Ultra-Compact Chip Antenna for the 2.4~2.5 GHz Band

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ABSTRACT Recently the development of information-intensive society around us is quite remarkable, making many innovative systems indispensable for our daily lives. There are, e.g., the explosive development and diversification of mobile phones, wireless communications technologies and car navigation systems for automobiles, and the domestic penetration of short-distance wireless communications equipment that are in conformity with Bluetooth or IEEE 802.11a and 11b. Antenna is one of the key components supporting the wireless technologies. Furukawa Electric has developed a high-performance ultra-compact chip antenna for the 2.4~2.5 GHz band. The antenna features the use of a functional resin material for its dielectric, and has been confirmed to be suitable for mass production ensuring high long-term reliability.

1. INTRODUCTION

Wireless communications in conformity with Bluetooth, IEEE 802.11b, etc. are generally used for handing over of data between various electronic equipment such as notebook PCs, mobile phones, headsets, PDAs (Personal Digital Assistant), and digital cameras. For wider acceptance of these equipment by society, it is necessary to make them small in size and low in cost.

In response to these needs, Furukawa Electric has succeeded in developing an antenna, one of the key components for communication equipment, based on the long-fostered core technologies of high-permittivity thermoplastic resins and high-conductivity, high-strength copper alloys for leadframes. This paper reports on the characteristics of this ultra-compact chip antenna.

2. DEVELOPMENT TASKS OF COMPACT CHIP ANTENNA

Development tasks for this antenna are described below.

2.1 Downsizing of Antenna

The role for an antenna is to radiate high-frequency energy generated in electronic circuits into the space as electromagnetic waves, and, vice versa, to gather electromagnetic waves in the space converting them as high-frequency energy into the electronic circuits. Thus a resonant antenna that resonates at a specific frequency is very efficient since it can induce large currents in the circuit.

The wavelength at 2.45 GHz is calculated to be about 12 cm, so that a linear antenna that resonates at this frequency to induce a large current has to have an element 12 cm in length, or at least 3 cm for a quarter wavelength. When an antenna is to be used, however, in mobile equipment such as mobile phones, headsets, and PDAs, it should be as compact as possible in order to save space and improve design flexibility.

2.2 Omnidirectional Radiation and High Gain

The intensity of electromagnetic wave radiated from an antenna changes, even at the same distance from the antenna, according to the direction. This is called directivity of antenna. The directivity of an antenna for mobile applications should be omnidirectional, since the direction of reception or transmission depends on the use conditions of the mobile equipment.

Mobile equipment such as mobile phones, PDAs, and notebook PCs are carried around everywhere, so that low power consumption is one of the important characteristics of these equipment. Accordingly, every electronic component used should be as low as possible in power consumption. Antennas are also required to efficiently radiate electromagnetic waves using small power, i.e., to have a high radiation gain.

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2.3 Broad Bandwidth

Basically the bandwidth of an antenna decreases as its size is reduced. When mounted on equipment, the resonant frequency of an antenna changes through the influence of the environment. Thus narrow bandwidth raises a practical problem of difficult adjustment. Mobile equipment of today are rapidly increasing their mounting density accompanied by size reduction, requiring every component to be small in size. Consequently, it is essential that the downsizing of an antenna is done while maintaining its wide bandwidth so as to cope with frequency changes due to influence of the mounting environment.

2.4 Cost Reduction

Recently communications equipment are coming down in price day by day. It is necessary therefore that our products meet the customers' needs for cost reduction, satisfactorily maintaining stable performance and mass producibility.

3. PRODUCT FEATURES

Features of the antenna developed here will be described in detail below.

3.1 Antenna Structure

Figure 1 shows an appearance of the antenna and Figure 2 its outer dimensions. Whereas it is generally said that an antenna size should be a quarter wavelength, the size of the antenna developed here is no more than one-tenth wavelength.

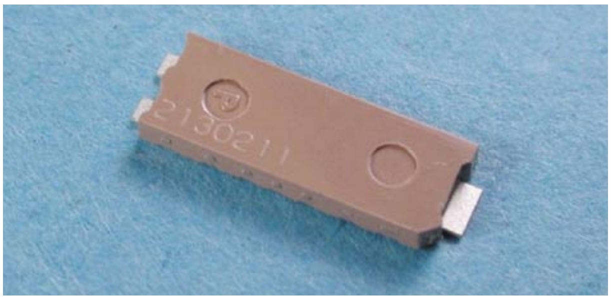


Figure 1 Appearance of antenna.

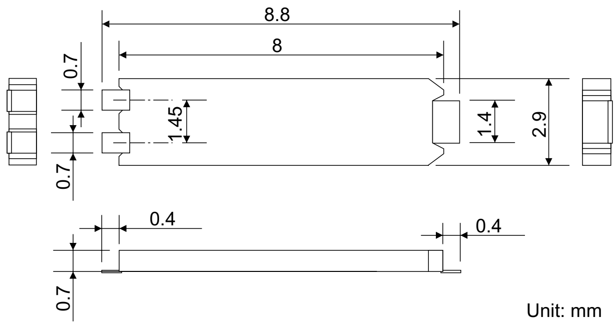


Figure 2 Outer dimensions of antenna.

Table 1 Comparison of antenna volume.

Resin	Antenna volume
Conventional (permittivity=3)	50.40 mm^3
New resin used here	16.24 mm^3

The materials employed in the antenna structure are as follows.

To increase the efficiency of an antenna, the electrical conductivity of antenna's radiation circuit should be improved. We have employed a high-conductivity copper alloy for leadframes as the conductor, and sheathed it using a high-permittivity thermoplastic resin that the company has proprietarily developed.

Table 1 shows a comparison of antenna volume between the resin used here and the one having a permittivity of three. It can be seen that that the antenna volume has been reduced to about one third. Meanwhile, the thermoplastic resin used here has both heat resistance and heat-and-humidity resistance sufficient for in-vehicle use in automobiles, thereby making the antenna available for all application environments.

Moreover, the antenna uses lead-terminal structures unlike conventional ceramics chip antennas. This lead-terminal portion relaxes the stress caused by the expansion and contraction due to the difference in thermal expansion coefficient between the resin and mounting board, thus improving the reliability of soldered joints after surface mounting. This provides the product with superior resistance against heat shock.

In addition, whereas much has been talked about environmental issues globally in recent years, these issues have to be taken into consideration with regard to electronic components also. Therefore, in response to such environmental issues, we have adopted a 100 % Sn-plating for the lead-terminal portion, thus realizing Pb-free plating.

3.2 Radiation Characteristics

As mentioned previously, the antenna developed here has adopted a structure such that, in order to obtain high-efficiency as well as ominidirectional directivity, the high-conductivity conductor is sheathed using a high-permittivity thermoplastic resin that the company proprietarily developed. A special meander configuration was adopted for the conductor that significantly influences radiation characteristics. A variety of conductor configurations were evaluated confirming that such factors as the aspect ratio of capacitive loading element and the spacing and layout of wires strongly influence the characteristics. Subsequently basic design was carried out using simulation techniques to determine the optimized meander configuration. Figure 3 and Figure 4 show an electric field distribution and radiation directivity, respectively, both are the results of simulation.

Measurement results of antenna characteristics will be described next.

Figure 5 shows the reference board for antenna

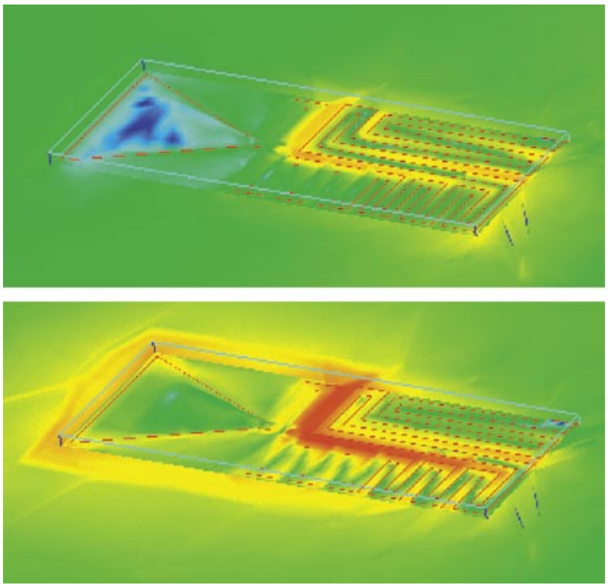


Figure 3 Typical electric field distribution.

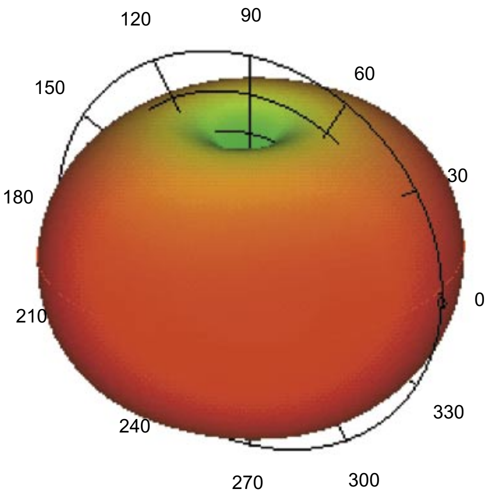


Figure 4 Typical radiation directivity.

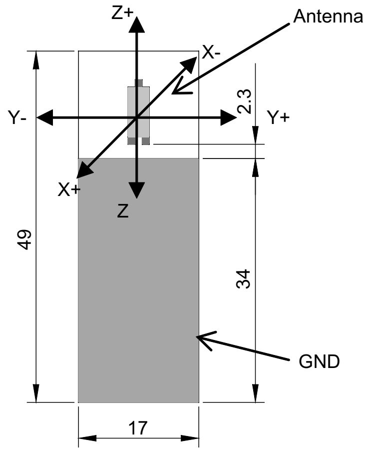


Figure 5 Schematic of reference board for evaluation of antenna together with antenna layout.

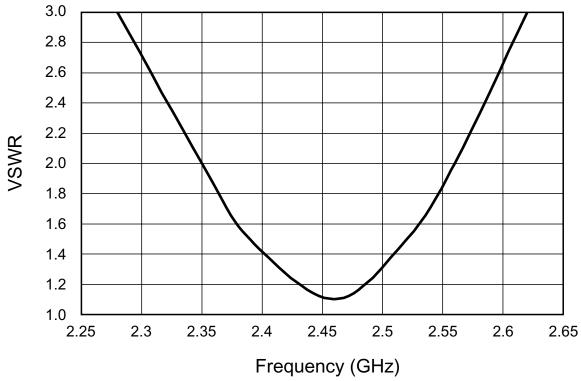
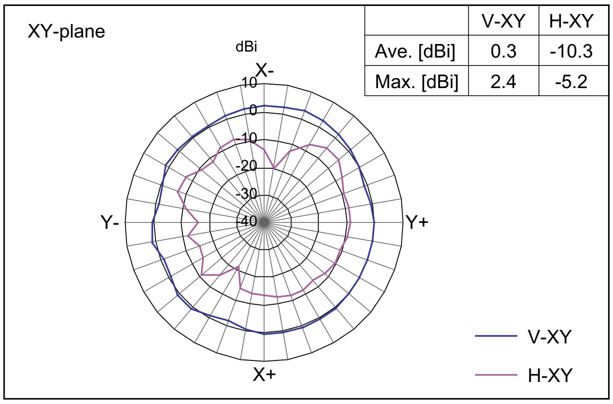


Figure 6 VSWR vs. frequency.



	V-XY	H-XY
Ave. [dBi]	0.3	-10.3
Max. [dBi]	2.4	-5.2

Figure 7 Radiation pattern.

characteristics evaluation together with antenna layout, and Figure 6 the result of VSWR measurement. It can be seen that the antenna has a broad bandwidth of more than 200 MHz for a VSWR of 2. This bandwidth is about three times the Bluetooth band of 2400~2480 MHz, so that it is sufficiently broad to assure the standard bandwidth even when subjected to the influences of the casing as well as human body.

Figure 7 shows the results of the gain and directivity measurements. It can be confirmed that the antenna has high gain and omnidirectional directivity, satisfactorily meeting the development tasks.

Meanwhile, the radiation efficiency of the antenna is assuredly 70~80 %.

3.3 Feeding Configuration

It is desirable that the antenna has sufficient flexibility, although it is under the severe constraint of equipment design, in mounting on the equipment. The antenna developed here has been designed to enable configuring two types of feeding, i.e., monopole type and inverted-F type, which can be selected at the time of mounting to improve mounting flexibility.

The two types of feeding configuration are shown in Figures 8 and 9, respectively. One of the two terminals is to be used for monopole feeding, and the other for inverted-F feeding. The two types of feeding can be suitably selected according to the form of GND and the relative position of antenna with respect to GND, thereby

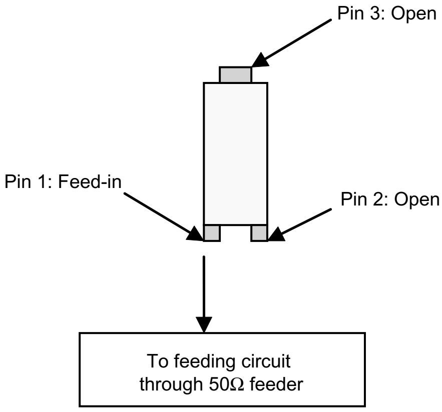


Figure 8 Monopole-type feeding.

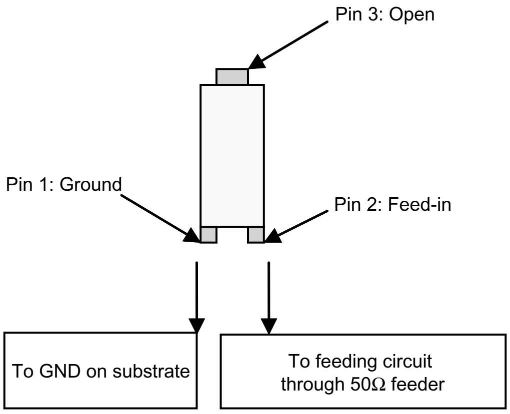


Figure 9 Inverted-F type feeding.

achieving high efficiency. Figure 10 shows the reference board used for feeding configuration evaluation together with antenna layout. Using this board the changes in characteristics of monopole feeding and inverted-F feeding were measured as the distance L between the antenna and GND was changed. Figure 11 shows the relationship between the distance and bandwidth and Figure 12 the relationship between the distance and efficiency, respectively.

Which of the two feeding configuration is more efficient depends on the antenna installation conditions in each equipment, so that adjustment and evaluation should be carried out equipment by equipment for final confirmation.

3.4 Manufacturing Process

The manufacturing process for the antenna developed here is described below.

The process permits continuous manufacturing of the product in the form of hoop on a reel-to-reel basis, covering the patterned sheet conductor, insertion molding into resin, and the final product. Details are as follows.

The patterned sheet conductor is manufactured from a high-conductivity, high-strength copper alloy for leadframes of Furukawa Electric's proprietary material using press stamping. Whereas, as mentioned before, the meander configuration of the radiating conductor significantly influences the characteristics, the accuracy of press stamping is sufficiently high, achieving stable configurations as well as mass producibility.

The patterned sheet conductor thus manufactured is continuously inserted into forming mold, and is sheathed with a high-permittivity thermoplastic resin using injection molding. The resin has a low contraction ratio, and thus contributes to achieving, helped by the dimensional stability of injection molding, a very high degree of dimensional stability in the final products.

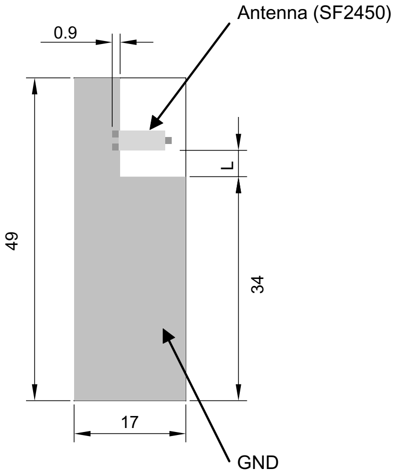


Figure 10 Schematic of reference board for evaluation of feeding configuration together with antenna layout.

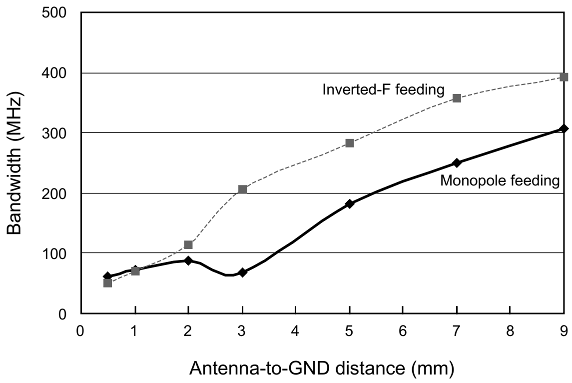


Figure 11 Relationship between bandwidth (VSWR=2) and antenna-to-GND distance.

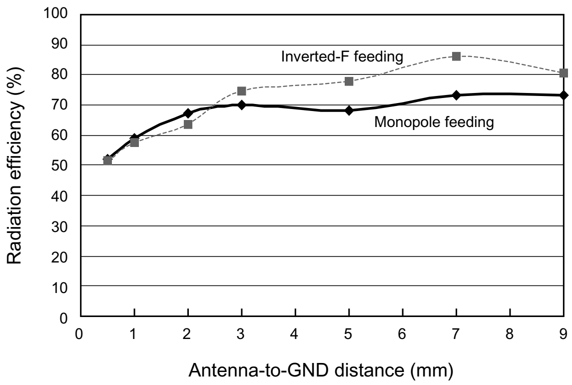


Figure 12 Relationship between radiation efficiency and antenna-to-GND distance.

Table 2 Reliability test conditions.

No.	Test item	Conditions	Time
1	Low-temperature storage	-40°C	1000 hrs
2	High-temperature storage	+90°C	1000 hrs
3	High-temperature and high-humidity storage	85°C·85 %	1000 hrs
4	Temperature and humidity cycling	-25~+85°C	10 cycles
5	Heat shock	-40°C↔+85°C, 30 min each	1000 cycles

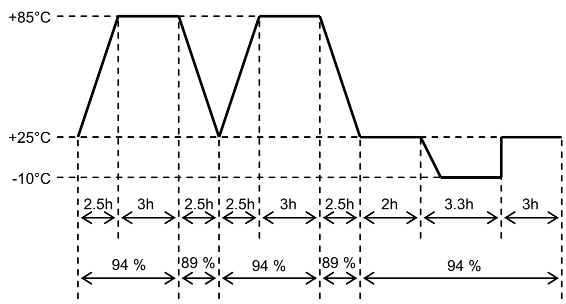


Figure 13 Conditions for heat and humidity test.

At the end of the process, the molded products in the form of hoop are separated one by one and are contained in trays and the like. But they are also available in the form of tape carrier for surface mounting.

To summarize, the manufacturing process for the antenna developed here is a continuous manufacturing method ranging from patterned sheet conductor to injection molding. The process is amply compatible with the current hoop-forming techniques, necessitates no dedicated instruments, has superior mass producibility, and thus enables low-cost production.

4. RELIABILITY EVALUATION

The results of reliability evaluations for the antenna are explained below. The conditions for evaluations are shown in Table 2 and Figure 13. The evaluations were carried out in terms of low-temperature storage, high-temperature storage, high-temperature and high-humidity storage, temperature and humidity cycling, and heat shock. The heat-shock test was preceded by a series of pre-processing comprising a humidity-absorbing process of 85°C/RH85 % × 168 hrs and three repetitions of reflow process at 230°C containing 250°C peaks of 30~40 sec duration.

Table 3 Results of reliability tests.

No.	Test item	Change after test	
		Resonant frequency	Bandwidth (VSWR=2)
1	Low-temperature storage	±1 % or less	5 % decrease or less
2	High-temperature storage	±1 % or less	5 % decrease or less
3	High-temperature and high-humidity storage	±1 % or less	5 % decrease or less
4	Temperature and humidity cycling	±1 % or less	5 % decrease or less
5	Heat shock	±1 % or less	5 % decrease or less

The results of evaluations are shown in Table 3. The electrical characteristics were measured using our proprietary instruments.

As shown in the table, the characteristics scarcely changed after tests, thus confirming that sufficient reliability has been achieved. Meanwhile, initial characteristics before the tests were as follows:

Averaged resonant frequency: 2465 MHz
Averaged bandwidth (VSWR=2): 260 MHz or more

5. CONCLUSION

As explained above, the antenna developed here has a number of features. It is compact, so that a limited space suffices to mount the antenna onto high-density mounted mobile equipment such as mobile phones, PDAs, etc. Because it has a broad bandwidth, it maintains satisfactory characteristics even when its resonant frequency changes under the influence of mounting environment. Thus it is believed that the antenna has many applications for 2.4~2.5 GHz wireless communications equipment.

Using the same manufacturing process, development of various antennas is under way including the main antenna of built-in type for CDMA (Code Division Multiple Access) equipment and multi-band antennas with dual- or triple-band. Based on these new products, we intend to develop our product lineup.