Radiating cables

by **R. Johannessen,** B.Sc., M.I.E.E., Standard Telecommunication Laboratories Ltd

During the past ten years radiating cables have found increased use in a number of applications. Many aspects of their performance can be specified simply, once they have been derived either empirically or from theory. For the communications engineer with a problem either of coverage or of frequency spectrum conservation, the article sets out where radiating cables may be useful and the aspects to which he needs to pay particular attention.

IN MOST MOBILE RADIO applications the base station aerial and the base station electronics are physically separated, so that the best possible coverage from the aerial is combined with easy access to the transceiver equipment. The link between the two is generally a coaxial cable, such as the UR67 and it is usually assumed that all energy transmitted from the base station goes to the transmitting aerial, no energy being transmitted from the coaxial cable. It is also assumed that the energy received by the base station has been picked up by the aerial, not by the coaxial cable itself. These assumptions are sufficiently valid where the mobile is some distance away from the cable, but are unacceptable if the propagation path between mobile and base station aerial is obstructed. If the obstruction is considerable and the mobile is only a few metres away from the cable, then the coupling between the mobile and cable could exceed the coupling between the aerials. In a radiating cable* system the cable is designed to couple with the surroundings and there are at least three ways in which this may be achieved: the outer conductor is made as a solid continuous sheet, but with a part missing in the form of a long slot, the edges of which run parallel to the cable axis; the outer conductor is constructed as a braid, woven loosely; or the outer conductor is constructed as a long sheet covering the entire cable circumference but with a series of holes or slots punched in the sheet.

Path loss components

In designing a communication system in which the base station aerial has been replaced by a radiating cable, the path loss between base and mobile can be conveniently split up into three components.

Coupling. This is the difference in dB between the power entering the radiating cable and the power picked up by a tuned dipole located some 2 to 5 metres from the cable's axis and close to the transmitter end. Due to the variations in the received power (see 'standing waves' below) the coupling tends to be the mean difference as the dipole is moved about in the region of the location indicated. Different sources quote coupling at different ranges, hence the 2-5 metres bracket. Cree and Giles tested eight different cables and give the measured coupling[1] in the region 50-110dB, depending upon cable type, carrier frequency and mounting method. The cable manufacturer will usually specify the coupling for his own cable, though care should be taken in interpreting the conditions under which that coupling is valid. In general, as the frequency is increased the coupling loosens, giving a weaker received signal. The results of Cree and Giles indicate a change of 6dB per octave over the range 42MHz-460MHz. Similar tests at STL over the range 69MHz-156MHz have given 4.8dB per octave, and tests on one particular cable at low and medium frequencies gave a relationship suggesting 3.5dB per frequency octave in the region 155kHz-790kHz with a very good fit to this curve, as shown in Fig. 1. Harms *et al*[2] studied the effect on cable coupling as the method of cable mounting is altered. Based on two different cable types (one with five small slots per inch of cable, and the other a 64° slot running along the cable axis) the path loss relative to a cable suspended one metre above ground was found to increase by the following amounts:

cable laid on grass	4dB
cable laid on concrete	6dB
cable located in stone drain	7dB
cable buried in soil inside a 3-inch plastic pipe	14dB
cable buried in soil with protecting pipe (moisture dependent)	13-22dB

Tests have shown that as the degree of moisture in the ground increases, the coupling loss drops. A number of tests have been carried out to establish the rate at which the coupling loss increases as the radial range is increased. Typical values for v.h.f. are 5dB/distance doubling for ranges 3 metres to 15 metres, increasing to some 10dB/distance doubling for 60 to 100 metres. At l.f./m.f. the rate of decay is greater, typical values being 8.5dB/distance doubling around 5 metres, increasing to 20.2dB/distance doubling around 10 metres. In all cases there is a fair spread between configurations, as shown in Fig. 2, the curves being based on some 63 v.h.f. combinations of cable type, mounting method, range and frequency.

Insertion loss. The definition and characteristics are as for standard coaxial cables. For radiating cables there is a wide choice, with typical values from 20 to 50dB/km at 100MHz. In general, the loss increases as the diameter is reduced, and cost is reduced. The loss increases with frequency at a rate which is similar to typical conventional cables such as the UR67. With some radiating cables the loss increases significantly when the cable is laid directly on a conducting or lossy surface such as concrete or iron. This is particularly so with some of the cables where the outer conductor is removed for more than 1/3 of the surface.

Standing waves. If the path loss is measured between a radiating cable and a mobile aerial which is moving in a direction parallel to the cable axis, a number of variations will be observed. Neighbouring path loss maxima are separated by a distance which is generally just under the free-space wavelength and the difference between such a maximum and the next minimum may be of the order of 30dB. The loss maxima are, however, very narrow and a small movement of the aerial will reduce the loss substantially. These standing waves are repeatable and can be found in different degrees with any frequency and on many sites. The author has studied many different cables but has never found a cable which is completely without them, although Yoshida suggests[3] that with a particular cable design this phenomenon may be removed. It is the presence of the standing waves which makes it imperative to average the coupling over some distance, as suggested above.

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*sometimes called "leaky feeders".

Modulation effects

The deep minima of signal level will give rise to an amplitude modulation which can be very noticeable in a moving a.m. receiver. It is sometimes assumed that this modulation effect can be completely bypassed by using f.m. transceivers and operating the receiver in the limiting condition. Recent work at STL has investigated the r.f. phase variation experienced by a receiver moving parallel to a cable energized at 105MHz. Figure 4 shows the result of some of this work, indicating large excursions from a linear phase relationship the average deviation being around 115°/metre. With a receiver moving at a speed of 150km/hour, this yields a modulation with a deviation of 0.013kHz. If the transceivers operate with a maximum deviation of ±2.5kHz this small f.m. noise still imposes an upper bound on the achievable s/n ratio. It is an improvement on the a.m. case, but may nevertheless prove unacceptable for some tone signalling applications where the broadening of the tone spectrum might introduce errors.

Applications

Propagation conditions in many tunnels are such that reliable v.h.f. or u.h.f. propagation is difficult to achieve with conventional base station dipoles or Yagi arrays. A much better result can be expected with a properly designed radiating cable system connected to the base station transceiver and laid along the tunnel wall or roof. Such systems have been successfully designed in many cities. Breitenbach[4] refers to the use of cables for the S-Bahn in Munich and for the U-Bahn at Hanover. Martin and Webster[5] describe work done for coal mines in Britain, and Yoshiyasu *et al*[6] describe test results from railways in Japan using radiating cables. Above ground a number of other applications exist. Harms and Martin[7] show that the UK Transport and Road Research Laboratory have been considering the feasibility of using radiating cables as a means of achieving a well-controlled radiation field for transmitting information from the roadside to drivers.

Johannessen and Blair[8] show how cables installed in a building can achieve a good coverage inside the building with minimum frequency spectrum occupancy. In this building a freely radiating antenna was considered as an alternative, but it was found that a conventional aerial located on the roof and giving the same coverage inside the building would pollute the spectrum well outside the required geographical coverage area, by an amount which was in the region of 50-70dB stronger than in the radiating cable case. Deane has shown[9] the remarkable feature of radiating cables, which is the rapid decay in signal beyond the cable end — one of the reasons for using the cables where pollution must be minimized. The cases quoted above substantiate the argument that a radiating cable can be used to advantage where it is known that the movements of the mobiles enable the cable always to be positioned within some 20-100 metres of them.

Power loss calculation

By way of an example of the kind of calculation necessary for an installation, consider a building with two floors and a ground floor layout as shown in Fig. 3. It is proposed to use a radiating cable with coupling at 3m of 80dB and insertion loss 50dB/km at 450MHz. The receiver is assumed to need —132dBW from an aerial which has a loss of 8dB relative to a dipole. Reasonable coverage should be achieved by locating the base station in the security area and locating a radiating cable in the ceiling of the ground floor with one arm towards each of the extremes of the building. In the factory area the cable is looped to overcome the extensive shadowing likely to exist with large machinery and extra shelving. Maximum distance from the cable becomes 25 metres, giving a coupling of around 100dB. Maximum cable length will be 150 metres, with an insertion loss of 0.15 × 50 = 8dB. From Fig. 1 of reference 8 is obtained a one-sigma variation of 6dB which must be increased to 12dB to give 95% probability of coverage. This factor is realistic, since extensive tests indicated that the distribution approximates closely to a normal distribution at least up to the 95% values. Allowing for a 3dB loss where the transmitter power is split into the two cable paths, we get a transmitter requirement of —132dBW + 8 + 80 + 6 + 6 + 8 + 8 + 12 + 3 = —1dBW, which is well within what a standard base station transmitter provides. A 10 watt transmission provides some margin for internal obstructions.

Measurement

Before measuring the performance of a radiating cable it is important to ensure that the transmitter connected to the cable is properly screened, so that the path between the transmitter and receiver is not bypassed. If it is bypassed, then the results will not allow extrapolation to other site conditions. It may be found convenient to derive the statistically best fitting straight line to a plot of received signal level against distance from the transmitting end of the cable, since the intercept of this line conveniently yields the coupling, and the slope approximates to the insertion loss. The paper in reference 2 indicates the weakness of this approach and outlines a more accurate method, using the probability distribution, which also includes an allowance for the standing waves.

Installation

Some cable manufacturers provide special connectors, since the cable dimension is likely to be different from standard coaxial cables. Where connectors are not available, small diecast

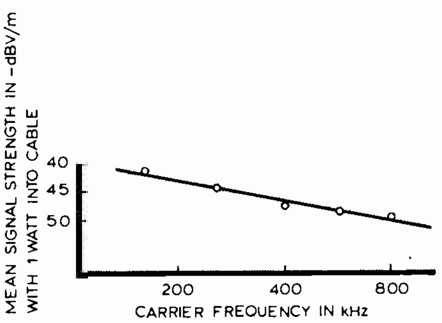

Fig. 1. Variation of coupling with frequency in the l.f./m.f. region.

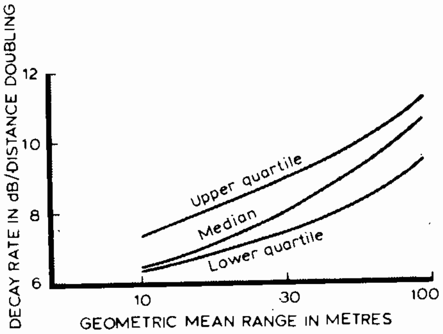

Fig. 2. Changes in decay rate as the mean radial distance is increased.

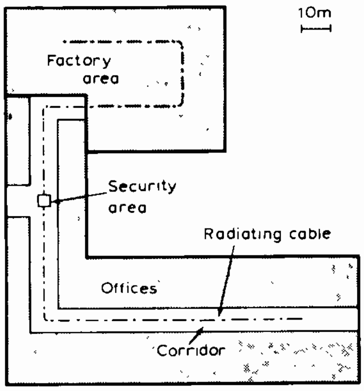

Fig. 3. Example of layout of radiating cable in a building with mixed contents.

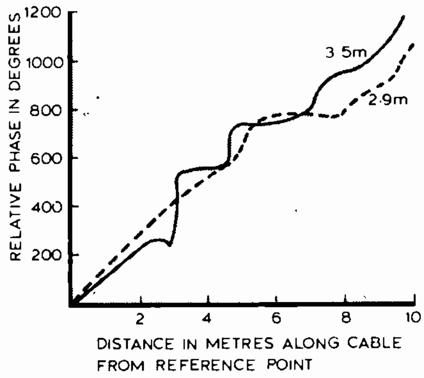

Fig. 4. Phase variation along a radiating cable.

boxes have been used. The end of the cable away from the base station may be terminated in a resistor to keep down standing waves on the cable itself. In some cases it is useful to connect the end of the cable to an aerial via a suitable attenuator if, for instance, a small yard or area outside the building is to be included in the coverage area. Many buildings will have an artificial ceiling to hide service ducts for feed cables to electric lights and gas pipes, heating pipes, etc., which can often be used for the radiating cables. If, after installation, it is found that a part of the building has too low a field strength, it will often be sufficient to break the radiating cable at the nearest point, form a T-junction and lay another arm of the cable into the area with the weak signal. A simple form of T is a hybrid, made up of standard cable with the same Z_0 as the radiating cable and three arms at 0.15 and one at 0.65 times the cable wavelength.

Cable costs

Cable cost is highly dependent on insertion loss, and from some cable manufacturers the radiating cable sells at about the same price as a coaxial feed cable of similar insertion loss. 1978 prices quoted for cables with a loss in the bracket 20—40dB/km at 100MHz are generally in the range £500-£2500 for one kilometre length.

The author

Mr Johannessen graduated from the University of St Andrews in 1962. For three years he worked with the Radio Division of Standard Telephones and Cables developing navigational aids for aviation. This was followed by a period at ICL, where he was particularly concerned with the efficient interfacing between computers and their peripherals. From 1969 he has been with Standard Telecommunication Laboratories where he is a principal research engineer. Recent responsibilities have included the study of more efficient use of communication and navigation systems, the development of low cost navigational aids and the evaluation of radiating cables for applications where spectrum conservation is of particular importance.

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