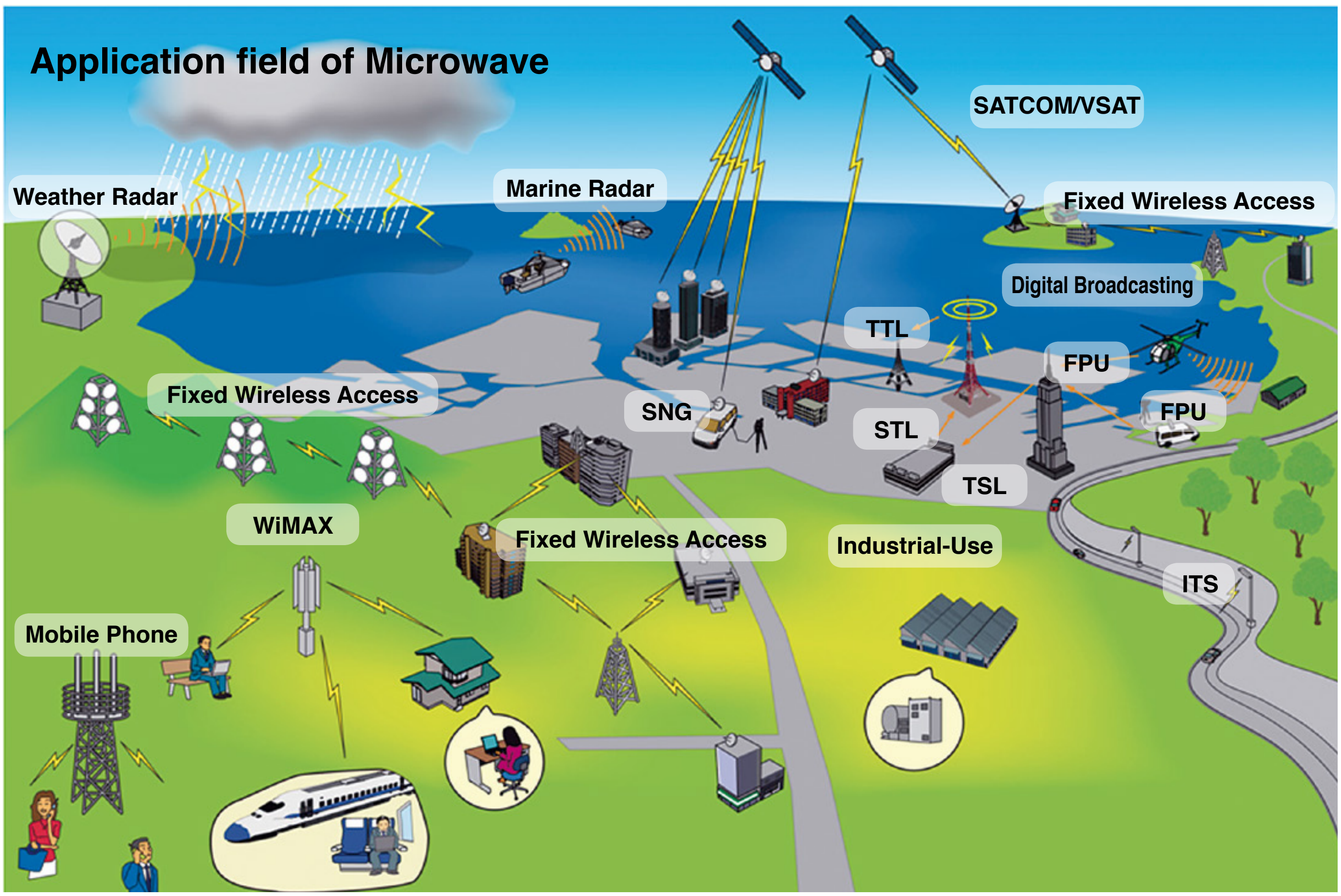
Communication Infrastructure Front Line

for Diffusion of Cellular Phones

—— Further acceleration via Development of High-performance Microwave Communication Devices

Reporting from **Toshiba Corporation Social Infrastructure Systems Company**
Microwave Solid-State Engineering Department, Komukai Complex



Data from Toshiba Corporation Social Infrastructure Systems Company

VSAT: Very Small Aperture Terminal
SATCOM: Satellite Communication
WiMAX: Worldwide Interoperability for Microwave Access
SNG: Satellite News Gathering
TTL: Transmitter to Transmitter Link
STL: Studio to Transmitter Link
TSL: Transmitter to Studio Link
FPU: Field Pickup Unit
ITS: Intelligent Transport Systems

More than 1.75 billion cellular phones are manufactured annually worldwide (2012 survey by Gartner, Inc.), and 94.5% of households in Japan have one or more cellular phones (2012 survey by the Ministry of Internal Affairs and Communications). In particular, it would be no exaggeration to say that almost everyone in their twenties and almost all university students have a cellular phone. In addition, it may be safely said that today, a cellular phone is also a must-have item for elderly people. Originally, wireless communication was achieved with wireless communication equipment that made use of short wave radio frequencies to connect two parties directly. Wireless communication via cellular phones is significantly different from wireless communication of the past in that cellular phones connect two communicating parties via communication stations, which are connected via a wired communication network. In other words, communication via cellular phones is achieved by combining the best features of two different communication systems: mobile “wireless communication” and networked “wired communication”. This issue of LIVING & ULVAC deals with the history and communication infrastructure of cellular phones, which have become a household item on a global scale, and focuses on the latest trends in microwave communication devices that play an essential role in that infrastructure.

Cellular Phone Market Reaching Global Scale As the Spread of Cellular Phones Continues

In Japan, the diffusion rate of cellular phones has been surveyed by two different approaches. The Cabinet Office has conducted surveys on households consisting of two or more family members, whereas the Ministry of Internal Affairs and Communications (MIC) has conducted surveys on all households including single-person households. The MIC has been compiling statistics on this diffusion rate since 1993. According to the figures released by the MIC, the diffusion rate, which was only 3.2% in 1993, reached more than 94% in just 10 years. For details, refer to **Figure 1**.

Before cellular phones made their market debut, large zone schemes, such as the scheme for wireless communication in taxis, were the main type of wireless communication. In large zone scheme wireless communication, each communication station covers a zone approximately 60 km in diameter. In this scheme, two users have to be in the same zone using the same communication service in order to communicate. On the other hand, the system for cellular phone communication consists of small zones approximately 6 km in diameter. The small zone is called a cell; this is where the name cellular phone comes from. The cellular communication system is characterized by the fact that the same radio wave frequencies can be used again and again without radio interference within each cell. Accordingly, this system is able to provide a large communication capacity even with the limited frequency resources that are available. The fact that a large number of users are able to communicate with each other on cellular phones at the same time is largely due to this technology.

High-performance Cellular Phones Contribute to Widespread Use

The world’s first mobile communication based on the cellular communication system was started in 1979 by Nippon Telegraph and Telephone Public Corporation (NTT; current NTT DOCOMO, INC.). NTT provided car-phone service using the 900 MHz band. The size of the radio set was 6,600 cc (slightly less than seven 1 L PET bottles). Needless to say, it was impossible to hold it by hand. Accordingly, the radio set was installed in the trunk with the antenna attached to the roof. It cost 200,000 yen as a deposit, 30,000 yen for the basic monthly service fee, and 10 yen for every six seconds of use.

In 1985, a portable terminal approximately 3,000 g in weight, a so-called “shoulder phone”, was developed. In 1987, the volume of a radio set became 500 cc (equivalent to the volume of one 500 mL PET bottle), and its weight became 900 g. In 1989, a foreign affiliated company developed a new device 220 cc in volume and 303 g in weight, amazing the world. It can be said that this device is the world’s first handheld cellular phone. Thus, a new era of tough competition for realizing smaller and lighter cellular phones was inaugurated.

The next year, in 1990, a cellular phone 203 cc in volume and 293 g in weight was released. Subsequently, competition to shave off

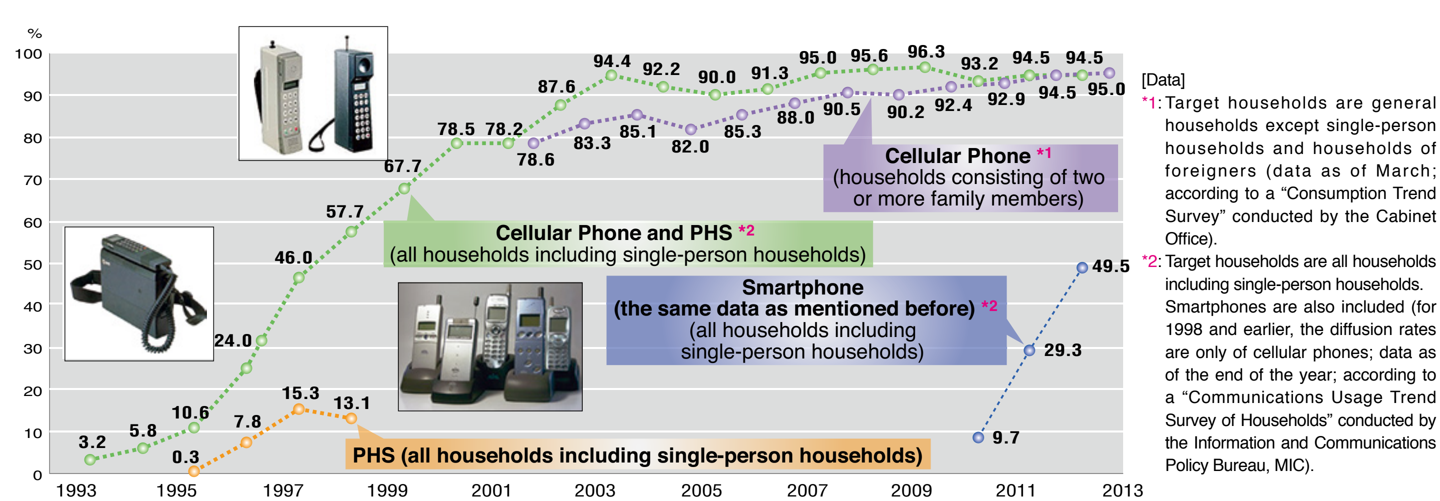
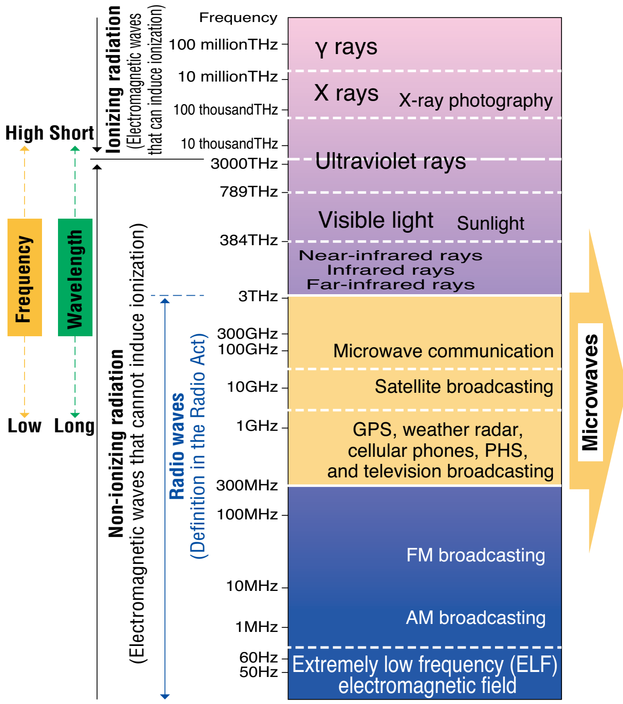


Figure 1. Change in diffusion rate of household cellular phones



Created by ULVAC based on “Radio Waves in Life” published by the Association of Radio Industries and Businesses

IEE’s classification of microwaves according to frequency and their applications

Band	Band frequency (GHz)	Application
W band	75 to 111	Radio astronomy
V band	40 to 75	Radar and communication satellites
Ka band	26 to 40	Communication satellites
K band	18 to 26	Communication satellites
Ku band	12 to 18	Satellite television broadcasting and satellite communication
X band	8 to 12	Military communication, weather satellites, earth observation satellites, navigation radar, surface search radar, air search radar, and fire control radar
C band	4 to 8	Satellite communication, fixed wireless systems, wireless access, surface search radar, and air search radar
S band	2 to 4	Fixed wireless systems, mobile digital satellite broadcasting, ISM band (microwave ovens, wireless LAN, WIDESTAR satellite phones, amateur radio, etc.), navigation radar, and air search radar
L band	0.5 to 1.5	Television broadcasting, cellular phones, Inmarsat satellite phones, 800 MHz band, and air search radar
P band	0.25 to 0.5	Mobile communication, analog cordless phones, and specified low power radio
G band	0.2 to 0.25	Military aeronautical radio
I band	0.2 or lower	

IEE: The Institute of Electronics Engineers, Inc.

Figure 2. Outline of classification of electromagnetic waves according to frequency and frequencies of microwaves

even 1 g or 1 cc continued for years, and new models were released once or twice a year. In 1999, the weight was reduced to as little as 57 g for the second generation digital cellular phones.

At that time, competition for developing new cellular phones started to make a transition from miniaturization to the development of multifunction cellular phones. In 1999, NTT DOCOMO, INC. started the i-mode service, and consequently, cellular phones underwent an enormous transformation from simple voice phones to information terminals that also provide a mail communication function and a browser function. Subsequently, new convenient features, such as large liquid crystal displays, camera functions, ability to use external memory, GPS, wireless LAN, and one-segment broadcast reception, were added to cellular phones one after another. As a result, the size of the phones themselves became larger, but the miniaturization on the inside was never brought to an end. This internal miniaturization led the competition onto a new stage of competing to incorporate as many new functions into the available internal space as possible.

In 2001, the third generation cellular phone service started for high-speed large-capacity communication. New radio frequencies and a new communication system were adopted for this service, and consequently, microwave communication devices that had not been used before made their debut.

After the year 2000, the number of cellular phone users rapidly increased worldwide where it had been limited to Japan, Korea, and major Western countries before that. Against this backdrop, various technological innovations for the communication infrastructure kept its development moving forward. For example, multi-band cellular phones that could automatically select a vacant frequency band to use from among multiple frequency bands, and multi-mode cellular phones that could be used in any communication system anywhere in the world.

In 2007, Apple Inc. released the iPhone which inaugurated the era of smartphones. Subsequently, in 2010, Apple Inc. released iPad and broke new ground of tablet PCs by adding a cellular phone function. Thus, the communication infrastructure for cellular phones has been increasing in importance.

We have looked at the history of the advancement cellular phone terminals. Next, let’s look at microwave communication technology, which plays an important role in communication infrastructures.

Microwave Technology Essential for the Infrastructure of Cellular Phone Communication

Radio waves are classified according to their frequencies. Microwaves are one type of radio wave. They occupy the shortest wavelength region of the radio wave spectrum. They are radio waves (electromagnetic waves) with wavelengths ranging from 100 μm to 1 m and frequencies ranging from 300 MHz to 3 THz. This region includes decimeter waves (UHF), centimeter waves (SHF), millimeter waves (EHF), and submillimeter waves. For details, refer to **Figure 2**.

Microwaves are oscillated by using circuits containing a device such as a magnetron, Klystron, traveling-wave tube (TWT), gyrotron, and Gunn diode. Generally, the oscillated microwaves are propagated through coaxial cables when they are not propagated through the air as radio waves via an antenna. However, for microwaves with high energy (high electric power or high wattage), a metal guide is used to propagate them. In recent years, transmitters integrating semiconductor devices with lines, such as microstrip lines, have been increasingly used as the mainstream means to propagate microwaves.

Microwaves have found widespread application in various areas, such as satellite television broadcasting, microwave communication, radar, microwave plasma, microwave heating (microwave ovens used in general households), microwave treatment, microwave spectroscopy, microwave chemistry, and microwave electric power transmission. Microwaves are also used in unexpected applications. The sensors attached to urinals for automatic flushing are microwave sensors.

Thus, cellular-phone wireless communication technology using microwaves and millimeter waves serves to make our lives more convenient. These conveniences have been realized with the aid of various new microwave communication devices that have been put into practical use.

A marvelous energy transmission method known as wireless electric power transmission has been devised as a future application of microwaves. It is said that the realization of this method of power transmission will eliminate the necessity of using different cables to send information and electric power separately and will allow us to send them through one wireless channel together.

High Expectations for GaN in New Microwave Communication Devices

Microwave communication is achieved with the aid of microwave communication devices containing semiconductors. One such semiconductor is GaN (gallium nitride). It has been thought that it would be difficult to put GaN into practical use. However, GaN and GaAs (gallium arsenide) are now expected to play an important role in microwave communication devices. GaN's characteristics make it a suitable material for producing high-power transistors for amplifying microwave signals.

We interviewed Toshiba Corporation Social Infrastructure Systems Company (Microwave Solid-State Engineering Department, Komukai Complex). This company has been developing microwave communication devices with their high technical capabilities and reliability in the area of compound semiconductors since the 1970s. They started development before cellular phones made their market debut.

In the past, microwave communication found application only in cutting-edge technologies such as space development and the defense industry. In recent years, however, it has been increasingly adopted in various areas, such as air traffic control radars, satellite communication base stations, and medical equipment. In Toshiba Corporation Social Infrastructure Systems Company, microwave communication is used in particularly widespread areas, such as weather radars for providing more detailed weather forecasts and broadcast relay devices that can transmit large quantities of images in real time.

In these areas, devices such as electronic tubes, which include magnetrons, Klystrons, and TWTs; FETs (field effect transistors) made of GaAs; and LDMOS (lateral double-diffused MOS) transistors made of silicon materials have been conventionally used. High-frequency, high-power GaN transistors have several advantages over these conventional devices in various respects. However, their high prices prevented them from finding widespread application, being adopted only in limited application areas. At present, thanks to technological innovations, GaN transistors have declined in price. In addition, various GaN transistor types supporting different frequency bands and providing different levels of output power have been developed. As a result, they find application in increasingly wide areas.

"Our major products include trunk communication base stations and satellite communication stations. We specialize in high-frequency, high-power devices for microwave communication. Our shipment of GaN high-frequency devices has been steadily increasing since we started the shipment in the first half of the 2000s", says Mr. Hideki Kimura, the technical group leader of the Microwave Solid-State Engineering Department, Toshiba Corporation Social Infrastructure Systems Company.

Mr. Kimura continues, "Although high-frequency GaN transistors are high-cost products, their excellent physical properties as semiconductors allow them to take the place of conventional devices. We will make full use of their features brought by their miniaturization, high power, and high efficiency. We will thus be able to contribute to the construction of social infrastructure systems".

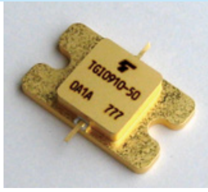
Price Reduction and Higher Performance The Potential of GaN Devices

GaN has a wider band gap than GaAs does. The wider band gap is advantageous to us in that GaN devices can be operated at higher voltages while ensuring reliability. High-voltage operation, which allows transistors to have high input-output impedance, is convenient for ensuring linearity. Consequently, distortion generated in their operation as amplifiers can be reduced. The wide band gap also allows GaN devices to operate at temperatures as high as 300°C. Therefore, structural components used for the cooling and heat-radiation of GaN devices can be simplified. This fact suggests that use of GaN devices will contribute to the miniaturization and cost reduction of equipment.

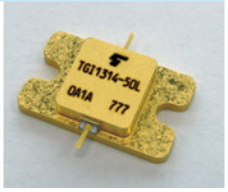
Toshiba Corporation Social Infrastructure Systems Company has commercialized high-power devices that can be used for various frequency bands including C band (4 GHz to 8 GHz), X band (8 GHz to 12 GHz), and Ku band (12 GHz to 18 GHz). According to Mr. Kimura, they will develop higher power, higher efficiency devices delivering higher performance. In this way they will contribute to the development of industry and the construction of the communication infrastructure, leading to a more convenient lifestyle.

Microwave communication devices (GaN devices) produced by Toshiba Corporation Social Infrastructure Systems Company

C-band GaN (120 W)



X-band GaN (50 W)



Ku-band GaN (50W)