Analysis and Design of a Low-Noise X-Band MIC Mixer 1-GHz IF Amplifier

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***Abstract*—The analysis and design of a low-noise 500-MHz bandwidth MIC image- and sum-enhanced 12-GHz mixer-IF amplifier is described. Typical midband noise figures of 6.3 dB have been achieved.**

A 500-MHz bandwidth integrated image- and sum-enhanced 12-GHz mixer-IF amplifier is described that has been developed for the ground station of a satellite communication system. The unit is shown in Fig. 1. The mixer and interstage network were fabricated on a single 0.75 × 1.50 × 0.025-in sapphire substrate using thin-film techniques. Nominal center frequencies include $f_S = 11.95$ GHz, $f_{LO} = 10.7$ GHz, $f_I = 9.45$ GHz, $f_\Sigma = 22.65$ GHz, $f_{IF} = 1.25$ GHz. The mixer-interstage network is shown in Fig. 2.

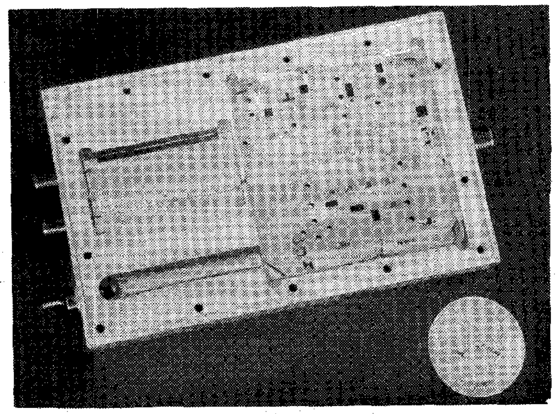

Fig. 1. Mixer-IF amplifier.

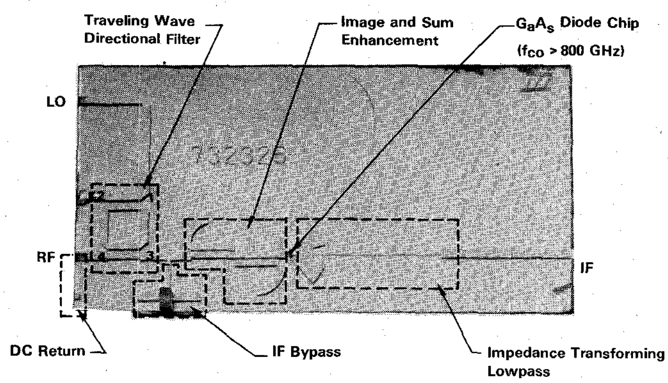

Fig. 2. Mixer-interstage network.

A traveling-wave ring-directional filter with circumference = λ_{LO} is used for LO and signal injection to the mixer diode. LO power entering port 1 is coupled over to port 3 with approximately 3.5-dB insertion loss. This transfer characteristic (port 1 to port 3) is bandpass while the signal path (port 4 to port 3) exhibits the complementary band-reject characteristic. The loss to the signal is ≈0.2 dB across the band.

Image- and sum-frequency enhancement on the RF input side of the diode is effected using a combination filter consisting of two $\lambda_I/2$ open-circuited stubs coupled to the main line over a quarter wavelength plus two open-circuited stubs which are a quarter wavelength long at the sum frequency. The 500-MHz bandwidth required for the image filter necessitated the use of a double-stub design. The latter stubs are spaced a nominal quarter wavelength apart at the signal frequency so as to present a good match to the signal.

On the IF output side of the diode, image- and sum-frequency filtering is accomplished by the low-pass filter shown in Fig. 2. This filter must pass the IF (transforming from 100 to 50 Ω in the process) and terminate the image LO signal, and sum frequencies. This filter was designed exactly using low-pass filter theory; however, during measurements on a 10:1 scale model, it was found necessary to experimentally alter the filter to improve its performance.

The IF bypass network consists of a high-impedance stub terminated by two low-impedance stubs (all $\lambda/4$ at the signal frequency) plus a shunt capacitor to ground. This combination is transparent to the signal, but is designed to be series resonant at 1.25 GHz thus preventing IF from propagating out the signal port. An advantage of this design is that an open will be presented to the signal frequency independent of the capacitor's X-band impedance. Finally, a grounded $\lambda_S/4$ stub is used to provide a dc return for the diode current.

Conversion loss for the complete mixer circuit was predicted using a nodal analysis program. The predicted curve uses a pulse duty ratio (PDR) [1] of 0.14. This was found to be the optimum achievable experimentally. Predicted performance and experimental results for the conversion loss versus RF for one of the final units is shown in Fig. 3. The minimum value achieved at band center is 3.5 dB rising to 4.4-dB band edge.

The 1–1.5-GHz IF amplifier, pictured in Fig. 1 was

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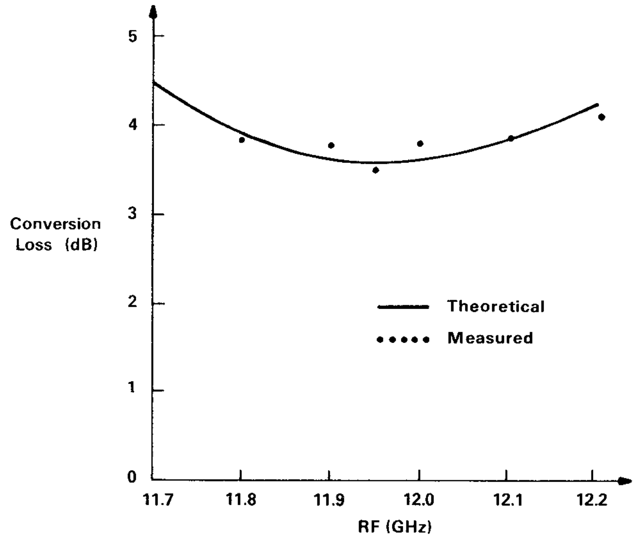

Fig. 3. Conversion loss versus frequency.

F (GHz)

Serial No.	11 7	11.8	11.9	12.0	12.1	12.2
001	7.0	6.3	6.1	6.5	6.5	6 8
002	7.1	6.3	6.3	6.7	6.5	6 7
003	7 0	6.2	6.3	6.6	6 6	6.9
004	7.2	6.5	6.5	6.6	6.6	7.0
005	7.1	6.4	6.3	6.5	6.6	7.0

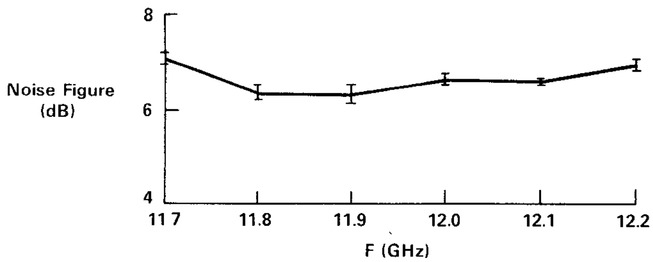

Fig. 4. Noise figure versus frequency.

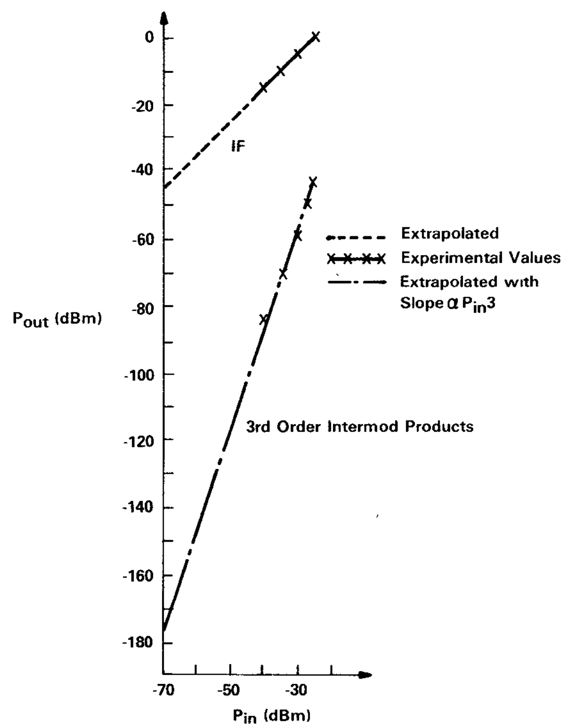

Fig. 5. Third-order intermodulation products.

fabricated using thick-film microstrip techniques in order to achieve high reliability, low cost, small size, and repeatability. The resistors were screened on the substrate using selected resistive inks, thus minimizing the number of components that require bonding.

A three-stage design was employed using a Fairchild MT4000 as the first-stage transistor. Optimum noise figure match for the first stage yielded an overall noise figure of 2.6 $\pm$ 0.2 dB across the 500-MHz band. The gain averaged 29 $\pm$ 0.5 dB.

Sufficient room was intentionally left on the mixer substrate to add an interstage matching network between the mixer and IF amplifier. The matching structure was determined experimentally by tuning for minimum overall noise figure after the mixer and amplifier were assembled in the final housing.

Conversion gain for the complete unit was nominally 25 dB. The IF return loss was $>$14 dB. Fig. 4 is a plot of overall noise figure versus frequency for five units. Fig. 5 shows IF output and third-order intermodulation products plotted versus RF power for the case of two RF signals 0.1 GHz apart. For an input level of -67 dBm, the intermod products are $\approx$125 dB below the desired IF output.

ACKNOWLEDGMENTS

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REFERENCES

[1] M. R. Barber, "Noise figure and conversion loss of the Schottky barrier mixer diode," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-15, pp. 629–635, Nov. 1967.