RECENT TRENDS AND STATUS OF JAPANESE RFIC's FOR COMMERCIAL APPLICATIONS

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Abstract

This paper describes the recent trends and status of Japanese development of RFIC's and related technologies for commercial applications. A focus will be put primarily on two markets: 800MHz-1.9GHz cellular phones to depict a existing high-volume rapidly growing market and millimeter-wave automotive radars to delineate a highest-frequency high-volume application in the foreseeable future.

Recent results of RFIC technologies are described and reviewed to observe the status of resolving issues specific to each application. Some examples are also given to implicate device technologies for future RFIC use.

Markets of RFIC's

There exist a variety of commercial applications in different frequency ranges either already in service or intended to cover with RFIC's in Japan[1], which include 800MHz-1.9GHz cellular phones, 2.4GHz wireless LANs, 5.8GHz electronic toll gates and multimedia mobile access & communications, 12GHz DBS, 19GHz ATM wireless access, 51GHz wireless link, 60GHz wireless LANs[2], 60/77GHz automotive rardars, and 10/40Gbps optical fiber links.

Digital cellular phones, particularly handset terminals, represented by the 900MHz/1.5GHz PDC, the 1.9GHz PHS in Japan, are among the highest-volume applications existing today. The 1.9GHz IS-95 CDMA and the W-CDMA or IMT-2000 will become additional formats in the near future. The GSM and PCN, although not in service in Japan, are also addressed by Japanese manufacturers for their attractive market size. As shown in Fig.1, the size of a handset terminals has been reduced significantly in recent years, accompanied by weight reduction, which enables the incorporation of the terminal functions into wireless multimedia applications. Technology evolution of RFIC is dictated by the demands for small size, light weight, low cost, higher integration, high efficiency or low power dissipation for single-voltage battery operation.

A 77GHz band was allocated in 1997 along with a 60GHz band for automotive radars by the Ministry of Posts and Telecommunications in Japan. The automotive forward-looking radars represents the highest-frequency commercial application with high-volume market potentials. Technical challenges exist in the low-cost realization of MMIC's and module assembly and packaging, in order to compete with laser radars already in market.

RFIC Technologies Today

For the digital cellular phone applications, the improvement of power-added efficiency of power amplifiers has been achieved mainly by device development, predominantly GaAs. Fig.2 shows the PHS performance of a 0.8um-gate InGaAs/GaAs MODFET MMIC which achieved a 41.7% efficiency with 22dBm output power from a 3.0V single supply voltage with a 1.1mm^2 chip size[3]. An HBT-based MMIC exhibited comparable performance for PHS with 37% efficiency at 21dBm output from a 2.7V single power supply in an SSOP-28 plastic package[4]. Fig.3 demonstrates a power-added efficiency of 52% at 31dBm output from a 900MHz HMIC amplifier module for PDC using discrete 0.7um-gate InGaAs/GaAs HEMTs operating at 3.4V. Si power MOSFET's compete very favorably for GSM applications where a device can operate near full saturation. Fig.4 exhibits a Si MOSFET two-stage HMIC amplifier module which outputs 4.0W with 47% power-added efficiency in a 3.6V operation for 900MHz GSM[5]. In general, an intelligent choice between MMIC, HMIC and their combinations has been made for a higher-power amplifier configuration to achieve best cost/performance characteristics[6].

Higher levels of integration and multifunctional operations for cellular phone applications have been investigated and realized in many different aspects. Fig.5 shows a block diagram of a single-chip RF front-end GaAs MESFET MMIC chip for 1.9GHz PHS[7]. It incorporates a 21.5dBm power amplifier(PA) with 35% efficiency, a low-noise amplifier(LNA) with 1.7dB noise figure, a T/R switch, a step attenuator and a negative-voltage generator to bias the gates of depletion-mode FETs used in the PA from a 3.0V single supply voltage. Silicon technologies seem to be a preferred choice today for higher levels of integration for low-cost and low-power consumption. Fig.6 shows a block diagram of a 2.7V 900MHz GSM tranceiver IC which fully integrates all functions from baseband I/Q modulator/demodulator,

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IF circuits to a RF LNA. The design employs a 0.6μm emitter Si bipolar process with 15GHz f_T[8]. Other examples of Si LSI include a 1.9GHz PHS tranceiver chip which integrates all baseband to RF blocks but LNA, RF VCO and power amplifier, using a BiCMOS process with 12GHz bipolar transistors[9]. The extension of Si LSI technology to incorporate RF front-end functions up to a few GHz range is a major focus of on-going R&D activities[10,11], one example of which is shown in Fig.7 where a LNA with 2.9dB NF, a T/R switch and RF mixer are implemented for 1.9GHz PHS.

RF functions for 60/77GHz automotive radars are almost exclusively realized in MMIC forms by predominantly employing GaAs-based P-HEMTs with 0.1-0.18μm gate length[12,13]. Fig.8 shows a 77GHz fundamental frequency VCO designed as part of a MMIC chip set for forward-looking radars[14]. A critical issue lies in packaging and assembling technology which should enable the deployment of mm-wave performance in a high-volume commercial application at low cost with high reliability. MFIC(Millimeter-wave Flip chip IC) depicted in Fig.9 exemplifies such a technology developed to date, where devices or MMICs are flip-chip mounted in an HMIC configuration on a thin dielectric film substrate attached to a Si wafer for mechanical support[15]. This technology was successfully applied to a 50GHz HBT amplifier.

RFIC and Device Technologies for Future

Fig.10 shows a basic structure of the 3-D GaAs MMIC with multi-layer polyimide film used to build stacked circuit layers[16]. This new technology has drastically reduced a MMIC chip size and demonstrated high levels of multi-functional integration in a few GHz to millimeter-wave frequency ranges. The technology is also applicable to Si MMICs by offering an effective way of circumventing the loss problems due to conductive substrate, exemplified by a 10GHz amplifier.

For cellular phone applications, major R&D activities on GaAs is focused on both FET and HBT devices to offer higher power-added efficiency and lower distortion characteristics at low supply voltages[17]. Fig.11 shows the performance of a P-HEMT which demonstrated a 52% efficiency with 30dBm output at 1.2V for 900MHz PDC[18].

A Si bipolar transistor has recently achieved a 100GHz f_T [19], as is shown in Fig.12, thus demonstrating a great potential for low-GHz RF analog front-end integration. The device has been successfully applied to exhibit satisfactory circuit performance for 40Gbps optical fiber links. A discrete Si MOSFET can be a strong contender for 1.9GHz CDMA power amplifiers[20].

Investigation of CMOS technology for RFIC and RF LSI is somehow still limited in Japan, focusing today mainly only on device technology and fundamental functional blocks such as LNA and mixer. Respective RF performance, however, has been demonstrated with a f_T of 20GHz, a f_{max} of 48GHz and a NF of 0.6dB at 2GHz by an NMOS device with a practical gate length of 0.2μm[21].

The 60/77GHz automotive radar applications have been and will be addressed exclusively with short-gate-length PHEMTs for the first generation products. GaAs-based HBTs, recently demonstrating a f_T of 100GHz and a f_{max} of 250GHz for 40Gbps optical link[22], may provide a convincing alternative to PHEMTs.

Discussion

Universal demands on RFIC's exist for low cost, small size, light weight and higher levels of integration, independent of the types of commercial applications and operating frequencies. Low power consumption with a single power supply is crucial for battery operations. The recent progress in device performance will eventually make Si technology a preferred choice for system-on-chip including RF analog functions up to a low GHz range although high power amplifiers will be left to GaAs. The use of multi-layer substrate with thin dielectric film either in a HMIC form or built as part of a MMIC structure seems most adequate to achieve the small size and high integration of RF analog functions. An intelligent choice has to be made between MMIC, HMIC and their combinations for optimum cost/performance. Low-cost packaging technology will be the key for the success of commercial mm-wave applications.

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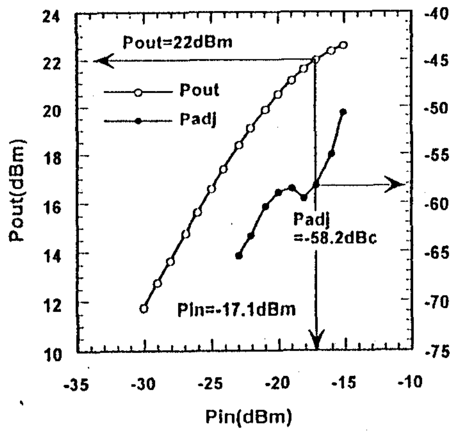


Fig.2 A power-amplifier MMIC for 3V single-voltage operation for 1.9GHz PHS

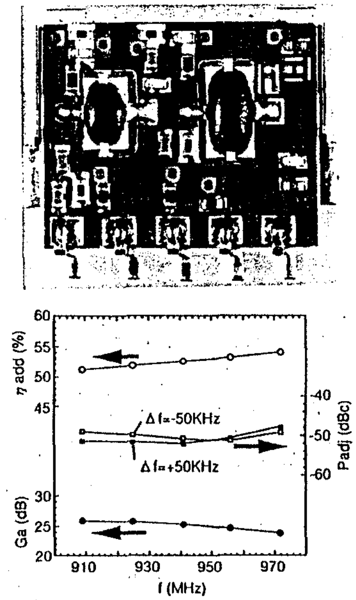


Fig.3 A PDC power amplifier module and its performance at 3.4V

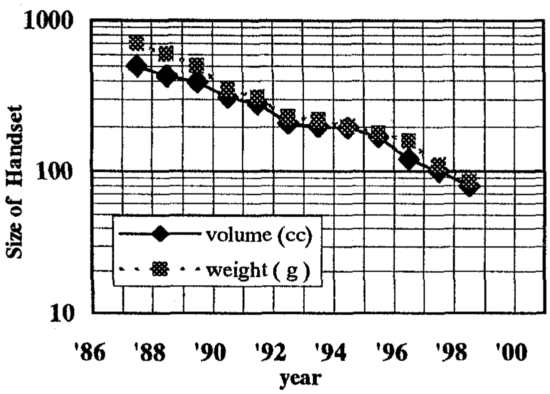
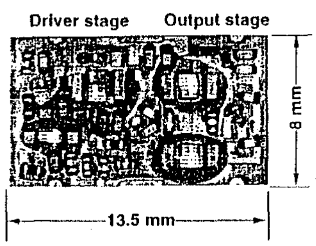


Fig.1 The size of handset terminals



Characteristics of the GSM-PA Module

Operating frequency	880 - 915 MHz
Supply voltage	3.6 V
Output power(1)	4.0 W
Overall efficiency (at 3.5 W)	47%
Input VSWR	2.0
3rd harmonic distortion	- 50 dBc
Isolation	- 40 dBm
Output power(2) at 3.0 V, 85℃	2.6 W

Fig.4 A Si MOSFET power amplifier module for 900MHz GSM.

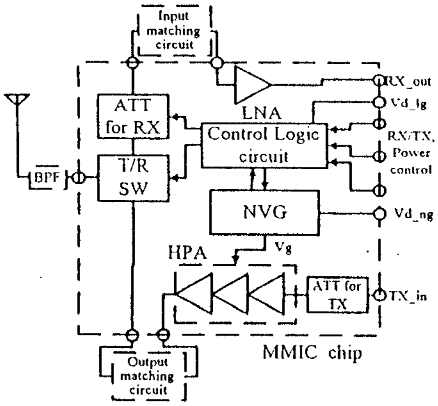


Fig.5 A single chip RF front-end GaAs MMIC in 3V single-voltage operation for 1.9GHz PHS.

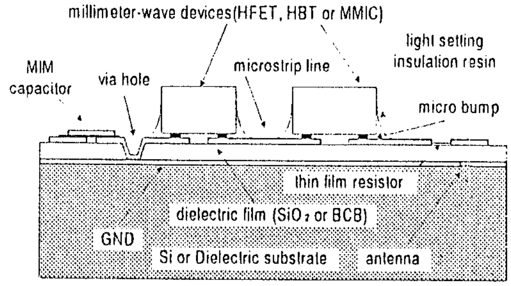


Fig.9 MFIC for mm-wave low-cost applications

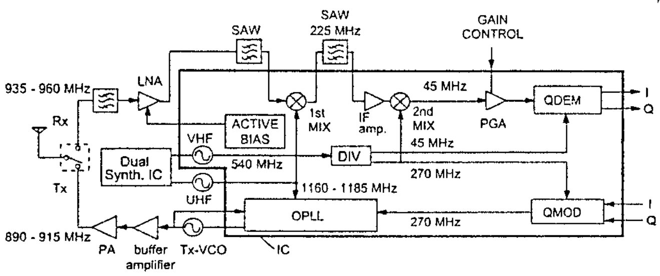


Fig.6 A 2.7V GSM RF Tranciever IC

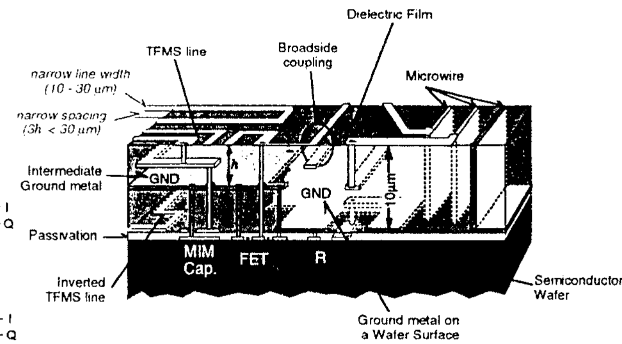


Fig.10 The basic structure of a 3-D MMIC applicable to both GaAs and Si.

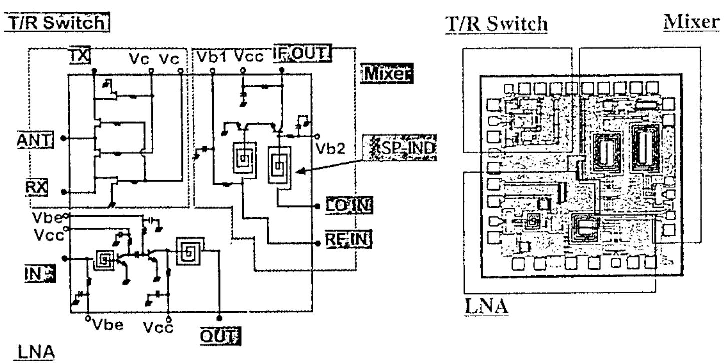


Fig.7 A Si MMIC front-end for 1.9GHz PHS

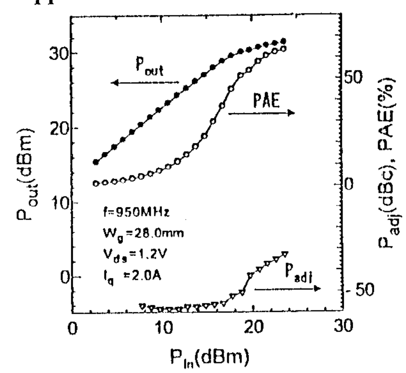


Fig.11 Power performance of a P-HEMT operating at 1.2V supply voltage for 900MHz PDC.

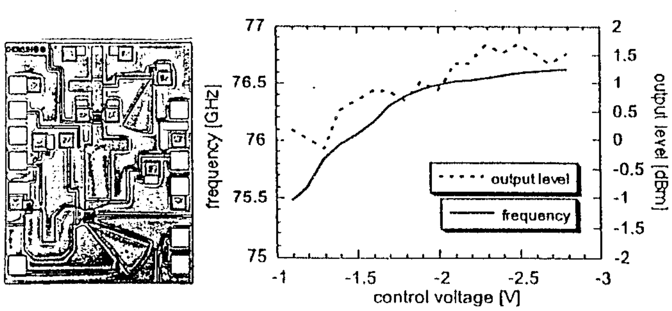


Fig.8 A 77GHz VCO for automotive radar application

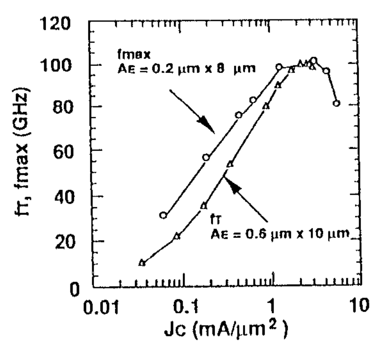


Fig.12 The f_T characteristics of a Si bipolar transistor