RF Circuit Technology that Realizes Wireless LSI Products

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A radio frequency (RF) circuit is the interface to the antenna in a wireless equipment. Due to increasing circuit integrations, triggered by the miniaturization of electronic devices, many parts of internal circuits for wireless equipment have become digital circuits. For the RF circuit, however, sophisticated analog circuit technology is necessary.

In the past, RF circuits were composed of discrete components, such as transistors and coils. In recent years, however, there has been a rapid integration of the circuits into monolithic LSIs, which gave rise to an expectation for significant improvements in the miniaturization of wireless equipment, lower power consumption and increased convenience.

This paper describes the RF circuit technology with CMOS devices, developed by Oki Electric and explains its effectiveness for the development of low power consuming, highly sensitive and user-friendly wireless LSI products.

Functions of the RF circuit

RF circuits are used in all wireless equipments, such as television sets, radios, mobile telephones, radio controlled watches and clocks, as well as wireless LANs. The frequencies of the radio waves and the method used to carry information onto the radio waves, namely the modulation methods, vary greatly according to the application of the equipment. The suitable kind of RF circuits are used for each application.

The frequencies of radio waves for some applications are shown in Figure 1. Devices and circuit methods that are suitable for the particular frequency to be handled are selected for the RF circuit. In the past, bipolar devices and gallium arsenide (GaAs) devices were used in various frequency ranges, but currently the CMOS transistors are capable of realizing RF circuits for any of these frequency range.

An example of the configuration of an LSI for shortrange wireless communications, using a frequency of the 2.4GHz band, is shown in Figure 2, as a representative example for RF circuits that have been integrated into one chip. RF circuits are composed of the transmitter circuit from which signals are output to the antenna, the receiver circuit that operates by receiving signals from the antenna as input, and the frequency synthesizer circuit that provides the reference signal of the 2.4GHz band to the transmitter circuit and the receiver circuit.

In the transmitter circuit, input digital information is used to generate superimposed signals of the 2.4GHz band using methods, such as phase changes, in the modulation circuit. The signal is then amplified by a power amplifier up to an adequate power output and emitted from the antenna as a radio wave.

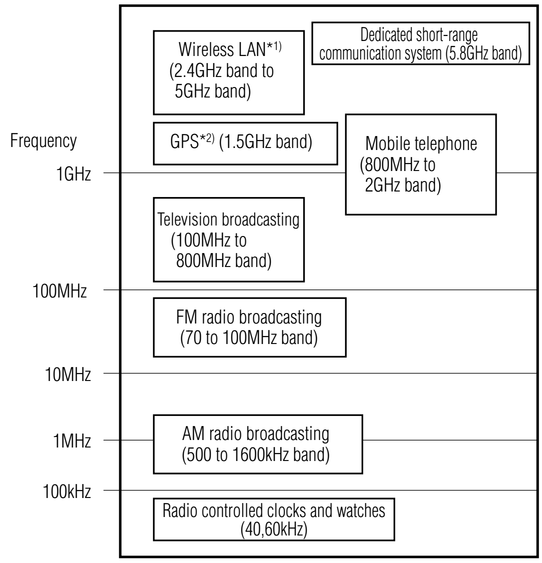

Fig. 1 Radio frequencies for wireless equipments

Received signals of various strengths from the antenna are input to the receiver circuit. These weak signals are first amplified by a low-noise amplifier then converted from the frequencies of the 2.4GHz band into the frequencies of several megahertz (intermediate frequency signal). The intermediate frequency signal is input into the filtering circuit, wherein only the signals of desired channels are selected. The amplitude of these signals are further amplified by the high-gain amplifier and then put through the demodulation circuit to retrieve the digital information that was carried onto the radio wave.

The frequency synthesizer circuit provides a stable sinusoidal signal of the 2.4GHz band to the transmitter circuit and the receiver circuit. It is composed of the Voltage Controlled Oscillator (VCO), which is composed of inductors arranged inside the chip, as well as the Phase Locked Loop (PLL).

Performance items required of each circuit element are shown in Table 1.

*1): Local Area Network *2) GPS: Global Positioning System

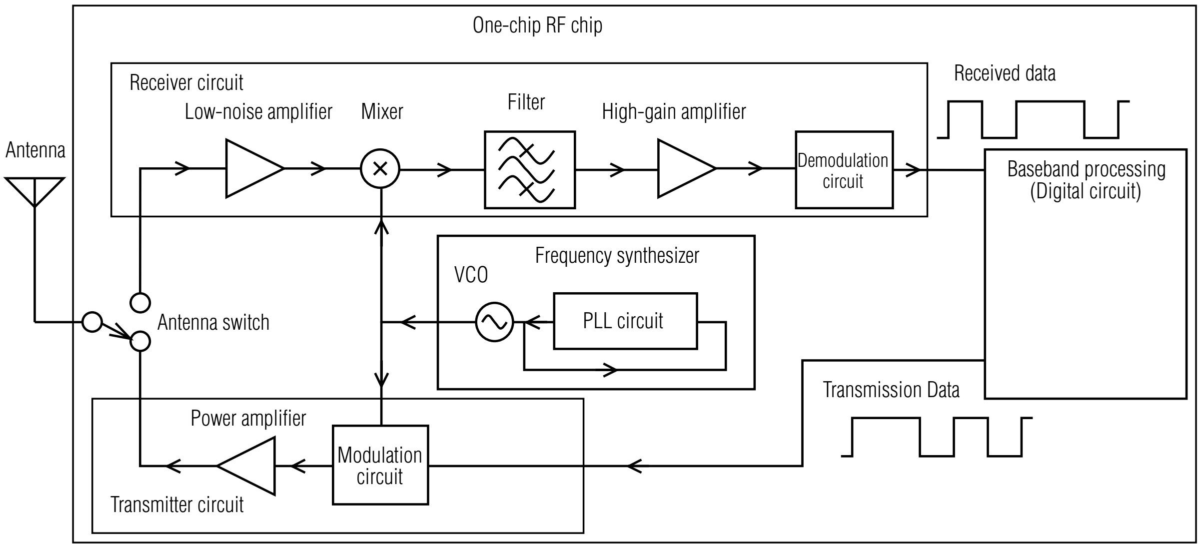

Fig. 2 Configuration example of RF circuit

Table 1 Requirements for circuit elements

	Circuit element	Requirements
Transmitter circuit	Modulation circuit	Modulation accuracy
	Power amplifier	Output power, distortion characteristics
Receiver circuit	Low-noise amplifier	Noise characteristics, distortion characteristics
	Mixer	Noise characteristics, distortion characteristics
	Filter	Frequency characteristics, distortion characteristics
	High-gain amplifier	Voltage gain
	Demodulation circuit	Error rate characteristics
Common	Frequency synthesizer	Phase noise characteristics
	Antenna switch	Isolation

The transmitter circuit is required to have the capability to emit stable and clean radio waves, in compliance with the laws and the regulations. The modulation circuit conducts accurate modulation (phase change, frequency change and amplitude change) according to the input digital signal. The power amplifier takes the output from the modulation circuit and amplifies it to the specified power level without distortion and emits the radio wave from the antenna.

High sensitivity is important characteristics for the receiver circuit, but is not enough. The distortion characteristics of the circuit becomes critical, due to the fact that nowadays there are situations where a lot of wireless equipment are used in close proximity, requiring equipment to capture the faintest reception signals even where several strong interference waves exist. Noise characteristics are indeed important for low noise amplifiers and mixers as they handle weak signals, but the occurrence of distortion components, due to interference waves input at the same time, is also a critical factor contributing to the deterioration of sensitivity. This is an important performance item along with noise characteristics.

Phase noise characteristics (cleanliness of spectrum of the output sinusoidal wave signal) of the frequency synthesizer are important for the accuracy of the transmitter modulation signal and assurance of receiver sensitivity as well as the interference wave resistance characteristics.

Features of Oki Electric's RF circuit technology

RF circuits have long been composed of discrete components, such as bipolar transistors and GaAs devices. Only a few examples have transmitter functions and receiver functions that are combined into an integrated circuit on a single chip. Oki Electric has been promoting technology developments for the realization of RF circuit functions necessary for wireless equipment on a single chip by composing RF circuits with CMOS devices[1) 2)]. The features and effectiveness of Oki Electric's RF circuit technology are described below and summarized in Figure 3.

(1) Utilization of CMOS device

Oki Electric has been developing an RF circuit that uses the CMOS device, SOI[*3)] device and SOS[*4)] device. In all cases, RF circuits are composed of CMOS transistors.

The performance of the CMOS transistors have improved dramatically due to their miniaturization made possible through the advancements in device technologies. This means that CMOS transistors can now provide an adequate performance in the fields of several GHz band, where previously bipolar transistors and GaAs devices had to be applied.

By using CMOS transistors, it is not only possible to operate circuits with a power supply voltage of 2 volts or less but also to configure RF switches quite easily. Further, sophisticated filtering circuit technologies, such as switched capacitor circuits that can only be realized with CMOS and analog-to-digital conversion circuit technologies, can be used.

*3): SOI: Silicon On Insulator *4) SOS: Silicon On Sapphire

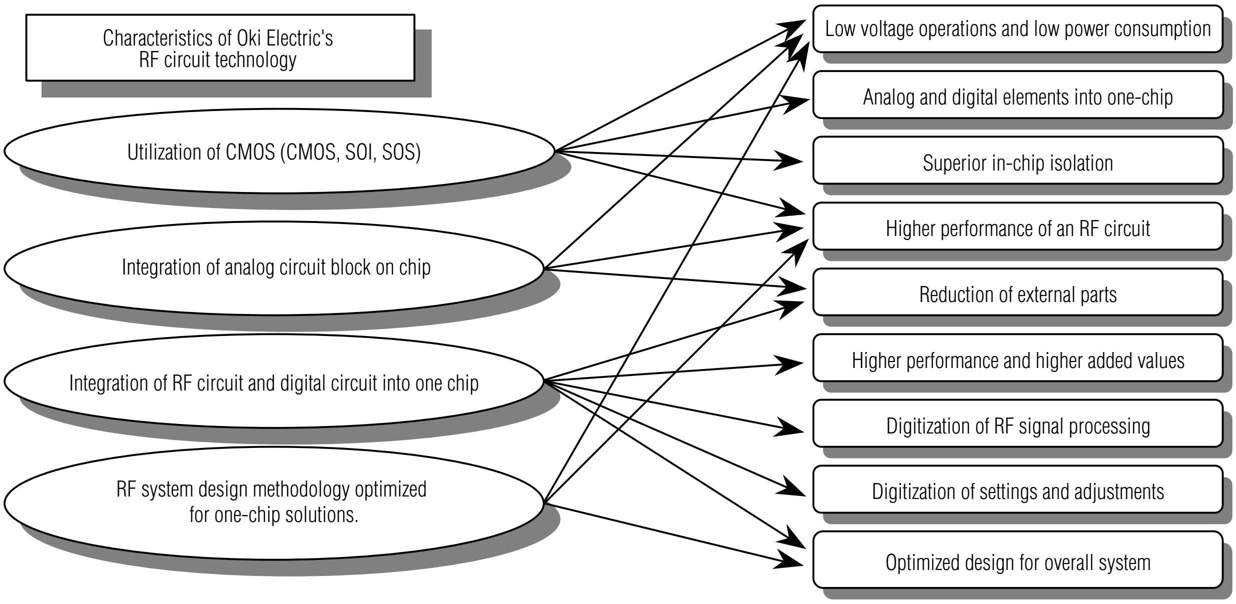

Fig. 3 Features and effectiveness of Oki Electric's RF circuit technology

A CMOS transistor is formed on a buried silicon oxide layer for SOI devices and a CMOS transistor is formed in the silicon layer on the sapphire substrate for SOS devices. In the case of each of these devices, the on-chip inductor with a superior performance can be fabricated, due to the high insulation of the substrates. Since the isolation (prevention of signals leaking) between circuits can be improved as well, it is possible to configure RF circuits with an extremely high performance.

(2) Integration of an analog circuit block on chip

RF circuits have been composed of not only transistors, but also of many discrete analog parts, such as inductors and filters. The number of external parts can be minimized through ingenious circuit configurations and the integration of high performance circuits inside the chips. Examples of functions that are integrated into a chip, which were previously separate discrete parts, are shown in Figure 2. These include an antenna switch, VCO, channel filter and voltage regulator, which can contribute to the reduction in number of component parts installed in equipment. By incorporating external filters into a chip, it is possible to reduce the power of signals used on filters and create configurations that are favorable both in terms of electrical characteristics and power consumption.

Table 2 Realization of functions from discrete parts by circuits in a chip

Individual part	Chip integrated circuit
RF switch	CMOS analog switch
Oscillator circuit module	Chip integrated oscillator circuit
Ceramic filter	Active filter circuit
Power source regulator	Chip integrated regulator

(3) Integration of an RF circuit and digital circuit into one chip

In the past, the realization of integrated RF circuits and digital circuits was believed to be difficult because of the deterioration of RF characteristics from noise generated by the digital circuit. However, it has now become possible to configure LSIs, which are sufficiently practical due to a decreased level of noise generated by the source of the noise, the digital circuit, since it has been miniaturized and consumes very little power. It is also due to the prevention of noise transmitted through the substrate by the use of SOI devices and SOS devices, as well as through the adoption of differential circuit technology for RF circuits that receive less influence from noise. Integration of large-scale digital circuits, with over 100k gates into a single chip, with RF circuit has already been realized and it is possible to configure high value added chips that incorporate digital signal processing as well as communication protocol processing along with RF circuits.

By integrating an RF circuit and a digital circuit into a single chip, it is possible to expect an advantage that supersedes a simple combination of the two. Adjustments and settings necessary for the RF circuit can be performed using sophisticated controls from the digital circuit in the same chip. For example, adjustment of the transmission power and compensation for temperature characteristics have in the past been conducted through such methods as the manual turning of preset resistors or the use of an external voltage from the digital analog converter on the external control chip. Once a single chip integration has been completed, the RF circuit can be adjusted and set directly from the digital circuit that is integrated into the same chip. RF circuit blocks, which can be effectively adjusted or set by digital circuits, include the amplification circuit, oscillation circuit, filtering circuit and modulation circuit.

Replacing functions, which have in the past been realized by analog circuits with digital processing, has been progressing due to the improvement of speed of digital circuits. The application of digital circuits is particularly effective for sections that handle intermediate frequency signals in the receiver circuit, where frequencies are relatively low. The demodulation of signals, which had been phase modulated, for example, was in the past conducted using delay elements and coils in an analog circuit, but this can be configured in a digital circuit to eliminate analog parts to realize an adjustment-free demodulator with stable operations. Higher speeds of circuit operations and higher performances will also become possible, as the limitations by the characteristics of the analog parts are removed by use of digital circuit.

(4) Application of RF system design methodology accommodating single chip integrations

In order to realize a high-performance chip through a single chip integration of the RF circuit, improvement of the individual circuit block performance, as well as design technology for the overall wireless system, are essential.

Unlike the design approach of discrete RF circuits, in which individual component functions are stacked on top of one another, the single chip integration of an RF chip requires a design in a top-down procedure for the entire RF circuit as a system.

For example, the noise characteristics and distortion characteristics fluctuate greatly, depending on how the amplifier gain, which is necessary for the entire receiver circuit, is distributed to individual elements that configure the circuit. High performance and lower power consuming wireless equipment can be realized with the single chip integrations of RF circuits by optimizing the design of functions and features of the individual receiver circuit and transmitter circuit for the entire system.

The design environment have to handle large-scale circuits, wherein a mixture of a high frequency circuit, filtering circuit, PLL circuit and digital circuit, and the simulators have to have quite a high performance, but once the environment structure is established, this type of overall optimized fabrication is much more advantageous than a design with individual components.

Conclusion

RF circuit design using CMOS, SOI and SOS devices can contribute to the realization of compact and low power consuming, yet high-performance wireless equipment that have thus far not been possible through conventional configurations using discrete components.

Applications of the RF circuit technology described in this paper are shown in Table 3[3]. A ZigBee®[*5] compatible 2.4GHz single chip LSI and a single chip LSI for radio controlled clocks have been developed. In each case, the integration of an RF circuit and a sophisticated digital processing circuit into a single chip has been successful, achieving high performance RF characteristics with a low power consumption using the features of the CMOS and SOI devices.

Table 3 Application examples of the RF circuit technology

ZigBee® compatible 2.4GHz single-chip LSI (ML7065)	
Application	LSI for short-range wireless networks
Function	IEEE802.15.4 compliant 2.4GHz RF function, physical layer processing function and Media Access Control (MAC) function.
Feature	Realization of a high performance product with a 0.22μm low-leak CMOS process and low power consumption that makes it possible to run equipment for a long time using dry battery cells.
Single chip LSI (ML6191) for radio controlled clocks	
Application	LSI for radio controlled clocks.
Function	Radio wave receiving function, time-code decoding function and real-time clock function.
Feature	Highly sensitive reception circuit, time-code decoding function and real-time clock function are all integrated into a single chip using the SOI-CMOS technology. Low voltage operations: 1.1 to 3.6V. Low current consumption: 0.25μA on standby mode at 32kHz.

We believe that there will be further integration of RF circuits and single chip solutions will be used for a variety of applications. We intend to keep on working toward continuing sophistication of the RF circuit technology.

References

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*5): ZigBee is a registered trademark of Koninklijke Philips Electronics N.V.