E-PLANE COMPONENTS FOR A 94-GHz PRINTED-CIRCUIT BALANCED MIXER

Paul J. Meier

Eaton Corporation AIL Division
Melville, N.Y. 11747

Summary

E-plane components for a new form of a 94-GHz printed-circuit balanced mixer are described. The components include a low-loss printed-probe hybrid, advanced beam-lead diodes, and fin-line mounts. The E-plane approach features production economy, effective shielding, high (> 400) unloaded Q, light dielectric loading, and simple waveguide interfaces.

Introduction

Recent interest in the 3-mm atmospheric window has underscored the need for low-cost, high-performance receivers. Balanced mixers are of special interest in radiometers, where the IF is generally low, or in those applications where LO radiation must be minimized. A key component of a balanced mixer is the hybrid coupler, which can be constructed in various forms. At millimeter wavelengths, the most common forms of printed-circuit hybrids have been the ring hybrid[1], the branch-line coupler[2], and the slot/coplanar/microstrip junction[3, 4]. Although existing designs can be scaled into the 3-mm band, problems are to be expected in terms of radiation, stray coupling, Q limitations, manufacturing tolerances, and interaction with waveguide transitions.

As an alternative to the older forms of IC hybrids, the printed-probe E-plane coupler has been developed[5]. Through recent work, a high-performance E-plane hybrid has been developed in the 3-mm band[6]. By integrating such a hybrid with fin-line diode mounts, a balanced mixer can be constructed entirely from E-plane lines. Advantages of the E-plane approach at millimeter wavelengths include printed-circuit economy, negligible radiation and stray coupling, high unloaded Q (> 400 at 94 GHz), low-equivalent dielectric constant (for eased tolerances), and simple wideband transitions to standard waveguide instrumentation.

The following paragraphs describe the design and performance of E-plane components for a 94-GHz printed-circuit balanced mixer.

Components and Integration Goal

Figure 1 shows a preliminary layout of a balanced mixer assembly. The major components, a seven-probe hybrid and a pair of fin-line diode mounts, are printed on a single board which is suspended in the E-plane of a four-port housing. All four ports were required in early tests of the hybrid alone; in the illustrated assembly, only the two waveguide ports at the left are utilized. These ports serve as the RF and LO inputs. The IF outputs leave the housing through SMA connectors and are combined in a coax tee (not shown).

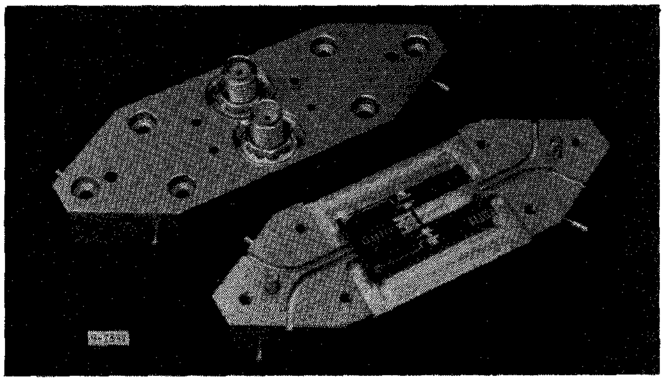


Figure 1. E-Plane Balanced Mixer

Figure 2 identifies the components of the printed-circuit assembly. Included are:

- Quarter-wave notches (a) which provide a match between the air-filled and slab-loaded waveguides.
- Mounting holes (b) which align the 5-mil, Duroid 5880 board within the housing.
- Foil tabs (c) where dc bias can be applied.
- Seven-element printed-probe coupler (d).
- Fin-line mounts for the beam-lead diodes (e); the mounts include RF transformers (f) and gold wire (g) which provides the ground return for the RF, LO, IF, and dc bias.
- IF output, containing high-impedance lines (h), dc-blocking capacitors (i), and connector contacts (j).
- Resistors (k) which block the IF from the dc bias circuit.
- Printed-circuit E-plane bifurcations (ℓ) which reactively terminate the diode mounts at RF and LO.

Details on the major components follow.

Printed-Probe Hybrid

At the center of the housing, illustrated in Figure 1, parallel waveguides share a common broadwall, which is slotted to accept a pair of dielectric boards. An array of coupling probes is printed on one board, and insulated from the common wall by a second board, fabricated from 2-mil Teflon.

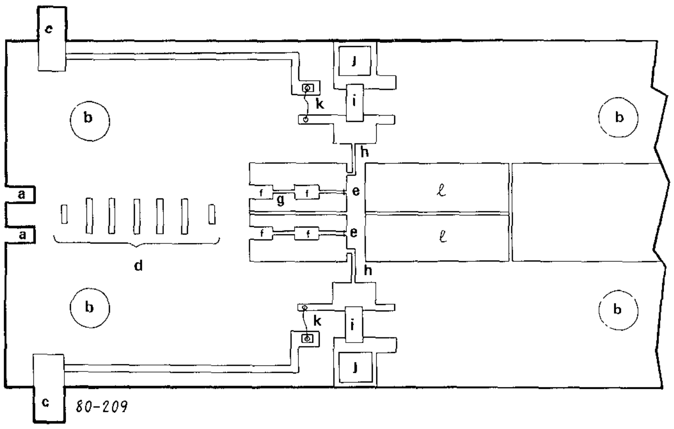
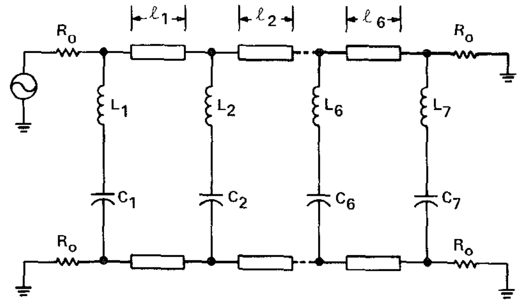


Figure 2. Balanced Mixer Components



ELEMENT NO	MIDBAND COUPLING (dB)	L (nH)	C (fF)
1 AND 7	-24.1	4.97	0.271
2 - 6	-18.1	5.55	0.345

80-210

Figure 3. Hybrid Equivalent Circuit

The hybrid was designed with the aid of the equivalent circuit shown in Figure 3. The coupling probes were modeled as L-C branches, interconnected by lengths of slab-loaded waveguide. The characteristic impedance of the waveguide and terminations was calculated from the power-voltage definition. Based on a computer-aided technique, unique L-C combinations were found which modeled the measured coupling/frequency response for probes of various lengths and widths[6].

After studying a variety of array configurations, a seven-probe equal-element coupler was chosen for the final design. The configuration is simple and compact, and it avoids the large range in coupling levels found in more complex distributions (such as Tchebycheff). The L-C values for the final design are tabulated in Figure 3. The interprobe spacings were initially set a quarter-wavelength, and then optimized by a gradient-search technique.

Figure 4 shows the measured and calculated performance of the seven-probe coupler. Across a 3.7-GHz band, centered at 94 GHz, the measured isolation is 22 dB or better, and the coupling to either output port is 3.4 ±0.9 dB. In comparing the measurements with calculations, it should be noted that the measured isolation includes the effects of waveguide bends, [illegible] discontinuities, and detector mismatch, where[illegible] [illegible]l assumes perfect terminations.

At midband, the coupling is only 0.4 dB below the ideal 3-dB value. Since the housing alone has an insertion loss of 0.3 dB, the hybrid contributes only 0.1 dB to the total loss. Based on an axial length of 1.5 wavelengths, the unloaded Q in the printed probe region is greater than 400.

Diode Mounts

Other important parts of the assembly depicted in Figure 2 are the GaAs beam-lead mixer diodes and the fin-line circuit in which they are mounted. The diodes chosen for this program were developed by Calviello, et al[7], and have the following characteristics:

Zero-bias junction capacitance:	15 fF
Package capacitance:	20 fF
Series resistance:	2.5 ohms
Ideality factor:	1.07

The initial dimensions for the fin-line mount were scaled from a related design[4]. The circuit was then optimized as a single-ended mount (i.e., without the E-plane hybrid). By observing the reflected power with an external waveguide coupler, the circuit was adjusted to be matched, across the band of interest, under typical bias conditions.

Figure 5 shows the return loss versus frequency, for the single-ended fin-line mount. Across a 4-GHz band centered at 94 GHz, the return loss is 16.5 ±4.5 dB.

After obtaining a satisfactory RF/LO match, the conversion loss of the single-ended mount was measured. The RF and LO were coupled to the mount through the main and decoupled arms, respectively, of an external waveguide coupler. The RF and LO power levels were measured with a bolometer, calibrated against a wet calorimeter (TRG V981). The IF output was measured with a coax thermistor (HP478A).

Figure 6 shows the measured conversion loss as a function of the LO power at the input to the single-ended mount. The measurements were performed with an LO of 94 GHz and an RF of 93 GHz; the plotted performance is typical of that recorded in the lower part of the passband depicted in Figure 5. At each LO power level, the bias was adjusted to minimize the conversion loss. The optimum bias levels are also plotted in Figure 6. For an LO drive of 5.7 dBm (3.7 mW), the conversion loss is 7.2 dB. Although the final balanced-mixer design will require 3.4 dB more LO drive, this is well within the capability of existing, fundamental Gunn oscillators.

Conclusion

The major components for a new form of printed-circuit 94-GHz balanced mixer have been completed. Included are a low-loss printed-probe hybrid, low-parasitic GaAs beam-lead diodes, and fin-line matching circuits. This E-plane approach provides advantages in terms of production economy, effective shielding, high (> 400) unloaded Q, low equivalent dielectric constant, and simple waveguide interfaces. An integrated balanced mixer is now being optimized, and performance data will be available shortly.

Acknowledgements

The work reported was sponsored by AIL, under the direction of M. Lebenbaum, K. Packard, and J. Whelehan. The diodes were developed by J. Calviello and co-workers in our Central Research Laboratory, under the direction of J. Taub. Technical assistance was provided by A. Cooley, A. Kunze, J. Pieper, A. Rees, C. Thompson, and K. Walsh.

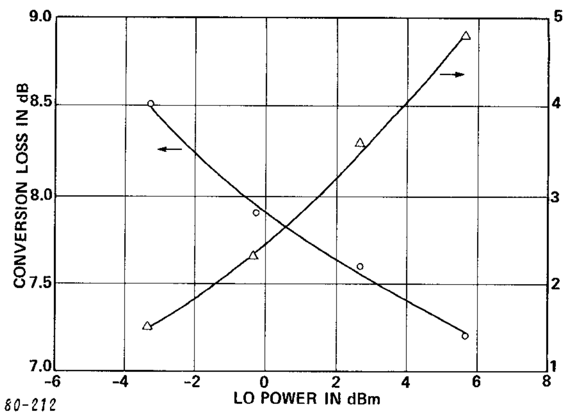


Figure 6. Conversion Loss of Single-Ended Mount

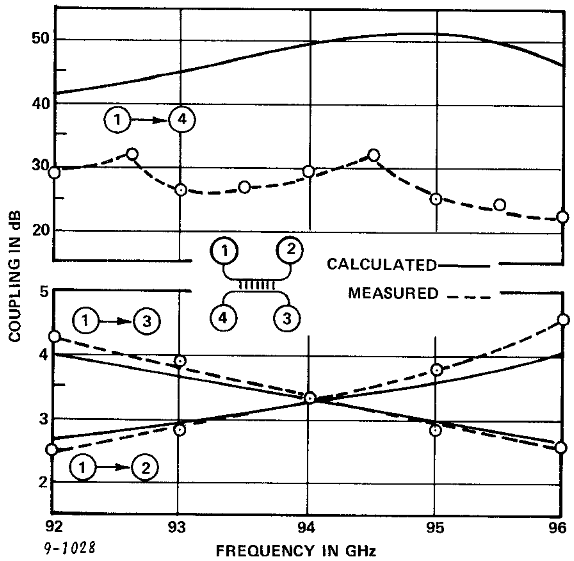


Figure 4. Performance of 7-Probe Hybrid

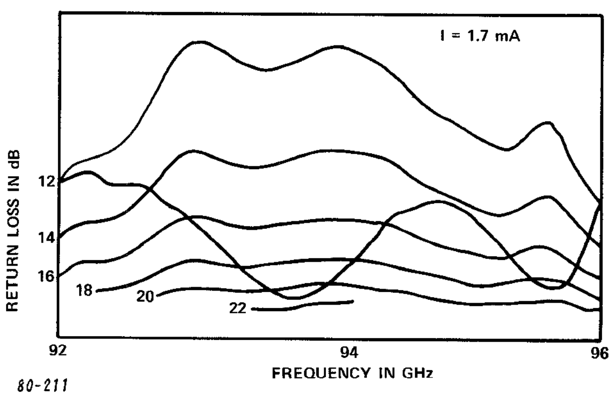


Figure 5. Return Loss of Diode Mount

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