Large-scale-integrated High-efficiency Radio-frequency Devices and Their Applications to Mobile Terminals

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OVERVIEW: As the design rule for integrated circuits becomes smaller and smaller, the number of transistors that can be integrated on a single chip becomes larger and the output and dissipated power efficiency of radio-frequency circuits becomes higher. These qualities make mobile telecommunication terminals using radio-frequency integrated circuits less expensive. In the near future the number of transistors integrated in radio-frequency integrated circuits is forecasted to be over several tens of thousands. These circuits with improved linearity have been a major contributor to data telecommunication such as mobile access to the Internet. Hitachi, Ltd. developed three new radio-frequency integrated circuits: (1) a bipolar complementary metal-oxide semiconductor (Bi-CMOS) analog signal processing IC, (2) a GaAs low noise amplifier (LNA) and mixer (MIX) monolithic microwave IC (MMIC), and (3) a dual-band radio-frequency power amplifier module. They are designed to achieve large-scale integration and high efficiency. In the future, we plan to develop low-distortion, large-scale-integrated, high-efficiency devices for the third generation of mobile telecommunication systems.

INTRODUCTION

RAPID advancement of semiconductor integrated-circuit technology has reduced the cost of mobile telecommunication terminals year by year. The global systems for mobile communications (GSM), which was standardized mainly by European countries, has enhanced the large scale integration of radio-frequency circuits because mobile telecommunication systems of European countries do not require very strict linearity for the radio-frequency circuits, as do systems of other countries. Fig. 1 shows the number of transistors on GSM transceiver ICs. The mid 1990s saw the development of single-band frequency (900-MHz) circuit technology for GSM. Soon after, in the late 1990s, many dual-band frequency transceivers that can handle both the GSM and digital cellular system 1800 (the DCS1800) frequencies were developed. Recently, a phase-locked loop (PLL) and a low noise amplifier (LNA) were integrated in a single chip, and a radio-frequency IC was reported. This IC integrates almost all of the active radio-frequency devices of a transceiver. Furthermore, we forecast that an analog-to-digital converters (ADCs) and digital-to-analog converters (DACs) to interface the base-band signal processing IC will be integrated on the same chip in the next few years.

It has recently become popular to access the Internet using a mobile terminal. To access the Internet and transmit large amount of data, mobile terminals must have a high transmission. A new mobile system that has such a transmission rate, the IMT-2000 (International Mobile Telecommunication 2000) is under development and is now being standardized.

Fig. 1—Trend of the Number of Transistors in GSM Transceiver ICs.
Large scale integration of radio-frequency devices using Si will include not only RF/IF circuits, but also part of base-band circuits, ADC, and DAC, and so forth.
This system requires severe linearity to radio-frequency circuits, therefore, improvement of linearity is one of the very important technical points for next-generation radio-frequency integrated circuits. We expect radio-frequency ICs for dual-band dual-mode GSM and this new IMT-2000 system will be available early in the next decade.

Power amplifiers for providing power to antennas to transmit microwave signals are an important semiconductor device in mobile terminals. The amplifier must be mounted in a small package and be highly efficient for a long battery life. We are currently working to improve the transistor’s characteristics of metal-oxide semiconductor field-effect transistor (MOS-FETs) and GaAs devices for such amplifiers.

LNAs are also an important device for determining the minimum sensing level of a receiver. Many LNAs consist of GaAs because it enhances the radio-frequency performance, for example, large gain, low noise, and low distortion. Furthermore, the use of GaAs enables many peripheral components of radio-frequency circuits to be integrated in a single chip, because it is easy to design input- and output-matching circuits.

Mobile terminals consist of many different kinds of devices for processing radio-frequency signals including multiple frequency bands of a base-band signal. Therefore, it is important to select appropriate devices, taking into consideration their advantages and disadvantages, for the radio-frequency circuits.

Hitachi developed three radio-frequency devices for high-performance mobile terminals. This paper describes the new technologies for large-scale integration and high efficiency for circuits of these new devices.

**LARGE-SCALE INTEGRATION TECHNOLOGY FOR RADIO-FREQUENCY CIRCUITS (1)**

**Bi-CMOS Analog Signal Processing IC**

We have already completed the development and begun mass production of the RF transceiver LSI, HD155121F7, for GSM/DCS1800 dual-band applications. Now, we are developing a single-chip transceiver LSI HD155131TF which includes an LNA and dual synthesizer, with TTP Communications, Ltd., a company in the UK. Figs. 2 and 3 show a block diagram and photograph of the HD155131TF chip. The chip uses a new 0.35-µm Bi-CMOS process that adopts silicon on insulator (SOI) substrate and deep trench isolation.
trench isolation. The parasitic capacitor value of the transistor is therefore reduced to 3.3 fF, which is only one tenth of the parasitic capacitor value of the conventional transistor that uses the 0.6-µm Bi-CMOS process. The new process makes the high-frequency performance, low power consumption, and large-scale integration of the radio-frequency IC possible.

The receiver’s measured minimum sensitivity level using the HD155131TF chip is less than –108.5 dBm (the specification is less than –102 dBm) for both GSM and DCS1800.

**LARGE-SCALE INTEGRATION TECHNOLOGY FOR RADIO-FREQUENCY CIRCUITS (2)**

**GaAs LNA and MIX MMIC**

Receiver GaAs monolithic “microwave” ICs (MMICs) operating at 1.5 GHz have already been produced for personal digital cellular telecommunication Systems (PDCs). We developed on-chip spiral inductor technology with thick gilding. This technology gives the PDC receiver GaAs MMICs low-noise and low-distortion characteristics. Furthermore, to satisfy the size requirement of the cellular mobile telephones, the LNA MMIC, HA22033, and the receive mixer MMIC, HA22040, have been developed with small plastic packages.

Hitachi has developed a multifunctional receiver MMIC, HA22041, which integrates the two MMICs mentioned above in one chip.

HA22041 consists of an LNA, a low-distortion mixer (MIX), and a local amplifier (Lo). Fig. 4 shows a block diagram of HA22041. We developed a new high-capacitance dense technology using metal insulator metal (MIM) capacitor, a new small package, SON-12, and internal matching circuits to achieve suitable performance for the PDC telephone. The size of the SON-12 package is 3.4 mm x 3.6 mm with a narrow lead pin interval of 0.4 mm.

Fig. 5 shows measured frequency characteristics of the conversion gain and the output 3rd order intercept point (output IP3) at 1.5-GHz band of the mixer using 0.4-µm gate-length, dual-gate GaAs MESFET. A high conversion gain of 9.5 dB and an output IP3 of 10.5 dBm were attained over the frequency range (1,460 MHz to 1,520 MHz). The photograph of the HA22041 chip is shown in Fig. 6.

The GaAs LNA and MIX MMIC, HA22041, reduce the number of external components by 20% compared with Hitachi’s conventional products.
HIGH-EFFICIENCY AND HIGH-PERFORMANCE RADIO-FREQUENCY CIRCUITS

Dual-band RF Power Amplifier Module with MOS-FET

The efficiency of RF power amplifier module is usually specified at maximum output power. Therefore, the transistor performance of the RF power amplifier module is continuously improved to increase its efficiency at maximum power level. However, mobile terminals do not always output RF signals at the maximum power level in normal operation. The output power is usually medium or low, much lower than the maximum power level.

Taking this lower power level into consideration, Hitachi developed a small RF power amplifier module, PF08109B, which has variable bias for controlling the output power level and uses a multi-layer ceramic package.

PF08109B actually consists of two power amplifiers: GSM and DCS1800, shown in Fig. 7. Furthermore, the module is equipped with a switching function for switching between two output power levels, because the GSM power amplifier consumes more power than the DCS1800. The two switching modes are the normal mode and the low-power mode. When the low-power mode is selected by an external switching signal (Vsw), each of the bias conditions of the three stage amplifiers are readjusted to minimize power consumption.

Fig. 8 shows the relationship between power output and operating current. In the low-power mode, the operating current is reduced more than 50% of the current of the normal mode at an output power of around 10 dBm.

A sub-micron process is introduced for the MOS-FETs to improve the transistor’s radio-frequency characteristics. An enhancement mode MOS-FET is applied to the RF power amplifiers, because it can be used with a single supply voltage, makes it easy to control the output power level, and is thermally stable.

At the normal mode of the GSM frequency band, the measured output power and the efficiency are respectively 35.5 dBm and 50%, and at the DCS1800 frequency band, they are respectively 32.7 dBm and 45%.

The size of the package is minimized by utilizing a multilayer ceramic substrate and by using strip lines inside the layers. A thermal via is introduced to achieve a thermal resistance of 10°C/W and to reduce the source inductance to the ground. Fig. 9 shows a cross section of the PF08109B package and Fig. 10 shows a photograph of the inside of the module.
CONCLUSIONS

Hitachi is developing many different kinds of radio-frequency devices. In this paper, we described three radio-frequency devices that Hitachi has developed for mobile terminals. They have good performance and high efficiency for radio-frequency signal processing.

The first device is Bi-CMOS analog signal processing IC for GSM/DCS1800 applications. It integrates PLL and LNA with radio-frequency transceiver circuits, for example, mixers and amplifiers, using a new SOI-isolated 0.35-µm Bi-CMOS process.

The next device is GaAs LNA and MIX MMIC. This device is miniaturized by using a new MIM capacitor process as well as a small surface package.

Finally, the third device is a dual-band RF power amplifier module with MOS-FET. This module adopts a controllable variable bias current technique, which controls the current according to the output power levels and reduces the module power consumption at relatively low output power levels.

Hitachi is developing larger-scale integrated devices with higher efficiency for the next generation of mobile terminals. The Bi-CMOS analog signal processing IC will be mounted in a C-CSP (ceramic chip size package), and the C-CSP module will be integrated with a variety of peripheral components of the IC. For the GaAs LNA and MIX MMIC, we are developing large-scale-integrated and low-distortion devices. For the RF power amplifier module, we are developing a finer design rule technology for MOS-FET devices and hetero-junction bipolar transistors to achieve better efficiency and low distortion.

REFERENCES

(1) “European digital cellular telecommunications system,” European Telecommunications Standards Institute.

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