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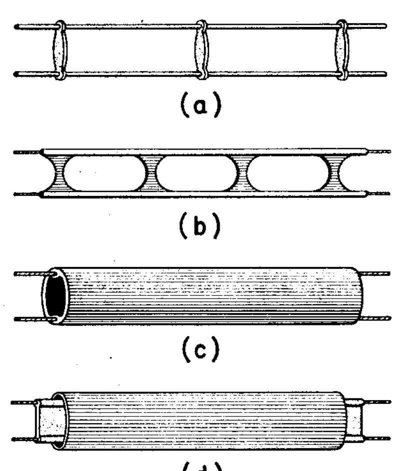
New Trends in Transmission Lines

By the Engineering Department, Aerovox Corporation

THE engineering problem of transferring radio frequency power from one point to another by metallic conductors assumes more fromidable proportions as the frequency involved increases. In the portions of the frequency spectrum which are presently being exploited for UHF television, radio relay, radar, and amateur communications, the transmission lines commonly employed at low frequencies are no longer practical. Open wire lines radiate excessively, with attendant high losses. Flexable solid dielectric coaxial lines may also prove excessively lossey, while solid conductor coaxial and waveguide lines are too expensive for many applications. For these reason, much research effort is being expended in developing efficient and economical substitutes for such transmission lines. This paper discusses some of the innovations which have resulted from this effort.

The conventional 300 ohm "twinlead" employed as a standard in television practice has never been entirely satisfactory, even for VHF low band use in certain conditions. During wet weather, excessive attenuation results from the formation of a moisture film on the web between the conductors. In coastal regions, where there is a high salt content in the fogs during storms, entire areas have undergone television "black outs" for several days at a time due to the condensation of salt fog on the transmission lines. At such times, television service agencies are swamped with calls from customers demanding that their sets be fixed.



VARIOUS IMPROVED TWO-WIRE TRANSMISSION LINES
FIG. 1

Improved Twinleads

Several expedients have been adopted to alleviate the "fog-out" problem and other shortcomings of standard twinlead. Considerable improvement over the solid polyethylene web line has been achieved by resorting to the use of high quality open-wire line in which the conductors are molded into spaced dielectric spreaders, as in Fig. 1a. High impedance line of the type long used in amateur practice (400-600 ohms), has only about one-tenth the loss of twinlead in the low-VHF channels. It is somewhat more difficult to handle, however.

The same end has been attained by removing most of the dielectric web material between the conductors of conventional twinlead, leaving only a narrow spacer at intervals to maintain proper spacing, as in Fig. 1b. The approaches of Fig. 1a and 1b both minimize the leakage losses by removing as much of the leakage path between the conductors as possible. Of course, the spacing between the wires must be increased somewhat to maintain the same characteristic impedance when the continuous dielectric web is removed. This probably increases the losses due to radiation somewhat.

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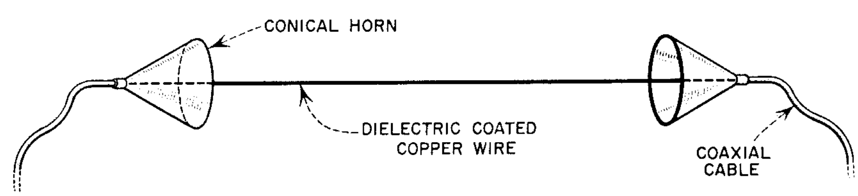
Another approach to loss minimization in two wire line is illustrated in Fig. 1c. Here the two wire conductors are molded into diametrically opposite walls of a hollow polyethylene tube. Losses due to the precipitation of moisture on the line are reduced because the length of the leakage path is increased considerably. Dielectric losses, too, are lessened because the dielectric is now out of the high field region directly between the conductors.

Still another special form of twinlead, similar to Fig. 1c in principle, is that shown in Fig. 1d. In this variety, the condensation of moisture on the web between the conductors is avoided by covering the twinlead with a plastic moisture sheath. The twinlead may be of a solid web variety or may have part of the web removed, as in Fig. 1b.

Although the special open wire lines illustrated in Fig. 1 exhibit vastly improved performance for VHF television applications, they leave much to be desired at frequencies above 300 megacycles. Even solid dielectric coaxial cables, such as the popular RG-8/U, become excessively lossey at UHF television frequencies and almost out of the question for microwave use, except for short lengths. Its losses are about 6db per hundred feet at the low end of the UHF television band and rises to 8db at the high end (890 mc.). At 3000 mc this figure rises to almost 16db, which means that only *one-fourtieth* of the power entering one end of a hundred foot length reaches the other end. Such losses are prohibitive for most usage.

The "G-String" Line

A new type of transmission system which may prove extremely useful in some applications has been pioneered by scientists of the U. S. Army Signal Corps and dubbed the "G-String", or, more aptly, a *surface wave* transmission line. (Ref. 1) The elements of this system are shown in



ESSENTIALS OF SURFACE-WAVE TRANSMISSION LINE
FIG. 2

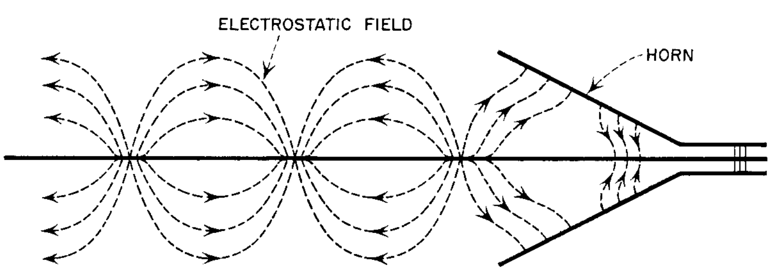
Fig. 2. The conductor is an ordinary single copper wire covered with a thin coating of a dielectric material. The special surface wave is launched on this wire by means of a conical horn, which is fed by coaxial cable. The arrangement is identical at the receiving end; a similar horn transforms the surface wave back into coaxial cable. A transmission line of this kind is capable of transmitting microwave energy with substantially less loss than the best solid dielectric coaxial cable. For example, at 1000 mc the attenuation of a good surface wave transmission system is less than 2db per hundred feet, while RG-8/U approaches 9db for the same length.

The low losses of the "G-String" transmission line is attributed to the special configuration of the electromagnetic wave launched on the single wire. Fig. 3 illustrates the assumed distribution of the surface wave on the wire. The electric field lines start on the wire and end on it, while the magnetic field lines are concentric circles around it. This wave is prevented from radiating freely, as in a long wire antenna, by the dielectric film on the wire. This film serves to reduce the *phase velocity* of the wave and thus, to concentrate the fields of the wave closer to the wire. The reduction of the radiation is proportional to the thickness of the dielectric, but beyond a certain optimum thickness, the losses in the dielectric become as serious as the radiation losses. Therefore, for lowest losses, the dielectric coating is usually made only thick enough to reduce the phase velocity of the wave on the wire only a few percent below the velocity of light (c), which is the speed at which the wave would travel on a bare wire. For this small reduction the thickness of the coating is only a few thousandths of an inch. Actually, ordinary No. 12 enamelled copper wire was used in some of the early experiments with this means of transmission.

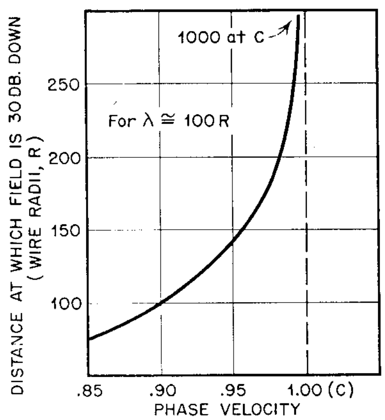
The manner in which the field is concentrated by control of the phase velocity is shown in Fig. 4. This shows the distance from the wire at which the field strength has fallen to 1/1000th of that at the surface of the wire, as a function of the phase velocity, for a system in which the wavelength is 100 times the radius of the wire. Note that for a velocity reduction of only 1% the field extends only about 250 times the wire radius (or about 2.5 wavelengths) from the wire, whereas at the velocity of light the wave extends four times that distance, and would radiate considerably more.

To launch a surface wave mode with good efficiency and intercept most of the energy in it at the far end, the horns should be at least as large in diameter as the extent of the fields indicated in Fig. 4. Thus, for a phase velocity of .90 (90% that of light), the horns should be about 2 wavelengths in diameter, 2.8 wavelengths for 95% of c, and 5 wavelengths for 99% of c. The space around the transmission line should be essentially free of reflecting obstacles within this same diameter. The supports for the line should be as nearly reflectionless as possible. In addition, bends and sharp corners must be avoided, since the "G-String" is essentially a straight line transmission device. Corners can be negotiated by transposing back into coaxial line at the bend and then out again, using another pair of horns.

Inasmuch as the diameter of the launching horns assume impractical dimensions for most VHF television applications, little use for the surface wave transmission line is envisioned for this frequency range. However, in some special community television installations, where a signal from a

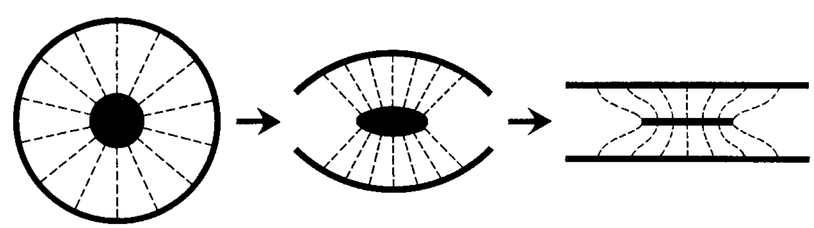


DISTRIBUTION OF SURFACE-WAVE ON WIRE
FIG. 3



DEPENDENCE OF SURFACE-WAVE CONCENTRATION UPON PHASE VELOCITY

FIG. 4



EVOLUTION OF CLOSED-STRIP LINE FROM COAXIAL LINE

FIG. 5

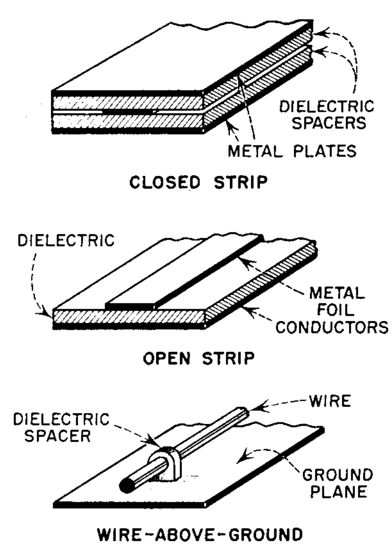
large antenna on a hill must be transmitted hundreds or thousands of feet into a valley for distribution, this type of transmission line would be economically feasible. For UHF television use, the same would apply, although at the high end of this band the use of a "G-String" for long lead-ins in standard installations might also be practical. The best application for this mode of transmission lies in the microwave region, however, where it is more economical than rigid coaxial or waveguide, has less weight and wind resistance, and can compete as far as losses are concerned.

Strip Transmission Lines

Another new family of transmission lines which are currently being pioneered are variously known as *planar, flat-strip, microstrip,* or *strip* transmission lines. These lines are evolved from ordinary coaxial line in the manner depicted in Fig. 5. Like the surface wave line, they are useful principally at microwave frequencies, where they show considerable promise for simplified and miniaturized components. Three types are in common experimental usage; *open-strip* line, *closed-strip* line, and *wire-above-ground* line. (Ref. 2, 3.) These forms are shown in Fig. 6. The open-trip line and the wire-above-ground type may be thought of as being further evolutions of the closed-strip form, brought about by removing the upper strip. They are inferior to the closed-strip line in some respects, but are more desirable in others. These chararteristics can be compared as follows:

(a) The *closed-strip* line exhibits the lowest losses from radiation since the fields are more completely confined between the outer conductors. These are usually made at least three times the width of the center strip for effective field concentration. The Q of this line type is higher than the other two types, making it applicable for use in filter circuits and other components which require this property. Closed-strip line and circuit elements such as directional couplers, power absorbers, power dividers, transitions, and slotted sections are easily fabricated by laminating the flat center conductor between sheets of a low loss dielectric and, in turn, clamping this "sandwich" between the flat metal plates which form the outer conductors. Circuit components and lines of this type have also been built by the use of printed circuit techniques. (See **AEROVOX RESEARCH WORKER** for April, 1951) Transitions between closed-strip line and coaxial cable are easily designed. Characteristic impedances up to about 200 ohms are practical.

(b) The *open-strip line* is less efficient than the closed type since the removal of the top ground plane allows more radiation. It is considerably easier to construct, however, and can be made by printed circuit techniques or from commercially available metal-plastic-metal laminated materials by "stripping" the metal foil from one side to form the desired pattern. As with the closed-strip type, the ground plane "outer" conductor is made at least three times the width of the narrow strip. Transitions from coaxial to open-strip line are more difficult to manage and Q factors are lower. Typical dimensions for a 50 ohm open-strip line are; conductor spacing .050 inch, strip width .250 inch, and ground plane width .750 inch.



THE NEW STRIP TRANSMISSION LINES

FIG. 6

(c) The *wire-above-ground* system is similar to the open-strip variety in that it is an unbalanced system which exhibits low Q because of higher radiation losses. It usually employs air as a dielectric and maintains the proper spacing above the ground plane by the use of dielectric beads at intervals. Its main advantages lie in its simplicity and its higher power handling capacity than the open-strip type because of the rounded conductor. It cannot be made conveniently by printed circuit methods. A typical 50 ohm line would consist of a 1/8 inch copper wire spaced .025 inch above a ground plane.

The losses in the new strip-type transmission lines are lower than those of solid dielectric cable but higher than rectangular waveguide with air dielectric. Their greater compactness, elimination of precision machining, and economy, are expected to make them very useful, especially for within-the-chassis microwave wiring where size reduction is important and the metal chassis can serve as the ground plane.

REFERENCES

(1) G. Goubeu, Jour. Appl. Phys., Nov. 1950.

(2) R. M. Barrett and M. H. Barnes, Radio and TV News, Sept. 1951

(3) D. D. Grieg and H. F. Engelmann, Proc. I.R.E., Dec. 1952.

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