What's Behind DBS Services: MMIC Technology and MPEG Digital Video Compression

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***Abstract*—This paper discusses recent developments in Direct-Broadcast Satellite (DBS) television systems, and specifically how these developments are implemented using today's MMIC technology. A brief review of Raytheon's experience in supplying low cost GaAs devices to the commercial DBS market place is included. A description of a dual-channel downconverter is provided as an example of applying GaAs MMIC technology to the advanced technical needs of the DBS market. A discussion of the MPEG-2 digital compression standard and its relationship to DBS is also included.**

I. Introduction

DIRECT-BROADCAST Satellite television systems (Fig. 1) are making their way to the US consumer market. Satellites continue to be deployed as several ventures, like Primestar and Hughes' DirecTv, continue to penetrate the DBS service market [1], [2]. Hughes, launching DBS-1 and DBS-2 in 1993 and 1994, respectively, has begun to deliver service to several regions of the country. Hughes DirecTv satellite dish and reception equipment is priced around $700, with a monthly service fee comparable to that of cable services. Primestar, in contrast, has been operating since 1990 using existing fixed satellite services (FSS), and does not require the consumer to purchase the satellite dish and decoder.

As the US market for DBS services and equipment begins to grow, the ability to meet the technical challenges and the volume requirements are key to gaining a competitive foothold in the expanding market. The introduction of digitally encoded and compressed television signals places new operational criteria on the performance of the complete DBS system. Increases in DBS system complexity have also driven the need to integrate more functionality into the existing low noise blocks (LNB's) and, in a trickle down fashion, more functionality into MMIC based downconverters. Common practice now dictates using dual-polarized signals to maximize channel capacity in the limited bandwidth allotted to DBS services (Fig. 2). Simultaneous access to two or more channels is becoming a necessity as picture-in-picture (PIP) television options and VCR recording become a way of life. To support this customer preference, DBS system designs will have to provide parallel frequency conversion paths for the horizontal and vertical polarization channels. Likewise, the in-door unit (IDU) converter will be expected to provide multiple channel access. With out such capability, DBS systems will have a hard sell competing against cable options that already support accessing multiple channels.

Manuscript received June 30, 1994; revised February 16, 1995.
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IEEE Log Number 9412077.

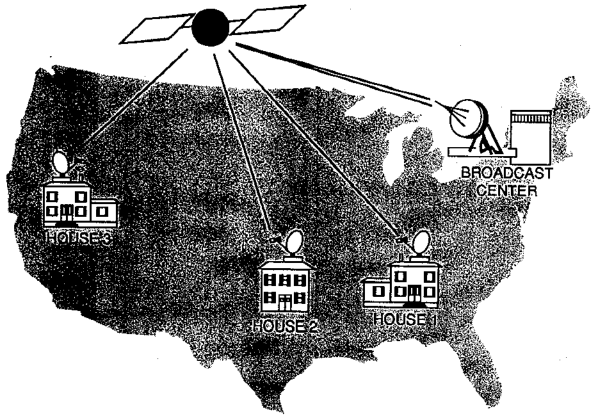

Fig. 1. Direct-broadcast satellite system architecture.

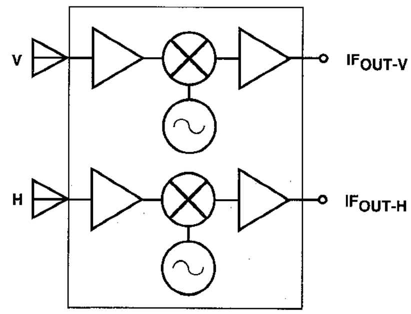

Fig. 2. Conventional dual-polarized DBS LNB.

As the technology underlying the DBS services continues to advance, two major overriding system concepts must be used to provide direction. The first is the use of the full microwave bandwidth available for DBS services. Europe, having spent a fair amount of its DBS history in the 10.95–11.70-GHz frequency band, will have systems using the entire 10.70–12.75-GHz band based upon the next generation of ASTRA satellites that cover this entire range [3]. This poses a significant problem in defining how the 2.05 GHz of RF bandwidth is selectively fit into the 0.95–1.95-GHz IF frequency range of most IDUs.

The second system advancement having a profound impact on DBS services is the use of digital encoding, and even more importantly, the compression of that digital encryption. Whereas advances such as dual-polarization and increased bandwidth provide, at best, a twofold increase in channel capacity, digital encoding, and compression provides up to 10 times the channel density of a single analog channel [4].

The trends toward broader RF bandwidths and the use of digital technology expands the potential channel capacity to over 500 [5], which will be an entertaining challenge for

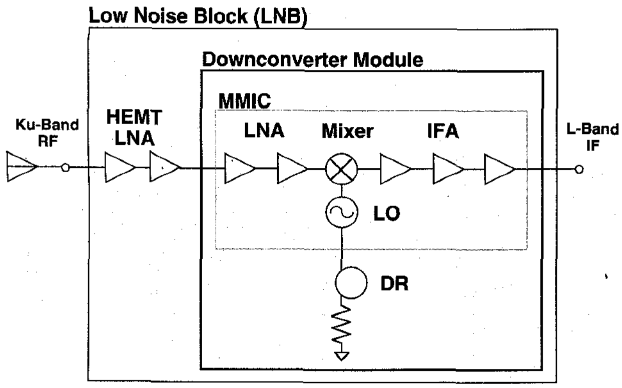

Fig. 3. Single-channel downconverter block diagram.

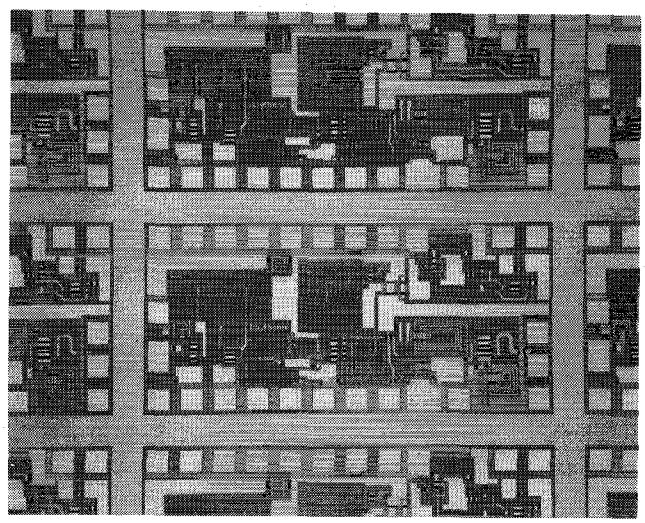

Fig. 4. Single-channel GaAs MMIC downconverter.

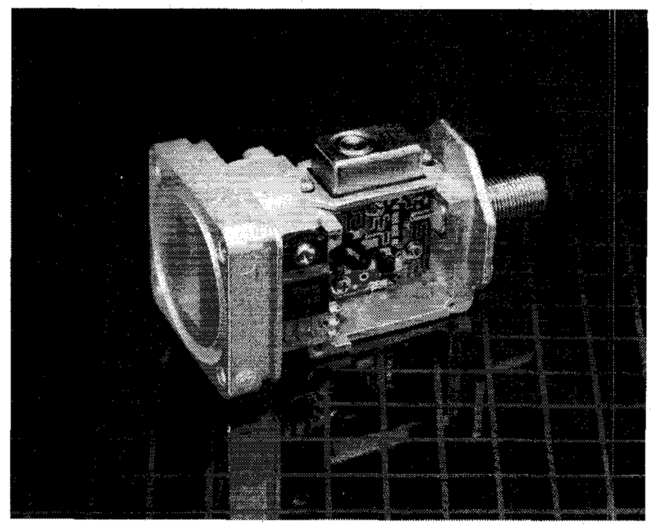

Fig. 5. Single channel low noise block.

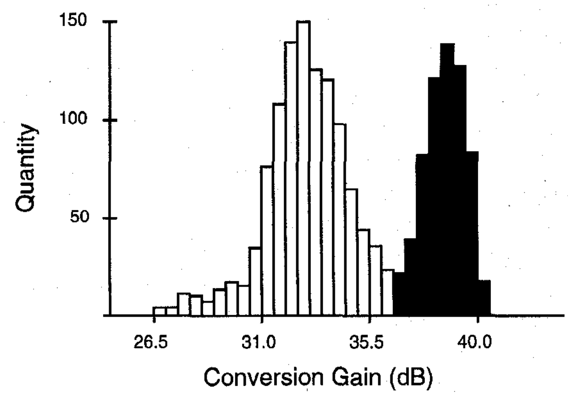

Fig. 6. Conversion gain bimodal distribution.

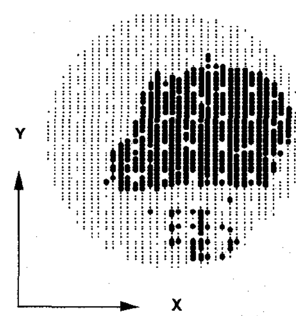

Fig. 7. Conversion gain wafer map.

the DBS service provider to fill with programming. Various factors, such as distortions due to the digital compression, still need further fine tuning. Yet the entrance of viable DBS television services into the video market place has finally been made.

II. GaAs Manufacturing Experience

Raytheon's Advanced Device Center has been manufacturing GaAs devices since 1988. Designed for volume GaAs wafer fabrication, the Advanced Device Center brought the vast GaAs device experience of Raytheon Company to the commercial market place. One such product, introduced to the market in 1991, is a single channel Ku-band DBS downconverter (Figs. 3 and 4). To address the multiple frequency bands utilized by various DBS systems, a family of three downconverters provide coverage of the most common bands in the 10.95–12.75 GHz range. Designed for use in standard single and dual channel downconverter LNB's (Fig. 5) [6], the downconverter provides 35 dB of conversion gain with an associated noise figure of 6 dB. The downconverter operates from a single +8 V supply with 90-mA typical bias current. Output power at 1-dB compression is greater than +5 dBm.

The volume manufacturing of the single channel downconverters has provided valuable insight into the many factors that contribute to cost and yield performance. Processing and design improvements have been successful at increasing die yield. By way of example, a bi-modal distribution sporadically appeared in the conversion gain performance for several wafers. The means of the two distinct distributions differed by nearly 10 dB, and the physical location on the wafer of the two distributions could be clearly seen, as shown in Figs. 6 and 7, respectively. The cause of the dramatic gain variation was traced to a missing inter-level metal contact that was caused by photoresist remaining in the inter-level contact via. The process parameters and the design layout were both changed in order to eliminate this intermittent phenomenon.

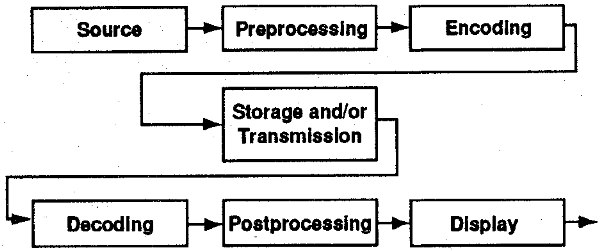

Fig. 8. MPEG encode/decode flow diagram.

Manufacturing costs have seen a tremendous downward pressure as the competitive market price of GaAs devices has fallen below \$2/mm^2 and is heading quickly to the \$1/mm^2 range. Excess process steps, and even process levels, have been eliminated to remove cost from the manufacturing of GaAs wafers. Metalization steps not utilized in the MMIC downconverter have been taken out of the process flow to reduce the total processing cost, and cycle time, by several percentage points.

Spreading the total manufacturing cost per wafer over a greater quantity of die per wafer clearly shows the motivation for increasing GaAs wafer size from 3 to 4 in. Processing and material cost increases, associated with 4-in. wafer processing, are insignificant compared to the $2\times$ increase in the total number of available die sites per wafer.

The experienced gained delivering high volumes of GaAs devices provides a strong foundation upon which to leverage further DBS product development. The expansion of DBS service technology into dual polarizations and compressed digital video increases the need to build on the existing manufacturing capability and provide improved MMIC solutions for the increased system complexity.

III. MPEG-2

MPEG (Motion Pictures Expert Group) was initiated by the International Organization for Standardization (ISO) in 1988 and tasked with developing an industry standard for the encoding and decoding of compressed digital video (Fig. 8). The MPEG standard targets the digital compression of video from a system point of view, bundling video and the corresponding audio channels together into a single transmission format.

The MPEG-1 specification, adopted by ISO in 1991, defines a process for removing several types of data redundancies from single frames of video data, thereby compacting the total volume of digitized frame data. Motion estimation algorithms are also covered under the MPEG specification. The goal of such algorithms is to predict the current frame's content based upon that of past and future frames. The estimation method interpolates the content of some video frames reducing the total quantity of digitized data required for a sequence of video frames.

The MPEG-2 specification [7], which followed MPEG-1 in 1993, provides compression of higher resolution video and data transmission at higher bit rates than MPEG-1. Responding

TABLE I
MPEG SPECIFICATION PROFILES AND LEVELS

		Simple Profile	Main Profile	Next Profile
High level 1,920 pixels/line (up to 60 Mbits/s)	Lines/frame	1,152	1,152	1,152
	Frames/s	60	60	60
	Pixels/s	62.7 million	62.7 million	62.7 million
High level 1,440 pixels/line (up to 60 Mbits/s)	Lines/frame	1,152	1,152	1,152
	Frames/s	60	60	60
	Pixels/s	47.0 million	47.0 million	47.0 million
High level 720 pixels/line (up to 15 Mbits/s)	Lines/frame	576	576	576
	Frams/s	30	30	30
	Pixels/s	10.4 million	10.4 million	11.6 million
High level 352 pixels/line (up to 4 Mbits/s)	Lines/frame	288	288	Not decided
	Frames/s	30	30	
	Pixels/s	2.53 million	2.53 million	

SOURCE: MPEG COMMITTEE

U.S. HDTV   European HDTV   Industry at large

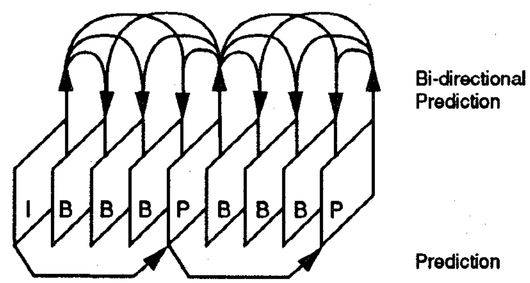

Fig. 9. B-frame bidirectional decoding.

to urging from the broadcast industry [8], MPEG realized the need to provide a standard by which HDTV could be integrated into the digital transmission format. The MPEG-2 compression standard was partitioned in order to accommodate both US and European HDTV concerns. MPEG-2 is divided into three related profiles (Main, Simple, Next) that provide different options. Each profile is further divided into four levels based upon the image resolution (High 1920, High 1440, Main 720, and Low 352—Table I [9]).

MPEG-2 Main profile covers the largest number of potential applications. It provides "a generic solution for television worldwide, including cable, direct-broadcast satellite, fiber, optical digital storage media and VCR's," according to Didier Le Gall, MPEG-2 Video chairman and vice president of R&D at C-Cube Micro Systems Inc. [9]. Data rates for the Main profile at Main level are in the 2–15 Mbts/s range; the data rate could reach as high as 60 Mbts/s for the High level; and 4 Mbts/s for the Low level. The Main profile also incorporates the use of B-frames (Fig. 9). B-frames, or bi-directional decoding, provides a mechanism to deal with transmission errors. The use of B-frames, that is, holding the digital information as snapshots in memory, supports the ability to recover from faulty environments.

The Simple profile drops the requirement for B-frames. The simple profile is the same, in all other aspects, as the Main profile, just without B-frames. Implementing B-frames

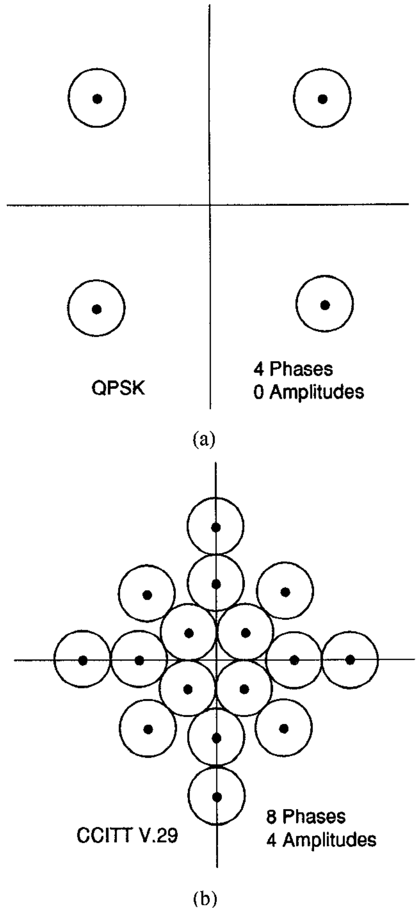

Fig. 10. (a) QPSK versus (b) CCITT V.29 QAM.

requires an HDTV or DBS service provider to install additional memory into its decoder to manage the increased quantity of data. Without B-frames, an HDTV system requires less DRAM, so manufacturing becomes easier and less expensive according to Robert Hopkins, executive chairman of the Advanced Television Systems Committee [9]. The use of B-frames also increases the time required to switch channels. The loading of the initial frame and its adjacent frame require twice as much data and twice as much time to be retrieved [10].

The Next profile was defined to address the European request for scaleability. Europe's HDTV system manufacturers want to be able to retrieve a standard definition TV image from a high definition signal. The approach would permit a form of "backwards compatibility" with the existing television technology. The added flexibility in resolution would allow the most appropriate resolution to be picked for the screen size used, reducing costs and system complexity for some manufacturers (e.g., LCD pocket television).

Coupled with the MPEG-2 digital video compression standard is the comparable MPEG Audio standard. Under the specification, five full bandwidth channels—left, right, center and two surround channels—along with several multilingual channels are defined. The broadcast industry, in transmitting both video and audio signals to its service subscribers, will be one of the largest users of the MPEG Audio digital format.

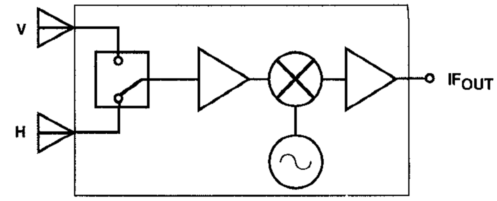

Fig. 11. Selective single-channel downconversion.

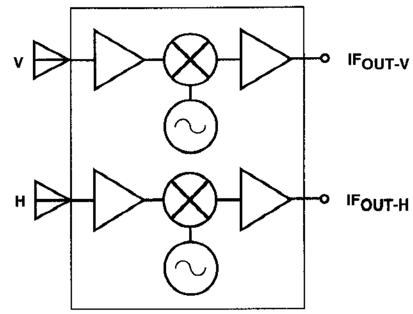

Fig. 12. Dual-channel downconversion.

IV. MPEG AND DBS

As DBS services are expanding into digital transmission formats, the rush is on at several IDU receiver manufacturers to become fully MPEG-2 compliant. Existing digital receivers that were released before the finalization of the MPEG-2 specification may be found to be too noncompliant to provide a transparent decoding interface [11]. The analog transmission of an MPEG encoded digital signal via satellite will be virtually unaffected by the digital signal format [9], provided the phase noise contributions and the Signal-to-Noise Ratio (SNR) of the entire up and down links are designed to meet the minimum phase and magnitude errors of the selected modulation scheme [12]. In fact, the improved SNR of the digital IF signal actually provides added margin compared to an analog equivalent at the same power level. Ku-band transmission systems will still be required to minimize noise contributions to minimize the Bit-Error-Rate of the entire system [12]–[14]. And as more intricate QAM modulation schemes (Fig. 10) find their way to satellite transmissions [15], the existing noise performance margins will be hard-pressed to meet the even lower phase and magnitude error requirements.

V. PRODUCT DEVELOPMENT: DUAL-CHANNEL DOWNCONVERTER

The development of a dual-channel downconverter has been driven by an increased usage of dual-polarized transmissions of DBS services. DBS services providing stated channel selections of up to 500 have been dependent upon two important concepts. The first being the emerging technology of compressed digital video, and the second being dual polarized microwave signals. The use of dual-polarized signals suggests that two parallel downconversion paths would be needed to provide continuous access to the dual polarities. Presently, there are two common approaches to handling the signal selection/routing as shown in Figs. 11 and 12. The first approach uses circuitry in the front-end of the LNB to select the single

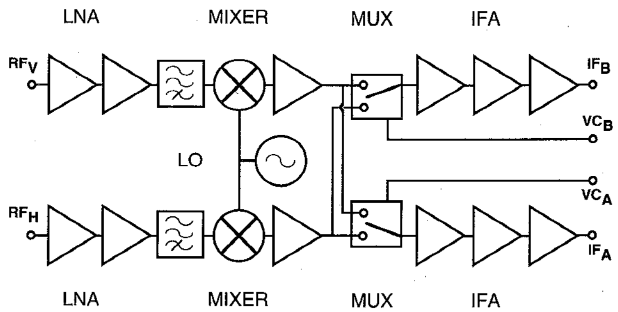

Fig. 13. Dual-channel downconverter block diagram.

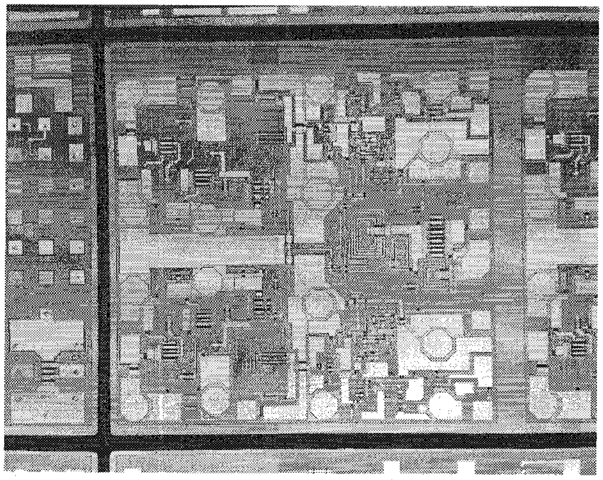
Fig. 14. Dual-channel GaAs MMIC downconverter.

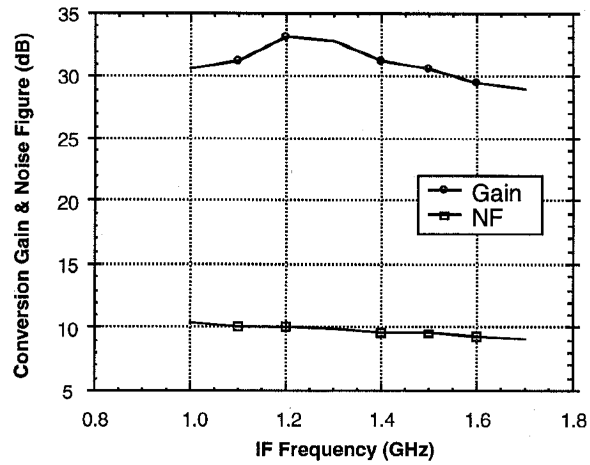

Fig. 15. Conversion gain and noise figure performance.

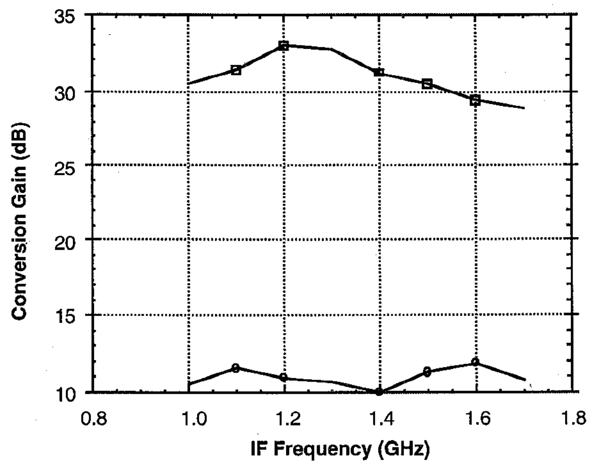

Fig. 16. Channel isolation performance.

polarization that will be downconverted to the satellite receiver IDU. The second approach packages two virtually identical LNB units in a single housing and downconverts both signals to the IDU for selection and routing. The need for higher levels of integration in the MMIC downconverters has motivated the development of a dual-channel GaAs MMIC downconverter.

The functional block diagram of a dual-channel downconverter is depicted in Fig. 13. Each channel is comprised of an RF low noise amplifier (LNA) that minimizes the overall noise contribution of the downconverter. The LNA consists of two self-biased, reactively matched gain stages that result in a gain level of 12 dB and an associated noise figure of 4 dB. The received signal is then sent through a filter/matching network to the dual-gate mixer. The dual-gate device is biased so that the first FET of the cascode chain is biased in the linear region while the second is biased in the saturated region. The RF signal drives the gate of the first FET while the LO signal drives the second gate. The LO signal is generated by an integrated local oscillator that is frequency stabilized using a single external dielectric resonator (DR). The DR is coupled to the gate terminal of the LO MESFET device and the parallel resonate circuit connected at the source controls the range of instability. The single local oscillator is used to drive both downconverting channels. Using just one LO removes redundant circuitry and eliminates the need for two separate resonate cavities, thereby providing an advantage over having two separate LO circuits. On the other hand, the single, common LO drive signal is a factor that degrades the inter-channel isolation performance of the dual-channel downconverter.

To provide flexibility in signal routing of the two distinct polarization signals, a simple multiplexer circuit was integrated into the intermediate frequency amplifier (IFA) chain of the downconverter (Fig. 13). The multiplexer uses MESFET switches to route the signal from the first IF stage to the output IF stages. The multiplexer routes the two input signals to either of the output ports according to the state of the multiplexer. To control the multiplexer operation, TTL input signals are used by an internal driver that generates the control voltages for the MESFET devices of the multiplexers. Each multiplexer, with its associated driver, requires just 0.16 mm^2 of GaAs real estate to implement. The size of the complete dual-channel downconverter circuit, shown in Fig. 14, is less than 2 mm × 2 mm.

The dual-channel downconverter achieves 32 dB of conversion gain with an 8.5 dB noise figure over the 12.2–12.7 GHz RF band with the local oscillator operating at 11.2 GHz (Fig. 15). The single, on-chip local oscillator, operates at the specified frequency with an appropriate dielectric resonator and resonator cavity. The isolation between channels is typically 20 dB for the "Thru" state and 16 dB for the "Switched" states (Fig. 16). The performance achieved shows the potential for fully integrating the dual-channel concept. Channel isolation is a critical performance specification needed to assure signal quality and minimize phase and distortion errors introduced to the QPSK IF signal.

VI. Conclusion

The potential for future growth of Direct-Broadcast Satellite services in the US and foreign markets looks very positive. The ever increasing satellite coverage, the availability of digitally compressed video technology, and the use of the complete DBS bandwidth serve to promote the proliferation of various DBS systems and services. GaAs MMIC downconverters, targeting the DBS market, will need to integrate more functionality into the existing block diagrams in order to meet the demands of these systems. In addition, the performance levels must also increase to assure that SNR's are maintained well above that required to meet the maximum bit error rates demanded by the digital modulation schemes. As MPEG and HDTV become well known as industry standards, the pressure will be on to move from a QPSK encoding scheme to a more advanced algorithm, such as a QAM constellation pattern, to push even more data through the existing bandwidth.

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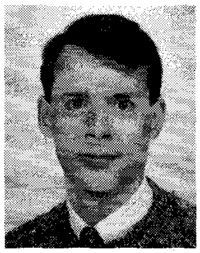

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