TELEPHONE INTERFERENCE

Portable telephones have become very popular, and their number is increasing rapidly. In North America, in Europe, and in Japan, more than 20% of the population has portable telephones at the time of this writing. The frequencies used by these telephones lie mainly in the 800 MHz to 900 MHz and 1.8 GHz to 1.9 GHz bands. In Japan, the 1.5 GHz band is also utilized. The 2 GHz band will be used for the next, third generation of telephones, which will be capable of being used all over the world because a common worldwide standard will be developed for them. Today, the output power at the antenna terminal is about 0.5 W to 2 W for high-tier telephones and ranges from 10 mW to 500 mW for low-tier telephones.

These telephones are very widely used, and people everywhere are beginning to become aware of telephone interference. This awareness often becomes a social problem, which is then picked up by the news media and further exacerbated.

There are many kinds of portable telephone interference. Interference may be active or passive, and there are many reasons for its occurrence. In this article, telephone interference is classified and explained in accordance with the following categories.

CATEGORIES OF INTERFERENCE

There are several types of interference possible for portable telephones:

1. Interference caused by the nonlinearity of the radio frequency (RF) circuit
2. Interference between the antenna and the RF components
3. Interference between two telephones that are operating very close to each other
4. Interference with the antenna by the human body, causing degradation of sensitivity
5. Interference with the human body owing to its absorption of radiation power

Here each type will be explained briefly.

In type 1, harmonics and spurious signals are generated in the RF circuit by its nonlinearity. To avoid this problem, frequencies, especially in the intermediate frequency (IF) range, need to be chosen very carefully. Sometimes filters are adequate to remove the interference. The telephone designer should consider all harmonics and their combinations.

In type 2, the power radiated from the antenna onto its chassis affects the performance of the RF components. A typical example is a voltage-controlled oscillator (VCO) module. The oscillator circuit is very susceptible to the radiated power from the antenna, as will be explained in detail later. There are two paths over which the radiated power can degrade the component performance. One is a direct path, where the radiated power directly enters the circuit block from the antenna through imperfect shielding. The other is an indirect path, where the power radiated from the antenna is first received by the ground plane and then acts on the circuit block. In this case, the grounding is usually poor.

In type 3, the radiated power from one telephone interferes with another telephone when the two are operating close to each other. Usually, a filter that is part of an antenna duplexer rejects the transmission signal from the other telephone. However, if the distance between two telephones is very short, a strong transmission signal may affect the performance of its counterpart. When the telephone is far from its counterpart, the radiated power is decreased owing to propagation loss. Thus the shortest distance at which a telephone does not interfere with another depends on the attenuation performance of the antenna duplexer.

In type 4, the directivity gain of the antenna is degraded by a human body. In order to optimize its performance, an antenna is usually designed to operate in an ideal free space. However, in a real life situation where the telephone is used, this assumption is false. The human body absorbs the energy transmitted from the antenna, and the radiation pattern and antenna impedances are disturbed. Therefore a practical antenna design must take the body effect into account.

In type 5, the human body absorbs the energy transmitted from the antenna, as mentioned above. Some people are afraid that physical damage can be caused by electromagnetic waves. Many consider them to cause cancer. So far, in spite of many intensive studies, such a relationship has not been recognized medically. However, current technology can calculate a fairly

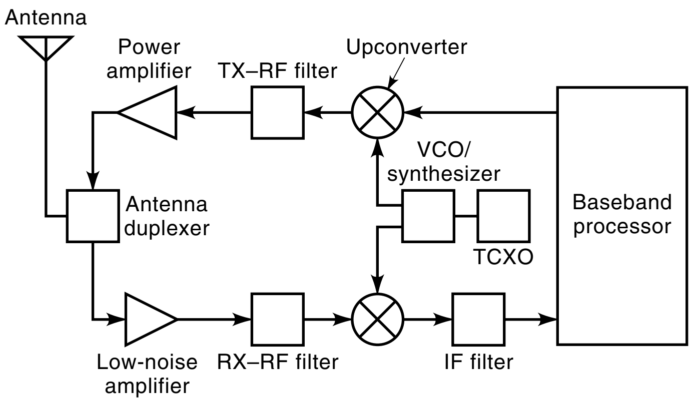

Figure 1. Block diagram of telephone.

exact estimate of the human body's absorption power, and direct measurements are estimated by using a virtual body.

In the following sections, interference and methods of dealing with it will be discussed in detail.

INTERFERENCE CAUSED BY THE NONLINEARITY OF THE RF CIRCUIT

Image-Signal Interference

Figure 1 is a block diagram of the RF circuit of a telephone. The circuit structure is a so-called superheterodyne structure. The frequencies of the receiving and transmitting signals are converted into other frequencies by using a mixer and upconverter. These circuits are usually nonlinear. The principle of frequency conversion is explained as follows. The IF is obtained by utilizing the nonlinearity of a circuit, such as a mixer. The IF is related to the local-oscillator frequency and the received frequency as follows:

$$f_{r\pm} = f_{\mathrm{LO}} \pm f_{\mathrm{IF}} \tag{1}$$

where $f_{r\pm}$ denotes the received signal frequencies, f_{LO} the local-oscillator frequency, and f_{IF} the IF. This means two frequencies could be received by the telephone. This relation is illustrated by Fig. 2.

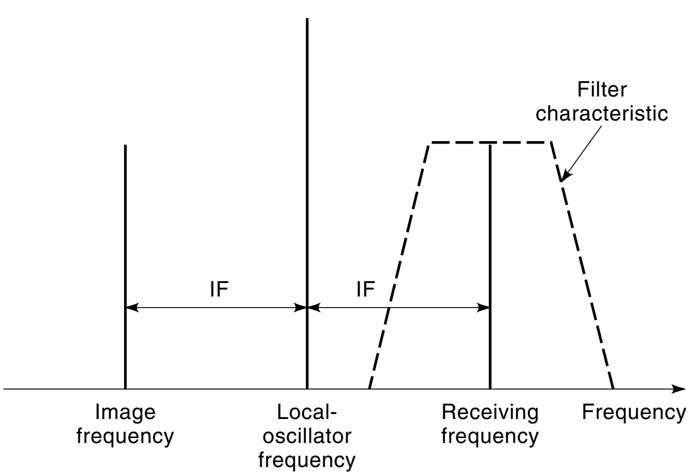

Figure 2. Image interference.

Usually, by using a filter, only one frequency is chosen to be received. The signal not chosen is called the image interference signal. The image interference level depends on the attenuation of the filter. Thus the selection of IF is very important in the suppression of this interference. If the IF is set low, a highly selective filter is required. If the IF is set high, the selectivity requirement is somewhat relaxed.

Spurious Signal Interference

Similar phenomena occur for all the harmonics of signals. Therefore the circuit designer has to consider any possible spurious signals generated by harmonics of all orders and their respective subtracting and adding frequencies expressed by

$$f_s = |\pm m f_1 \mp n f_2| \tag{2}$$

where f_s is the frequency of a possible spurious signal, f_1 and f_2 are the frequencies of signals under consideration (for example, the frequency of the internal oscillator), m and n are arbitrarily selected integers, and $|x|$ expresses taking the absolute value of the operand x.

The designer checks for the spurious signal by using a chart that shows where spurious signals will occur. Usually, it is impossible to avoid all spurious signals. Generally speaking, the higher the order of a harmonic, the lower the incidence of spurious signals. Thus the lower-order harmonics and their related spurious signals need to be considered carefully, and high-performance filters need to be designed to suppress interference.

Countermeasures for Image Interference and Spurious Interference

The use of filters is an appropriate solution for dealing with these types of interference. Recent trends in portable telephone design stress compactness. Thus compact high-performance filters are required. In response to this demand, a laminated planar filter featuring high performance with very small volume has been developed. Figure 3 is a photograph of such a filter, and its performance characteristics are shown in Fig. 4 (1). A large attenuation is obtained near the passband. It is called an attenuation pole and appears as an indentation on the attenuation curve. The attenuation pole near

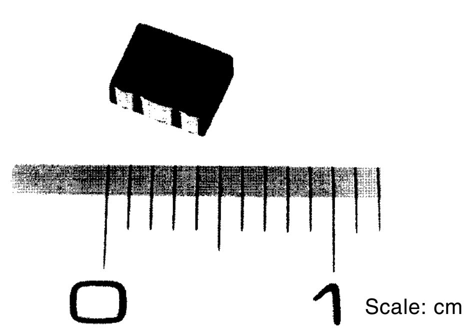

Figure 3. Photograph of laminated planar filter.

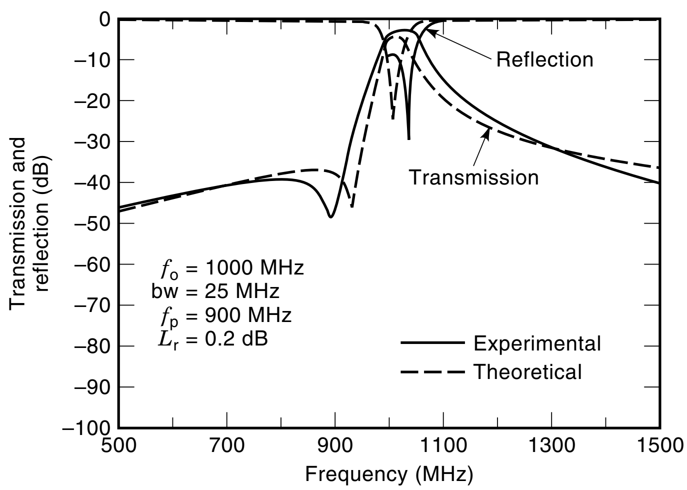

Figure 4. Characteristics of a laminated planar filter (1).

the passband greatly contributes to the suppression of the interference.

Adjacent-Channel Interference

In transmission, the nonlinearity of the circuit, as in the case of a class-AB power amplifier, causes a distortion that turns out to be adjacent-channel interference. This noise interferes with another telephone using the adjacent frequency channel. Figure 5 illustrates adjacent-channel interference noise. The triangles indicate the amount of the interference. To suppress this interference, the circuits must have excellent linearity, both in amplitude and in phase. This interference is inherent in systems that use nonconstant-envelope signals such as QPSK and QAM. It does not occur with FM and GMSK signals. (Regarding the modulation methods, see Refs. 2 and 3.) Therefore the AMPS and GSM systems are free from this interference.

This interference is very similar to the third-order intermodulation distortion. This is the case in Eq. (2), where $m = 2$, $n = 1$, and the $+$ and $-$ signs are selected, or $m = 1$, $n = 2$, and the $-$ and $+$ signs are selected. These distortions are explained in Fig. 6. The distortion signals appear with a frequency spacing of Δ, which equals $f_2 - f_1$. The circuit has to be strictly linear in amplitude and in phase to suppress this distortion.

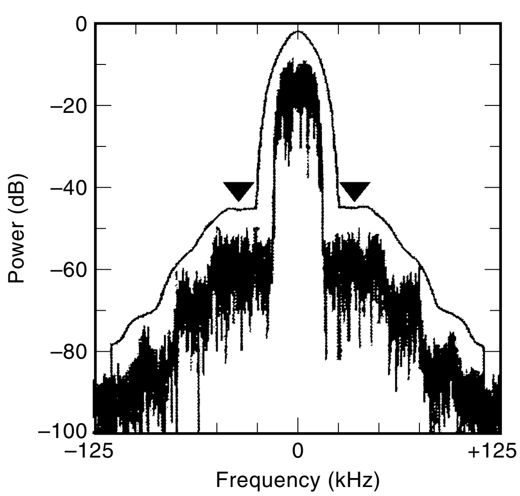

Figure 5. Adjacent-channel interference noise.

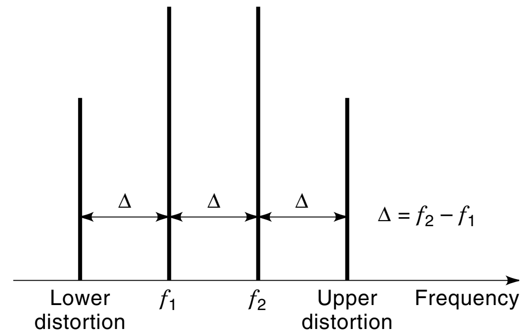

Figure 6. Third-order intermodulation distortion.

INTERFERENCE BETWEEN AN ANTENNA AND THE RF COMPONENT

Two Paths for Interference from an Antenna

The radiated power from an antenna interferes with some RF components inside the telephone. For mass-produced supercompact telephones, this sometimes leads to major problems. A good illustration of this is the VCO. In the case of VCO interference, some undesired modulation is superimposed on the original oscillation, which turns out to be distinctive noise on the modulation signal. Therefore the quality of the transmitted and the received signal is degraded. In digital systems this is equivalent to raising the bit error rate. As mentioned above in the section "Categories of Interference," there are two paths to degrade performance. One is a direct path through imperfect shielding. The other is an indirect path owing to poor grounding. These will be illustrated below.

Interference Caused by Imperfect Shielding

Usually, a VCO is constructed as a compact surface-mounted device (SMD) module. The whole module is covered with a metal cap to prevent interference. However, even a small aperture or a narrow gap may allow an electromagnetic wave to enter, thus acting like a small slot antenna. Even in modular construction it is very difficult to achieve perfect shielding. In the future, VCOs will also be included in RF integrated circuits (ICs). Thus perfect shielding will become more difficult, and the present problem will become even bigger in the foreseeable future.

Interference Caused by Poor Grounding

Ordinarily an RF circuit requires a very large ground plane to ensure stable performance. Since telephone dimensions are becoming ever smaller, this means it is becoming difficult to prepare an effective ground terminal. The area of the ground plane is becoming smaller and is divided into small pieces, which provide insufficient grounding.

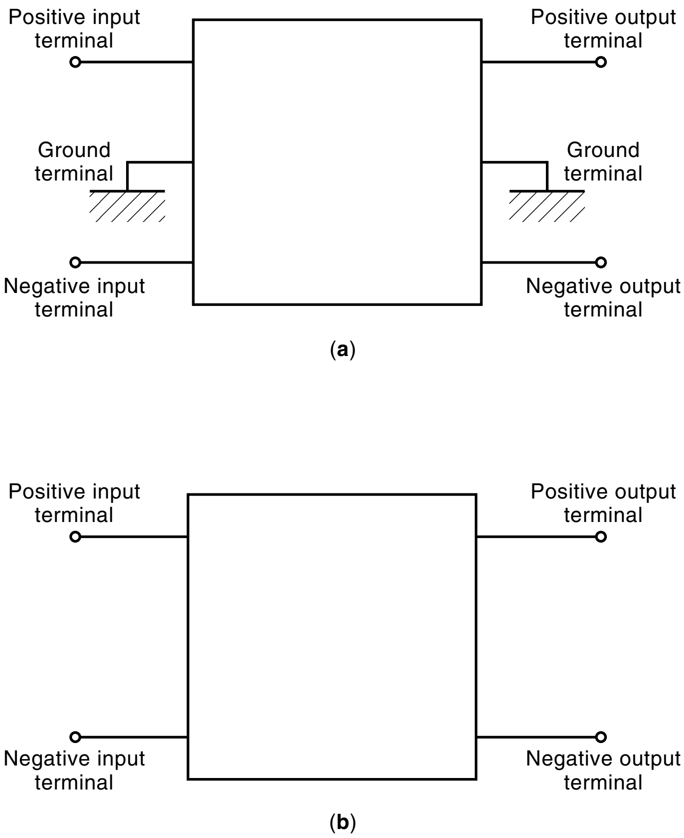

Figure 7. Concept of balanced circuit: (a) conventional balanced configuration, (b) earthless balanced configuration.

Balanced Configuration of the RF Circuit

Figures 7(a) and (b) illustrate the basic concept of the balanced circuit. The conventional balanced configuration has a positive input terminal, a negative input terminal, a positive output terminal, a negative output terminal, and two ground terminals for input and output, respectively. The positive and negative terminals are functioning differentially from each other. Thus the currents at the ground terminals shown in Fig. 7(a) are canceled for the desired signal. So it becomes a virtual ground for the signal. According to this idea, these ground terminals can be removed without affecting the circuit functions. This new concept is shown in Fig. 7(b) as an earthless balanced configuration. It can solve the above problems, that is, imperfect shielding and poor grounding. Generally, the interference is superimposed on the two balanced terminals in phase. It is so-called *common-mode noise.* Common-mode noise can be rejected by differential operation. Therefore this configuration is valid for suppressing the interference, and the method is applicable to various components.

A balanced VCO is an effective way of suppressing common-mode noise. Consider two oscillator circuits connected to ground terminals and placed above and below in opposite phase. They now appear to have mirror symmetry about the ground line as the axis. Here the ground terminals are virtual. This circuit can avoid the effects of poor grounding owing to the differential operation. Some other examples will be presented.

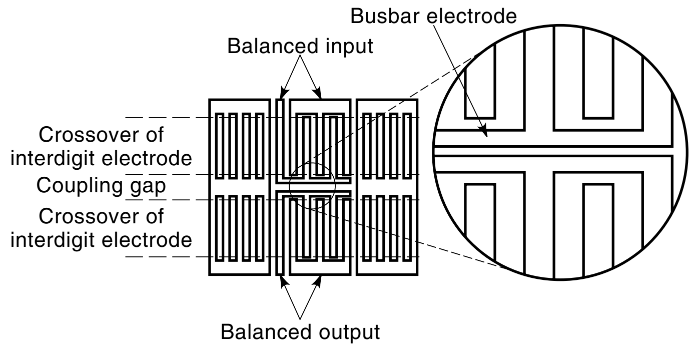

Figure 8. Electrode pattern of balanced IF SAW filter (4).

Balanced IF SAW Filter

Another example is a balanced IF SAW (surface acoustic wave) filter. Figure 8 (4) shows the electrode pattern of a transversely coupled resonator filter. This type of SAW filter has inherently unbalanced input and output terminals. To make this an earthless balanced configuration, some ingenuity was required. The busbar electrode was divided to separate the input and output terminals. This is not easy, because the width of the narrow coupling gap is determined by the filter specification. A new design technique had to be used to determine the busbar pattern.

Figure 9 (4) shows the performances of IF SAW filters. The solid line indicates the balanced filter, and the dashed line the unbalanced filter. The attenuation amounts in the vicinity of the passband are compared. The balanced filter is superior to the unbalanced one. In the case of the unbalanced filter, attenuation is insufficient owing to poor grounding. However, for the balanced filter, virtually perfect grounding is obtained without ground terminals. Therefore ideal performance can be achieved.

Balanced Laminated Planar Filter

Another example is a balanced laminated planar filter. So far, no balanced dielectric filters have been available. The recent

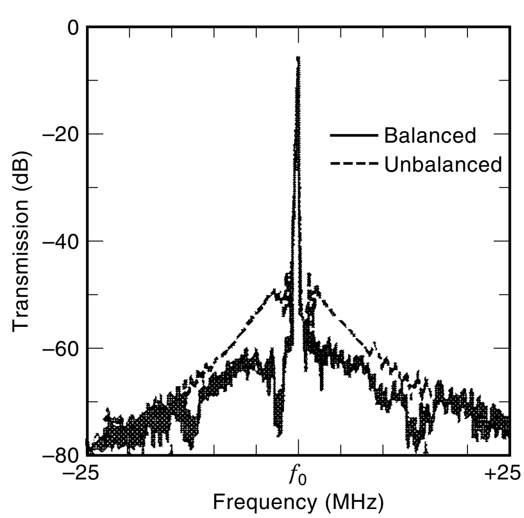

Figure 9. Characteristics of IF SAW filters (4).

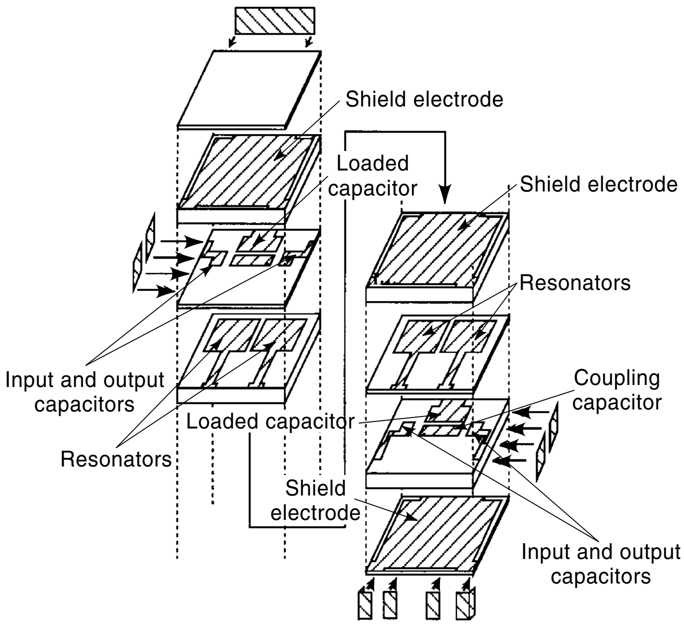

Figure 10. Exploded view of balanced laminated planar filter.

development of the ceramic lamination technique makes such a filter with compact dimensions possible. Figure 10 shows an exploded view of a balanced laminated planar filter. Two quarter-wavelength resonators in different layers are connected at the ends to construct a half-wavelength balanced resonator. The effect is the same as for the above components.

INTERFERENCE BETWEEN TWO TELEPHONES OPERATING VERY CLOSE TO EACH OTHER

Two telephones operating very close can interfere with each other. The radiated power from the antenna of one telephone affects the performance of the RF components of the other. Although this phenomenon is very similar to the interference explained in the preceding section, there is some difference. The interference in the telephone in the previous section is with itself. This means that the transmitting timing never overlaps with the receiving timing. Thus there is no need to consider the direct interference between the transmitter and the receiver. However, the timing of two different telephones is not synchronized. Therefore we have to consider the interference between the transmitter and the receiver. Figure 11 illustrates the relationship between two telephones.

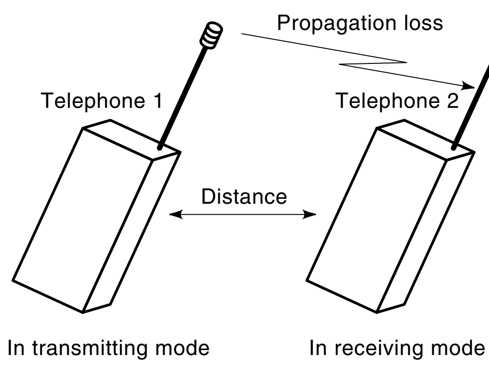

Figure 11. Two telephones operating very close together.

There is propagation loss between two telephones, which depends on the distance between them. This interference becomes a problem only when the two telephones are very close. A few years ago, there was no need to consider such interference, because the number of telephones was small. However, with the increase in the number of telephones in use, this possibility cannot be ignored. Furthermore, the problem will become more serious in the future.

The receiving-band noise that the transmitter generates is a typical example of this interference. The noise generated in the upconverter or modulator is amplified by a power amplifier. It can pass through the receiving filter with small attenuation and appear in the receiver as an interference noise.

At this time, the only effective countermeasure is a high-performance filter with large attenuation. A bandpass filter, a band elimination filter, a low-pass filter, or a high-pass filter is adequate for this purpose.

ANTENNA INTERFERENCE AS A RESULT OF THE HUMAN BODY CAUSING DEGRADATION OF SENSITIVITY

The radiation power from the antenna is absorbed by the human body resistively and/or reactively. The power absorbed resistively becomes an ohmic loss or heat production, which will be explained in the next section. The power absorbed reactively influences the directivity pattern and the antenna impedance. It leads to degradation of the antenna performance. The directivity and the impedance in actual use are different from those designed with a free-space assumption.

There are two different ways to influence antenna performance. One is physical contact, where the current on the telephone chassis is conducted or blocked by hands. The other is noncontact, where the head near the antenna disturbs the directivity pattern.

Figure 12(a,b) (5) shows an outside view and the wire grid model of a diversity antenna. According to this model, we can calculate the current distribution by the moment method. The result of the calculation is shown in Figure 13 (5). As shown in the figure, there is a fairly large current on the chassis. Thus there would be a large effect caused by a human hand. The current on the chassis depends on the size of telephone. Generally speaking, the smaller the telephone, the larger the current. Thus, the smaller the telephone, the more susceptible it is to interference. This is the most important interference problem in the effort to make a supercompact telephone.

INTERFERENCE EFFECTS ON THE HUMAN BODY OWING TO ABSORPTION OF RADIATED POWER

In contrast to the previous section, the human body might be affected by the power radiated from the antenna. There is the possibility of physical damage caused by the electromagnetic wave. The main problem is temperature rise owing to Joule heating. In addition, people are afraid of contracting cancer. So far, although many studies have been done, the relationship between the radiation absorption and cancer has not been recognized definitively. However, many governments have set preliminary rules for the protection of people. The rules are described in terms of the specific absorption rate (SAR), which is defined as the rate of absorption of energy per unit body weight per unit time. Figure 14 is an illustration of

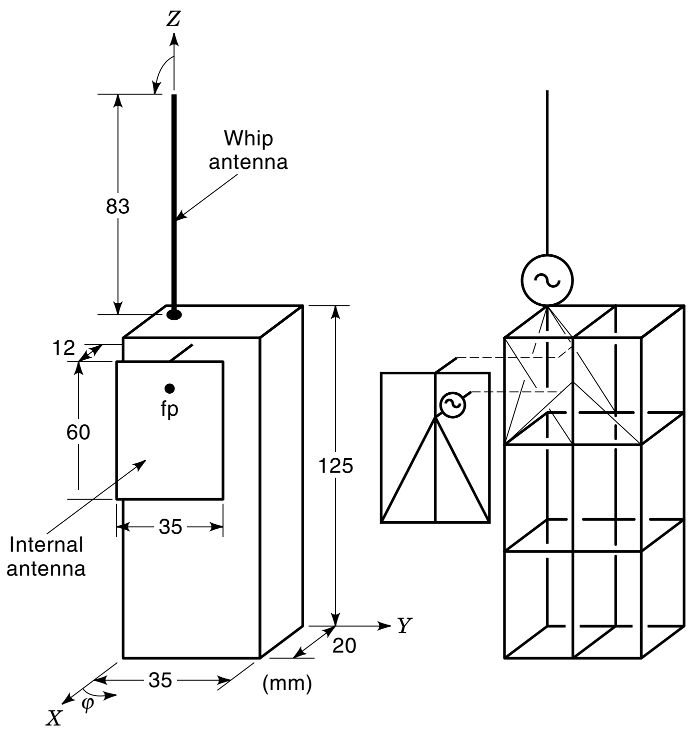

Figure 12. Outside view and wire grid model of diversity antennas (5).

interference with the human body. At this time, many intensive studies are taking place. There are two approaches. One is a numerical simulation approach. For example, the finite-difference time-domain (FDTD) method is a very powerful tool for estimating absorption power. Complicated shapes are easily treated, and excellent accuracy can be obtained in a reasonable time. Another is an experimental approach using a virtual body. The body is exposed to the radiation, and the intensity of the wave is measured by using a miniature probe in three dimensions. A robot arm and a computer are used for measurement. The measurement results are displayed by computer graphics. These studies allow us to analyze what is happening when we are using telephones, and we can visualize and measure telephone interference.

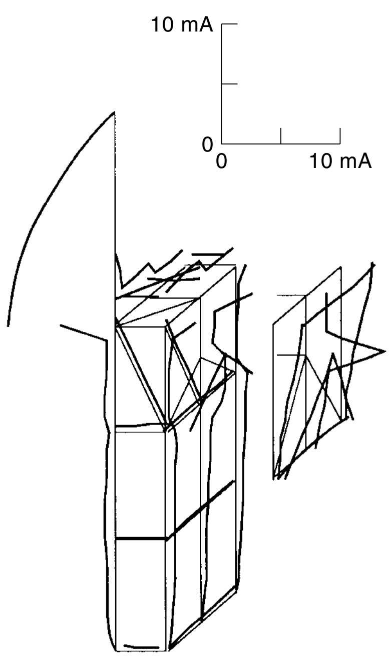

Figure 13. Current distribution on the wire grid (5).

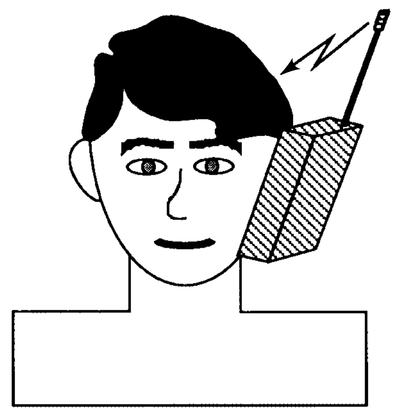

Figure 14. Interference to the human body.

SUMMARY

As we have seen, there are many kinds of telephone interference. There are various reasons for it and various resulting phenomena. Telephone designers are responsible for dealing with some types of interference. Others, such as absorption by the human body, are our own problems, and we must find ways of dealing with them. In the future, the number of telephones in use will certainly increase. Research in telephone interference will continue to be very important. We hope that in the future we shall be able to use telephones more conveniently, more comfortably and more reliably.

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