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INTEGRATED KA-BAND FRONT END WITH MONOLITHIC MIXER

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ABSTRACT

A Ka-band front end has been developed that integrates a low-loss wide-band monolithic mixer, a two-stage IF amplifier on semi-insulating GaAs, and a lumped-element Gunn LO. Small size (0.5 in^3) and good performance (11-dB gain with a DSB noise figure of 7 dB) have been obtained by applying synergistic IC construction techniques.

INTRODUCTION

In recent years, it has become increasingly important to reduce the size and cost of millimeter-wave receiver front ends. Applications where such reductions are particularly important include electronic warfare (EW) frequency-extension programs, radiometric seekers, and phased-array radars. To address these needs, we have developed a microminiature Ka-band front end, which can be assembled using low-cost IC techniques.

Figure 1 shows the block diagram of the front end, which is assembled in two modules. This configuration was selected to address a broad range of system applications and exploit the capabilities of synergistic IC construction techniques. Module A includes a monolithic balanced mixer and a two-stage IF amplifier. Rather than directly integrating these components, and risking local oscillator (LO) feedthrough via higher-order modes, a short length of 50-ohm line (a mode barrier) is utilized. Also contained in Module A is a 7-dB pad, which ensures a good LO input VSWR during unpumped (start up) conditions. Module A can be tested with a remote LO, or it can be integrated with the Gunn LO contained in Module B. Details on the design and performance of the front-end components are contained in the following paragraphs.

MONOLITHIC MIXER

The balanced Ka-band mixer is shown in Figure 2. The full circuit of Figure 2A measures 5 by 140 by 180 mils, and includes a single-section branch-line coupler, diode-matching network and an IF output filter. Each of these circuit elements was independently tested and optimized before the mixer integration. As a further step in the optimization, the complete mixer was tested as a hybrid circuit before the monolithic realization (1).

Figure 2B is an enlarged view of one mixer diode. This diode is a high-cutoff mesa device, similar in construction to our earlier discrete devices (2). The processing features tantalum-gold metalization and plasma dry-etch techniques. These techniques result in excellent uniformity and high yield over large wafer areas (up to 6.5 cm^2).

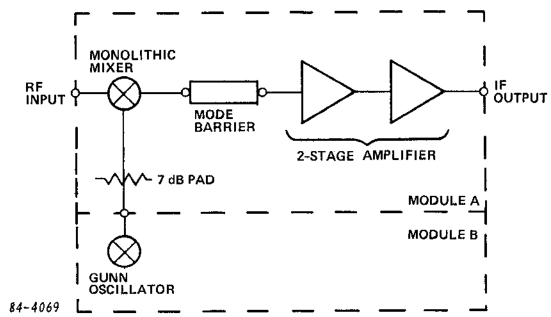

Figure 1. Block Diagram of Integrated Front End

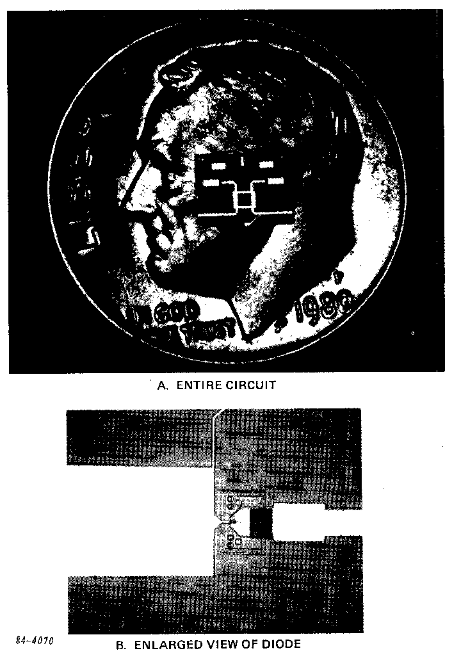

Figure 2. Monolithic Ka-Band Mixer

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The mixer is fabricated on an epitaxial GaAs wafer that has an N-layer carrier concentration of 3 - 5 x 10^{16} cm^{-3}, and a thickness of 0.1 micron after processing. the underlying N^{+} layer has a thickness of 1.0 to 1.5 microns, with a carrier concentration of 2 x 10^{18} cm^{-3}. High reliability is assured by double passivation (sputtered SiO_2 and Si_3N_4 layers) that also serves as the base for the distributed-circuit metalization. Windows were opened through the passivation layer to evaporate ohmic contacts consisting of AuGe-Ni-Au. Finally, the circuit was completed by pulse-plating a gold air-bridge connection between the ohmic contact and the distributed circuit.

Voltage-current (V-I) characteristics will be presented to show that the ideality factor of these devices is less than 1.1, and the series resistance is less than 3 ohms.

To measure the radio frequency (RF) performance of the mixer, the chip was mounted in a three-port fixture with special (40-GHz) SSMA connectors and coax/waveguide transitions. Figure 3 shows the conversion loss of the mixer, as measured at the optimum LO drive level of 13 dBm. With the LO fixed at 36 GHz, the minimum conversion loss is 6.3 dB and the 3-dB bandwidth is 7 GHz. Correcting for the connector and transition loss, the minimum conversion loss of the mixer is estimated to be 5.3 dB. This performance compares favorably with the best reported results for Ka-band monolithic mixers (3, 4).

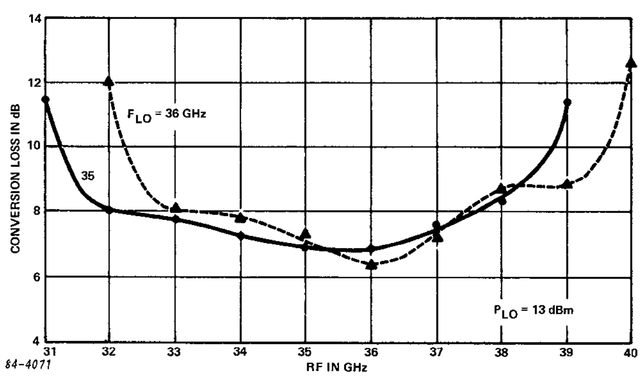

Figure 3. Conversion Loss of Monolithic Mixer

IF AMPLIFIER

Another key component in the front end is the two-stage IF amplifier. Each stage is realized as a hybrid IC with lumped circuit elements monolithically integrated on a 5-mil semi-insulating GaAs substrate. This approach allows for compatibility in the processing of the mixer and IF chips. Moreover, the IF chip can be upgraded to a fully monolithic circuit, when desired, with further work. (A long-range goal of this program is to produce an entire receiver on a single chip.) However, at this time a commercially available GaAs device (Mitsubishi MGFC 1402) is utilized.

The circuit layout, shown in Figure 4, utilizes parallel feedback for gain flatness and reduced input/output VSWR. Reactive input/output networks are included for further VSWR reduction and to provide convenient bias-injection points. The feedback resistor, R_1, is achieved with a tantalum-film meander line whose width is 25 microns. All capacitors are overlay types, with a tantalum-oxide dielectric and an air-bridge connection to the adjacent element. The bypass capacitors (C_2 and C_4) include via-holes that connect the bottom plate to the microstrip ground plane. Typical Q's and self-resonant frequencies, as determined from tests of isolated elements, will be presented.

After completing the characterization of individual elements, a one-stage amplifier was designed and tested. Across the design band of 1 to 2 GHz, the measured gain was 10.5 $\pm$0.4 dB and the noise figure was 2.5 $\pm$0.2 dB. This performance is in good agreement with the computer-aided design analysis.

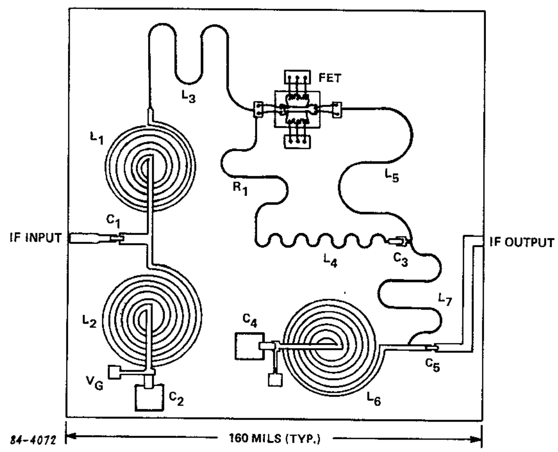

Figure 4. Circuit Layout for One-Stage IF Amplifier

LOCAL OSCILLATOR

Module A contains a 7-dB pad that ensures a good LO input VSWR during unpumped (start up) conditions. A coax connector can be attached to the input of the pad for external LO operation. Alternatively, a lumped-element Gunn LO (in Module B) can be substituted for the LO connector.

As in an earlier design, the lumped-element LO features small size (0.1 cubic inch) and minimum parts count (5). The output of the LO is a subminiature coax cable (UT-34), which can interface with a waveguide test fixture (to be described) or Module A. The oscillator requires 4.9 vdc at 1.1 amp and provides a power output of +18.7 dBm at 35 GHz.

INTEGRATED FRONT END

The previously described components have been integrated to form microminiature Ka-band front ends. Module A was first tested with an external klystron oscillator. After satisfactory performance had been demonstrated, Modules A and B were integrated. Figure 5 shows the complete assembly, which includes the monolithic mixer, LO pad, mode barrier, two-stage IF amplifier and Gunn LO. In addition to the RF and IF connectors, the housing contains bias pins for dc inputs to the amplifier and oscillator.

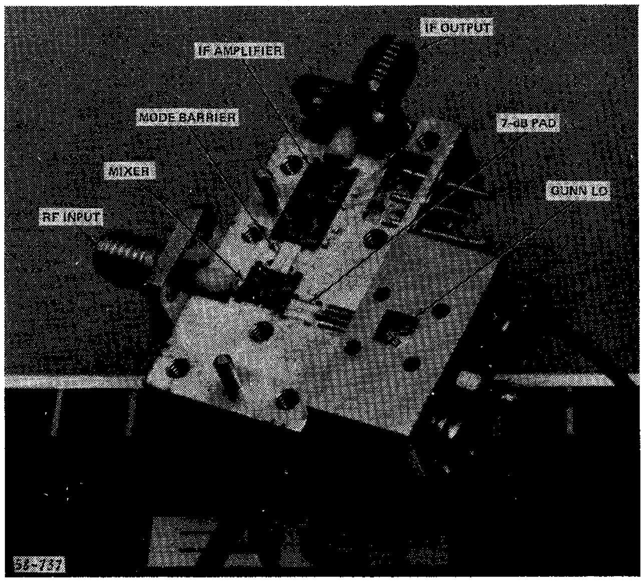

Figure 5. Integrated Ka-Band Front End

Figure 6 shows the measured RF/IF gain of Module A with external LO drive. For each of the indicated LO frequencies, the drive level was held at +12.5 dBm, referenced at the mixer input (i.e., +19.5 dBm at the input to the 7-dB pad). As expected, upper- and lower-sideband responses appear symmetrically about the LO frequency. An RF/LO gain of 11 dB or better can be achieved across a wide (7.5 GHz) band by step tuning the LO from 33.5 to 36.5 GHz.

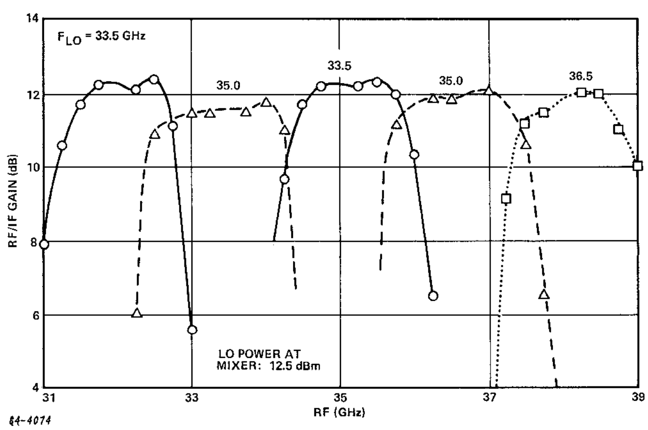

Figure 6. Conversion Gain of Front End

The noise figure of Module A was also measured. With the LO fixed at 35 GHz, the DSB noise figure was 7 dB for power levels of 11 to 13 dBm at the mixer input. From this measurement, and the known conversion loss of the mixer and the gain of the IF amplifier, it can be shown that the excess noise ratio of the mixer diodes is unity.

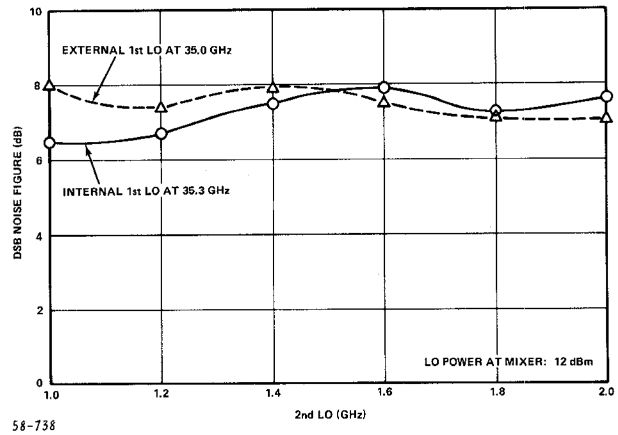

Figure 7. Noise Figure of Front End

After completing the tests of Module A with an external LO, the module was integrated with Module B. As shown in Figure 7, good agreement was obtained between the noise-figure measurements with internal and external LO's. Additional measurements, including RF/IF gain, confirm that the LO integration has been successfully completed.

CONCLUSIONS

A Ka-band front end has been developed that integrates a low-loss wide-band monolithic mixer, a two-stage hybrid IF amplifier, and a lumped-element Gunn LO. Small size (0.5 in^3) and good performance (11-dB gain with a DSB noise figure of 7 dB) have been obtained by applying synergistic IC construction techniques. This type of front end is applicable to a wide range of system applications, including EW frequency-extension programs, radiometric seekers, and phased-array radars.

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