AN 8 - 15 GHz GaAs MONOLITHIC FREQUENCY CONVERTER

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ABSTRACT

An MMIC frequency converter with an RF bandwidth of 8-15 GHz and an IF bandwidth of 1.5 GHz has been designed and built. The MMIC chip has 15 dB conversion gain and includes a two-stage RF amplifier, a two-stage LO buffer amplifier, a double-balanced mixer and a three-stage IF amplifier. This high level of integration is realized on a 48 x 96 mil area, resulting in good RF yields. The circuit employs a push-pull configuration to eliminate the need for via-holes (low-inductance grounds) and facilitate a compact layout.

INTRODUCTION

Microwave frequency converters are widely used in commercial and military communication systems. At present, these are primarily hybrid-MIC subsystems that integrate RF amplifiers, mixers and IF amplifiers. Each of these components has to be built, tested and tuned separately and then interconnected using short cable lengths or microstrip lines. The cost of the individual components as well as the additional tuning necessary to reduce the effect of interconnection mismatches makes this an expensive system. The size and weight of such a product is substantial.

MMIC converters provide great advantages of cost, size, weight and reliability over their MIC counterparts. However, few broadband MMIC converters have been built to date because of the difficulties involved in realizing broadband amplifiers and mixers at Ku-band frequencies, and combining them with IF amplifiers within a single chip of reasonable size. A previously reported MMIC frequency converter [1] showed excellent performance across the 3.7-4.2 GHz band. Novel transformer-coupled circuits were used, which resulted in high levels of integration and compact size. At higher frequencies, it is harder to realize such complex subsystems on a chip due to difficulties in modeling interaction between the various components of the system, grounding problems, and parasitic effects.

Our work, reported in this paper, shows that broadband lossy-match amplifiers using lumped element matching networks and transformer-coupled diode mixers operating at Ku-band frequencies can be integrated along with IF amplifiers to obtain a complete high performance receiver IC. This Ku-band down converter has one of the highest levels of integration reported to date in high frequency analog MMICs, with 20 FETs, 35 spiral inductors, 40 resistors and 26 MIM capacitors on a single chip.

MMIC FREQUENCY CONVERTER CIRCUIT DESCRIPTION

The cell library approach, reported earlier [2], was used in developing this subsystem MMIC. In this approach, each component required for a system is first developed and fully characterized individually. Then these different cells are integrated within a single MMIC. Because of the extremely short interconnection lengths involved, the resultant parasitics are kept to a minimum, resulting in a predictable, high-performance IC.

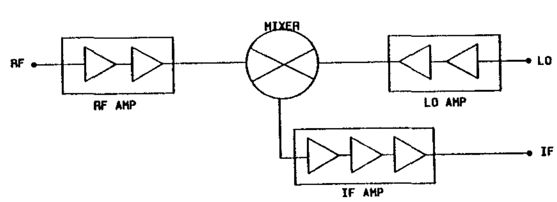

FIGURE 1. BLOCK DIAGRAM OF MMIC DOWN CONVERTER.

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Figure 1 is the block diagram of the fully integrated receiver chip. The chip consists of a two-stage, broadband RF amplifier, a two-stage LO buffer amplifier, a double-balanced mixer, and a three-stage IF amplifier. In addition, all the matching, biasing, blocking and bypass circuits are included on the chip. The amplifiers compensate for the mixer conversion loss, provide buffering to the mixer, and increase the isolation from port to port.

PUSH-PULL APPROACH

The push-pull circuit technique has been used extensively for low-frequency amplifiers. Recently its use has been successfully demonstrated at microwave frequencies [3,4]. In this chip, the push-pull configuration has been used throughout for the design of the individual component cells, for several reasons. One of the features of the push-pull technique is the presence of a virtual ground between the push-pull amplifiers. This eliminates the need for critical RF grounding by means of via-holes and allows close packing of the various components. The yield is also increased since via-holes are no longer necessary during wafer processing and the foundry process is less complex. These factors are of special significance for complex subsystem ICs where large chip size tends to reduce the yield.

Even though push-pull circuits tend to be larger and more complex and require baluns at the input and output, they are capable of higher output power and can directly drive balanced loads (for example, a diode quad mixer). Also, in a complex subsystem composed of many balanced circuits, the internal connections within the system can be made directly and baluns are required only at the input and output ports.

RF AMPLIFIER DESIGN

Figure 2 is the schematic of the RF amplifier. The RF amplifier is a two-stage, push-pull circuit designed to operate over the 8-16 GHz band. The lossy match technique for broadband amplifiers [5,6], is used to obtain flat gain response over the octave badwidth, along with low input and output VSWR. Only lumped elements are used in the matching networks, so that the circuit size is minimized. Proprietary computer programs have been used to design the spiral inductors. The amplifier was limited to two stages to minimize dc power consumption. The RF amplifier has been characterized separately and provides 8±1 dB gain over the 8-16 GHz band while drawing 40 mA from an 8 volt supply. The input and output VSWRs are less than 2:1.

The LO buffer amplifier is similar in design and is capable of delivering the required drive power for the mixer. It also uses an 8 volt supply and draws 50 mA.

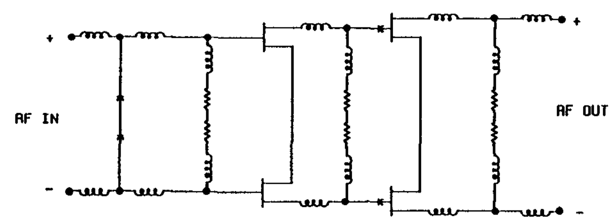

FIGURE 2. FUNCTIONAL SCHEMATIC OF RF AMPLIFIER.

DOUBLE-BALANCED MIXER AND IF AMPLIFIER DESIGN

The successful implementation of an MMIC converter requires the design of a wideband mixer, with low conversion loss, that can be realized in a small size, monolithic form. The mixer used here is a planar version of the double-balanced, transformer-coupled, diode mixer widely used at lower frequencies; its schematic is shown in Figure 3. It occupies very little area, and consumes no power since it is a passive circuit. Planar transformers are used to couple signals into the diode quad consisting of 1 micron gate interdigitated GaAs diodes. The mixer response measured separately showed 8-12 dB of conversion loss over the 8-16 GHz band.

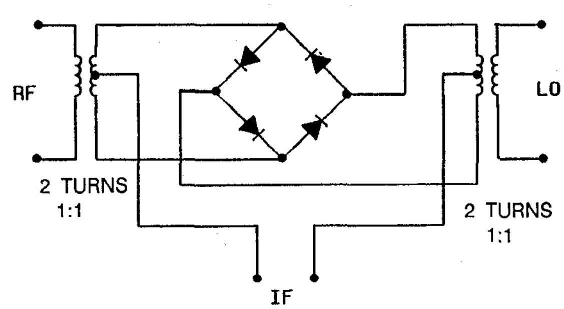

FIGURE 3. SCHEMATIC OF DOUBLE-BALANCED DIODE MIXER.

The IF amplifier uses two common source stages and one source follower stage to deliver approximately 15 dB of gain over the 0.1-2 GHz band. It is also a compact push-pull amplifier designed for easy integration with the mixer, and occupies only a 24 x 24 mil area. Figure 4 is a photograph of the complete converter chip.

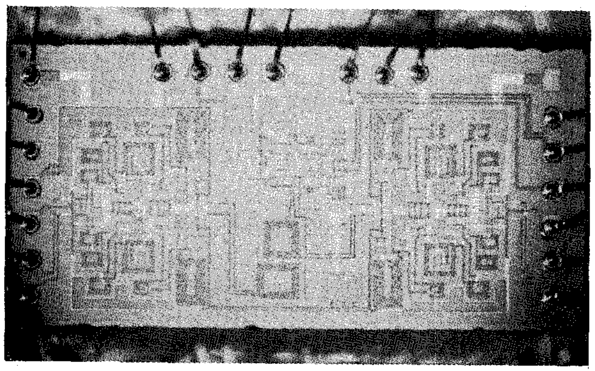

FIGURE 4. PHOTOGRAPH OF MMIC DOWN CONVERTER CHIP.

RF PERFORMANCE

RF measurements were performed on the MMIC converter with baluns at the RF and LO ports. Even though the IF output was also push-pull, one of the ports was terminated for ease of measurement and single-ended data were recorded. For determining the RF response of the converter, an IF frequency of 1 GHz was chosen, and the LO frequency adjusted suitably as the RF input was varied from 7 GHz to 17 GHz. The resultant conversion gain is plotted in Figure 5. The gain varies from 12 to 16 dB in the 8-15 GHz band with a peak conversion gain of 16 dB at 12 GHz. The LO power applied was less than 8 dBm in all cases, while the RF level was maintained at -20 dBm. The IF response of the converter is plotted in Figure 6 with the LO frequency held at 12 GHz. The IF response indicates an IF bandwidth of 1.5 GHz for a conversion gain flatness within ±2 dB. It should be noted that the mixer limits both the RF and the IF bandwidths, whereas the RF and IF amplifiers only affect their respective bandwidths.

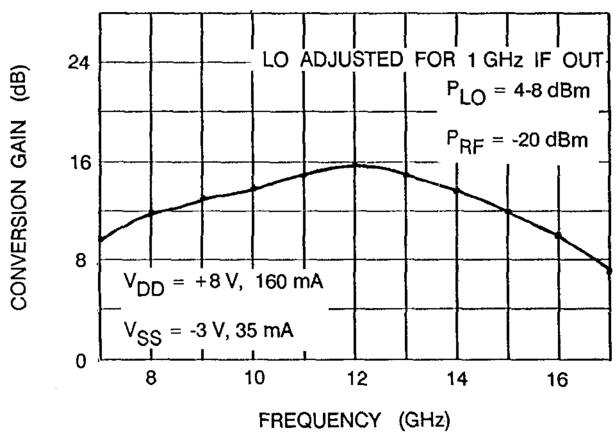

FIGURE 5. CONVERSION GAIN vs. RF FREQUENCY.

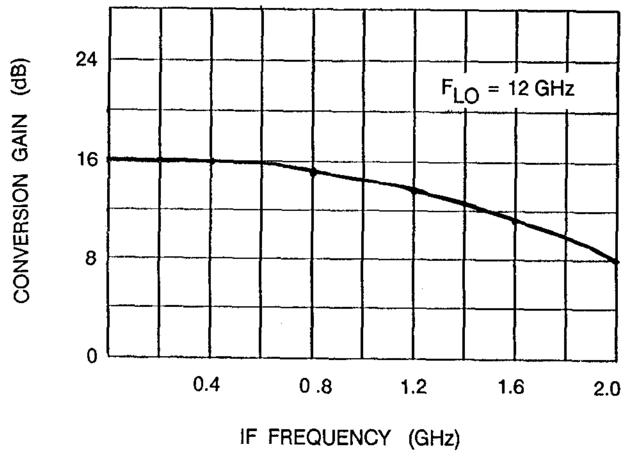

FIGURE 6. IF RESPONSE OF MMIC CONVERTER.

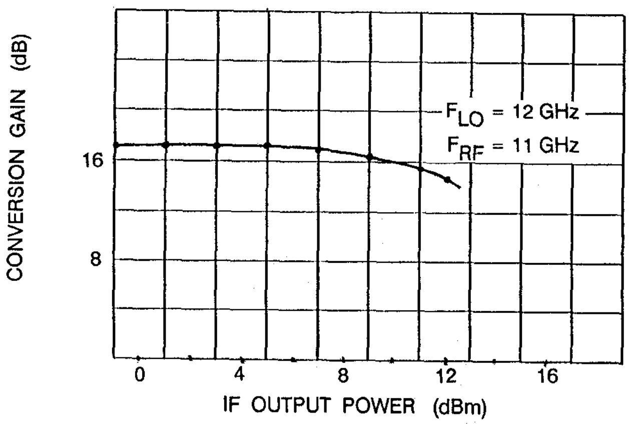

FIGURE 7. CONVERSION GAIN vs. IF OUTPUT POWER.

Figure 7 is a graph of the conversion gain as a function of the IF output power. The 1 dB compression point for the converter is approximately 10 dBm. The return loss and isolation measured on the chip are plotted in Figure 8. The VSWR at the RF and LO ports is less than 2:1. Use of the double-balanced mixer and buffer amplifiers also results in over 40 dB isolation from port to port. Figure 9 is a photograph of the MMIC chip assembled in a housing along with thin-film MIC support circuitry. The typical conversion gain of the assembled system is plotted in Figure 10. The conversion gain is approximately 15 dB in the 11 to 13 GHz band, and closely matches the chip in performance.

CONCLUSIONS

It has been demonstrated that, using a cell-library approach, a high level of integration is possible in GaAs MMICs. Several analog functions can be combined on a single chip to build high-performance subsystem ICs at low cost. An 8-15 GHz GaAs monolithic frequency converter IC has been developed which exhibits repeatable and predictable performance with high yield.

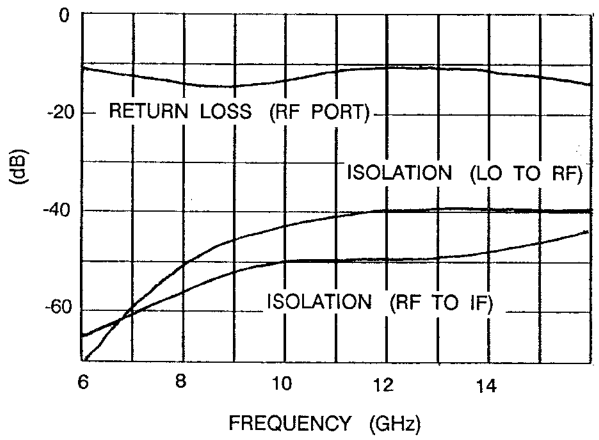

FIGURE 8. RETURN LOSS AND ISOLATION.

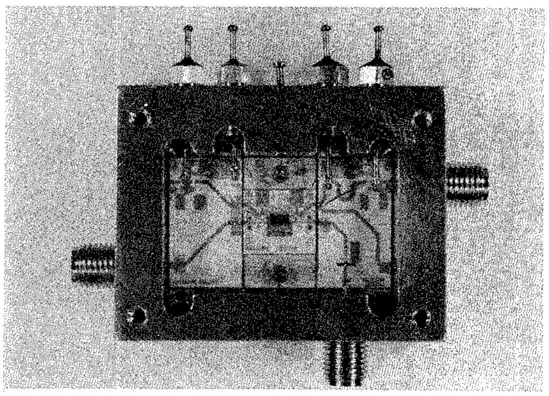

FIGURE 9. MMIC DOWN CONVERTER ASSEMBLED IN HOUSING.

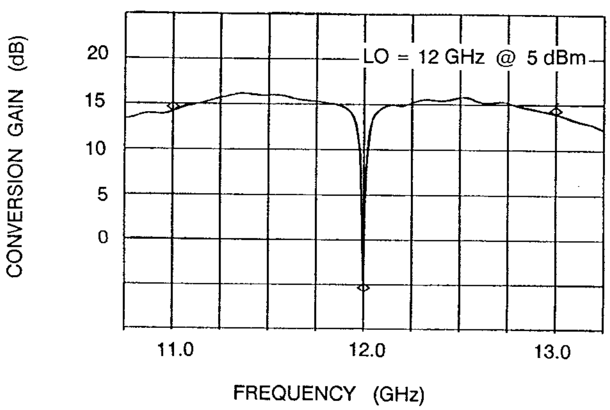

FIGURE 10. TYPICAL RESPONSE OF MMIC CONVERTER ASSEMBLED IN HOUSING.

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