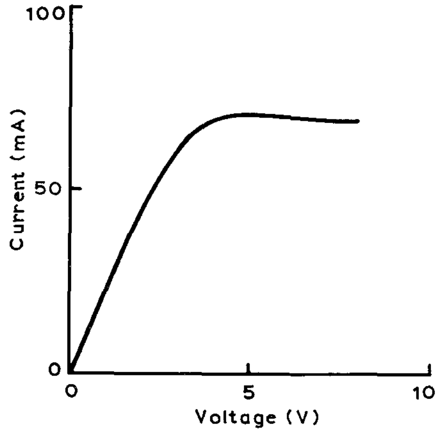

Fig. 1. A dc current–voltage characteristic of a typical Gunn device (CXY 11).

TABLE I

CW Transmission Loss Characteristic of Gunn Device as a Function of Incident RF Power Level

Input Power Level (dB)	Insertion Loss (dB)
−14	0
−12	0.4
−10	1.0
−8	2.0
−6	2.6
−4	3.4
−2	4.0
−1	4.2
0 (850 mW)	4.4

TABLE II

Pulsed Transmission Loss Characteristic of Gunn Device as a Function of Incident Peak RF Power Level

Input Power Level (Peak) (dB)	Insertion Loss (dB)
−20	0
−18	0
−16	+0.1
−14	−0.1
−12	+0.4
−10	−0.2
−9	−0.2
−8	−0.1
−7	+0.6
−6	+1.6
−5	+2.8
−4	+3.8
−3	+4.7
−2	+5.3
−1	+5.8
0	+6.0

due in part to a significant voltage swing over the characteristic. Similarly, the bias situation will change due to the mean (time average) value of dc resistance changing. Both of these effects will result in an absorption of power since the shunt conductance will increase.

III. Experimental Results

In an endeavor to test the principal of this hypothesis the following simple experiment has been performed. A Gunn sample mounted in a pill encapsulation has been placed across a 50-Ω coaxial line and biased to 4.5 V and the transmission characteristic examined with CW power at 6 GHz as the power level was increased. The insertion loss of the system was measured at each power level. Table I shows the results obtained using a CXY 11.

The VSWR at all levels was not large (less than 2.4). It should be noted that the bias value was adjusted to give limiting in the range of power levels shown above. Limiting at higher levels should be obtainable at lower bias levels.

A similar pulse power experiment has been undertaken at 9375 MHz with a pulse length of 10 μs and a PRF of 5 kHz. A bias voltage of 4.6 V was applied.

Table II shows the variation of insertion loss as a function of frequency 0 dB is $1\frac{1}{2}$-W peak and 75-mW mean.

It will be noted that the limiting action occurs at a peak power similar to that of the CW case, suggesting that the limiting action is essentially a peak effect.

IV. Comments

It is clear that there is evidence of limiting action. Since neither the impedance of the line nor the Gunn-effect characteristics have been selected to optimize any limiting effect, it is reasonable to assume that a design system would produce more than $4\frac{1}{2}$ dB of compression.

It is interesting that compression is observed with a Gunn device since unlike other semiconductor limiters it does not rely on the behavior of a junction. It is therefore possible that the behavior under pulse conditions will be attractive, particularly as typical Gunn samples can dissipate substantially more than 1 W of mean power.

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Top-Wall and Branch-Waveguide Hybrids for Millimeter Wavelengths

MARTIN F. BOTTJER and HOWARD E. KING

***Abstract*—Top-wall and multiple-branch waveguide couplers were developed as hybrid junctions for millimeter wavelengths, and their electrical characteristics were measured. For construction of the 55-GHz top-wall coupler, electroforming techniques were used; for the 94-GHz branch-guide coupler, the branch lines were cut directly into the wall of the main guide. Copper losses were less than 0.2 dB for the two types of couplers.**

I. Introduction

The hybrids discussed herein were developed for radiometer RF circuits operating at 55 and 94 GHz. The physical features, the design and construction details, and the measured performance characteristics are described.

II. Description and Construction of Hybrids

Two forms of hybrids were designed for two frequency ranges in the millimeter wavelength region: 1) a top-wall coupler [1] for the 53.5- to 56.2-GHz frequency range, and 2) a multiple-branch waveguide 3-dB coupler [2] for the 88- to 96-GHz range. The exploded views of the two hybrids are illustrated in Figs. 1 and 2, respectively.

A. Top-Wall Hybrid, 53.5 to 56.2 GHz

The top-wall hybrid is a junction between two parallel lengths of waveguide joined along a common broad-wall surface. Coupling slots introduced in this common broad wall of the waveguide facilitate the

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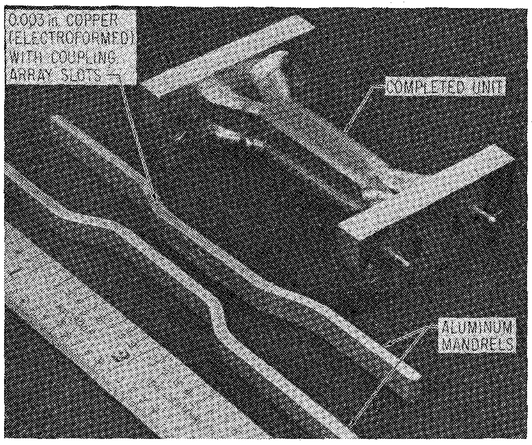


Fig. 1. Top-wall 3-dB hybrid.

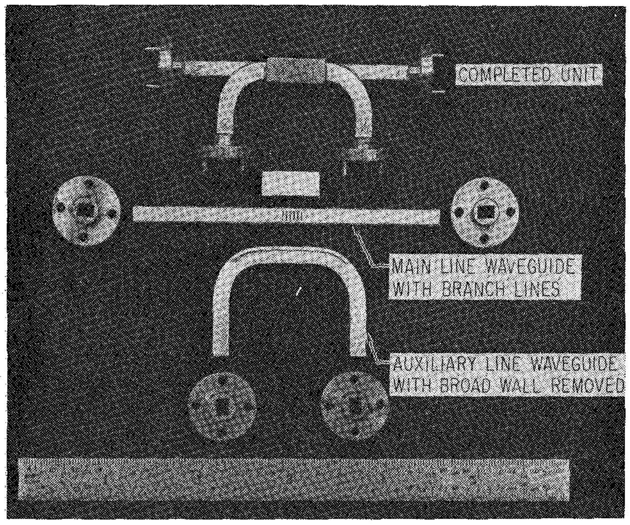


Fig. 2. Multiple-branch waveguide 3-dB hybrid.

coupling. The design of the coupling array followed standard waveguide techniques. The array was formed on the thin (with respect to wavelength) sheet of common wall between the two coupled waveguides. Instead of using the usual circular holes, an array of rectangular slots was used, because of the convenience in machining with an electrical discharge machine (EDM).

Fig. 1 depicts the construction technique and the assembled hybrid. The waveguides are WR-15 (0.148×0.074-in ID). Aluminum mandrels [3] with cross-sectional dimensions equivalent to the inner dimensions of WR-15 were formed to the desired mechanical shape. Next a 0.003-in thickness of copper was electroformed over that portion of the mandrel required for the coupling array. By means of the EDM, the array was machined to the desired dimensions, with shim stock being used as the cutting tool. Fig. 3 shows the dimensions to achieve the 3-dB coupling and bandwidth. After the slots were cut, the two mandrels were clamped together and then electroformed as an integral unit. With the flanges attached, the entire assembly can be viewed in the photograph of Fig. 1.

B. Branch-Guide Hybrid, 88 to 96 GHz

For the 3-mm hybrid, a multiple-branch coupler was designed. The WR-10 (0.100×0.050 in ID) waveguide has a wall thickness of 0.040 in, which is approximately $\lambda_g/4$ at the design frequency.[1] A

[1] Subsequent branch-guide hybrids for 60 GHz have been constructed by use of a 1/16-in thick copper plate sandwiched between the two waveguides, with their top walls machined off.

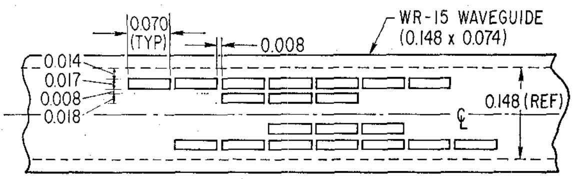


Fig. 3. Dimensions of coupling array for top-wall hybrid coupler.

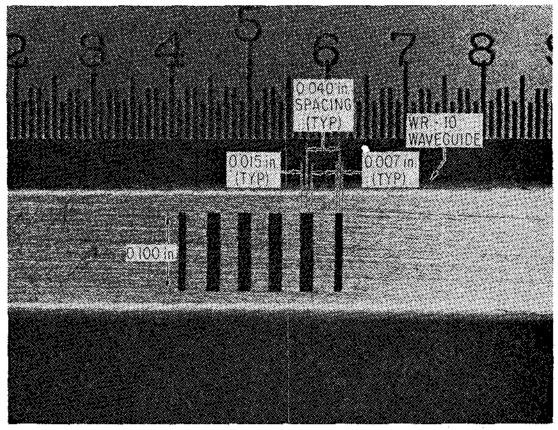


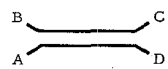
Fig. 4. Branch-line guides in main line for the WR-10 multiple-branch waveguide coupler.

TABLE I

Electrical Characteristics of Top-Wall 3-dB Coupler

Frequency, GHz	Loss A-C, dB	Loss A-D, dB	Isolation A-B, dB	VSWR		
				A	C	D
53.5	2.73	3.60	>25	1.12	1.05	1.10
55.0	2.97	3.34	>25	1.18	1.13	1.05
56.2	3.18	3.18	>25	1.16	1.10	1.07

Legend: A, B, C, and D refer to points on completed unit:

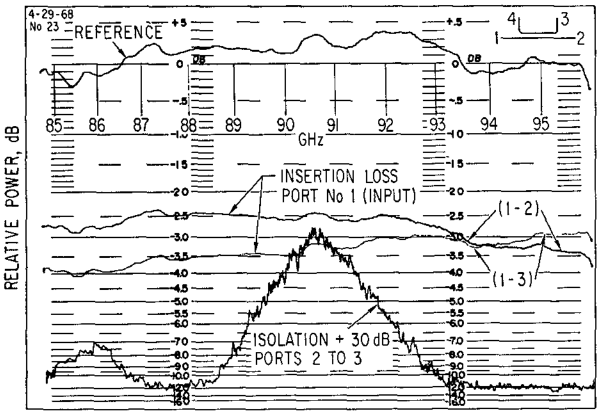


branch waveguide coupler consists of n connecting branch lines, $\lambda_g/4$ long, made of waveguide of the same width as the main line but of reduced height. The branch lines are formed in the wall of the main line waveguide, as illustrated in Figs. 2 and 4. The branch-guide coupler assembly procedure (Fig. 2) avoids the electroforming process. To minimize the distortion of two H-plane bends, an aluminum mandrel was inserted into a straight length of WR-10 waveguide prior to bending. A portion of the top wall was milled off, and then the aluminum was removed from the waveguide with a solution of sodium hydroxide. Design constants were obtained from Reed [2] to determine the dimensions of the six branch lines (Fig. 4). After the machining of the branch lines was completed, the two waveguides were assembled and soldered, as illustrated in the top view of Fig. 2.

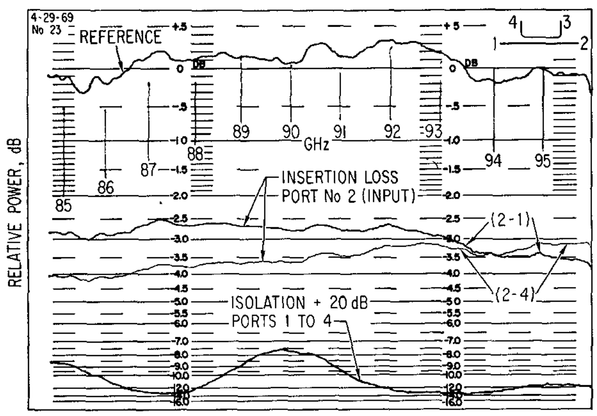
III. Electrical Characteristics of Hybrids

The performance characteristics of the top-wall hybrid junction are tabulated in Table I.

The branch-line coupler characteristics are depicted in the sweep curves of Fig. 5. The top sweep represents the reference curve with the generator connected directly to the bolometer. Frequency markers are shown for every 1 GHz. The ordinate scale is calibrated in decibels. The insertion-loss curves between the input port and the two output terminals and the isolation response to the fourth port are shown. Fig. 5(a) shows the sweep curves, with port 1 used as the input terminal, while in Fig. 5(b) port 2 is the input terminal. The



(a)



(b)

Fig. 5. Characteristics of multiple-branch 3-dB coupler.

isolation from terminals 2 and 3 [Fig. 5(a)] was measured with 30 dB removed from the bolometer amplifier; hence, the worst isolation is approximately 33 dB at 90.5 GHz. For the isolation curves for terminals 1 through 4 [Fig. 5(b)], 20 dB was removed from the bolometer amplifier, representing a minimum isolation of 27.5 dB.

Equal power split was obtained at 94 GHz, the design frequency. The power differential is approximately 0.5 dB for a ± 2-GHz band. At 85 GHz, the difference in power between the two coupled arms is only 1.1 dB. From past experience it should be pointed out that if each of the slot widths (Fig. 4) were increased by 0.001 in, the frequency for equal power division would be at approximately 88 GHz.

The VSWR at 94 GHz of the various input ports with matched terminations on the other ports are as follows:

Input Port	VSWR
1	1.06
2	1.03
3	1.08
4	1.07

IV. Conclusions

A top-wall and a multiple-branch waveguide coupler were developed as hybrid junctions for millimeter wavelengths. Conventional microwave design techniques were used. The top-wall coupler was constructed by means of electroforming techniques. For the 94-GHz branch-guide coupler, the waveguide wall thickness was approximately $\lambda_g/4$ thick; therefore, the branch lines were cut directly into the wall of the main guide. It was found that the coupling array was predictable from existing design information. The copper losses are less than 0.2 dB for the two types of couplers. The isolation is greater than 25 dB and 27.5 dB for the top-wall and branch-guide couplers, respectively.

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High-Efficiency High-Power TRAPATT Operation of a Single "Poor Man's" Diode

ELIOT D. COHEN

***Abstract*—The operation of a single Fairchild FD-300 diode at approximately 40-percent efficiency is reported. Peak power output was 90 W at 502 MHz. These diodes are of particular interest because they are exceptionally inexpensive commercially available diodes which have been found to exhibit TRAPATT behavior.**

Chaffin and EerNisse [1] first reported high-power TRAPATT oscillations from a Fairchild FD-300 computer diode. At that time, efficiencies on the order of 15 percent were achieved taking into account the starting delay characteristic of TRAPATT oscillators. Recently, two reports [2], [3] of high-efficiency TRAPATT operation at UHF frequencies of several Fairchild FD-300 diodes connected in parallel have been published. Each author reported substantially lower efficiency with a single diode as compared to what could be achieved with three of these diodes connected in parallel. Kostishack [2] reported attaining 75-percent efficiency by operating three diodes in parallel as compared to 19-percent efficiency for a single diode and Chaffin [3] reported 46-percent efficiency for three diodes in parallel as compared to 15-percent efficiency for a single diode. One would expect that with the proper circuit, one diode should operate with *at least* as much efficiency as a larger number connected in parallel.

The circuit shown in Fig. 1 is similar to one used by Prager, Chang, and Weisbrod [4]. The diode is mounted in the HP 440A detector mount. This mount has a sliding short located behind the diode for tuning purposes and a built-in capacitor in the bias arm. Both the PRD 306A tuner and the homemade tuner are double stub tuners. The homemade tuner was used to provide a low insertion loss impedance match between the low-pass filter and the high-pass filter. Its physical appearance and electrical characteristics are similar to that of the PRD 306A tuner. With the first stub of the PRD 306A tuner completely removed and the other stubs and sliding short behind the diode properly adjusted, output power of 90 W with 39-percent efficiency was achieved from a single diode at 502 MHz taking into account the starting delay. Note that this circuit differs from circuits used by others (e.g., [1]) in that the attenuators are not an integral part of the oscillator. They are used solely to reduce the power from the oscillator to a reasonable level for measurement; hence all of the output power is accessible at plane AA'. Fig. 2 indicates the input bias voltage, bias current, and rectified RF output pulse. Two diodes in parallel were also operated in a similar circuit with a four-slug tuner inserted between the first stub tuner and the

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