Design of a Coaxial Hybrid Junction*

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Summary—**The design of a coaxial hybrid junction is discussed. The hybrid consists of a shunt junction and a series junction. The shunt junction is a broad-band stub compensated tee, and the series junction is basically a balun of the type used to excite a slotted dipole. There is inherent isolation between the shunt and series terminals. The useful bandwidth of the hybrid is at least 10 per cent, while the bandwidth of the shunt junction alone exceeds this by a factor of four.**

Design data are presented for frequency bands centered at 425 Mc and 220 Mc. Many of these hybrids have been manufactured for application, and the performance repeats very well. Performance data are given for VSWR, isolation, and peak power capacity.

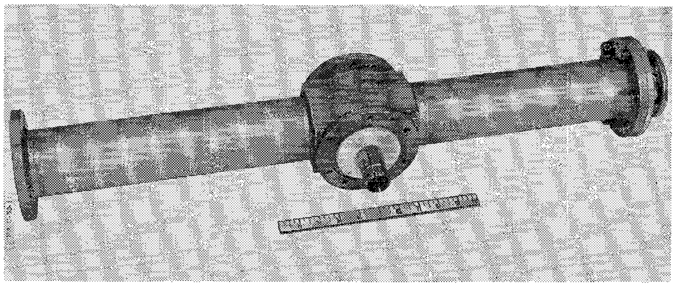

Fig. 1—Photo of 220-Mc hybrid junction.

INTRODUCTION

A COAXIAL hybrid junction has been developed which is suitable for VHF and UHF. The development was motivated by high-power antenna feed system applications including monopulse circuits and power dividers for antenna arrays.[1] A simple analysis of the device will be given and sufficient detailed design information will be furnished to allow construction of the hybrid.

Previous analysis and design of hybrids has been given by Alford and Watts,[2] Jones,[3] and others, of which a comprehensive listing can be found in Jones' paper.

The present design is similar to one reported by Alford and Watts.[2] It was developed before the results of this excellent reference were available. The Alford and Watts design appears to have more bandwidth capability, but the design reported here is simpler and should satisfy many requirements where bandwidth is of the order of 10 per cent.

Two designs were developed for application. The first junction which evolved was for operation over the band 400–450 Mc. The shunt arm and side arms were in $3\frac{1}{8}$ inch coaxial line (RG-154/U) and the series arm was in $1\frac{5}{8}$ inch coaxial line (RG-153/U). Following this, a junction was developed for another application for operation centered at 220 Mc. The shunt and side arms were again fabricated in $3\frac{1}{8}$ inch line and the series arm in $1\frac{5}{8}$ inch line. A photograph of the 220-Mc hybrid is shown in Fig. 1. The mechanical features of these hybrids show that the hybrids are rugged, easy to manufacture, and they give repeatable high quality performance, as evidenced in production of over 300 units for various applications.

ANALYSIS OF SHUNT AND SERIES JUNCTIONS

A drawing of the hybrid is shown in Fig. 2. It consists of a shunt junction and a series junction; the series excitation is brought out from the inside of the shunt junction. The shunt junction is basically a stub supported tee where the inner conductor is slotted down its length for a distance of approximately $\lambda/4$ each side of the junction point with the side arms. When the shunt arm is excited, a wave passes to the side arms and there is no potential difference across the slots in the inner conductor. The difference excitation of the side arms is provided by exciting a voltage difference across the slots at the junction point. This is accomplished with a balun of the type used to excite a slotted dipole.[4] An inner conductor is placed inside the slotted conductor and is connected to one segment of it at the junction point. The inner conductor runs an additional quarter wavelength beyond the junction point to provide a rigid stub support. The balun provides an out-of-phase excitation to the side arms which is independent of frequency. Likewise, the shunt junction provides an in-phase excitation which is independent of frequency. There is, therefore, an inherent isolation between shunt and series arms provided by the geometry of the junction, as in the case of the waveguide magic tee. This is superior to the ring-type of hybrid, which is frequency sensitive.

An ideal hybrid has no cross coupling between the shunt and series arms and is matched looking into the shunt arm and the series arm when matched loads are placed on all other arms. It can be proved from the scat-

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[1] L. Stark, "A helical line scanner for beam steering a linear array," IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-5, pp. 211–216; April, 1957.

[2] A. Alford and C. B. Watts, "A wide-band coaxial hybrid," 1956 IRE NATIONAL CONVENTION RECORD, pt. I, pp. 171–179.

[3] 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.

[4] H. J. Riblet, "Slotted Dipole Impedance Theory," M.I.T. Rad. Lab., Cambridge, Mass., Rept. No. 772; November 1945.

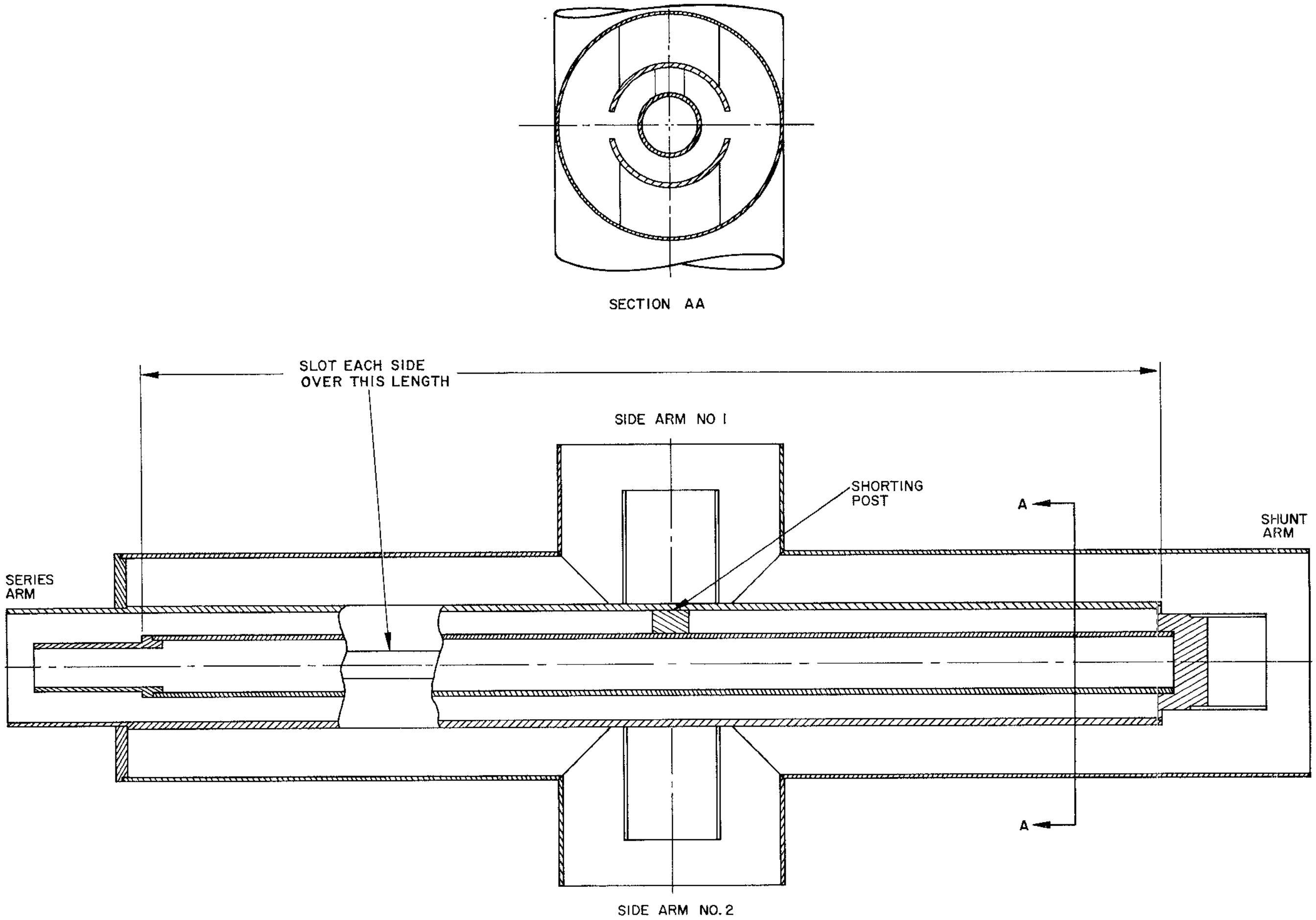

Fig. 2—Drawing of coaxial hybrid junction.

tering matrix of the junction[5] that it will then follow that the side arms will be matched and isolated from each other. A study of the series and shunt junctions will show the steps necessary to provide the matched condition in each of these junctions and thus approach the ideal performance.

Shunt Junction

The shunt junction is a stub-supported tee as shown in Fig. 3. The broad-band design of this type of junction has been studied extensively.[6–8] A simple and effective method having ample bandwidth is to design the quarter-wave transformer and the stub support so that characteristic impedances of these line sections are the same

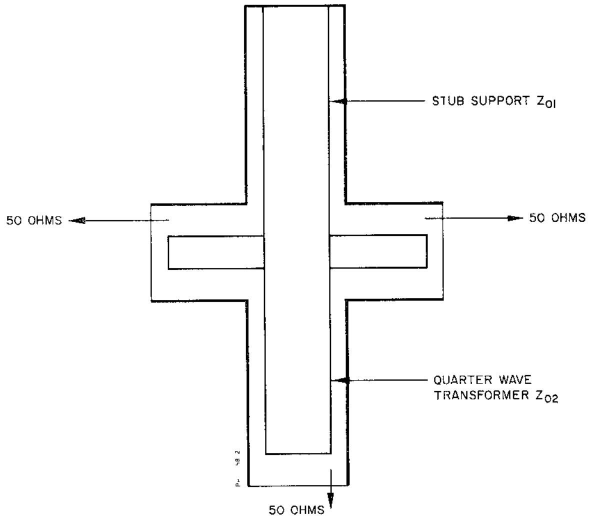

Fig. 3—Schematic drawing of stub-supported tee junction.

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[5] C. G. Montgomery, "Technique of Microwave Measurements," M.I.T. Rad. Lab. Ser. vol. 11, McGraw-Hill Book Co., Inc., New York, N. Y., pp. 518–519; 1947.

[6] V. H. Rumsy, "Design of Frequency Compensating Matching Sections," Combined Res. Group, Naval Res. Lab., Washington, D. C., Rept. No. 89; September 1945.

[7] J. Reed and G. Wheeler, "A broadband fixed coaxial power divider," 1957 IRE National Convention Record, pt. I, pp. 177–181.

[8] G. L. Ragan, "Microwave Transmission Circuits," M.I.T. Rad. Lab. Ser., vol. 9, McGraw-Hill Book Co., Inc., New York, N. Y., pp. 516–519; 1948.

and equal to $R_0/\sqrt{2}$, where R_0 is the common impedance value to which all arms are to be matched, in this case 50 ohms. The frequency sensitivity of the stub support then cancels the frequency sensitivity of the quarter-wave transformer to a first order and the junction is much broader band than without the stub. The theoretical bandwidth is 33 per cent for a VSWR less than 1.07.[7] The characteristic impedance of the line sections with the slotted conductor is changed by a negligible amount by the presence of the slots, even though the slots are rather wide. That this should be so was predicted on the basis of calculated results for a slotted *outer* conductor where the slot subtended the same angle,[9,10] and this assumption was verified by measurement. The lengths of the nominal quarter-wave transformer and stub support sections were determined by experiment so as to include the junction effect. Design data were taken in the 425 Mc band for $3\frac{1}{8}$ inch line and $1\frac{5}{8}$ inch line. By scaling, the latter data served for the design of a 220 Mc-junction in $3\frac{1}{8}$ inch line. The data are summarized in Table I. The characteristic impedance of these line sections is 35.35 ohms, which is obtained with a diameter ratio of 1.805.

TABLE I

TRANSFORMER AND STUB LENGTHS FOR OPTIMUM PERFORMANCE OF SHUNT JUNCTION

	425 Mc		220 Mc	
	L_{Trans}	L_{Stub}	L_{Trans}	L_{Stub}
$1\frac{5}{8}$ inch line	7.000 inches	7.445 inches		
$3\frac{1}{8}$ inch line	6.750	7.500	13.500 inches	14.350 inches

Series Junction

In the design of the series junction, the side arms are energized in series by means of a balun. The balun is fed at the input by a 50-ohm coaxial transmission line. Across the output of the balun is a stub support for the inner conductor. The voltage and current transformations which occur along the balun have been investigated by Riblet.[4] He analyzed the balun as a three conductor system on which two TEM modes can propagate. One mode has the configuration shown in Fig. 4(a), and the second mode has the configuration shown in Fig. 4(b). For the first mode, the potential difference between the two halves of the outer conductor is zero. This is a perturbed ordinary mode of coax.

For the second mode, the potential of the inner conductor is half way between the potential between the split outer conductors and the net current on the center conductor is zero. The amplitudes of the mode currents are related to the voltages by the characteristic impedances of the modes, which are calculated in reference 10.

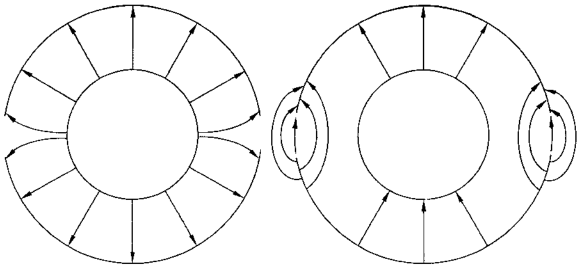

Fig. 4—Field patterns of coaxial modes. (a) First. (b) Second.

By applying the following appropriate end conditions to the three-wire system,

1) voltage between outer conductors is zero at input end,
2) voltage between inner conductor and one half of outer conductor is zero at output end,
3) load impedance Z_L is connected between inner conductor and the other half of outer conductor,

an equivalent circuit is derived which is shown in Fig. 5. The balun has the property of dividing the load impedance by four in transforming it from the terminals to the ordinary coaxial line mode. In shunt with the load are two parallel stubs, one due to the stub support and the other due to the slotted outer conductor extending towards the input from the junction. The Z_0 of the stubs is the characteristic impedance of the mode shown in Fig. 4(b), and the shunt impedance presented by the stubs is divided by 4. The length of each stub is the length of the corresponding slot measured from the junction.

The characteristic impedance of the input line section is the Z_0 of Fig. 4(a), and is negligibly different from the impedance of ordinary coax with slot widths that have been used.

The impedance presented to the balun by the side arms is 100 ohms. Since the balun divides the impedance by four, a 35.35-ohm quarter-wave transformer is used in the feeding coaxial section to bring the impedance to 50 ohms. The diameter ratio of outer to inner conductor is thus 1.805, as in the case of the shunt junction. An optimum broad-band stub support for this transformer can be calculated as in the case of the shunt junction but the required value of characteristic impedance places an impractical value on the slot width. The equivalent stub should have a characteristic impedance of 35.35 ohms, as seen by the ordinary coaxial line mode. This would require that each of the parallel stubs across the balun have a Z_0 of $4\times2\times35.35=283$ ohms, which is too high to be achieved with this configuration. The hybrids which have been developed in $3\frac{1}{8}$ inch line have used a slotted conductor which is 1.60 inches mean diameter with slots which were 0.375 inch wide. These parameters gave a characteristic impedance of approximately 75 ohms.[10] The bandwidth of the series arm is thus more restricted than that of the shunt arm, for which an

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[9] "Reference Data for Radio Engineers," IT&T Corp., New York, N. Y., 4th ed., p. 594; 1957.

[10] J. Smolarska, "Characteristic impedance of the slotted coaxial line," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-6, pp. 161–166; April, 1958.

optimum broad-band stub is practical. In the design of the series junction, the lengths of the slots and the quarter-wave transformer were made equal to a quarter wavelength at the center frequency. The junction effect proved to be small and therefore the impedance match at band center was quite favorable.

Measured Performance Data

Two hybrid junctions have been designed, one for the frequency band 400–450 Mc and the second for a band centered around 220 Mc. A large number of these hybrids have been produced for antenna feed applications. The electrical features of the design are essentially as discussed above. One additional modification has been introduced to lengthen electrically the stub support for the balun. As shown in Fig. 6, a block of teflon has been placed at the input end of the stub support. The physical length of the stub is less than $\lambda/4$ because the slot is milled in the conductor which provides the quarter-wave transformer for the shunt junction (*cf.*, Table I). The stub support is teflon filled for a length of 1.0 inch for each of the designs.

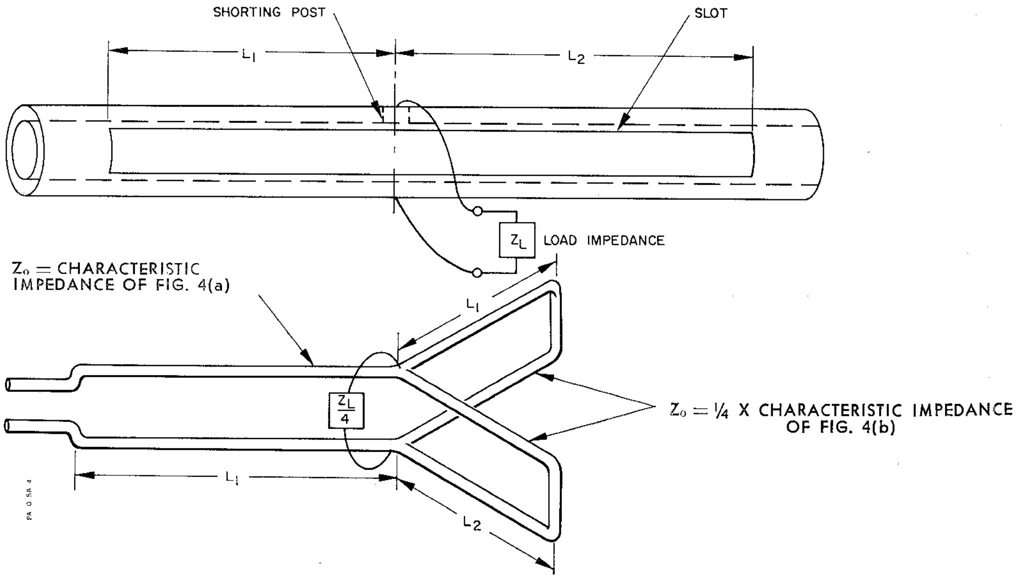

Fig. 5—Equivalent circuit of series junction.

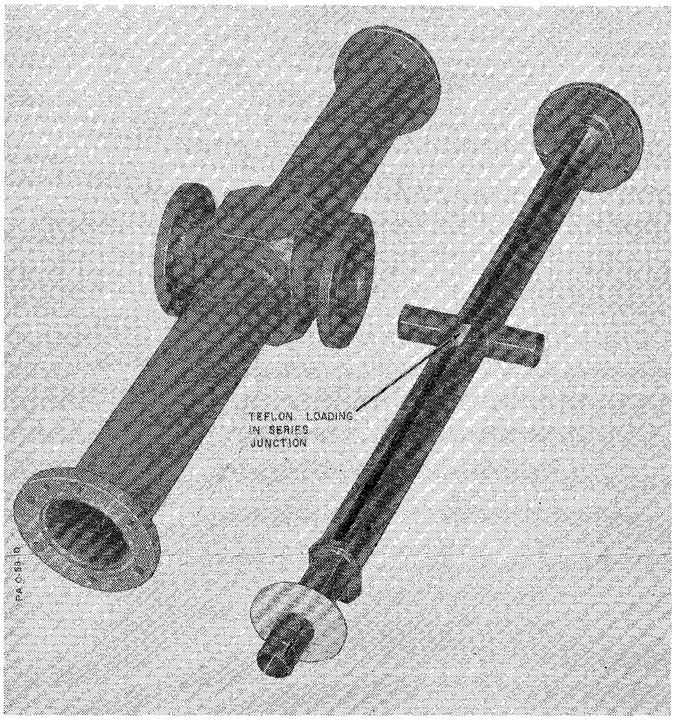

Fig. 6—Photo showing teflon loading in series junction.

Measurements of VSWR and isolation are shown in Figs. 7, 8, 9 and 10 for the two designs. The frequency independence of isolation between the shunt and series arms is noted. The shunt junction is very broad band and the series junction has a VSWR less than 1.40 over a 10 per cent band. The side-arm VSWR is intermediate between the shunt and series-arm VSWR's. The isolation between side arms is dependent upon the match of the shunt and series arms and is thus frequency dependent. The isolation is greater than 20 db over a 10 per cent band.

The hybrids have been tested and operated under high peak power conditions. The shunt junctions have been tested with 2.5 Mw of peak power with no arcing. The 220 Mc hybrid was tested at a reduced pressure of 0.33 atmosphere and no arcing was observed at 0.5 Mw of power. This indicates a power capacity of 4.5 Mw at one atmosphere. The shunt junction appears to be able to handle as much power as a uniform length of 50 ohm $3\frac{1}{8}$ inch line. A contributing factor to the high power capacity is the 35-ohm characteristic impedance of the line sections, which is nearly optimum for voltage breakdown considerations.

The series junction of the 220-Mc hybrid was high

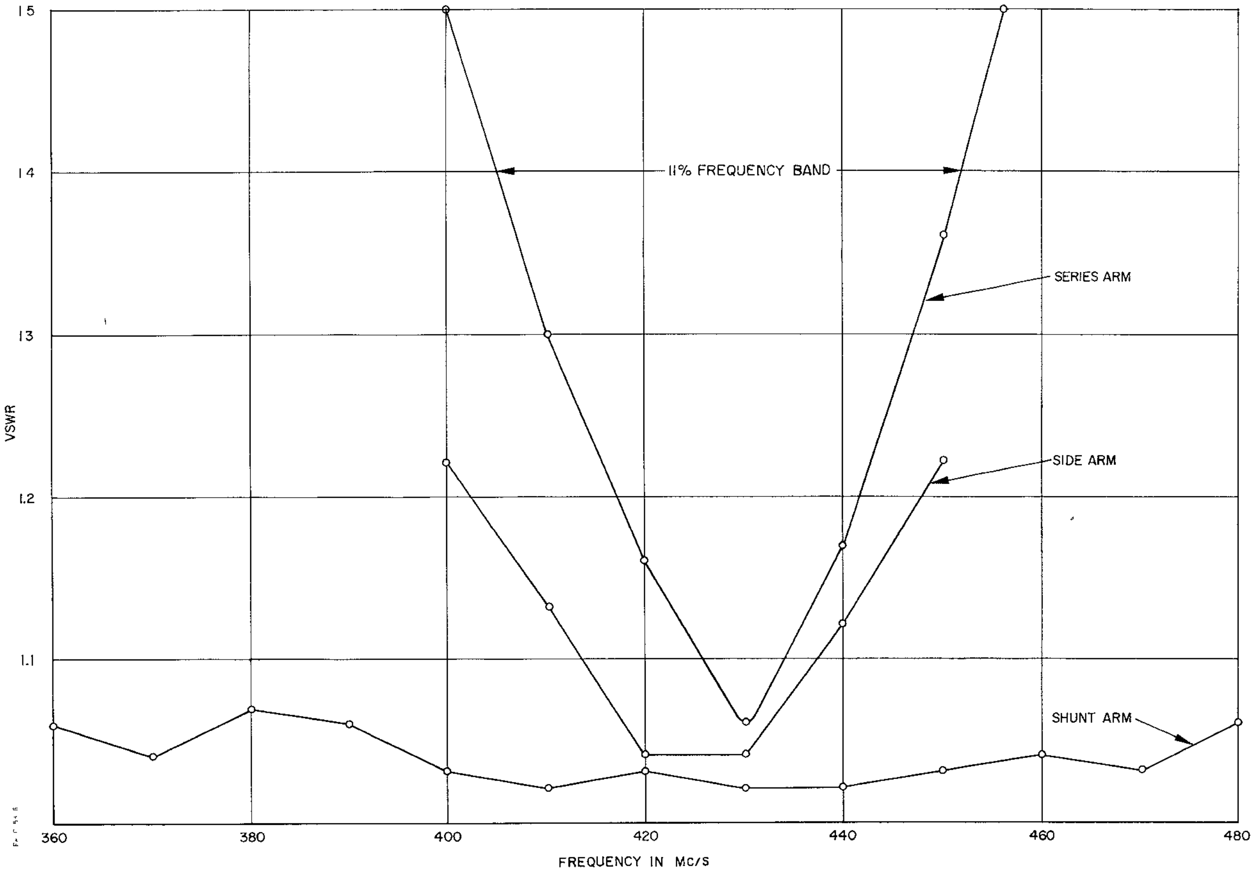

Fig. 7—VSWR of 425-Mc hybrid.

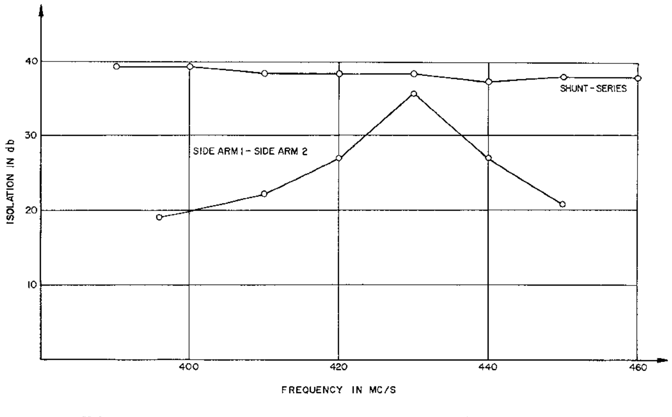

Fig. 8—Isolation between arms of 425-Mc hybrid.

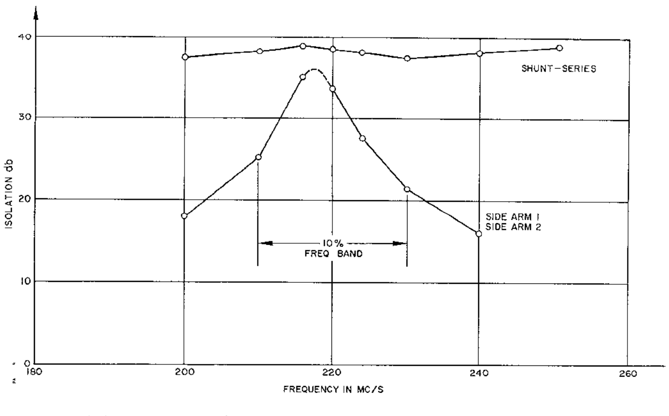

Fig. 9—Isolation between arms of 220-Mc hybrid.

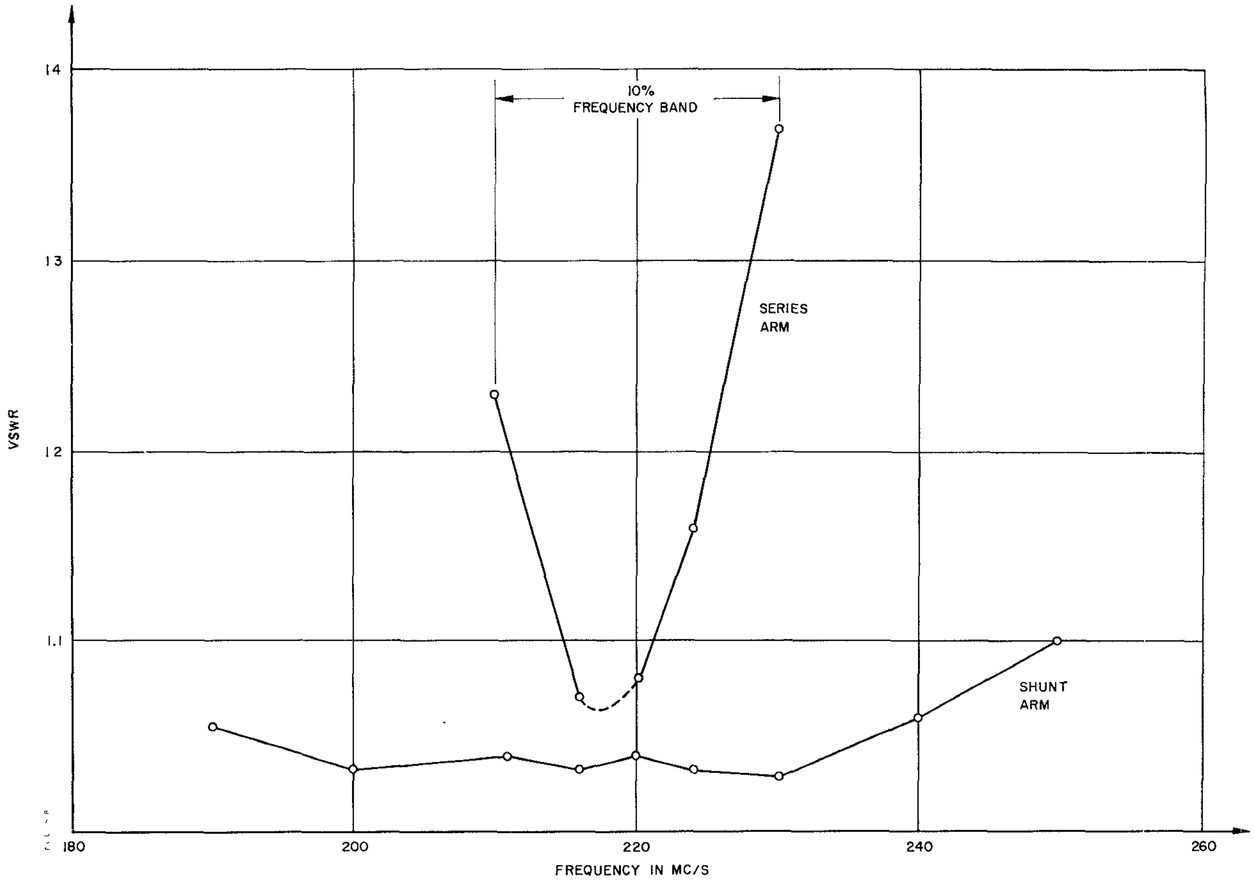

Fig. 10—VSWR of 220 Mc hybrid.

power tested at 1 atmosphere pressure and arcing occurred at 200 kw. The position of arcing was across the slot at the teflon filler for the stub support. The power capacity could be increased substantially, if required, by grooving the teflon piece and rounding the corners of the slot in the conductor.

Conclusions

The theory and design of a coaxial hybrid junction has been presented. The hybrid has inherent isolation between the shunt and series arms. The shunt arm has a nearly optimum broad-band impedance match by virtue of stub compensation. The series arm cannot be compensated in an optimum manner; however, the VSWR is less than 1.4 over a 10 per cent frequency band. Hybrid designs were given for bands centered at 425 Mc and 220 Mc. Many hybrids have been produced with repeatable results. Typical performance data have been given.

Acknowledgment

The author would like to acknowledge the assistance of R. Tang in carrying out a detailed set of high-power measurements for the 220-Mc hybrid and the assistance of W. E. Bullen, Jr. in obtaining VSWR and isolation measurements.