TWO NEW INTEGRATED-CIRCUIT MEDIA WITH SPECIAL ADVANTAGES AT MILLIMETER WAVELENGTHS*

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Abstract

This paper describes two new integrated-circuit media called integrated fin-line and oversized microstrip. Their advantages over conventional microstrip at millimeter wavelengths include: reduced radiation, single-mode operation, less stringent tolerances, compatibility with hybrid devices, and ease of transition to standard waveguide.

Recent programs have been directed toward exploiting the advantages of integrated circuit (IC) technology at ever higher frequencies. Although standard microstrip techniques can be applied to millimeter components (references 1 and 2), several problems arise. These problems include critical tolerances, fragile substrates, thin conductor strips which are not completely compatible with hybrid devices, and difficulty in obtaining a simple transition to conventional waveguide.

Figure 1 shows how small the dimensions of a 50-ohm microstrip must become, if the radiation loss in the 5-mm band is restricted to 20 percent per half-wave resonator (reference 3). A loss of 20 percent per resonator is perhaps a loose specification in general, but losses of this magnitude are commonly accepted, as in the case where an alumina substrate with a thickness of 0.025 inch is operated at X-band (reference 4). Accepting this standard, one may refer to Figure 1 to find the maximum substrate thickness (H) and strip width (W) at 60 GHz as a function of the dielectric constant of the substrate. The substrate must be as thin as 0.0016 inch if it is made of teflon glass (ϵ = 2.5), but can be as thick as 0.006 inch if it is made of magnesium titanate (ϵ = 16). Regardless of the substrate material, the width of a simple 50-ohm strip is small relative to many chip and beam-lead devices. Thus, millimeter microstrip is not entirely compatible with hybrid IC techniques, requires thin (fragile) substrates, permits only a limited range of characteristic-impedance variation, and poses many tolerance problems.

To overcome these problems, two new IC transmission lines are presently under study. Figure 2 shows the essential features of the first of these media, which is called integrated fin-line. Here, metal fins are printed on a dielectric substrate, which bridges the broad walls of a rectangular waveguide. This adaptation of ridge-loaded waveguide permits circuit elements to be fabricated by low-cost printing, and is compatible with thin-film hybrid techniques. The degree of miniaturization can be limited, which is an advantage at millimeter wavelengths. The fins increase the separation between the first two modes of propagation, thereby providing a wider useful bandwidth than conventional waveguide. Owing to the similarity between integrated fin-line and conventional ridged waveguide, a wealth of design information (references 5 and 6) is available.

In passive circuits, such as filters, the fins may be directly grounded to the waveguide, and lumped elements, such as beam-lead capacitors, may be added. Figure 2 also suggests how the gap between the fins can be varied along the longitudinal axis, to provide low-cost circuit elements. When semiconductor devices are to be added, at least one of the fins must be insulated from ground at dc, to permit the application of bias. Figure 3 shows how this may be accomplished without disrupting the RF grounding of the fins. In both approaches, the waveguide is parted along a plane where the current flow is parallel to the break, as in a common slotted line. For maximum mechanical strength, the substrate should function as a gasket, which is possible for teflon-fiber glass, mylar, and related materials. In Figure 3A the coplanar fins are insulated at dc from ground by a second gasket, but are RF grounded through a quarter-wave choke. The fins may also be printed on opposite sides of the substrate, as shown in Figure 3B. In this case, the bias may be introduced across the insulated halves of the waveguide housing. Bias then reaches the semiconductor device, which can be mounted in a hole drilled through the substrate. Of these two approaches, the choke of Figure 3A is preferred, as it does not require substrate drilling, and provides shielding of the bias line, which may also carry modulation or IF signals.

For thin moderate-ϵ substrates, the dielectric will have a minor effect (reference 7), and the single-mode bandwidth and attenuation of integrated fin-line may be estimated from existing data (reference 6). Such estimates lead to the conclusion that integrated fin-line can provide bandwidths in excess of an octave, with less attenuation than microstrip. In addition to eliminating spurious modes and radiation, the new line is compatible with hybrid IC devices and amenable to low-cost printed-circuit techniques. The performance advantages will be experimentally investigated with a cavity test-fixture which is now under construction.

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The cavity consists of a length of integrated fin-line, terminated at both ends in a short circuit. Measurements will be performed through loosely coupled ports, to determine the cutoff frequencies and attenuation for practical materials and configurations.

The second new IC medium which is now under study is called oversized microstrip. Normally, the thickness of a microstrip substrate (H) is held to a small fraction of a guided quarter-wavelength to restrict the radiation loss. If, however, we intentionally set the substrate thickness at a quarter-wavelength, an efficient radiator may be printed on the ungrounded surface of the substrate. When mounted in a waveguide, as shown in Figure 4, this radiator will couple to the TE-10 waveguide mode and all the power may be delivered to an impedance-matched load (such as a mixer diode), provided that no energy is reradiated in some other mode such as the crossed TE-01 mode. For this reason, the air-filled portion of the waveguide should not support the TE-01 mode, which is automatically accomplished when a standard waveguide is operated within its normal frequency range. Moreover, the dielectric-filled portion of the waveguide should not support the TE-01 mode, in order to prevent resonances within the substrate. This may be accomplished by reducing the waveguide size within the dielectric region, or by printing the radiator on a thin substrate which is suspended above the ground plane.

Figure 4 illustrates the essential features of a mixer constructed in oversized microstrip. Both the local oscillator and the signal are coupled from the waveguide by a monopole, whose length and shape are selected to provide a wideband impedance match to the diode. In the intended application, both the local oscillator and signal will be close in frequency, and fed to an array of mixers by quasi-optical techniques. In each mixer, the diode is returned to ground at RF and dc by a direct connection to the waveguide housing. Bias is injected, and the IF signal is extracted through an RF-blocking network, which does not couple to the TE-10 mode.

Figure 5 shows an experimental model of a mixer constructed in oversized microstrip. The monopole, diode-mounting lands, and RF-blocking network are all printed on a mylar gasket whose thickness is 0.005 inch. The conductor patterns were formed by photoetching copper and nichrome layers vacuum deposited on the mylar, followed by a protective gold flash. The gasket is then sandwiched between two UG-385/U flanges, one of which is the input to a short-circuit termination. The other flange has been modified to accept a pair of rectangular choke grooves and a radial channel for the bias port. Each choke groove is a quarter-wave deep and spaced a quarter-wave from the main WR-15 waveguide. The choke was evaluated separately, by measuring the insertion loss through the main waveguide with an unmetallized 0.005-inch mylar gasket in place. The loss measured less than 0.2 dB across the 55 to 63 GHz band. A radial channel was next milled in the special flange to accommodate the bias line and RF-blocking network. This channel has a negligible effect on the insertion loss of the system. Work is now in progress to select the optimum type of mixer diode and to impedance match the monopole to this diode. Two types of Schottky-barrier diodes are presently under evaluation: a silicon beam-lead device (Alpha D5600A) and a gallium-arsenide chip device (Aertech A2G-100). Design tradeoff information and measured performance data will be presented.

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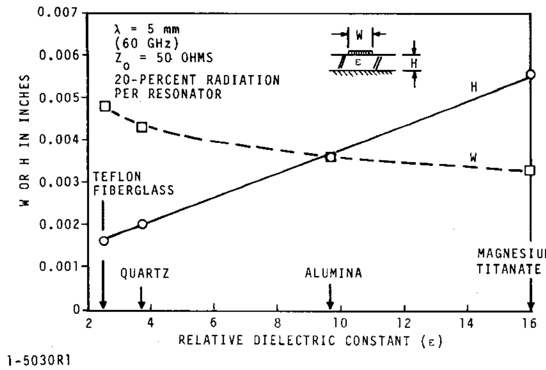

FIGURE 1. MAXIMUM MICROSTRIP DIMENSIONS

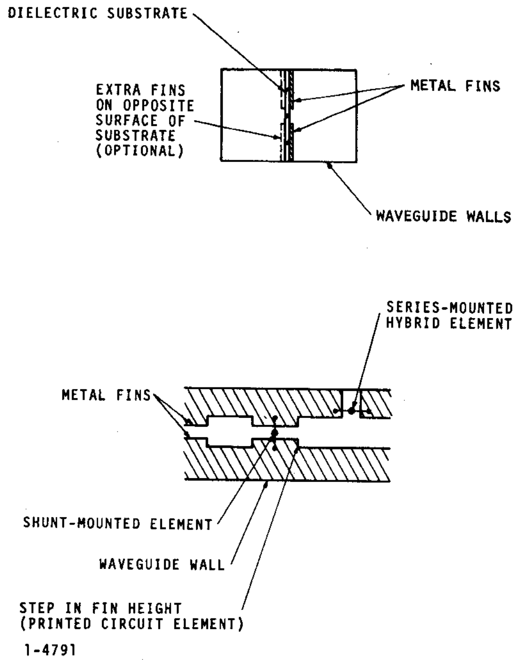

FIGURE 2. INTEGRATED FIN-LINE

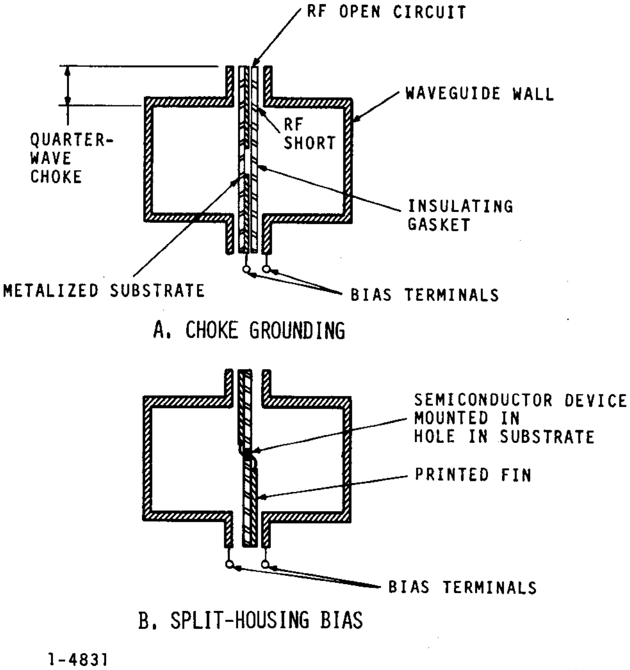

FIGURE 3. DC INSULATION OF FINS

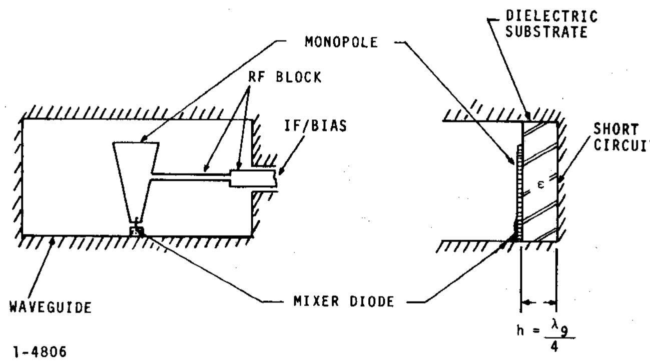

FIGURE 4. MIXER IN OVERSIZED MICROSTRIP

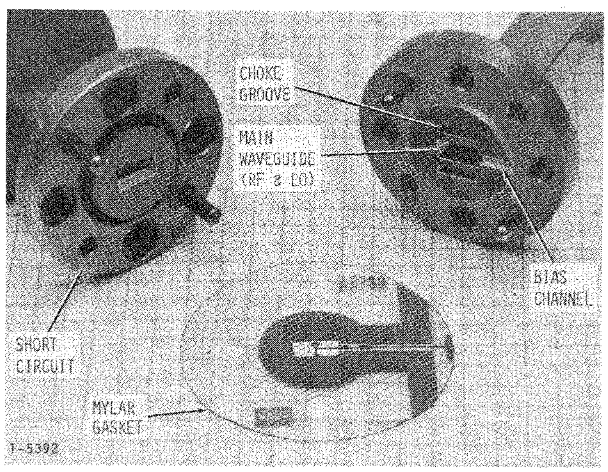

FIGURE 5. EXPERIMENTAL MIXER MODEL