Key Materials and Components for Mobile Information Devices for Supporting Highly Information-oriented Society

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OVERVIEW: As the advancement of wireless-communication technologies, such as embodied by mobile phones, continues apace, the realization of the "ubiquitous information society"—namely, a society in which information is freely available at any time and place—is before our eyes. In addition to traditional voice telephony, offered services are ranging from data communications such as e-mail and file transmission up to multimedia information such as video streaming; consequently, communication bandwidth is increasing dramatically. As the communication bandwidth is expanded, the frequency range available is also widened. Accordingly, it is necessary to realize high-speed wireless transmission that can handle broadband and multiband ranges. To meet this requirement, as regards key devices such as antennas and switches for handling RF signals, as well as compactness and low-loss characteristics, a broad range of functions—from multiple-frequency-range compatibility and noise resistance—are required. To create highly functional portable information devices with improved user-friendliness, Hitachi is developing RF ceramic components and highly functional, compact antennas and implementing them in manufactured products.

INTRODUCTION

SEVERAL years have passed since the slogan "ubiquitous information society"—namely, a society in which information is available to anybody, anytime, anywhere—was first coined. During that time, the popularization of the mobile phone and the wireless LAN (local area network) has brought about the possibility of high-speed wireless communication from not only one's workplace or home but also from "hot spots" in town.

Moreover, in addition to traditional voice telephony, services ranging from data communications such as

Fig. 1—Portable Information Devices (Such as Mobile Phones and Notebook PCs) and RF Components. Aimed at continuously being upgraded mobile phones and ever-expanding LANs (local area networks), RF (radio-frequency) ceramic materials and their application products, and a multiple-band high-gain antenna—which will help to realize the "ubiquitous information society," have been developed.

TABLE 1. Comparison of Characteristics of RF Multi-layer Substrate Materials
Characteristics of materials used for RF, multi-layer substrate materials are compared. Propagation loss of an RF signal is determined by resistance and dielectric loss of electrode material.

Item	LTCC		HTCC	PWB
	Developed material	Conventional material		
Substrate material (Sintering temperature)	Lead-free (900°C)	Lead-containing (900°C – 1,000°C)	Alumina (– 1,500°C)	FR4, etc.
Internal electrode (Resistivity: Ω·cm)	Ag (2×10^{-8})	Ag or Cu ($2 – 4 \times 10^{-8}$)	W/Mo ($4 – 6 \times 10^{-8}$)	Cu ($– 4 \times 10^{-8}$)
Dielectric ratio	8.1	6 – 8	8 – 9	4 – 5
Dielectric loss Tanδ ($\times 10^{-4}$)	7 – 10	10 – 20	10 – 20	60 – 200
Transverse strength (MPa)	300	200 – 250	– 400	400 – 500

LTCC: low-temperature cofired ceramic
HTCC: high-temperature cofired ceramic
PWB: printed wiring board

e-mail and file transmission up to multimedia information such as video streaming are becoming more popular. As a consequence of this trend, the volume of information transmission is increasing dramatically.

In the case of mobile phones, to achieve high-speed wireless communication under a limited power capacity, along with the necessity to reduce power consumption of the electric circuit, it is necessary to implement RF (radio-frequency) circuits for trasmitting and receiving RF signals efficiently. Above all, the antenna—along with its directly connected filter and switch—is the key device dominating the performance of wireless communication. Furthermore, together with RF design techniques, advanced processing and materials technologies are important. By expanding and strengthening these technologies, Hitachi is advancing product development aimed at various mobile information devices ranging from mobile phones up to notebook PCs (see Fig. 1).

Taking up RF ceramic components and antennas, the rest of this paper describes the current status of their development and application in products.

RF CERAMIC MATERIALS AND COMPONENTS

RF Ceramic Materials and Processing Technology

As regards a filter and diplexer for RF signals, circuits that consist of transmission lines and capacitances are heavily used. Transmission lines require a predetermined length determined by the wavelength of the transmitted signal; in contrast, in the case of mobile devices with a constrained mounting area, device size must be scaled down. As a result, a structure using a multilayered substrate is becoming common.

Regarding low-loss transmission of RF signals, it is necessary to decrease the dielectric loss of the substrate materials and the resistivity of the electrode materials. Moreover, for the sake of scaling down device size, a high-permittivity substrate is desirable. The main characteristics of various materials for RF multilayered substrates are compared in Table 1.

Since HTCC (high-temperature cofired ceramic)—with alumina as the main ingredient—requires sintering at high temperature, heat-resistant metals such as tungsten must be used; consequently, electrode loss becomes large. This means that HTCC is not suitable as a substrate for RF components. At the same time, in the case of organic substrates, while electrode loss due to copper wiring can be lowered, the dielectric loss of the substrate material increases; moreover, since the permittivity is low, application of enlarged substrates is considerably constrained.

Since LTCC (low-temperature cofired ceramic) is a material which can be sintered at approximately 900°C, low-resistivity metals such as silver and copper can be used as an electrode material. Consequently, since the 1990s, LTCCs have been widely used for RF components. Mechanical strength of an LTCC substrate is, however, low. In particular, in the case of a mobile device, it is required that the device is resistant against the impact exerted when it is dropped. Problems therefore still remain as regards the use of LTCCs for such mobile devices. In addition, as a result of low-temperature sintering, lead-based glass materials are widely used. From the viewpoint of environmental responsiveness, it is thus desirable to improve these materials.

Aimed at solving the above-mentioned problems, lead-free high-strength LTCC materials have been developed. The structures of LTCC material and a conventional material are compared in Fig. 2. In the case of the developed LTCC, the density decrease in sintering is lowered, and as a result of forming a refined crystalline structure, a fine structure with low porosity is obtained. Owing to this crystal structure, the transverse strength of the developed LTCC is about 300 MPa, which is significantly higher than that of a conventional LTCC.

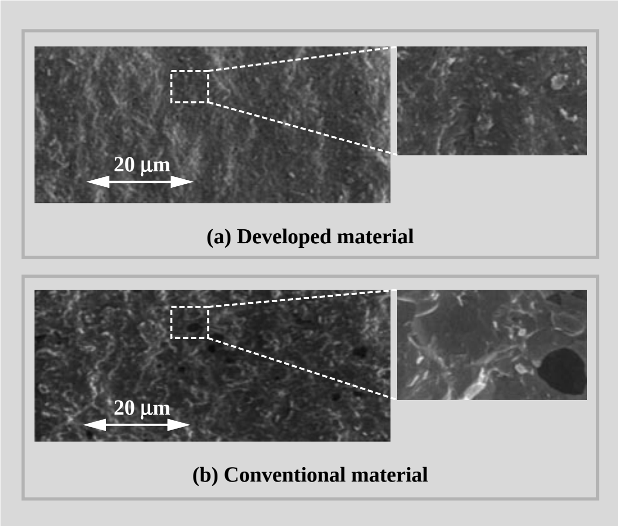


Fig. 2—Comparison of Structure of Developed LTCC Material with Conventional Material.
Compared with the current material, the structure of the developed LTCC material is finely crystallized, and the density of porosity is considerably lower.

LTCC is cast in the form of a sheet, and following via-hole processing and electrode printing, laminating and sintering processes are used to form RF components with predetermined functions. Aiming at even higher integration density and improved performance, Hitachi has reduced sheet thickness to 25 μm, via-hole diameter to 75 μm, and print-pattern width to 80 μm (line) by 80 μm (space), and achieved high-precision lamination with misalignment of less than 50 μm. By combining these features, we have successfully produced a highly integrated internal element substrate.

Antenna Switch Module for Mobile Phones

An example of an RF component using an LTCC

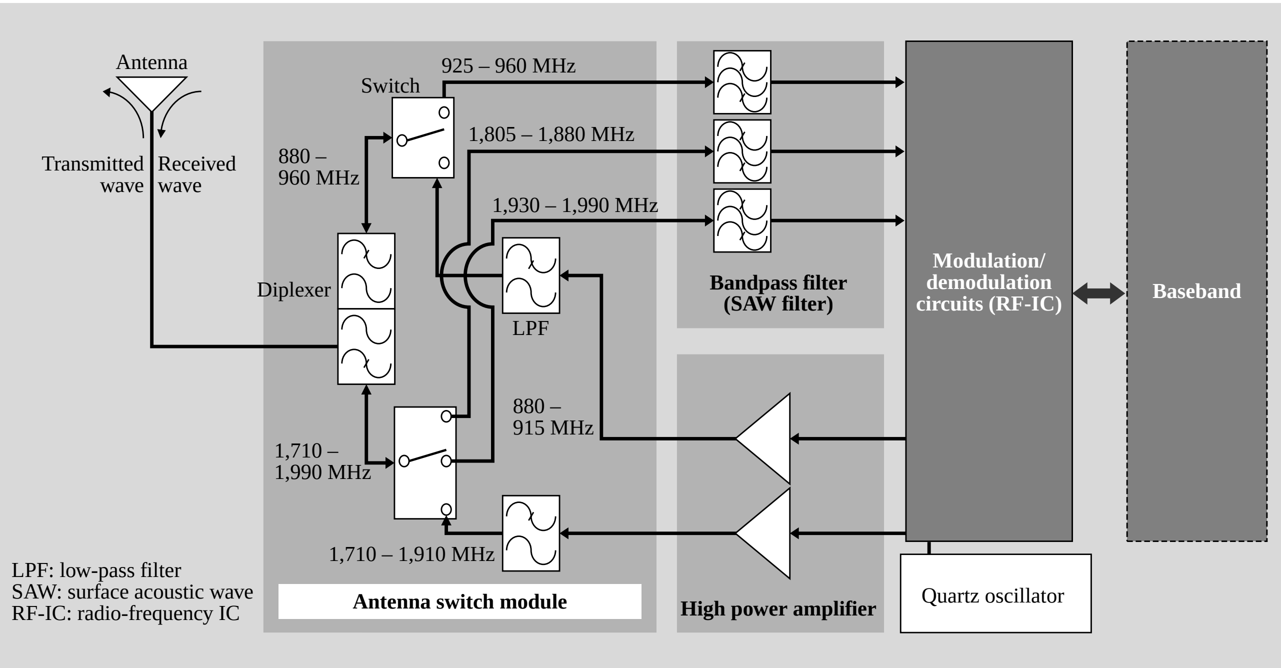
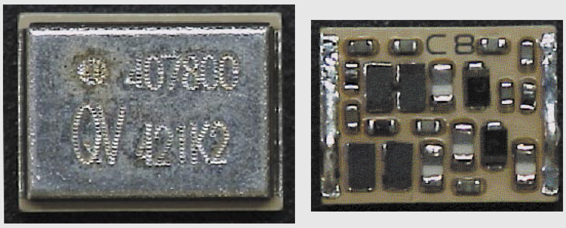
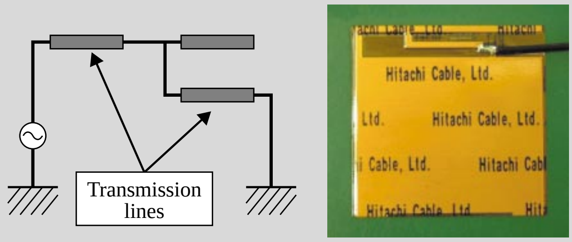


Fig. 3—Structural Overview of GSM Mobile Phone RF Components and Antenna Switch Module.
Overall configuration of RF signal components of mobile phones covering three bands: European GSM (Global System for Mobile Communications) band (880–960 MHz), DCS (Digital Cellular System) band (1,710–1,880 MHz), and the American PCS (Personal Communication Services) band (1,850–1,990 MHz). As regards the antenna switch module, multiple T/R (transmission/receiving) switching circuits (for switching transmitted and received signals), a diplexer, and a filter for damping the radio wave generated by a high-power amplifier are mounted on an LTCC substrate.



(a) Upper surface (b) Appearance of mounted components

Fig. 4—Four-band-use Antenna Switch Module.
About 30 transmission lines and corresponding bandwidth are built into a 15-layer LTCC laminated substrate, and more than 20 switch components are mounted on this substrate.



(a) Configuration of three-stub transmission line (b) Appearance of dual-band antenna

Fig. 5—Configuration of Three-stub Transmission Line Based on Transmission Line Theory (a) and External Appearance of the Dual-band Antenna (b).
As for the equivalent circuit using a three-stub transmission line (a), by establishing in-house simulation technology, the optimum line can be extracted, thereby shortening design time. The dual-band antenna (b)—covering two frequencies (2.4-GHz and 5-GHz bands) and designed according to a transmission line model—has dimensions of 30 (length) × 30 (width) × 0.2 (thickness) mm, so it can be fitted into a compact information device like a notebook PC.

substrate is the antenna switch module used in mobile phones complying with the GSM (Global System for Mobile Communications) specification. As a global standard accounting for about two thirds of the mobile phones shipped worldwide, GSM is evolving to cover multi-band transmissions in accord with the expansion of the available frequency range being necessitated by the rapid growth in the number of mobile-phone users. A block diagram of the RF components used in mobile phones—handling the three bandwidths used in Europe—is shown in Fig. 3.

Integrating circuits such as multiple T/R (transmission/receiving) switches, a diplexer, and filters, the antenna switch module mounts the chip components on an LTCC multilayered substrate.

An antenna switch module covering four bandwidths, namely, the American GSM850 standard (824–894 MHz) as well as the three above-mentioned European bandwidths, is shown in Fig. 4. This module produces transmission lines and capacitances within sheets with thickness ranging from 25 to 75 µm packed at high density. At the same time, scaling down mounted components and improving packing accuracy have led to dimensions (5.4 × 4.0 × 1.5 mm) in the world's smallest class.

Complex electromagnetic interference is generated between the elements integrated in the multilayered substrate. As element integration density is increased with the scaling-down of devices, on the one hand, this interference increases, while, on the other hand, RF characteristics are degraded. Aiming at solving these problems, Hitachi has developed highly accurate, 3D electromagnetic simulation technology for precisely evaluating the interference between circuit elements. At the same time, by optimizing configurations of various components, we have achieved world-beating antenna performance, that is, insertion loss of less than 1.2 dB and high second harmonic attenuation of over 35 dB (GSM band, during transmission).

INTERNAL ANTENNA FOR INFORMATION TERMINALS

Wireless-LAN Antenna for Notebook PCs

In recent years, the wireless standard IEEE802. 11a/b/g has become into widespread use for handheld information terminals like noteboook PCs. In the case of notebook PCs, simultaneous use of the 2.4-GHz and 5-GHz bands is common, and to enable transmission and reception in both frequency ranges, so-called "dual-band" handling is necessary. To make this possible, Hitachi has developed a new internal antenna for handling dual-band transmission and reception with improved mountability concerning the LCD (liquid crystal display) panel of notebook PCs.

The internal antenna has several benefits, namely, increased design latitude for the device body (e.g. design without protrusions) and for omission of parts like covers; on the other hand, it has several shortcomings, namely, susceptibility of antenna characteristics to the influence of the device body and the difficulty of design. In our current work, to support antenna design (which has tended to depend on

TABLE 2. Main Specifications of Dual-band Antenna
The antenna handles all specifications in IEEE802.11a/b/g. In particular, it can be applied in all regions in the world using the 5-GHz band. (Namely, in addition to Europe, Japan, USA, etc. are covered.) The table shows the average gains as the arithmetic mean of horizontal and vertical polarization in all directions when the antenna is operated using coaxial cable (length: 500 mm, diameter: 1.13 mm).

Item	Standard specifications
Frequency range	2.3 – 2.6 GHz 4.8 – 6.2 GHz
Voltage standing wave ratio	2.0 or less
Average gain	-2 dBi
Polarization/directivity	Linear/omnidirectional
Impedance	50 Ω

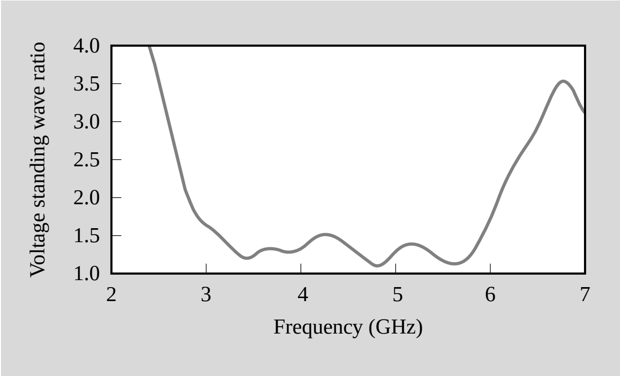


Fig. 6—Measurement Results on Voltage Standing Wave Ratio of UWB Antenna.
In the 3- to 6-GHz band range, excellent characteristic (i.e. voltage standing wave ratio: less than 2.0) is achieved. As a UWB (ultrawide band) antenna, this antenna covers the practical-application range (including mountability).

experience and trial and error), we have implemented a simulation based on a transmission-line model (1).

In this simulation, at first, multiple models with transmission lines in the two- to four-stub range are devised. Equivalent circuits are used for each model, and simulation is performed. As regards each transmission line, loss and RF characteristics obtained empirically are input. By getting the optimum transmission-line length and line combination, as well as return-loss characteristic, from the simulation in this way, a unique dual-band antenna was developed (see Fig. 5).

Next, a radiating element satisfying the obtained optimum transmission-line length and configuration is designed and fabricated. The external appearance of such a fabricated dual-band antenna based on the above-described simulation procedure is shown in Fig. 5(b). The radiating element is constructed of copper alloy, and to prevent deformation or discoloration, both sides of the element are laminated with polyimide film. One end of the micro coaxial cable is connected to the feed point of radiating parts; the other end is connected to a wireless system module located separately.

The measured characteristics of the antenna mounted in an actual LCD panel of a notebook PC are listed in Table 2. In particular, the average gain (which indicates sensitivity) is high, i.e.–2 dBi (including cable loss of about 2 dB), and under a wireless-LAN connection, the antenna exhibits considerable non-directionality.

Antenna for UWB Use

As the standard for next-generation, short-haul communications at transmission speeds of over 100 Mbit/s, UWB (ultrawide band) is in the spotlight. In particular, as the first stage of UWB implementation, operation in the 3- to 6-GHz range will commence in 2006. To cover this wide bandwidth, technology developed for wireless-LAN antennas will be utilized, and a "triple-band" antenna—with peaks at 3, 4, and 5 GHz—has been developed. By combining these three peaks, wider bandwidth has been created.

Measurement results for VSWR (voltage standing wave ratio) of the developed UWB antenna are plotted in Fig. 6. These results indicate that in the entire broad range used for UWB, the VSWR characteristic is excellent, that is, below the specified value of 2.0. In a similar fashion, in the 3- to 6-GHz range, average gain is –2.0 dBi and above, and variation in group delay (which is critical in regards to UWB bandwidth) is less than 1.1 ns. These antenna characteristics are thus confirmed to be suitable for LCD panels (2).

CONCLUSIONS

As components and technologies to support the ubiquitous information society, RF ceramic materials and components for high-functionality, multi-frequency compact antennas are described in this report. Aiming to further improve user-friendliness for our customers from now into the future, Hitachi is developing technologies and products that will provide a superior competitive edge in order to contribute to the advancement of wireless technology for mobile information devices.

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