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QUASI-OPTICAL POLARIZATION-DUPLEXED BALANCED MIXER

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A millimeter-wave antenna-mixer structure on a dielectric substrate is described. Measurements of a 10-GHz model in a quasi-optical system show good conversion loss and LO-to-RF isolation exceeding 30 dB. A GaAs monolithic integrated circuit seems feasible.

Introduction

Recent advances in fabrication of millimeter-wave diodes make it possible to consider the construction of mixer circuits with integral diodes directly on GaAs or other dielectric substrates. Also, the very low losses afforded by quasi-optical techniques make them a desirable alternative in millimeter-wave work. The antenna-mixer circuit to be described combines concepts from both areas to yield a receiver front end of appealing simplicity. To test the idea, a 10-GHz model was constructed and gave favorable results.

Theory

The antenna is one of a class of slot antennas which consist of a gap or hole in an otherwise continuous metallic sheet, backed on one side by a dielectric. Specifically, it is the dual of the familiar microstrip ring resonator (see Fig. 1). The microstrip resonator is a segment of microstrip bent into a loop; the slot ring resonator or antenna is a segment of slot line bent into a loop.[1] Like the microstrip resonator, the slot ring structure's resonant modes occur at frequencies for which the ring circumference is an integral number of guide wavelengths.

To use the slot ring resonator as an antenna, the first-order mode is excited as shown in Fig. 2. An approximation for the radiation pattern treats the ring as a loop of magnetic current, and predicts a field similar to a full-wave wire loop, except that the electric and magnetic fields are interchanged. These patterns are characterized by bidirectional main lobes with maxima along the axis of the ring, perpendicular to the plane of the antenna. The presence of dielectric on only one side of the metallic sheet can be expected to increase the radiation on the dielectric side.

The slot ring antenna can support two independent first-order modes, just as the microstrip ring resonator can. This allows a form of polarization duplexing in which two feed points, if separated by 90° along the ring, can couple independently to horizontally and vertically polarized waves, with little or no cross-coupling between the two feeds. Polarization duplexing is used to feed RF and LO signals to the single-balanced mixer shown in Fig. 3.

The RF signal arrives as a horizontally polarized plane wave incident perpendicular to the antenna, on the dielectric side. The LO signal is vertically polarized, and can illuminate either side of the structure. V_{rf} and V_{lo} show the electric field vectors on the antenna plane. By resolving each vector into two perpendicular components, it is easy to see that mixer diode D_1 receives $\frac{V_{lo} - V_{rf}}{\sqrt{2}}$, while D_2 receives $\frac{V_{lo} + V_{rf}}{\sqrt{2}}$. In effect, each diode is an independent mixer, with the IF outputs added in parallel. The IF signal appears as a voltage between the central metal disc and the surrounding ground plane, and is removed through an RF choke. A double-balanced mixer can be made when two additional diodes D_3 and D_4 are added as indicated.

This antenna-mixer can be introduced in a quasi-optical arrangement in its present form with good RF-to-LO isolation. Additional improvement is easily achieved by introducing grid-type polarization filters on either side, as shown in Fig. 4. Horizontally polarized RF energy entering from the left passes through the front filter with little attenuation, and is received by the antenna. The rear filter is oriented to reflect the horizontally polarized RF wave, increasing antenna directivity in the forward direction. Vertically polarized LO energy not absorbed by the antenna is blocked by the front filter and reflected back to the antenna, allowing a high degree of LO-RF isolation.

Experiments

The model tested was designed for an RF center frequency of 10 GHz. Because of the inhomogeneity of the dielectric in this open structure, simple frequency scaling rules cannot be used to predict the behavior of millimeter-wave-size devices from the results of 10-GHz tests. Nevertheless, qualitative information about the behavior of the device has been obtained, and the results show good agreement with the elementary theory above.

Using rough estimates for the mixer diode impedance and the antenna feedpoint impedance, a slot ring antenna was designed and built with a detector diode at the feedpoint. The H-plane radiation pattern (Fig. 5) shows the characteristic two-lobed pattern of the full-wave loop antenna. Based on the measured E- and H-plane patterns, the antenna's directivity on the dielectric side was calculated to be 7 dB. This figure was used in estimating mixer conversion loss.

Next, the two-diode antenna-mixer shown in Fig. 3 was built, and tested in the setup shown in Fig. 4, with and without polarization filters. The antenna and filters are pictured in Fig. 6. The results follow:

Measured Antenna-Mixer Characteristics

DIMENSIONS: Average ring diameter: 9.3 mm

Gap width: 1.5 mm

Dielectric: 3.18 mm thick, dielectric constant = 2.23

DIODES USED: Aertech A2S250 low-barrier Schottky detector diodes (measured R_s = 350 Ω average)

NEC ND4131 silicon mixer diodes (R_s = 12 Ω)

ANTENNA-MIXER SYSTEM:

Two-diode mixer - RF frequency: 10 GHz

IF frequency: 10 MHz

RF polarization: Horizontal

LO polarization: Vertical

Measured conversion loss with Aertech diodes: 19 dB ± 2 dB

Measured conversion loss with NEC diodes: 8 dB ± 3 dB

LO-RF isolation: ≥ 30 dB

RF Cross-polarization rejection: 20 dB

A measurement of a four-diode configuration with Aertech diodes was also performed and showed approximately 20 dB conversion loss. In a paper by Held and Kerr[2], it is shown that DC series resistance of mixer diodes gives rise to losses at both RF and IF frequencies. The poorer results of the experiments using the diodes with high R_s are predicted well by their theory. The 8 dB figure was the best obtained, and compares favorably with conventional mixer configurations.

Conclusions

The concept of a planar antenna-mixer using a slot ring structure has been shown to be workable at X-band. While more theoretical work is needed to permit scaling down to millimeter-wave frequencies, the basic structure is simple, easy to fabricate, and lends itself to monolithic construction and quasi-optical feed techniques.

Acknowledgment

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References

1. S. B. Cohn, "Slot Line on a Dielectric Substrate," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-17, pp. 768-778, October 1969.

2. D. N. Held and A. R. Kerr, "Conversion loss and noise of microwave and millimeter-wave mixers: Part I - Theory," IEEE Trans. Microwave Theory and Techniques, Vol. MTT-26, pp. 49-54, Feb. 1978.

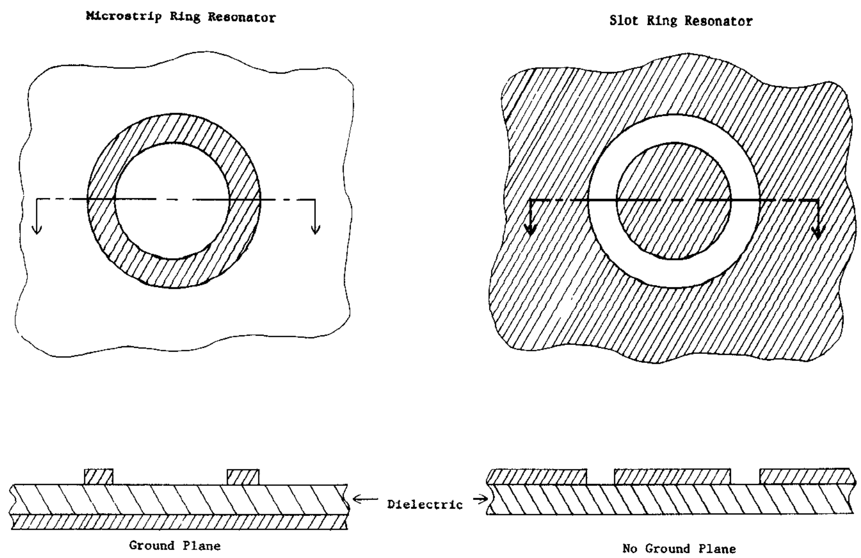

FIG. 1. COMPARISON OF MICROSTRIP RING AND SLOT RING STRUCTURES.

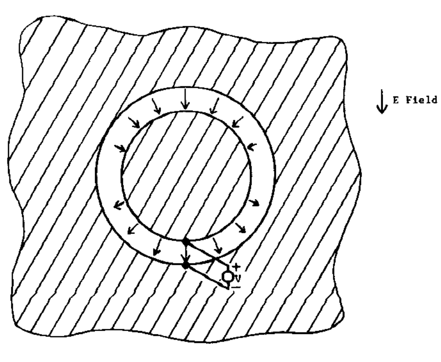

FIG. 2. SLOT RING FEED METHOD SHOWING ELECTRIC FIELD IN PLANE OF DEVICE

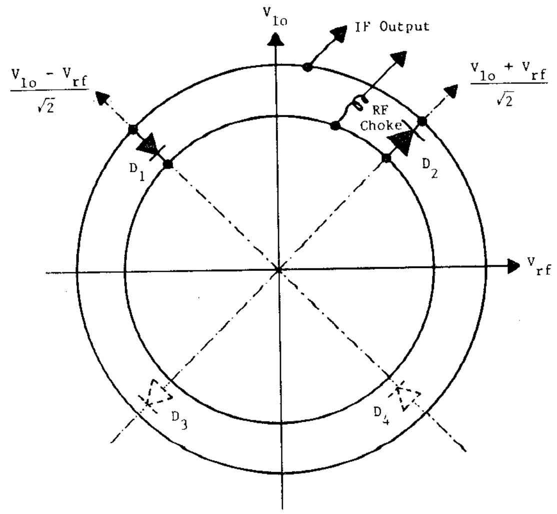

FIG. 3. ANTENNA-MIXER SHOWING DIODE INPUT VOLTAGES

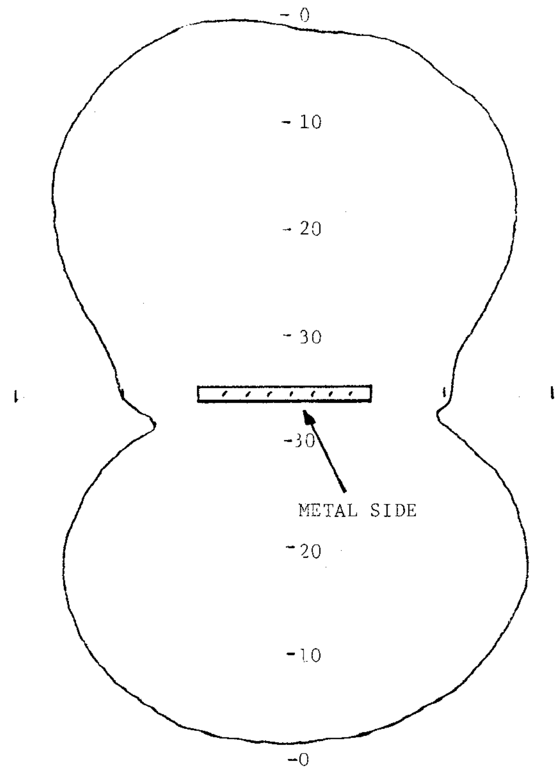

FIG. 5. MEASURED H-PLANE RADIATION PATTERN
(dB DOWN FROM MAXIMUM AT 10 GHz)

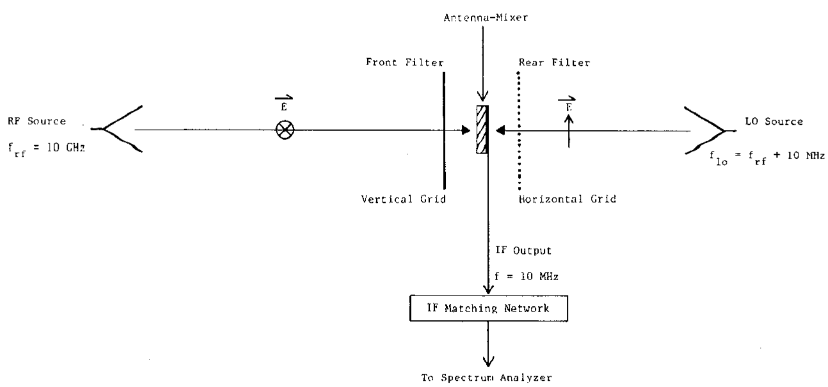

FIG. 4. QUASI-OPTICAL TEST SETUP

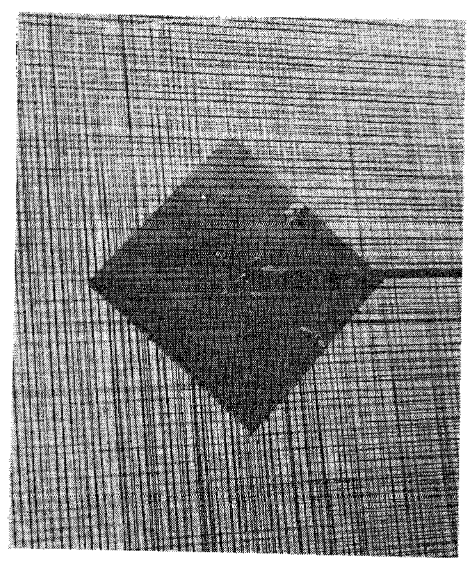

FIG. 6. PHOTOGRAPH OF ANTENNA-MIXER WITH POLARIZATION FILTERS. (REAR VIEW)