HIGH CW POWER WITH MULTI-OCTAVE BANDWIDTH FROM POWER-COMBINED MINI-TWTs

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ABSTRACT

Several mini-TWTs were recently power-combined in the band 2.0 to 8.0 GHz to achieve 250 W of CW power at better than 90 percent combining efficiency. Graceful degradation was demonstrated by successively turning off each of the TWTs. The combining device, known as the spatial field power combiner, is especially suited for high average power applications. This approach has the potential for achieving CW powers in excess of 1 kW over multi-octave frequency bands up to 20 GHz. This paper focuses on a four-way combiner and discusses the results obtained in combining mini-TWTs.

INTRODUCTION

High CW powers (500W to 1 kW) over multi-octave frequency bands up to 20 GHz are required in several ECM type of applications. Normally the high power TWT is used but only partially satisfies the power, bandwidth requirements. Also the "single bottle" high power TWT has limitations in terms of life, reliability, efficiency, etc. An alternate approach that has been pursued by us, was to power combine mini-TWTs. Since these tubes are highly reliable, efficient and perform over multi-octave bands the problem then is transferred to the power combiner which should have bandwidth and high average power handling capability along with several other features.

The technique of power combining several devices to yield high power is commonly used with solid state devices such as GaAs IMPATTS, GaAs FETs and bipolar transistors. For instance, GaAs IMPATTS have been combined in a TM_{020} cavity to produce peak powers up to 1 kW at X-Band[1]. GaAs FET amplifiers are frequently combined using different versions of the radial combiner[2,3]. Wilkinson, modified Wilkinson and traveling wave are other types of combiners normally used depending on power and bandwidth requirements.

In our application, however, high CW power handling (~1 kW) over a multi-octave bandwidth is an important requirement on the combiner. Since each of the devices to be combined have outputs in the range of 50 to 250 W CW it is essential that a high degree of isolation be maintained between the combiner ports not only in the balanced mode but also with some of the devices failed. As such a compact three-dimensional combining circuit has been developed satisfying the above named requirements. This paper focuses on a four-way spatial field power combiner designed for the band 2.0 to 8.0 GHz and the results obtained in combining 70 W CW mini-TWTs. The same design principles may be extended to a combiner with a greater number of ports, for instance 6, 8, 10 etc.

DEVICE DESCRIPTION

A compact, lightweight, three dimensional circuit known as the spatial field power combiner has been developed for traveling wave tubes and solid state devices. This circuit is especially suited for high average power applications. The combiner has the following features:

- Balanced TEM mode of propagation
- Low loss, high combining efficiency (>90 percent)
- Multi-octave bandwidth operation
- High degree of isolation between amplifier modules
- Graceful degradation characteristics
- Excellent heat sinking properties.

In terms of a circuit schematic the spatial combiner may be represented as shown in Figure 1. It has a single coaxial high power output port, as shown in the photograph of Figure 2. A ridge waveguide/coax transition may be attached to the output port, if necessary, for applications above the one kW level. The coax line divides into multi-stepped transmission lines that transform from a high impedance to the desired low impedance at the input port. At the end of the stepped transformer section, a transition region is provided that performs a mode transformation from the transmission line TEM mode to the coaxial TEM mode of the input.

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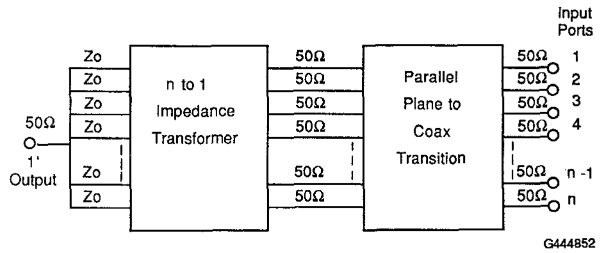

Fig. 1 Circuit Schematic, Spatial Power Combiner

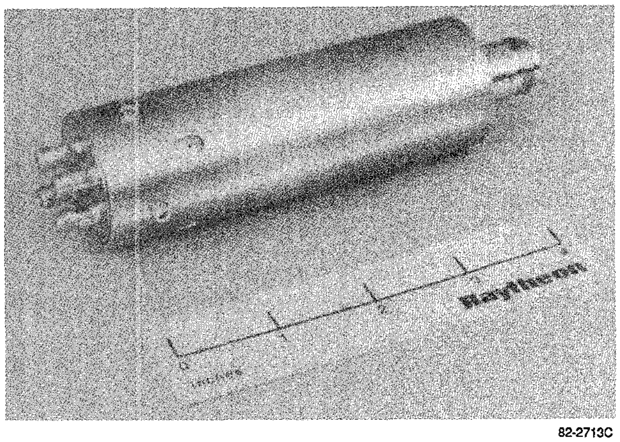

Fig. 2 Four-Way Power Combiner

With four balanced signals fed into the coax input ports (for a four-way combiner) the device operates at maximum combining efficiency (90 to 95 percent) and a TEM mode propagates in each of the transmission paths of the combiner. Should any of the amplifiers connected to the combiner fail, then, in addition to the balanced mode, unbalanced modes are generated. The field structure of these unbalanced modes is also TEM but orthogonal to the primary mode. They are effectively filtered out by spatial damping loads located in the combiner external to the circuit path. The balanced mode is unaffected and the combiner power output follows the theoretical graceful degradation relation given by the equation below:

$$P_o = \eta \cdot \left[\frac{n-f}{n}\right]^2 \cdot P_T$$

where

P_o = Output Power
P_T = Total Input Power
n = Number of Devices
f = Number of Failed Devices
η = Combining Efficiency.

Heat sinking is provided within the combiner to effectively remove unbalanced mode power.

Another important consideration in a combiner is the isolation between ports. The filtering property of the combiner whereby the unbalanced modes are damped out by the loads, leads to the high degree of isolation that is maintained between the input ports of the combiner. Isolation as high as 25 dB between ports may be expected from this device.

EXPERIMENTAL RESULTS

Passive test data on one model of the four-port spatial combiner with a 3:1 design bandwidth is shown in Figures 3 and 4. The frequency range of operation of this device is from 2.3 to 7.1 GHz with interport isolation in the range of 18 to 25 dB. The VSWR over this band was better than 1.5:1 and the insertion loss varied from 0.3 to 0.7 dB.

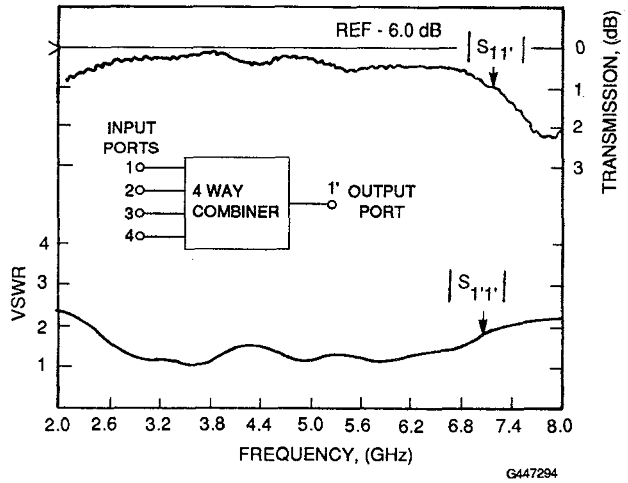

Fig. 3 Impedance Match and Transmission, Four Way Combiner

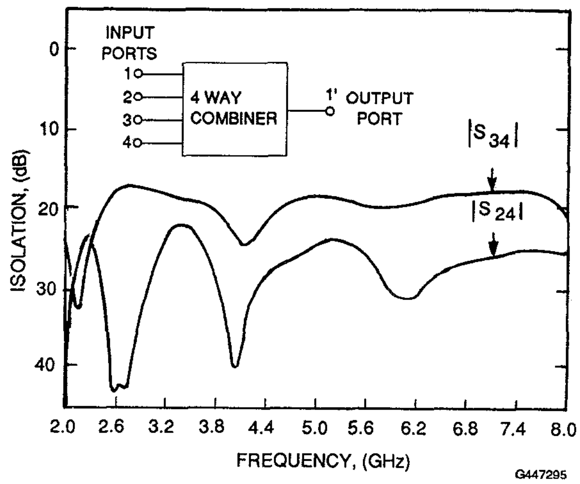

Fig. 4 Interport Isolation, Four-Way Combiner

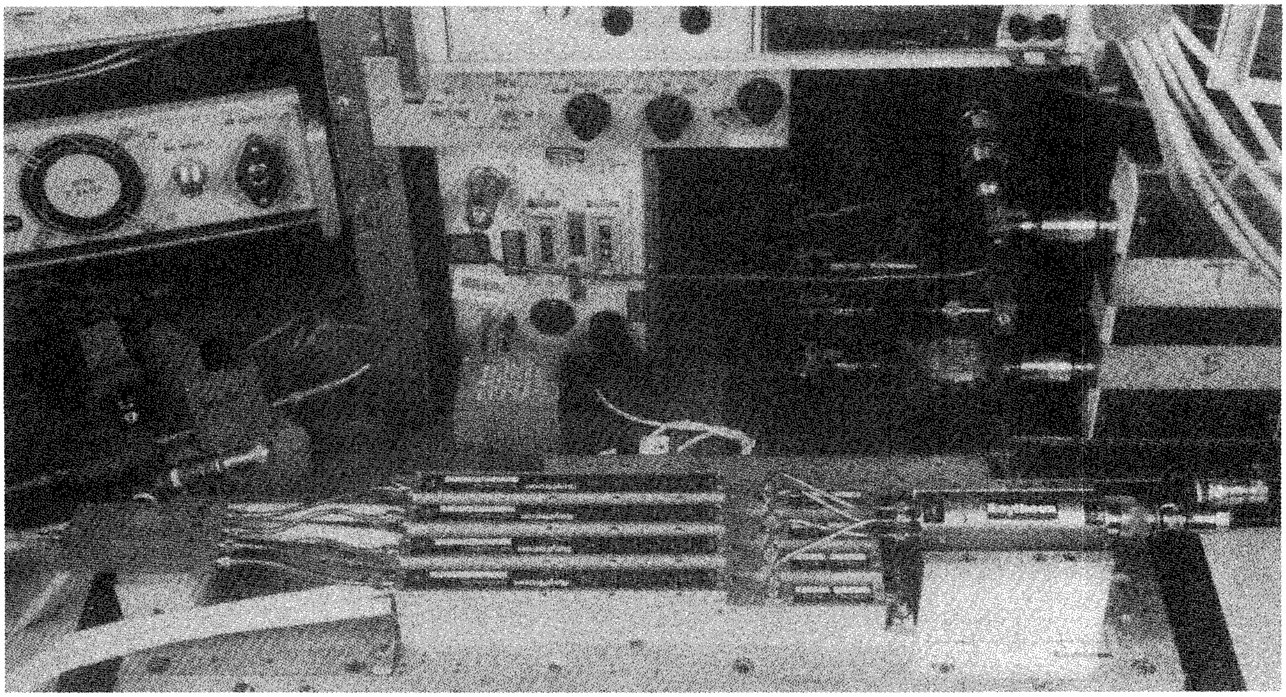

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Fig. 5 Four-Way Combiner/TWT High Power Test

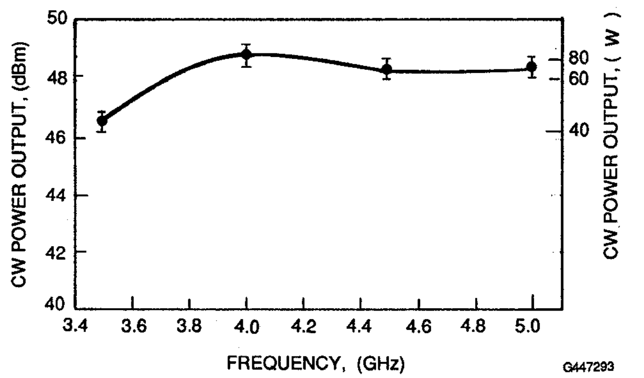

Fig. 6 Average Saturated Power Output of Each of Four TWTs Used for Combining and Their Amplitude Spread.

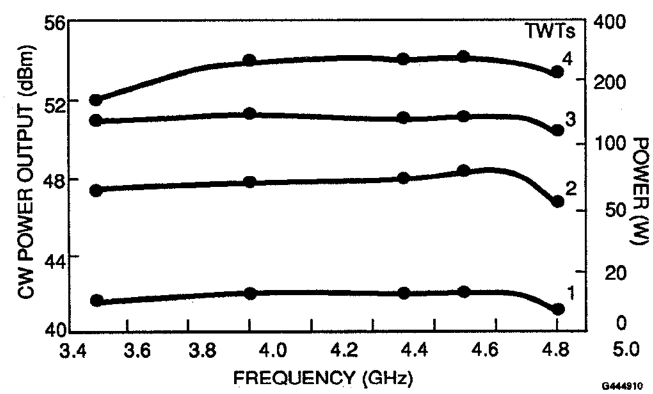

Fig. 7 CW Power Output of Four-Way Combiner/Amplifier and Graceful Degradation Data.

To establish feasibility of this combining approach at high power levels and to show compatibility between the combiner and the TWTs, four 65 to 70 W TWTs were connected to the input ports of the combiner and the device was tested over a limited band from 3.5 to 5.0 GHz. The test set up is shown in Figure 5. Each of the mini-TWTs to be combined were phase matched but had a maximum amplitude deviation of 0.6 dB (Figure 6). The key results, plotted in Figure 7, show that combining efficiencies up to 93 percent were achieved with the combiner yielding 251 W of combined power. Graceful degradation tests were performed by successively turning off each of the four tubes. With three out of four tubes operating, the output power decreased by 2.5 dB and with two tubes off, the power fell by 6dB. This power reduction fits the theoretically calculated graceful degradation curve.

Noise measurements made on the device showed that the four-way combiner/amplifier has superior performance. The filtering action of the load within the combiner cancels the broadband noise from the four tubes and the noise performance of the combined amplifier is better than or equivalent to that of an individual tube.

The high combining efficiencies (90-93%) obtained from this device result from the fact that the combiner operates in the balanced TEM mode and the only contribution to the losses comes from phase and amplitude mismatches and circuit resistivity. In this experiment the TWTs were phase matched; but computations show that a phase deviation $\Delta\phi$ of $\pm 15°$ between the input signals will add only 0.3 dB to the total insertion loss.

CONCLUSION

A three-dimensional combining circuit has been developed with multi-octave bandwidth capability for frequencies up to 20 GHz and potential for performing at the 1 kW CW level. This device is compact and lightweight. Performance has been demonstrated at the 250 W CW level by combining four 70 W mini-TWTs. Combining efficiencies in excess of 90 percent along with graceful degradation was achieved. The device operates in the TEM mode. Its unique mode damping feature allows the device to maintain balanced mode operation under all conditions. Although performance of this combiner has been demonstrated with mini-TWTs, it may also be used to combine high power solid state modules.

REFERENCES

1. C. A. Drubin, et al, "1 kW Peak 300 W Average IMPATT Diode Injection Locked Oscillator", 1982 IEEE, MTT-S Int. Microwave Symposium Digest, pp. 126-128.

2. I. Stones, et al, "An 18 GHz 8-Way Radial Combiner", 1983 IEEE, MTT-S Int. Microwave Symposium Digest, pp. 162-165.

3. E. Belohoubek, et al, 30-Way Radial Power Combiner for Miniature GaAs FET Power Amplifiers", 1986 IEEE, MTT-S International Microwave Symposium Digest, pp. 515-518.