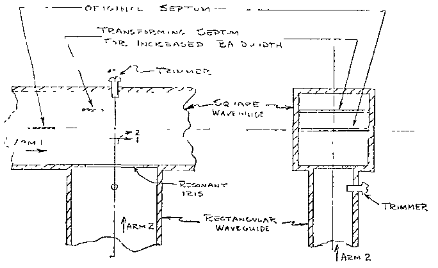


Fig. 1—Mode-selecting coupler.

nant iris. Placement of a septum in the square guide perpendicular to the electric field of arm 1 and parallel to the electric field of arm 2 provides the required degree of isolation between the two arms.

Ohm reported a match for the side-arm 2 input of greater than 35 db return loss (VSWR = 1.036:1) for the 8.94 per cent band of 10.7 to 11.7 Gc. He did not report performance outside this band as it was not then of current interest.

It has been found that the bandwidth can be improved by adding an additional septum, as shown in Fig. 1. In the model developed coupling WR-187 rectangular guide (1.872×0.872) into square guide (1.55×1.55), a match of 34 db return loss (VSWR = 1.04:1) was obtained for a 14.6 per cent band. This was better than 30 db return loss (VSWR = 1.065:1) over a 22.0 per cent band.

It is believed that the improved performance is due to a transforming action between the rectangular guide impedance and the square guide impedance. For the model evaluated, at 4.7 Gc the rectangular guide has an impedance of 520 ohms. The square guide has an impedance of 1280 ohms. Considering the guide below the added septum as partial height square guide, it has an impedance proportional to the square guide impedance. The performance reported was obtained with this added septum at 3/4 height which would produce an impedance of 960 ohms. Thus without the added septum the impedance ratio is 2.44:1, and with the added septum it is 2.44:1.83:1.

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## A New Formula for Attenuation in Coaxial Cables

Attenuation in matched coaxial cables is expressed by the formula for 100 feet (db),[1] $A = 4.34R_t/Z_0 + 2.78f\epsilon^{1/2}F_p$ with $R_t = 0.1(1/d + 1/D_i)\sqrt{f\cdot\rho/\rho Cu}$. This attenuation, however, deviates heavily from the measured values, as it does not consider the skin effect with its changes over the frequency range. In the cable RG-58-U, for example,[2] the error reaches 47 per cent at 3000 Mc. Before setting up a new, empirical formula, the author has taken averages from hundreds of measurements on coaxial cables between 0.2 and 3000 Mc. The inner conductors had diameters from 0.012 to 0.036 inch.

A skin factor $F_s$ in Table I (allowing interpolation) takes care of the skin effect and of the ensuing inductance change. Thus the attenuation, in decibels per 100 feet, is

$$A = F_s 8.4\sqrt{f}R/Z_0.$$

Here $f \cdots$ frequency in Mc, $Z_0$ = characteristic impedance in ohms; the attenuation $A$ of matched coaxial cables for 100 feet is based on the dc resistance of 100 feet inner conductor ($R$). In the metric system, $R$ for 100 meters is listed in manuals; accordingly, attenuation for 100 meters will be obtained by the same formula, using this different $R$. The new formula is tried out for nonmagnetic conductors, tinned, blank or silver-plated, and with shields of tinned copper-braid.

For frequencies from 0.2–1 Mc, the true $R$ of a composite conductor enters. Thus, for stranded copper-covered steel, take $R$ as listed by the maker for a single strand but divided by the number of strands. For frequencies above 1 Mc, take $R$ of copper from the right-hand column of Table I, filling the diameter solid.

In most cases, the error against average measurement is smaller than 5 per cent. While the attenuation of rectangular pulses with duty-cycle $\Delta = 0.5$ is practically the same as that of those with sine waves, correction factors $F_\Delta$ should be empirically found for other duty cycles. Extrapolations might be misleading. Table II gives an example for the investigation of $F_\Delta$ in a 100 kc-200 kc range of pulse cycles per second ("repetition rate").

TABLE I

Skin Factor $F_s$

| Conductor diameter in mils | Take composite $R$ | | Take $R$ of outer metal solid | | | |
|---|---|---|---|---|---|---|
| | 0.2 Mc | 1 Mc | 10 Mc | 140–400 Mc | 3000 Mc | $R/100$, $\Omega_\omega$ |
| 7/38 AWG = 12 | 1.6 | 1.1 | 1 02 | 1.2 | | 9.8 |
| solid 12 | 1 4 | 1.05 | 1.02 | 1 2 | | 6.3 |
| 12.6 | 1.4 | 1.05 | 1 02 | 1.2 | | 6.5 |
| 15 | | 1.05 | | 1.4 | | 4 4 |
| 15.9 | | 1.05 | | 1.4 | | 4.08 |
| 7/34 AWG = 19 | 2.0 | 1.17 | | 1.8 | | 2.7 |
| 20 | 2.15 | 1 25 | | 1.9 | | 2.57 |
| 23 | 2.25 | 1.43 | | 2.1 | 2.45 | 1 9 |
| 25 | | 1.55 | | 2.2 | | 1 6 |
| 28 5 | | | | 2.3 | 2.8 | 1 28 |
| 19/34 AWG = 32 | 2.3 | 1.97 | 2.2 | 3.5 | 4.0 | 1.01 |
| 27/36 AWG = 35 | | 2.25 | | 4.3 | | 0 84 |
| 35 9 | 2.35 | 2.35 | 3.28 | 4 4 | 6 2 | 0.805 |
| 96 | | | | 16 | | 0.11 |

TABLE II

Correction Factor $F_\Delta$ for Attenuation of Rectangular Pulses with a Repetition Rate of 100–200 kc

| $\Delta$ | $F_\Delta$ at 35–36 mil conductor | $F_\Delta$ at 19–23 mil conductor | $F_\Delta$ at 12 mil conductor |
|---|---|---|---|
| 0.5 | 1.0 | 1.0 | 1 0 |
| 0.4 | 1 086 | 1 08 | 1 025 |
| 0.2 | 1.32 | | 1.08 |
| 0.1 | 1.33 | | 1 115 |
| 0.05 | 1 57 | 1 55 | 1 4 |

$\Delta$ = pulse width/pulse cycle.

### Examples

*Example 1*

A cable of $Z_0 = 75$ ohms has a conductor made of a copper alloy, 90 per cent conductivity of copper, 7 strands of AWG 38. Over-all conductor diameter: 12 mils. Attenuation at 1 Mc:

$$A = 1.1 \times \frac{8.4 \times 1}{75} \times 9.8/0.90$$

$$= 1.34 \text{ db}/100 \text{ ft}.$$

Attenuation at 400 Mc:

$$A = 1.2 \times \frac{8.4 \times 20}{75} \times 6.3/0.90$$

$$= 18.85 \text{ db}/100 \text{ ft}.$$

*Example 2*

A cable of $Z_0 = 50$ ohms has a copper conductor of 19 AWG 34 strands, tinned. Over-all conductor diameter: 32 mils. Attenuation at 10 Mc:

$$A = 2.2 \times \frac{8.4 \times 3.16}{50} \times 1.01$$

$$= 1.17 \text{ db}/100 \text{ ft}.$$

Attenuation at 1 Mc:

$$A = 1.97 \times \frac{8.4 \times 1}{50} \times 1.01$$

$$= 0.331 \text{ db}/100 \text{ ft}.$$

Interpolation: Attenuation at 5 Mc; the interval between 1 and 10 Mc is 9 Mc, and 1.17db − 0.331 db = 0.839 db.
$A = 0.331 - 0.839 \times 4/9 = 0.704$ db/100 ft.

Manuscript received November 14, 1963; revised February 3, 1964.

[1] "Reference Data for Radio Engineers," International Telephone and Telegraph Corp., New York, N. Y., p. 574; 1956.

[2] *Ibid.*, p. 614.

*Example 3*

A field cable of $Z_0 = 25$ ohms has a solid conductor with 40 per cent of the conductivity of copper, made of copper-covered nonmagnetic steel, diameter 25 mils.

Attenuation at 200 Mc (the outer metal is copper, which alone is to be considered at 10 Mc and higher frequency):

$$A = 2.2 \times \frac{8.4 \times 14.14}{25} \times 1.6$$

$$= 16.7 \text{ db}/100 \text{ ft}.$$

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## Broad-band Coaxial-to-Stripline Transitions

Butt transitions between coaxial line and shielded stripline are simple and economical to manufacture. Levy[1] has pointed out that such transitions are not properly matched because the fringing field of the stripline is intercepted by the outer conductor of the coaxial line, and in addition the inner conductors of the two lines have different dimensions. His broad-band coaxial-to-stripline transition requires a tapered length of rectangular coaxial line and he deduced that the VSWR of this system is less than 1.02 up to 11 kMc.

This communication will show that a broad-band transition may be obtained using a compensated butt junction. The discontinuity capacity introduced by the butt is compensated for by displacing the junction of the inner conductors with respect to that of the outer conductors.

Transitions from 50-ohm coaxial line to two types of 50-ohm shielded stripline are described below.

### STRIPLINE WITH BRASS CENTER STRIP

This type of stripline [Fig. 1(a)] consists of a brass strip between two parallel flat brass plates. The dimensions are such that the characteristic impedance of the line is 50 ohms.

The compensated butt junction and its connection to a coaxial slotted line[2] are shown in Figs. 2 and 3.

The performance of the 50-ohm coaxial slotted line mated to a special N-type connector containing a standard polytetrafluotoethylene support bead [Fig. 3(c)] was first assessed. A VSWR plot from 3 to 12 kMc is shown in Fig. 4 and it can be seen that the maximum VSWR is 1.035.

The standard P.T.F.E. support bead was replaced by the compensated but junction (Figs. 2 and 3). Optimum performance was obtained when the inner conductor of the coaxial line projected into the stripline by 0.033 inches. A VSWR plot from 3 to 12 kMc is shown in Fig. 4 and the maximum VSWR is 1.035. It was found that the length of the compensating section could be varied by ±0.002 inches without increasing the maximum VSWR.

From a comparison of the two VSWR plots shown in Fig. 4 it can be seen that the compensated butt junction has no greater effect on the maximum VSWR than one end of the standard P.T.F.E. support bead. If we assume that each end of the two compensated P.T.F.E. support beads (one being within the slotted line) contributes equally to the maximum VSWR then we may conclude that the maximum VSWR of the coaxial-to-stripline transition alone is probably better than 1.01.

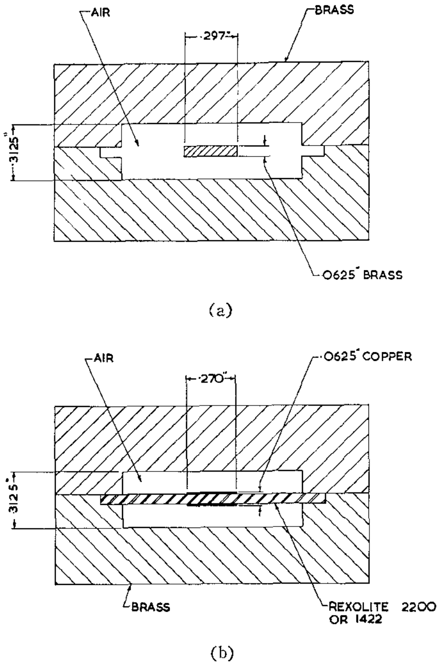


Fig. 1—Shielded stripline systems. (a) Solid brass strips. (b) Copper clad rexolite card.

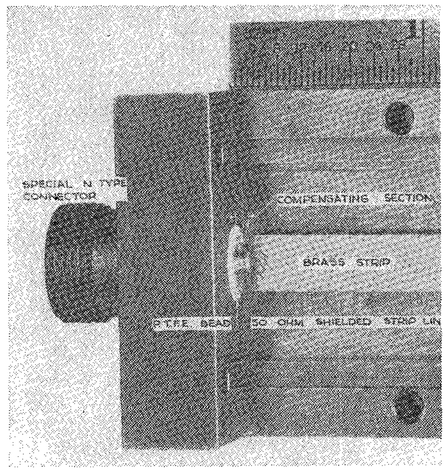


Fig. 2—Compensated coaxial-to-stripline butt transition.

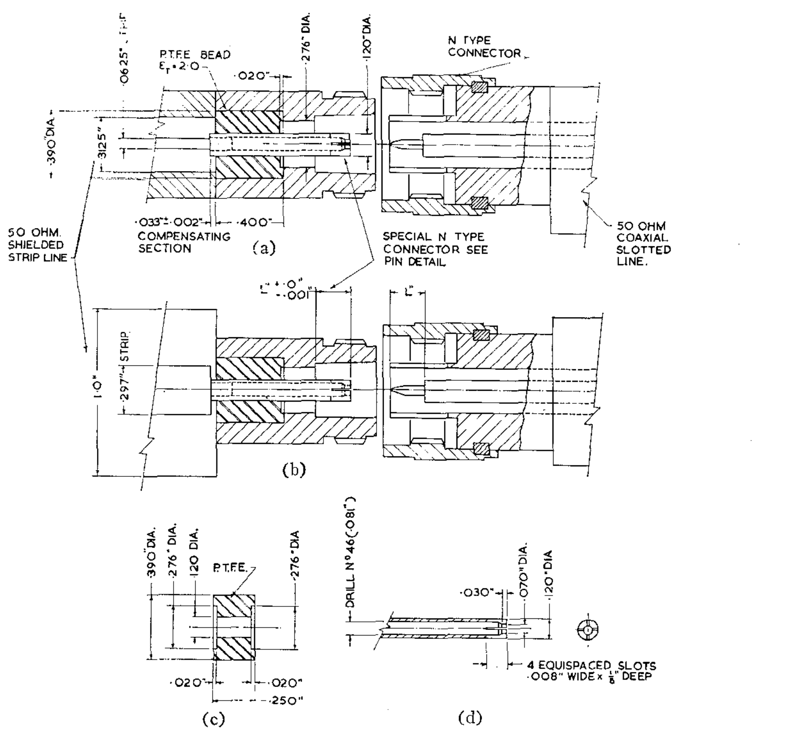


Fig. 3—Details of the compensated coaxial-to-shielded stripline butt transition mated to a coaxial slotted line. (a) Elevation. (b) Plan. (c) Standard 50-ohm air coaxial line support bead. (d) Pin detail.

Manuscript received February 3, 1964.

[1] R. Levy, "New coaxial-to-stripline transformers using rectangular lines," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-9, pp. 273–274; May, 1961.

[2] A Hewlett Packard Model 806B Coaxial Slotted Line was used for this investigation.