PAPER Special Issue on Recent Progress in Electromagnetic Compatibility Technology

Method of Predicting Disturbance to TV Signal Reception Caused by Information Technology Equipment

Tetsuya TOMINAGA†, Nobuo KUWABARA†, *and* Mitsuo HATTORI††, *Members*

SUMMARY A method of predicting disturbances to TV signal reception has been developed in order to workout countermeasures for interference caused by unwanted emissions from information technology equipment (ITE). The prediction parameters were determined by measuring the emission levels from ITE at an open test site, propagation characteristics of unwanted emissions from ITE in a building, the output power of the TV transmitting station, the propagation characteristics of the TV radio waves, and the directivity of the TV receiving antenna. The possibility of disturbances occurring in the Kanto area was predicted and the results show that, in the worst case, a disturbance will appear in about 11% of the areas within 30 m of a building containing such equipment. This also shows that the disturbance can be suppressed by improving the shielding of the equipment or building by as little as 10 dB.

key words: *EMC, emission, TV disturbance*

1. Introduction

Radio reception interference is often caused by unwanted emissions from the digital processing circuits in information technology equipment (ITE). The rising speed of digital-signal processing circuits is increasing the likelihood of disturbances.

The IEC started investigations to reduce the disturbances several decades ago. In 1985, IEC/CISPR published limits on the level of unwanted emissions [1] and the publications have since been modified [2]. It is difficult to suppress disturbances perfectly because it would increase the cost of ITE to impractical levels. Thus, CISPR publishes a limit to suppress disturbances in most places. Since disturbances may appear even if the recommended limits are satisfied, specific countermeasures are needed when disturbances [3] do occur.

Being able to predict interference before installing ITE would help reduce the cost and time needed to initiate countermeasures. A method of predicting disturbances was considered in CISPR [2]. It considers the shielding effects of buildings and protection ratio [4], electric field strength of the radio wave, and the actual distance to neighboring buildings. However, we need to predict the area requiring countermeasures, and no method for doing this has been reported yet. In particular, to predict it we need to obtain the relationships between the test levels of ITE and the emission levels from buildings.

In this paper, we describe a method predicting the disturbances area based on ITE emission levels measured at a test site. The conditions that appear disturbances are obtained based on the mechanisms. The electric field strength emitted from buildings was measured for eight environments, and the coefficient between test and emission levels was obtained. The other factors for predicting the area requiring countermeasures were determined from the literature. Using these parameters and factors we predicted the areas in the Kanto region. Based on the results, we discuss the requirement of shielding efficiency to suppress it.

Manuscript received June 29, 1999.
Manuscript revised October 1, 1999.

† The authors are with NIPPON TELEGRAPH AND TELEPHONE CORPORATION Lifestyle and Environmental Technology Laboratories, Musashino-shi, 180-8585 Japan.
†† The author is with NIPPON TELEGRAPH AND TELEPHONE EAST CORPORATION Technical Assistance and Support Center, Musashino-shi, 180-8585 Japan.

2. Conditions for Disturbances to Appear

The mechanism of a disturbance caused by emissions is illustrated in Fig. 1. Unwanted emissions from the ITE pass

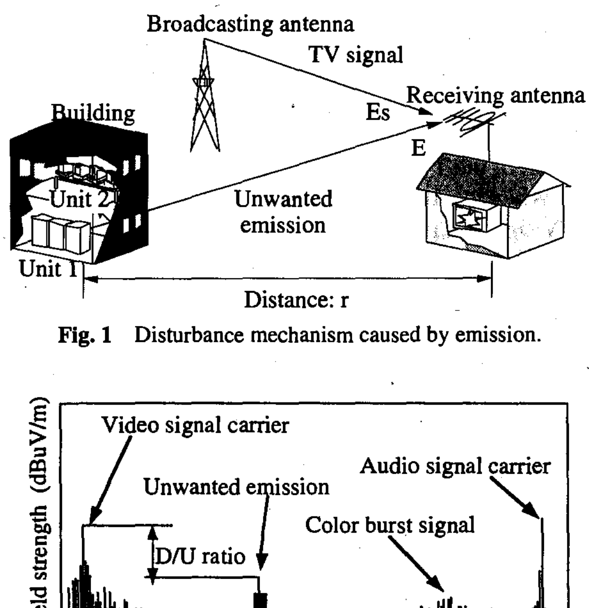

Fig. 1 Disturbance mechanism caused by emission.

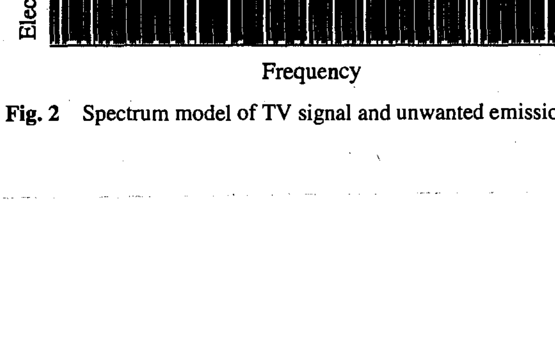

Fig. 2 Spectrum model of TV signal and unwanted emission.

through the wall of the building and are picked up by a nearby TV antenna. A spectrum model of the TV radio wave and unwanted emission is shown in Fig. 2. TV radio waves contain a video signal, a color signal, and an audio signal. When an unwanted signal appears in between the video and audio signals, a disturbance appears on the TV screen.

Equipment emission levels are usually checked at a specified distance, either 3 or 10 m from the ITE, at an open test site [1], [3]. When the equipment is located inside a building, the level of unwanted emissions arriving at the TV antenna after passing through the building wall (as shown in Fig. 1) is given by

$$E(\mathrm{dB}(\mu\mathrm{V/m}))=E_I(\mathrm{dB}(\mu\mathrm{V/m}))-A(\mathrm{dB})-B(\mathrm{dB}), \quad (1)$$

where E is the electric field strength emitted from the building at TV receiving antenna; E_I is the unwanted emission level of the ITE; A is a factor representing the distance dependence of the emission levels that is normalized by the value at the distance where the emission level is measured at an open test site; and B is a factor relating the emission levels at an open test site to the field strength at 3 or 10 m. The level should be sufficient low compared with the wanted signal to suppress the disturbance, as expressed by

$$E(\mathrm{dB}(\mu\mathrm{V/m})) < E_s(\mathrm{dB}(\mu\mathrm{V/m}))-\{DU(\mathrm{dB})+S(\mathrm{dB})\}, \quad (2)$$

where E_s is the desired signal strength at TV receiving antenna; DU is the ratio of the desired to undesired levels; and S is a parameter representing the relationship between the directivity of the TV antenna and the direction of the unwanted emission. A TV antenna has sharp directivity and its angle is tuned to get the best sensitivity for TV signals. Therefore, the received level of unwanted emission is influenced by the angle between the radio wave propagation direction and the emission propagation direction. A TV antenna is at its most sensitive when it is aligned with the direction of the TV radio wave propagation. In this case, S is 0 dB. When the direction of emission is different from that of the TV signal, S is less than 0 dB. This means that the area in which disturbances appear depends on the location of the antenna.

From Eqs. (1) and (2), the condition for no disturbances to appear is given by

$$E_I(\mathrm{dB}(\mu\mathrm{V/m})) < E_s(\mathrm{dB}(\mu\mathrm{V/m})) -\{DU(\mathrm{dB})+S(\mathrm{dB})\}+\{A(\mathrm{dB})+B(\mathrm{dB})\}, \quad (3)$$

where the value of E_I is usually known because the emission level of the ITE should be checked at an open test site prior to installation. Then, the area in which disturbances appear can be predicted from the factors E_s, DU, S, A, and B. The next section describes the method of determining these factors.

3. Determining Prediction Factors

3.1 Distance Coefficient

The factor A represents the distance dependence of the emission levels. It is difficult to calculate because the propagation of the emissions is influenced by the environment around the building containing the ITE and models of emissions from buildings have not yet been developed. Therefore, we determined it by measuring the emission levels around the buildings.

Eight buildings locating the same kind of equipment were selected. The building types and their surrounding environments are shown in Table 1. RC means a reinforced concrete building and ALC means an autoclaved lightweight concrete prefabricated building. Four buildings were in urban areas and the other four were in rural areas. We used frequencies whose levels were sufficiently steady and which had already been measured at an open test site. The VHF TV band is divided into two sub-bands. One from 90 to 108 MHz and the other from 170 to 220 MHz. Therefore, the frequencies were selected within those bands. We measured the electric field strength at each point around each building. An example of the measurement points is shown in Fig. 3.

The system used for measuring the electric field strength is shown in Fig. 4. Measuring equipment was set up

Table 1 Building types and surrounding environment for measuring sites.

No.	Type of building	Environment	Points	Num. of Frequency
A	RC	Urban	11	9
B	ALC	Rural	20	4
C	RC	Urban	10	4
D	ALC	Rural	10	5
E	ALC	Rural	73	4
F	RC	Urban	20	4
G	RC/ALC	Urban	74	5
H	ALC	Rural	12	4

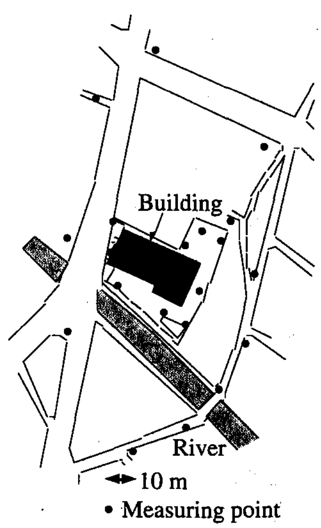

Fig. 3 Example of measuring points.

in a cart to facilitate transportation between measurement locations. The measuring conditions are summarized in Table 2. The measured level was sufficient low because it was lower than that at test sites and the distance was greater than that at test sites. The resolution bandwidth was reduced from 120 kHz to 7.5 kHz to improve sensitivity. The narrowing of the bandwidth did not influence the measured emission level because the selected emissions were narrowband noise.

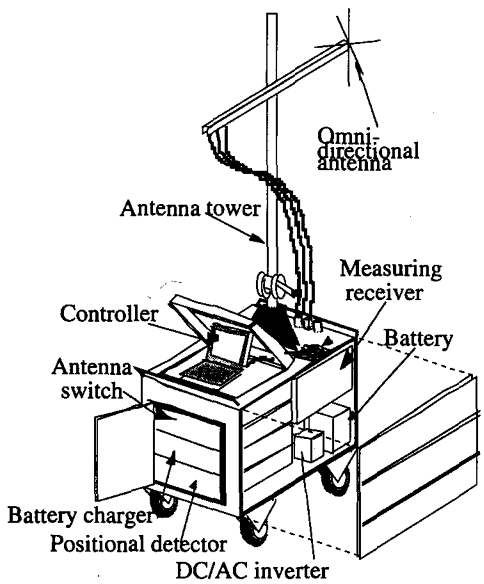

Fig. 4 Measuring system.

Table 2 Measuring conditions.

Resolution bandwidth of measuring receiver	7.5 kHz
Detection mode	Average
Height	4 m
Antenna	Omnidirectional antenna

Electromagnetic field from ITE measured by the antenna differs by the antenna height caused by the interference between direct wave and reflection wave from the ground. The CISPR 22 specifies that the maximum values should be measured when the antenna height is scanned from 1 m to 4 m. We set the antenna height of 4 m because at least one of the peak value exists below 4 m in the frequency band used for TV, the influence surrounding object can be reduced when the antenna height is as high as possible, and the maximum height of our equipment is 4 m. The measured level differs at the measurement position because the antenna height is fixed. So, we obtain the regression line from the data which is measured at the different frequency and point. The receiving antenna was set at 4 m above the ground considering the vehicle-body effect [5].

It was an omnidirectional antenna [6], [7] with three orthogonal shorting dipole antennas. The electric field strength, which is calculated from the output of each dipole, is given by:

$$E = \sqrt{E_x^2+E_y^2+E_z^2}\ , \tag{4}$$

where E_x and E_y are the measured values of the horizontal polarization and E_z is the measured value of the vertical polarization. The polarization of radiated field from ITE changes caused by surrounding conditions. The deviation of the absolute value of the electric field vector presented in Eq.(4) is smaller than that of the absolute value of the horizontal or vertical electric field vector. So, we used the absolute value of the electric field vector as the field strength. Since the value is lager than the absolute value of the horizontal and vertical electric field vector, The severer level can be evaluated using this value.

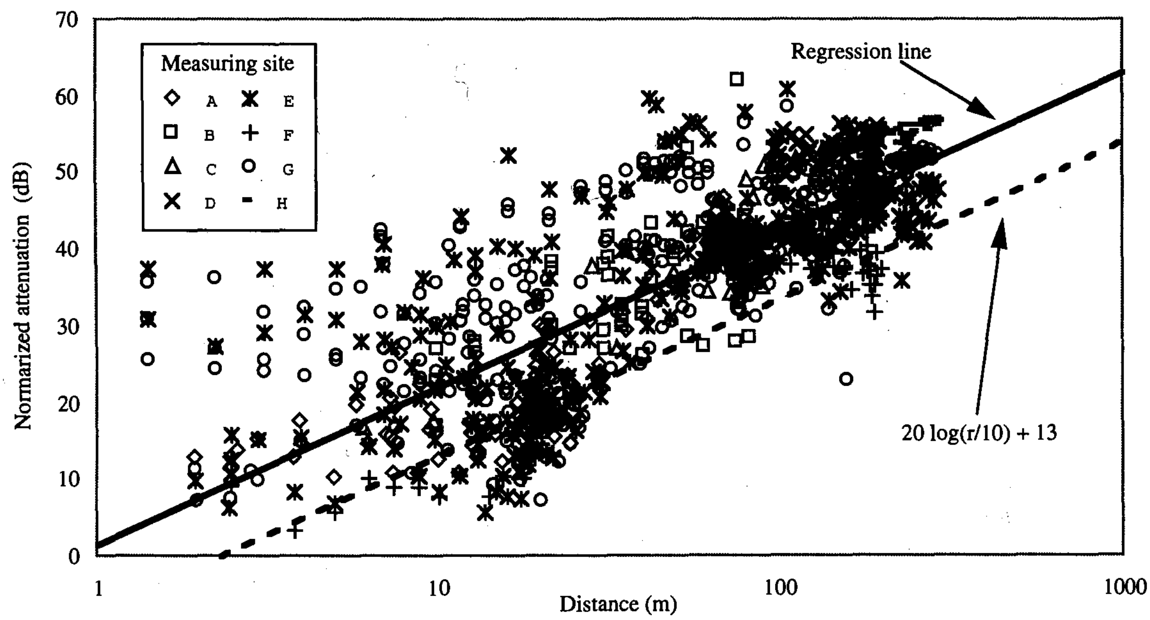

Fig. 5 Attenuation and coefficient.

The results are shown in Fig. 5. The vertical axis represents the attenuation from the emission levels calculated for each measurement by using

$$F_i(\mathrm{dB})=E_1(\mathrm{dB}(\mu V/m))-E_{mi}(\mathrm{dB}(\mu V/m)), \quad (5)$$

where E_{mi} is the measured value; F_i is the attenuation of the emission levels; the horizontal axis is the distance from the building; and A-H represent the measurement levels at the places in Table 1. Over 1000 data were measured at eight places. It is well known that the emission level in proportional to the distance in free space. For the first approximation, the log-linear regression line between the distance and the electric field strength value was calculated as

$$F_i(\mathrm{dB})=P\times\log_{10}(r)+Q, \quad (6)$$

where

$$P=20.4\ (\mathrm{dB}),$$

$$Q=1.4\pm 8.9\ (\mathrm{dB}).$$

The average measured value of P was 20, which matches the theoretical value, so we used P = 20 for our calculations.

From Eq. (1), A is a factor representing the distance dependence of the emission levels normalized by the value at the distance where the emission level was measured at an open test site. Using Eq. (6), A is given by

$$A(\mathrm{dB})=20\log_{10}(r/r_m), \quad (7)$$

where r is the distance from the building and r_m is the distance where the emission level was measured at an open test site.

3.2 Factor Relating the Emission Levels at an Open Test Site

B in Eq. (1) is a factor relating the emission levels at an open test site to the field strength at 3 or 10 m. In this experiment, the emission level of the equipment was measured at a distance of 10 m at the test site, so r_m in Eq. (7) is 10 m. Radiation pattern from ITE depends on the type and the installation condition of the ITE. In this paper, we assume that the radiation from the ITE is isotropic and the level is determined from the value measured at a test site. Since the level measured at a test site is close on the maximum radiation level from the ITE, this assumption derives the severer value than that obtained by using the actual radiation pattern.

The CISPR 22 specifies the at least 80% of the type of ITE complies with the limits (with at least 80% confidence) by the statistical method. In this paper, B value is calculated by using standard deviation because the 84% of measured value is more than the standard deviation and this is near 80%. Therefore, the value of B is obtained where the regression standard deviation line crosses the 10 m intercept. We consider the standard deviation to predict it for severe side. From Eq. (6), the value is 12.9 dB. Therefore, A+B in Eq. (3) is given by

$$A(\mathrm{dB})+B(\mathrm{dB})=20\log_{10}(r/10)+13(\mathrm{dB}). \quad (8)$$

The residual error distribution from the regression line is shown in Fig. 6. More than 85% of the measured data were above the regression standard deviation line.

3.3 Determining DU

An investigation of the ratio of desired to undesired levels (DU) for TV radio waves [8] showed that a DU greater than 40 dB is needed to achieve satisfactory quality, so we used 40 dB for the DU.

3.4 Determining TV Signal Level

An investigation [9] of the propagation characteristics of TV radio waves determined the relationship between the electric field strength of the waves and the distance from the transmitting station for effective radiated power of 1 kW; this is shown in Fig. 7. The field strength was smaller than

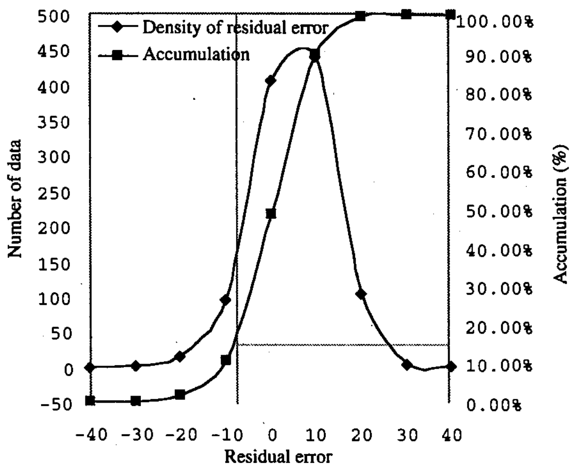

Fig. 6 Residual error distribution and accummulation.

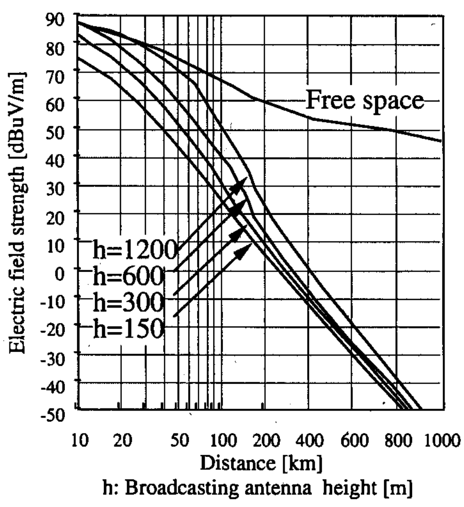

Fig. 7 Propagation of TV signals at E_{erp} = 1 kW.

the calculated value in free space due to ground undulation, the Earth's uneven surface and so on. The investigation also found that the electric field strength depended on the height of the transmitting antenna. Using the relationship shown in Fig. 7, the signal level is approximately given by

$$E_s(\mathrm{dB}(\mu\mathrm{V/m}))=E_g(\mathrm{dB}(\mu\mathrm{V/m}))+10\log_{10}(E_{erp}(\mathrm{kW})), \quad (9)$$

where E_g is the field strength obtained from Fig. 7 at an arbitrary distance and E_{erp} is the effective radiated power of the transmitting station.

3.5 Determining the Receiving Antenna Directivity

S is the factor representing the effect of a TV receiving antenna's directivity. It is important in determining which area will be affected. When the direction of the unwanted emission is the same as that of the TV signal, the receiving antenna's directivity does not affect the disturbance. However, when the direction of the emission is different, a change in antenna directivity can reduce the interference. For example, when the angle between the direction of the TV signal and the unwanted emission is 90 degrees, the unwanted emission level is lower than that of 0 degrees because antenna gain is usually very small in the side directions. The antenna is usually installed to get the best gain for receiving TV signals.

Yagi antennas are normally used for receiving TV signals. In particular, ones with more than eight elements are used in areas where TV signals are weak. While many theoretical analyses have been carried out to calculate the directivity of a Yagi antenna, it is difficult to calculate when there are more than three elements. We thus separately approximated the directivities for the forward and backward directions.

The directivity in the forward direction is approximated by the point source equation [10]:

$$U=U_m\{\cos(\theta)\}^k, \quad (10)$$

where θ is the receiving angle, U_m is the maximum receiving power, and k is the coefficient determined from the beam angle.

When the beam angle is ϕ, we get

$$k=\log(U'/U_m)/\log\{\cos(\phi/2)\}, \quad (11)$$

Table 3 Factors and constants.

Term		Constants							
A		20 log(r/10) r: distance from ITE							
B		13 [dB]							
DU		40 [dB]							
E_s		E_g+10log(E_{erp})							
S	angle [deg]	0	10	20	30	40	50	60	70-180
	gain [dB]	0	0	-1	-3	-6	-9	-10	-10

where

$$U'/U_m=0.5. \quad (12)$$

Since directivity D is defined as the ratio from maximum sensitivity,

$$D(\mathrm{dB})=10\log_{10}(U/U_m)$$
$$=10k\log_{10}\{\cos(\theta)\}\ [\mathrm{dB}] \quad (-\pi/2<\theta<\pi/2). \quad (13)$$

The backward directivity cannot be approximated by Eq. (13) because it has a complicated form. We thus assume that the backward directivity is uniform and equal to the maximum backward sensitivity.

From these assumptions, the directivity of a TV antenna is approximately given by

$$S\ (\mathrm{dB}) = D\ (D \geqq -FB)\ (\mathrm{dB}) \quad (14)$$

$$S\ (\mathrm{dB}) = -FB\ (D < -FB)\ (\mathrm{dB}), \quad (15)$$

where FB is the ratio of the forward and backward maximum sensitivities. FB and ϕ are typically 10 dB and 60 degrees, respectively, when the number of elements is less than ten [11].

The factors for predicting disturbances are summarized in Table 3.

4. Predicting Disturbances

4.1 Prediction Disturbance Area

The area where disturbances may appear is calculated using Eq. (3). An example of the predicted disturbance area is shown in Fig. 8. This figure presents the condition when we look the antenna from the building. In this case, an antenna gain for measuring the emission of ITE is the maximum when the angle is 0 degree. The direction of TV signal is 180

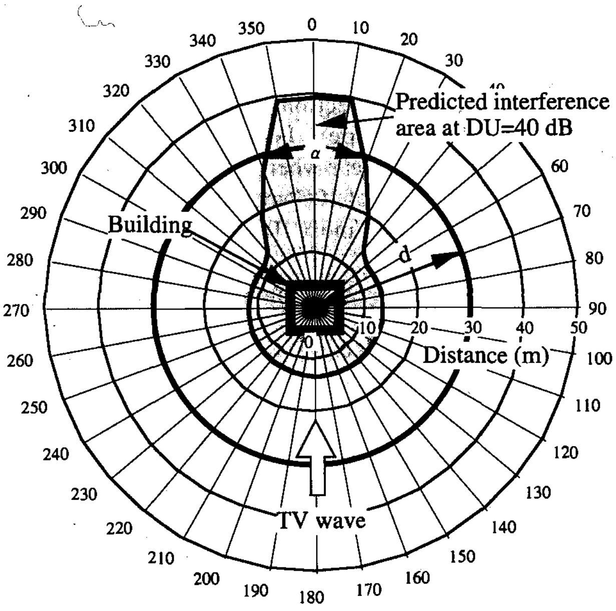

Fig. 8 Predicted disturbance area.

degree because the direction of antenna is usually set toward the TV station. The desired signal level of E_g was 55 dB(μV/m), which is the minimum field strength for TV broadcasting [12], and the emission level of E_1 was 40 dB(μV/m), which is the Class A limit recommended by the CISPR[1]. The other constants used are summarized in Table 3. Figure 8 shows that a disturbance still appears when the direction of the wanted signal is aligned with that of the unwanted emission. In the worst case, about 11% of the area suffers a disturbance when the TV receiving antenna is within 30 m of a building containing ITE. Although one of the reason is that we determine B value considering with the standard error, countermeasures may be thus needed in this area, such as improved shielding and reduced ITE emissions.

4.2 Predicting Disturbance Probability

It is important to predict areas where disturbances might occur. The probability of disturbance is directly proportional to the distance from the transmitting station. Using Eq. (3), we calculated the probability of disturbance as a function of the distance from the transmitting station.

In this calculation, we used a frequency in the upper band, a transmitting antenna height of 300 m, an effective radiated power of 370 kW, and data for the Kanto area as the broadcasting service model.

It is difficult to calculate the disturbance rate because we can not determine the minimum and maximum distance. In this paper, we define the maximum disturbance rate as shown in Eq. (16). The maximum disturbance rate I_s is defined as the ratio between the arc including the disturbance area (α_d) and the circumference of the entire circle at a radius of 30 m from the ITE. the The equation is,

$$I_s(\%) = \alpha_d / 2\pi d \times 100. \tag{16}$$
$$d = 30\ (\mathrm{m})$$

In Eq. (16), d is the minimum disturbance where the reduction of the disturbances should be considered. We use d of 30 m, which is protection distance presented by the CISPR 22, in this paper. Is of 0% means that the disturbances do not appear when the distance from ITE is more than 30 m, and Is of 10% means that the disturbances may appear less than at most 10% of the area. This is, of cause, over estimation.

For example, in Fig. 8, the maximum disturbance rate is 11%.

The calculation results are shown in Fig. 9. The maximum disturbance rate was found to increase rapidly at distances of more than 70 km from the transmitting station. By superimposing the results in Fig. 9 on a map showing the satellite broadcasting stations, we obtained the results shown in Fig. 10. The black dots are the satellite stations and the white circles represent areas free of disturbance effects when the ITE satisfies the CISPR Class A limits. There are still some disturbances in the gray zones, despite the many satellite stations. Therefore, when ITE is used in these zones, it may be necessary to reduce the emissions from their buildings.

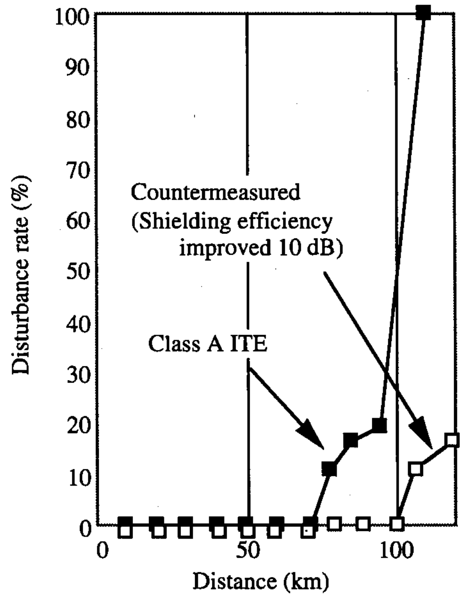

Fig. 9 Example of disturbance probability.

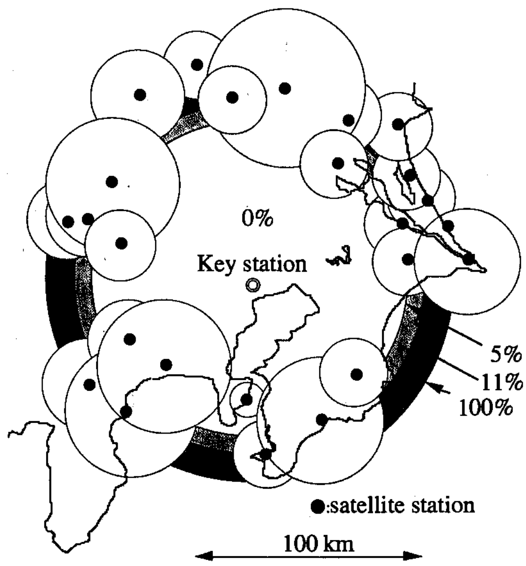

Fig. 10 Example of predicted disturbance areas.

5. Calculating the Improvement Value

The investigation shows that disturbances may appear in a particular area even if the equipment satisfies the specifications published CISPR. Therefore, countermeasures may be needed in these areas. Countermeasures include improving the shielding efficiency of buildings [13] and cabinets [14].

The improvement in the shielding is reflected by the values of B or E_1. However, the effect is the same. So, we calculated the effect of the countermeasures using Eq. (3). The results are shown in Figs. 9 and 11. In this calculation, B