MMIC DOWNCONVERTER TRANSLATES SIGNALS FOR DBS SYSTEMS

This unique configuration relies on a low-noise mixer to eliminate components from a traditional GaAs LNB design.

DOWNCONVERTERS for direct-broadcast-satellite (DBS) systems include a wide range of GaAs monolithic microwave integrated circuits (MMICs). Most combine a low-noise amplifier (LNA) with an image-reject filter to reduce the noise figure of the active mixer. However, by incorporating a low-noise mixer in a new configuration, the LNA and image-reject filter can be eliminated. The new device achieves a noise figure of less than 7 dB with more than 50-dB conversion gain compared to a maximum noise figure of 8 or 9 dB and conversion gain of typically 32 dB in conventional designs. It requires half the current and real estate of existing DBS downconverters.

In recent years, several authors have presented GaAs MMICs that implement varying portions of the DBS low-noise block downconverter (LNB) function.[1-3] Those downconverters with an LNA, image-reject filter, mixer, local oscillator (LO), and intermediate-frequency (IF) amplifier typically are aggressively priced to meet the demands of this high-volume consumer market.

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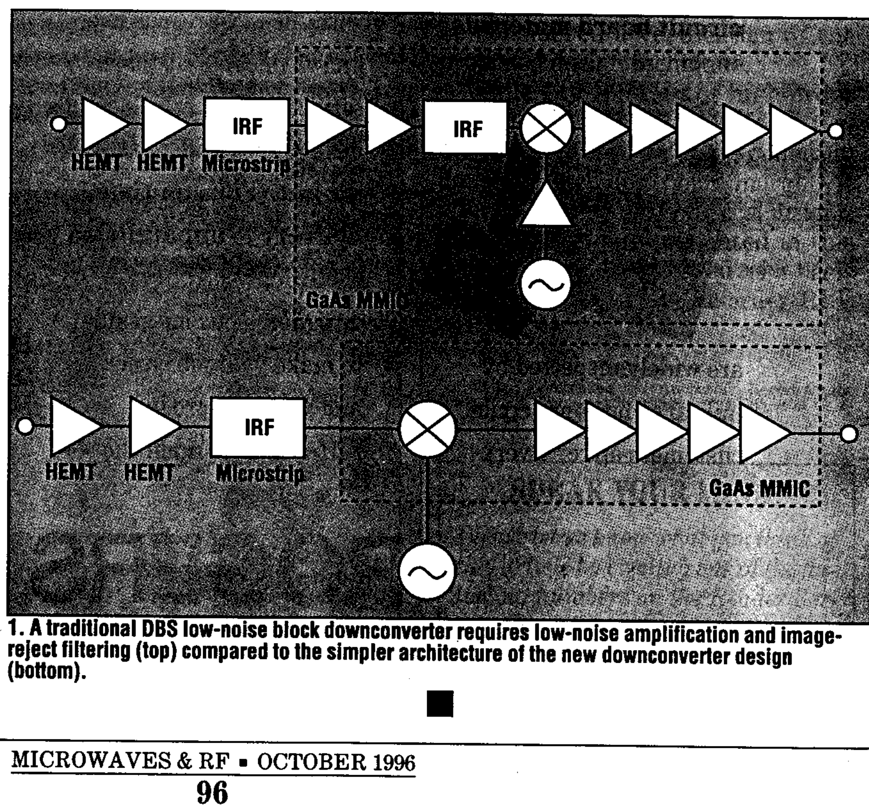
By redesigning the basic DBS LNB, however, it is possible to achieve the same functionality in about one-half the size of a traditional DBS downconverter. The inclusion of a low-noise mixer eliminates the need for integrated low-noise amplifier stages and the image-reject filter. In traditional DBS LNB architectures (Fig. 1, top), the downconverter MMIC and two discrete high-electron-mobility transistors (HEMTs) are used to increase conversion gain to more than 50 dB and reduce overall noise figure to about 1 dB. The RF path of the LNB consists of four LNAs stages and two image-reject filters. Two LNA stages and one image-reject filter are included on the MMIC to reduce the noise figure of the mixer to an acceptable level.



1. A traditional DBS low-noise block downconverter requires low-noise amplification and image-reject filtering (top) compared to the simpler architecture of the new downconverter design (bottom).

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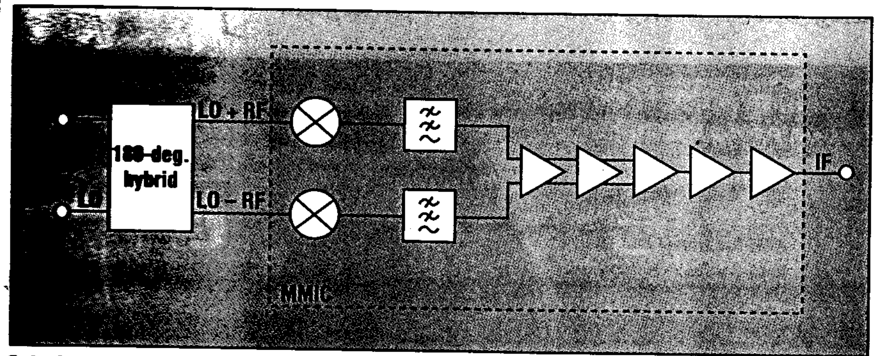
MMIC DOWNCONVERTER



2. In the novel downconverter configuration, the low-noise mixer is a single-balanced, gate-pumped GaAs FET design.

There are two main differences between the new design approach (Fig. 1, bottom) and the traditional LNB architecture: two LNA stages and an image-reject filter are eliminated from the GaAs MMIC and the RF path in the new design, while the LO is implemented externally to the GaAs MMIC downconverter. The first difference is achieved by using a low-noise mixer that does not require preamplifiers to meet noise-figure requirements. Additional IF amplification is provided to boost the total conversion gain to the desired level; these gain stages are smaller and more efficient in their use of current than RF gain stages. As a result, the chip area and DC current consumption are reduced by approximately 50 percent compared to the GaAs MMICs used in the traditional approach.

The external LO does not reduce the level of integration of the MMIC but does offer several advantages:

1. There is more flexibility in architecture.
2. There is more flexibility in layout.
3. A low-phase-noise process may be used for the oscillator to meet the requirements of new digital systems.

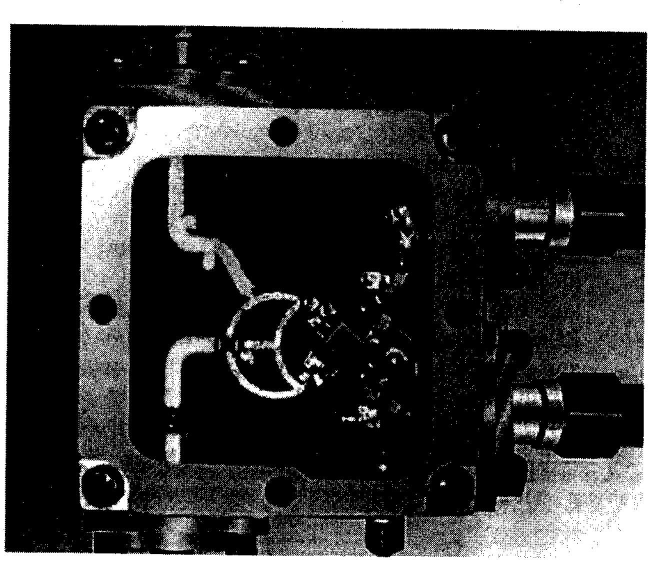
The GaAs MMIC downconverter is fabricated with a GaAs MMIC process from Fujitsu Limited (Kawasaki, Japan) which features 0.6-μm self-aligned depletion (D)-mode and enhancement (E)-mode GaAs field-effect transistors (FETs) formed by ion implantation on 4-in. wafers. The process achieves typical transition frequencies (f_T) of better than 20 GHz at a drain voltage (V_{DS}) of +3 VDC and 50-percent maximum drain current. The E-mode threshold voltage is nominally +0.10 V. Resistors are formed by selective ion implantation or thin-film metal. Capacitors are metal-insulator-metal (MIM) types with silicon-nitride dielectric material.

CIRCUIT DESIGN

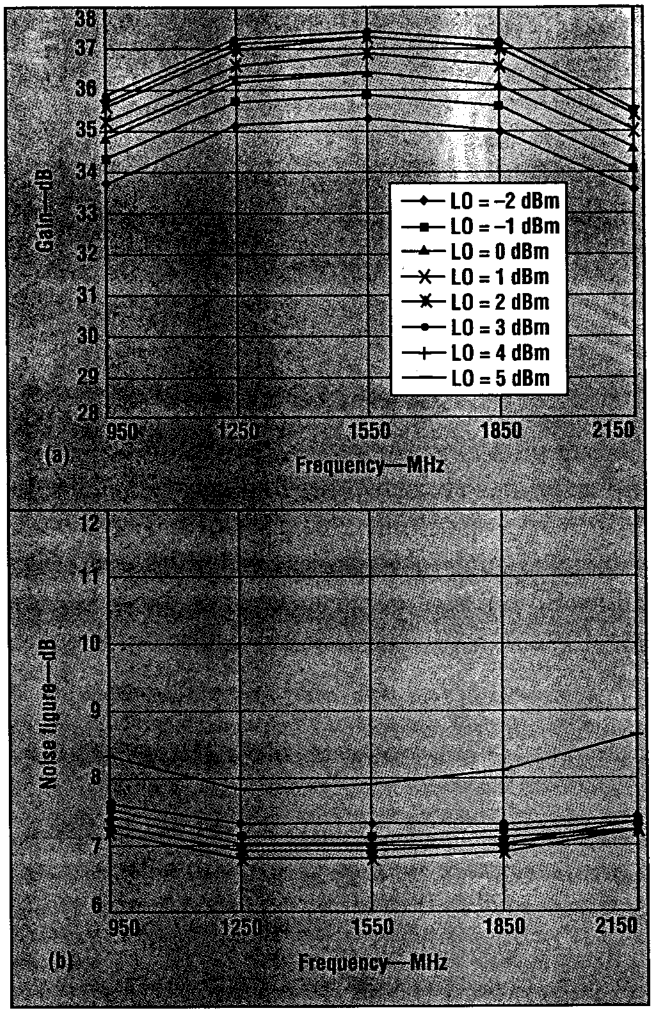
In the new downconverter configuration (Fig. 2), the low-noise mixer is a single-balanced, gate-pumped GaAs FET mixer that is described in detail elsewhere.[4] Gate-pumped mixers offer the lowest figure and highest conversion gain among the various active mixer topologies.[5] Other popular FET-based active mixers are dual-gate FETs and drain-pumped FETs, although they offer a noise figure of about 10 dB and conversion gain of no more than 4 dB at X-band. In contrast, gate-pumped mixers typically achieve 5-to-6-dB noise figure with more than 6-dB conversion gain.

The single-balanced, gate-pumped mixer consists of a 180-deg. hybrid, two matched common-source FETs, and lowpass filters. The single-balanced mixer is somewhat more complex than a single-ended mixer, but it offers excellent LO-to-RF isolation and virtual RF and IF ground points on the surface of the chip. The latter are used to achieve good performance and stability without via holes. The 180-deg. hybrid was chosen over a 90-deg. hybrid because it offers better LO-to-RF isolation and low sensitivity to mismatches at the RF/LO ports of the gate-pumped mixers. Area on the GaAs MMIC can be conserved by using a passive 180-deg. hybrid external to the MMIC. A ratrace-type hybrid was chosen for its performance and ease of fabrication. The ports are "folded" in order to simplify the connections into and out of the MMIC.

The gate-pumped GaAs FET mixer consists of a highpass input-matching circuit, an E-mode FET biased at pinchoff, and a lowpass filter on the drain to short the LO signal and to pass the IF signal. The highpass input-matching circuit is implemented entirely with bond wires within the package. This circuit provides very-low loss and can be designed to match the downconverter to any frequency range with-



3. The packaged MMIC is mounted into a test fixture that includes a folded ratrace hybrid.



4. The downconverter's gain and noise figure were measured with an HP 8970N noise-figure meter from Hewlett-Packard Co. (Palo Alto, CA).

in 6 to 18 GHz. Compared to a D-mode gate-pumped mixer, it offers lower noise figure, higher conversion gain, and single-supply bias operation. Typical performance at X-band includes a noise figure of 5 to 6 dB and conversion gain of 7 dB at a bias of +6 V and 5 mA.

The single-balanced mixer generates two IF signals that are 180 deg. out of phase. In conventional single-balanced mixers, the signals are combined with an additional 180-deg. hybrid coupler or balun on the IF port. These components are physically large and relatively expensive. In the new downconverter, however, the signals are combined in the IF amplifier, which consists of five stages—two differential stages, one differential-to-single-ended converter, and two single-ended stages. All of the stages are self-biased to allow single-supply operation; they employ resistive loads to minimize the chip area. Gate widths were optimized to provide the best balance between noise figure, bandwidth, output power, and DC current consumption. The IF amplifier provides about 30-dB gain from 950 to 2050 MHz with a noise figure of approximately 6 dB.

The downconverter was designed with both small- and large-signal (harmonic-balance) circuit-simulation tools. Nonlinear models were developed for both the D-mode and E-mode FETs, and were used to simulate conversion gain for the full downconverter. The predicted conversion gain is better than 35 dB over an RF frequency range of 10.7 to 11.8 GHz. Predicted LO-to-RF isolation is 22 dB and predicted LO-to-IF isolation is 36 dB.

MEASURED RESULTS

To compare actual measurements to these simulated results, a downconverter MMIC was assembled into a single-layer ceramic package sealed with epoxy. The packaged MMIC was then mounted into a test fixture that included the folded ratrace hybrid (Fig. 3). The printed-circuit board (PCB) has a dielectric constant of 2.17 and is 20 mils thick. The folded ratrace hybrid does require one crossover in the LO path, which is accomplished by means of a chip resistor. The resistor also improves the mixer's LO-port VSWR.

The packaged MMIC was evaluated for a variety of DBS frequency bands, including Astra Enhanced (10.7 to 11.8 GHz), Astra Universal (10.7 to 12.75 GHz), and DirecTV (12.2 to 12.7 GHz). Figure 4 shows the measurements for the Astra Universal band with the MMIC biased at +6 VDC and 63 mA. Maximum noise figure is 8.5 dB while the conversion gain is better than 34 dB with +3 dBm LO. Gain flatness is less than ±1 dB. The minimum third-order intercept point was +19 dBm and the RF return loss is typically better than 8 dB. LO-to-RF and LO-to-IF leakages are typically –25 dBm at 10.6 GHz.

As these measurements show, the novel GaAs MMIC downconverter provides the performance necessary for modern DBS systems. Since it employs a simple architecture compared to traditional DBS downconverter circuits, it is well-suited for high-volume, cost-driven markets such as DBS. Its small size and low power consumption can translate into cost savings for both designers and end users over wide frequency ranges. ••

Note

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References

1. P. Wallace *et al.*, "A Low Cost High Performance MMIC Low Noise Downconverter for Direct Broadcast Satellite Reception," *IEEE 1990 Microwave and Millimeter-Wave Monolithic Circuits Symposium*, pp. 7-10.
2. P. Bacon *et al.*, "A Dual-Channel Ku-Band DBS Downconverter," *1993 GaAs IC Symposium*, pp. 233-236.
3. K. Hubbard *et al.*, "A Family of Low Cost High Performance HEMT MMICs for Commercial DBS Applications," *IEEE 1995 Microwave and Millimeter-Wave Monolithic Circuits Symposium*, pp. 133-136.
4. E. Camargo and W. Kennan, "An E-Mode GaAs FET Operating as a Single Balanced Gate Mixer," *1996 IEEE MTT Symposium*, San Francisco, CA.
5. S. Maas, *Microwave Mixers*, Artech House, Norwood, MA, 1986.

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