PLANAR MULTIPORT MILLIMETER INTEGRATED CIRCUITS

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Abstract

Recent progress with a class of planar millimeter circuits is reported. The potential of such circuits is demonstrated by examples which include a wideband low-loss 5-mm PIN attenuator, high-Q (1600 to 1735) planar filters, and a new type of printed-circuit directional coupler.

Introduction

This paper reports recent progress with a class of integrated circuits which are suspended in the E-plane of a housing of uniform rectangular cross section. Such circuits are amenable to low-cost batch processing and offer special features not found in other types of millimeter IC's (reference 1). The class of circuits includes fin-line (references 1 and 2), the planar structure introduced by Konishi (reference 3), and a new "printed-probe" circuit which is suitable for multiport couplers and contiguous-channel multiplexers. The following paragraphs describe a fin-line PIN attenuator with a 20-GHz bandwidth, recent millimeter measurements with a high-Q planar structure, and a printed-probe four-port directional coupler.

V-Band PIN Attenuator

Figure 1 shows a new V-band PIN attenuator, to the right of an older model which was developed to interface with WR-28 waveguide. The new housing is compatible with WR-15 instrumentation and features metal-to-metal contact in the flange regions for superior mechanical strength. The fin-line circuit is printed on a 0.010-inch board (Duroid 5880) and includes a pair of multiwavelength tapers to the low-impedance line across which two beam-lead PIN diodes are mounted.

Figure 2 summarizes the performance of the new attenuator in the band of 50 to 70 GHz. Across the region of 50 to 67 GHz, where the diode spacing is optimum, the reverse-bias loss is 1.1 ± 0.3 dB and the forward-bias rejection is 20 ± 2 dB. Based on the availability of thinner substrates (such as 0.005-inch Duroid or 0.002-inch quartz) and the known parasitics of beam-lead devices (reference 1), fin-line can be easily scaled to significantly higher frequencies.

High-Q Planar Circuit

It has been shown (reference 3) that high-Q multipole filters can be constructed by inserting a perforated metal sheet into the E-plane of a waveguide. Since unloaded Q's of 2000 to 2500 have been demonstrated at 12 GHz, it is reasonable to assume that this approach is applicable to low-loss millimeter filters. To experimentally verify this assumption, a group of one-pole planar filters were constructed and tested in an existing fin-line housing. Figure 3 shows the aluminum WR-28 housing and E-plane inserts which were milled from 0.020-inch aluminum or tellurium copper. Although a thickness of 0.020 inch was selected for compatibility with the existing housing, thinner sheets would be preferred in production runs where punching or photoetching is economically sound. The unloaded Q was determined by measuring the half-power bandwidth and insertion loss of the filters at their resonant frequency (32 GHz). When mounted in the aluminum housing, the aluminum sheet provided an unloaded Q of 1600, whereas the copper sheet provided a Q of 1735 in the same fixture. It is expected that the Q would be higher still for an all-copper configuration. The millimeter measurements agree with the expected $(1/\sqrt{f})$ variation of Q with respect to frequency, and demonstrate the feasibility of low-loss millimeter filters which are amenable to low-cost planar production techniques.

Four-Port Planar Circuit

The class of E-plane circuits under discussion has been shown to be applicable to one-port components such as oscillators (reference 4), a wide variety of two-port components (reference 1), and three-port components such as circulators (reference 2). Moreover, the technique can be extended to networks having four or more ports. To illustrate this principle, consider the four-port network whose cross section appears in Figure 4. In this configuration, two parallel waveguides share a common broad wall which is slotted along the E-plane to accept a pair of dielectric boards. Directional coupling between the waveguides is obtained by an array of probes which is printed on one of the boards. The other board centers the probes in the slot and insulates them from the common wall. Radiation from either of the outer broad walls is negligible because the slot is centered, and the wall thickness is chosen to be a quarter wavelength in the dielectric (as in fin-line).

Figure 5 shows a four-port housing which was constructed to demonstrate the feasibility of the printed-probe coupler. The housing was fabricated in two parts with E-plane symmetry and it incorporates four waveguide bends for compatibility with WR-22 instrumentation. The edges of the dielectric boards contain quarter-wave notches to provide an impedance match between the air-filled and slab-loaded waveguides. The boards are aligned by rexolite dowels which are external to the broad walls of the waveguides. The housing was tested by measuring the input VSWR and the coupling to the other ports with blank (unclad) boards. Across an 11-percent band centered at 35 GHz, the input (port 1) VSWR was 1.15 or better, the forward isolation (to port 3) was 27 dB or better, the reverse isolation (to port 4) was 42 dB or better, and the insertion loss (to port 2) was 0.5 ± 0.1 dB.

The design of a multiprobe directional coupler began with measurements of the coupling provided by a series of boards, each containing a single probe.

By measuring the (bidirectional) coupling for probes of various dimensions, a preliminary "design library" was compiled for single-probe coupling levels of 29 to 43 dB. Based upon well-known techniques (reference 5), a multi-element array was designed to demonstrate the capability of achieving tight coupling and high directivity. Figure 5 shows the array chosen for this demonstration--a 17-element array formed by superimposing a series of 5-element Tchebycheff arrays. This configuration was chosen for its inherent simplicity (all 13 of the central elements have equal coupling) and the agreement between the required and known coupling values.

Figure 6 shows a summary of the performance of the 17-element printed-probe coupler. Across an 11-percent band centered at 35 GHz, the forward coupling is 7.75 $\pm$0.75 dB and the directivity is 24 dB or better. Since the input is well matched (VSWR $\leq$1.19) and negligible power reaches port 4, the insertion loss may be calculated by adding the fractional power in ports 2 and 3. Such a procedure shows the insertion loss to be 0.6 $\pm$0.1 dB, which is only 0.1 dB greater than the fixture loss without probes.

Work is now in progress to characterize probes with tighter coupling levels and to examine other probe shapes which could provide more uniform coupling with respect to frequency. The object is the development of planar wideband 3-dB couplers which could be combined with planar high-Q filters to form low-cost contiguous-channel millimeter multiplexers.

Conclusions

Recent progress with a class of planar millimeter integrated circuits has been reported. New data have been presented on a wideband low-loss 5-mm PIN attenuator, high-Q planar filters, and a four-port printed-probe directional coupler. The recent work shows advances in terms of operating frequency, unloaded resonator Q, and multiport capability. The versatility of these planar circuits and their compatibility with batch processing techniques offer unique performance/cost tradeoffs which give new options to those developing future millimeter systems.

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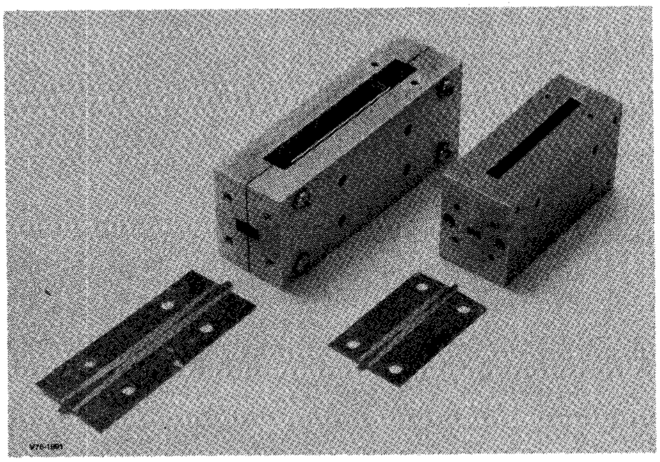

Fig. 1-Fin-Line PIN Attenuator

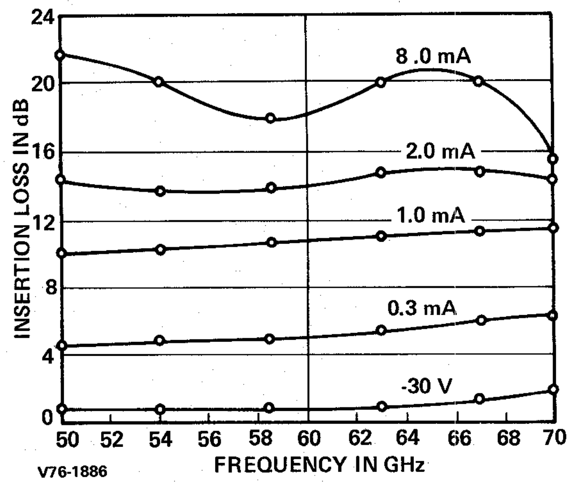

Fig. 2-Performance of PIN Attenuator

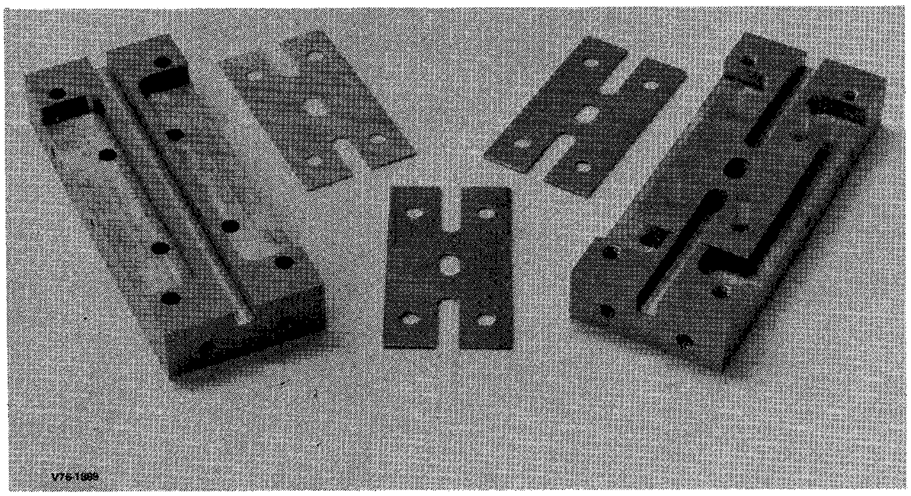

Fig. 3-High-Q Planar Millimeter Filters

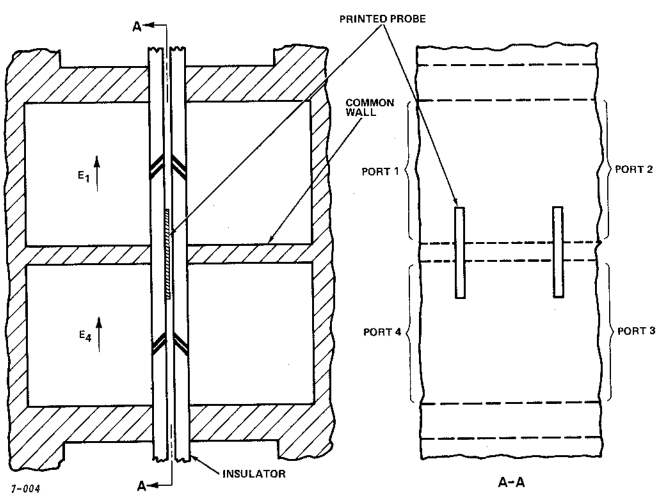

Fig. 4-Printed-Probe Four-Port Network

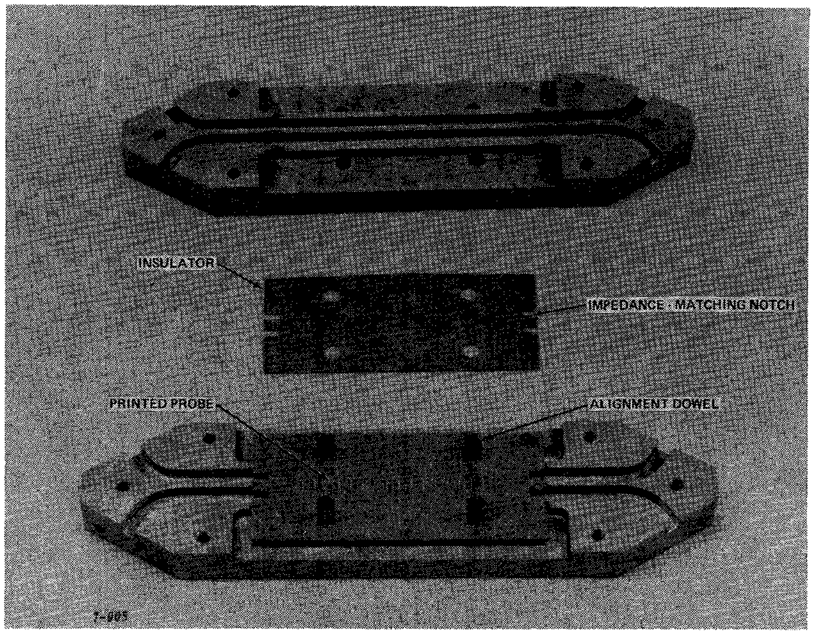

Fig. 5-Printed-Probe Coupler

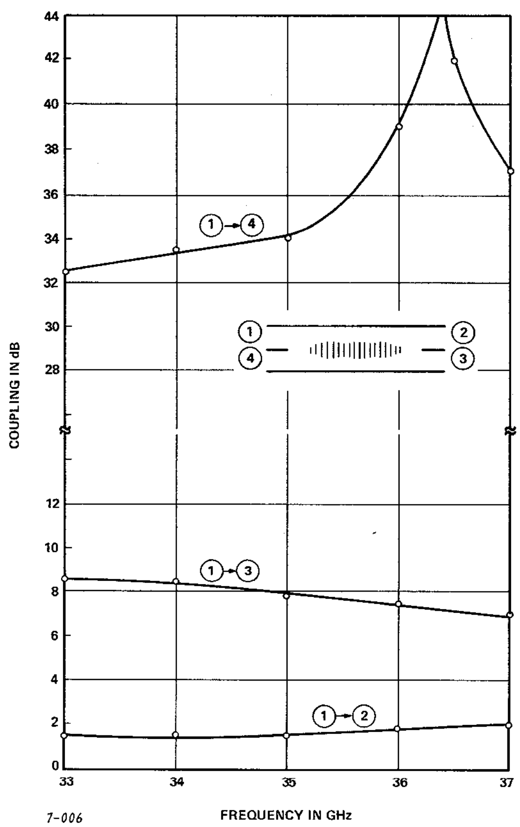

Fig. 6-Printed-Probe Coupler Performance