Base Station | Antenna | Multi-band

Technology Reports

Five-band Base Station Antennas for Introduction of 700 MHz Band Services

The 700 MHz band has recently been allocated to handle the rapid increases in mobile communication traffic. Space limitations make it difficult to add new antennas where current base stations are installed, so antennas able to accommodate multiple frequency bands with weight and size similar to the existing antennas have become necessary. With multi-band antennas, radiation pattern distortion due to coupling between different band elements is an issue. NTT DOCOMO has developed five-band base-station antennas, introducing a proprietary radiation pattern-improving technology. These antennas will simplify coverage expansion that includes the 700 MHz band.

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1. Introduction

With the rapid spread of smartphones and tablets in recent years, mobile communication traffic is increasing dramatically. To handle this, the 700 MHz band was allocated for mobile communications on June 27, 2012.

On the other hand, to handle high traffic demand, mobile communication base stations have been installed with high density in urban areas. In particular, they are installed every two to three-hundred meters in downtown business and shopping areas with very high traffic. Most base stations in central-city areas are installed on the roofs of ordinary buildings such as offices or apartments, so space for base station equipment and antennas is limited and there is no room to install additional antennas. Base station antenna location is also closely related to the service area, so the possible locations are limited. For these reasons, multi-band base station antennas that accommodate the bands already in service as well as the new band are needed, rather than installing additional antennas for the new band [1]. Such antennas must be designed with weight and size similar to the existing base-station antennas [1]-[3], and with consideration for Passive InterModulation (PIM)*1, since they will be sending and receiving in multiple frequency bands.

Due to these requirements, we have developed new, five-band base station antennas, adding the 700 MHz band to the 800 MHz, 1.5 GHz, 1.7 GHz and 2 GHz bands already in service. With these antennas, we introduce a proprietary DOCOMO radiation pattern improving technology [4][5]. This reduces the coupling among different frequency band elements, which is an issue with multi-band antennas, and enables implementation with size similar to the earlier antennas. In addition to the low-PIM design of the antennas, we have proposed a PIM evaluation method [6] and used it to ensure that the degradation in reception characteristics due to PIM is below a specified value. This is the first implementation of five-band antennas

*1 **PIM**: Distortion occurring when two or more frequencies are input and frequencies other than the input frequencies are produced due to nonlinearities.

for mobile communication systems within Japan, and it has facilitated building areas that include the 700 MHz band.

In this article, we describe an overview of these five-band base station antennas.

2. Antenna Lineup

As shown in **Figure 1**, NTT DOCOMO has developed several base station antennas, considering various traffic and usage scenarios such as indoor or outdoor, enabling us to design optimized areas. For outdoors, there are omni-directional base station configurations, able to create a single area 360° around the base station, as well as sector base station configurations, which divide the 360° around the base station into multiple units called sectors. Omni-directional base stations are used mainly in areas where traffic is low, while sector base station configurations are used in urban and other areas where traffic is high. In particular, NTT DOCOMO uses six-sector configurations as well as three-sector configurations to implement adequate communications in environments with high traffic. The base station antennas described here are used for sector base station configurations.

3. Development of Five-frequency Base Station Antennas

3.1 Requirements and Antenna Structure

1) Requirements

As discussed in section 1, installation space limitations and other factors made it necessary to design antennas with the same size as the antennas currently installed, and accommodating the 800 MHz, 1.5 GHz, 1.7 GHz, and 2 GHz bands already in service as well as the new 700 MHz band. The specifications for the five-band base station antennas developed for these conditions are summarized in **Table 1**.

2) Antenna Structure

An example structure of a five-band base station antenna is shown in **Figure 2**. To realize the desired radiation pattern*2 in the vertical plane, antenna elements are placed vertically at set intervals and the amplitude and phase in each element are controlled by a phase-shifter*3[7]. Two different types of antenna element are used; one for the 700 and 800 MHz bands, and one for the 1.5, 1.7 and 2 GHz bands; and each type are placed at the optimum element spacing. If only a single type of antenna element that can accommodate all five bands is used, the spacing for vertically aligned 2 GHz band elements is 2.6 times larger than for 700 MHz band elements when normalized to wavelength of each frequency band. As a result, if the antenna was designed for a 700 MHz band

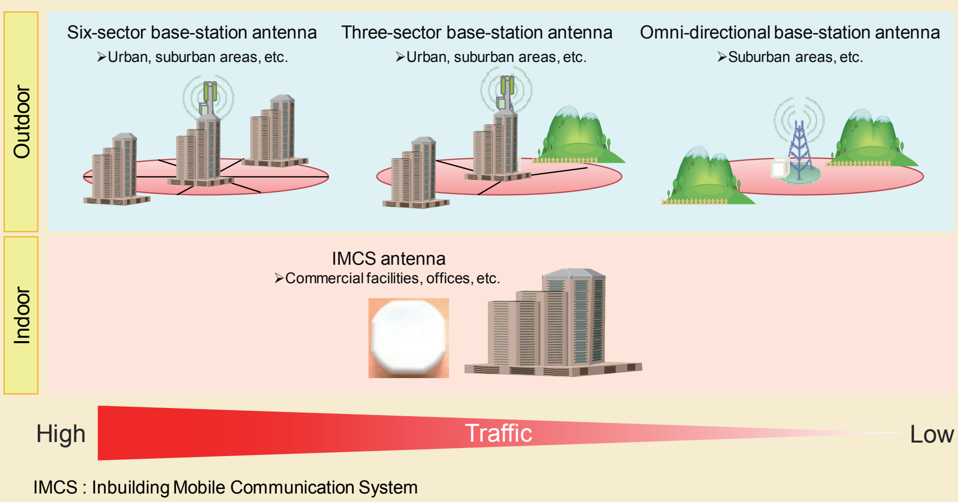

Figure 1　Base station antennas

*2 **Radiation pattern**: Expresses the strength of radio waves radiated in different directions.

*3 **Phase-shifter**: A circuit that can change the phase going to each antenna element.

wavelength, the radiation pattern of the 2 GHz band in the vertical plane would be significantly degraded, increasing interference in the direction of neighboring cells*4.

To realize the desired radiation pattern in the horizontal plane, a reflector is placed behind the antenna elements [7]. If the radiation pattern in the horizontal plane is too narrow, there will be coverage holes in the area. If it is too wide, it will interfere with neighboring sectors, so the size and shape of the reflector and antenna element are designed with consideration for the number of sectors and service area for each frequency band. Design of this radiation pattern in the horizontal plane was an issue in creating the five-band antennas, and it was resolved using a proprietary technology to reduce coupling between bands.

Table 1　Five-frequency base-station antenna requirement specifications

Sectors	Three sector	Six sector
Frequencies	700 MHz band (728-793 MHz) 800 MHz band (830-890 MHz) 1.5 GHz band (1,448-1,511 MHz) 1.7 GHz band (1,765-1,880 MHz) 2 GHz band (1,940-2,150 MHz)	
Polarization	Horizontal/Vertical polarization	
VSWR	1.5 or less	
Gain	15.5–18dBi	
Size	Length: 2,700 mm or less Diameter: 200 mm or less	Length: 2,400 mm or less Diameter: 300 mm or less

Polarization: Direction of electrical field plane relative to ground plane
Voltage Standing Wave Ratio (VSWR): A value expressing the ratio between a propagating wave and the reflection. The smaller the VSWR value, the better the power efficiency.

3.2 Technology to Decrease Coupling Between Different Band Elements

1) Radiation Pattern Distortion in the Horizontal Plane

As described above, the antennas are

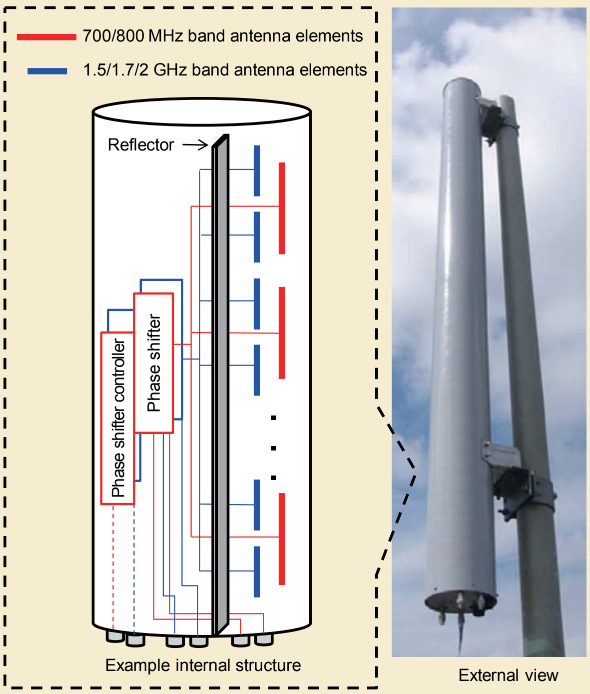

Figure 2　Example configuration for a five-frequency base-station antenna

*4 **Cell**: The smallest unit of area in which transmission and reception of wireless signals is done between a cellular mobile communications network and mobile terminals.

composed of two types of antenna elements, one for the 700 and 800 MHz bands, and one for the 1.5, 1.7, and 2 GHz bands. Since the antenna diameter is limited, these two types of elements must be placed close to each other. To understand the radiation pattern in the horizontal plane in such conditions, we conducted computer simulations such as the example shown in **Figure 3**. As shown in the figure, the results indicated that significant undesired 2 GHz band current is produced on the 700/800 MHz band element, and this clearly distorts the 2 GHz radiation pattern in the horizontal plane. With this analytical model, the radiation pattern is expanded, and can cause problems such as increasing interference in neighboring sectors.

2) Proposed Technology

We have proposed two structures [4] [5] for the 700/800 MHz band elements, as shown in **Figure 4**, to improve the radiation pattern distortion described above. These techniques reduce the undesired 2 GHz band current flowing on the 700/800 MHz elements, as shown in the figures, and make it possible to achieve the same radiation pattern as if

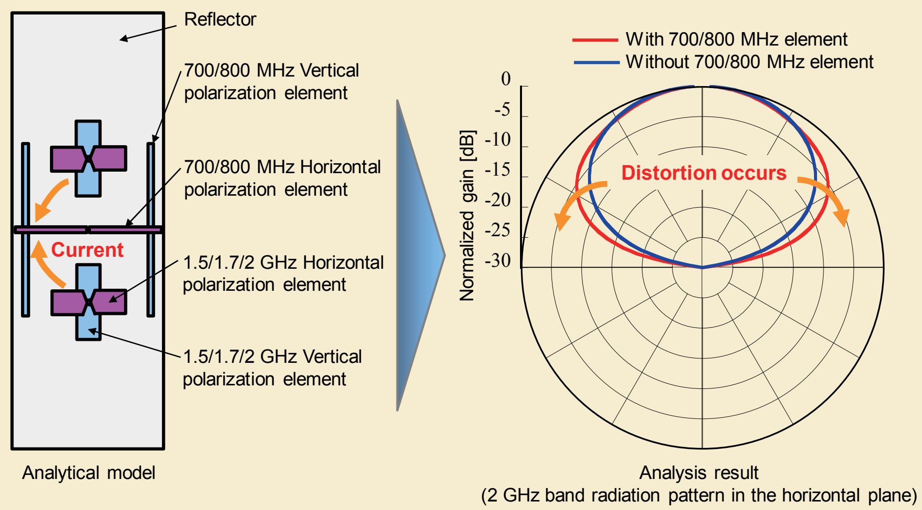

Figure 3 Example analysis of radiation pattern in the horizontal plane

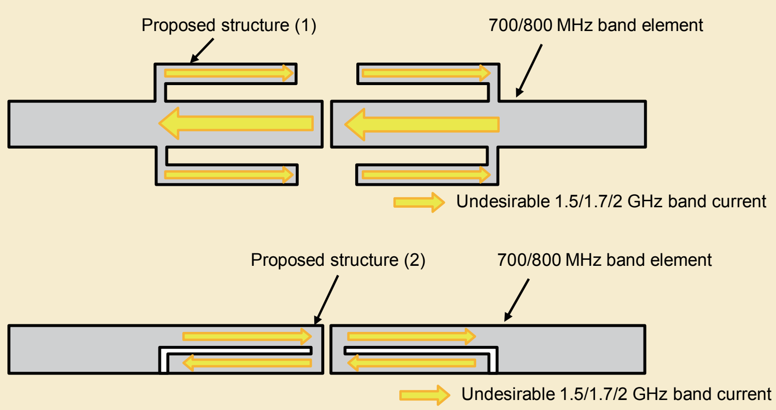

Figure 4 Proposed structures to improve distortion in radiation pattern

the 700/800 MHz band elements were not there.

Another way to improve radiation pattern distortion would be to add metallic structures called parasitic elements*5[3]. However, as more frequency bands are added, the number of frequency bands needing radiation pattern improvement increases, so the design parameters increase and the structures become more complex. The proposed technique is simpler than the conventional approach because only a few changes in antenna structure are needed. Structure (2) in Fig. 4 was adopted for the five-band base station antennas.

3.3 Evaluation Method for Implementing Low PIM Antennas

1) PIM Occurrence in Multiband Antennas

When more than one frequency is input to a base station antenna, distortion in other than the input frequencies, called PIM, is generated due to non-linearities*6 in the antenna. For example, when transmitting two frequencies, f_1 and f_2, 2nd order PIM frequencies at $f_1 \pm f_2$ and 3rd order PIM frequencies at $2f_1 \pm f_2$ are generated. When transmitting three frequencies, f_1, f_2 and f_3, 3rd-order PIM frequencies from $f_1 \pm f_2 \pm f_3$ occur. Generally, the lower the order*7 of PIM generated, the higher their level, but they are 100 dB or more below the transmission power level. However, the level of received signal from mobile terminals is similarly very low, so if PIM occurs in the reception band, reception characteristics can be degraded if the level of PIM is not sufficiently suppressed [8].

The probability that PIM will occur in the reception band increases dramatically as the number of transmission frequencies increases, as is the case with the five-band antennas. More specifically, **Table 2** shows combinations of transmission frequency bands that result in PIM for NTT DOCOMO's five-band base station antennas. Note that this table only considers the three types of combinations described above: $f_1 \pm f_2$, $2f_1 \pm f_2$ and $f_1 \pm f_2 \pm f_3$. From the table, for example, if three bands; 800 MHz, 1.7 GHz and 2 GHz, are being multiplexed, only a combination of two transmission frequencies in the 800 MHz band generates PIM in the 1.7 GHz reception band, but when transmitting five frequency bands at the same time, PIM occurs in three reception bands: 800 MHz, 1.7 GHz and 2 GHz. Thus, we have found that it is even more important to consider lower PIM in the design.

2) Example of Measures to Reduce PIM

Normally, base station antennas are composed of linear elements, and non-linear elements such as diodes are not used. However, discontinuities such as contact points in cable connectors and between different types of metal produce non-linearity. Thus, to design for reduced PIM, we reduced non-linearities in the antenna by eliminating cable connectors and increasing contact-point area between metals to distribute the current.

3) Evaluating PIM Level

It is necessary to evaluate the effect of PIM on reception characteristics, and to ensure it is below a specified value before the antennas are shipped. It would be desirable to be able to connect the antenna to the base station equipment and directly evaluate the reception characteristics, but this is difficult to achieve in a product line due to the scale of the test equipment and amount of measurement work it would require. The amount of degradation in the reception characteristic can also be calculated if a PIM distribution

Table 2 Frequency bands where PIM occurs and combinations of transmission frequency bands

Frequency bands where PIM occurs	Transmission frequency bands
Occurring in the 800 MHz reception band	Transmitting in 1.5 and 2 GHz bands simultaneously.
Occurring in the 1.7 GHz reception band	Transmitting in the 800 MHz band
	Transmitting in 700 and 800 MHz and 1.7 GHz bands simultaneously.
	Transmitting in 1.5, 1.7 and 2 GHz bands simultaneously.
Occurring in the 2 GHz reception band	Transmitting in 700 and 800 MHz and 1.7 GHz bands simultaneously.

*5 **Parasitic element**: Elements placed near the feeding antenna elements but not directly fed themselves, which contribute to emission of radio waves.

*6 **Non-linearity**: When the output level does not change with constant slope relative to the input level. Materials used as linear circuits also have small amounts of non-linearity.

*7 **Order**: The number of combinations of input frequencies producing intermodulation distortion. For example, if it occurs for $mf_1 \pm nf_2$, the order is m+n.

caused by transmitting modulated signals the same as an actual transmission from base station equipment and spread out in the reception bands [9] [10] is observed as shown in **Figure 5**. However, the PIM level itself is very low and the reception sensitivity of measuring instruments is lower due to the wide observation bandwidth, so this approach is also difficult to achieve. Accordingly, we focused on the fact that PIM level can be measured with relative ease when Continuous Wave (CW)*8 signals are transmitted. We proposed a method to measure this PIM level produced by CW signals to estimate the PIM level occurring in the reception bands when transmitting modulated signals, and validated the method [6]. We have used this simple CW measurement method to ensure that the degradation on the reception characteristic due to PIM is below a specified level.

3.4 Reducing Cables between Antenna and Base Station Equipment

Different Radio Equipment (RE)*9 for each frequency band is connected to the five-band antennas, so the number of Radio Frequency (RF)*10 cables increases as the number of bands increases. For the current, five-band antennas, if the frequency multiplexers*11 were integrated into the antenna, ten RF cables and ten input terminals (five frequency bands, two polarizations) would be required on the bottom end of the antenna, as shown in **Figure 6**. This caused concern over the feasibility of securing space to install the RF cables from antennas on the top of towers down to the RE on the roof below, so frequency multiplexers were placed in separate cabinets near the RE to reduce the number of cables installed between the rooftop and the top of the tower by 60%, to four (700/800 MHz band and 1.5/1.7/2 GHz band, two polar-

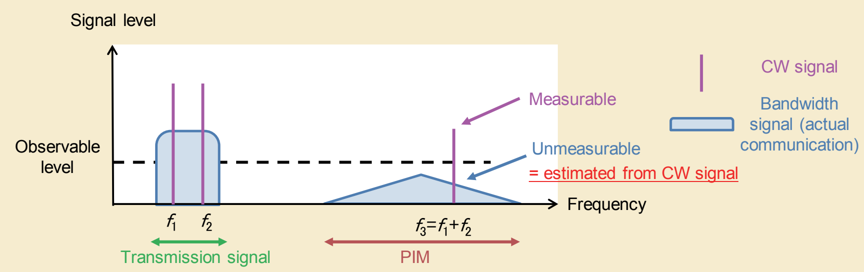

Figure 5 PIM generated with CW signal and bandwidth signal

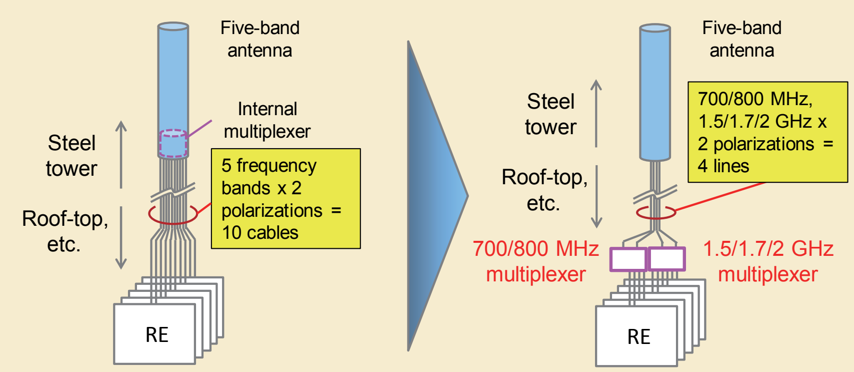

Figure 6 Relation between multiplexer installation and number of cables

*8 **CW**: Unmodulated continuous wave. The signal does not change, so measurements are easier to take.

*9 **RE**: Radio equipment installed at a location remote from the base station by using optical fiber or other connection.

*10 **RF**: High-frequency bands used for radio communications and other applications.

*11 **Multiplexer**: A device which combines the transmission signals from the RE for each frequency band, and separates the received signal from the base station antenna into each of the frequency bands.

izations each). This improves feasibility and reduces the cost of antenna installation.

4. Conclusion

This article has given an overview of the first five-band base station antennas developed in Japan and described technology to reduce coupling among different frequency band elements, initiatives for reducing PIM, and a method for evaluating PIM. This antenna will make it easier to create areas that include the 700 MHz band, helping to expand communications areas further, and improve communications quality.

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