Recent Development of GaAs MMIC's for Wireless Communication Systems

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Abstract

This paper describes the recent development of GaAs MMIC's for wireless communication systems such as the digital cellular phone, the satellite communication system, the local area network and the automatic radar system.

The InGaP-emitter heterojunction bipolar transistor (HBT) for the 1.5-GHz digital cellular phones exhibited the output power of 31dBm at 1.5 GHz with the power-added efficiency of 68.8% and the adjacent channel power (ACP) of - 48 dBc at 50 kHz offset. The GaAs microwave signal processor developed for the 2.5-GHz active phased array antenna aboard the satellite has one thousand circuit-elements which is 100 times higher than conventional MMIC's.

The 60-GHz 4-stage buffer-amplifier MMIC newly designed for a cost-effective local area network can offer the $|s_{12}|^2$ of less than –38 dB and the $|s_{21}|^2$ of larger than 17 dB at 60 GHz. The InGaP/ InGaAs/ GaAs HEMT with the 0.15-μm gate and the flip chip structure was developed for the 76-GHz automotive radar system. The two-stage amplifier MMIC provides the small-signal gain of 10.6 dB at 76.5 GHz.

1. Introduction

More than one hundred million cellular phones are now used in the world and their growth rate is very significant. So the CDMA cellular phone system starts to prevent from the shortage of the channel. The CDMA which can offer the larger channel number requires the linear amplification to avoid interference to adjacent channels. The key RF device used in the handset is a power amplifier which mainly determines the linearity and power consumption of the systems.

The lower voltage operation is also preferable because it enable to use the Lithium-ion battery or to reduce the number of battery cells, which makes phone small and light.

As well as terrestrial cellular systems, high performance GEO/LEO communication satellites are rapidly being developed. The satellites with the high EIRP and the high G/T will be required to offer hand-held telephone services. The active phased array is a viable solution for this purpose.

The local area network (LAN) using the millimeter-wave and the optical-fiber is expected to be practically utilized as the Fiber to the Home (FTTH), for example. In the construction of the LAN system, one of the most important subjects is the drastic reduction in the cost of the system.

Among the millimeter-wave applications proposed so far, the potential markets for the automotive radar systems are expected to be the biggest. The total number of car products in the world exceeded 40 million and is increasing constantly every year. The demand for the driving safety is also increasing, so that several motor companies have proposed radar systems such as the collision warning or the adaptive cruiser control. U.S.A., Europe and Japan assigned 76 GHz band as the frequency for the automotive radar in 1997.

2. HBTs for Digital Cellular Phone Systems

The heterojunction bipolar transistors (HBTs) are used for power amplifiers in digital cellular phones such as CDMA due to the high efficiency- and low distortion-characteristics even at the low bias-voltage with only single dc-power supply.

The good linearity of HBTs has been attributed to the cancellation of the base-emitter and base-collector nonlinear currents[1][2]. Compared with FETs, HBTs have a stronger nonlinear input current in a base-emitter junction caused by the nonlinearity of base-emitter conductance. By optimizing the harmonic load-[1] and/or input-reflection coefficient [2], total input- and output-nonlinear currents can be cancelled and good intermodulation characteristics such as IM3 and ACP can be achieved.

Under these optimizations, InGaP-emitter HBTs achieved the output power of 31 dBm at 1.5 GHz with the power added-efficiency of 68.8% and the ACP of -48 dBc in PDC standard based on the phase distortion analysis as shown in Fig.1 [3].

The CDMA scheme which can offer the high data-rate service such as pictorial information service with no perceptible delay, requires the higher linearity for the transmitter than the conventional CDMA. HBTs as a high-linearity and high-efficiency power device are greatly demanded.

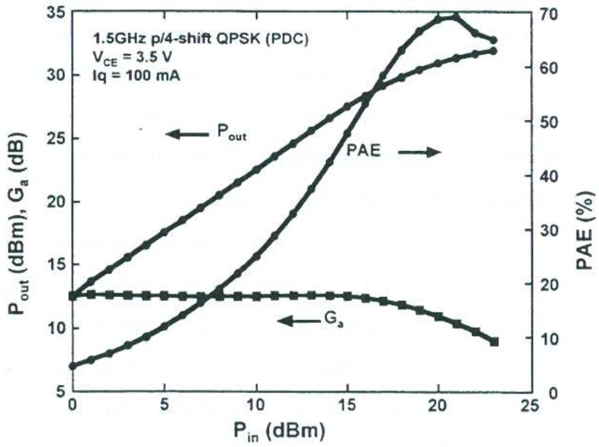

Fig. 1. Power performance of InGaP/GaAs HBT for PDC standards at 1.5 GHz.

3. GaAs Microwave Signal Processor for Satellite Onboard Phased Arrays

A conceptual in-orbit outlook of the future global mobile ISDN communication satellite is shown in Fig. 2[4]. A block diagram of the active phased array is shown in Fig. 3. The key component for the active phased array is the beamforming network (BFN). The beamforming function can be carried out by the digital signal processing (DSP). The digital signal processors, however, dissipates considerably the high dc power so that they sometimes disagree with the satellite system-requirement.

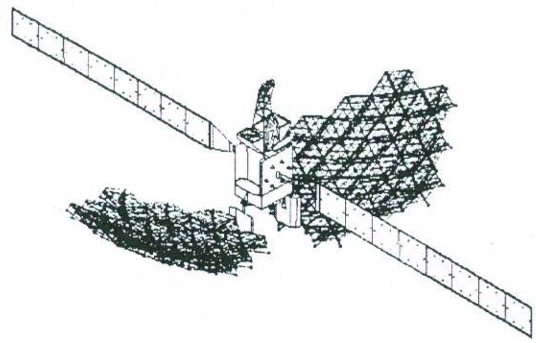

Fig.2. Future global mobile ISDN communication satellite (after Ref. [4]).

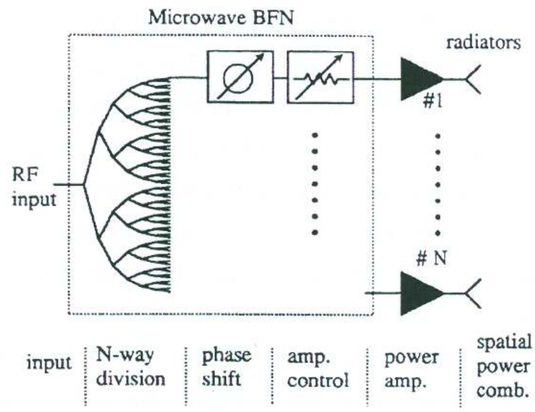

Fig. 3. Active phased array system configuration.

As a novel alternative of DSP, the GaAs microwave signal processor (MSP) as shown in Fig.4 was developed by T. Ohira et al [5]. The MSP is a large scale integration of microwave analogue functional circuits. The concept of MSP is analogous to that of DSP, but MSP will offer the direct analog signal processing functionality in the microwave frequency. Since MSP operates on the linear analog basis, modulated FDM or multi-carrier signals can be handled simultaneously without employing any demultiplexers or demodulators. This is very cost-and space-effective in various phased array antennas. This MSP chip consists of more than one thousand circuit elements and the integration level is 100 times higher

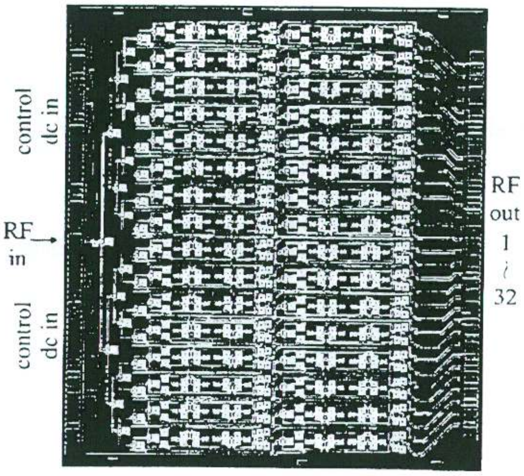

Fig.4. GaAs monolithic microwave BFN (chip photo by courtesy of NTT Wireless Systems Labs.).

than that of conventional MMICs. Circuit topologies newly developed for this MSP are 1) the pyramidally cascadable power divider, 2) the bi-phase variable attenuator, and 3) the orthogonal complete vector generator. The die measures 11 mm x 13 mm.

The device used in this MSP is "Cold MESFET". MESFETs have an advantage in application to zero-current control circuits. This is called "Cold MESFET" since it operates in the condition of Ids = 0 and does not generate heat. The circuit topology for this zero-current application is quite different from the normally biased analog amplifier or the logic applications. Cold MESFETs are used in this MSP as linear varistors and varactors, which offer amplitude and phase controled microwave multi-carrier signals, respectively. Since this MSP operates as an entire beamformer for 32-element phased array antennas, it is extended to a 64-beam x 32-element multiple beamformer by piling up 64 chips of MSP in an outstandingly-fine-pitch 3-D microwave interconnection architecture [6]. The beamformer employing this MSP is now ready to get aboard Japan's most progressive satellite ETS-VIII [7] which will be launched by NASDA in 2002.

4. 60-GHz MMIC's for Local Area Network

An example of a cost-effective millimeter-wave fiber-optic link system developed by N.Imai et al [8] is shown in Fig.5. This system distributes millimeter-wave signals from a control station (CS) to a base station (BS) over an optical-fiber. At the BS, the optical signals are transformed to millimeter-wave signals without using a mixer and a local oscillator.

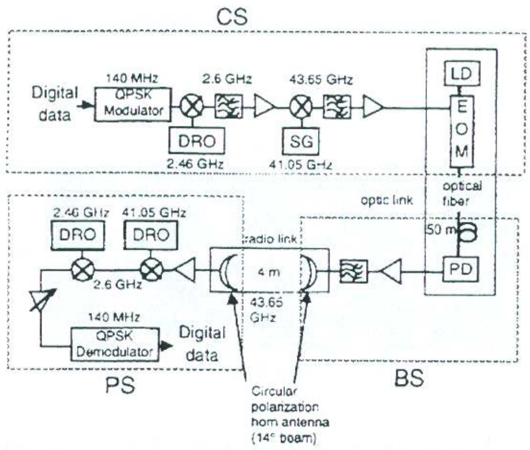

Fig.5. An example of the cost-effective millimeter-wave fiber-optic link system.

In the block diagram in Fig.5, the circulators between the amplifier and the antenna in the radio link are eliminated also to reduce the cost. This means, according to author's analysis, that the amplifier should have a function of the circulator. Figure 6 shows the simulated $|s_{12}|^2$ of the 3-stage-amplifier MMIC (gain-matched) and the buffer-amplifier MMIC (4-stage and loose-matched).

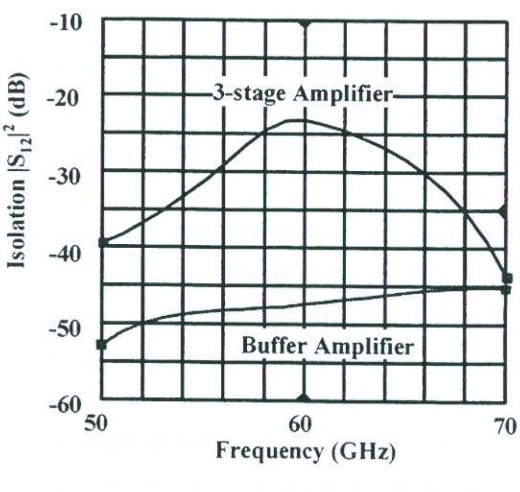

Fig.6. Simulated $|s_{12}|^2$ of the 3-stage-amplifier MMIC (gain-matched) and the buffer-amplifier MMIC (4-stage and loose-matched)

The simulation suggests that the buffer-amplifier will have the capability of the $|s_{12}|^2$ of less than – 40 dB at 60 GHz and have the function of the circulator. The developed 4-stage buffer-amplifier MMIC could offered the $|s_{12}|^2$ of less than –38 dB and the $|s_{21}|^2$ of larger than 17 dB at 60 GHz. The pattern photograph of the developed buffer-amplifier MMIC is shown in Fig.7.

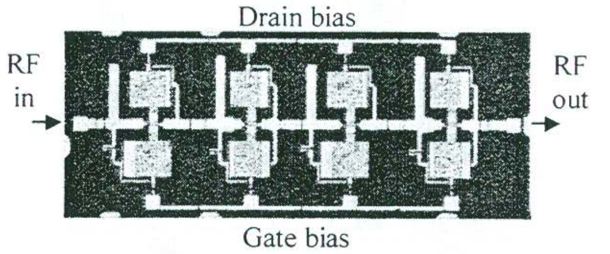

Fig.7. The pattern photograph of the developed buffer-amplifier MMIC.

The elimination of parts such as the mixer, the local oscillator and the circulator allows us to a chive simple-, small- and low cost-systems, which will accelerate the practical utilization of the LAN using the millimeter-wave of 60 GHz and the optical-fiber link.

5. 76-GHz MMICs for automotive radar systems

The monolithic integration is effective for reducing the cost, but still expensive if using the conventional technology in W-band. Because of the short wavelength, the peripheral elements including wires, packages or die-positioning, seriously affect on the device performance. In order to meet the requirements from 76-GHz automotive radar, these assembling technologies play a more important role rather than in the lower frequency application.

The flip-chip structure is effective for avoiding these difficulties[9]. Using the flip-chip bonding, the die-positioning can be automated with accuracy. Due to the short wave length, however, too much chip-height causes the transmission-loss but too small height causes the proximity-effect.

Fujitsu has developed the pillar interconnection technique to provide the precisely controlled-height of the flip chip[10-12]. Pillars are formed in the MMIC wafer process. Fig. 8 shows the SEM image showing HEMTs and pillars on the chip.

Figure 9 shows the 76-GHz amplifier MMIC with

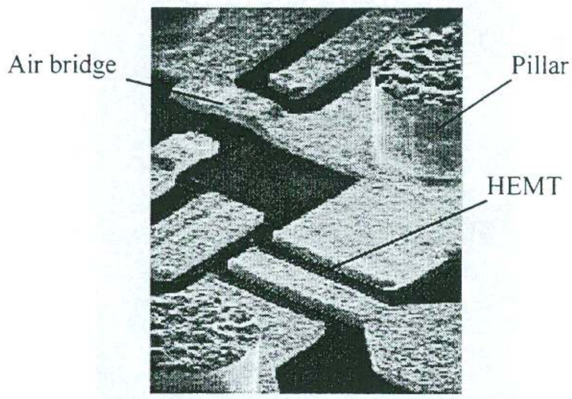

Fig.8. SEM microphotograph of the grounded pillars beside the HEMT.

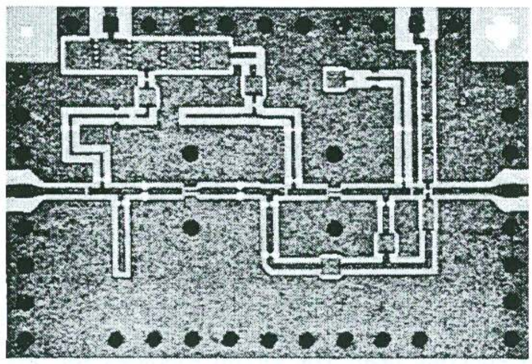

Fig.9. Photograph of the 76-GHz amplifier MMIC. The chip size is 1.2 x 1.9 mm^2.

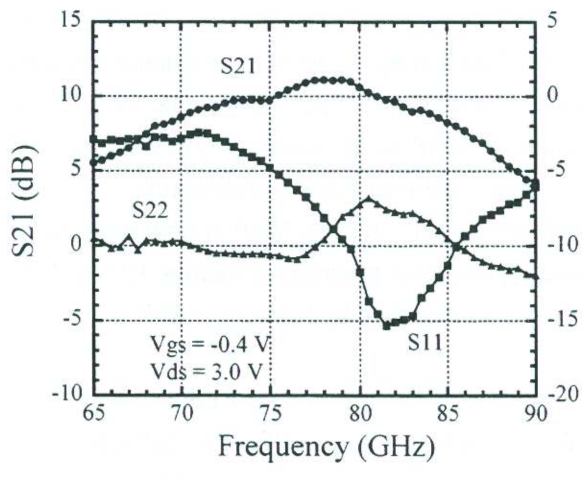

Fig.10. Measured S-parameters of the 76-GHz two-stage amplifier MMIC.

the pillar-structure. The co-planar wave guide is designed to form 50 ohms transmission-line under the flip chip condition. The two-stage amplifier MMIC provides the small-signal gain of 10.6 dB at 76.5 GHz as shown in Fig.10 [12]. Fig. 11 also indicates SEM image of flip-chip MMIC faced down.

Now, the technology for 76GHz MMICs is ready to start. However, there remain several subjects for mass production. Packaging and testing technologies have many subjects to be improved. The productivity must also be improved by the time of market.

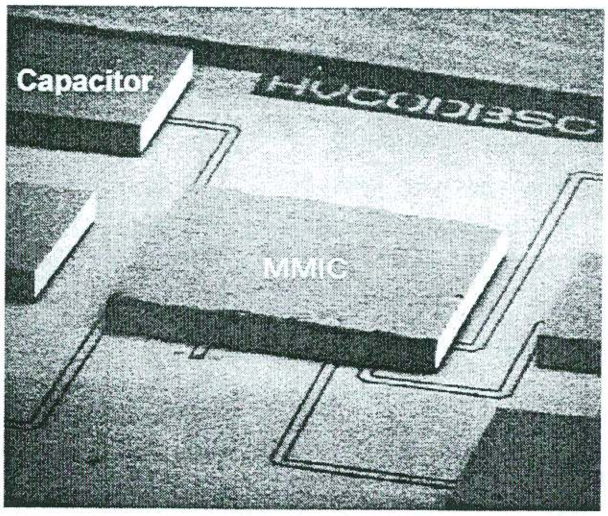

Fig.11. Flip-chip MMIC for 76GHz automotive radar

6. Summary

In this paper, we have reported some GaAs MMIC'S developed for wireless communication systems which will create the new big markets. The InGaP-emitter heterojunction bipolar transistor (HBT) developed for CDMA applications exhibited the output power of 31 dBm at 1.5 GHz with the power-added efficiency of 68.8% and the adjacent channel power -48 dBc at 50 kHz offset.

The GaAs microwave signal processor with one thousand circuit-elements has been developed for the 2.5-GHz active phased array antenna aboard the satellite ETS-Ⅷ which will be launched in 2002.

The 60-GHz 4-stage buffer-amplifier MMIC newly designed for a cost-effective local area network system can offer the possible isolation-function to eliminate the circulator between the front-end device and the antenna.

The pillar interconnection technology was developed to provide the precisely controlled-height of the flip chip. The InGaP/InGaAs/GaAs HEMT MMIC with the pillar-structure for the automotive radar system achieved the small-signal gain of 10.6 dB at 76.5 GHz.

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