ADVANCES IN E-PLANE PRINTED MILLIMETER-WAVE CIRCUITS*

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ABSTRACT

Recent work is reported on printed millimeter-wave circuits mounted in the E-plane of rectangular waveguide. The circuits include wideband four-port coupling elements and one-port GaAs and InP Gunn oscillators providing 20 to 60 mW in the range of 55 to 70 GHz, with mechanical tunability up to 8 GHz.

Introduction

It has been shown that multiport components can be constructed at millimeter wavelengths by suspending printed circuits in the E-plane of rectangular waveguide.[1,2] Such circuits feature standard-flange ports, printed-circuit economy, wide single-mode bandwidth, and compatibility with packaged or hybrid IC devices. The following paragraphs summarize recent progress with E-plane circuits, including wideband four-port coupling elements, and one-port mechanically tunable oscillators in the 5-mm band employing GaAs and InP Gunn devices.

Four-Port Coupling Elements

It has been demonstrated that directional coupling can be obtained at millimeter wavelengths with an array of printed capacitive elements, mounted in the E-plane common to a pair of parallel waveguides.[2] Such couplers feature printed-circuit reproducibility, housings with axially uniform coupling regions, and compatibility with other E-plane circuits such as filters and mixers. The following paragraphs will describe E-plane coupling elements with enhanced bandwidth capability.

Figure 1 shows the structure of the E-plane four-port coupling network. Also illustrated are three types of printed coupling elements: capacitive probe, L-C probe, and loop. Since the coupling of the capacitive probe increases monotonically with frequency, the bandwidth capability of this simple element is limited. The series inductance associated with the L-C probe can reverse the capacitive coupling trend and, for certain configurations, provide a relatively constant coupling across a wide band. Frequency compensation can also be obtained with the loop--a coupling element which has been extensively applied to nonplanar components at lower frequencies.[3] Since the loop dimensions can be adjusted to independently control the electric and magnetic coupling, highly directional coupling is feasible with one element. However, the printed-circuit approach is well suited to multielement couplers which are inherently directional. Thus, the shape of the printed loop can be optimized for coupling flatness, without regard to single-element directivity.

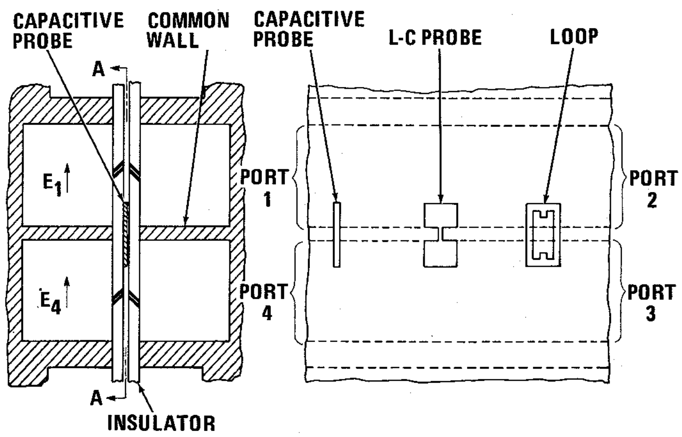

Figure 1. E-Plane Four-Port Coupler

Figure 2 shows the measured coupling versus frequency for representative E-plane coupling elements. The coupling characteristics for compensated elements and simple capacitive probes are compared for the case of tight (-8 dB) and loose (-23 dB) coupling. Across the band of 33 to 40 GHz, the L-C probe provides a coupling of -8.5 ±0.3 dB, whereas the capacitive-probe coupling is -7.7 ±1.5 dB. The L-C probe has also been investigated for the loosely coupled case. However, superior flatness has been demonstrated for the printed loop. Figure 2 shows that the measured coupling is -22.5 ±0.5 dB for the loop versus -22.7 ±2.2 dB for a comparable capacitive probe. The plotted coupling for the loop is in the forward direction (port 1 to port 3) which is relevant to multiple-element arrays. The backward loop coupling is approximately 6 dB weaker across the band.

The characterization and optimization of E-plane coupling elements is important to the development of a wide variety of E-plane wideband components including couplers, balanced mixers, and multiplexers.

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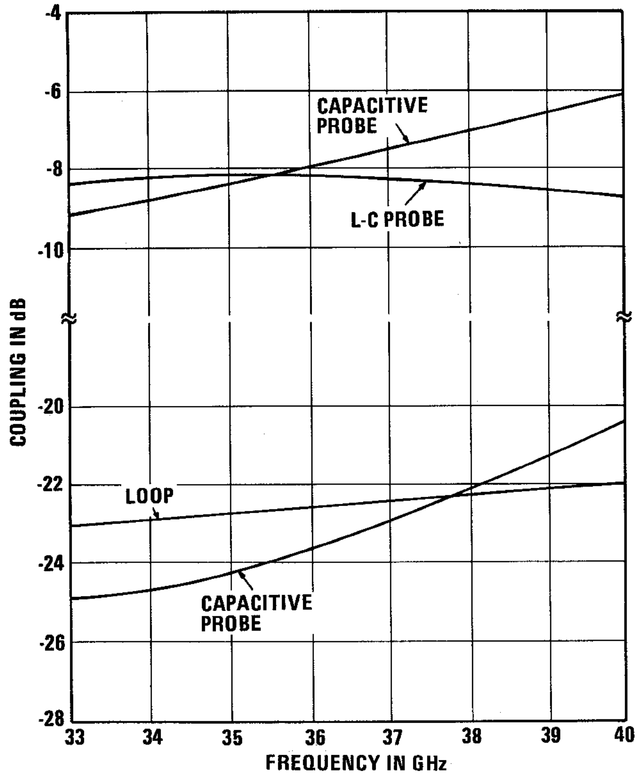

Figure 2. Coupling Versus Frequency

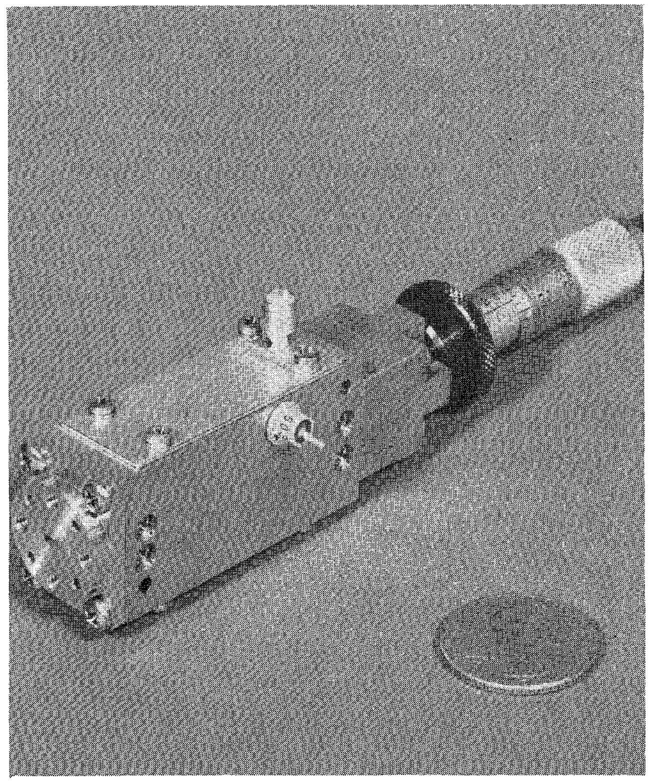

Figure 3. Mechanically Tunable Gunn Oscillator

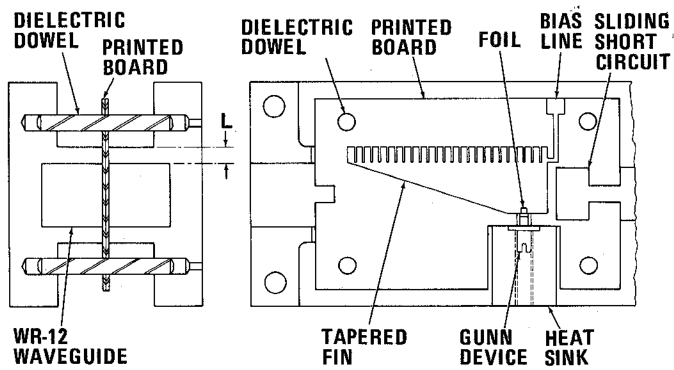

Figure 4. Oscillator Cross Section

Fin-Line Gunn Oscillators

Single-ridge fin-line[4] is an E-plane transmission line which has proven to be useful in the construction of Gunn oscillators at millimeter wavelengths.[5] The printed fin can be easily biased and tapered to provide wideband single-mode coupling between a packaged Gunn device and a standard waveguide port. The following paragraphs report recent progress with tunable fin-line GaAs and InP Gunn oscillators in the 5-mm band.

Figures 3 and 4 show the external and internal features of the mechanically tunable oscillators. The housing is split along the E-plane to accommodate two 0.005-inch boards (Duroid 5880) which are aligned by dielectric dowels. One of the boards contains the printed circuit, whereas the other board is unclad to insulate the tapered fin from the housing. This allows dc bias to be applied (via the printed pattern and a foil bond) to a packaged Gunn device. The Gunn device is threaded into a removable copper block which is bolted to the housing to provide a heat sink and the dc return. The tapered fin, which couples the Gunn device to standard WR-12 waveguide, is RF grounded to the upper wall of the housing by a serrated choke pattern within the broad wall. The length of the choke region (dimension L in Figure 4) is chosen to be a quarter wavelength in the dielectric medium. The serrations prevent longitudinal current in the choke and thereby ensure single-mode propagation. The Gunn device is reactively terminated by a sliding noncontracting short circuit, which is mechanically driven by a resetable micrometer head with a nonrotating spindle.

The oscillator has been tested with commercially available GaAs Gunn devices (Varian VSE-9220) and Government-furnished InP devices (see acknowledgments). Measurements were performed of frequency and power output as a function of the spacing between the device and the short-circuit termination. Power output was measured with a fixed-tuned thermistor mount (Hitachi F2512) which was calibrated against a dry calorimeter (PRD 666) across the band of interest. Measurements are referenced at the output of a commercially available isolator having a forward loss of 0.4 to 0.5 dB.

Figure 5 shows the measured power output of the GaAs Gunn oscillator as a function of the short-circuit micrometer dial. As the short is moved 0.14 inch, the frequency varies smoothly across an 8-GHz band centered at 58.75 GHz and the CW power output is typically 16 dBm (40 mW) at the output of the isolator. Correcting for isolator loss, the power output of the oscillator is 18 dBm (63 mW) at the center of the operating band. The measured pushing factor is -220 MHz/volt.

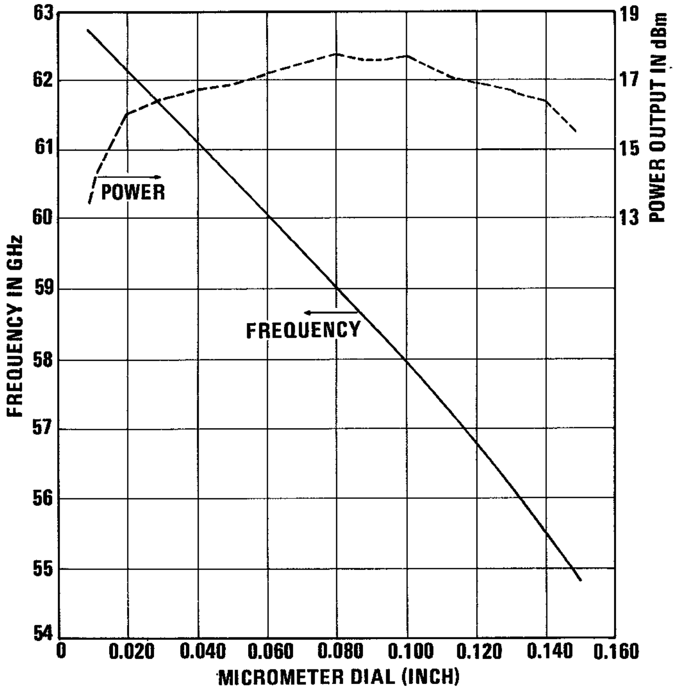

Figure 5. Oscillator Performance With GaAs Gunn Diode

Figure 6 summarizes the oscillator performance with an InP Gunn device. As the short is moved 0.09 inch, the frequency varies smoothly across a 6-GHz band centered at 66.8 GHz and the power at the isolator output is 15.1 dBm ±1.2 dB. Correcting for the isolator loss, the maximum output of the InP Gunn oscillator is 46 mW.

Work is now in progress to further optimize the mechanically tunable oscillators and add varactor-tuned FM capability. The fin-line pattern will be modified to accommodate an independently biased varactor, mounted a half wave from the Gunn device. Such oscillators will be applicable to transmitters as well as widely tunable local oscillators.

Conclusions

Recent work with printed E-plane millimeter-wave circuits has been reported. Improved bandwidth has been demonstrated with four-port coupling elements which are applicable to printed millimeter-wave couplers, balanced mixers, and multiplexers. Fin-line GaAs and InP Gunn oscillators have also been described which demonstrate advances in terms of operating frequency and mechanical tunability. Further progress in fin-line oscillator development is expected as improved InP Gunn devices become available and circuit refinements (including varactor tuning) are added. Multiport E-Plane circuits are applicable to a variety of millimeter systems and feature standard waveguide interfaces, printed-circuit reproducibility, wide single-mode bandwidth, and compatibility with packaged and hybrid IC devices.

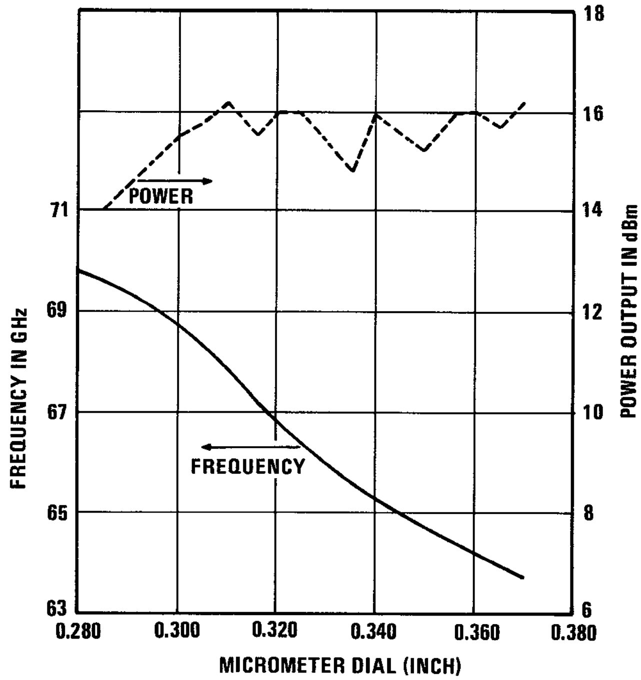

Figure 6. Oscillator Performance With InP Gunn Diode

Acknowledgments

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