LOW NOISE MICROWAVE AND MILLIMETER WAVE INTEGRATED CIRCUIT MIXERS

by

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Abstract

This paper describes the use of integrated circuit technology to achieve enhanced performance in low noise X- and K_a-band mixers. Particular examples of low noise MIC mixer receivers using high-quality GaAs Schottky diodes include a 9.0 - 10.0 GHz image-recovery downconverter exhibiting 4.2 - 5.5 dB SSB noise figure and a 36.5 - 38.5 GHz radiometric downconverter exhibiting 6 dB DSB noise figure.

Introduction

The term "Microwave Integrated Circuit" (MIC) is most generally associated with microstrip. However, there are numerous planar transmission media (stripline, co-planar waveguide, slot line, etc.) which lend themselves to the integration of microwave devices and circuitry at frequencies well into the millimeter region.

Because the significant dielectric loading inherent in these media yields guide wavelengths considerably less than those in air, and since all of these media lend themselves to batch processing, MIC's have generally been associated more with circuit miniaturization and low production cost than with the realization of improved performance. Specifically, the above is usually traded off against the higher loss per wavelength in these media, as compared to that achievable in conventional media, e.g., waveguide or coaxial line.

It is the purpose of this paper to demonstrate that integrated circuit techniques can be applied to the implementation of very low noise microwave and millimeter wave mixers, by virtue of:

- the small physical dimensions of MIC conductor patterns, which permit the use of semiconductors that are either unpackaged (chips or beam-leaded devices) or encapsulated in sealed micro-packages.
- the tight tolerances obtainable with standard MIC delineation techniques which lend themselves to tight amplitude and phase balance.
- the small physical dimensions of MIC components significantly reduce interconnecting line lengths, as compared to conventional media.

As examples of the above, two mixers are described, an X-band image recovery mixer (ultra-low noise figure single sideband design) implemented in both stripline and microstrip versions, each with an integral VHF transistor IF preamp, and a balanced K_a-band double sideband mixer, fabricated on a low dielectric constant microstrip substrate.

X-Band Image Recovery Mixer

It has long been established (Ref. 1) that the conversion loss of a resistive mixer is minimized when real power flow is allowed to take place only at the signal and intermediate frequencies. This means that all other mixing products must be properly reactively terminated, particularly the image frequency (f_{im}) generated during the mixing process, i.e.:

$$f_{im} = (2 \cdot f_{LO}) - f_{SIG}$$

Traditionally, in this type of "image enhanced" mixer, the image is terminated by means of a properly designed RF input filter (Ref. 2). This generally dictates the use of a high intermediate frequency and imposes restrictions on achievable bandwidths.

An alternative technique for image enhancement has been evolved, whereby in a properly designed image phasing (single-sideband) mixer (see Figure 1), the generated image can be properly terminated by means of circuit symmetries rather than filters (Ref. 3). This technique offers the advantage that low IF's may be utilized (e.g., 60 MHz) and, that signal bandwidths are only limited by those of wideband RF coupling networks.

As part of a program to rigorously analyze and evaluate the technique of "image recovery" (Ref. 4), individual versions of an X-band MIC mixer and integral preamp were constructed in both stripline and microstrip transmission media. The stripline construction, however, offered the following advantages:

- Comparable volume to microstrip configuration, taking into account size of overall housings.
- Lower conductor loss than microstrip, thereby providing the least possible signal frequency loss.
- Accommodatability of GaAs Schottky diodes in a hermetically sealed micro-pill package.

The measured performance of the stripline and microstrip mixers, shown in Figures 2 and 3, respectively, is seen to include SSB noise figures (obtained with a precision hot/cold load), of 4.2 to 4.9 dB over 9.1 to 9.9 GHz (stripline), and 4.7 to 5.5 dB over 10.4 to 11.3 GHz (microstrip). Each case includes the 1.2 dB noise figure contribution of the 60 MHz IF amplifier. The additional 0.5 dB noise figure associated with the microstrip downconverter is primarily due to the slightly larger losses inherent in the vacuum deposited microstrip metallization as compared with the stripline laminate. In both instances, the measured X-band noise figure is second only to that achievable with a paramp.

K_a - Band MIC Mixer

A further area of interest, of late, has been the extension of MIC techniques up into the millimeter region. LNR recently completed a program which demonstrated that a high performance mixer can be realized, in upper K_a-band, on microstrip.

Interestingly, the best results were obtained using a very uniform, low-loss, low-K substrate (Ref. 5). The mixer, a balanced design utilizing a K_a-band "rat-race" signal/LO coupler, was fabricated on a half-by-half inch, ten mil thickness substrate as shown in Figure 4. High quality beam-lead GaAs Schottky diodes were used. The signal and LO ports of the hybrid were probe coupled to K_a-band wavequide. When integrated with a discrete component 500 to 1000 MHz, 2.5 dB noise figure IF preamp, the resultant measured double sideband noise figure for an LO setting of 37.5 GHz was 6 dB (this translates to a 5 dB double sideband noise figure with a 1.5 dB noise figure IF amplifier). This compares quite favorably with the performance of any K_a band mixer today available. Moreover, the diodes used are relatively inexpensive, making this an attractive mixer for applications where both cost and size are factors.

The mixer substrate represents a very small contribution to the total structure size. Most of the volume of the prototype mixer consisted of the housing itself, including the two feed waveguides (signal and LO). By judicious design, however, it is possible to incorporate a thin film IF amplifier into this housing, at no increase in volume. Moreover, there is sufficient room in the LO feed waveguide to incorporate a Gunn diode oscillator. The resultant complete front end would have a volume less than 3 cu. in.

Conclusions

The work described has demonstrated that very low noise figures mixers can be fabricated in MIC media, and that one need not sacrifice performance for small size, light weight and low cost. Moreover, these mixers can be applied to the design of miniature, high performance mixed media front ends.

Acknowledgments

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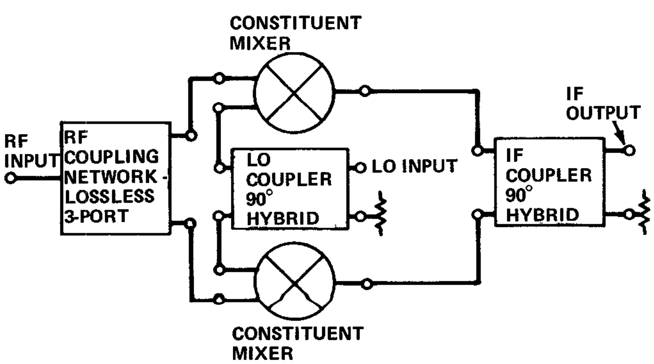

Figure 1 - Block Diagram of Image Recovery Mixer

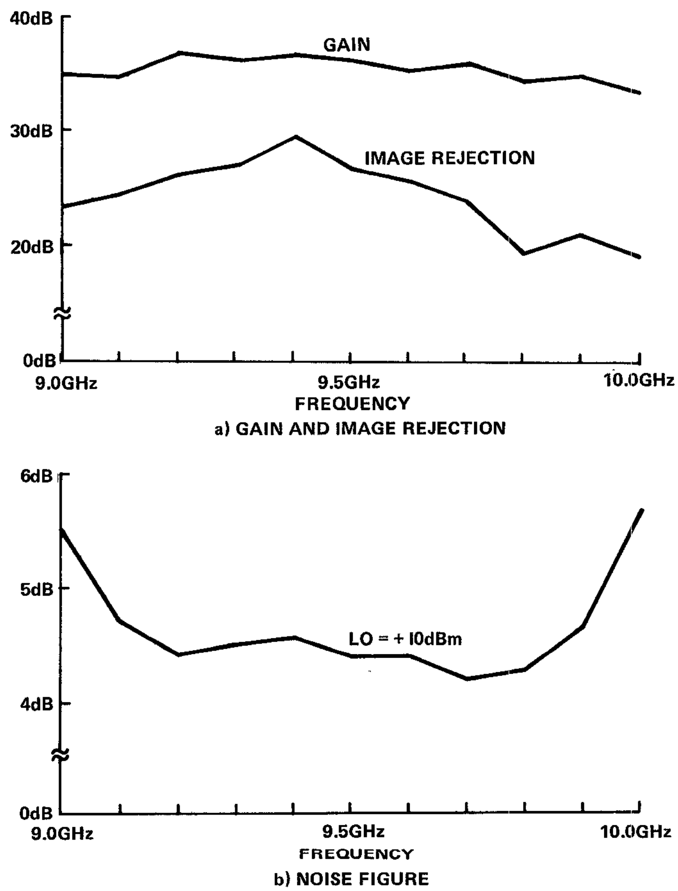

Figure 2 - Measured Performance of X-Band Image Recovery Mixer Preamplifier

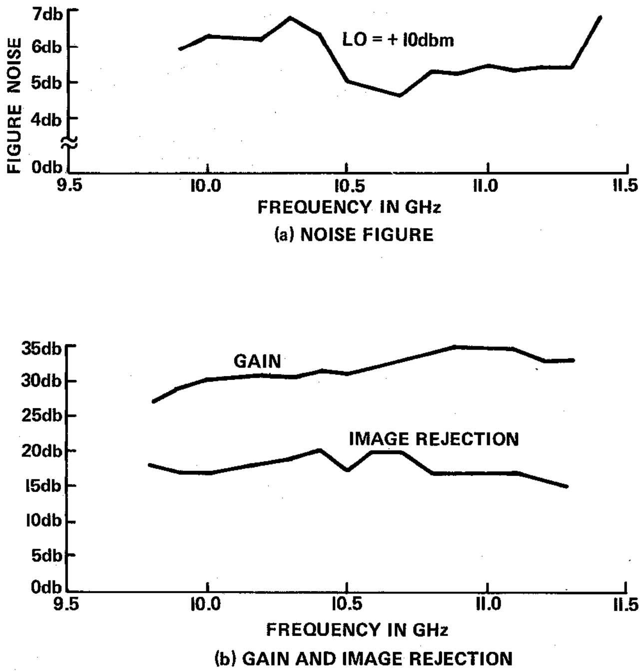

Figure 3 - Measured Performance Data-Microstrip Image Recovery Mixer and 60 MHz Preamplifier

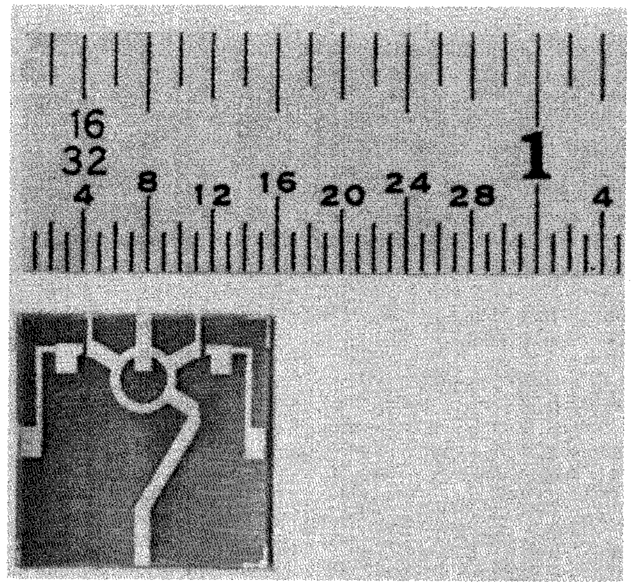

Figure 4 K_a — Band Microstrip Mixer