A Lossless Radially Symmetric TEM-Line IMPATT-Diode Power Combiner

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ABSTRACT

Verification of a new approach to circuit-level power combining of negative resistance devices is presented. Lossless combining networks and band-limited IMPATT-diodes are utilized to provide stable combiner designs of improved bandwidth without resistive stabilization.

I. INTRODUCTION.

The purpose of this paper is to present results associated with a new approach to circuit-level power combining of multiple negative-resistance devices. The proposed approach[1] utilizes properties of radially symmetric lossless TEM-line combining networks together with band-limited negative-resistance devices to achieve a "device-circuit" interaction which results in a stable combiner design having improved bandwidth over other approaches.

These combining networks fall into the category of N-way non-resonant combiners which are often associated with various band-limiting resistive stabilization techniques for suppressing non-power-producing interactions among devices. The combining design requires no such stabilizing scheme. Suppression of undesired, non-power-producing modes is accomplished in lossless circuits by an appropriate "marriage" of device and circuit which provides the necessary conditions for a stable combiner.

An experimental realization of the simplest example of a lossless symmetric combiner design is presented. The combiner utilizes two IMPATT-diodes in a symmetric circuit configuration fabricated using microstrip technology. The combiner design provides stability from nonpower-producing device interactions, without the use of any resistive stabilization. Improved performance over single device operation is shown.

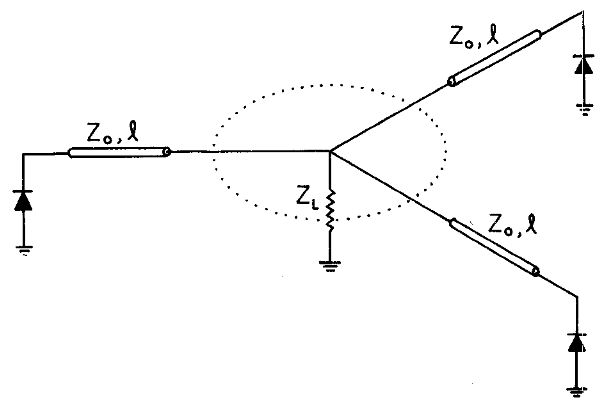

Figure 1 General Radial-Symmetric TEM-line Combining Network.

II. NETWORK DESCRIPTION & UNDESIRED MODE SUPPRESSION.

A network that illustrates the radial symmetry of the combiner circuit is shown in Figure 1. TEM-transmission lines are arranged symmetrically around a central "hub" which functions as a common RF power combining point. Each transmissions line is terminated at one end with an IMPATT-diode, providing a negative-resistance termination over a band of frequencies.

The combiner, in general, can be viewed as a lossless N+1 port network as shown in Figure 2. The structure incorporates N device ports for the active terminations. Each active device can be associated with an impedance describing function which is dependent on frequency and RF amplitude. One combining port provides common excitation and RF power extraction. The properties of the radially symmetric lossless combiner network are reflected in a circulant circuit impedance matrix associated with the combiner

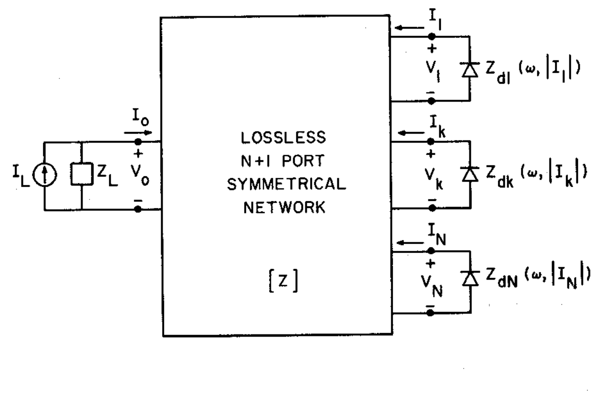

Figure 2 General Combiner Network Description.

network. For combining networks that exhibit circulant matrix properties, it has been shown[1,2] that the various modes of device interactions (i.e. modes of oscillation) can be specified by examining the eigenvalves and associated eigenvectors of the circuit impedance matrix under the condition for oscillation:

$$([Z]+[Z_d])\bar{I}=\bar{O} \tag{1}$$

where $[Z_d]$ is a diagonal matrix with each of the diagonal elements being the device impedance, and $\bar{I}$ is a vector of port currents. The circuit impedance matrix is given by [Z] and reflects the properties of a circulant matrix.

Examination of the circuit eigenvectors and eigenvalves results in the possibility of N modes of oscillation for the combiner system. N-1 of these modes are antiphase or "odd" modes and have the property that no RF power can be extracted from the network when they are excited. One mode, the "even" mode, can exist and does contribute to the extraction of combined RF power under the appropriate circuit conditions. These conditions are specified by the circuit matrix eigenvalues, which can be interpreted as the circuit impedance of the combining network viewed from the device ports. Under the assumption of nearly identical devices and small levels of coupling between adjacent TEM combining lines, the circuit eigenvalues are degenerate and can be associated with straightforward equivalent circuits. The equivalent circuit impedance associated with the odd and even mode of oscillation for the combiner system are given by:

$$Z_{c_{ODD}}=jZo\tan\beta\ell \tag{2}$$

and

$$Z_{c_{even}}=Zo\frac{NZ_L+jZo\tan\beta\ell}{Zo+jNZ_L\tan\beta\ell} \tag{3}$$

The odd-mode equivalent circuit can be recognized from equation (2) as a shorted section of transmission line. The even-mode equivalent circuit is a transmission line terminated in an effective impedance of NZ_L, where N is the total number of devices being combined and Z_L is the load impedance presented to the network at the combining port. Stability from non-power-producing, odd mode oscillations can often be realized by an appropriate selection of circuit parameters.

The circuit conditions for odd-mode stability can best be visualized when the properties of the odd-mode equivalent circuit and the active device are plotted on a Smith chart as shown in Figure 3. The circuit appears as a shorted length of TEM transmission line and follows the outside of the Smith chart as shown. To suppress odd-mode instabilities, the TEM-line length and characteristic impedance are selected to avoid any intersections between the circuit and device over the device active bandwidth. This constraint generally imposes a limitation on the active bandwidth of potential devices.

III. TWO-IMPATT-DIODE COMBINER EXAMPLE.

A lossless symmetrical Two-IMPATT-Diode combiner has been constructed to verify this approach to circuit level power combining. The combiner circuit is shown in Figure 4 and consists of two symmetrically arranged microstrip transmission lines fabricated on a 0.025 inch alumina substrate. One end of each transmission line is connected to the common combining point. The other end is terminated with a silicon double-drift IMPATT diode. Each device was operated in a CW mode and at low current levels. The individual device active bandwidth was found to be very narrow (i.e. from approximately 4.6 GHz to 4.9 GHz) as shown in Figure 5. Also indicated in Figure 5 is the point that the device curve would have to intersect for an odd-mode instability to occur, as measured at the reference plane shown in the inset. Clearly, the narrow device active bandwidth provides a large stability margin in this case.

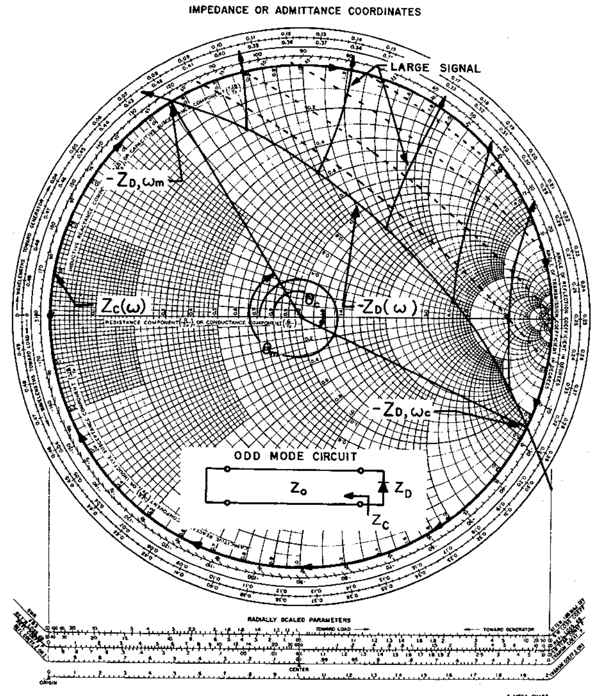

Figure 3. Smith Chart visualization of odd-mode stability design criteria. The angles Θc and Θm specify the circuit constraints required to suppress undesired odd mode instabilities.

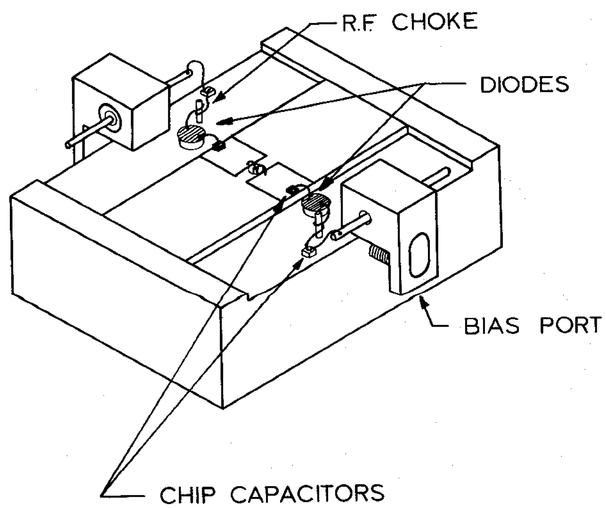

Figure 4a. Two IMPATT-diode microstrip combiner test fixture.

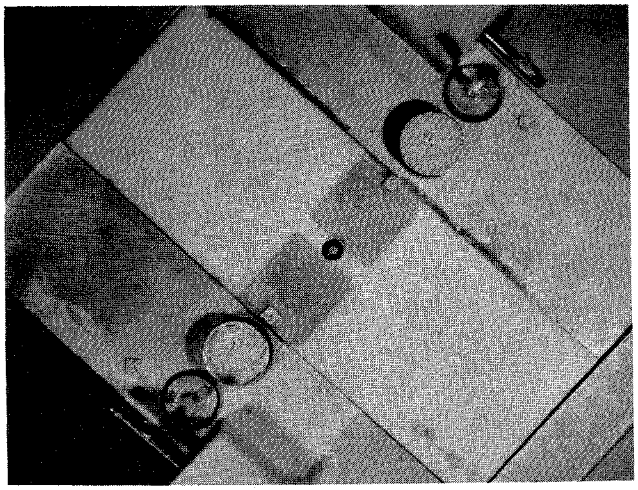

Figure 4b. View of combiner microstrip circuit board.

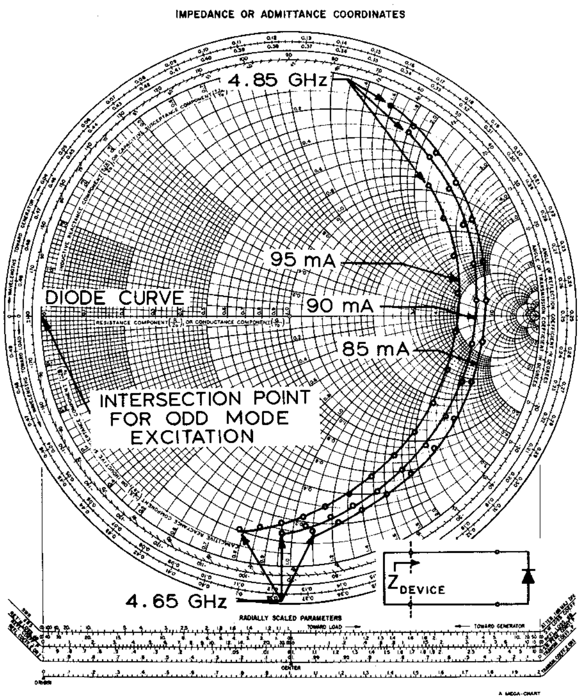

Figure 5. Individual diode small-signal curve for three different bias current levels. Negative device impedance is plotted and normalized to 50Ω. The data is referenced to the measurement plane shown in the inset.

The measured small-signal combiner impedance for three different bias current levels is shown in Figure 6. Essentially, the transformed properties of the two diodes add in parallel at the combining point, halving the impedance of a single device and permitting only even-mode operation. The small signal reflection gain measured at the combining point improved from 3.5 dB for a single device in the combiner circuit to 9 dB for the two-diode combiner at a bias current of 95mA. A three percent fractional bandwidth centered at approximately 4.8 GHz. was measured for this example. Larger combiner bandwidths are possible if the large stability margin exhibited by these diodes could be traded for larger active diode bandwidth. Under large signal conditions, 140 mW of added power was measured for two-diode operation. Approximately 45 mW of added power was measured for a single diode in the same combiner circuit. This value was measured under low gain conditions and hence is more susceptible to circuit losses.

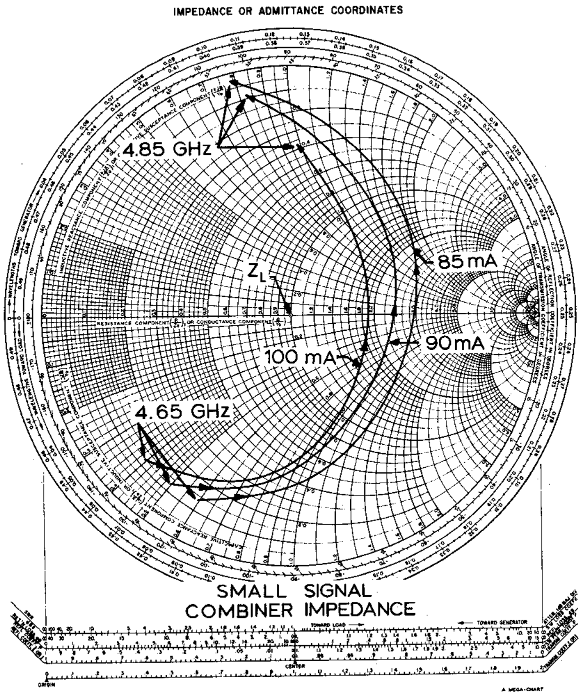

Figure 6. Small-signal measured combiner impedance under three current-bias levels. The load impedance, Z_L, presented at the combining point corresponds to 50Ω.

IV. SUMMARY.

Verification of a new approach to circuit-level power combining of negative-resistance devices has been presented. N-way radially symmetric combining networks are utilized with band-limited negative-resistance IMPATT diodes to successfully provide stable combiner performance of improved bandwidth without the use of resistive stabilization techniques. A two-IMPATT-diode power combiner example has been described which illustrates the basic lossless combiner design principles.

V. ACKNOWLEDGEMENTS.

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VI. REFERENCES

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