show the spacing of repeaters on cables of different diameters. In each case the system capacity has been chosen to optimize costs for the transmission rates assumed. For comparison with analogue methods of transmission it is convenient to consider three particular cable diameters, namely 1.0 in (2.54 cm), 1.47 in (3.73 cm) and 1.7 in (4.32 cm), since these have been used for actual analogue type submerged systems and can give a firm base for achievements in the case of analogue transmission. With these particular cable diameters, an analogue system using a single cable for both directions of transmission can achieve the circuit capacities shown in figure 7 if the repeater spacing for each of the cables is chosen to be equal to that of the digital system on each of the cable sizes. If now it is assumed that repeater costs are similar for the two methods of transmission then relative costs can be readily found for one telephone circuit at the various system capacities, and these are also shown in figure 7.

The cost advantage of the analogue systems over the digital ones is marked but does decrease as capacity increases. By the method chosen for comparison, the analogue system capacities may not give rise to optimum circuit costs on a given cable as is the case for the digital systems, and this may distort the cost comparisons to some degree, but this distortion favours the digital systems. Since differences decrease as system capacities increase it could be argued that digital systems will eventually be preferable. However, to achieve cost parity on the assumptions made would require digital systems in the gigabit/second range and repeaters for such transmission rates may be difficult to achieve and suffer similar limitations due to frequency range as those anticipated for high frequency analogue systems. For systems of capacities of 10000–15000 circuits, which will be required in the mid-1980s, analogue transmission will continue to be economic relative to digital communication on similar cables as indicated in figure 7.

It should be remembered that the fundamental assumption made is that traffic in the future will remain largely telephonic. If this is not so the comparisons above could well be very erroneous. Analogue systems are ideally suited to telephone needs but are inefficient for digital transmission and with heavy digital traffic the conclusions could well be reversed.

7. Transmission on optical fibres

Such systems are currently at the stage of field demonstration with transmission rates of 140 Mbit/s over a single optical fibre. For applications to a submerged system it will be assumed that a number of optical fibres could be extruded within the dielectric of a conventional lightweight submarine cable. The diameter of the cable will be taken as 1.0 in (2.54 cm) although as will be seen later this is not significant. Such a cable would enable power to be transmitted to repeaters via the conventional centre conductor and provided that the entry of such a cable into a pressure resisting housing can be achieved, a submerged system is possible. Within the pressure housing would be fitted the regenerative repeaters for each of the optical fibres in the cable. It is obvious that, unlike transmission over a coaxial cable, such a system would not be limited by cable diameter since the capacity of the cable can be readily increased by adding further optical fibres. It will be assumed that there is no practical limit to this increase in capacity in what follows.

For optical fibre transmission cost comparisons with analogue transmission will be made. To do so, further assumptions about the capability of optical fibres are necessary. For the moment monomode fibres will not be considered and a transmission rate of 140 Mbit/s per fibre will be assumed. The loss in such fibres is under constant change but a figure of 4 dB/km will be taken. With such a loss a repeater spacing of 6.5 nautical miles (about every 12 km) is judged achievable. Smaller fibre losses may not yield larger spacings since mode dispersion is also a limitation on repeater spacing. Taking for the moment a cable with only 2 fibres embedded in the dielectric the number of telephone circuits that could be carried is 1920, assuming some 64 kbit/s are needed for a telephone channel. For the same repeater spacing and the same diameter coaxial cable an analogue system would be capable of carrying 900 circuits. This results in a cost advantage in favour of the optical fibre system when circuit costs are compared and this is shown in figure 8 at the capacity of 1920 circuits. Larger capacity systems are also shown in figure 8 and these have been costed in the case of optical fibre systems on the assumption that system capacity has been increased by the addition of further pairs of optical fibres and their corresponding regenerative amplifiers. As analogue capacity increases it has been assumed that circuit costs decrease at the rate shown in figure 4.

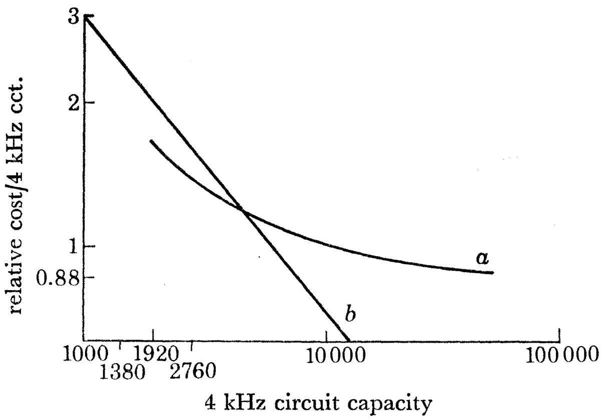

FIGURE 8. Relative costs of optical (*a*) and analogue (*b*) on coaxial.

It will be seen that as capacities increase the individual circuit costs eventually favour the analogue systems. This is because the optical fibre systems considered achieve the higher bandwidths by the addition of fibres and regenerative amplifiers and this gives rise to an asymptotic minimum cost per channel when the cost of the cable in which the glass fibres are embedded becomes negligible and the repeater housings are insignificant.For this reason, although it is likely that optical fibre systems will be used on submerged systems, they may well need to achieve capacities considerably greater than the 140 Mbit/s per fibre considered here to be cost effective relative to analogue systems on coaxial cable.

8. CONCLUSIONS

If future submerged systems continue to carry largely telephonic traffic, as assumed in this paper, then analogue transmission on coaxial cables will be the preferred system solution for minimum costs per circuit for the next generation of systems which will carry between 10000 and 15000 circuits. Beyond such capacities optical fibre systems may come into contention but to do so the capacity achieved on a single pair of fibres may need to be considerably larger than the 140 Mbit/s taken in this paper.

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