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A 1 KW_{peak}, 300 W_{avg} IMPATT DIODE INJECTION LOCKED OSCILLATOR

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ABSTRACT

Design procedures were developed for and applied to a circularly cylindrical resonant cavity combiner (CCRCC) operating in the TM_{020} mode. Thirty-two (32) GaAs double-drift IMPATT diodes were power combined in such a structure yielding 313 watts average and 1043 watts peak at X-Band.

INTRODUCTION

Power combining of IMPATT diodes in rectangular waveguide structures was first proposed by Kurokawa & Magalhaes.[1,2] The familiar TM_{010} mode circular cavity combiner became a popular adaption of their circuit, allowing the combination of more devices in a given volume.[3] The TM_{020} mode combiner is an attractive extension of this circuit enabling efficient operation with more than twice the number of devices.

COMBINER DESIGN

The design of a TM_{020} cavity combiner is more complicated than the design of a TM_{010} cavity combiner due to the presence of certain unwanted modes, in particular the TM_{210} and the TM_{110} modes. If these are sufficiently suppressed, the desired TM_{020} mode of operation is also adversely affected. In the design, shown in Figure 1, a compromise solution was developed in which unwanted modes were moderately suppressed, and were also tuned away from the TM_{020} mode.

Mode suppression was accomplished by incorporation of a sufficient number of radial slits in one cavity face. Slits located adjacent to the diode holes were found to be more effective than if they were aligned with them. The slits were filled with a lossy material, recessed away from the surface. A dielectric ring was positioned at the null of the electric field of the TM_{020} mode. A ring of the full cavity height was utilized. The TM_{110} and TM_{210} modes were thus tuned lower in frequency, with minimal influence on the TM_{020} mode. To avoid oscillations unrelated to the TM_{020} mode, increased diameters of the center conductors were used in the cavity. They helped to provide a stable impedance transformation of the load off cavity resonance by reducing the discontinuity of the cavity in series with the coaxial diode line.

The remaining design features were similar to TM_{010} combiner design. The diodes were mounted in a water-cooled plate at the ends of 32 coaxial lines uniformly spaced around the periphery of the cavity and magnetically coupled to it. At the other end of the coaxial lines, microwave absorbing loads provided a stable transformation to the diodes away from cavity resonance and isolated the microwave from the bias circuit. The RF power was coupled out of the cavity via an E-field probe at the cavity center.

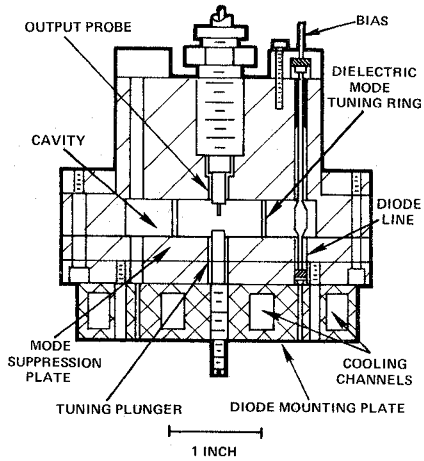


Figure 1 - 32-Diode TM_{020} Cross-Sectional View

The coaxial diode line diameter, δ (Figuare 2), was chosen to accommodate the diode package, to maximize the number of diodes around the cavity periphery, and to utilize standard machine tools. The location of the diode lines from the cavity center was determined empirically from a test cavity. As can be seen from Figure 2, the solution was a compromise between efficiency and diode number (circumference). The position that corresponds to 70 percent efficiency was chosen.

The cavity diameter, D, was specified by conventional formulation[4] which for the TM_{020} mode becomes:

$$D = \frac{20.74}{\left(f_o + \Delta f\right)} \text{ inch-GHz}$$

where f_o = X-band operating frequency in GHz
Δf = 0.25 GHz, an allowance for frequency adjustment above f_o

The cavity height was selected small enough to gain frequency separation from modes with an axial field variation, e.g., the TE_{111} mode, as shown in Figure 3, yet large enough for high cavity Q.

Automatic Network Analyzer measurements were used to characterize the cavity combiner alone (without diodes). Diodes were replaced with short circuits and the S parameters of the cavity measured. By repeating the measurement for three short positions, the complete S matrix was obtained.[5] From the S matrix, cavity efficiency, and impedance presented to the diode ports was determined.

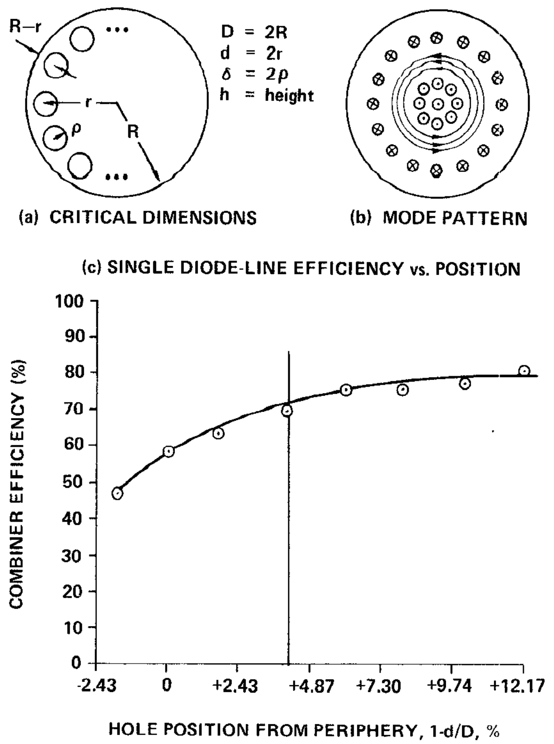


Figure 2 - Combiner Parameters

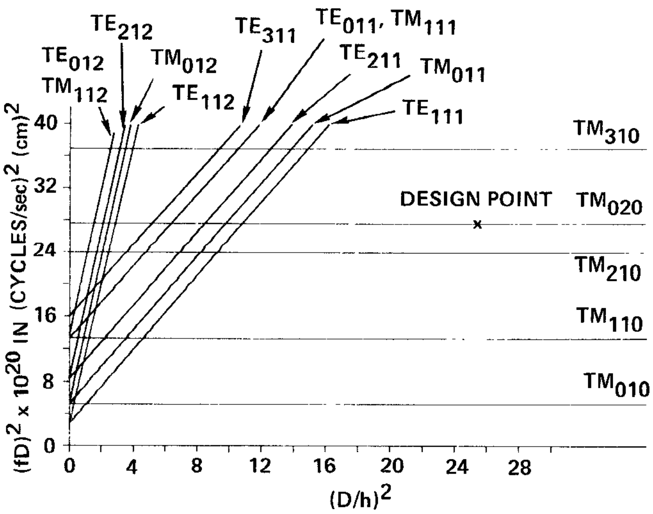
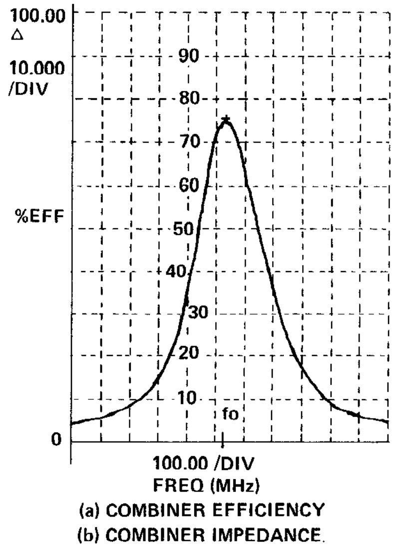


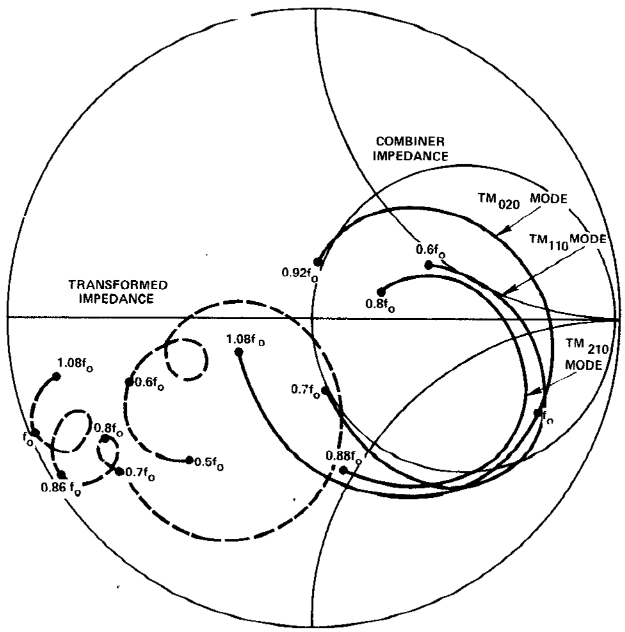
Figure 3 - Mode Chart for Right Circular Cavities

Figure 4a shows the resultant efficiency versus frequency for the 32-line TM_{020} mode combiner. The center operating frequency was f_o. This represented the maximum efficiency determined for a series of output probe couplings. To realize the efficiency shown, signals at each of the diode ports must be of equal amplitude and phase. In practice, some additional losses were introduced as a function of differences in diode characteristics and physical tolerances. Hence, Figure 4a shows the best case achievable.

Figure 4b shows the corresponding combiner impedance presented to each diode and referenced to the cavity center. Since this impedance is a measured quantity, it contains the effects of the mode avoidance techniques discussed above which provide loading and tuning of the unwanted modes.



(a) Combiner Efficiency versus Frequency



(b) Combiner Impedance versus Frequency

Figure 4 - Combiner Characteristics

Also shown is the transformed locus of the impedances referenced to the package plane of the diode. The impedance transformation was achieved by a simple two-section scheme as shown in Figure 1. Each diode line module contained an identical transformer; no provisions were made for individual diode tuning.

IMPATT DIODES

Both silicon IMPATT diodes at X- and Ku-band and GaAs IMPATT diodes at X-band have been combined. The silicon devices, manufactured by Hewlett Packard, were double-drift, flat-profile. The X-band devices were capable of 14 watts peak and the Ku-band devices were capable of 11 watts peak power output. The GaAs devices, fabricated at Raytheon's Research Division, were double-drift, Read-profile offering the advantages of higher power and efficiency. Tested on an individual basis, the diodes that were later combined for the 313 watt result delivered power in excess of 10 watts average, 33 watts peak, with greater than 18 percent dc to RF efficiency. These devices were selected from five different material growth lots.

EXPERIMENTAL RESULTS

A 32-diode TM_{020} aluminum cavity combiner was fabricated and tested at X-band. Figure 5 shows the disassembled combiner with its internal structures and the IMPATT diodes mounted on the copper heat sink.

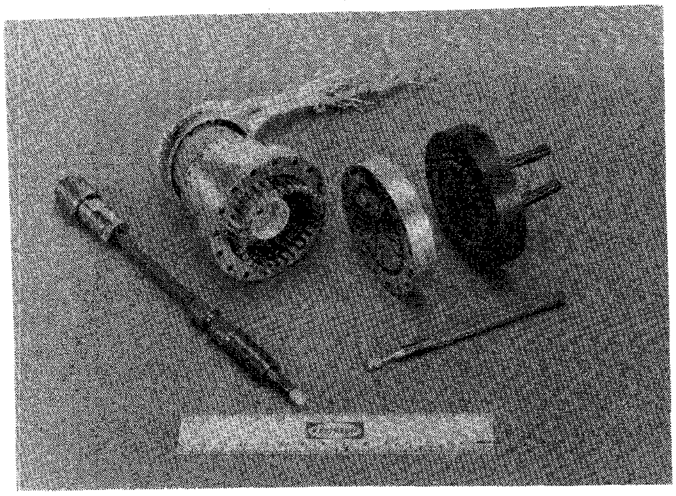


Figure 5 - TM_{020} Combiner Disassembled

Initial operation of the cavity combiner was as a free-running oscillator. After preliminary tuning, an RF drive signal was injected into the cavity through a circulator for locked oscillator operation. The RF drive level was varied from 50 watts average to 115 watts average after setting the diode peak current level. This was repeated for different diode currents, the results appear in Figure 6.

A maximum of 313 watts average was attained with 4.3 dB gain. At the 313 watt average power level, the diode's junction temperatures were in the range of 280° - 300°C. Operating at this power level and with 1.8 amps peak current per diode, the IMPATTs had a power-added efficiency of 17.5 percent. At the 4.3 dB level achieved above, the cavity combiner demonstrated a 1.3 percent locking bandwidth with the diode peak currents reduced to 1.5 amps per diode.

SUMMARY

The TM_{020} cylindrical cavity structure has been built and operated at X- and Ku-band. Table 1 summarizes the best results obtained with GaAs and silicon IMPATTs in different but similar combiners at the two frequency bands.

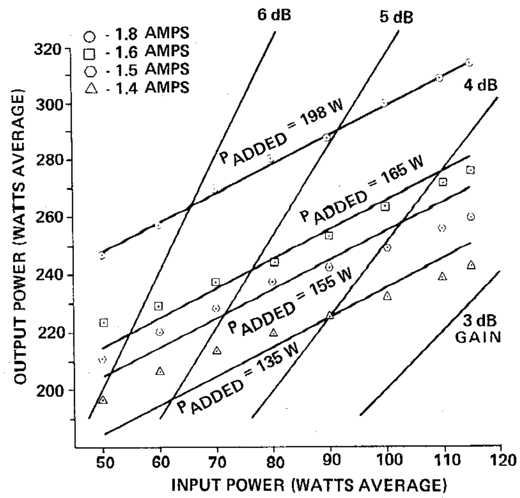


Figure 6 - Output Power versus Input Power and Diode Current

ADKNOWLEDGEMENTS

The authors wish to acknowledge the significant contribution of J. Lampen for development of the measurement techniques.

REFERENCES

1. K. Kurokawa and F.M. Magalhaes, "An X-band 10-Watt Multiple-IMPATT Oscillator", Proc. IEEE (Lett.). Vol. 59, Jan. 1971, pp. 102-103.

2. K. Kurokawa, "The Single-Cavity Multiple-Device Oscillator", IEEE Trans. On MTT, Vol. MTT-19, No. 10, Oct. 1981, pp. 793-801.

3. R.S. Harp and H.L. Stover, "Power Combining of X-Band IMPATT Circuit Modules", 1973 IEEE International Solid State Circuits Conference Digest, pp. 118-119.

4. Harrington, "Time Harmonic Electromagnetic Fields", New York, McGraw Hill, 1961.

5. J. Lampen, G. Jerinic, C.A. Drubin, and L. Wagner, "ANA Measurement of IMPATT Diode Cavity Combiner Efficiencies and Impedances", to be published.

TABLE 1

STATE-OF-THE-ART (Dec. 1981) TM_{020} IMPATT COMBINERS

Frequency	Power (W) Peak	Power (W) Avg	P.W. μsec	Diodes No. Mat'l	Diode Manufacturer	Comments
X-Band	1043	313	0.3	32 GaAs	Raytheon	Injection Locked
X-Band	400	120	0.3	20 GaAs	Raytheon	Free Running
X-Band	212	53	0.3	20 Si	HP	Free Running
KU-Band	86	21.5	0.3	12 Si	HP	Injection Locked