Technology Reports

Multiband Mobile Terminals

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In order to accommodate the ever-expanding areas of FOMA service and increasing network capacity, we have developed a new series of mobile terminals adopting multi-band technology. With this technology, it becomes possible to use the optimal frequency bands for a given situation, from heavy traffic areas such as urban districts to light traffic areas such as mountainous regions.

1. Introduction

At the World Administrative Radio Conference-92 (WARC-92), it was decided to use the 2-GHz band globally for the allocation of frequencies for IMT-2000 systems. The 800-MHz, 1.7-GHz, and 2.5-GHz bands were later added at the World Radio communication Conference-2000 (WRC-2000) in 2000. Accordingly, the 2-GHz band was first allocated to the IMT-2000 systems in Japan. Later, the 800-MHz band, which was conventionally used for the Personal Digital Cellular (PDC)[*1] systems and other purposes, was reorganized and the 1.7-GHz band additionally allocated due to a lack of frequency resources caused by the rapid increase in mobile terminal users, as well as from the standpoint of efficiently using frequencies [1]. These frequencies were eventually made available for IMT-2000 systems. Consequently, the Ministry of Internal Affairs and Communications permitted DoCoMo the use of these frequencies for IMT-2000 systems, which is now using said frequencies to introduce FOMA services.

The FOMA services were launched in October 2001, initially using only the 2-GHz band. Services using the 800-MHz band were subsequently launched in June 2005 to efficiently cover various mountainous regions and other areas (FOMA Plus-Area). More recently, in May 2006, services using the 1.7-

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[*1] PDC: A Second-Generation mobile communication system widely used in Japan, adopted by DoCoMo and others.

GHz band were launched, specifically aimed to address the high concentration of traffic in urban districts brought about by the recent rapid increase in subscribers to the FOMA services.

Given this frequency expansion, it is now necessary to adopt the 800-MHz band to enable communication using a single mobile terminal throughout all the areas covered by FOMA. On the other hand, the 1.7-GHz band must also be used to secure a sufficient number of communication channels to address the distribution of traffic in certain areas. For these reasons, we first developed dual-band (2-GHz/800-MHz bands) of 901iS series and then triple-band (2-GHz/1.7-GHz/800-MHz bands) of 902iS series mobile terminals.

This article describes how these multiband mobile terminals are configured, focusing in particular on how the transceiver and antenna are implemented.

2. Basic Specifications for Multiband Mobile Terminals

Table 1 shows the frequency bands specified by the 3rd Generation Partnership Project (3GPP) TS25.101 (User Equipment radio transmission and reception for Frequency Division Duplex (FDD)*2 characteristics technical specifications)[2]. Among these frequency bands, three (I, VI and IX) are currently allocated to IMT-2000 systems in Japan. **Figure 1** shows these frequency bands. The multiband mobile terminals that we developed this time support all three bands.

Table 2 shows the basic specifications of the multiband mobile terminals. The bands assigned to DoCoMo constitute only parts of the frequency bands shown in Fig. 1, but in consideration of future international roaming and other developments, the terminals support the full range of each frequency

Table 1 3GPP frequency bands

Band	Uplink frequency	Downlink frequency	TX-RX frequency separation	Remarks
I	1,920–1,980 MHz	2,110–2,170 MHz	190 MHz	Europe, Japan
II	1,850–1,910 MHz	1,930–1,990 MHz	80 MHz	US
III	1,710–1,785 MHz	1,805–1,880 MHz	95 MHz	Europe
IV	1,710–1,755 MHz	2,110–2,155 MHz	400 MHz	US
V	824–849 MHz	869–894 MHz	45 MHz	US
VI	830–840 MHz	875–885 MHz	45 MHz	Japan
VII	2,500–2,570 MHz	2,620–2,690 MHz	120 MHz	Europe
VIII	880–915 MHz	925–960 MHz	45 MHz	Europe
IX	1,749.9–1,784.9 MHz	1,844.9–1,879.9 MHz	95 MHz	Japan

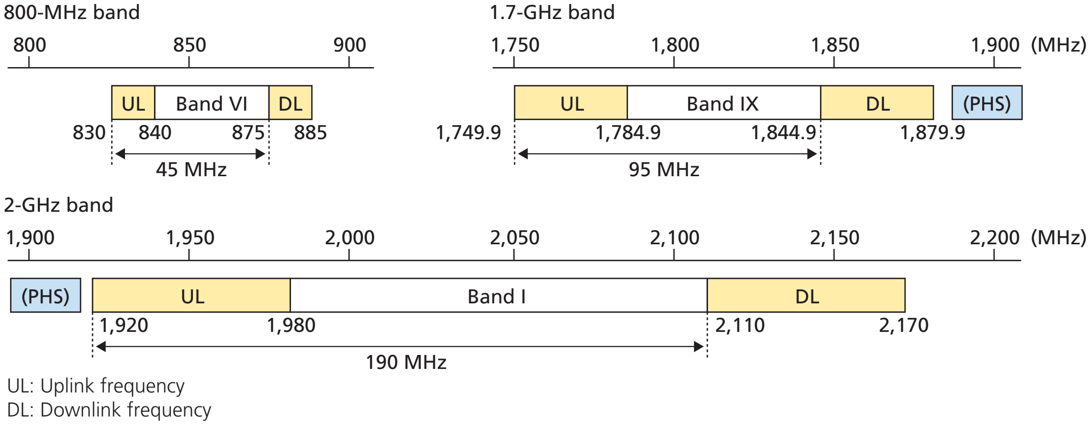

Figure 1 Frequency bands conforming to 3GPP specifications in Japan

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*2 FDD: A communication method where different frequencies are used for transmission and reception.

Table 2 Basic specifications of multiband mobile terminals

Transmission frequency band	Band I: 1,920–1,980 MHz Band VI: 830–840 MHz Band IX: 1,749.9–1,784.9 MHz
Reception frequency band	Band I: 2,110–2,170 MHz Band VI: 875–885 MHz Band IX: 1,844.9–1,879.9 MHz
TX-RX frequency separation	Band I: 190 MHz Band VI: 45 MHz Band IX: 95 MHz
Number of channels	Band I: 275 (at 200-kHz intervals) Band VI: 29 (at 200-kHz intervals, 100 kHz in some cases) Band IX: 151 (at 200-kHz intervals)
Multiple access	DS-CDMA
Duplex	FDD
Chip rate	3.84 Mcps
Modulation (data/spreading)	Uplink: BPSK/HPSK, downlink: QPSK/QPSK
Occupied bandwidth	5 MHz or less
Maximum transmission power	Class 3: +24 dBm
Power leakage to adjacent channels	–33 dBc (5 MHz detuning) –43 dBc (10 MHz detuning)

BPSK (Binary Phase Shift Keying): A digital modulation method where binary information is transmitted via two phase states.
dBc: "c" stands for carrier. It indicates the ratio of a signal power to carrier power.
DS-CDMA: Direct Sequence-Code Division Multiple Access. A method adopted in W-CDMA.
HPSK (Hybrid Phase Shift Keying): A phase modulation method that reduces the peak power of transmission signals.
QPSK (Quadrature Phase Shift Keying): A digital modulation method where 2-bit information is transmitted via four phase states.

band.

Moreover, while there is a constant demand for the size reduction of mobile terminals, the number of components installed in the terminals is increasing in line with the growing number of applications requiring dedicated hardware such as high-definition cameras and FeliCa®[*3], and the circuit board area available to implement the transceiver is limited. Consequently, we set a development goal of achieving a circuit area used for the transceiver no larger than that in the 900i series.

3. Implementation of the Multiband Transceiver

Unlike the near expansion of frequencies conducted for the 800-MHz PDC systems [3], it was necessary to expand frequency band support so as to support all three different frequency bands shown in Fig. 1. When expanding frequency support for the 800-MHz band, the band must be treated as an entirely new band because the frequency interval is far from the 2-GHz band. Conversely, for expansion of the 1.7-GHz band, two methods could be considered: (1) increasing the operating frequency range of each component or (2) setting 1.7 GHz as a new band. **Table 3** shows the advantages and disadvantages of each method.

Method (1) is difficult to realize immediate commercial availability under current circumstances since the issues involved are still being actively studied [4]. Conversely, the major issue regarding method (2)—the size reduction of W-CDMA devices—can basically be considered resolved with stable performance secured thanks to accumulated terminal development know-how. Consequently, device development to achieve size reduction is currently underway.

For these reasons, we decided to adopt method (2) emphasizing on performance for expansion of the 1.7-GHz band, and focus our efforts on size reduction of components and related implementation. **Figure 2** shows one example of the wireless section configurations of 902iS series that we developed this time. Specific examples of size reduction in the configuration are described below.

1) Integration of Main Components

In the 902iS series, a Radio Frequency Integrated Circuit (RFIC)[*4] adopts the direct conversion method[*5] from the receiver adopted in the 900i series. In order to support the three bands, the RFIC was made smaller than the single (2GHz)-band RFIC by sharing quadrature modulator with bands, allowing the 1.7-GHz and 800-MHz bands to share Voltage Control Oscillators (VCOs)[*6] by means of a fixed frequency division ratio[*7] and taking other component circuit design measures, as well as switching to a new IC technology (from 0.3 to 0.18 μm). Moreover, a design where some peripheral devices, such as the matching circuits[*8], are incorporated within the RFIC is adopted to reduce the number of external components. By integrating the RFIC, Low Noise Amplifier (LNA), interstage filters, and other components into a single module, the circuit board area required for the transmission/reception module shown in Fig. 2 was reduced by approximately 20% compared to the 900i series.

2) Configuration of Power Amplifier (PA) Modules

Next, we compared a configuration where several multiband

[*3] FeliCa®: FeliCa is a registered trademark of Sony Corporation; it is a non-contact type of IC card technology method developed by Sony.

[*4] RFIC: Used for high-frequency analog communication circuits adopted in mobile terminals and others.

[*5] Direct conversion method: A method of directly converting radio frequency signals received by an antenna to base band signals without going through intermediate frequencies.

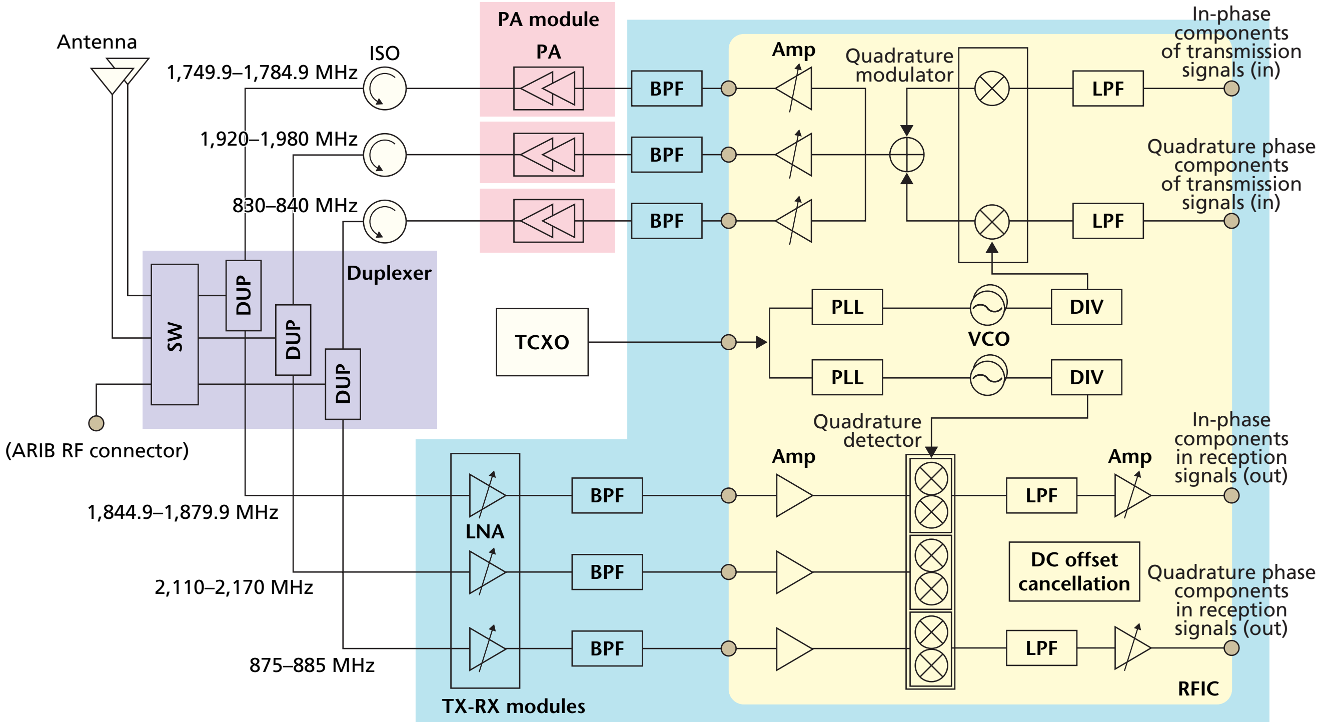
[*6] VCO: An oscillator that can change frequencies by controlling the input voltage.

[*7] Division ratio: A ratio used when converting an input frequency to a frequency obtained by multiplying by 1/n, where n is an integer.

Table 3 Comparison of 1.7 GHz band expansion methods

	Expansion method	Advantages	Disadvantages
(1)	Expansion by increasing the operating frequency range of each component	Since the number of components does not change, the increase of occupied area and weight can be kept low.	The PA efficiency and NF of LNA are likely to decrease due to the shift to broadband (leading to shortened call time and deteriorated reception sensitivity).
(2)	Expansion by setting 1.7 GHz as a new band	Since components optimized for each band are available, the performance can be as good as or better than conventional solutions.	Since the number of components is significantly increased, the occupied area and weight are likely to increase as well.

NF: Noise Figure. The ratio between the SN ratio (signal-to-noise ratio) of input signals and the SN ratio of output signals.



Amp: Amplifier
BPF: Band Pass Filter
LPF: Low Pass Filter
DC offset cancellation: Used to remove DC components generated by the direct conversion method.
DIV: DIVider. A circuit that converts an input frequency to a frequency obtained by multiplying by 1/n, where n is an integer.
DUP: DUPlexer
ISO: ISOlator. A directional component that prevents reflected waves by letting only transmission waves pass.
PLL: Phase-Locked Loop. A circuit that synchronizes the output signal frequency with a standard frequency.
SW: SWitch
TCXO: Temperature Compensated Crystal Oscillator. A crystal oscillator equipped with a function that compensates for temperature-dependent frequency bias.

Figure 2 Example of 902iS series transceiver configuration

PA modules are placed in a single package with a configuration based on ultra-miniaturized PA modules only 3 × 3 mm in size, which reflects current cutting-edge technology in terms of economy and implementation. As a result of this examination, we chose to adopt a triple-system configuration where each band is completely independent of the others, because an independent configuration for each band allows the incorporation of devices for dual-band mobile terminals and is more flexible in terms of implementation layout and wiring. With this configuration, we were able to improve the power added efficiency*9 in all bands

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*8 Matching circuit: A circuit that prevents power loss due to reflection or similar phenomena generated between an output circuit and input circuit in a transmission line in order to secure the quality of electric signals. It is used to improve the transmission performance of the electric power conductors in antennas to enable efficient power conversion.

*9 Power added efficiency: Ratio between the power output and the power supplied to an amplifier.

compared to the 900i series without increasing the circuit board area by any more than a factor of 2.5.

3) Configuration of Duplexers

Dielectric duplexers were used in mobile terminals prior to the 900i series. However, these devices are much larger than other components of mobile terminals and not suited for implementation in multiband mobile terminals. Fortunately, the so-called Surface Acoustic Wave (SAW) duplexers[*10] that possess excellent W-CDMA performance characteristics have recently been developed. By adopting a module configuration where the antenna switches and other components are incorporated in the duplexer, it is possible to reduce size while improving overall performance. With this configuration, the circuit board area was reduced by approximately 20% compared to the 900i series.

Through the measures described above, we were able to reduce the size of the multiband transceiver while at least maintaining comparable performance levels matching those of conventional terminals or better. **Figure 3** shows the measured transmission spectrum characteristics of each band as an example of performance. As can be seen, there is no difference in characteristics among the frequency bands, with a sufficient margin achieved regarding the specification values.

Figure 4 shows an example of changes in the transceiver implementation area compared to the 900i series. This graph compares the area, while setting the transceiver implementation area of the 900i series to 1. In the 902iS series that we developed this time, we managed to design multiband mobile terminals with the same overall size as single-band mobile terminals, although with a larger area occupied by the PA modules.

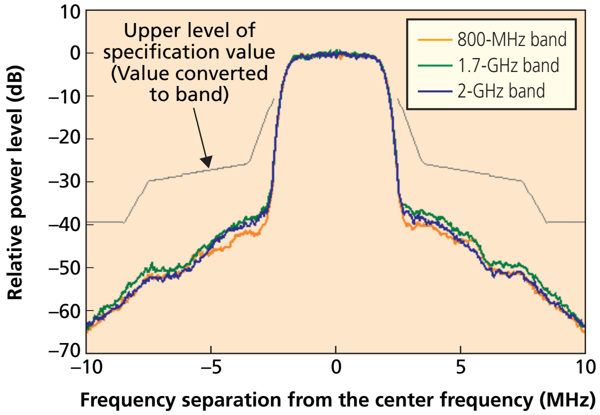

Figure 3 Transmission spectrum waveform

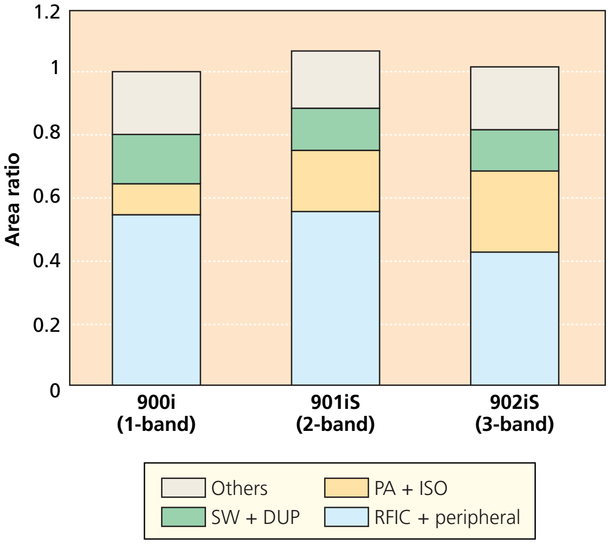

Figure 4 Example of changes in transceiver implementation area

4. Development of Multiband-supporting Antenna

Since the antenna performance of a mobile terminal is an important factor that largely affects both efficient area design and good user communication quality, it requires adopting an antenna design that yields high performance under actual usage conditions in order to ensure that the mobile terminals will provide high user satisfaction.

Given the growing trend toward building antenna into recent mobile terminals, it is necessary to secure space for installing the antenna within the chassis. From the standpoint of marketability, however, a good design is also necessary. Therefore, antenna that yields sufficient performance within strict volume limitations must be developed.

Of course, the prerequisites listed above apply to the antenna for multiband mobile terminals as well. The predominant antenna now being used for FOMA terminals is sheet-metal-type antenna for which the antenna elements are constructed by processing sheets of metal. The main reason for adopting this type of antenna is that it yields a high degree of freedom in

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[*10] SAW duplexer: A component that separates transmission and reception frequencies, allowing the use of a single antenna for both transmission and reception. It is configured with filters that utilize precipitous transit characteristics, which is a property of SAW.

arranging the antenna elements and forming patterns; we thus considered whether it could be used for multiband terminals as well. **Figure 5** shows the configuration principle of multiband antenna and the design method is explained below.

4.1 Design of Antenna Elements and Chassis Structure

In the design of the antenna elements, we made use of the antenna design know-how accumulated from the mova series when adding the 800-MHz band. We did so because the frequency intervals of the 2-GHz and 800-MHz bands are far apart and there is little deterioration in antenna performance due to electric coupling. As a result, implementing dual-band technology was achieved without any loss of performance compared to conventional terminals.

Next, the 2-GHz/1.7-GHz/800-MHz antenna was designed based on the 2-GHz/800-MHz antenna. Since the frequency interval of the 1.7-GHz band is close to the 2-GHz band, the following two methods were considered for implementing the antenna elements.

1) Designing broadband antenna elements that cover the entire frequency range from 1.7 to 2 GHz
2) Adding independent antenna elements that resonate with the 1.7-GHz band

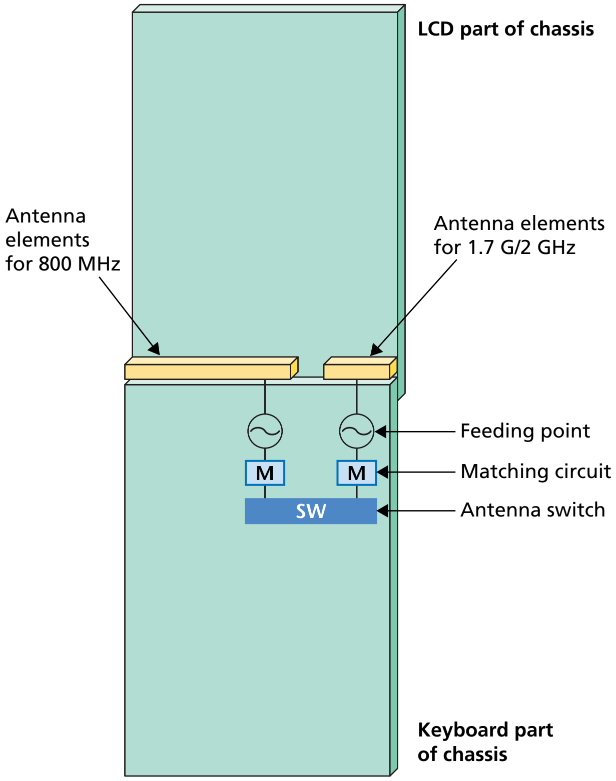

Figure 5 Configuration principle of multiband antenna

The initial tests revealed, however, that it was quite difficult to achieve the target performance within the same antenna volume as in the 901iS models, and it was thus concluded that increasing the antenna volume for both methods in order to achieve satisfactory performance was necessary. We therefore optimized the antenna installation conditions by focusing on the antenna elements and chassis structure as shown in **Figure 6** to achieve the target performance.

First of all, to optimize the antenna elements, we quantitatively analyzed the effect of improved performance made possible by increasing the volume in directions along the length and width axes of the mobile terminals, and then computed the minimum volume increase required to achieve the necessary performance (leading to an increase of 3 cc). Based on this result, we subsequently changed the Mg alloy used to maintain chassis rigidity to a non-metal hardening resin, secured sufficient physical distance between the antenna elements and adjacent metal components and inner substrate, and then took other measures to create conditions suited for mounting the antenna without changing the external appearance of the mobile terminals.

As a result, we managed to implement the 1.7-GHz band antenna without adversely affecting performance in the 2-GHz and 800-MHz bands, while limiting the increase in chassis volume to no more than 0.5 cc.

Figure 7 shows the multiband antenna frequency characteristics. The figure shows the amount of reflection relative to antenna input power at each frequency. Here, the amount of reflection represents the electrical power of the input signals returning to the antenna feeding point. When the reflection is low, power is efficiently transmitted to the surrounding space. Fig. 7 also shows that the amount of reflection is low in the frequency bands available for DoCoMo, thus resulting in the conclusion that a 3-band antenna is feasible with this construction.

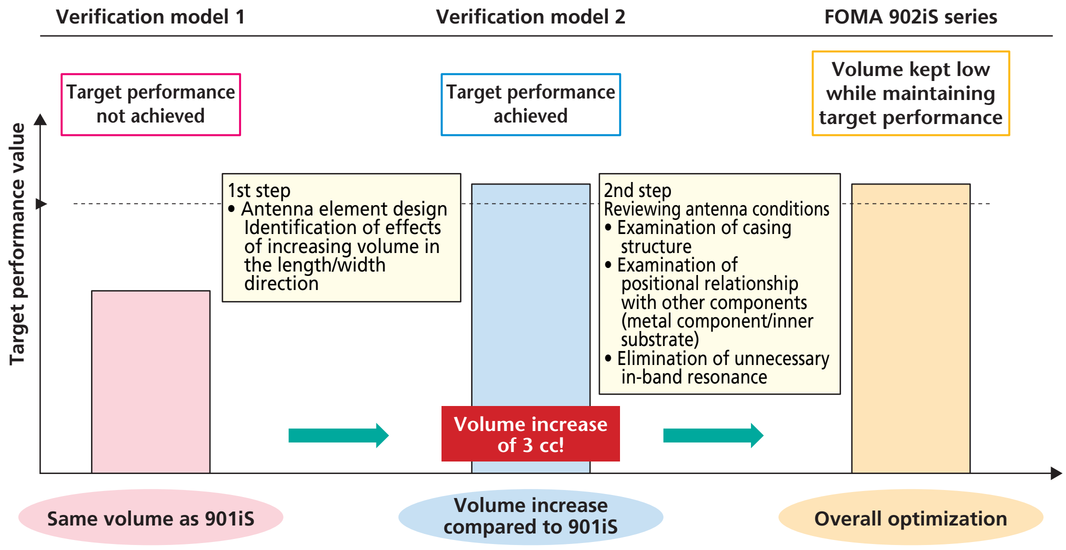

Figure 6 Optimization to achieve target performance values

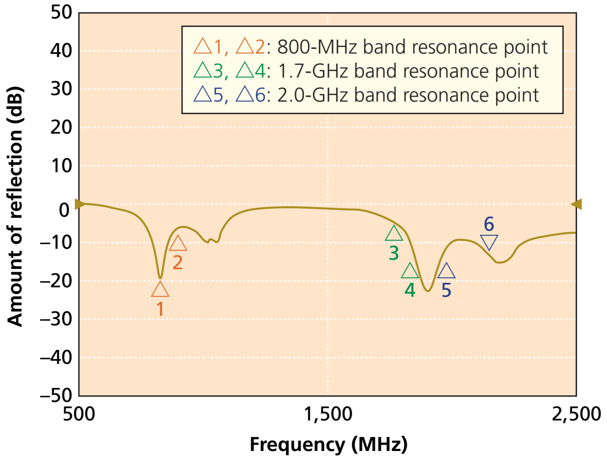

Figure 7 Frequency characteristics

These characteristics were measured using an antenna implemented according to method 1) and confirming that the amount of reflection is low in a wide frequency range from 1.7 to 2 GHz.

4.2 Stabilization of Performance at Practical Usage

In highly optimized antenna designs for compact mobile terminals, it is possible to improve the reflection efficiency by reducing the loss generated in the chassis itself. Especially, with antennas that use inner substrate as GrouND (GND), the size of GND changes based on how each base plate is connected, as well as whether the chassis is opened or closed, which significant impacts antenna performance.

For this multiband antenna, in order to overcome these problems without making the design remarkably complex; an approach was taken whereby the mobile terminal switches to and uses an appropriate matching circuit for each frequency, thus eliminating the deterioration factors posed by the chassis and ensuring that stable performance is achieved.

4.3 Influences from Human Bodies

When considering the actual FOMA terminal usage conditions (e.g., speech mode, data mode), it has been noted that the user's body absorbs some of the power emitted from the antenna, thus contributing to the deterioration of antenna performance. Moreover, communication devices used near the temporal regions of human beings must satisfy the local Specific Absorption Rate (SAR)[*11] standard values, which are guidelines for protection against radio waves.

Most antennas adopted by existing FOMA terminals are implemented as part of the hinge mechanism[*12]. This is also assumed to be the case for multiband mobile terminals, thus lessening the influence of human bodies. The following specific

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[*11] SAR: The fraction of electromagnetic waves emitted from a mobile terminal that is absorbed by a human body.

[*12] Hinge mechanism: A structure that connects two parts together and allows opening and closing, just like a hinge. Also used in folding-type mobile terminals.

optimization methodologies were used, although the actual effects depend on the chassis design in question.

1) Optimization of layout and positioning of antenna elements when forming the antenna
2) Implementation of sub-antennas for supplementing main multiband antenna performance and associated selection control

For methodology 1), we mainly considered the actual usage environments and conditions under which mobile terminals are held by users, and then optimized antenna performance with respect to the amount of deterioration in order to strike a good balance between both conditions. Methodology 2) was implemented to complement main antenna performance under various particular usage conditions. By adopting both methodologies, we were able to reduce the influence from human bodies under actual usage conditions for both speech mode and data mode in multiband mobile terminals.

5. Conclusion

This article described the transceiver and antenna configuration of multiband mobile terminals. The construction of these multiband mobile terminals enables the distribution of traffic to multiple frequency bands. This technology makes it possible to use the optimal frequency bands for a given situation, ranging from heavy traffic areas such as urban districts to light traffic areas such as mountainous regions, and thus a significant improvement in user convenience can be expected.

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