# UHF Strip Transmission Line Hybrid Junction*

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*Summary*—**A hybrid junction has been developed using a symmetrical strip transmission line for application in the UHF range. It has a frequency band of ±20 per cent where the input voltage standing-wave ratios at all ports are less than 1.26 (2 db), the power divisions are within 0.1 db, and the difference in power between the series input and parallel input ports is less than 0.3 db. The isolation is greater than 40 db and 24 db, respectively, for the two pairs of conjugate ports. These circuits are relatively small, light-weight, simple to build and reproduce, and are inexpensive.**

**The approximate equivalent circuit of the configuration assuming transmission in the TEM mode is presented. The results of the analysis and the important features in the design and fabrication and a few modifications of the configuration are discussed.**

## Introduction

A HYBRID junction is a four-port network which, when properly terminated, has the characteristic of transferring energy from any one port equally to two of the other ports with no energy appearing directly at the fourth or conjugate port. Some typical forms of hybrid junctions are the magic tee, hybrid ring and the 3-db directional coupler. These hybrid junctions are useful in balanced mixers, impedance measuring devices, modulators, phase adjusters, tuners, comparators, etc.

The hybrid junctions discussed here appear in printed symmetrical strip transmission line forms. They are designed for the UHF region. They have a broad bandwidth, good power division, isolation, and impedance match. They are relatively small, lightweight, simple to build and reproduce, and are inexpensive.

## Printed-Circuit Hybrid Junction

A sketch of the printed-circuit hybrid junction constructed in strip transmission line is shown in Fig. 1. The side view of the circuit shows the transmission line with conductors I and II embedded in a dielectric layer sandwiched between two ground planes. Conductors I and II are mirror images except in the region of $A$–$B$–$B'$–$A'$. The circuit is assembled by laying conductor I over on II so that the corresponding parts align. At the center of conductor II, a thin dielectric sheet is located such that when assembled, the horizontal line 2 will not make contact to the pieces of conductors beneath the dielectric sheet. The purpose of the pieces of conductors is to connect points $A$ to $A'$ and $B$ and $B'$. The lines are connected to the ground planes at four points marked with $X$. These form short-circuited quarter-wavelength elements. The boards are assembled and the ground planes tied together with screws spaced about one inch apart. The number of grounding screws is increased in the vicinities of corners and transitions, in order to prevent undesirable higher-order modes of propagation. All screws are located beyond the major portion of the TEM field. A photograph of the circuit is shown in Fig. 2.

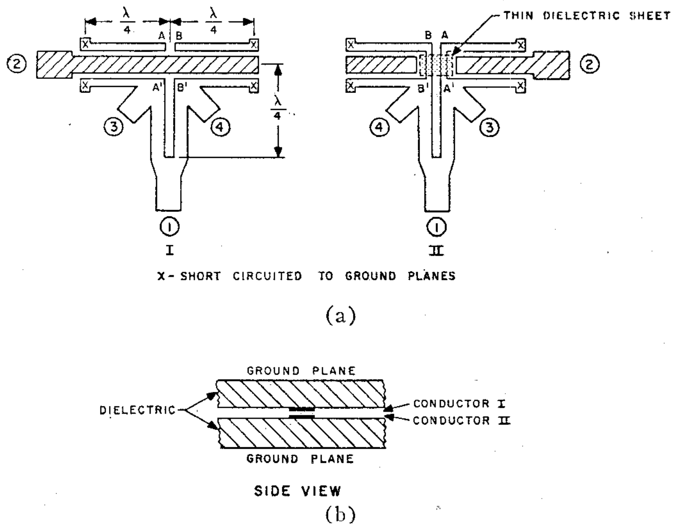


Fig. 1—Strip transmission line hybrid junction; (a) top view, (b) side view.

Fig. 2—Photograph of hybrid junction.

Referring to Fig. 1, we see that ports 1 and 2 are one pair of conjugate arms and ports 3 and 4 are the other pair. Port 1 feeds 3 and 4 in parallel through a directly-coupled quarter-wavelength transformer. Its characteristic impedance should be equal to

$$Z_0' = \sqrt{\left(\frac{Z_3 \quad Z_4}{Z_3 + Z_4}\right) Z_1},$$

where $Z_n$ is the impedance terminating port $n$.

Port 2 feeds 3 and 4 in series through a quarter-wavelength coupled section. Its characteristic impedance was determined empirically. As a first approximation, it was set equal to

* Received by the PGMTT, February 26, 1960; revised manuscript received, July 25, 1960. The work reported in this paper was supported by Army Ordnance under Military Contract No. DA-30-069-ORD-1955.

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$$Z_0'' = \sqrt{(Z_3 + Z_4)Z_2},$$

where $Z_0''$ was equal to the characteristic impedance of an isolated line. This value will be decreased by the proximity of the short-circuited quarter-wavelength line used as part of the coupling device. To obtain sufficient coupling to the loads with a short-circuited quarter-wavelength line placed along only one edge of line 2, we would have to use a very narrow coupling gap which would be impractical. A gap of practical width can be realized by using short-circuited quarter-wavelength sections placed along both edges of line 2. The characteristic impedance of these elements should be high in order to maintain a broad band response.

The open-circuited quarter-wavelength section of line 2 is used to compensate for the variation in load impedances as seen from port 2. It also makes the circuit symmetrical. This should improve the balance characteristics.

Assuming a TEM mode of transmission, we can derive an approximate equivalent circuit from the hybrid junction configuration shown in Fig. 1. Starting at port 2, the two loads 3 and 4 are fed by a quarter-wavelength coupled section in series with an open-circuited quarter-wavelength stub. The short-circuited quarter-wavelength sections used in the coupling from port 2 and with the open-circuited stubs appear in shunt across the two loads. In addition, the loads are fed in parallel by a quarter-wavelength transformer which is connected to port 1. This equivalent circuit configuration is shown in Fig. 3.

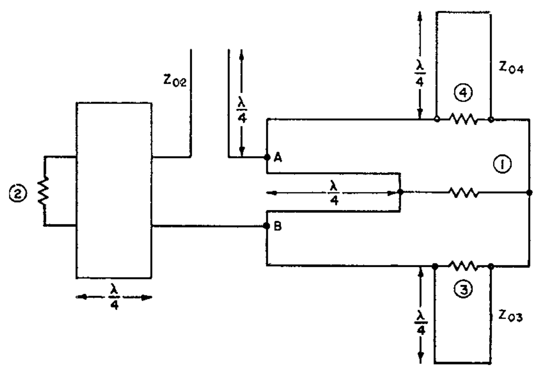
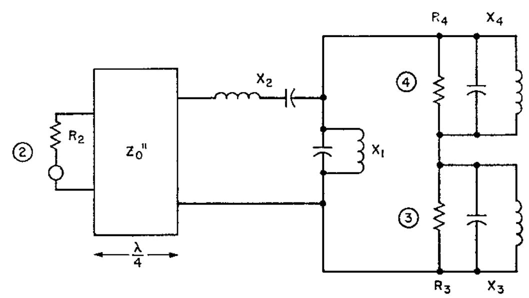



Fig. 3—Equivalent circuit of hybrid junction.

The operation of the hybrid junction can easily be analyzed from the equivalent circuit of Fig. 3. A signal applied at port 2 appears in series across the loads at 3 and 4. No energy appears at port 1 because it is tapped at the mid-point of points $A$–$B$. A signal applied at port 1 appears in parallel across the loads 3 and 4, and no energy appears at 2 because points $A$–$B$ are at the same potential. This assumes matched conditions. Ports 1 and 2 are isolated from each other and are one pair of conjugate arms. Ports 3 and 4 are the other pair of conjugate arms which are also isolated from each other. The quarter-wavelength transformer at port 1 is directly coupled to the two loads in parallel. The $Z_0$ necessary to match the input circuit is low and port 1 is relatively broadband. The transformer at port 2 requires a relatively high $Z_0$ in order to match the input to the two loads in series and also the coupling to the loads is across an air gap. This makes this port relatively narrow band and the input impedance quite dependent on the dimensions of the coupling gap.

Port 2 is the most critical terminal, and to determine its characteristics a simplification can be made to the equivalent circuit. A simplified circuit is shown in Fig. 4. Analysis of this circuit indicates that $Z_{0_3}$ and $Z_{0_4}$ of the short-circuited quarter-wavelength line should be high and the $Z_{0_2}$ of the open-circuited quarter-wavelength line should be low. For an idealized case, the $Z_0$ of the lines could be chosen to give maximum bandwidth at port 2, but this optimum condition requires the use of characteristic impedances which may be difficult to realize in practice. Although the optimum values may not be practical, the analysis does indicate the improvement that can be achieved by the proper choice of impedances.




$R_2 = R_3 = R_4 = 50\Omega$ $\quad X_1 = Z_{01}$ TAN $\beta l_1$
$X_3 = X_4 = Z_{03}$ TAN $\beta l_3$ $\quad X_2 = -Z_{02}$ COT $\beta l_2$
$l_3$ = Length of short-circuited stub
$l_1$ = Length of short-circuited line connecting terminal 1 to 3 and 4
$l_2$ = Length of open-circuited stub
$Z_0'' = \sqrt{(R_2)(R_3+R_4)}$

Fig. 4—Modified equivalent circuit.

## Experimental Hybrid Junction

A printed-circuit hybrid junction is shown in Fig. 5 along with typical dimensions. Reactive elements shown at ports 1 and 2 are used to obtain the proper impedance characteristics. The measured input impedance characteristics, balance and isolation curves are shown in Figs. 6 and 7. The input VSWR at port 2 is less than 1.26 (2 db) over $\pm 20$ per cent band. The other ports show a better response. The power divisions are within 0.1 db over the same band. The difference in power between the series and parallel input ports is about 0.3 db. The isolation for the two pairs of conjugate ports is greater than 24 db and 40 db.

Similar characteristics can be achieved in other forms of printed-circuit hybrid-junction configurations but with somewhat narrower bandwidths. A typical "Ring" hybrid junction may give a bandwidth in the order of

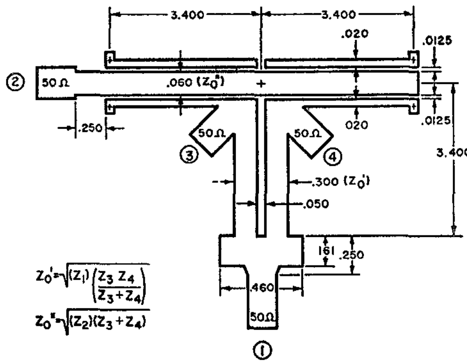



Fig. 5—Strip transmission line hybrid junction.

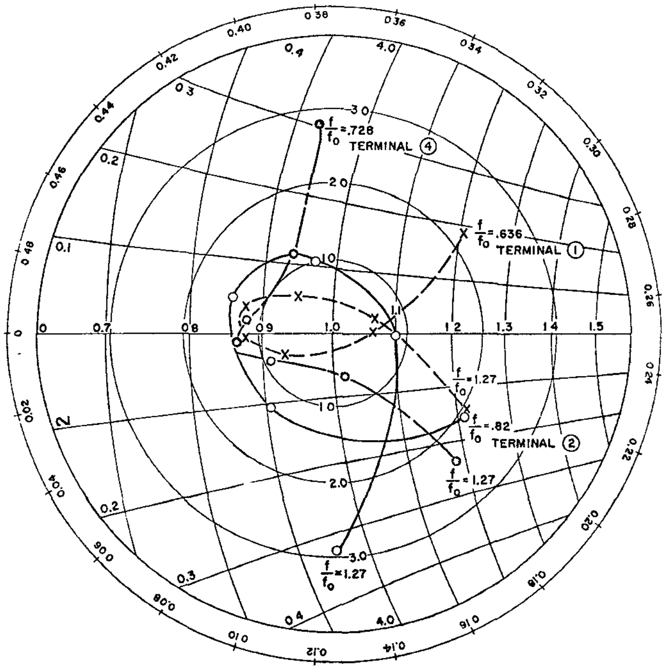



Fig. 6—Measured input impedances.

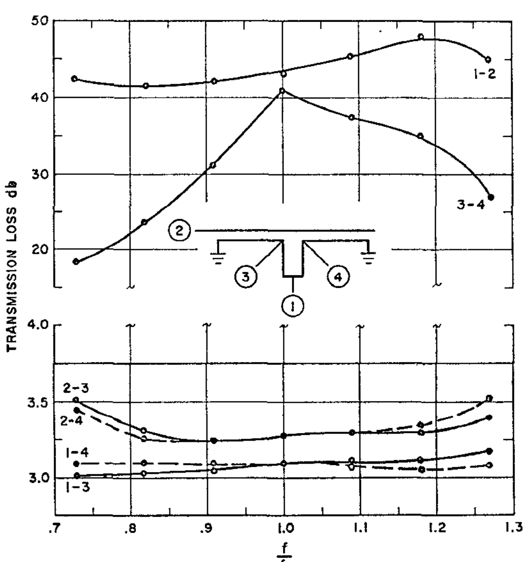



Fig. 7—Transmission loss vs $f/f_0$.

±5 per cent. Good bandwidths can be realized with 3-db strip line directional couplers, but with a 90° phase shift.[1] A quarter-wavelength 3-db directional coupler gives a bandwidth of ±15 per cent. A three-quarter-wavelength 3-db directional coupler may give a very wide bandwidth of ±50 per cent. These directional couplers have theoretically infinite directivity but experimental models have been constructed with directivity less than 40 db.

The hybrid junction discussed here differs chiefly from other strip transmission line hybrid junctions[2–4] in the method of coupling from the series input port to the two loads. This is accomplished with a single-plane configuration using quarter-wavelength short-circuited lines placed along both edges of the main line. Others have done this by using a multiple-plane configuration or by the use of shorted and open-circuited quarter-wavelength elements.

## Precautions and Modifications

In the fabrication of a hybrid junction circuit, there are several precautions which should be observed. The most critical dimension is the width of the coupling gap. Any drastic deviation from the design value will affect the input impedance of port 2. This, therefore, puts a tight registration requirement in the assembly of the circuit. When the two halves of the boards are assembled, the corresponding parts of the circuit should mate, especially the coupling gap.

Symmetry is another requirement necessary in order to maintain the proper balance characteristics. This implies symmetry in the original master made by the draftsman to the symmetrical and accurate etching of the printed circuit boards. Other precautions are the frequent use of grounding screws in order to prevent the propagation of higher-order modes, the use of low-loss dielectric material and the use of well-matched transducers. A circuit made with care in observing all the precautions should give satisfactory results.

In the fabrication of the circuit there may also be a problem involved with overetching the narrow coupling gap. This problem can be eliminated by machining the critical dimension. It is possible to increase the width of the coupling gap to relieve the tolerance, but if this is done it becomes necessary to insert a low-loss, high dielectric-constant material in the gap to maintain the same effective coupling.

A modification in circuit configuration can be made to relieve some of the critical registration tolerance in

[1] J. K. Shimizu, "Strip-line 3-db directional couplers," 1957 IRE WESCON Convention Record, pt. 1, pp. 4–15.
[2] A. Alford and C. B. Watts, Jr., "A wide band coaxial hybrid," 1956 IRE National Convention Record, pt. 1, pp. 171–179.
[3] H. G. Pascalar, "Strip-line hybrid junction," IRE Trans. on Microwave Theory and Techniques, vol. MTT-5, pp. 23–30; January, 1957.
[4] E. M. T. Jones, "Wide-band strip-line magic-T," IRE Trans. on Microwave Theory and Techniques, vol. MTT-8, pp. 160–168; March, 1960.

the assembly of the unit. The circuit can be etched only on one board and the necessary connection in the center of the configuration can be made by soldering a small strip of copper between the desired points. If such a modification is made, it may be necessary to use a thicker layer of copper or a narrower coupling gap in order to maintain the same effective coupling across the gap.

## Conclusion

A printed-circuit strip transmission line hybrid junction with input voltage standing-wave ratio less than 1.26 (2 db) over ±20 per cent band, power division within 0.1 db, and isolation of the two pairs of the conjugate ports greater than 24 db and 40 db has been developed for the UHF band. Circuits have been fabricated which operate satisfactorily up to 1500 mc. These hybrid junction circuits have many useful applications and can easily be reproduced if a few precautions are taken in the etching and assembly of the circuit.

## Acknowledgment

The author gratefully acknowledges the many discussions and helpful suggestions by W. W. Mumford on the subject of hybrid junctions. Appreciation also goes to W. H. Conway for his help in the course of this investigation.

# Gallium-Arsenide Point-Contact Diodes*

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*Summary*—**This paper describes some of the work on gallium-arsenide point-contact diodes which is currently in progress at the Bell Telephone Laboratories, Holmdel, N. J. Gallium arsenide, one of the Group III–V intermetallic compounds, possesses properties which tend to make it superior to either silicon or germanium for many high-frequency diode applications. By controlling the resistivity of the gallium arsenide and the point-contact processing techniques, diodes have been fabricated specifically for use as millimeter wave first detectors, high-speed switches, and reactive elements for microwave parametric oscillators and amplifiers. The operating characteristics of several different types of gallium-arsenide reactive diodes are discussed and mention is made of simple design formulas which may be used to tentatively evaluate the performance to be expected from such diodes. Noise figure measurements are included in a résumé covering some of the experimental results that have been obtained using gallium-arsenide point-contact diodes as variable reactance elements in microwave parametric amplifiers.**

## Introduction

GALLIUM arsenide, one of the Group III–V intermetallic compounds, possesses properties which tend to make it superior to either silicon or germanium for many high-frequency diode applications. By controlling the resistivity of the gallium arsenide and using the proper processing techniques, point-contact diodes have been fabricated specifically for use as millimeter wave first detectors, high-speed switches, or reactive elements for microwave parametric oscillators and amplifiers.[1–6] The important operating characteristics of different types of experimental gallium-arsenide varactor diodes will be discussed in this paper, and mention is made of the general fabrication methods employed in assembling the diodes.

## Materials

All the single-crystal gallium-arsenide (GaAs) material used in this work was prepared by J. M. Whelan, Bell Telephone Laboratories, Murray Hill, N. J. Purified material was doped to the required resistivity by regrowing the crystals in an arsenic atmosphere containing donor impurities such as sulphur, selenium, or tellurium. In order to realize the full electron mobility of the GaAs, efforts were made to avoid compensated doping. The final single crystal $N$-type material was sliced into thin disks, given a back contact of deposited

* Received by the PGMTT, August 8, 1960.
† Bell Telephone Labs., Inc., Holmdel, N. J.

[1] W. M. Sharpless, "High frequency gallium arsenide point contact rectifiers," *Bell Sys. Tech. J.*, vol. 38, pp. 259–270; January, 1959.
[2] B. C. DeLoach and W. M. Sharpless, "An $X$-band parametric amplifier," Proc. IRE, vol. 47, pp. 1664–1665; September, 1959.
[3] M. Uenohara and W. M. Sharpless, "An extremely low noise 6-kMc parametric amplifier using gallium arsenide point contact diodes," Proc. IRE, vol. 47, pp. 2113–2114; December, 1959.
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[6] W. M. Goodall and A. F. Dietrich, "A fractional millimicrosecond electrical stroboscope," Proc. IRE, vol. 48, pp. 1591–1594; September, 1960.