Commercial Satellite Applications for Heterojunction Microelectronics Technology

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Abstract— **Future commercial satellite-based communication systems will be supporting a variety of high data-rate consumer and business applications, including universal telephony access, computer networking, teleimaging, telecommuting, videoconferencing, and high-speed Internet. In response to the anticipated system-performance requirements, heterojunction technology for ultra-low noise amplifiers (LNA's), high-efficiency power amplifiers, and high-speed analog/digital circuits capable of operating at multigigabit per second rates are being developed. An overview of the status and issues related to this development effort is presented.**

I. Introduction

As WIRELESS technology moves into the next century, the importance of the satellite as part of the network (see Fig. 1) increases with each new demand on the system. There is intense competition in the satellite industry to set the new standard for the global information infrastructure, with systems such as Iridium, ICO, Globalstar, Odyssey, Teledesic, Astrolink, Spaceway, AMSC, and many others vying for their share of the market. In order to meet the needs of ever-increasing commercial and personal data throughputs, satellite carrier-link frequencies are moving from L-band into the higher *Ku*- and *Ka*-bands and V-band for crosslinks. These higher frequencies make possible the wider channel bandwidths required to relay the amount of data traffic demanded by two-way voice, video telephony, medical imagery, Internet data transmission, and other simultaneous communication supported by the satellites. A comparison of several of the proposed commercial systems is given in Table I.[1] The ability to quickly adapt to changing customer needs requires a very flexible on-board switching network, which allows resources to be reallocated to high-demand users at a moment's notice. In order to minimize the power needed by the ground-based user's transmitter or receiver, sensitive low-noise receivers, high-power high-efficiency linear power transmitters and error-correcting coding techniques will be incorporated. Additionally, the electronics must operate at ultra-low power consumption in order to minimize excess heat, maximize the amount of hardware which can be flown on the satellite, and maximize the life of the satellite's power source.

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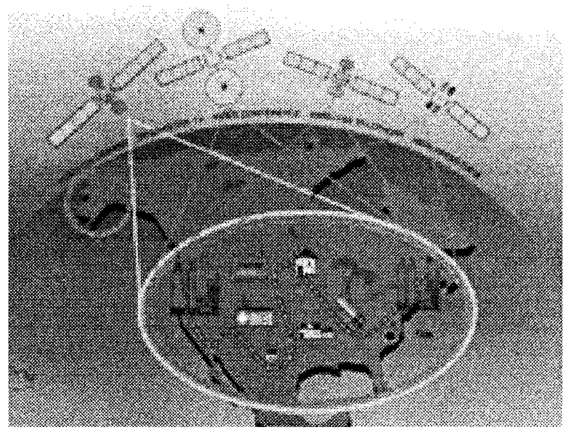


Fig. 1. Wireless communication network.

TABLE I
Satellite Communications Systems

System	Orbit	Up Link	Down Link	Cross Link	Capacity
		GHz	GHz		
Odyssey	MEO	1.6, 29	2.5, 19		3000–9500 voice channels
ICO	MEO	2.2, 5	2.0, 7		4500 voice channels
Globalstar	LEO	1.6, 5	2.5, 7		2000–3000 voice channels
Iridium	LEO	1.6, 28	1.6, 19	23	1100 voice channels
Teledesic	LEO	Ka	Ka	60	100 000 voice channels
Milstar	GEO	0.336, 44	0.240, 20		192 voice channels, 32 data channels
ACTS	GEO	30	20		1728 voice channels
Astra 1D	GEO	13	11		
Spaceway	GEO	30	20	60	230 000 voice channels

The high cost of designing and launching such a sophisticated satellite network demands the use of new components, which satisfy the state-of-the-art technical requirements, but are reliable enough to withstand the rigors of space needed to recoup the investment in satellite hardware.

II. Satellite Communication System

Significant enhanced performance of the satellite will be made with the utilization of heterojunction device technologies. A simplified generic block diagram of a satellite communication system is shown in Fig. 2. In this paper, we examine

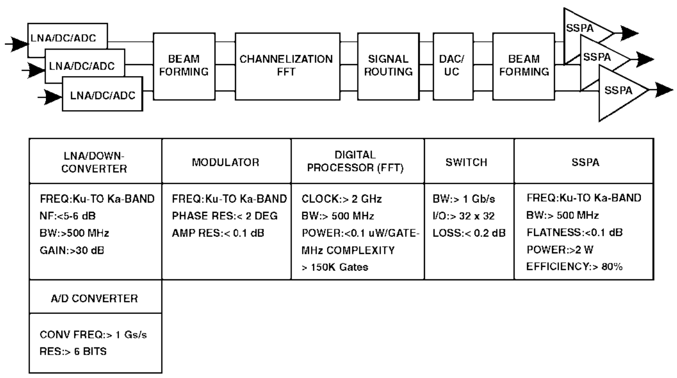


Fig. 2. Satellite communication system.

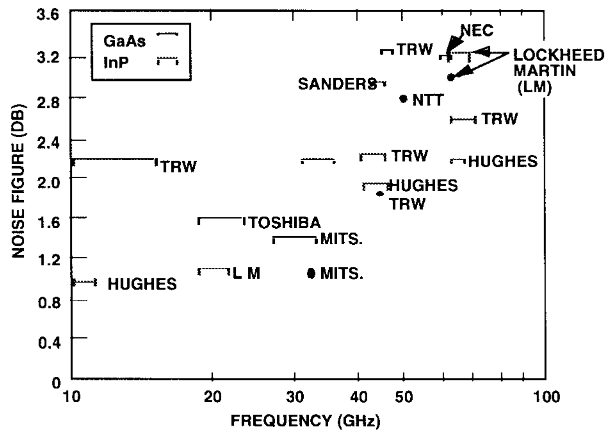


Fig. 3. Low-noise MMIC performance.

the potential impact of heterojunction technologies on the following different subsystems of this block diagram:

1) low-noise devices for the front-end electronics;
2) high-power output amplifiers for the transmitters;
3) high-speed analog/digital circuits for beamforming, signal processing and routing.

The performance requirements for each of the subsystems is also listed in Fig. 2 [1]. The low-noise amplifiers (LNA's) need to provide low-noise amplification at *Ku*- or *Ka*-bands with flat, distortion-free operating bandwidths of 500 MHz. Enhanced performance will be achieved by digitizing the signal as close to the LNA's as possible. Beamforming networks operating at *Ku*- and *Ka*-bands will allow the satellite to create smaller "spot" areas of ground coverage, which has the effect of increasing the relative gain within the spot coverage, thus lowering the transmit/receive power requirements to the ground user. These spot beams can be reconfigured to continually adapt to changing user-data bandwidth requirements. The new satellites must also be capable of "smart" on-board reconfiguration. A fast Fourier transform (FFT), which processes and detects the actual in-use data, is critical in such a system. Existing FFT's implemented in CMOS technology are not capable of processing the data throughputs needed in these satellites, and improved technologies are needed to operate at the gigabit/s rates at ultra-low power levels. Output power transmitters are needed at the operating frequencies to complete the satellite link. Traditional traveling-wave tube amplifiers (TWTA's) have low overall system efficiencies at these frequencies and require heavy power supplies. The use of heterojunction power devices to build solid-state power amplifiers (SSPA's) offers an attractive viable alternative for the satellite back-end.

A. Low-Noise Receivers

Over the last ten years, significant progress has been made in developing an ultra-low-noise device technology. The InP-based high electron-mobility transistor (HEMT) technology with the highest cutoff frequency of any three terminal device [2] has superior low-noise performance over the entire microwave/millimeter-wave frequency range. (see Table II) [3]. These results demonstrate the superior high-frequency performance of the InP-based HEMT. A four-stage Hi-Rel InP-based LNA with noise figure (NF) $<$ 2.0 dB at V-band demonstrates the excellent progress in low-noise technology. Low-noise monolithic microwave integrated circuit (MMIC) amplifiers utilizing either GaAs- or InP-based HEMT's have demonstrated outstanding performance over this entire frequency range, as shown in Fig. 3 [3]. The performance demonstrated by the low-noise device technologies has reached the point of diminishing returns, in which additional reduction in the NF has very little effect on system performance. Future efforts in these technologies should be focused on: 1) increasing complexity while reducing cost; 2) combining device types, i.e., HEMT's and heterojunction bipolar transistors (HBT's) to increase functionality and performance; and 3) developing device technologies for submillimeter-wave applications.

TABLE II
LOW-NOISE InP HEMT PERFORMANCE

Reference	FREQ (GHz)	Gatelength (μm)	Passivation	Noise Figure (dB)	Associated Gain (dB)
Martin Marietta 1990	18	0.15	—	0.3	17.1
Hughes 1995	44	0.1	—	12K*	XX
Hughes 1988	60	0.2	—	0.7	8.6
Martin Marietta 1994	60	0.1	—	0.7	8.6
Martin Marietta 1994	60	0.1	Si_3N_4	0.8	7.6
Mitsubishi 1994	60	0.15	SiON	0.9	7.0
GE 1991	94	0.1	—	1.2	7.2
TRW 1992	94	0.1	—	1.3	8.2

B. High-Power Transmitters

The biggest challenge for power devices for satellite communications is achieving the desired high power-added efficiencies (PAE's) with linearity. At microwave frequencies (L- through X-band), the GaAs MESFET and pseudomorphic high electron-mobility transistor (PHEMT) are the solid-state device technologies challenging the TWTA. At these frequencies, the TWTA with linearizers has Po$>$ 100 W with

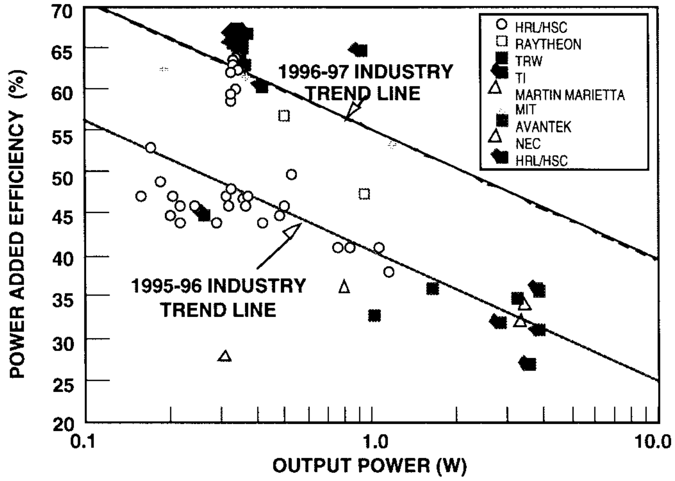
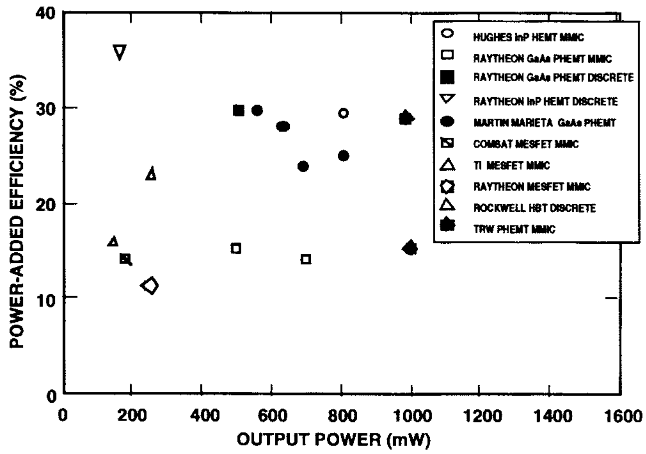
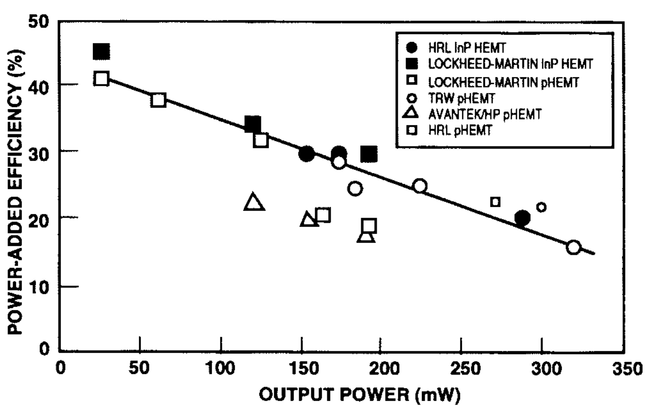


Fig. 4. K-band-power device-performance in current industry trends.



(a)



(b)

Fig. 5. (a) Q-band power-amplifier performance. (b) V-band power-device performance.

50%–65% PAE. The state of the art for Po and PAE of solid-state power amplifiers (SSPA's) is rapidly advancing at K-band, as shown in Fig. 4 [4]. For millimeter–wave frequency applications where the transmitter will be a phased array for multiple spot beams, an array of GaAs PHEMT's is the technology of choice because of the achievable gain and PAE; however, linearity with efficiency is still an issue at Q- and V-bands [see Fig. 5(a) and (b)] [4]. There is a large

TABLE III
MICROWAVE-POWER DEVICE-PERFORMANCE CURRENT INDUSTRY TRENDS

Organization	Technology	F (GHz)	Pout (W)	PAE (%)
Mitsubishi '90	GaAs MESFET	4	25	40
Fujitau '95	GaAs MESFET	4	20	68
HRL/HSC '96	GaAs pHEMT	4	2.5	74
Toshiba '96	GaAs MESFET	1.8	42.7	42
NEC/CEL '97	GaAS MESFET	2.5–2.7	60	33
NEC/97	GaAS MESFET	2.5	30.9	60
HRL/HSC'97	GaAs pHEMT	2	20	62
Cree '97	SIC MESFET	2.1	15	54
N G '97	SIC MESFET	10	6.35	34

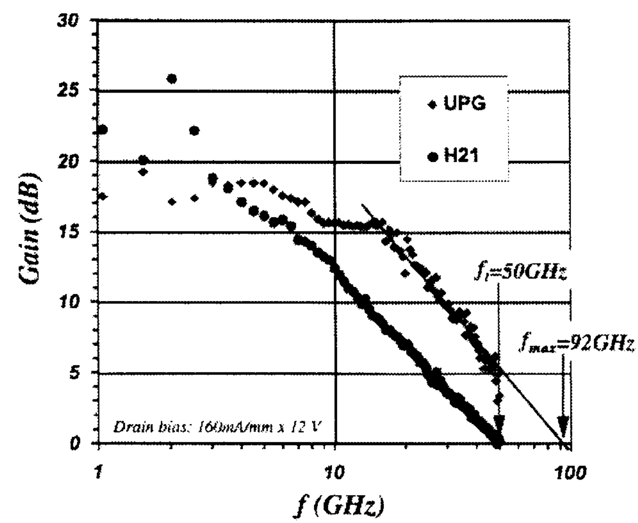


Fig. 6. GaN-power MODFET.

return on investment in developing higher performance power devices for millimeter-wave applications.

Two new material technologies being developed for power applications are the SiC MESFET and the GaN MODFET. The SiC MESFET has demonstrated outstanding performance at X-band and below, as shown in Table III [5]. Because of the material parameters and the device structure, the SiC MESFET will be limited to frequencies of X-band and below, where it must compete with high-power TWTA's. The newer and less-mature GaN MODFET has demonstrated K-band performance with RF parameters similar to the GaAs PHEMT, as shown in Fig. 6 [6]. Though this technology appears to be extremely promising with the combination of high breakdown voltage and high f_t and $f_{\max}$, a great deal of fundamental work needs to be performed before this technology can be considered for satellite applications.

C. High-Performance Analog/Digital IC's

In order to improve system performance and reduce weight and size, all of the beamforming, routing, and signal processing should be digital. Key to this requirement is a high-speed analog/digital (A/D) converter (ADC) requiring the minimum

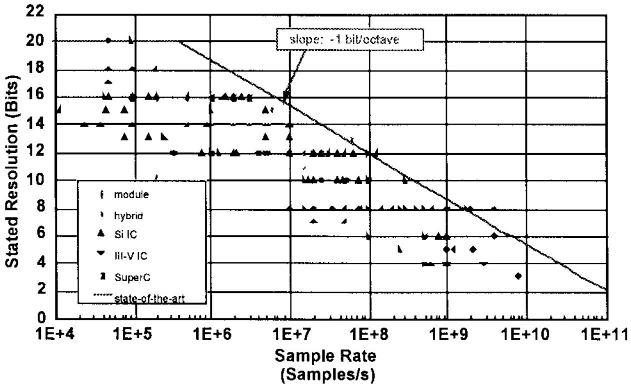


Fig. 7. A/D converter data: stated resolution.

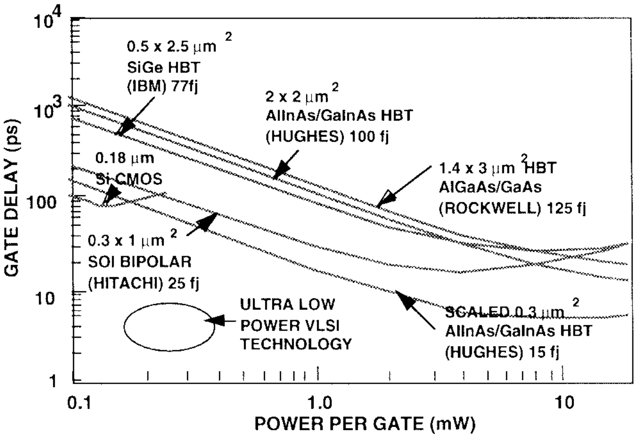


Fig. 8. Low-power IC technology.

amount of down conversion after the LNA. Today's state-of-the-art A/D converters are summarized [7] in Fig. 7 in which the stated resolution in bits is plotted versus the sampling rate. At low sampling rates, <1 mega-sample per second (MSPS), resolution is limited by thermal noise. For sampling frequencies ranging from ~1 MSPS to ~4 gigasample per second (GSPS), resolution falls off by ~1 b/octave. This behavior can be attributed to uncertainty in the sampling process (aperture jitter). For ADC's operating at multi-GSPS rates, the speed of the device technology is a limiting factor (regeneration time constant). Technological progress as measured by the product of the resolution and sampling rate is improving only 1 b for any given sampling frequency for every six to eight years. Many different approaches are being attempted to enhance the ADC performance, delta–sigma architecture, resonant tunneling diodes, optical sampling, and superconducting devices. Developing A/D converters operating at these frequencies and resolution is an extremely complex and challenging problem.

Other high-performance integrated circuits (IC's) required include high-performance multiplexers/demultiplexers (MUX/DEMUX's) to form parallel and serial data streams into and out of the FFT's and digital-to-analog converters (DAC's) for transmission of an analog signal back to earth. The challenge for this IC technology is high speed with low-power dissipation at large-scaled integrated (LSI) complexities. The leading technology for this application is SiGe HBT's, which have demonstrated both the speed and complexities required.

The heart of the digital signal processing are the FFT's, which are very large complexity (100–500K gates) IC's. Because of the complexity of the FFT's, an extremely low-power high-speed IC technology is required. The only reasonable choice for this technology is a variation of Si CMOS. However, the projected power levels are currently too high to accommodate the complexity required for this function. Fig. 8 [8] shows the speed power product for high-performance IC technologies along with the projected required speed power product.

III. Conclusion

The rapidly increasing demand for voice, video, and data transmission around the globe is requiring the development of a family of satellites which can handle and process several orders-of-magnitude of more information. High-performance heterojunction devices and IC's will be required to provide the low-noise receivers, high-power high-efficiency linear transmitters, and ultra-low-power high-bandwidth switching, routing, and signal processing.

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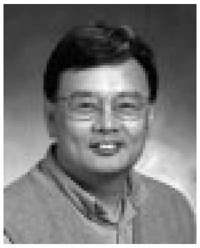

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