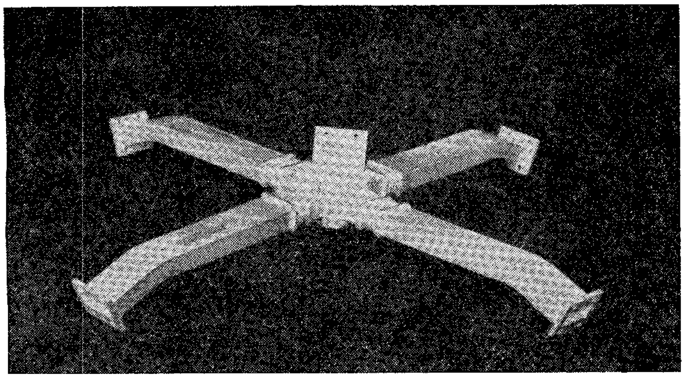

Fig. 11—Turnstile junction as a symmetrical 4-way power divider.

Thus, if a signal is impressed into the circular arm with its polarization along E_C, it will divide with equal amplitude in the four rectangular arms, giving us a symmetrical four-way power divider.

Fig. 11 shows a photograph of this arrangement. The equality of division is a function of the accuracy of orientation of the rectangular feed to the turnstile and the impedances on the rectangular arms.

An equal power split of 0.2 db is not difficult to achieve if care is taken to preserve symmetry in the construction of the junction. Fig. 12 shows a basic turnstile junction.

Three-Way Power Divider

In addition to the four-way power dividing properties of the Junction, it is also possible to modify the characteristics to a three-way power divider.

Referring to Fig. 7, if $E_1 = A \sin wt$, the initial signal division will be as follows:

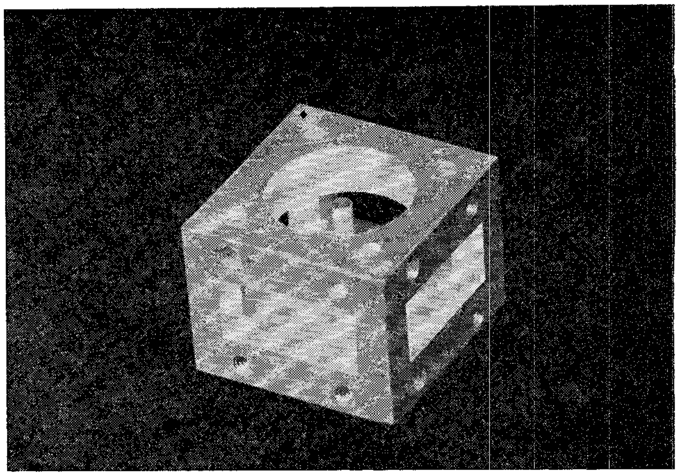

Fig. 12—Basic turnstile junction.

$$E_3 = \frac{A}{2} \sin wt \qquad E_4 = \frac{A}{2} \sin wt.$$

$$E_A = \frac{A}{\sqrt{2}} \sin wt$$

If the circular guide is now terminated in a short circuit, E_A will divide into arms 1 and 2 with

$$E_{1R} = \frac{A}{2} \sin (wt + 180°)$$

$$E_{2R} = \frac{A}{2} \sin wt.$$

If we now match the input to arm 1 with a simple post or iris we will have the incident power to arm 1 divided equally into arms 2, 3, and 4, thus affecting another useful application for the Junction.

The Ultra-Bandwidth Finline Coupler*

SLOAN D. ROBERTSON†

Summary—**The "finline coupler" is a recently developed microwave circuit element with which it has been possible to assemble hybrid junctions, directional couplers, and polarization-selective couplers capable of operating over bandwidths of at least three-to-one in frequency. Constructional details and experimental results are given.**

THE ACCELERATED development of modern communication technology in the past few years has been characterized by two readily discernible patterns; the progression to higher and higher frequencies in the spectrum, and the corollary demand for greater bandwidths. The requirements of the latter have been met in part by the development of traveling-wave amplifiers and backward-wave oscillators capable of operating over enormous bandwidths of the order of two-to-one in frequency. It would appear that a point has been reached where further development in the direction of increasing bandwidths is being inhibited by the lack of sufficiently wide-band microwave circuit components, such as directional couplers, hybrid junctions, and waveguide bends. It is the purpose of the present paper to describe the "finline coupler," a new microwave circuit element, in a form evolved jointly by H. T. Friis and the author, with which it has been possible to design hybrids, directional couplers, and polarization-selective couplers capable of operating over bandwidths of at least three-to-one in frequency.

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The basic finline coupler is shown in Fig. 1. As shown in the figure, the device consists, in this particular case, of a length of circular waveguide fitted with a pair of diametrically opposite, thin fins which taper in from the outer wall of the guide until their opposing edges are separated by a small gap at the center. Thus, substantially all of the energy associated with the electric field E_p (where the subscript p denotes that the vector is parallel to the plane of the fins) is concentrated from the dominant mode of propagation in the circular waveguide to a finline mode in which the energy is largely confined to the gap and its immediate vicinity. This energy may then be removed from the circular guide by curving the finline and bringing it out through a small hole in the side wall. It may then be launched into another waveguide, as shown.

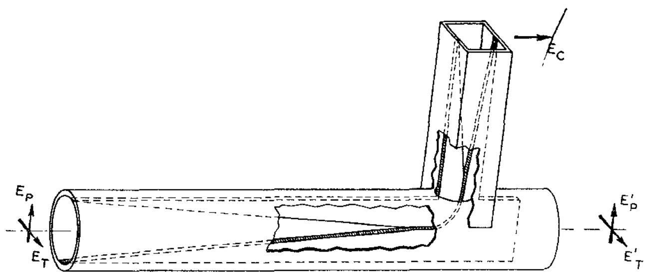

Fig. 1—Basic finline coupler.

On the other hand, a wave characterized by the transverse field E_T will pass on through the guide, relatively undisturbed by the presence of the fins, and will emerge as E_T'.

One can readily see that the finline coupler offers a means whereby it is possible to separate two waves perpendicularly polarized to one another. The fact that this is done with smooth tapers several wavelengths long suggests that the coupler ought to work over very wide bands. Such has been found to be the case.[1]

If one wave only is present in the guide, it is found that one may abstract any desired proportion of its energy by simply rotating the coupler about its axis so that the fins are inclined with respect to the plane of polarization of the wave. The abstracted field will then be proportional to the cosine of the angle.

Fig. 2 shows how two finline couplers may be arranged to form an hybrid junction. When the planes of the fins are inclined at an angle of 45 degrees, as shown in the figure, one obtains a 3-db hybrid. A wave entering at E_1 passes through the left-hand coupler without modification. Upon entering the second coupler, however, it is split into two equal components, one of which emerges at E_3, and the other emerges at E_4. Likewise, a wave entering E_2 travels through the first coupler and is split by the second coupler into two equal components. Degrees of coupling other than 3 db may be obtained by inclining the fins at angles other than 45 degrees.

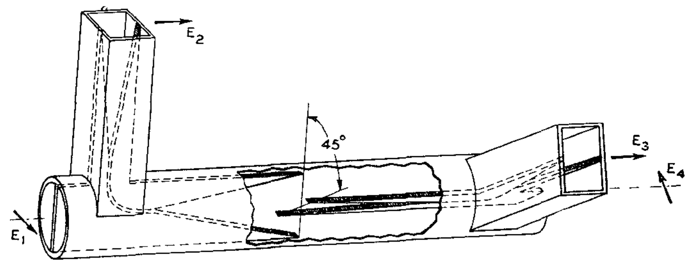

Fig. 2—Ultra-broad-band hybrid junction using two finline couplers.

In order to learn something of the performance of the coupler, an experimental model was built having the dimensions shown in Fig. 3. The dimensions selected were obtained largely by guesswork, and the successful results obtained with this coupler only serve to point out the fact that a truly broad-band circuit element must, by its very nature, be relatively uncritical in its dimensions. Other couplers have been made having a 1/32-inch gap between the fins and a 7/8-inch hole in the side wall which performed substantially as well as the one illustrated. It may be said in general that the required hole size is proportional to the gap spacing.

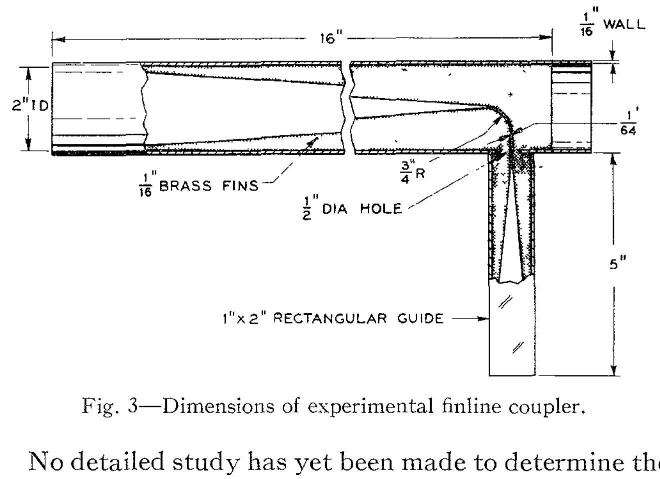

Fig. 3—Dimensions of experimental finline coupler.

No detailed study has yet been made to determine the optimum length and proportions of the fin tapers. Longer tapers would no doubt give lower standing-wave ratios. The tapers are linear except at those points where they join the walls of the waveguides and where they meet the circular arcs at the turn-off. They were curved at these points to provide a more uniform change of finline impedance. The input standing-wave

[1] It may be noted that the finline coupler bears a superficial resemblance to the ridged waveguide-to-coaxial transitions described by S. B. Cohn, "Design of simple broad-band waveguide-to-coaxial-line junctions." Proc. IRE, Vol. 35, p. 926; September, 1947. Attention is called, however, to the fact that the particular geometry of the finline coupler permits it to be used as an eight-terminal circuit element whose four pairs of terminals are defined by E_p, E_c, E_T, and E_T'. The latter two pairs are not permitted by the geometry of Cohn's transducer. In order to obtain the additional two pairs, it is necessary to use very thin fins and to select a waveguide cross section whose cutoff frequency will allow the transmission of a wave polarized in the plane of E_T.

ratios for these tapers were less than 3 db at all measured points in the band extending from 3.75 to 12.0 kmc.

Fig. 4 is a plot of the measured transmission losses between the various terminals of the coupler. Losses measured from E_p to E_c are shown in the upper part of the figure. It will be noted that they are less than one db over the entire range of frequencies from 3.75 to 12.0 kmc. Over most of the range, the losses are only a few tenths of a db. The rise in loss at the higher frequencies is believed to be due in part to higher ohmic losses (perhaps 0.2 db), and to mode conversion losses. The latter have been reduced in several cases by giving careful attention to the measuring equipment circuit components, which suggests that not all of the mode conversion losses may be due to the coupler itself but rather to auxiliary circuit elements used in the measurement. Since one is dealing with waveguide dimensions which will support higher-order modes at these frequencies, it is necessary to consider the coupler in relation to its environment of associated equipment.

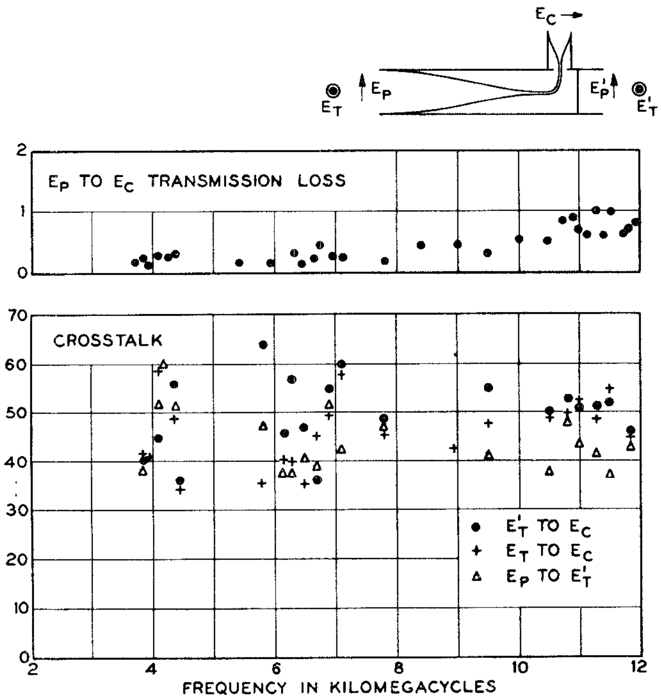

Fig. 4—Transmission properties of a finline coupler.

Losses of the transverse wave through the coupler from E_T to E_T' were measured and found to be of the order of 0.1 db or less, and are not plotted in the figure.

The points plotted in the lower parts of Fig. 4 represent three of the six possible "crosstalks" which are believed to be of particular interest. It will be noted that they are all in excess of 34 db. Other crosstalks such as E_p to E_p', E_c to E_p', and E_T to E_p' were also measured at a few frequencies and were found to be of the same order of magnitude as those plotted here. It is believed that the crosstalk discrimination can be increased substantially by maintaining closer dimensional tolerances on the coupler and by lengthening the fin tapers.

Fig. 5 presents some oscillographic traces of the same transmission characteristics already given in Fig. 4, but confined to the frequency band from 5.8 to 6.6 kmc.

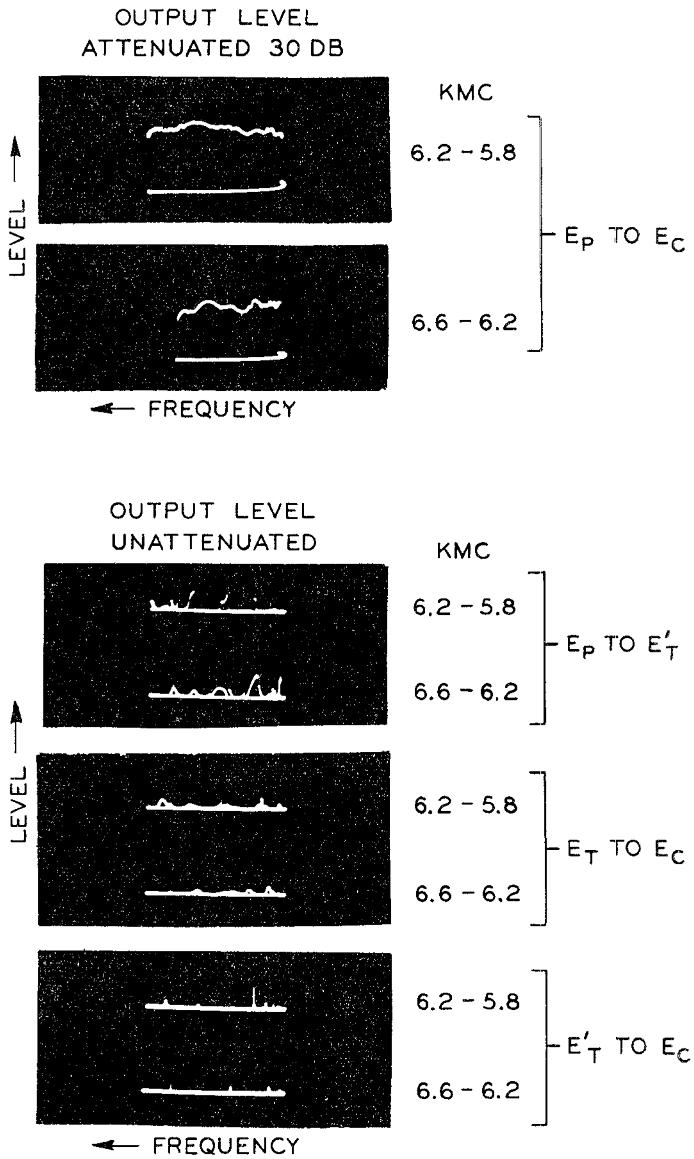

Fig. 5—Oscillographic traces of the transmission characteristics of the coupler in the 6-kmc band.

These traces were made with a broad-band sweeper for this band developed by D. A. Alsberg.[2] They are of importance in that they show that there are no serious "holes" in the loss measurements in this particular frequency band which may have been missed in the earlier point-by-point measurements. To be sure, several sharp peaks are noted in the transmission levels of some of the crosstalk components, but they are still 35 db or more below the input signal. It should be pointed out that the

[2] To be published in Trans. IRE, PG on Instrumentation.

E_p to E_c traces were obtained with an additional 30 db of rf attenuation in the circuit above that used in obtaining the crosstalk traces.

Conclusions

It appears that the finline coupler may be of considerable utility as a basic ultra-bandwidth circuit element which may be used as a variable coupler, an hybrid junction, or as a polarization selector. Other applications will probably be found.

Acknowledgment

The author wishes to express his appreciation to his colleagues at Bell Telephone Laboratories for much helpful advice and encouragement. Mr. C. F. Chapman was of great assistance in the experimental part of the work. Messrs. H. E. Heskett, A. P. King, and R. W. Dawson very kindly made their microwave measuring equipment available for obtaining the necessary experimental data.

Microwave Traveling-Wave Tube Millimicrosecond Pulse Generators

A. C. BECK† AND G. D. MANDEVILLE†

Summary—**For some time, short pulse techniques have played a useful part in the microwave art. In order to obtain better resolution, equipment for generating and viewing microwave pulses about six millimicroseconds long was developed and described previously. The regenerative pulse generator in that equipment was rather complex and difficult to build and adjust. A much simpler generator of pulses with about the same time duration is now being used. It produces short pulses by properly gating a conventional microwave signal source with a traveling-wave amplifier having suitable transient voltages applied to both its helix and its beam-forming electrode. It is easier to construct and operate, requires fewer components, and gives a more stable output. It can be used at any frequency where a signal source and a traveling-wave amplifier are available. The pulse frequency can be set anywhere within the amplifier bandwidth.**

Both generators are described and compared. Equipment for receiving, displaying, and measuring the pulses is also briefly discussed. Pulse shapes and resolutions are shown on oscilloscope photos.

Introduction

PULSE TECHNIQUES have been useful at microwave frequencies for some time. In many of their applications, the need for greater resolution has led to the use of shorter and shorter pulses. Recently, equipment has been described which generates and displays 9,000-mc pulses having a length of about 6 millimicroseconds (mμsec).[1] Such pulses occupy a few feet of path length in a transmission medium, so good resolution is obtained. They have been used for measuring radio repeater waveguides and antennas and have found many applications to multimode waveguide studies.

Regenerative Pulse Generator

In the original equipment, these short pulses were produced by a regenerative pulse generator suggested by C. C. Cutler of these Laboratories.[2] This was a very useful device, but rather complicated and hard to build and adjust. A brief description of it will permit comparisons with a simplified pulse generator which has recently been developed.

Fig. 1 is a block diagram of the regenerative pulse generator. The fundamental part of the system is the feedback loop drawn with heavy lines in the lower central part of the figure. This includes a traveling-wave amplifier, a waveguide delay line about sixty feet long, a crystal expander, a band-pass filter, and an attenuator. This combination forms an oscillator which produces very short pulses of microwave energy. Between pulses, the expander makes the feedback loss too high for oscillation. Each time the pulse circulates around the loop it tends to shorten, due to the greater amplification of its narrower upper part caused by the expander action, until it uses the entire available bandwidth. A 500-mc gaussian band-pass filter is used in the feedback loop of this generator to determine the final bandwidth. An automatic-gain control operates with the expander to limit the pulse amplitude, thus preventing amplifier compression from reducing the available expansion.

To get enough separation between outgoing pulses for reflected pulse measurements with waveguides, the repetition rate would need to be too low for a practical delay line length in the loop. Therefore a 12.8-mc fundamental rate was chosen, and a gated traveling-wave tube amplifier was used to reduce it to a 100-kc rate at the output. This tube is kept in a cutoff condition for 127 pulses, and then a gate pulse restores it to the normal amplifying condition for fifty millimicroseconds (mμsec), during which time the 128th pulse is passed on to the output of the generator, as shown on Fig. 1.

The synchronizing system is also shown on Fig. 1. A 100-kc quartz crystal controlled oscillator with three cathode follower outputs is the basis of the system. One output goes through a seven-stage multiplier to get a 12.8-mc signal, which is used to control a pulser for

† Bell Telephone Laboratories, Inc., Holmdel, N. J.

[1] A. C. Beck, "Microwave testing with millimicrosecond pulses," Trans. IRE, vol. MTT-2, pp. 93–99; April, 1954.

[2] C. C. Cutler, "The regenerative pulse generator," Proc. IRE, vol. 43, pp. 140–148; February, 1955.