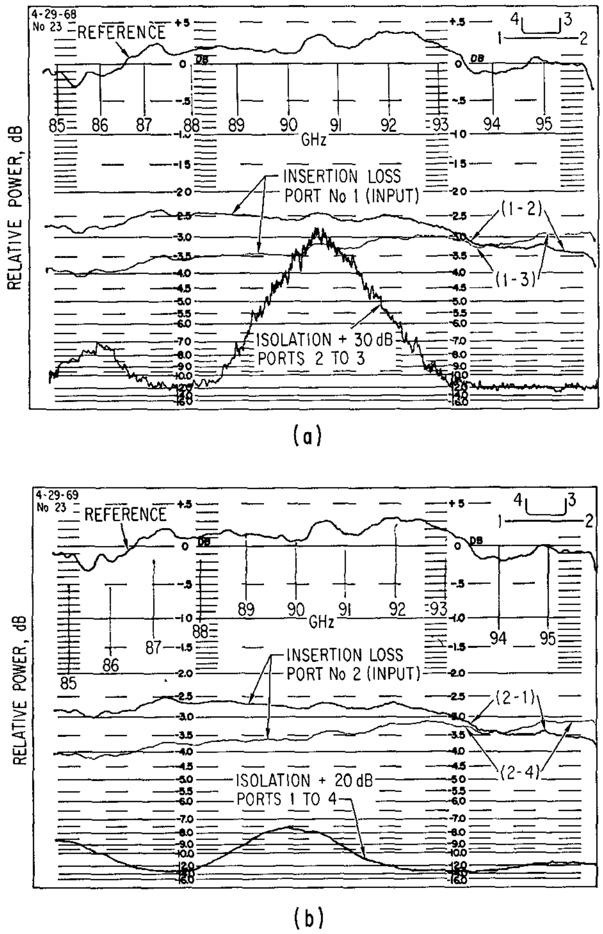

Fig. 5. Characteristics of multiple-branch 3-dB coupler.

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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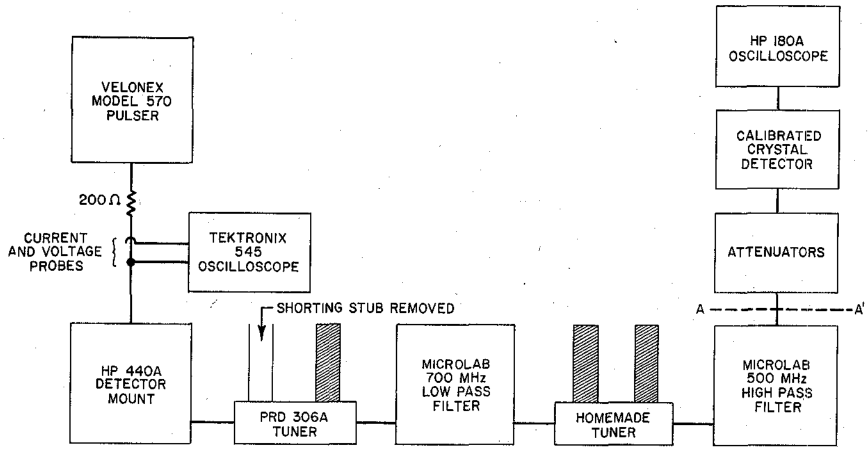

Fig. 1. Experimental circuit block diagram for high-efficiency single-diode oscillator.

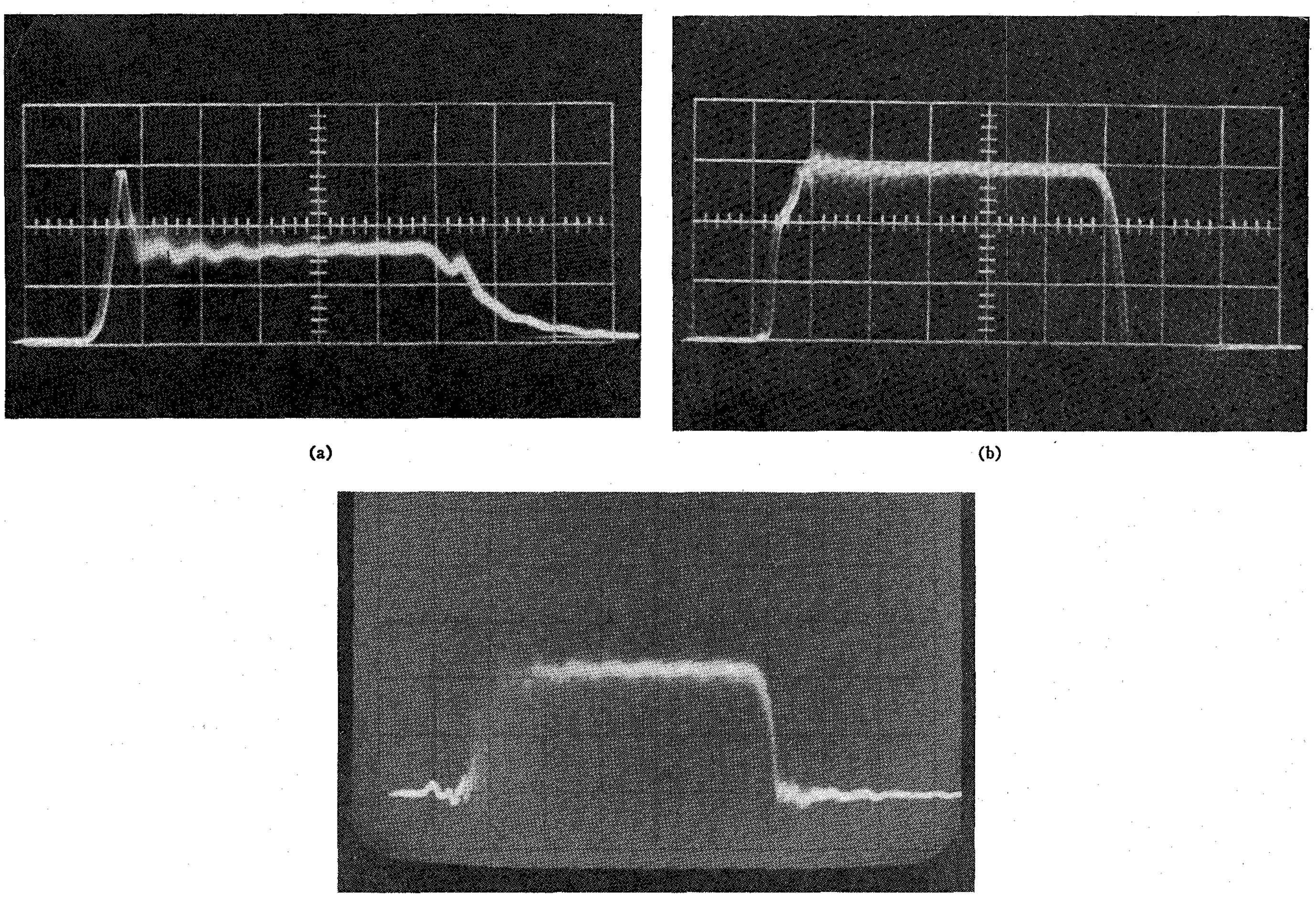

Fig. 2. Bias and rectified output pulses for single diode. (a) Voltage: 100 V/div. (b) Current: 0.5 A/div. (c) Detected RF. Horizontal scale: 100 ns/div.

Microlab low-pass filter. Output power of 182 W with 36-percent efficiency at 506 MHz was achieved. However, the output was noisier than with one diode and the input pulse length had to be increased from about 0.6 μs to 1.0 μs because of leading edge pulse jitter over a much greater portion of the rectified RF output pulse.

In earlier experiments, using a four-slug tuner connected directly between the HP 440A detector mount and the Microlab low-pass filter with no stub tuners the results in Table I were achieved. In this case, the circuit again was obviously optimum for the single diode.

A wide-band Nytek spectrum analyzer was used to monitor harmonics of the fundamental TRAPATT frequency. At the output, no higher harmonics were observed. However, at a point near the diode, harmonic oscillations were observed approximately every 500 MHz up to 7 GHz.

TABLE I
RESULTS USING FOUR-SLUG TUNER CIRCUIT

Number of Diodes	Diode Voltage (V)	Diode Current (A)	Peak Power Output (W)	Efficiency (%)	Frequency (MHz)
1	180	1.35	78	32.1	496
2	210	2.8	170	29.0	488
3	220	4.2	180	19.5	510
4	210	6.2	300	23.0	510

It should be noted that only two FD-300 diodes out of approximately 12 tested produced TRAPATT oscillations with efficiency as high as 38 percent. Both of these diodes had identical breakdown voltages of 223 V and both had a substantially higher voltage drop than the other diodes tested when operating in the TRAPATT mode. Several other diodes produced TRAPATT oscillations in this circuit but with slightly less efficiency and in some cases greater noise.

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Application of Deschamps' Graphical Method to Measurements of the Scattering Coefficients of Multiport Waveguide Junctions

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Abstract—**A method for measuring scattering coefficients of a multiport waveguide junction is presented. It is based on the application of Deschamps' graphical technique to reduced multiport junctions, and analysis of measurements done with either matched or nearly matched loads terminated at all but the input and output ports. Averaging and least-square fitting are introduced to reduce errors from measurements.**

In an earlier correspondence, Stein [1] presented an extension of Deschamps' graphical method [2] to measurements of scattering coefficients of multiport waveguide junctions. In that method, reflection coefficients are measured at the input port with all other ports terminated by movable shorts. By changing the positions of the movable shorts systematically, a series of Deschamps' graphs may be constructed. Scattering coefficients may then be calculated from the results obtained in these graphs. Since this method requires a large number of measurements with still larger numbers of constructions of Deschamps' graphs, it becomes impractical for junctions with more than four ports. In the present correspondence, we report a direct application of Deschamps' graphical method to a multiport waveguide junction, which is terminated with matched or nearly matched loads at all but the input and output ports. This enables one to reduce the required VSWR measurements and the Deschamps-type constructions drastically. A brief description of our method is presented in the following paragraphs.

Without losing generality, let the input port be port one and the output port be port two. One arrives at the following determinant equation from the definition of scattering matrix.[1]

$$\begin{vmatrix} S_{11}-\frac{1}{\Gamma_1} & S_{12} & S_{13} & \cdots & S_{1n} \\ S_{12} & S_{22}-\frac{1}{\Gamma_2} & S_{23} & \cdots & S_{2n} \\ S_{13} & S_{23} & S_{33}-\frac{1}{\Gamma_3} & \cdots & S_{3n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ S_{1n} & S_{2n} & S_{3n} & \cdots & S_{nn}-\frac{1}{\Gamma_n} \end{vmatrix} \equiv 0 \tag{1}$$

where $\Gamma_j = a_j/b_j$, and a_j and b_j are complex numbers representing incoming and outgoing waves to the junction. Using standard expansion rules for determinant and assuming that the mismatches from port three through port n are small, one neglects some of the higher order terms of Γ_j with $j \leq 3$, and arrives at

$$\frac{1}{\Gamma_1} = S_{11}' + \frac{S_{12}'^2\Gamma_2}{1 - S_{22}'\Gamma_2} \tag{2}$$

where

$$S_{ii}' = S_{ii} + \sum_{j=3}^{n} \frac{S_{ij}^2\Gamma_j}{1 - S_{jj}\Gamma_j}, \qquad \text{with } i = 1 \text{ or } 2 \tag{3}$$

$$S_{12}' = S_{12} + \sum_{j=3}^{n} \frac{S_{1j}S_{2j}\Gamma_j}{1 - S_{jj}\Gamma_j}. \tag{4}$$

A comparison shows that (1) is in the same form as [2, eq. (11)], where the scattering coefficients S_{11}, S_{22}, and S_{12} of the two-port junction are replaced, respectively, by modified scattering coefficients S_{11}', S_{22}', and S_{12}' of the reduced multiport. One can then obtain these modified scattering coefficients by adopting Deschamps' method with input and/or output connected at different ports for different sets of measurements. With perfectly matched loads, $\Gamma_j = 0$ for $j = 3$ to n. The multiport scattering coefficients are directly measured.

In the case of slight mismatches at port three through port n, S_{11} may be solved from measurements done according to the following procedure.

1) Measuring the reflection coefficient Γ_1 at an input port with nearly matched loads at all other ports. The reflection coefficient can be obtained from (2) with higher order terms of Γ_j, $j = 2$ through n neglected,

$$\frac{1}{\Gamma_1} = S_{11} + \sum_{j=2}^{n} \frac{S_{1j}^2\Gamma_j}{1 - S_{jj}\Gamma_j} \equiv S_{11}^{(0)}. \tag{5}$$

2) Replacing the load at port k with a movable short with the other ports remaining unchanged. By using Deschamps' measuring process, S_{11}', S_{kk}', and S_{1k}' can again be measured. Let this S_{11}' be $S_{11}^{(k)}$, then

$$S_{11}^{(k)} \equiv S_{11} + \sum_{j=2}^{n}{}' \frac{S_{1j}^2\Gamma_j}{1 - S_{jj}\Gamma_j} \tag{6}$$

where $\sum'$ signifies summation over j, except for the $j = k$ term. The

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[1] It should be noted that a reciprocal junction is implied in this definition and also that the characteristic impedances of all arms are assumed to be equal. However, the method can be easily extended to apply to the nonreciprocal junctions and junctions with unequal characteristic impedance on different arms.