MICROWAVE STRIP CIRCUIT RESEARCH AT TUFTS COLLEGE*

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Research into some of the basic aspects of the electrical and mechanical characteristics of microwave strip line components was initiated at the Research Laboratory of Physical Electronics at Tufts College in November 1952, under the sponsorship of the Antenna Laboratory of the Electronics Research Directorate, Air Force Cambridge Research Center. The work was planned at that time as a continuation and development of the original investigations carried out by Mr. Robert M. Barrett of the Antenna Laboratory.

The areas of primary interest which were first to be considered were (a) the experimental measurement of the characteristic impedance of strip line structures, (b) the effects of the proximity of strip line to the boundaries of the transmission medium provided by the dielectric and ground planes, and (c) the development of transition coupling sections from strip lines into conventional microwave system components such as Type N or BNC connectors or into hollow waveguides.

Initial measurements of characteristic impedance were made on strip lines using solid dielectric support for the center conductor. The three types of laminar construction are shown in Fig. 1 and designated <u>full section</u>:having a strip center conductor bounded on each side by a dielectric layer and ground plane; <u>3/4 section</u>:having a strip center conductor bounded on each side by dielectric layers of equal thickness but with a single ground plane; and the <u>half section</u> or <u>open line</u> in which the center conductor is separated from the ground plane by a single layer of dielectric.

Since then we have confined our work to the totally shielded or full section line, and the work reported here and in our Interim Technical Reports is based on this mode of construction. A major portion of the strip line structures considered in the first 18 months of this work have incorporated a solid dielectric. These lines were prepared by the electrodeposition of copper on circuit patterns prepared using silver conducting paint. The paint is applied to the base dielectric sheet of polystyrene through a mask corresponding in its apertures to the desired circuit. Copper is then electroplated onto this electrode surface to the desired thickness. Air-dielectric lines of the edge-supported type have been utilized in the more recent phases of our investigations. In particular, the work resulting from the extension of our interest to resonant systems indicated that a method of line support having less dielectric loss was required in these cases. The center conductor is supported by a transverse septum as shown in Fig. 2. Copper-clad Teflon-glass has proved to be a satisfactory material for this layer. Duplicate patterns of the desired strip line configuration are photo-etched in accurate register on each of the copper-clad surfaces. This gives a center conductor that is no longer "thin" but approximates the characteristics of a solid center conductor 1/32" thick. The spacing of the associated ground planes is established by suitable posts and bushings at the edge of the supporting septum, beyond the fringe field of the center conductor.

An approximate estimate of the extent of the lateral fringe field about the center conductor can be derived from capacitance measurements made at low frequencies on model lines. The effective capacitance between the center conductor and the ground planes will rise to a limiting value as the margins "a" as shown in Fig. 3 are increased. On the basis of these measurements we have maintained margins of from 2 to 2.5 times the ground plane separation distance. Later experience has tended to indicate that this is a conservative figure. The locations of posts or spacers somewhat closer than this figure have had in most cases slight observable effect on line performance.

An efficient connector or transition between two wave-guiding systems represents a successful conversion of the energy in the field distribution of the source guide into the desired propagating mode in the receiving guide. From the close relationship between the strip line and the coaxial line in structure and in field configuration, it is evident that a parallel connection such as that shown in

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Fig. 4a requires the minimum re-orientation in wave field. In the case of 50-ohm strip line having a 1/2" ground plane spacing, a satisfactory and simple transition is possible to a conventional coaxial system using a type N connector as shown. Obviously in those cases where, for reasons of size, impedance range, operating wavelength, or other pertinent considerations, such a ground plane spacing is inadmissible; some other connector or method such as the perpendicular arrangement shown in Fig. 4b must be employed. Additional measures are usually required in the form of a shorted quarter-wave section or an array of conducting posts between the ground planes in order to insure proper operation.

With solid dielectric and "thin" electroplated center conductor the experimental measurements of characteristic impedance were in agreement with existing theoretical predictions for lines of zero thickness in the range from 30 to 100 ohms. Less extensive work with air-dielectric lines in the vicinity of 50 ohms has checked satisfactorily with more recent expressions developed for strip line configurations with rectangular center conductors.

At the same time that we initiated experiments on the design and testing of strip lines a program of theoretical investigations was also undertaken. This began with a critical survey of all available relevant work which had been done on the problem of the calculation of characteristic impedance. This survey has been followed by additional original investigation on this topic which has been carried forward with considerable success by Dr. Pease. These results have been the subject of a number of Interim Technical Reports and he will present in detail at the section tomorrow morning our latest results in this field.

We have been chiefly concerned with the individual characteristics of typical microwave circuit components rather than the fabrication of any specific equipment to externally-imposed design conditions. Typical of this interest have been our investigations of the properties of bends, corners, and resistive loads or terminations.

Measurements have been made on the discontinuity effect produced in otherwise uniform sections of strip line by the introduction of a single H-plane bend or corner as shown in Fig. 5. We have considered 90° circular bends with radii from 2 to 5 times the width of the center conductor, simple corners in the range from 15° to 90°, and compound 90° corners with average spacings ranging from 0.4 to 0.6 of a wavelength in the guide. The improvement in performance of a corner to be realized by a simple mitering or truncation of a corner has been investigated. In summary we can say that the latter technique is simple and effective. Since the effect of removing a portion of the center conductor in this manner is a function of the relative proportions of the guide with respect to the operating wavelength, the exact design procedure will depend on the center frequency and the strip line used. The compound corner when adjusted to operating conditions is superior to a circular bend of the same effective radius, at least for the guide proportions required for a 50-ohm line with 1/2" ground plane spacing.

In common with other transmission systems, strip line networks require termination elements or regions having ideally a reflection coefficient of zero. The initial use of so-called resistive paints applied directly in liquid form to strip lines produced quite uniformly unsatisfactory results. Since then we have used separately inserted segments of resistive or lossy material in bulk or sheet form. The advantages of uniformity in preparation and aging of a separate material is an obvious explanation for its demonstrated superiority.

In either form, tapered wedges having an included angle of 60° or less have been used with satisfactory results with VSWR of less than 1.1 in many cases. Depending on the geometry of the line, it has been found necessary to a greater or lesser degree to provide conducting boundaries on the resistive material at those points where it is in contact with the center conductor and the ground planes. This is easily done with silver conducting paints. While this is possible to adjust for small differences in the properties of the resistive material by changes in the effective profile or thickness, the needs of production would dictate the establishment of better control of the tolerances of the material as manufactured.

More recent investigations have considered the effective equivalent circuit or the scattering parameters of simple step discontinuities in solid- and air-dielectric lines. These discontinuities represent symmetrical step changes in the width of the center conductor as shown in Fig. 6.

In addition, we have done a limited amount of work with simple hybrid junctions, and open- and short-circuited stubs. Our most recent experiments have been in the rather large and general field of wave filters. A number of these have been prepared and their transmission characteristics established. They have been for the most part band-pass systems involving a series array of capacitance-coupled resonant elements. Other forms such as band-stop and low-pass filter arrangements have been considered but not in great detail. We plan in the future to extend our interests to the allied field of cavity resonators.

The strip technique in itself represents a basic step toward the simplification of many complex microwave components. The first phase in the exploitation of this idea, namely that of the analog expression in strip form of existing transmission-line or wave-guide components, has been carried on with evident success. The next phase, the evolution of accessory components specifically intended for integration with strip systems, and the evolution of extended applications possible only in the microwave strip form, is a logical development to be expected.

During this period we have enjoyed numerous discussions, at our laboratory and elsewhere, with many persons working on or interested in these problems. The exchange of basic ideas, of objectives, and of methods which we have enjoyed has proved illuminating and stimulating to our efforts here at Tufts. As much as will be true for any group represented here, I am sure that both the direction and the character of our future work will be significantly influenced by the papers and the discussion to be brought forward during this symposium.

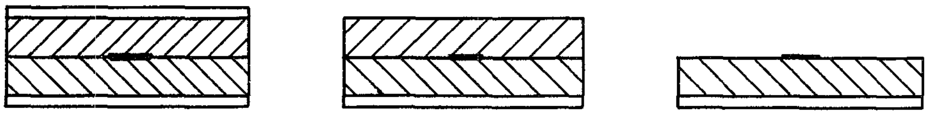


Fig. 1

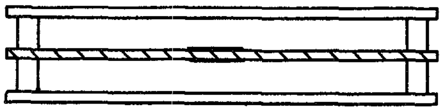


Fig. 2

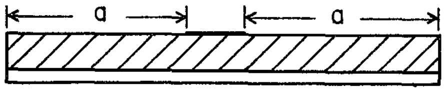
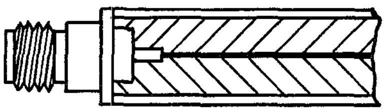
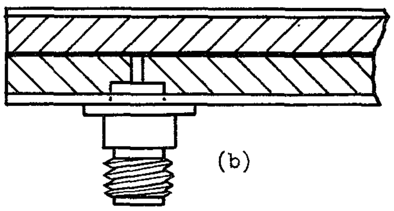


Fig. 3



(a)



(b)

Fig. 4

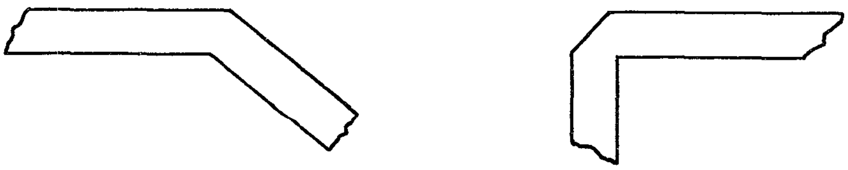


Fig. 5

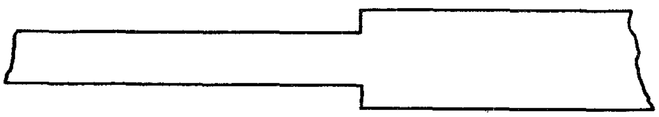


Fig. 6