International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R BT.2294-0

(11/2013)

Construction technique of DTTB relay station network for ISDB-T

BT Series

Broadcasting service (television)

International Telecommunication Union

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Electronic Publication
Geneva, 2014

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Construction technique of DTTB relay station network for ISDB-T

(2013)

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1 Introduction

DTTB networks can be constructed by using various signal distribution methods to the relay stations. Microwave links which are called station to transmitter link (STL), transmitter to transmitter link (TTL), and a broadcast wave(off-air) relay are mainly used for this purpose. The relay system is an important factor that decides the characteristics of transmitter facilities and quality of transmission signal. To decide on the relay system, the technical consideration to maintain long-term reliability and stability of the network operation and broadcasting reception in the service area would be required. After the necessary assessment of the transmission signal quality, a suitable relay system would be chosen taking into account the cost of building the facilities and the long-term maintenance.

For considering a relay system, first the quality of the relay network would be estimated based on the signal quality of the upper node station and the field strength of interference calculated by the simulation and the propagation characteristics calculated by the past measurement results.

Next, the field measurement result of the incoming waves such as the desired signal, interference, and multipath signals would be considered and reflected in the simulation result. Since the measurement investigation could lead to comprehending individual propagation situations such as interference due to mountain reflection, it is indispensable to the determination of a relay system.

To maintain whole DTTB networks at a certain quality level, the whole relay system should be decided with common criteria.

This Report provides how to determine relay system between a relay station and its upper node station, and single frequency network (SFN) delay time adjustment design.

In this Report, unless specified otherwise, the following transmission parameters[1] of ISDB-T are used:

TABLE 1

Transmission parameters of ISDB-T

Transmission parameter	Value
Mode	3
Modulation method	64-QAM
Inner channel code	3/4
Guard interval duration	1/8 (126 μs)
Inner interleaving	2

2 Selection of signal distribution system

2.1 Overview of signal distribution system consideration

There are four major methods to distribute a signal from the studio or upper node station to the transmitting station. Broadcast wave relay system and microwave, satellite and optical fibre links are commonly used for the construction of a DTTB network. Developing channel plans is essential, and they should be developed prior to choosing the method of sending signals to relay stations. Taking into account the delay adjustment for a SFN and propagation characteristics of the broadcast wave relay between stations, the most appropriate and cost effective means should be chosen. If the microwave link or TTL is chosen, the channel plan for the microwave link should also be arranged.

To determine the relay system at the relay stations, simulations and field tests should be conducted and results properly reflecting the quality of the link should be considered.

2.1.1 Broadcast wave relay system

A broadcast wave relay system is usually the most cost effective method to construct a relay station network. A relay station receives the DTTB signal from its upper node and retransmits to its service area. Since this system uses the signal of its upper node station, the network is relatively small due to the distance between the stations in the network.

2.1.2 Microwave link

Links from the studio to the transmitting station and transmitting station to another transmitting station are called Studio to Transmitter Link or STL and Transmitter to Transmitter Link or TTL, respectively. A microwave link is used when signal quality needs to be maintained or when delay time adjustment is required.

2.1.3 Satellite link

A satellite link can be the most efficient way to distribute signals via satellites from the studio to the transmitting stations in various locations. This system's construction stage cost less but the satellite operation costs, such as transponder usage cost, may go higher than other systems.

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1 See Recommendation ITU-R BT.1306.

When wide areas need to be covered, satellite links make the distribution more cost effective than microwave or optical fibre networks. In addition to the fact that it is possible to reach many stations with a single signal, satellite is, in many cases, the only way to feed relay stations that are far from the headend. Sun transit of the satellite, on the other hand, raises the reception noise level and may cause an interruption of the service. Also, a variation of the satellite position may disturb the SFN conditions between transmitting stations. These phenomena should be considered.

2.1.4 Optical fibre link

Optical fibre links can be used as the medium to distribute digital TV signals or can operate together with microwave links on a main/stand-by system, maintaining signal quality and permitting delay time adjustment on an SFN as well. It should be considered that the route switching may change the transmitting timing of the station which affects the SFN conditions.

2.2 Requirements for selecting relay system

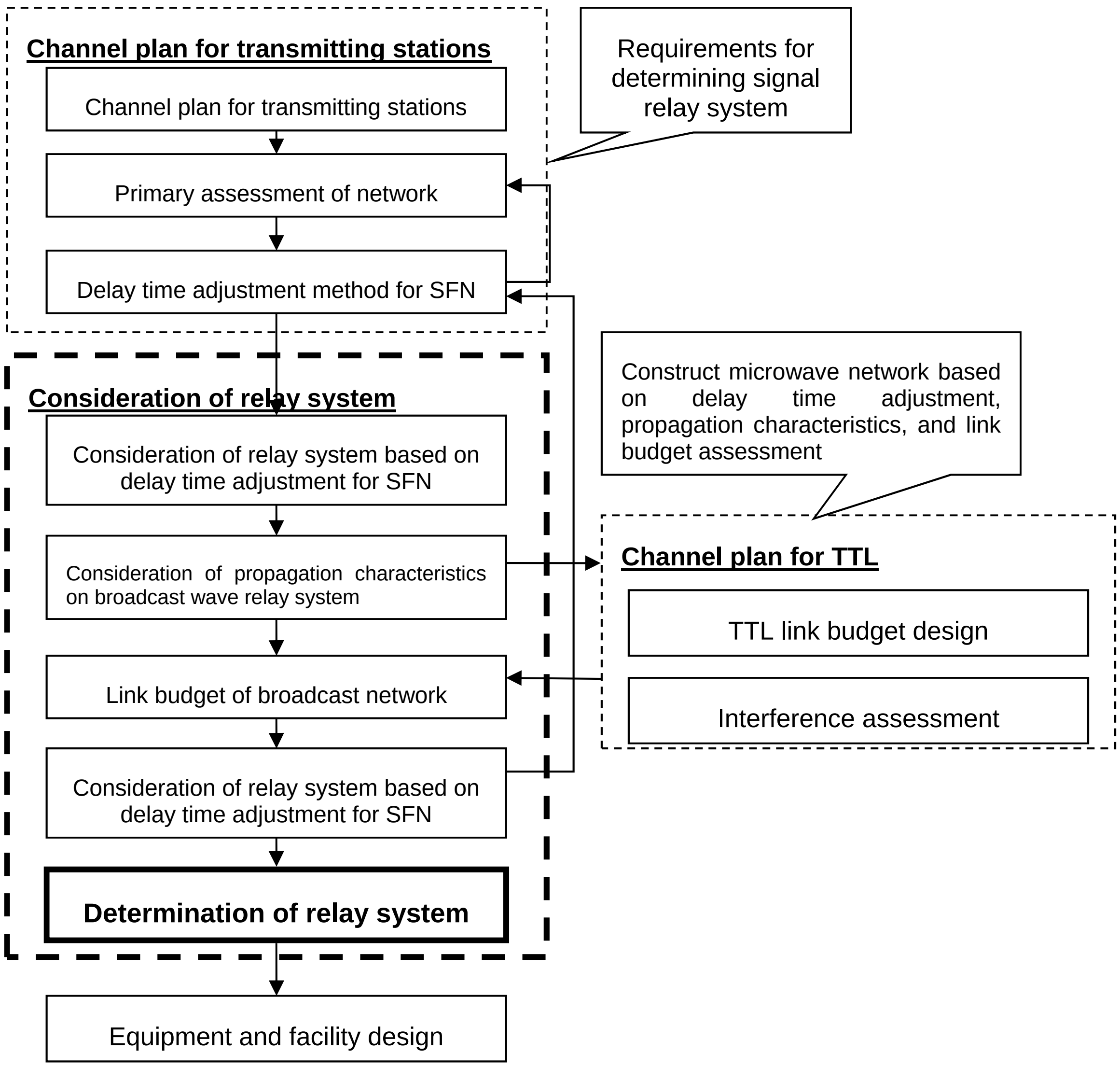
2.2.1 Channel plan for transmitting stations

The channel plan should determine the transmission specifications of the relay stations. Transmission specifications include the transmission power, directivity of the transmission antenna, and height of the antenna to satisfy the service area. Then, the transmission channel would be chosen by considering the interference with other stations taking into account the above transmission conditions.

In the ISDB-T network, it could be feasible to construct the SFN even though the protection ratio between stations with the same signal could not be satisfied. Therefore, the delay time adjustment and the network topology are also considered in the selection of the relay system.

FIGURE 2.1

Flowchart of selection of relay system

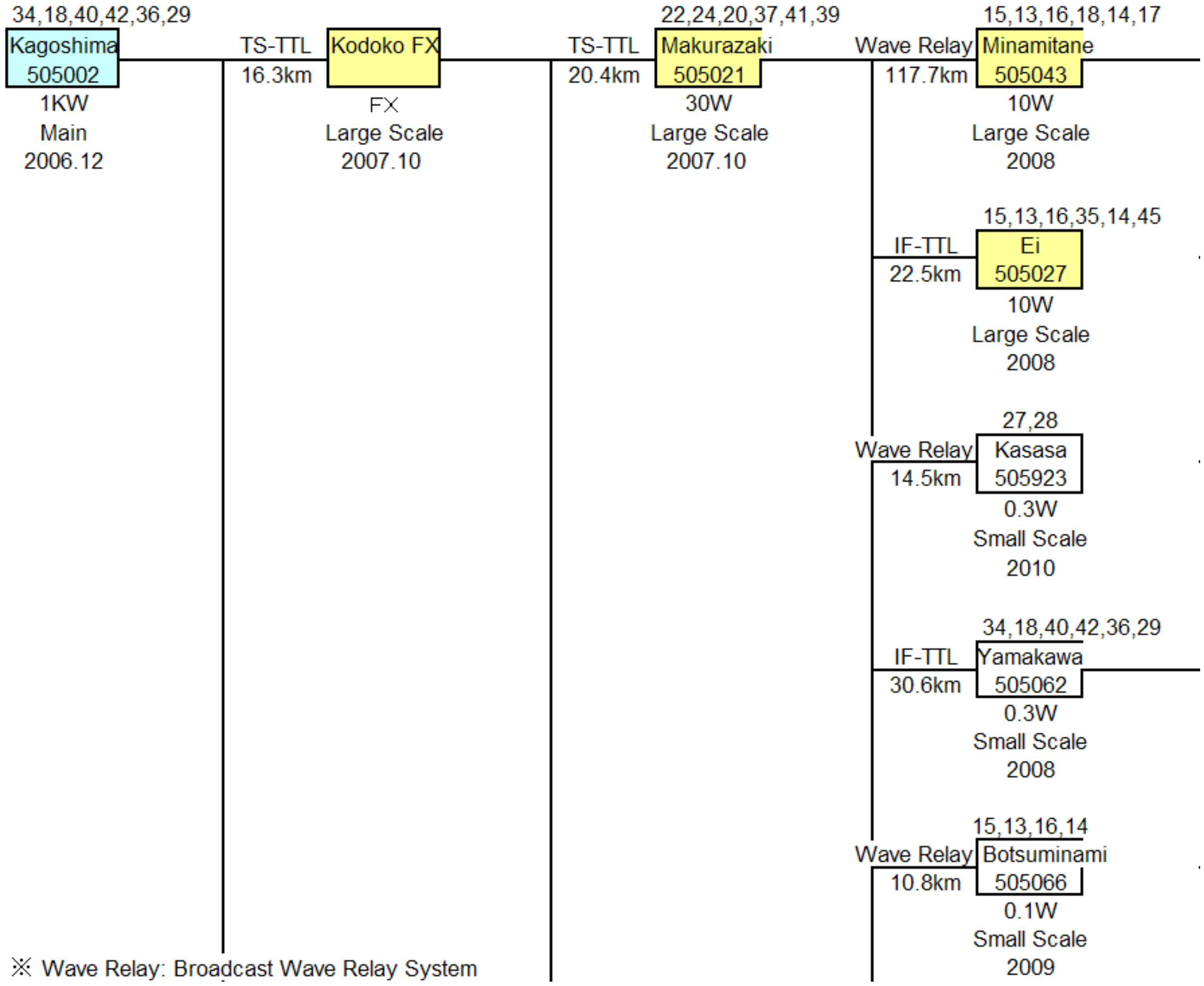


2.2.2 Primary assessment of constructing broadcasting network

A network identical to the existing analogue television network is the first step in considering the constructing of the broadcasting network. Figure 2.2 shows an example of a part of the network structure in Kagoshima prefecture, South Japan.

FIGURE 2.2

Example of broadcasting network structure in Kagoshima



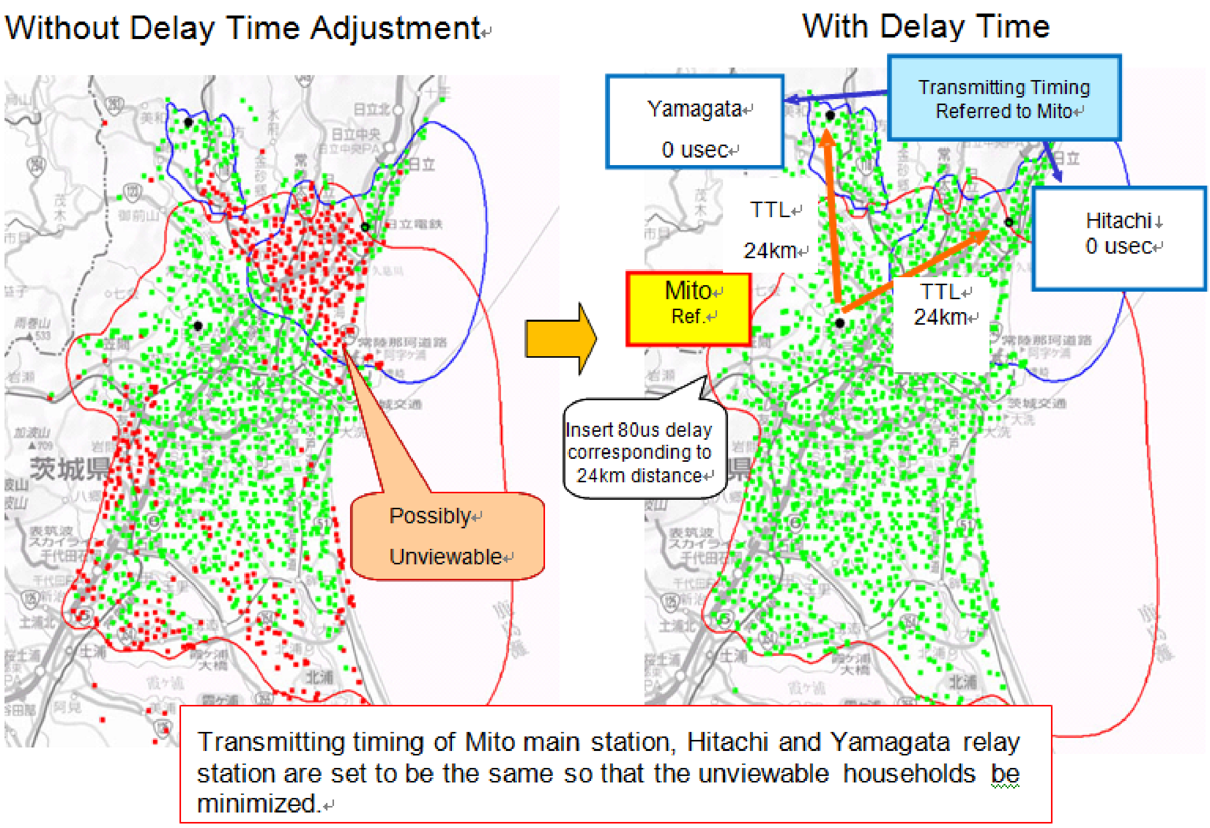
2.2.3 Delay time adjustment design for SFN

The SFN is a network constructed with an identical signal on the same frequency transmitted from a different location. For SFN transmission frequency precision, Inverse Fast Fourier Transform (IFFT) sampling frequency precision and transmitting waveforms are required. Also, all the signals in the service area should reach the reception point within a certain time called the guard interval (GI). A signal arriving at the reception point after the GI is considered as an interfering signal. If the signal over the GI is strong enough, the signal would not be decoded properly. To avoid this situation, the transmitting timing is adjusted, and this is called delay time adjustment of SFN.

Figure 2.3 shows an example of the delay time adjustment of a SFN in Mito Area, a suburb of Tokyo. The delay time depends upon the transmitting location, field strength at the reception points, and type and direction of reception antennas. It is important to minimize the number of households that cannot receive the signal properly by means of a computer simulation. The transmission delay time to minimize the number of households that cannot receive the signal is called the SFN delay time adjustment design. Delay time adjustment is required each time the transmitting timing changes by adding equalizers to the transmitter.

FIGURE 2.3

Example of SFN delay time design at Mito Station



2.3 Consideration of relay system

The broadcast wave relay system, which receives the UHF DTTB signal from the upper node station, is the primary choice because it is considered to be the most cost effective. However, other systems could be considered if the broadcast wave relay method is not feasible due to the SFN design or the quality of the UHF receiving signal not being sufficient.

2.3.1 Consideration of relay system based on delay time adjustment for SFN

In the SFN delay time adjustment design, all the delay time including the delay caused by the transmitting equipment such as equalizers are to be considered. For the assessment of the delay time adjustment, a delay time check sheet could be used. Figure 2.4 is an example of the sheet for Shizuoka Prefecture.

FIGURE 2.4

Example of time delay check sheet for Shizuoka Prefecture

The transmission delay time of each relay station is shown as the relative time to the maximum allowable delay time. One example of the maximum allowable delay time used successfully in Japan is 412 ms and this time is used in the following section. Usually the main station is 0 µs as a reference. The feasibility of the network structure can be checked by entering all the necessary data in the sheet.

Because the transmitting timing might be changed as the result of considering relay system by adding equalizers to the transmitter, it is necessary to check that the delay time is properly designed in the network after all the delay time adjustments have been conducted.

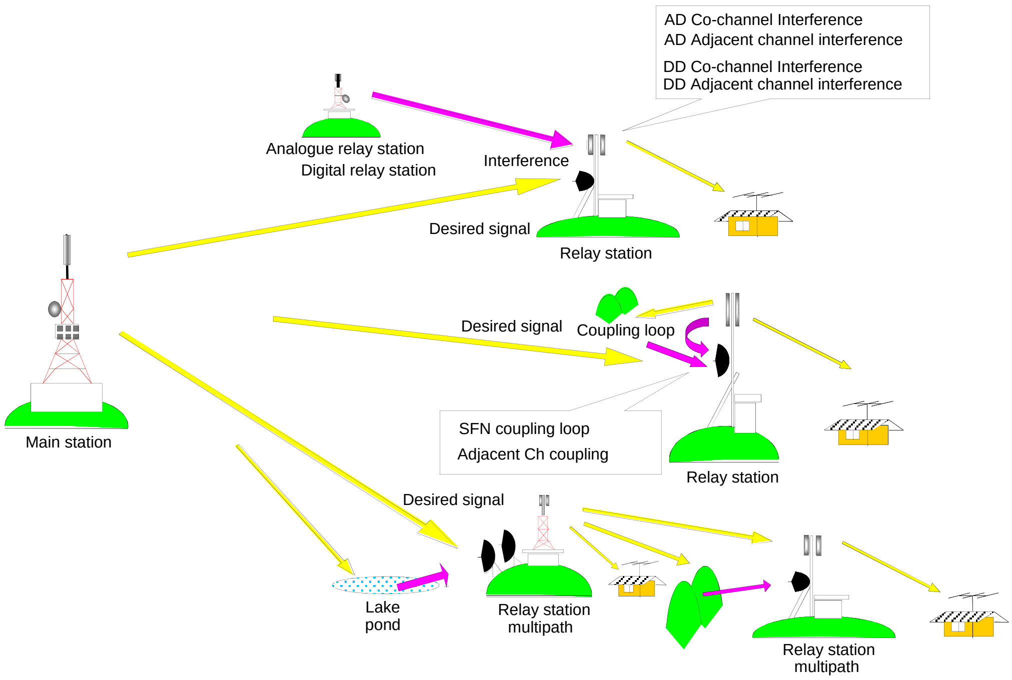
2.3.2 Consideration of propagation characteristics of broadcast wave relay

Propagation characteristics between a certain relay station and its upper node station include signal degradation by fading, multipath, and other interferences from other signals. Figure 2.5 shows a simple diagram of the propagation characteristics. The assessment and evaluation of propagation characteristics between the stations should be carried out based on data obtained from the propagation simulation and the result of field measurements.

In accordance with the propagation characteristics between the stations, an equalizer may be selected. If the propagation characteristics do not meet the operation requirements of the equalizer, another relay system such as TTL should be selected. The selection should also take into account the link budget of a certain network.

FIGURE 2.5

Typical propagation characteristics of broadcast wave relay



2.3.3 Link budget of broadcasting network

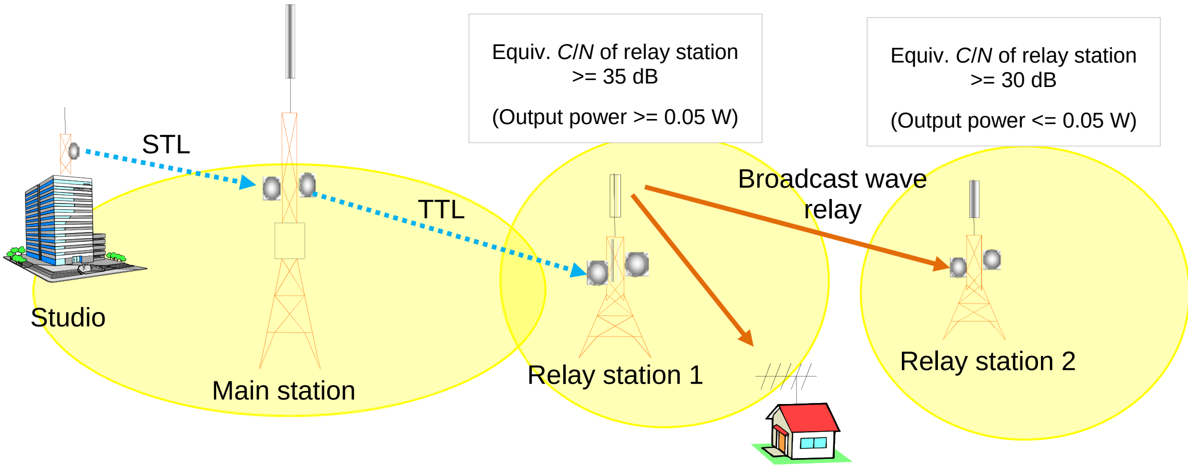
In this section, the entire network from the uppermost main station to the end node relay stations is discussed. The link budget should consider the various signal degradation factors in the network and calculate the quality of the signal of each transmitting station. The quality of the signal is expressed in the equivalent carrier-to-noise ratio (C/N). The equivalent C/N of the transmitted signals of all transmitting stations are necessary to satisfy the reference value. Figure 2.6 shows a diagram of a broadcasting network.

A DTTB program is transmitted from the studio to the main station through the microwave link called station-transmitter link (STL), and then the signals are transmitted to relay stations either by the broadcast wave relay or TTL. The quality of the transmitted signal of each transmitting station should meet the criteria depending upon the scale of the transmitting station.

The equivalent C/N of the transmitted signal can be calculated using the design sheet. The sheet can calculate the equivalent C/N by entering the type of relay system, distance from the upper node station, and the signal strength of the other interferences at a certain relay station. If the TTL is selected, the regulatory measures for the microwave link should also be taken into account in the design of the link.

FIGURE 2.6

Diagram of a broadcasting network



2.3.4 Channel plan for microwave links

Based on the results of the delay time adjustment, assessment of propagation characteristics, and link budget, if the TTL is required in a certain network, the network should be added to the TTL channel plan list. To choose using a channel, the link budget and interference assessment should be conducted for the channel plan. For efficient channel plan of the microwave links, channel grouping can be applied in the regions and same channel is repeatedly used.

For an efficient channel plan of the microwave links, channel grouping can be applied in the regions and the same channel is repeatedly used.

3 SFN delay time adjustment and relay system

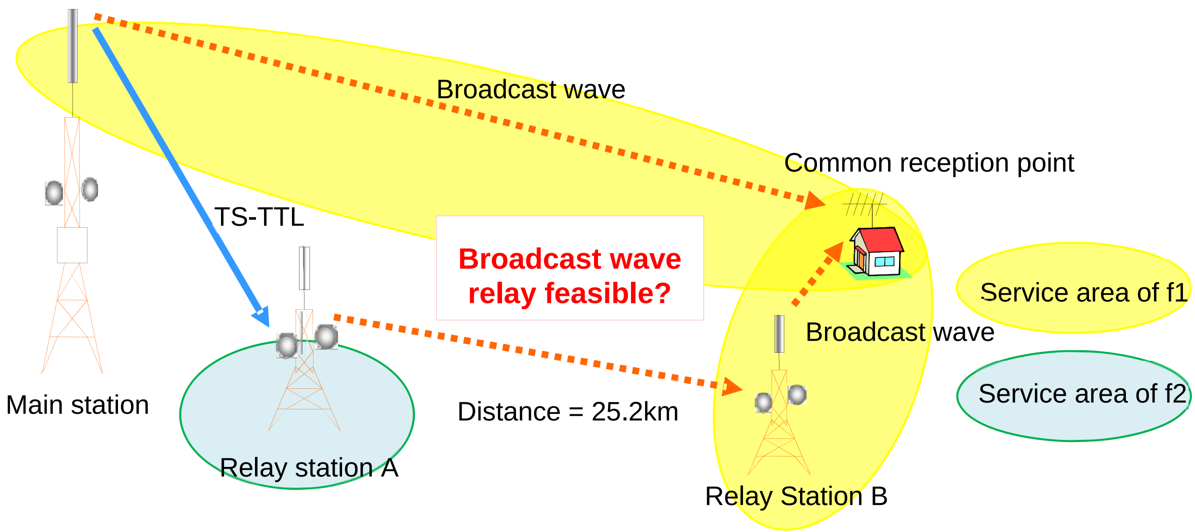
SFN delay time adjustment is an important factor to prevent SFN interference. Section 2.3.1 states that all the delay time in the broadcasting network should be taken into consideration to realize SFN delay time adjustment. This section describes the way of consideration.

3.1 SFN delay time adjustment

Figure 3.1 shows the overview of SFN delay time adjustment. The main station and relay station B, which transmits on the same channel in f1, comprise the SFN. The delay time difference between signals from these stations at the common reception point should be within the guard interval.

FIGURE 3.1

Overview of SFN network



If the relay system from relay station A to relay station B is the broadcast wave relay, the transmitting timing of relay station B delays the transmitting timing of relay station A for the total distance between the stations (25.2 km, 84 µs) and for the process time of the transmitting equipment in relay station B. Because the transmission delay time of relay station B is designed earlier than the transmitting timing decided by the broadcasting network composition, other relay systems such as TTL should be chosen.

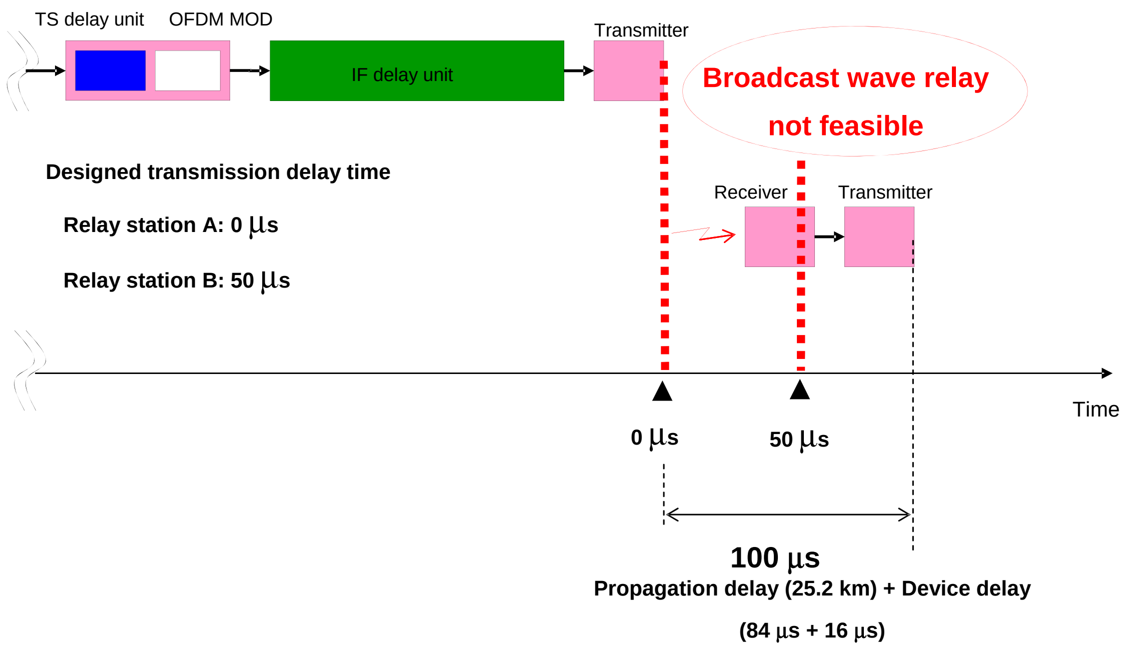
3.1.1 Case where transmitting timing exceeds designed transmission delay time

In Fig. 3.1, the transmission delay times of relay station B and relay station A are set to 50 µs and 0 µs, respectively.

In this case, as shown in Fig. 3.2, since the sum of the propagation delay and the device delay at relay station B is 100 µs, the transmitting timing exceeds the designed transmission delay time, so broadcast wave relay could not be chosen. In such a case, reconsideration of transmission delay time or choosing other relay system is required.

FIGURE 3.2

Case where transmitting timing exceeds designed transmission delay time



3.1.2 Case where transmitting timing is within designed transmission delay time

In Fig. 3.1, the transmission delay times of relay station B and relay station A are set to 200 µs and 0 µs, respectively.

In this case, as shown in Fig. 3.3(a), since the sum of the propagation delay and the device delay in relay station B is 100 µs, the transmitting timing is within the designed transmission delay time, therefore broadcast wave relay could be chosen. In such a case, as shown in Fig. 3.3(b), the transmitting timing should be adjusted to the designed transmission delay time with the IF delay unit.

FIGURE 3.3(a)

Case where transmitting timing is within designed transmission delay time

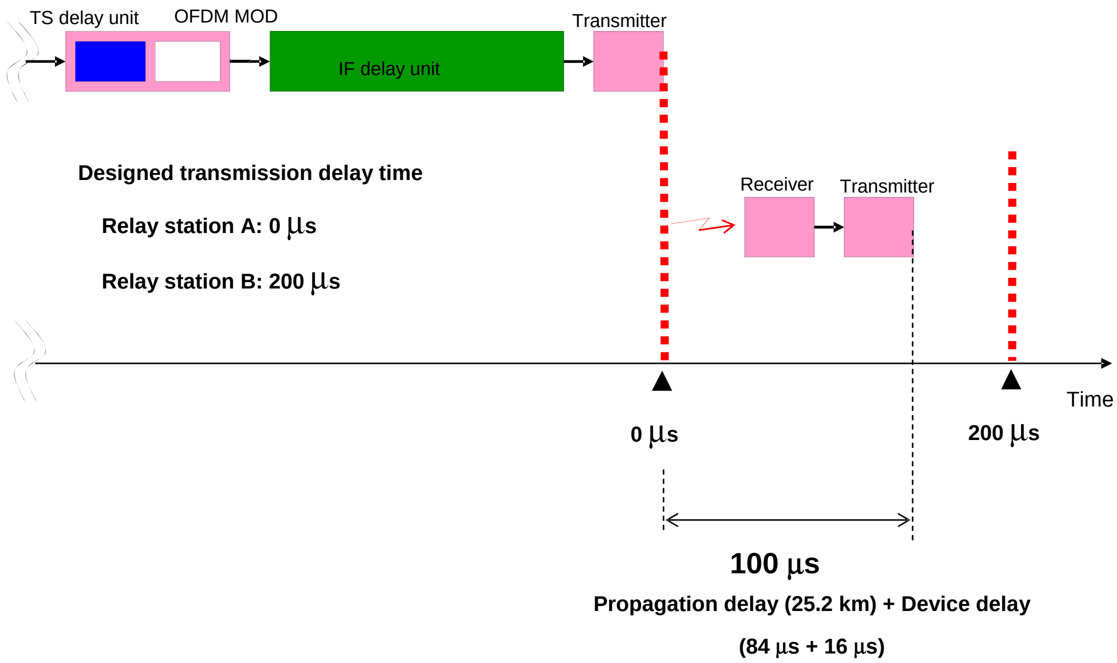
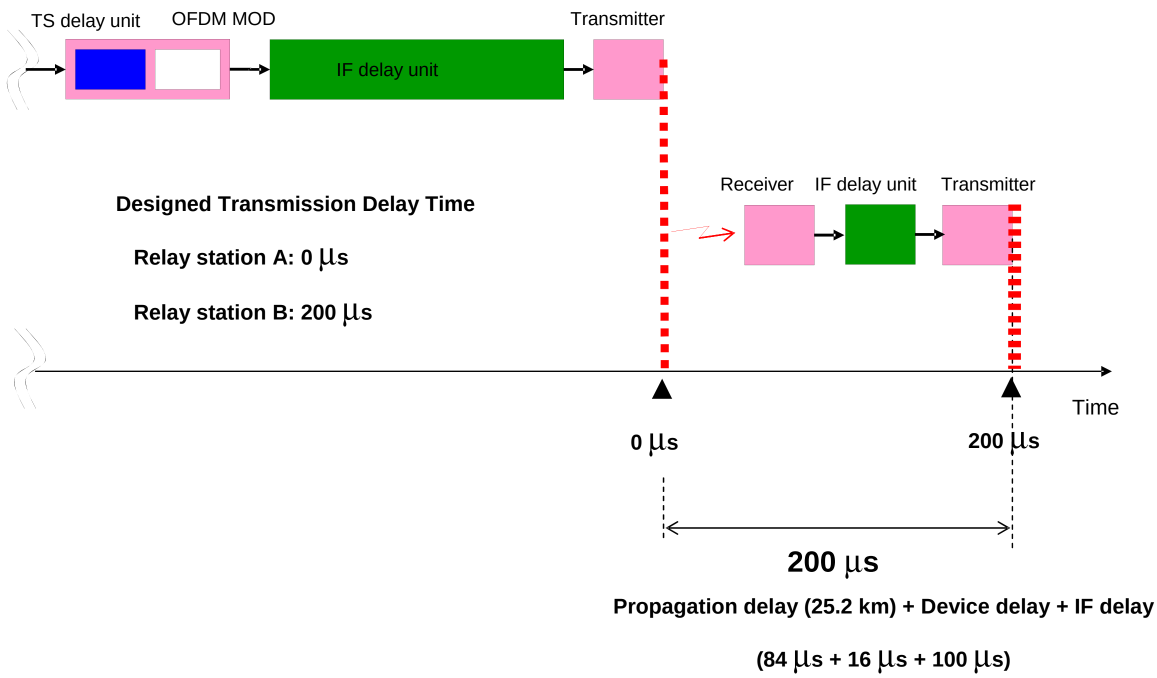


FIGURE 3.3(b)

Case where transmitting timing is set to 200 µs with IF delay unit



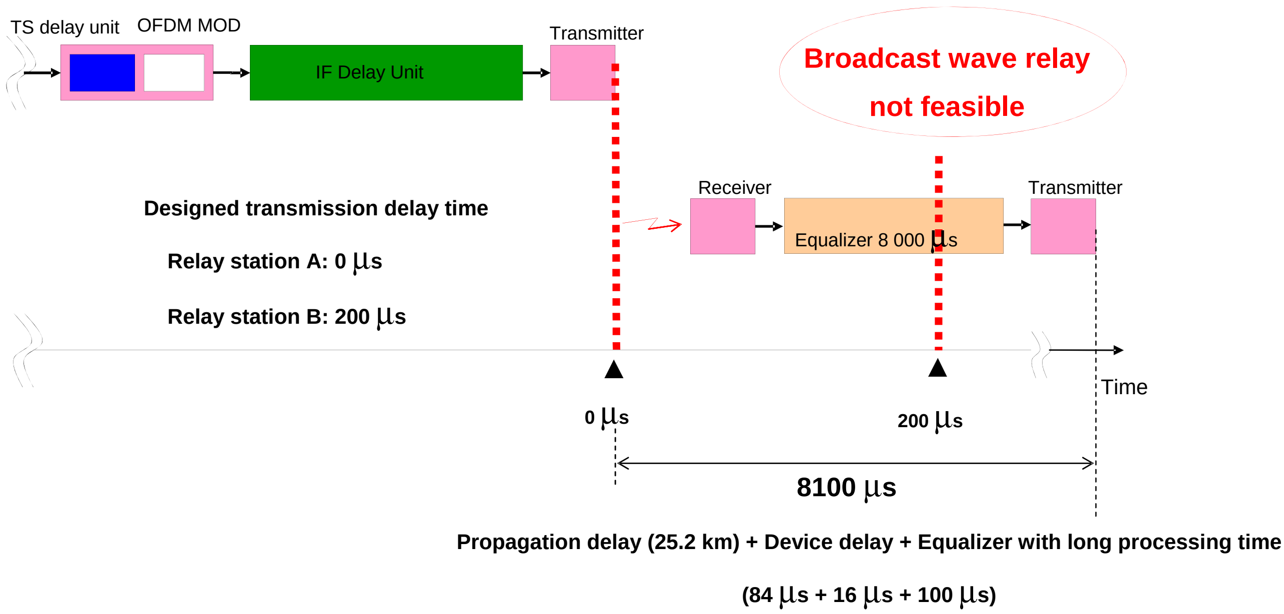
3.1.3 Case of use of equalizer with long processing time

In Fig. 3.1, the transmission delay times of relay station B and relay station A are set to 200 µs and 0 µs, respectively.

In this case as shown in Fig. 3.4, if an equalizer with a long processing time is used, the sum of the propagation delay and the device delay in relay station B is 8 100 µs. Therefore, the transmitting timing exceeds the designed transmission delay time, and broadcast wave relay could not be chosen. In such a case, reconsideration of transmission delay time or choosing other relay system is required.

FIGURE 3.4

Case of use of equalizer with long processing time



3.2 Criterion for delay time adjustment

The SFN delay time adjustment should be set for each media. The transmitting timing of each station is adjusted to the designed transmission delay time with the IF delay unit. When the transmission delay time satisfies the following conditions, the broadcast wave relay system including the IF-TTL relay system that receives the broadcast wave could be chosen.

Designed transmission delay time ≥ total delay time to the relay station

It is possible to adjust the delay time for TTL except for the IF-TTL relay which receives the broadcast wave by the maximum delay time adjustment method shown in § 3.2.1.

3.2.1 Maximum delay time adjustment method

To determine the optimum delay time, the following four conditions should be met:

1) suspending transmission at the upper node station is not required to adjust the delay time of a lower node station;
2) the cost of developing the network is minimized;
3) the delay time adjustment of every transmitting station is not complicated;
4) even after the transmitting station is launched, fine adjustment of the delay time is feasible.

To satisfy the four conditions, the maximum delay time adjustment method is proposed and successfully implemented in the network of the Japanese public broadcaster.

Figure 3.5 shows the concept of the maximum delay time adjustment method.

In this method, the delay time from the re-multiplexer (re-mux) in the studio to the transmitting equipment in the main station is set to 412 ms.

There are three reasons to set it to 412 ms:

1) The transmitting time of the one-span TS-TTL system is 6 ms (including propagation time)

   Even in the rural area, 10-span TS-TTL systems are enough for the entire network.

   ($6 \text{ ms} \times 10\text{-span} = 60 \text{ ms}$)

2) The processing time of the OFDM modulator is 350 ms.

   (All OFDM modulators must satisfy this processing time)

3) The transmitting time of the one-span IF-TTL system is 0.2 ms (including propagation time).

   Even in the rural area, 10-span IF-TTL systems are enough for the entire network.

   ($0.2 \text{ ms} \times 10\text{-span} = 2 \text{ ms}$)

   $60 \text{ ms} + 350 \text{ ms} + 2 \text{ ms} = 412 \text{ ms}$.

Even with a very long distance from the TV studio to the relay station, it is possible to connect from the re-mux equipment in the TV studio to the relay station's transmitter by 412 ms.

The maximum delay time adjustment method is based on the concept that the delay from re-mux equipment in the TV studio to all the transmitters' output should be equal (412 ms), and the delay from the re-mux equipment in the TV studio to all the OFDM modulators' output should be the same (410 ms).

Figure 3.6(a) shows a case of the delay time adjustment at TS-TTL, and Fig. 3.6(b) shows a case of the delay time adjustment at IF-TTL.

In both cases, the delay time can be adjusted independently and easily. No interruption of the service at the upper node station is required.

Additionally, even after the transmitting station is launched, fine adjustment of the delay time can be made with the IF delay unit.

FIGURE 3.5

Concept of maximum delay time adjustment method

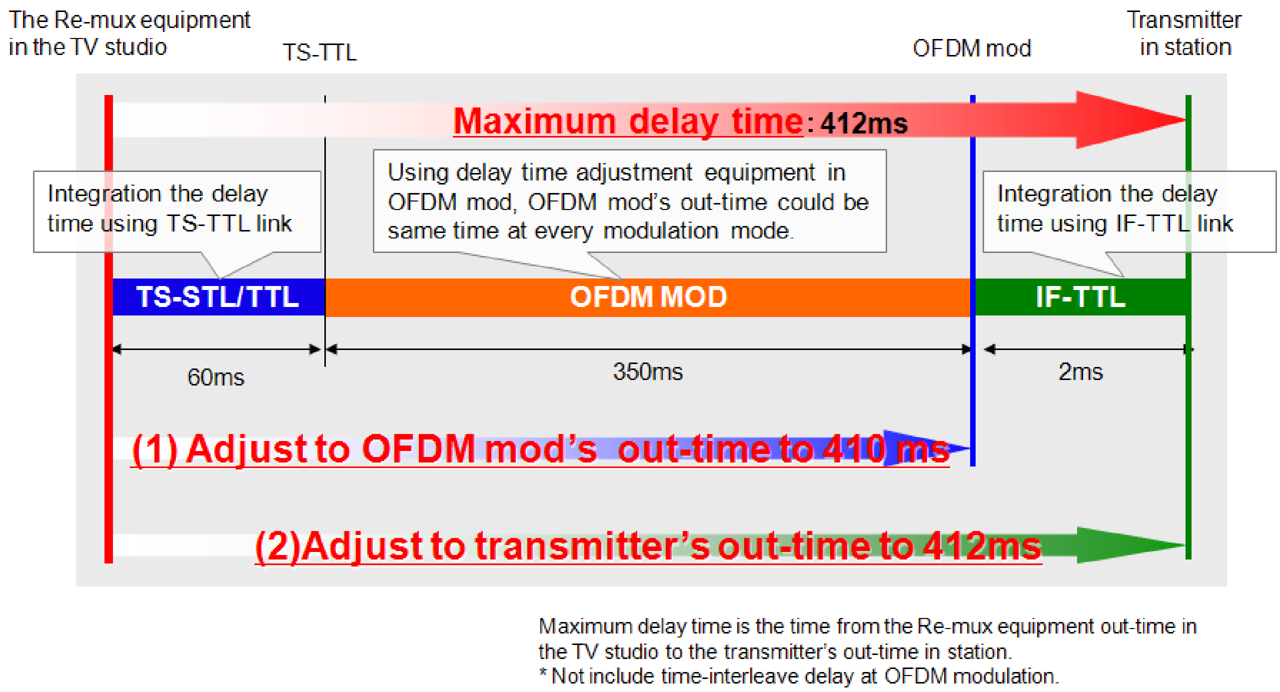


FIGURE 3.6(a)

Case of the delay time adjustment at TS-TTL network

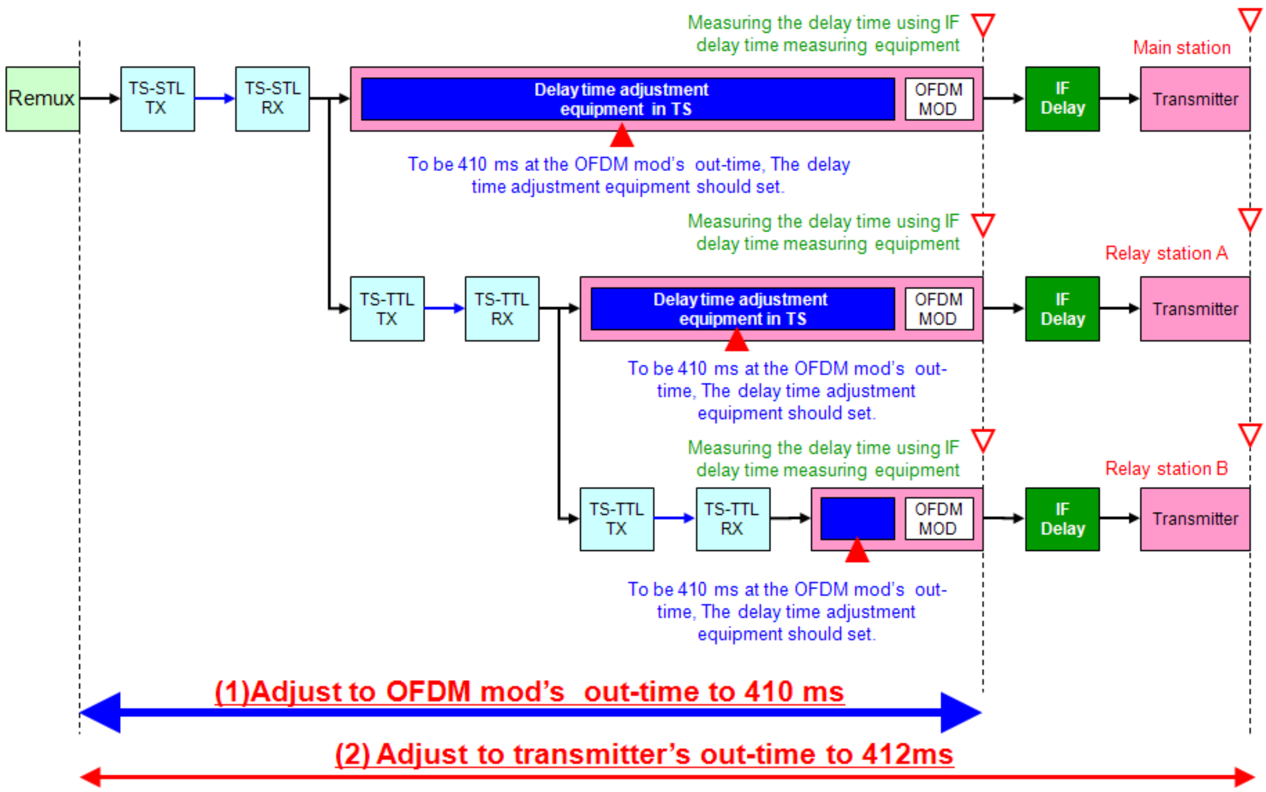
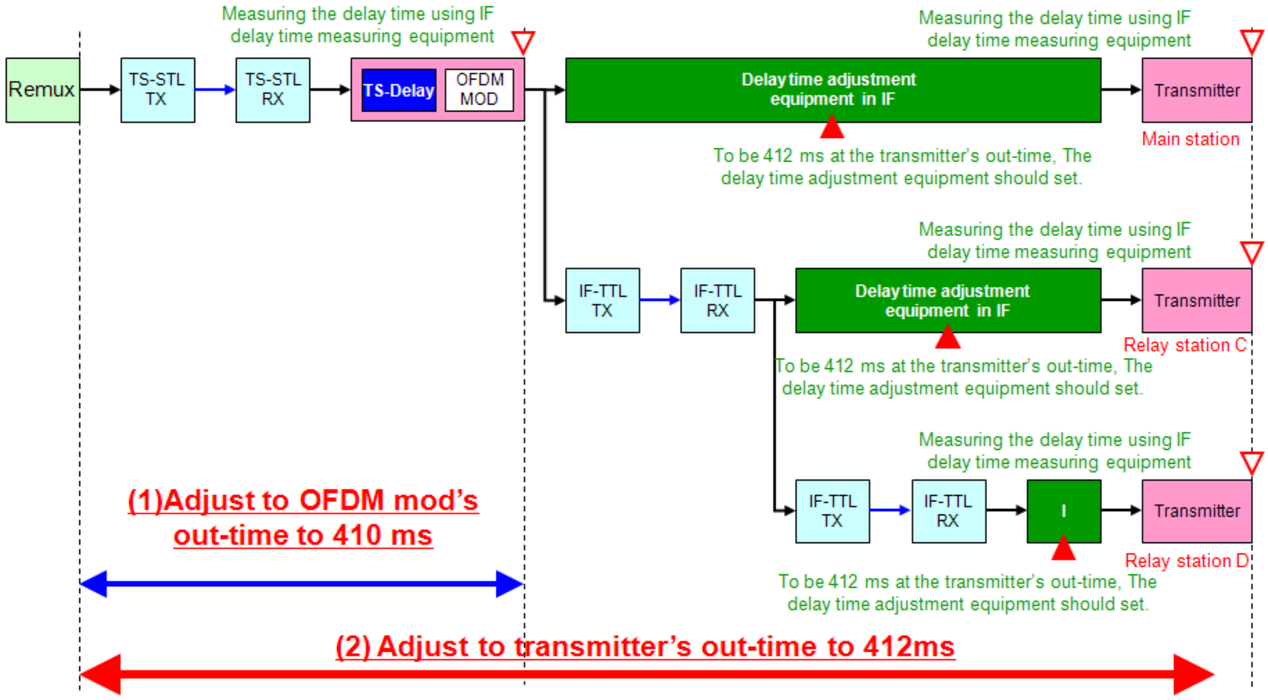


FIGURE 3.6(b)

Case of delay time adjustment at IF-TTL network

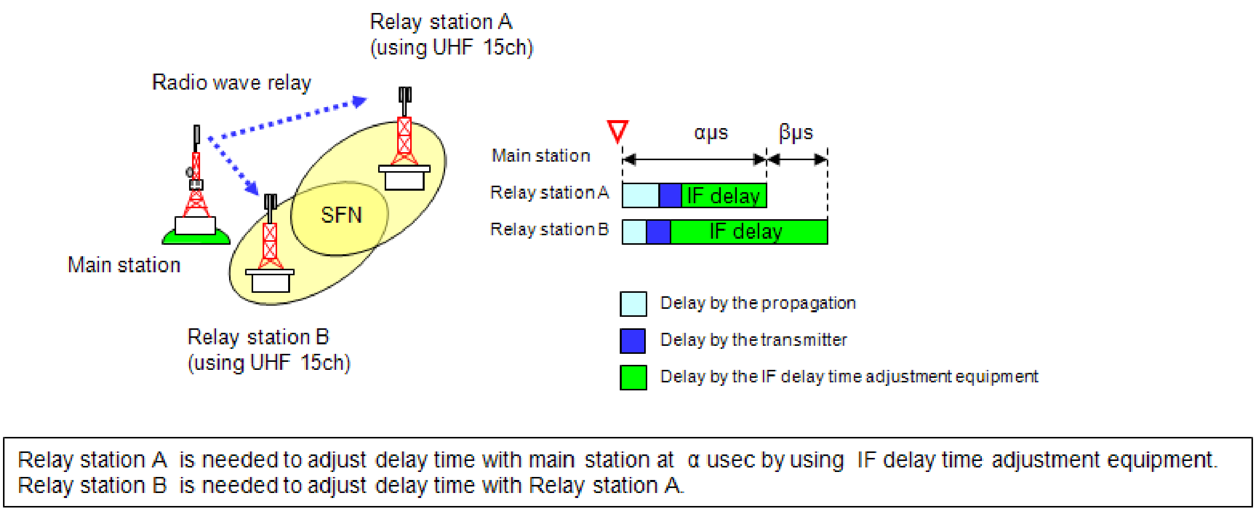


3.2.2 Delay time adjustment at broadcast wave relay system

In the broadcast wave relay system, the relative transmitting timing between relay stations using the same channel is considered. Figure 3.7 shows the concept of the delay time adjustment at the broadcast wave relay system. The objective is to set the reception timing at the location where two signals can be received to be within the guard interval.

FIGURE 3.7

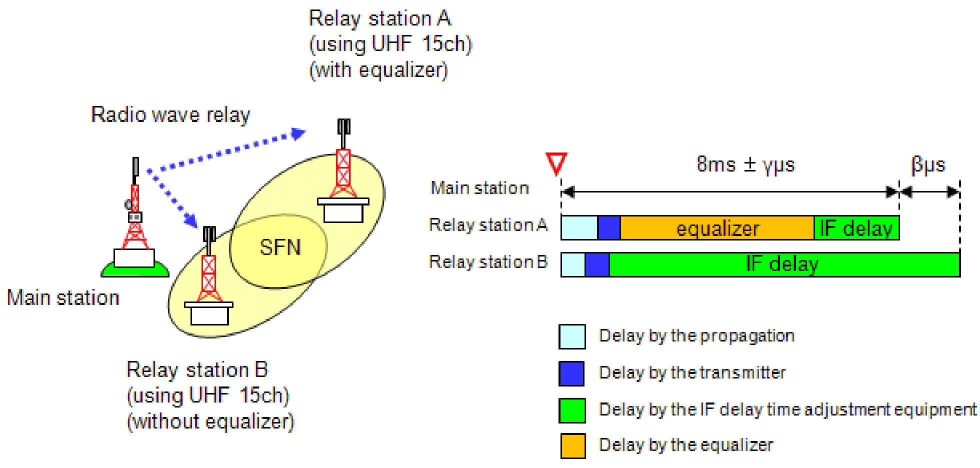
Concept of delay time adjustment at broadcast wave relay



If an equalizer with a long processing time is used at relay station A, relay station A has to adjust the total delay time to 8 ms, which is relative to the main station, by introducing the IF delay unit. If fine adjustment is needed, ± γ µs is added. Relay station B needs to adjust the delay time with relay station A in order for the two signals to be received within the guard interval, which is 126 µs. Figure 3.8 shows the concept of the delay time adjustment at the broadcast wave relay system with an equalizer.

FIGURE 3.8

Concept of delay time adjustment at broadcast wave relay with an equalizer



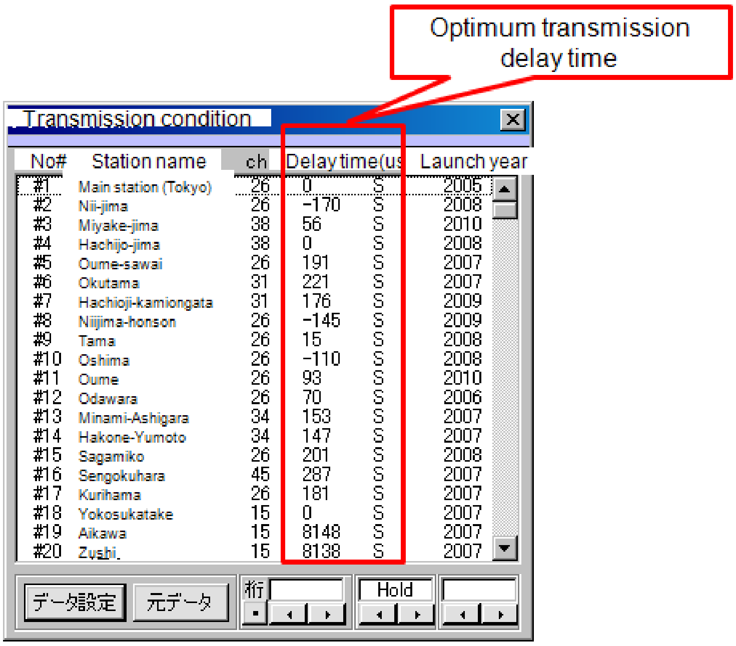
Relay station A is needed to adjust delay time with main station at 8 msec by using IF delay time adjustment equipment.
(If the fine adjustment is needed, ± γ μsec is added)
Relay station B is needed to adjust delay time with Relay station A.

3.3 SFN delay time adjustment

The SFN delay time can be designed by the simulation. The simulation calculates the number of households affected by the SFN interference in the network under varying conditions including transmitting timing. The simulation result shows the optimum transmission delay time where the number of households affected by the SFN interference is minimized. Figure 3.9 shows an example of a simulation result for the optimum transmission delay time at all stations in the network. The delay time of the main station is set to 0 µs, and the optimum transmission delay time of each station is shown in the window.

FIGURE 3.9

Example of simulation result of optimum transmission delay time



4 Quality of the broadcast wave relay

4.1 Equivalent *C*/*N* of signals transmitted by broadcasting stations

4.1.1 Concept

The requirements are to be defined for the equivalent *C*/*N* that must be satisfied by the signals transmitted by digital terrestrial broadcasting stations. These requirements apply to all broadcasting stations ranging from main stations to terminal relay stations. They are defined by broadcasting station size.

The equivalent ratio of transmitted signals is determined by the equivalent *C*/*N* of the signals transmitted by the upper-node station; interference, multipath characteristics and other propagation characteristics between the stations; thermal noise *C*/*N*, and the equivalent *C*/*N* of the transmitter.

If the required *C*/*N* is not satisfied, another technical measure must be reconsidered: for example, introduction of an equalizer, change of wave relay to TTL or another, and/or change of the relay route should be considered.

4.1.2 Requirements

Table 4.1.1 shows the requirements for the equivalent *C*/*N* of transmitted signals.

TABLE 4.1.1

Requirements for equivalent *C*/*N* of signals transmitted by broadcasting stations

Size of broadcasting station	Required equivalent *C*/*N* of transmitted signals
Stations with output of more than 0.05 W	35 dB or more
Stations with output of not more than 0.05 W	30 dB or more

4.2 Base of consideration

4.2.1 Reason for necessary to define the requirements for the equivalent *C*/*N* of transmitted signals

So far, link budgets have been based on the past implementation of the link budgets of ARIB STD-B31. It has been a rule to ensure that the equivalent *C*/*N* of the signals transmitted by individual transmitting stations are equal to those determined by these link budgets.

On the other hand, for small-sized relay stations, the channels and service areas were considered based on the digital reception simulation described in *Operational Guidelines for Digital Terrestrial Television Broadcasting,* Volume 9 of ARIB TR-B14. This simulation is performed with an assumption that the equivalent *C*/*N* of each transmitted signal is infinite as shown in Table 4.1.2. This means that if the required equivalent *C*/*N* of actual transmitted signals are not guaranteed, the service area may be smaller than that assumed at the time of channel planning.

TABLE 4.1.2

Difference between conventional link budgets and digital reception simulation

Characteristics	Conventional link budgets	Digital reception simulation
Equivalent *C*/*N* of transmitted signals	Locally and individually considered	∞
City noise	700 K	700 K
Surface temperature	300 K	300 K
Noise factor (NF)	3.3 dB	3 dB
Feeder loss	1 dB	1 dB
Deterioration caused by interference and multipath characteristics	25 dB	Individually considered at household representative points
Receiver degradation	28 dB	35 dB

Future link budgets based on ARIB STD-B31 may result in the effect described above. For this reason, the equivalent *C*/*N* to be guaranteed are predefined for signals transmitted by broadcasting stations.

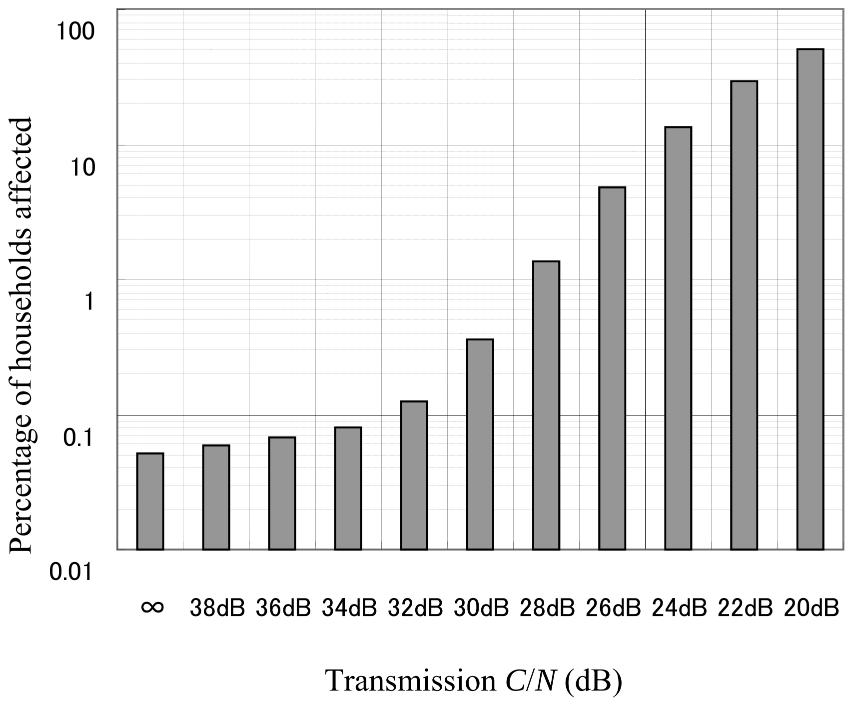
4.2.2 Relation between equivalent *C*/*N* of transmitted signals and the percentages of households affected

Based on the result of the survey on the digital interference conducted in June 2006 by the technical section (small TG) of Joint Council to Promote Terrestrial Digital Broadcasting, how changes in equivalent *C*/*N* affect the percentage of the affected households was determined. Figure 4.1.1 shows the result. The number of channels covered is 9.902 and the percentages of the households affected were calculated through equation (1) below.

$$\text{Percentage of households affected} = \frac{\text{number of households affected for all channels}}{\text{number of households for all channels}} \times 100 \ [\%] \quad (1)$$

FIGURE 4.1.1

Relation between equivalent *C*/*N* of transmitted signals and the percentages of households affected



4.2.3 Equivalent *C*/*N* of transmitted signals appropriate for each broadcasting station size

The relation between the equivalent *C*/*N* of transmitted signals and the percentages of the households affected as shown in Fig. 4.1.1 indicates that if the equivalent *C*/*N* is 35 dB or more, almost no affected households increase in the areas reviewed by the small TG; the link budget must ensure that the equivalent *C*/*N* is not less than this value.

Note that a broadcasting station with low output, which covers a small service area, does not experience a significant decrease in electric field strength due to fading, and therefore does not allow a great decrease in reception *C*/*N* due to the thermal noise at the time of reception. For this reason, for broadcasting stations with output of not more than 0.05 W, the required minimum equivalent *C*/*N* is 30 dB, a less strict requirement.

4.3 Time percentage of broadcast wave relay

4.3.1 Concept

To guarantee the quality of the signals received at a relay station even if the broadcast-wave link for experiences fading, the time percentage that the link budget should allow for is to be defined.

For a link that undergoes interference, consideration is also given to the time percentage for the desired-to-undesired channel ratio (*D*/*U*) to the interference waves.

4.3.2 Requirements for electric field strength, received power, and others

The broadcast-wave relay must allow for a time percentage of 99.9% for the worst month. The link budget must take into account the fading margin of the time percentage. Table 4.2.1 shows the time percentages along with the monthly numbers of hours not covered by the respective time percentages.

TABLE 4.2.1

Time percentages along with monthly hours not covered

Time percentages	Monthly hours not covered
90%	72 hours
99%	7.2 hours
99.9%	43.2 minutes

4.3.3 Concept of *D/U* ratio to interference waves

Even for a link that undergoes interference, the *D*/*U* that acts as the reference for the interference must be satisfied at the time percentage of 99.9%. The *D*/*U* depends on whether or not measured *D*/*U* are available.

(a) Measured *D*/*U* are available

If the 99.9% value of the *D*/*U* can be directly determined from long-term measurements, then that value is used.

(b) No measured *D*/*U* are available

If long-term measured desired and interference waves are available which were not measured at the same time, or if the *D*/*U* must be determined through computer simulation, then the 99.9% value of the *D*/*U* is determined from the individual fading margins of the desired and interference waves.

When the fading margin is not identified, the one described later is used.

4.3.4 Method to determine the *D/U* ratio to interference waves

When no measured *D*/*U* ratio is available, the *D*/*U* ratio is determined as follows.

Where the electric field strength for the time the percentage *T*% involves desired waves represented as *Ed* (*T*%), interference waves as *Eu* (*T*%), both fading margins for the time percentage of 99.9% as fm_1 and fm_2, and the 99.9% value for the fading margin as fm_t which takes into account the two waves at the time that the correlation efficient of the fluctuations in electric field strength of the two types of waves is ρ, the *D*/*U* (99.9%) for the time percentage 99% of the *D*/*U* ratio is determined as follows:

$$D/U(99.9\%) = Ed(50\%) - Eu(50\%) - fm_t \tag{2}$$

In this equation, *Ed* (50%) and *Eu* (50%) represent the electric field strengths at the time percentage of 50%, which may be considered as the electric field strength at normal times. It should be noted, however, that the *D*/*U* ratio in equation (2) is represented as an electric field strength ratio that does not take into consideration the antenna directivity.

fm_t, which takes the two types of waves into account, is determined as follows:

$$fm_t = \sqrt{fm_1^{\,2} + fm_2^{\,2} - 2\rho fm_1 fm_2} \tag{3}$$

For a normal link budget, the fading correlation coefficient ρ in equation (3) should be considered to be 0 assuming that interference waves come through a different route. In this context, ρ = 0 means that there is no fading correlation. The *D*/*U* (99.9%) determined from fm_t is considered to be the *D*/*U* ratio to interference.

$$fm_t = \sqrt{fm_1^{\,2} + fm_2^{\,2}} \tag{4}$$

$$D/U(99.9\%) = Ed(50\%) - Eu(50\%) - \sqrt{fm_1^2 + fm_2^2} \quad (5)$$

If the fading correlation is known, then that value must be used as D/U ratio. If this is the case, $\rho = 1$ when it is a completely positive correlation, or $\rho = -1$ when it is a completely negative correlation.

4.3.5 How to determine the *D*/*U* ratio to multiple interference waves

If the number of interference waves is one, the D/U ratio is determined as above; actually, there is more than one interference wave, however. Below follows a description of the concept about the total D/U ratio with consideration given to multiple interference waves (hereafter referred to as the total D/U ratio).

The total ratio is represented as the power sum of the following two D/U ratios:

(a) D/U_0 to one major interference wave

D/U_0 should be considered to be the D/U ratio when the time percentage for the desired and major interference waves is 99.9%. When no measured D/U ratio is available, it should be considered that there is no fading correlation (correlation coefficient $\rho = 0$) as shown in equation (5).

(b) D/U_i to each of the other interference waves

D/U_i, which is the ratio to each interference wave, should be considered to be the ratio between the electric field strength Ed (99.9%) at the time percentage of 99.9% and the electric field strength Eu_i (50%) at the time percentage of 50%.

$$D/U_i = Ed(99.9\%) - Eu_i(50\%) \quad (6)$$

$$\text{Here, } Ed(99.9\%) = Ed(50\%) - fm_1$$

If the number of interference waves is n, equation (6) is used to determine D/U_1, D/U_2, D/U_3, …, and D/U_n.

The total D/U ratio to multiple interference waves should be considered to be the power sum of D/U_0 determined in (a) and D/U_1, D/U_2, D/U_3, …, and D/U_n determined in (b).

4.4 Electric field strength ratio and *D*/*U* ratio

Assessment of interference levels requires determination of the D/U ratio. When determining the D/U ratio, consideration must be given to the electric field strength ratio and the reception antenna directivity.

4.4.1 Electric field strength ratio

The electric field strength ratio is obtained from equation (7):

$$\text{Electric field strength ratio} = E_d - E_u \quad (7)$$

where:

- E_d: Electric field strength of desired waves (dBμV/m)
- E_u: Electric field strength of interference waves (dBμV/m)

4.4.2 DU ratio

The D/U ratio is obtained from equation (8):

$$D/U \text{ ratio } (D/U) = (E_d - D(\theta_d)) - (E_u - D(\theta_u)) - X \quad (8)$$

where:

E_d: Electric field strength of desired waves (dBμV/m)

E_u: Electric field strength of interference waves (dBμV/m)

$D(\theta_d)$: Reception-antenna directivity attenuation in the desired-wave direction (dB)

θ_d: Direction from which the desired waves come toward the front of the reception antenna

$D(\theta_u)$: Reception-antenna directivity attenuation in the interference-wave direction (dB)

θ_u: Direction from which the interference waves come toward the front of the reception antenna

X: Polarization-plane effect (dB)

Normally, $D(\theta_d) = D(0) = 0$ dB because the reception antenna is oriented to the desired waves.

When measuring the arrival status of interference waves in a station setup survey, extra attention must be paid to the directivity of the reception antenna. When obtaining the electric field strength of the interference waves from measurements made with the reception antenna oriented to the desired waves, in particular, the directivity attenuation must be correctly converted using the antenna whose characteristics are known.

4.5 Time percentage of the *D*/*U* ratio for a link that undergoes interference

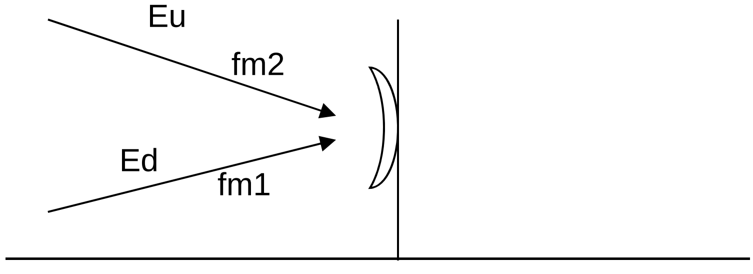
Figure 4.5.1 diagrammatically shows how a link that undergoes interference receives signals. Assume that the electric field strength of the fading is normally distributed in terms of time. If the time dispersions (standard deviations) of the fading for multiple paths fm_1 and fm_2 are represented as σ_1 and σ_2, and the fading correlation between them as ρ, then the time dispersion (standard deviation) σ_t of fm_t of the difference between the two waves is expressed as:

$$\sigma_t^2 = \sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2$$

$$\sigma_t = \sqrt{\sigma_1^2 + \sigma_2^2 - 2\rho\sigma_1\sigma_2} \qquad (9)$$

FIGURE 4.5.1

Link that receives interference waves



The x% fading of each path is represented as follows using a coefficient α corresponding to x%. If X = 99% (1%), then α = 2.33. If X = 99.9% (0.1%), then α = 3.09.

$$fm_1 = \alpha\sigma_1$$

$$fm_2 = \alpha\sigma_2 \qquad (10)$$

$$fm_t = \alpha\sigma_t$$

Equation (9) can be substituted into equation (10) to erase α and σ_1, σ_2, and σ_t to obtain the fading margin fm_t that takes the two waves into consideration.

$$fm_t = \sqrt{fm_1^2 + fm_2^2 - 2\rho fm_1 fm_2} \tag{11}$$

When ρ = 0, 0.5, –1, or 1, fm_t can be obtained from equation (11) as follows:

(a) ρ = 0 (no fading correlation)

$$fm_t = \sqrt{fm_1^2 + fm_2^2} \tag{12}$$

(b) ρ = 0.5

$$fm_t = \sqrt{fm_1^2 + fm_2^2 - fm_1 fm_2} \tag{13}$$

(c) ρ = –1 (fading correlation: completely negative –1)

$$\begin{aligned} fm_t &= \sqrt{fm_1^2 + fm_2^2 + 2\, fm_1 fm_2} \\ &= fm_1 + fm_2 \end{aligned} \tag{14}$$

(d) ρ = 1 (fading correlation: completely positive)

$$\begin{aligned} fm_t &= \sqrt{fm_1^2 + fm_2^2 - 2\, fm_1 fm_2} \\ &= |\, fm_1 - fm_2 \,| \end{aligned} \tag{15}$$

4.6 Lower limit of received power

4.6.1 Concept

To secure a required *C*/*N*, the lower limit of received power is defined.

The fading margin is taken into consideration to secure a required *C*/*N* even at descending fading. The received power at ascending fading must fall within the range of rated output of the receiver.

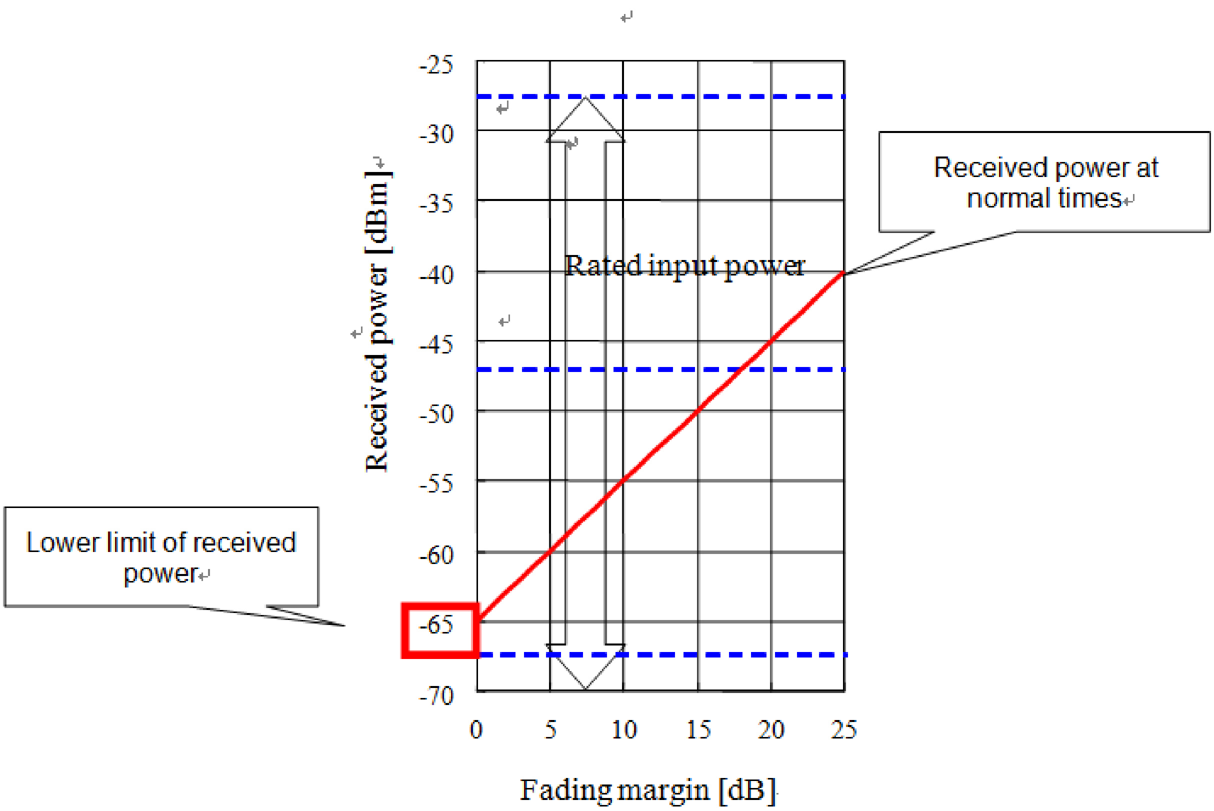
4.6.2 Requirements

The required received power is defined as power input into the receiver; the lower limit of it is –65 dBm, which is the minimum value required to ensure that the reception *C*/*N* is at least 35 dB.

For a link that undergoes fading, however, the fading margin is added to the lower received power limit of –65 dB; the obtained value should be used as the received power at normal times (when the time percentage is 50%) in order to ensure that the reception *C*/*N* is at least 35 dB even at descending fading, equivalent to 99.9% of the reception electric field strength. Figure 4.6.1 shows the relation between the fading margin and the received power at normal times as a red line.

FIGURE 4.6.1

Fading margin and received power at normal times



4.6.3 Base of consideration

If the NF of the receiver is 6 dB, then the thermal noise is approximately –100 dBm. To ensure that the reception *C*/*N* ratio is at least 35 dB at descending fading, the lower limit *Pmin* of received power must be as follows:

$$\text{Lower received-power limit } Pmin = -100 \text{ dBm} + 35 \text{ dB} = -65 \text{ dBm} \quad (16)$$

For a link with a fading margin of *fm* (dB), the received power at normal times (when the time percentage is 50%) is:

$$\text{Lower received-power limit } Pmin = -100 \text{ dBm} + 35 \text{ dB} + fm = -65 \text{ dBm} + fm \quad (17)$$

For space-diversity (SD) reception, the SD improvement *Ip*_SD (dB) is taken into account. As a rule, the SD improvement *Ip*_SD must be identified based on measurements.

$$\text{Lower received-power limit } Pmin = -100 \text{ dBm} + 35 \text{ dB} + fm - Ip\_SD = -65 \text{ dBm} + fm - Ip\_SD \quad (18)$$

4.7 Design of reception systems

4.7.1 Concept

With the lower limit of received power and interferences used as measures, reception antenna types, feeder lines, and transmitter lines must be reviewed.

4.7.2 Requirements

The lower limit of received power indicated in § 4.6 is used as the criterion for selecting reception antennas. The selection of reception antennas must be based on the lower limit of received power, electric field strength at normal times, and losses of the feeder lines, branching filter, and distributor. For a relay station that performs transmission and reception separately, the use of coaxial IF transmission or non-power-supply-type optical transmission should be also considered.

If the system is affected by interference waves, the required directivity attenuation is used as the criterion for selection of reception antennas. The required directivity attenuation is determined from the electric field strength and incoming direction of the interference waves and the required D/U ratio.

4.7.3 Base of consideration

(a) Reception system determined from the lower limit of received power

The standard reception system for relaying broadcast waves is supposed to be a 50 Ω reception system based on a parabolic antenna as shown in Fig. 4.7.1.

When the electric field strength at normal times and the absolute gain of the reception antenna are E (dBμV/m) and G (dBi), respectively, the received power Pr (dBm) is determined as follows:

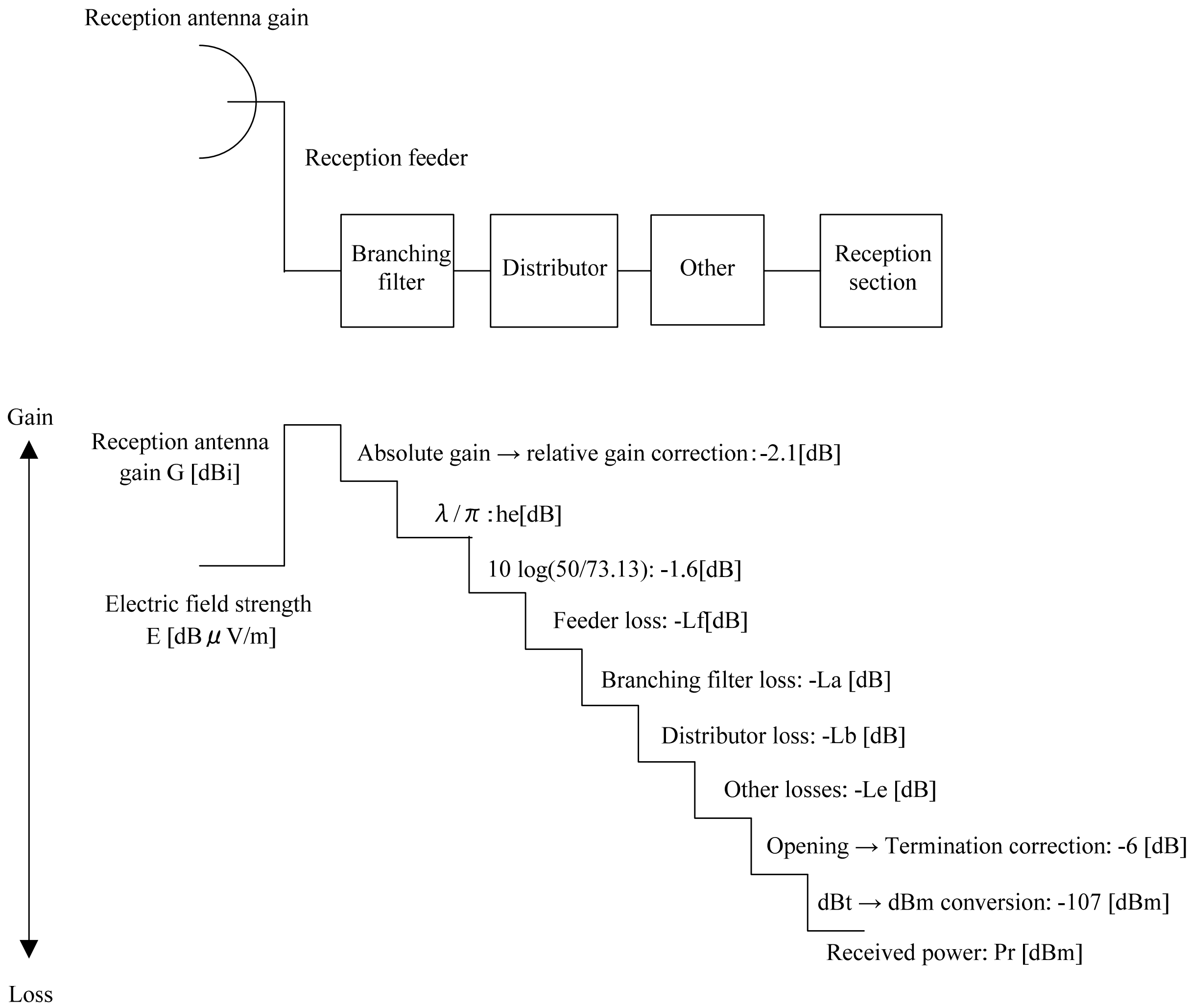
$$Pr = E + G - 2.1 - 1.6 + he - Lf - La - Lb - Le - 6 - 107 \text{ (dBm)} \quad (19)$$

where:

- he: 20 log (λ/π) (dB)
- Lf: Feeder loss (dB)
- La: Branching filter loss (dB)
- Lb: Distributor loss (dB)
- Le: Other losses (dB)
- G – 2.1: Relative gain (dBd)
- –1.6: Radiation resistance conversion 10 log (50/73.13) (for a feeder impedance of 50 Ω) (dB)
- –6: Converted termination voltage (dB)
- –107: dBm conversion (for a feeder impedance of 50 Ω) (dB).

FIGURE 4.7.1

Reception system and received power for relaying broadcast waves



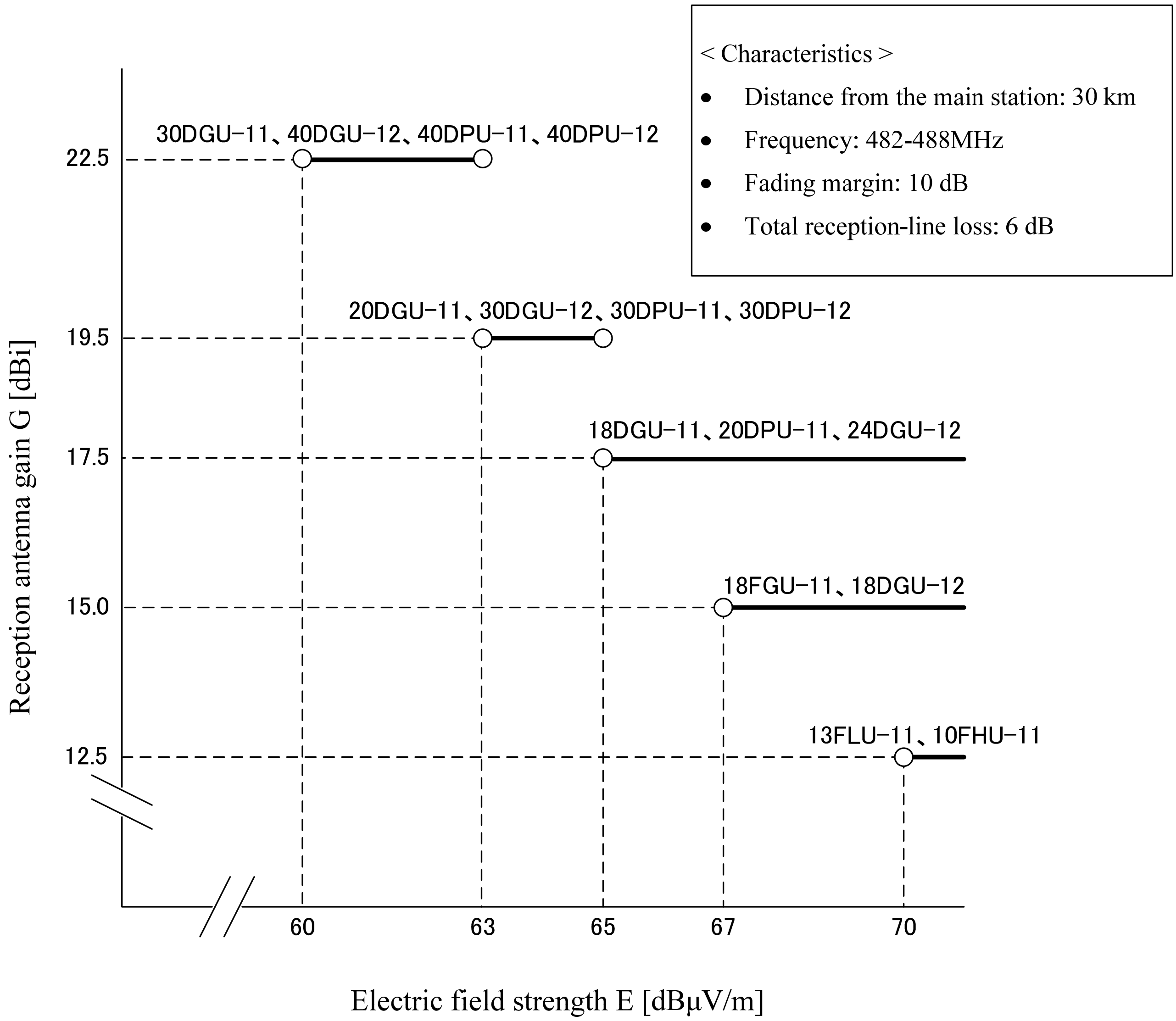
If the lower limit of received power and the fading margin is *Pmin* and *fm*, respectively, then the gain of the reception antenna should be determined so that the received power *Pr* will be as follows:

$$Pr \geq Pmin + fm \tag{20}$$

As the example reception antenna selection in Fig. 4.7.2 shows, the selection must be made so that the reception antenna will provide a gain appropriate for the electric field strength.

FIGURE 4.7.2

Example of reception antenna selection

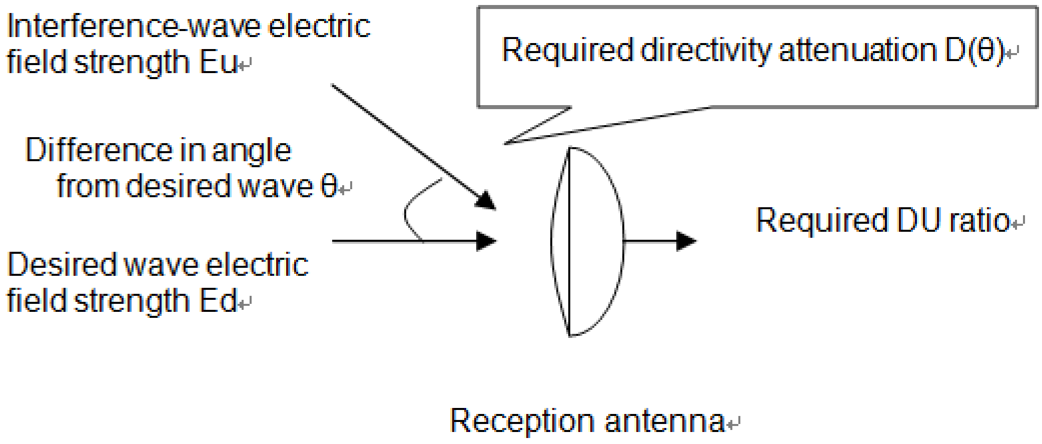


(b) Reception system determined from the incoming direction of the interference waves

Figure 4.7.3 diagrammatically shows the relation between desired and interference waves coming to a reception antenna. Interference waves arrive at the antenna with a certain difference in angle from desired waves.

FIGURE 4.7.3

Relation between desired and interference waves coming to a reception antenna



When the electric field strength of the desired waves is presented as *Ed*, the electric field length of the interference waves as *Eu*, the fading margin as *fm*, and the required directivity attenuation of the reception antenna in the interference-wave direction as $D(\theta)$, their relation with the required D/U ratio is expressed in equation (21):

$$Ed - Eu - fm + D(\theta) \geq D/U \tag{21}$$

5 Propagation characteristics of broadcast wave relaying

5.1 Multipath interference

5.1.1 Concept

For multipath interference caused by reflections and diffraction occurring in the propagation path, the equivalent C/N is determined from a chart modelled according to the propagation distance and incorporated into the link budget.

If the signal waves from the upper-node station are diffractive, extra attention must be paid to the multipath interference because the diffraction is expected to increase the effect of the ambient reflections (multipath waves). If this is the case, it is essential to measure the multipath interference.

5.1.2 Requirements

As the required equivalent C/N for the multipath interference, the values in Fig. 5.1.1 are used according to the propagation distance.

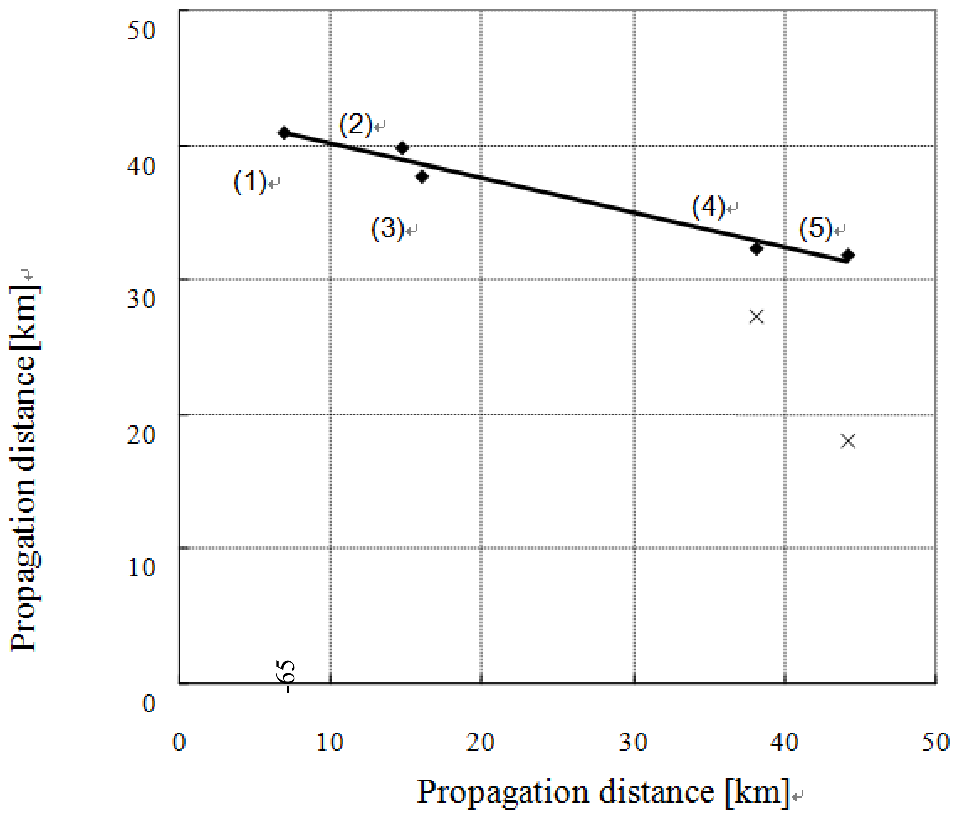
5.1.3 Base of consideration

Figure 5.1.1 shows modelled results of the past surveys on propagation characteristics.

The Figure provides guidelines as of January 2008, which will incorporate the results of the future network surveys and measurements of improved station-to-station propagation characteristics.

FIGURE 5.1.1

Propagation distances and equivalent *C*/*N* of multipath interference



Measured points
(1) Haseyama → Aoyama,
(2) Ise → Isobe,
(3) Isobe → Nansei,
(4) Kanazawa → Hakui,
(5) Kurume → Omuta.

The x's represent the equivalent *C*/*N* at fading, where the electric field strength is for a 99% time percentage of (4) and (5).

5.2 Necessity for multipath equalization

For OFDM signals, multipath interference causes ripples to occur within the band. Figure 5.2.1 diagrammatically shows the effect of multipath interference. This interference degrades the thermal noise *C*/*N* of the subcarrier with decreased amplitude, and therefore increases (degrades) the required *C*/*N* of the entire signals.

FIGURE 5.2.1

Effect of multipath interference

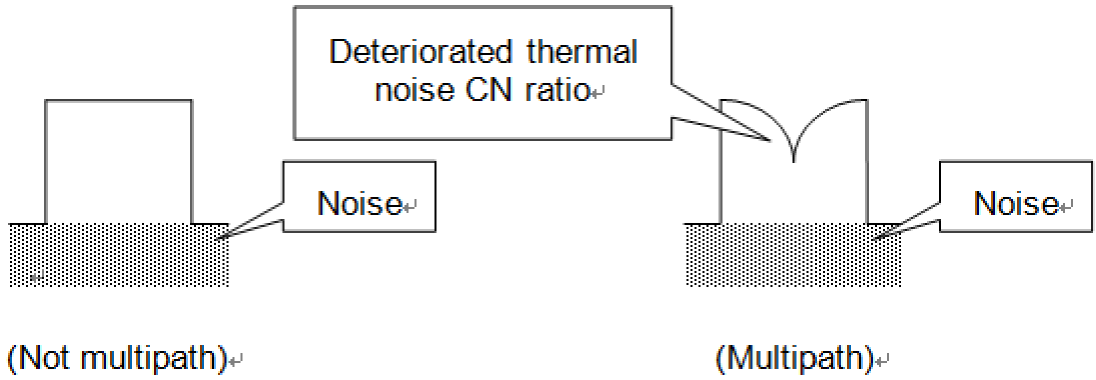
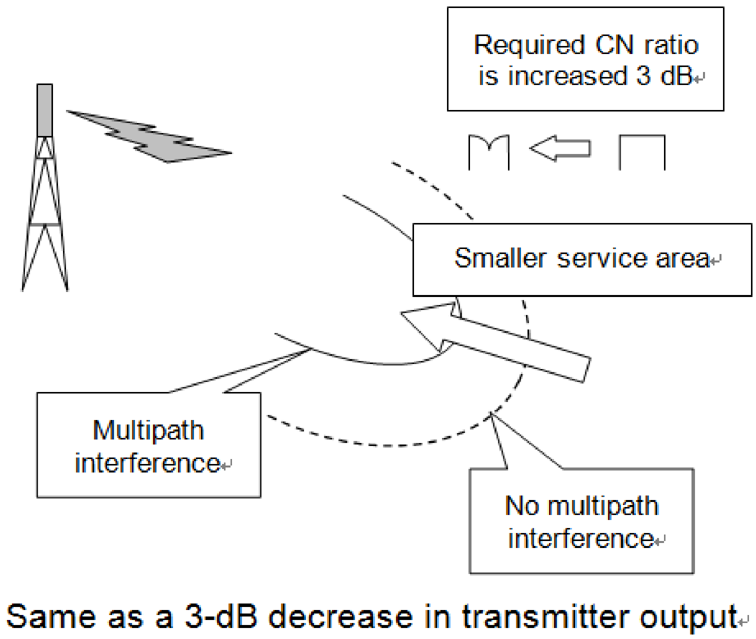


Figure 5.2.2 diagrammatically shows how multipath interference affects the service area. For example, consider a service area where the minimum allowable signal level is 51 (dBµV/m) when no multipath interference exits. If the required *C*/*N* of the signals is increased 3 dB by multipath interference, then the minimum allowable signal level in the area is 54 (dBµV/m). In other words, the latter case may be considered the same as a case where the transmission output is decreased 3 dB; it is important for relay stations to have the multiple paths equalized in order to secure the service area.

FIGURE 5.2.2

Effect of multiple paths on service area



5.3 Fading

5.3.1 Concept

In general, fading is likely to increase according to an increase in propagation distance. When no measurement is available, the fading must be obtained from Fig. 5.3.1.

For descending fading for desired waves, the 99.9% values in Fig. 5.3.1 must be used. For ascending fading for interference waves, the 98.5% value in Fig. 5.3.1 must be used if a ground propagation path is used or 99.9% values in Fig. 5.3.1 must be used if any other path is used.

These are guidelines as of April 2007, which will incorporate the results of the future network surveys and measurements of improved station-to-station propagation characteristics.

5.3.2 Requirements

When no measurement is available, Fig. 5.3.1 must be used as the criteria.

5.3.3 Base of consideration

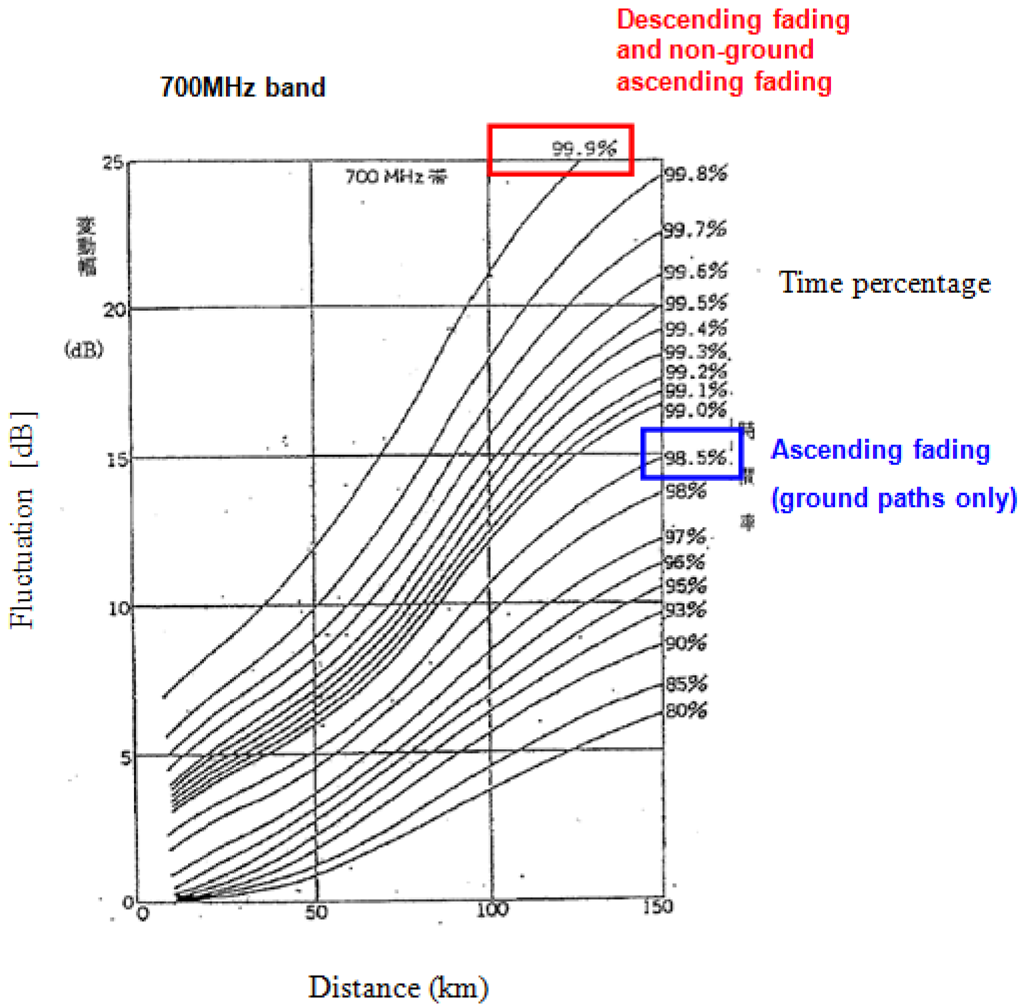
For ascending fading, it was decided to use the 98.5% values based on the past measurements only when a ground propagation path is used (the time percentage remains 99.9%, however). For the other propagation paths, the guidelines will also incorporate the results of the future network surveys and measurements of improved station-to-station propagation characteristics.

5.3.4 Types of propagation paths

A ground propagation path refers to a path with not more than 30% of marine transmission and/or inland-water routes in it. See the section about the propagation indicated by main-station interference assessment tool. Note that a marine propagation path is defined as a path with more than 70% of marine and/or inland-water routes and the others as the other propagation paths.

FIGURE 5.3.1

Relation between propagation distance and fading amount



Source: Tatsuo Hayashi, UHF Television Transmission and Reception.

5.4 Co-channel Interference

5.4.1 Concept

Co-channel interference waves are grouped into the following three categories: SFN waves, digital waves, and analogue waves. The equivalent *C*/*N* of interference waves can be obtained from the *D*/*U* ratios of desired and interference waves.

When more than one interference wave exists, the equivalent *C*/*N* is obtained from the *D*/*U* ratio after the individual power values are summed up.

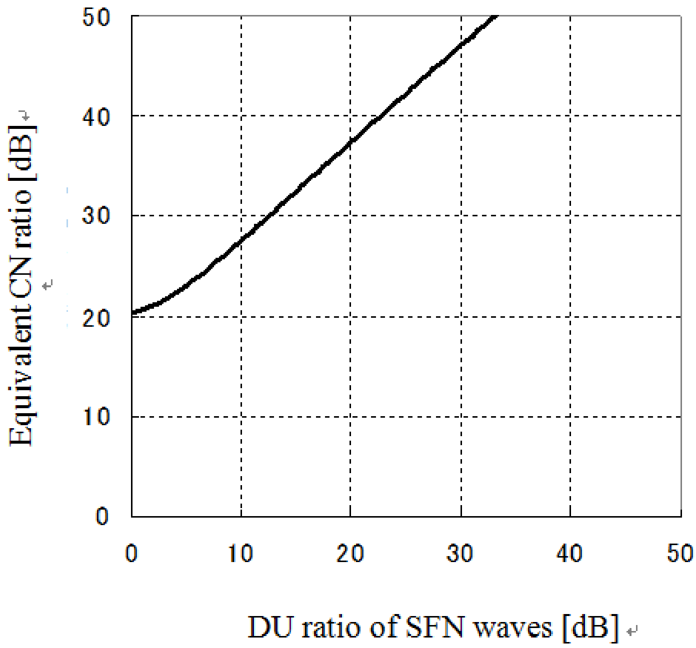
5.4.2 Requirements

(a) SFN waves

SFN waves refer to interference waves from a different broadcasting station included in a given SFN network. Figure 5.4.1 shows the relation between the *D*/*U* ratios of SFN waves and equivalent *C*/*N*.

FIGURE 5.4.1

Relation between *D*/*U* ratios of SFN waves and equivalent *C*/*N*

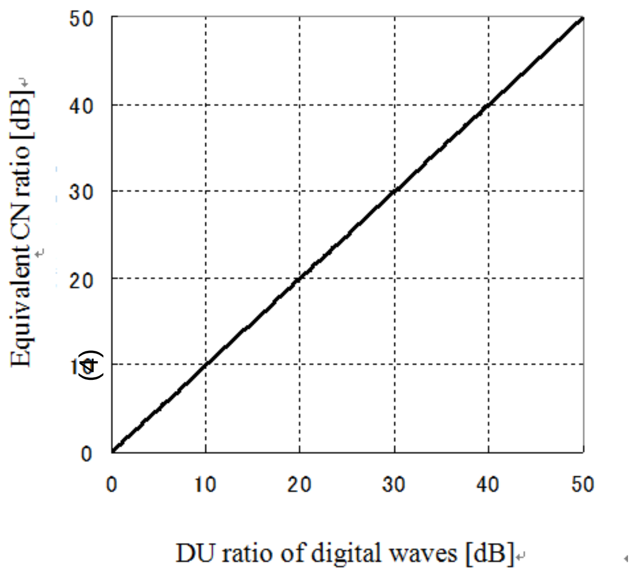


(b) Digital waves

Digital waves refer to interference waves from a broadcasting station not included in a given SFN network. Figure 5.4.2 shows the relation between the *D*/*U* ratios of digital waves and equivalent *C*/*N*.

FIGURE 5.4.2

Relation between *D*/*U* ratios of digital waves and equivalent *C*/*N*

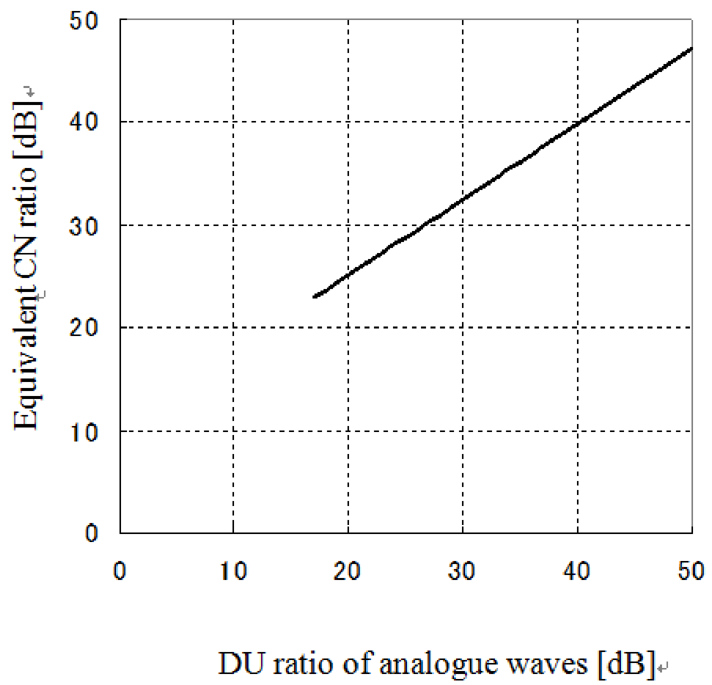


(c) Analogue waves

Analogue waves refer to interference waves of analogue broadcasting. Figure 5.4.3 shows the relation between the *D*/*U* ratios of analogue waves and equivalent *C*/*N*.

FIGURE 5.4.3

Relation between *D*/*U* ratios of analogue waves and equivalent *C*/*N*



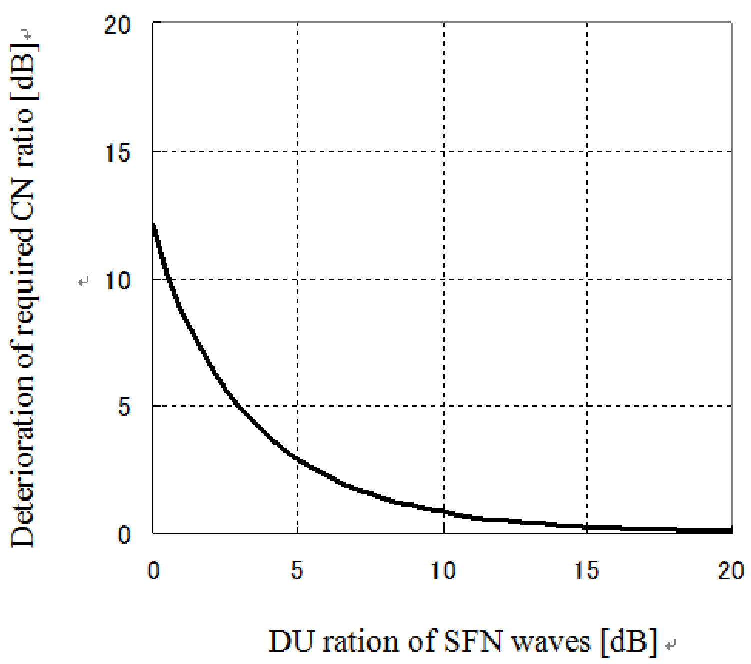
5.4.3 Base of consideration

(a) SFN waves

The model of ARIB TR-B14 is applied. When the code rate is 3/4, the required *C*/*N* deteriorates as follows:

FIGURE 5.4.4

Relation between *D*/*U* ratio of SFN waves and deterioration of the required equivalent *C*/*N*



The equivalent C/N is obtained from equation (22) considering that the required C/N is 20.1 dB.

$$\text{Required } C/N = -10\log\left(10^{-\frac{20.1}{10}} - 10^{-\frac{20.1+\text{deterioration of required } C/N}{10}}\right) \tag{22}$$

(b) Digital waves

Digital waves are treated as equivalent to Gaussian noise. It should be considered that the D/U ratio between the desired and digital waves is equal to the equivalent C/N of digital waves.

(c) Analogue waves

The equivalent C/N is defined based on measurements. It should be noted, however, that no adaptation treatment (disappearance soft decision treatment) was carried out on the receiver used for the measurements.

5.5 Adjacent-channel interference

5.5.1 Concept

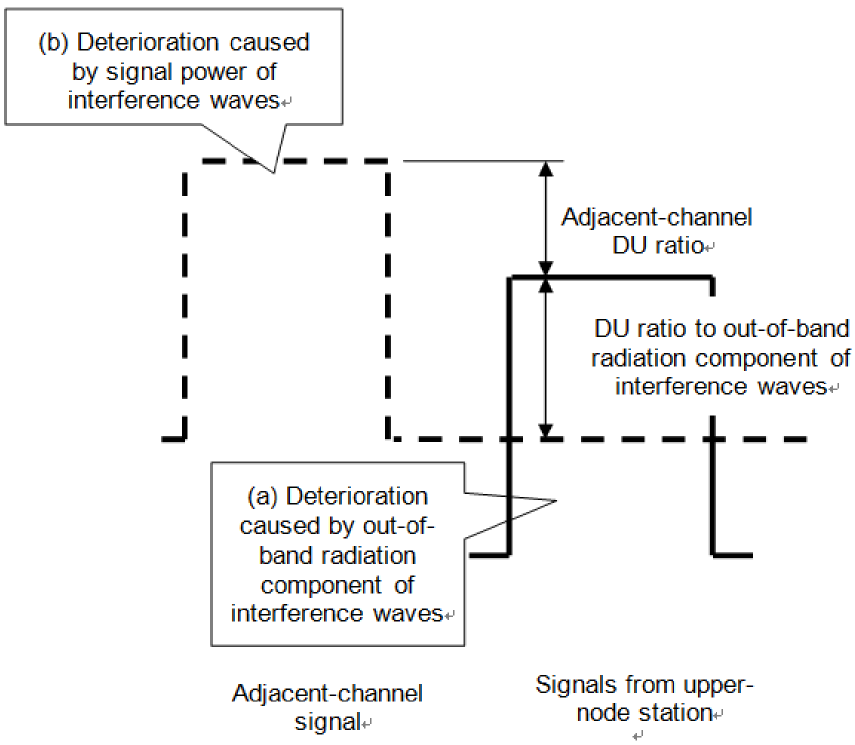
Adjacent-channel interference involves the following two factors:

(a) Deterioration of the equivalent C/N caused by leakage of the out-of-band (OoB) radiation component in the interference waves into the band of the desired wave (deterioration caused by the out-of-band radiation component).

(b) Deterioration of the equivalent C/N inside the receiver, which is caused when interference waves with received power higher than that of the desired wave are input into the receiver (deterioration caused by the signal power of the interference waves).

FIGURE 5.5.1

Adjacent-channel interference



5.5.2 Base of consideration

For (a) deterioration caused by the out-of-band radiation component and (b) deterioration caused by the signal power of the interference waves, the equivalent *C*/*N* are defined based on measurements. According to the *D*/*U* ratios of the desired waves and adjacent-channel interference waves, the equivalent *C*/*N* due to (a) and that due to (b) are calculated and then the sum of them is defined as the deterioration caused by the adjacent-channel interference waves.

It is known that (b) depends on the characteristics of the receiver to be used. The reciever data from the broadcasters will be collected and incorporated. For analogue adjacent interference, only data is available about the cases where no filter is available. This data will also be updated.

Figures 5.5.2 through 5.5.5 show digital adjacent interference and the characteristics of the equivalent *C*/*N* to the analogue adjacent interference.

FIGURE 5.5.2

***D/U* ratios of digital adjacent-channel waves and equivalent *C/N* (one-side adjacent)**

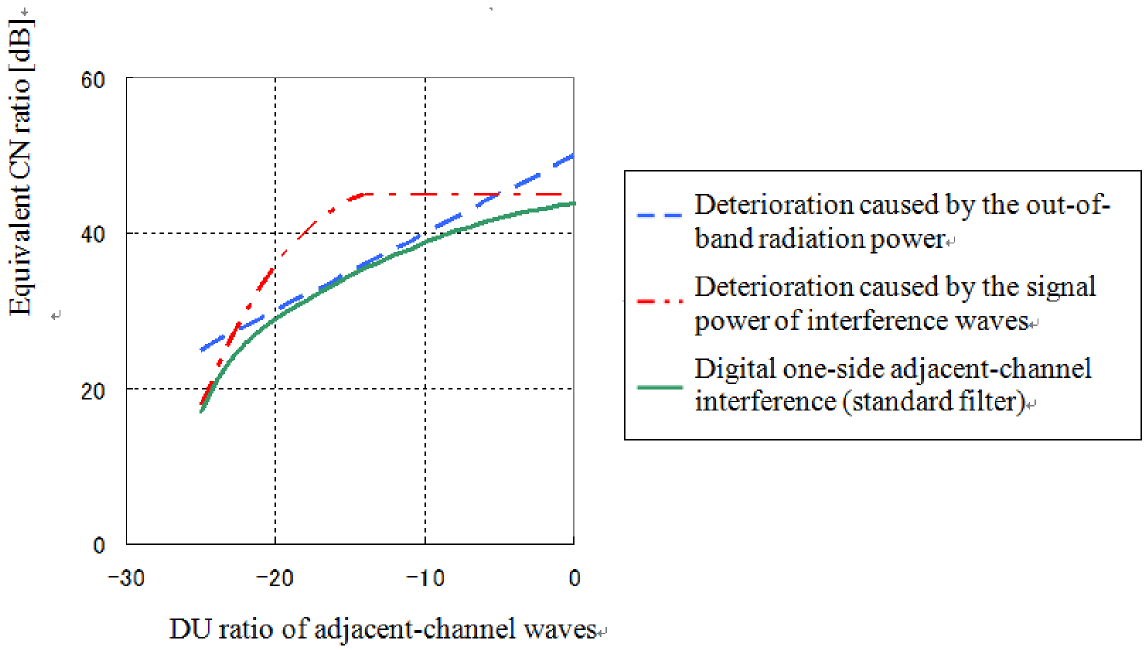


FIGURE 5.5.3

***D/U* ratios of digital adjacent-channel waves and equivalent *C/N* (both-side adjacent)**

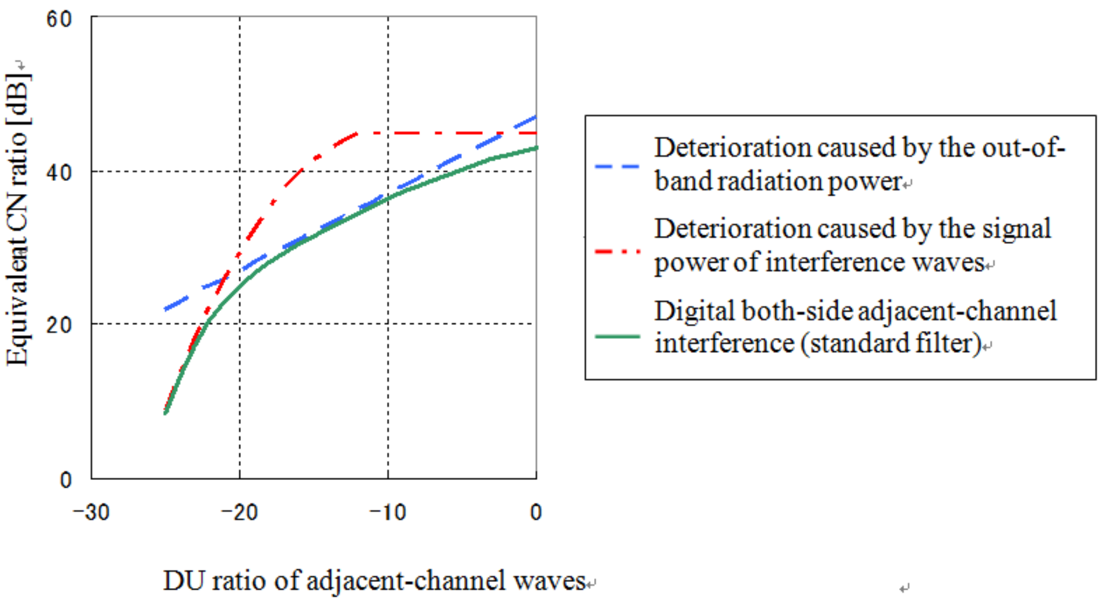


FIGURE 5.5.4

***D/U* ratios of analogue adjacent-channel waves and equivalent *C/N* (one-side adjacent)**

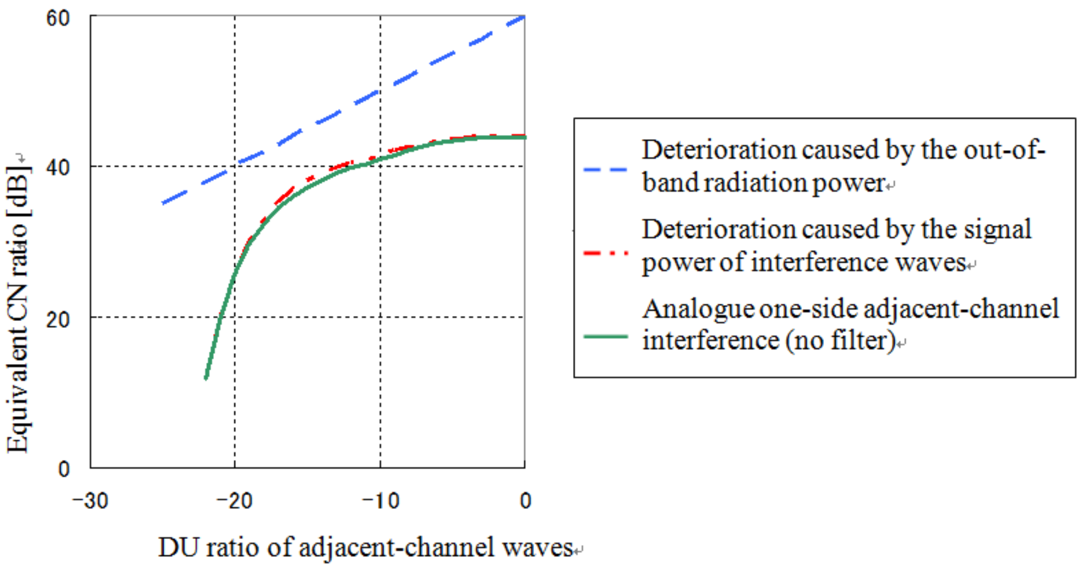
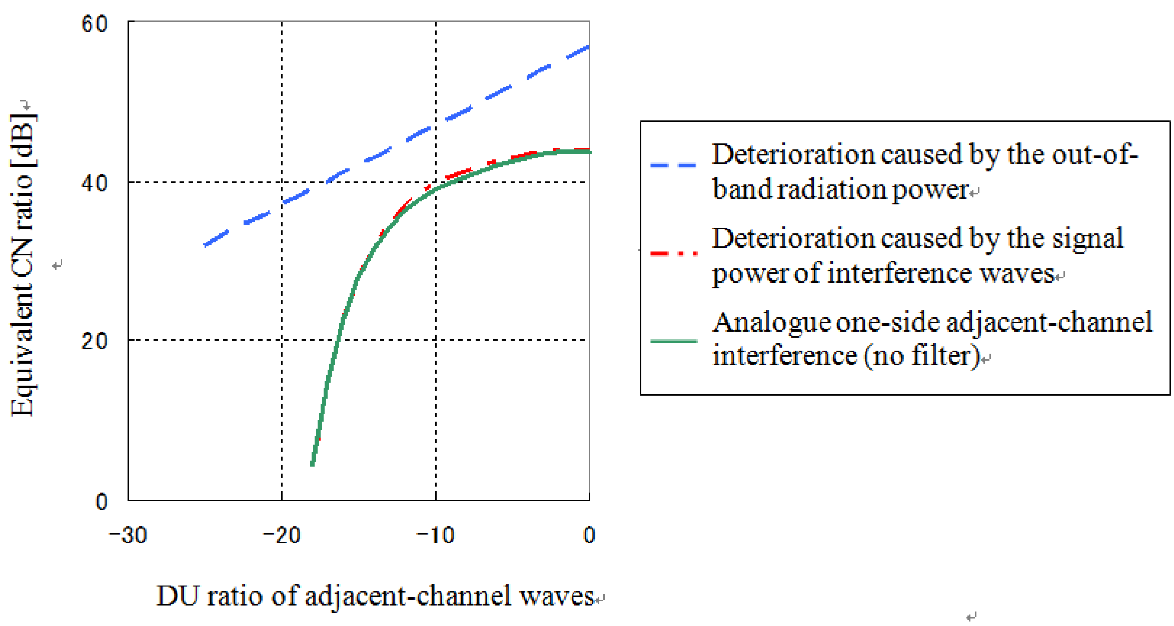


FIGURE 5.5.5

***D/U* ratios of analogue adjacent-channel waves and equivalent *C/N* (both-side adjacent)**



5.6 SFN coupling loop interference

5.6.1 Concept

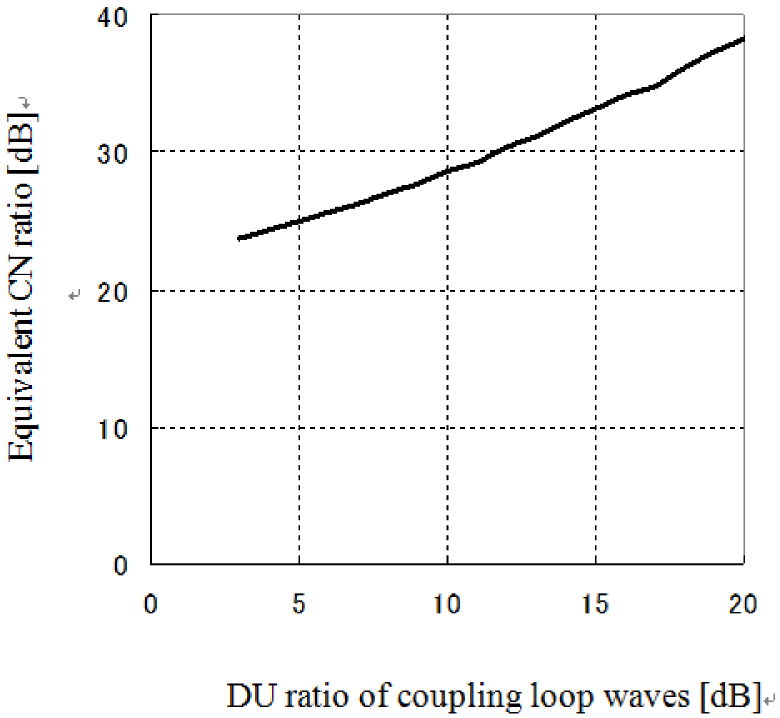
A SFN broadcast wave relay station undergoes signal deterioration caused by the reception of self-transmitted radio waves. The SFN coupling loop interference is assessed as the equivalent *C*/*N* according to the *D*/*U* ratio of the coupling loop waves to the waves from the upper-node station. When it is assessed, the fading of the radio waves from the upper-node station and the fluctuations of the coupling loop waves are also taken into account.

5.6.2 Requirements

The equivalent *C*/*N* of SFN coupling loop interference is determined by the *D*/*U* ratio of the coupling loop waves to the radio waves from the upper-node station as shown in Fig. 5.6.1.

FIGURE 5.6.1

Relation between *D*/*U* ratios of coupling loop waves and equivalent *C*/*N*



5.6.3 Base of consideration

The equivalent *C*/*N* is defined based on measurements. Figure 5.6.1 shows the equivalent *C*/*N* of single coupling loop waves.

5.7 Interference from the image frequency (VHF-UHF separation interference)

The receiver for terrestrial digital broadcasting generates IF signals using a local oscillator with a frequency which is 37.15 MHz higher than that of the RF signal. In this process, signals, if included in the image frequency (74.3 MHz (= 37.15 MHz × 2) higher than that of desired wave), may be frequency converted into the band of the IF signal and interfere. This is called image interference. Figure 5.7.1 shows the principle of it.

The image frequency is equivalent to the channel which is 12 or 13 channels higher than that of desired wave. If the transmission channel of the affected station is this channel, in particular, countermeasures are required.

In image interference, the *D*/*U* ratio of the reception conversion input is also the *D*/*U* ratio of the IF signal. To be able to ignore the effect of image interference on the IF signal, the *D*/*U* ratios shown in Table 5.7.1 must be secured at the time of reception conversion input. These *D*/*U* ratios ensure that the modulation error ratio (MER) of each subcarrier for the IF signal that suffered the image interference determined through simulation is at least 40 dB.

TABLE 5.7.1

Required *D*/*U* ratios for image interference (temporary values)

Interfering wave type	Required *D*/*U* ratio
Digital wave	45 dB
Analogue wave	60 dB

The Orange Book does not define any characteristics of the input filter at the image frequency. For typical standard filters, the attenuation of frequencies around the image frequency is 40 dB or so. If this is insufficient, the *D*/*U* ratio must be secured by, for example, inserting a low-frequency pass filter (LPF) to secure a required attenuation or reviewing the reception system (the type of the reception antenna, relocation of the reception site, etc.).

FIGURE 5.7.1

Interference from the image frequency
(Case where the reception channel that suffers interference from digital waves is Channel 39)

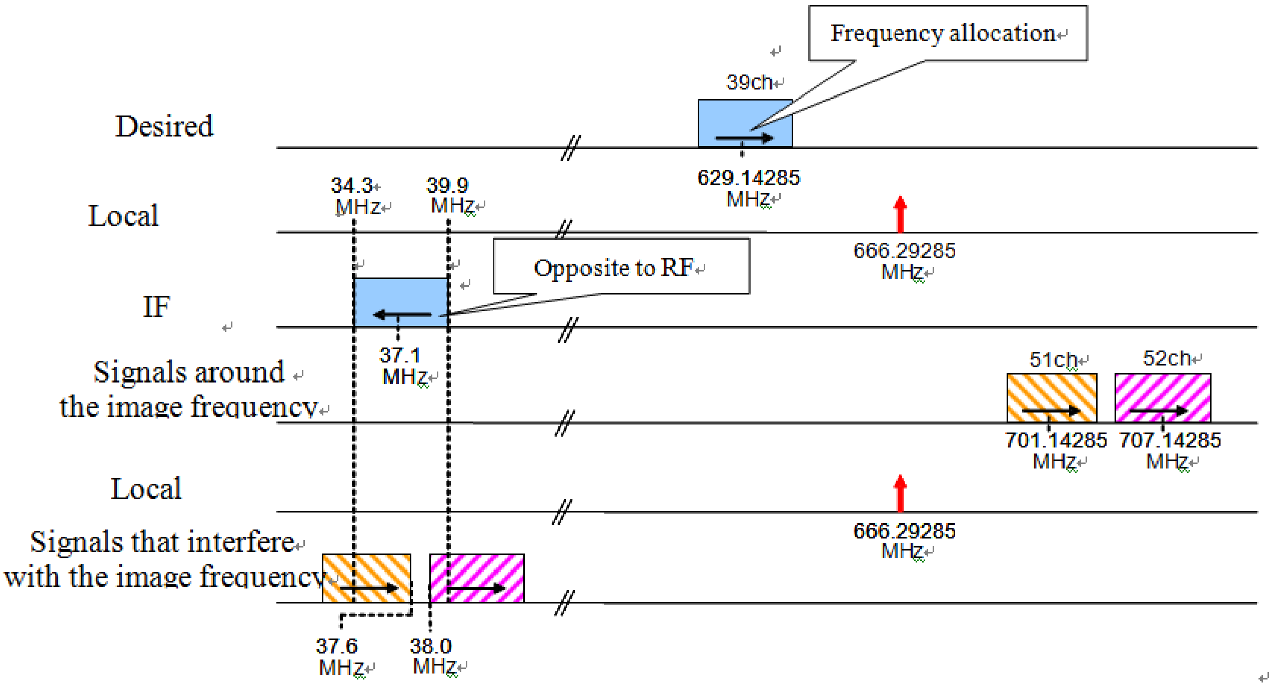
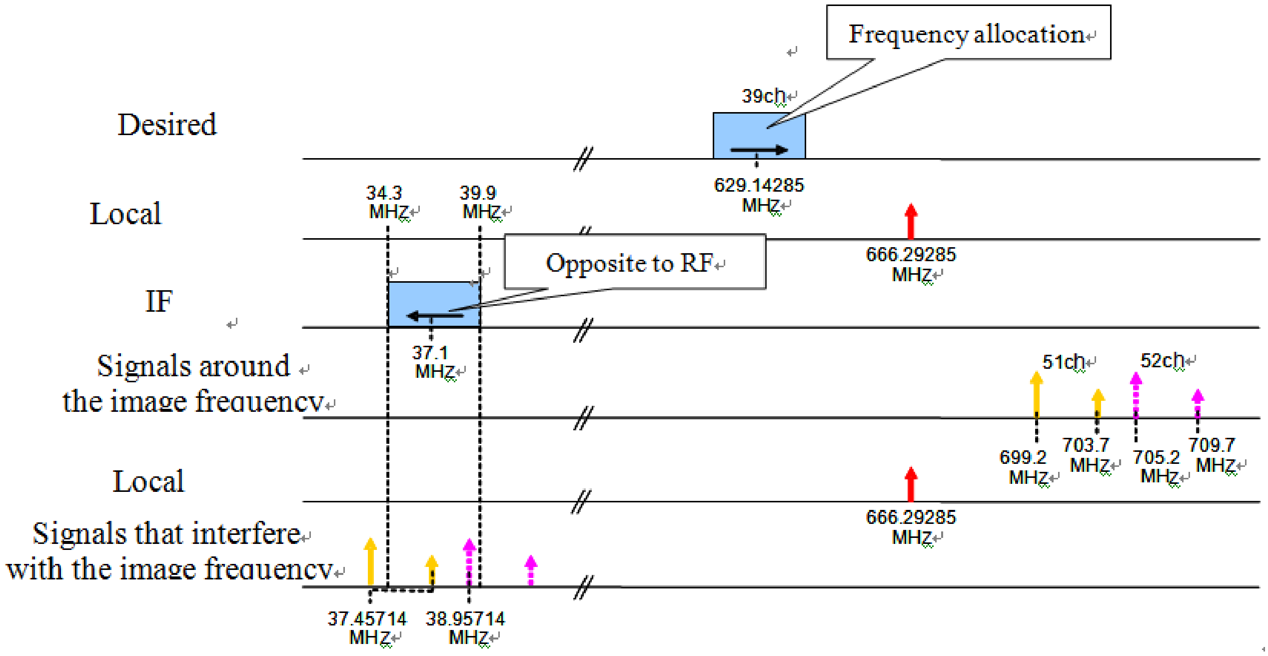


FIGURE 5.7.2

Interference from the image frequency
(Case where the reception channel that suffers interference from analogue waves is Channel 39)



6 Measures against interference deterioration

6.1 Filter-based measures against adjacent-channel interference

6.1.1 Concept

The deterioration caused by the out-of-band radiation component is controlled with the output filter at the side that causes interference. The deterioration caused by the signal power of the interference waves is controlled with the filter at the side that receives interference.

6.1.2 Requirements

The required filter type must be selected according to the *D*/*U* ratio of the adjacent-channel to the desired wave so that the equivalent *C*/*N* of the adjacent-channel interference will be at least 35 dB.

The *D*/*U* ratio of the adjacent-channel waves to the desired must take into account the fading of the desired waves and the fluctuations of the coupling loop waves. Note that as the fluctuation range for the coupling loop waves, 7 dB should be allowed for, the same as the fluctuation range for the SFN coupling loop waves.

Tables 6.1.1 to 6.1.4 provide guidelines on the filter-based measures. They show cases where the input filter is selected to ensure that the deterioration caused by the signal power of the interference waves is at least 38 dB of equivalent *C*/*N* and the output filter is selected to ensure that the deterioration caused by the OoB radiation component is at least 38 dB of equivalent *C*/*N*. Note that since the *D*/*U* ratios cover the fluctuations of the coupling loop waves, the *D*/*U* ratio at normal times must be 7 dB higher than this value.

TABLE 6.1.1

Guidelines on filter-based measures against analogue adjacent interference (one-side adjacent)

Filter type	Input filter	Output filter
Standard	$D/U \geq -15$ dB	$D/U \geq -22$ dB
Type I	-25 dB $\leq D/U < -15$ dB	Details to be reviewed(1)
Type II	-30 dB $\leq D/U < -25$ dB	(2)

TABLE 6.1.2

Guidelines on filter-based measures against analogue adjacent interference (both-side adjacent)

Filter type	Input filter	Output filter
Standard	$D/U \geq -11$ dB	$D/U \geq -19$ dB
Type I	-21 dB $\leq D/U < -11$ dB	Details to be reviewed(1)
Type II	-26 dB $\leq D/U < -21$ dB	(2)

(1) As a rule, no measures to be taken for the output filters for analogue broadcasting.

(2) According to the facility maintenance requirements, output filters of Type II not to be selected.

TABLE 6.1.3

Guidelines on filter-based measures against digital adjacent interference (one-side adjacent)

Filter type	Input filter	Output filter
Standard	$D/U \geq -19$ dB	$D/U \geq -12$ dB
Type I	-29 dB $\leq D/U < -19$ dB	-22 dB $\leq D/U < -12$ dB
Type II	-34 dB $\leq D/U < -29$ dB	(2)

TABLE 6.1.4

Guidelines on filter-based measures against digital adjacent interference (both-side adjacent)

Filter type	Input filter	Output filter
Standard	$D/U \geq -16$ dB	$D/U \geq -9$ dB
Type I	-26 dB $\leq D/U < -16$ dB	-19 dB $\leq D/U < -9$ dB
Type II	-31 dB $\leq D/U < -26$ dB	(2)

(2) According to the facility maintenance requirements, output filters of Type II not to be selected.

6.1.3 Base of consideration

The characteristics listed in § 5.5.2 (in Figs 5.5.2 through 5.5.5) are used as the criteria. For improvements based on filter for removing adjacent-channel waves, the requirements for adjacent-channel *D*/*U* ratios will be less strict as shown in Table 6.1.5. The relaxation level of the *D*/*U* ratio requirements should be the attenuation level within the band at f_c ± 3.2MHz.

TABLE 6.1.5

Characteristics of filter (according to Orange Book) and relaxation level of *D*/*U* ratios

		Standard input filters	Input Filter I for removing adjacent waves	Input Filter II for removing adjacent waves
Relaxation level of *D*/*U* ratios		0 dB	10 dB	15 dB
OoB attenuation	f_c ± 3.2 MHz	–	10 dB or more	15 dB or more

6.2 Equalizer-based measures

6.2.1 Concept

Broadcast wave relaying should basically use equalizers. The equalizer type is selected based on the station-to-station propagation characteristics and the result of the link budget. The selection criteria for equalizers, which are defined based on the station-to-station propagation characteristics and the operation requirements for equalizers, must be reviewed if the link budget requirement cannot be satisfied.

6.2.2 Requirements

Selection criteria for equalizers (normal)

Equalizers should be selected according to the *D*/*U* ratio of interference waves to the desired waves as shown in Fig. 6.2.1. The *D*/*U* ratio should take into account the fading of the desired and interference waves.

FIGURE 6.2.1

Selection criteria for equalizers based on *D*/*U* ratios of interference waves

	Normal requirements		
	Digital waves	**Analogue waves**	**SFN waves**
D/*U* ratio of 28 dB or more	Multipath equalizer (A)	Multipath equalizer (A)	Multipath equalizer (A)
D/*U* ratio of 10 dB or more	Co-channel interference canceller	Co-channel interference canceller	
D/*U* ratio of 6 dB or more	TTL	TTL	
Under 6 dB			TTL

Figure 6.2.1 only provides criteria for selecting equalizers based on the *D*/*U* ratios of interference waves. This means that if a more appropriate equalizer is found according to the link budget result, it should be used. A change to a different-type equalizer is made based on the operation requirements for each type of equalizers.

Selection criteria for equalizers (relaxation of the requirements for analogue waves)

If the following requirements are satisfied, the selection criteria for equalizers are relaxed as shown in Fig. 6.2.2.

The equalizer is located at an end point of the network. The equivalent *C*/*N* of the signals other than analogue waves are 35 dB or more. If the transmission output is not more than 0.05 W, then the equivalent *C*/*N* are 30 dB or more.

FIGURE 6.2.2

Relaxed selection criteria for equalizers for analogue waves

	Normal requirements	Relaxed requirements
	Analogue wave	
D/*U* ratio of 28 dB or more	Multipath equalizer (A)	Multipath equalizer (A)
D/*U* ratio of 20 dB or more	Co-channel interference canceller	Multipath equalizer (A) (symbol determination disabled)
D/*U* ratio of 10 dB or more		Co-channel interference canceller
Under 10 dB	TTL	TTL

If the *D*/*U* ratio is less than 28 dB, a co-channel interference canceller was selected in the past; however, multipath equalizers now may be used with its symbol determination feature disabled in a case where the *D*/*U* ratio is not more than 20 dB. The purpose is to relax the equalizer selection criteria to the protection-ratio level if the station affected is a relay station that covers a limited service area. When analogue broadcasting is finished, the symbol determination feature must be enabled.

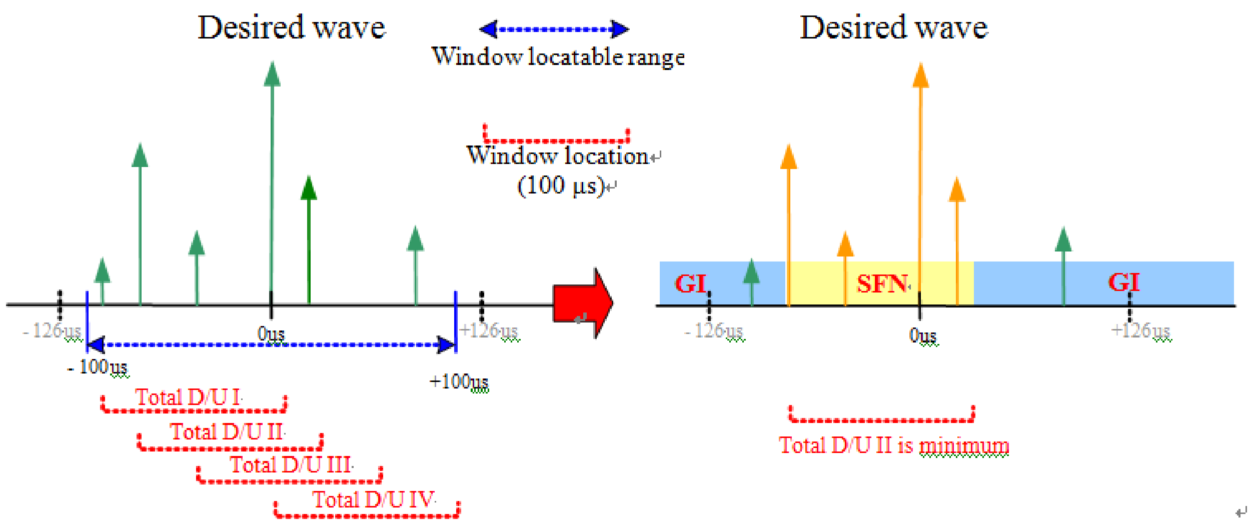
Distinction of SFN waves

A relay station that does not perform multipath equalization receives the SFN waves at its reception point together with the SFN waves within the service area; it is difficult to distinguish these SFN waves at the reception point of the station only. In this Report, the interference waves covered by the multipath equalization for equalizers are called SFN waves and the other waves are called digital waves with the assumption that equalizers are used.

Figure 6.2.3 is a conceptual rendering of the FFT window used for review. The FFT window has a width of 100 µs. Taking into account the delay time (9/10 of the guard interval) that can be equalized by the equalizer and the accuracy (around ±5 µs) of the delay adjustment process, this width is considered to ensure that the equalizer equalizes multiple paths. The FFT window is located at a position that minimizes the total *D*/*U* ratio of the SFN waves (*D*/*U* ratio to the power sum of the desired wave and the SFN waves included in FFT window) when the beginning position is changed from –100 µs to 100 µs as shown in Fig. 6.2.3.

FIGURE 6.2.3

Conceptual rendering of the FFT window used for review



Requirements for allowable symbol determination errors

Symbol determination errors are allowable when the following requirements are satisfied.

– They are caused by analogue waves; and

– The equivalent *C*/*N* after the symbol determination is 35 dB or more irrespective of the transmission output.

The requiems do not consider whether or not a lower-node station exists. Still, symbol determination errors should desirably be minimized.

It must be ensured that the equalizers selected according to the requirements above satisfy the operation requirements. If not, the reception system must be reviewed (for example, the reception point and/or reception antenna must be changed) to satisfy the operation requirements or the TTL must be selected.

6.2.3 Base of consideration

Here are the operation requirements for the equalizers.

Operation requirements for multipath equalizer (A)

Table 6.2.1 shows the operation requirements for multipath equalizer (A). Multipath equalizer (A) is defined as an equalizer with a device delay of 8 ms or less, and therefore cannot be user for relaying SFN broadcast waves. Attention should be also paid to whether or not it satisfies the required designed delay (setting) of the SFN network.

The equalizable multipath delay times are those for the multiple paths within the guard interval. The FFT window must be optimally adjusted according to the reception status.

TABLE 6.2.1

Operation requirements for multipath equalizer (A)

Characteristics	Requirements
Channel	The channel relays multi-frequency network (MFN) broadcast waves
Multipath *D*/*U* ratio	6 dB or more If more than one wave exists, power summing is required
Equalizable multipath delay time	Guard interval The maximum delay from the main wave must be within ±9/10 of the guard interval.

Operation requirements for multipath equalizer (B)

Table 6.2.2 shows the operation requirements for multipath equalizer (B). Multipath equalizer (B) is defined as an equalizer with a device delay of 17 µs or less, and cannot be user for relaying single-frequency network (SFN) broadcast waves because it is not provided with a capability of cancelling coupling loop waves. It should be also noted that multiple paths preceding the main wave cannot be equalized. In addition, it is not provided with a capability of symbol determination unlike multipath equalizer (A).

TABLE 6.2.2

Operation requirements for multipath equalizer (B) (temporary)

Characteristics	Requirements
Channel	The channel relays MFN broadcast waves
Multipath *D*/*U* ratio	12 dB or more If more than one wave exists, power summing is required
Equalizable multipath delay time	From –1 to 113 µs * 113 µs = 126 µs × (9/10)

Operation requirements for multipath equalizer (C)

Table 6.2.3 shows the operation requirements for multipath equalizer (C). Multipath equalizer (C) is defined as an equalizer with a device delay of 8 ms or less, and therefore cannot be user for relaying SFN broadcast waves. Attention should be also paid to whether or not it satisfies the required designed delay (setting) of the SFN network.

TABLE 6.2.3

Operation requirements for multipath equalizer (C) (temporary)

Characteristics	Requirements
Channel	The channel relays MFN broadcast waves
Multipath *D*/*U* ratio	10 dB or more If more than one wave exists, power summing is required
Equalizable multipath delay time	Within ±454 µs * 454 µs = (1008 µs/2) × (9/10)

Operation requirements for diversity receivers

Table 6.2.4 shows the operation requirements for diversity receivers. They are defined as receivers with a device delay of 8 ms or less, and therefore cannot be user for relaying SFN broadcast waves. Attention should be also paid to whether or not they satisfy the required designed delay (setting) of the SFN network.

The equalizable multipath delay times are the multiple paths within the guard interval. The FFT window shall be optimally adjusted according to the reception status.

For diversity receivers, the SD improvement level depends on the installation condition of the reception antenna. This will be explained in § 6.5.

TABLE 6.2.4

Operation requirements for diversity receivers

Characteristics	Requirements
Channel	The channel relays MFN broadcast waves
Multipath *D*/*U* ratio	3 dB or more If more than one wave exists, power summing is required
Equalizable multipath delay time	Guard interval The maximum delay from the main wave must be within ±9/10 of the guard interval.

Operation requirements for co-channel interference canceller

Table 6.2.5 shows the operation requirements for co-channel interference canceller. They are defined as devices with a device delay of 8 ms or less, and therefore cannot be user for relaying SFN broadcast waves. If any of the requirements in Table 6.2.5 is not satisfied, the network planning team must be consulted. How to install reception antennas will be explained in § 6.5.

TABLE 6.2.5

Operation requirements for co-channel interference canceller (temporary)

Characteristics	Requirements
Channel	The channel relays MFN broadcast waves
Number of interference waves	1
D/*U* ratio of interference waves	10 dB or more (Main antenna side for sub-antenna mode)
Arrival angle difference	Not less than 3 degrees and less that 357 degrees
Space correlation coefficient (Array antenna mode)	0.68 or less
Multipath *D*/*U* ratio (desired wave)	10 dB or more (Main antenna side for sub-antenna mode)
Difference in *D*/*U* ratio between the main and sub-antenna (sub-antenna mode)	20 dB or more
Received power of sub-antenna (Sub-antenna mode)	The receiver of the sub-antenna works when the interference-wave *D*/*U* ratio of the main antenna is less than 28 dB.

Operation requirements for coupling loop cancellers

Table 6.2.6 shows the operation requirements for coupling loop cancellers. They are used for relaying SFN broadcast waves. It should be noted that as with multipath equalizer (B), they cannot equalize the multiple paths preceding the main wave. In addition, they are not provided with a capability of symbol determination unlike multipath equalizer (A). The *D*/*U* ratio of coupling loop waves includes the following capability margin of the device for fluctuations of coupling loop waves. How to review coupling loop waves will be explained in § 6.5.

TABLE 6.2.6

Operation requirements for coupling loop cancellers (temporary)

Characteristics	Requirements
Channel	The channel relays SFN broadcast waves
D/*U* ratio of coupling loop waves	1 dB + *fm* or more
Multipath *D*/*U* ratio	12 dB or more If more than one wave exists, power summing is required.
Equalizable multipath delay time	From –1 to 113 µs * 113 µs = 126 µs × (9/10)

6.3 Cases where no coupling loop canceller is required

For broadcast wave relaying, basically an equalizer should be used. Based on the results of experiments at many places and other data, this section lists the cases where no coupling loop canceller is required.

Table 6.3.1 shows the cases where no coupling loop canceller is required.

TABLE 6.3.1

Cases where no coupling loop canceller is required

Size of relay station	Criteria
Relay stations with output of 0.05 or less	*D*/*U* ratio of coupling loop waves ≥ 23 dB + *fm*
Other relay stations	*D*/*U* ratio of coupling loop waves ≥ 28 dB + *fm*

Consideration of the necessity of a coupling loop canceller must take into account the following:

– Signal deterioration to be caused by coupling loop waves

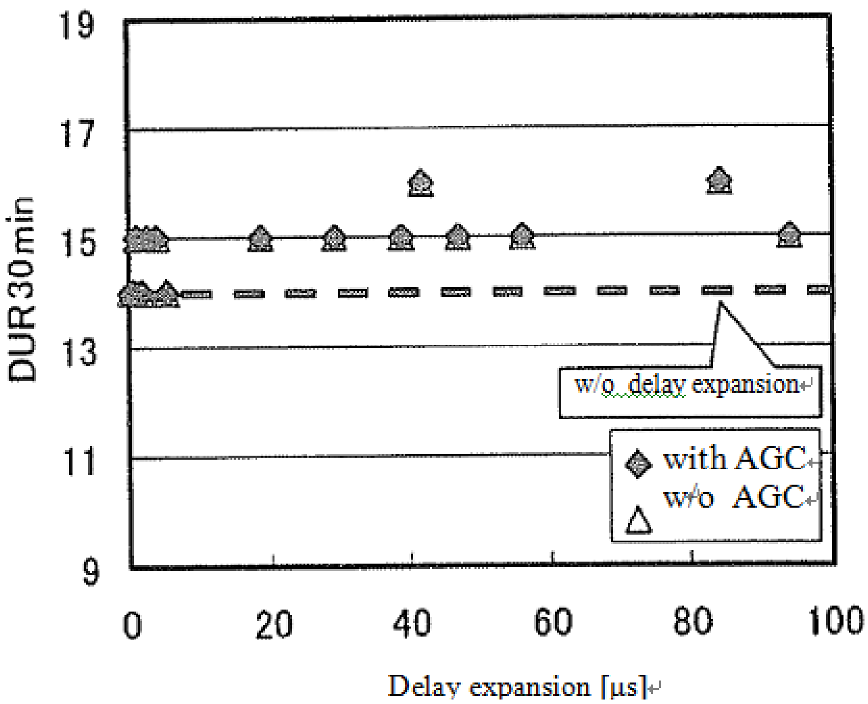
– Oscillation limit

It is known that as described in § 5.6, the characteristics of one wave is determined by the *D*/*U* ratio of the coupling loop waves. On the other hand, an actual relay station has delay expansion because coupling loop waves are reflected by many places before they are received by the station. For this reason, coupling loop waves measured at various relay stations were modelled to review the relation between the delay expansion and the characteristics of coupling loop waves.

Figure 6.3.1 shows the *D*/*U* ratio that ensures that equivalent *C*/*N* is 30 dB. This graph shows the characteristics of the coupling loop waved models at the stations with the delay expansion on the abscissa. This Figure indicates that in order to ensure that the *C*/*N* of the coupling loop waves is 30 dB or more, the *D*/*U* ratio of them must be at least 16 dB.

FIGURE 6.3.1

***D*/*U* ratio to ensure *C*/*N* = 30 dB**

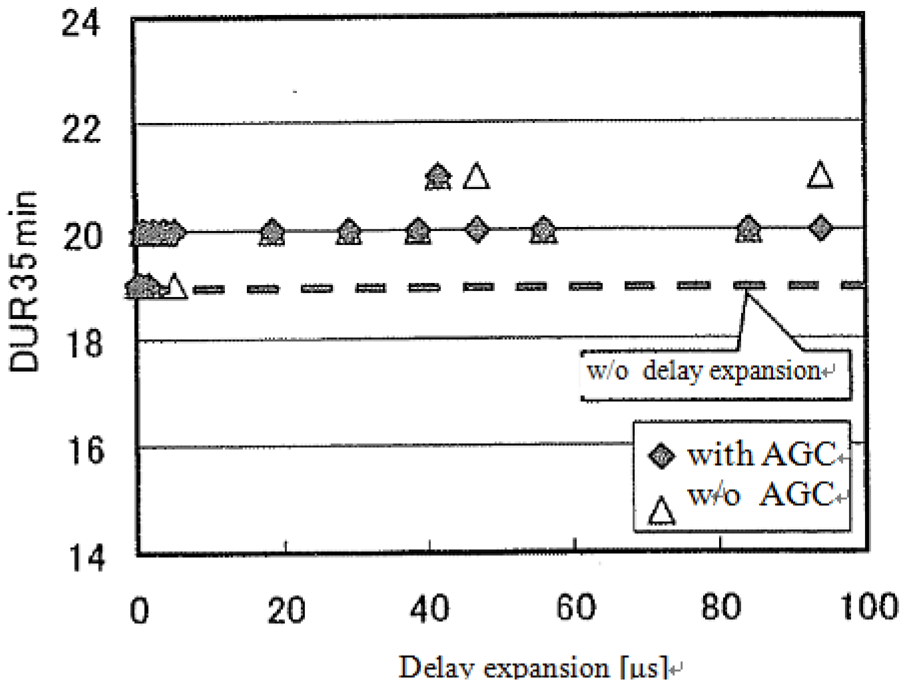


Similarly, Fig. 6.3.2 shows the *D*/*U* ratio that ensures that the *C*/*N* of the coupling loop waves is 35 dB. To ensure that the *C*/*N* of the coupling loop waves is 35 dB or more, the *D*/*U* ratio must be at least 21 dB.

The criterion values for eliminating the need for a coupling loop canceller were defined assuming that the equivalent *C*/*N* depends on the size of the relay station and with consideration given to the fading margin for the upper-node station and fluctuation margin for coupling loop waves. As the fluctuation margin for coupling loop waves, it was decided to use 7 dB based on the measurements at the various stations obtained so far.

FIGURE 6.3.2

***D*/*U* ratio to ensure *C*/*N* = 35 dB**



The oscillation limit has turned out to be a value sufficiently lower than the defined criterion value for eliminating the need for a coupling loop canceller; an oscillation limit of at least 4 dB is enough.

Operation requirements for *C*/*N* resetters

A *C*/*N* resetter demodulates signals, corrects errors, and modulates the signals again, making the device delay longer (the propagation parameter will be 0.5 seconds).

Symbol determination process and its improvement level

Multipath equalizers (A) and (C), diversity receivers, and co-channel interference canceller provides a *C*/*N* improvement capability called a symbol determination feature. Symbol determination improves the equivalent *C*/*N* by performing threshold determination on equalized signals. It may, however, substitute wrong transmission symbols while the process time is relatively short because it does not involve signal demodulation, error correction or signal re-modulation. This is called a symbol determination error. Because symbol determination errors cannot be corrected unless the errors are corrected and then re-modulated, it is important that upper-node stations in multi-layer relaying should not make symbol determination errors.

Figure 6.3.3 shows the improvement level of symbol determination on Gaussian noise.

FIGURE 6.3.3

Improvement level of symbol determination on Gaussian noise

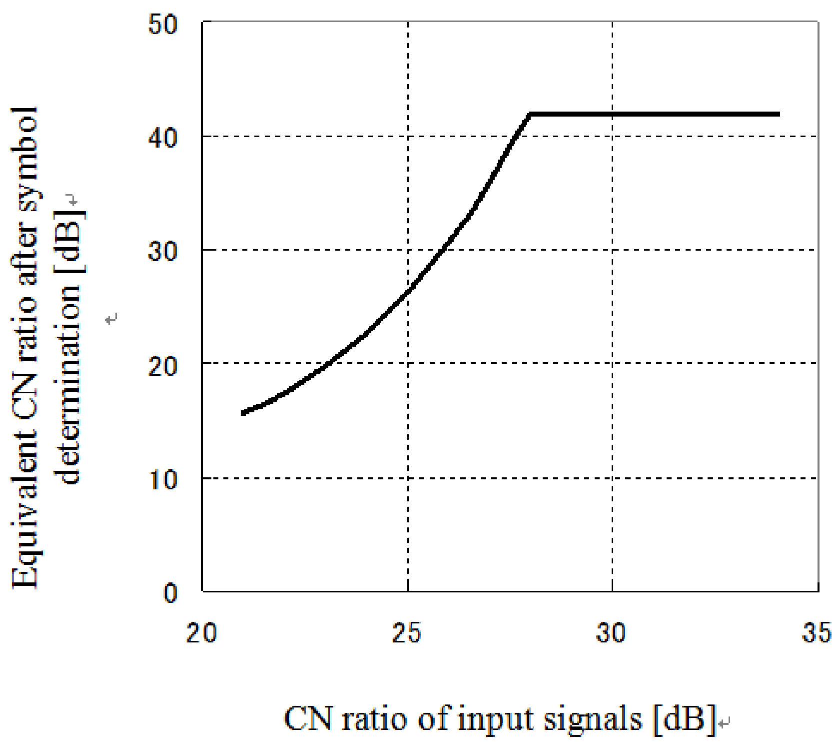


Figure 6.3.3 indicates that at the point where the ratio of input signals is around 28 dB, the equivalent *C*/*N* after symbol determination starts to sharply decrease. In this region, if the *C*/*N* of input signals is fluctuated by fading, then the *C*/*N* of transmitted signals significantly fluctuates. This situation should be avoided.

Figure 6.3.4 shows the improvement level of symbol determination when multipath interference exists. When the multipath *D*/*U* ratio is lower, the threshold of symbol determination error occurrences is higher because multipath interference causes ripples within the band, causing the *C*/*N* for each subcarrier to vary.

FIGURE 6.3.4

Multipath *D*/*U* ratio and improvement level of symbol determination

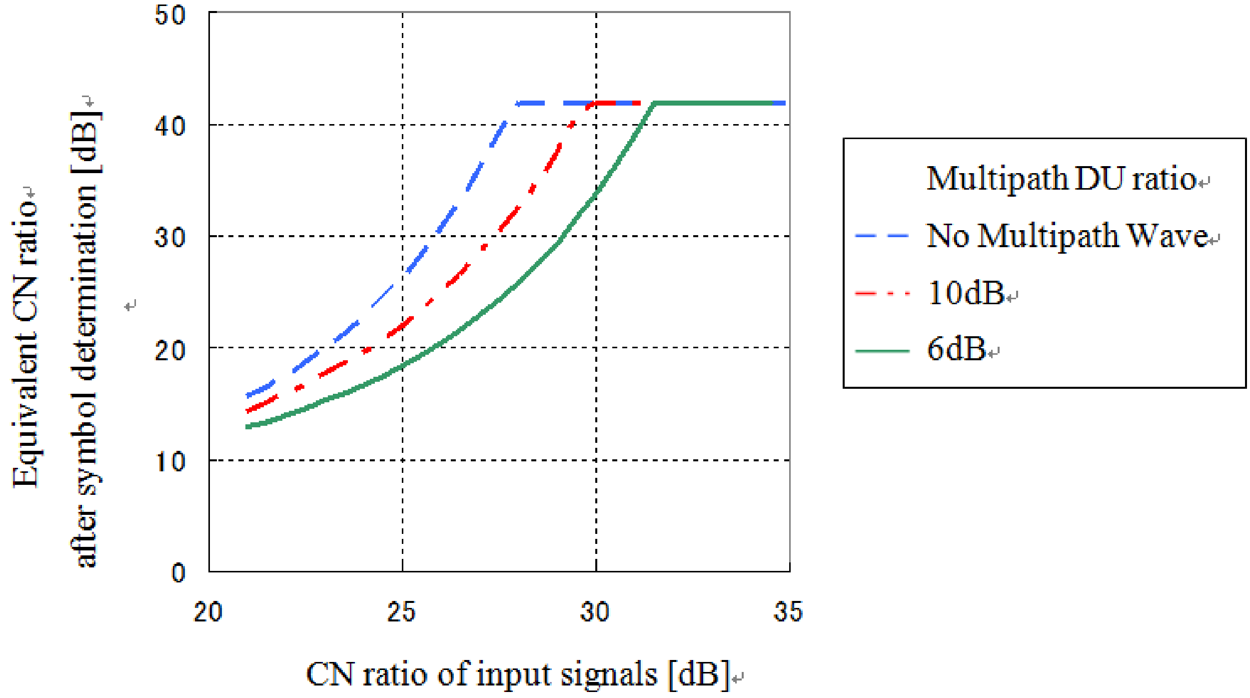
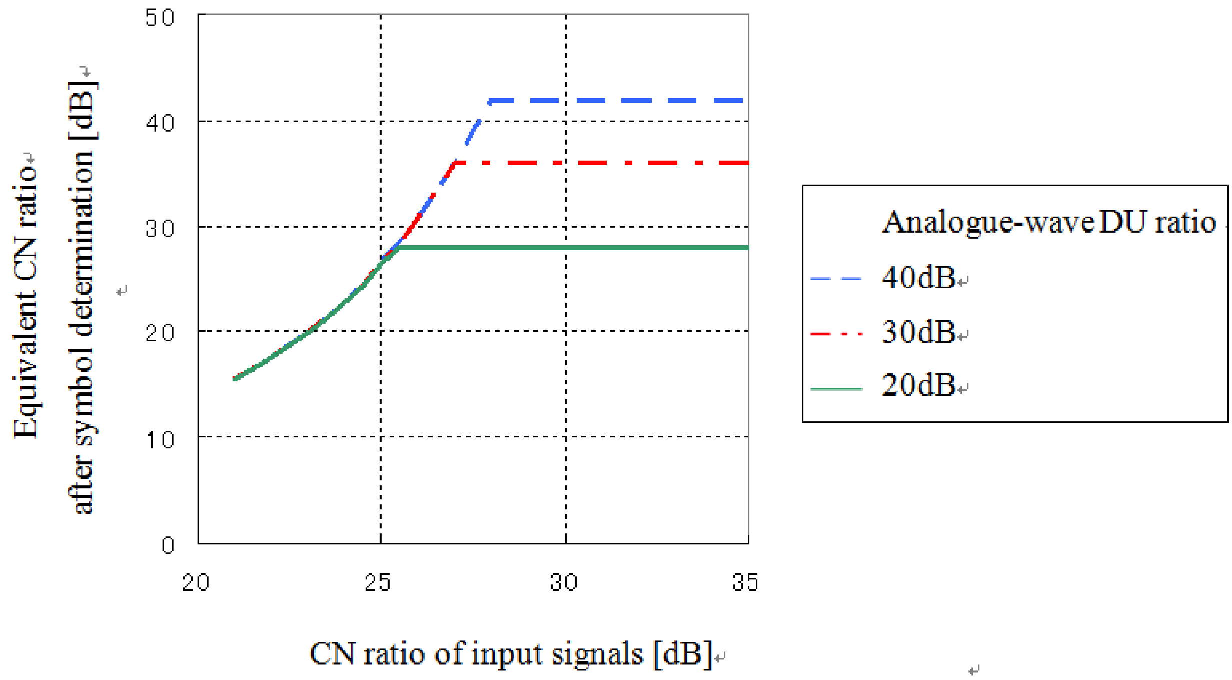


Figure 6.3.5 shows the improvement level of symbol determination when multipath interference takes place. When the *D*/*U* ratio of analogue waves is low, the equivalent *C*/*N* after symbol determination is saturated because the subcarriers around video and sound are affected in particular.

FIGURE 6.3.5

***D*/*U* ratio of analogue waves and improvement level of symbol determination (no multipath interference)**



6.4 Explanation of equalizers

6.4.1 Multipath equalizer (A)

Multipath equalizer (A) provides the following two capabilities:

Capability	Description
Multipath equalization	Compensates for the frequency response distortion of the received signals caused by multipath interference.
Symbol determination	Improves the *C*/*N* by performing symbol determination on equalized signals.

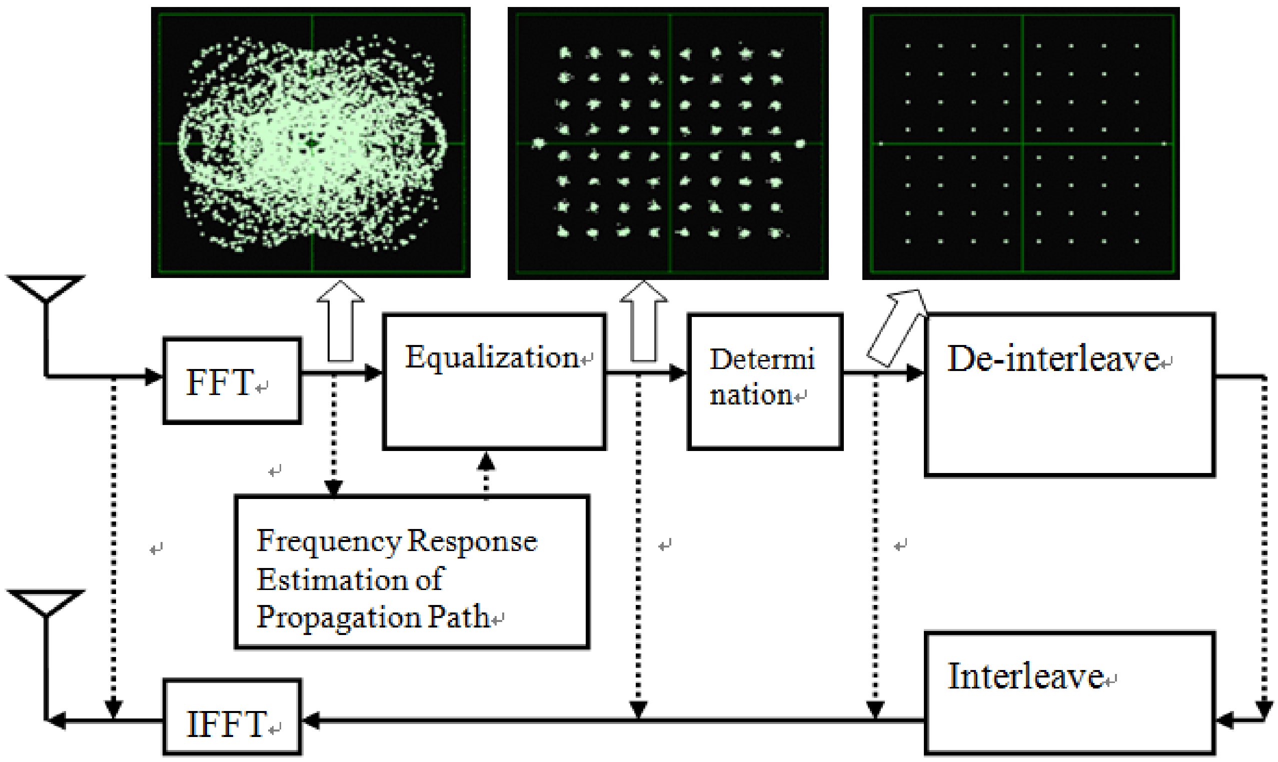
Figure 6.4.1 describes the relay system that uses equalization based on a frequency axis process. Multipath equalizer (A) consists of Systems (b) and (c) as shown in the Figure. For your information, System (d) demodulates signals, corrects errors, and modulates them again; it is a component of a *C*/*N* resetter.

Multipath equalization compensates for the frequency response distortion by dividing the FFT output signals by the frequency response of the transmission path estimated from the SP signals. Symbol determination improves the *C*/*N* by performing threshold determination on the equalized signals.

Delay devices are mainly based on FFT or another digital signal process; it processes signals within 7 symbols (approximately 8 ms for Mode 3).

FIGURE 6.4.1

Relay system that uses equalization based on frequency axis process



6.4.2 Multipath equalizer (B)

Multipath equalizer (B) provides the following capability:

Capability	Description
Multipath equalization	Compensates for the frequency response distortion of the received signals caused by multipath interference.

Multipath equalizer (B) is characterized by that its device delay is much shorter than that of multipath equalizer (A).

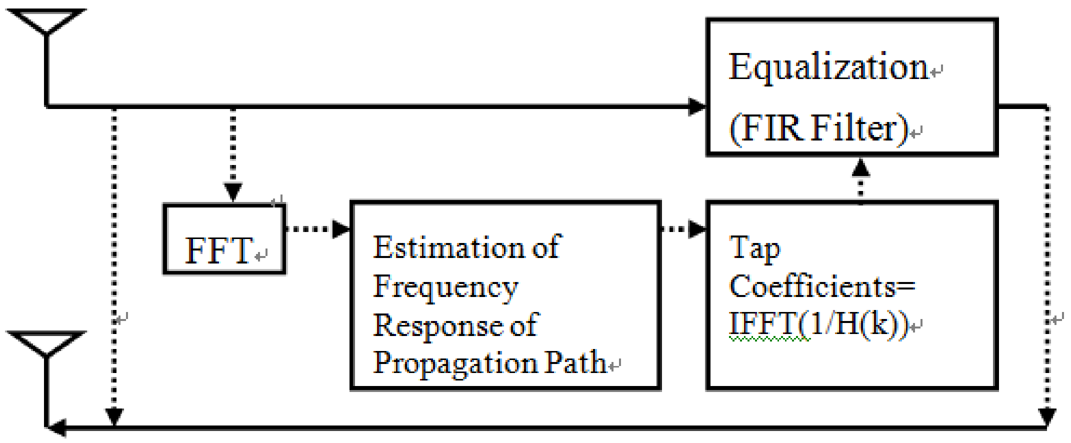
Figure 6.4.2 describes the relay system that uses equalization based on a time axis process. Multipath equalizer (B) consists of System (b) as shown in the Figure.

Multipath equalization compensates for the frequency response distortion by allowing signals to pass through the FIR filter with a coefficient assigned based on the frequency response of the transmission path estimated from the SP signals.

A delay device, which provides delay of more than 10 μs, is used for a system that cannot use a multipath equalizer (A) to adjust delay.

FIGURE 6.4.2

Relay system that uses equalization based on time axis process



6.4.3 Multipath equalizer (C)

Multipath equalizer (C) provides the following two capabilities:

Capability	Description
Multipath equalization	Compensates for the signal deterioration caused by the multipath interference within and beyond the guard interval.
Symbol determination	Improves the *C*/*N* by performing symbol determination on equalized signals.

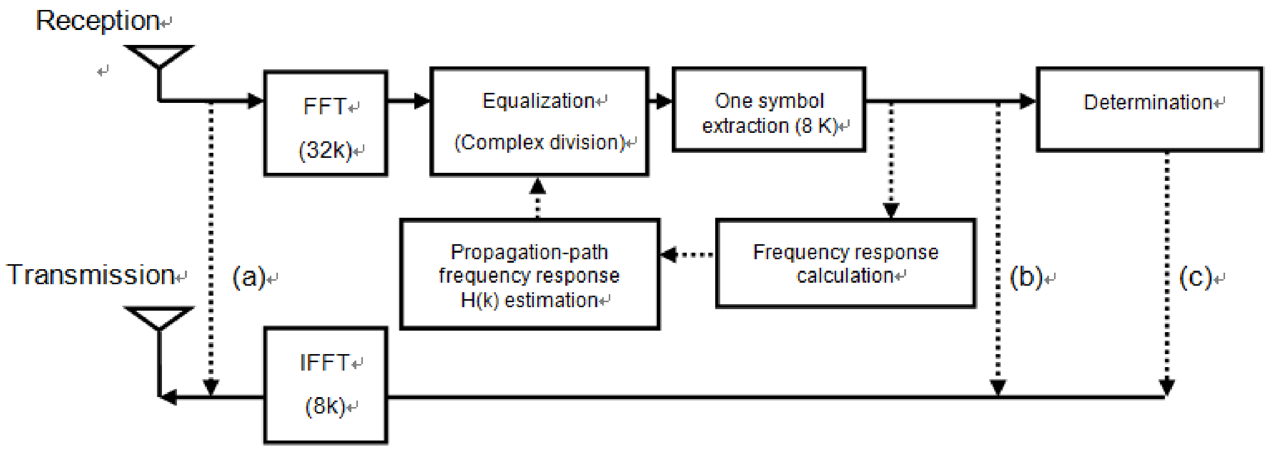
Figure 6.4.3 shows the mechanism of multipath equalizer (C).

Multipath equalization compensates for the frequency response distortion caused by the multipath interference within and beyond the guard interval and for the deterioration of the received signals by dividing the FFT output of the signals for the 32 k points that includes the data before and after the appropriate symbol by the frequency response of the transmission path estimated from all subcarrier data. It is characterized by the fact that it can equalize both of preceding (preghosts) and multipath delay (postghosts) at a time. Symbol determination improves the *C*/*N* by performing threshold determination on the equalized signals.

Delay devices are mainly based on FFT or another digital signal process; it processes signals within 7 symbols (approximately 8 ms for Mode 3).

FIGURE 6.4.3

Mechanism of multipath equalizer (C)



6.4.4 Diversity receivers

Diversity receivers provide the following three capabilities:

Capability	Description
Multipath equalization	Compensates for the frequency response distortion of the received signals caused by multipath interference.
Fading compensation	Uses diversity composition to compensate for the deteriorated *C*/*N* of received signals caused by fading.
Symbol determination	Improves the *C*/*N* by performing symbol determination on equalized signals.

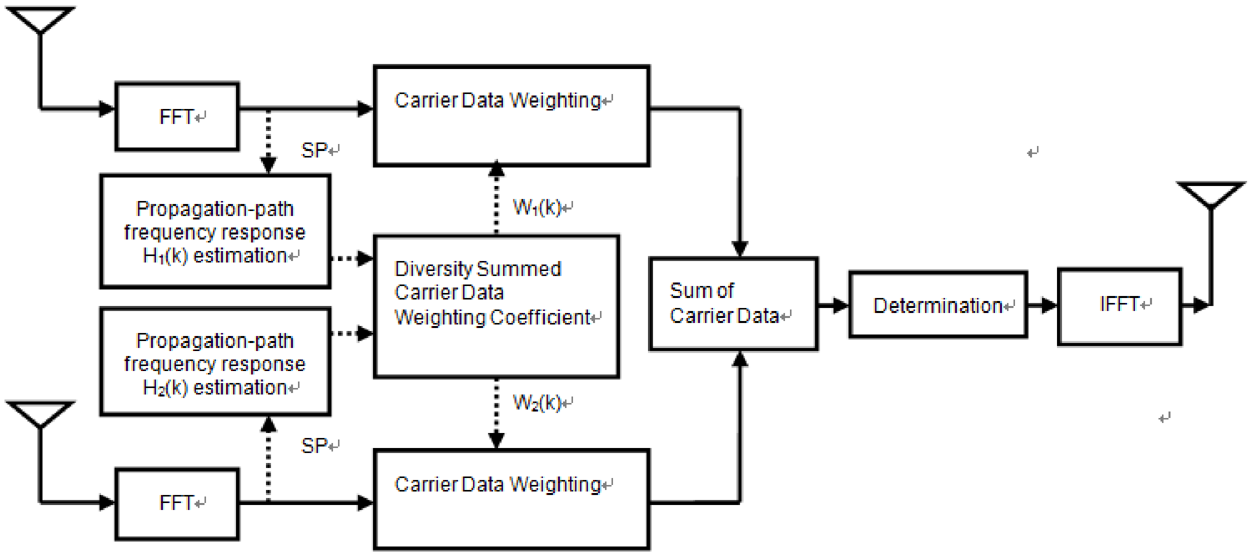
Figure 6.4.4 shows the mechanism of diversity receivers.

Diversity receivers perform maximum ratio combining on signals received through multiple antennas on a per OFDM signal subcarrier basis. The maximum ratio combining method assigns optimal weights to the signals having favourable *C*/*N* among the received signals before it combines the signals. Equation (23) is used to determine the weight.

$$W_l(k) = \frac{1}{H_l(k)} = \frac{H^*{}_l(k)}{|H_l(k)|} \qquad (23)$$

FIGURE 6.4.4

Mechanism of diversity receivers



6.4.5 Co-channel interference canceller

Co-channel interference canceller provides the following three capabilities:

Capability	Description
Co-channel interference	Removes digital- and analogue-wave interference in the same channel.
Multipath equalization	Compensates for the frequency response distortion of the received signals caused by multipath interference.
Symbol determination	Improves the equivalent *C/N* by performing symbol determination after interference removal and multipath equalization.

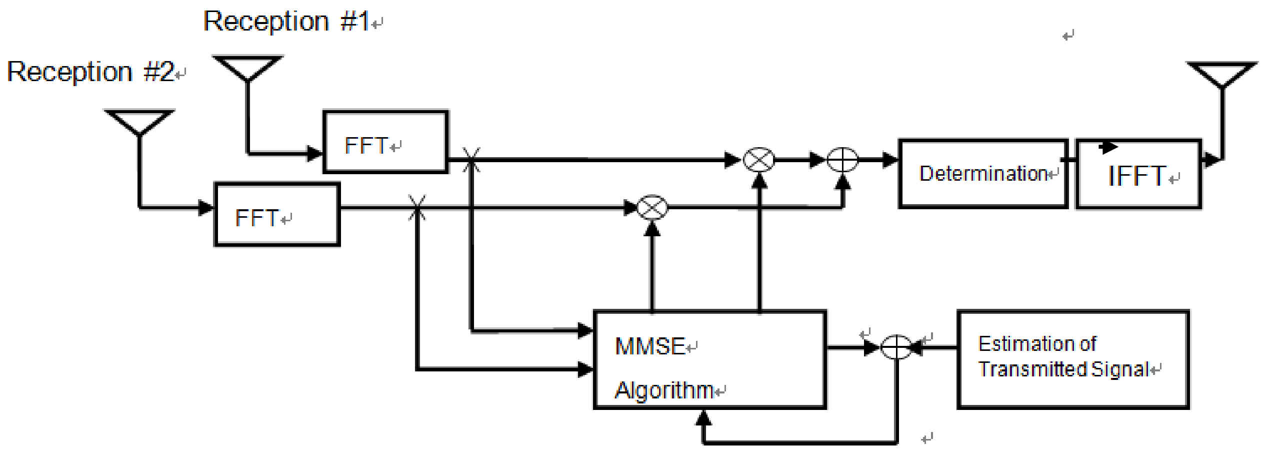
Figure 6.4.5 shows the mechanism of a co-channel interference canceller.

Co-channel interference canceller perform adaptation combining on signals received through multiple antennas on a per OFDM signal subcarrier basis. Using the estimated transmission signal as the reference, they calculate the weighting coefficient based on the MMSE (minimum mean square error) principle algorithm so that the error after the combination will be minimized. In array antenna mode, this produces synthesis-oriented null against interference waves to remove them. In sub-antenna mode, with changes to the algorithm so that the signals from the main antenna will have precedence, they replicate interference waves from the signals from the sub-antenna to remove them.

Delay devices are mainly based on FFT or another digital signal process; it processes signals within 7 symbols (approximately 8 ms for Mode 3).

FIGURE 6.4.5

Mechanism of co-channel interference canceller



6.4.6 Relation between the array antenna spacing *d* and space correlation coefficient β

Where the arrival angles of the desired and interference waves are θ_D and θ_U, respectively, the space correlation coefficient for array antennas is given by equation (24). In this equation, $g(\theta)$ is an array propagation vector, which is defined with the antenna spacing d and wavelength λ as shown in equation (25).

The space correlation coefficient β can be a value between 0 and 1 inclusive. When β = 0, the difference in propagation path length between the interference waves received through the antennas is 1/2 the wavelength (or an odd multiple of 1/2 of the wavelength). This means that the interference waves are completely cancelled when they are combined with the array antennas, providing receiving characteristics with no interference waves. Conversely, when β = 1, the interference waves cannot be suppressed at all.

$$\beta = \frac{\left|g^H(\theta_D)g(\theta_U)\right|}{\sqrt{\left|g^H(\theta_D)g(\theta_D)\right|\left|g^H(\theta_U)g(\theta_U)\right|}} \tag{24}$$

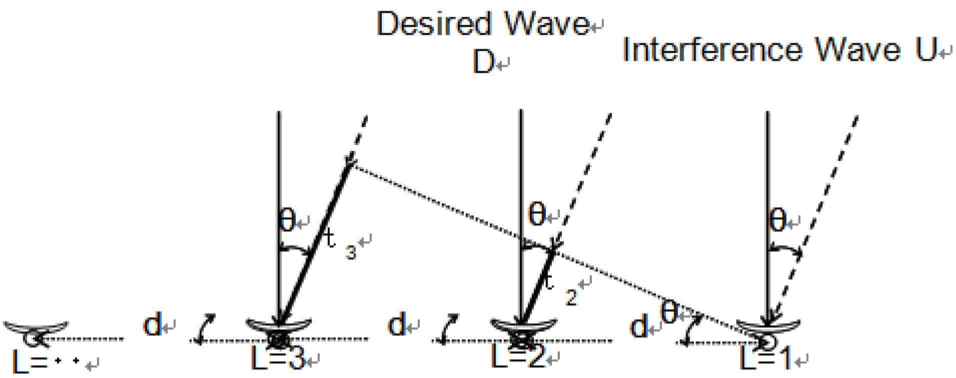
$$\begin{aligned} g(\theta) &= \left[1 + j0 \quad \exp(j\frac{2\pi d}{\lambda}\sin\theta) \quad ..... \exp(j\frac{2\pi d(L-1)}{\lambda}\sin\theta)\right]^T \\ &= \left[1 + j0 \quad \exp(j\frac{2\pi}{\lambda}t_2) \quad ..... \exp(j\frac{2\pi d}{\lambda}t_L)\right]^T \end{aligned} \tag{25}$$

Based on the relation between the array antenna spacing and the arrival angle of the interference waves as shown in Fig. 6.4.6, the propagation path length difference t_l is given by the following equation:

$$t_2 = d\sin\theta\,, \quad t_3 = 2d\sin\theta, \quad \cdots\cdots\cdots, t_L = (L-1)d\sin\theta \tag{26}$$

FIGURE 6.4.6

Array (*L*) antenna spacing and difference in propagation path length



6.4.7 Array antenna (two antennas) spacing *d* and space correlation coefficient β

When array antennas arranged with the spacing *d* as shown in Fig. 6.4.7 are used against interference waves with a wavelength of λ and an arrival angle of θ, the difference in interference-wave propagation-path length between antennas t_2 and the phase difference φ_2, which is obtained from the sad difference in length, are given by the following equations, from which the space correlation coefficient β is derived.

$$t_2 = d\sin\theta \tag{27}$$

$$\varphi_2 = \frac{2\pi}{\lambda} t_2 = \frac{2\pi}{\lambda} d\sin\theta \tag{28}$$

$$\beta = \sqrt{\frac{1+\cos(\frac{2\pi d}{\lambda}\sin\theta)}{2}} \tag{29}$$

If the antenna spacing *d* is half the wavelength, then β is:

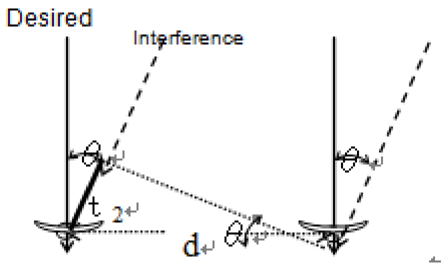
$$\beta = \sqrt{\frac{1+\cos(\pi\sin\theta)}{2}} \tag{30}$$

As equation (30) above indicates, the space correlation coefficient β can be a value between 0 and 1 inclusive. If the interference arrival angle θ = 0, then β = 1. If θ = 90, then β = 0. If θ = 30, then β = 1/1.414.

The array antenna spacing design tool, a network review tool, determines the space correlation coefficient based on the calculations above.

FIGURE 6.4.7

Array antenna (two antennas) spacing and difference in propagation path length



Consider a case where a so-called stacked antenna (which involves no electrical signal processing) is used. When β = 0, the difference in propagation path length between the interference waves received through the antennas is 1/2 the wavelength (or an odd multiple of 1/2 of the wavelength). This means that the interference waves are completely cancelled when they are combined with the array antennas, providing receiving characteristics with no interference waves. Conversely, when β = 1, the interference waves cannot be suppressed at all.

For a co-channel interference canceller, which performs electrical signal processing, the antenna should be spaced so that β will be 0.68 or less for efficient interference wave removal.

6.4.8 Desired-wave arrival angle θ_D and space correlation coefficient β

When the desired-wave and interference-wave arrival angles are θ_D and θ_U, respectively for the two-antenna array above, the interference-wave phase difference φ'_2 between antennas is determined from the desired-wave propagation-path length difference between antennas t_D and the interference-wave propagation-path length difference between antennas t_U as follows, from which the space correlation coefficient β is derived.

$$t_D = d\sin\theta_D$$

$$t_U = d\sin\theta_U$$

$$t'_2 = t_U - t_D \qquad (31)$$

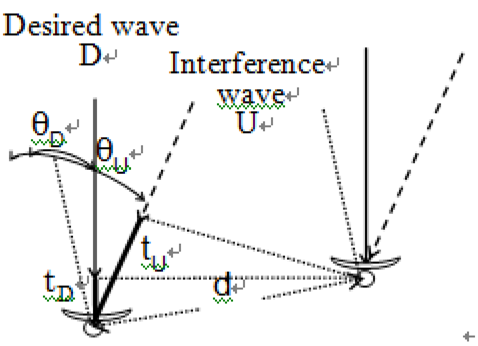
$$\varphi'_2 = \frac{2\pi}{\lambda} t'_2 = \frac{2\pi}{\lambda} d\left(\sin\theta_U - \sin\theta_D\right) \qquad (32)$$

$$\beta = \sqrt{\frac{1+\cos\left\{\frac{2\pi d}{\lambda}\left(\sin\theta_U - \sin\theta_D\right)\right\}}{2}} \qquad (33)$$

When the arrival angle of the desired wave $\theta_D > 0$, the desired-wave propagation-path length difference between antennas $t_D > 0$. If the desired waves are made to be in phase between antennas in order to ensure that the directivity of the array antennas is oriented to the desired-wave direction, the final interference-wave propagation-path length difference between antennas is the length less the desired-wave propagation-path length difference between antennas as shown in equation (31).

FIGURE 6.4.8

Difference in propagation path length between desired and interference waves



Basically, array antennas are placed so that the arrival angle of the desired wave $\theta_D = 0$. If they are subject to the restriction of the premises and/or facility conditions, the above calculations are required.

6.4.9 Two-antenna array spacing *d* and space correlation coefficient β (details)

$$g(\theta_U) = g(\theta) \tag{34}$$

$$= \left[1 + j0 \quad \exp(j\frac{2\pi d}{\lambda}\sin\theta) \right]^T \tag{35}$$

$$\beta = \frac{\left|g^H(\theta_D)g(\theta_U)\right|}{\sqrt{\left|g(\theta_D)^H g(\theta_D)\right|\left|g^H(\theta_U)g(\theta_U)\right|}}$$

$$= \frac{\left|[1+j0\ \ 1+j0]\left[1+j0\ \ \exp(j\frac{2\pi d}{\lambda}\sin\theta)\right]^T\right|}{\sqrt{\left|[1+j0\ \ 1+j0][1+j0\ \ 1+j0]^T\right|\left|\left[1+j0\ \ \exp(-j\frac{2\pi d}{\lambda}\sin\theta)\right]\left[1+j0\ \ \exp(j\frac{2\pi d}{\lambda}\sin\theta)\right]^T\right|}}$$

$$= \frac{\left|1+\exp(j\frac{2\pi d}{\lambda}\sin\theta)\right|}{\sqrt{\left|1^2+1^2\right|\left|1^2+\left\{\cos^2(\frac{2\pi d}{\lambda}\sin\theta)+\sin^2(\frac{2\pi d}{\lambda}\sin\theta)\right\}\right|}}$$

$$= \frac{\left|1+\exp(j\frac{2\pi d}{\lambda}\sin\theta)\right|}{\sqrt{\left|1^2+1^2\right|\left|1^2+1^2\right|}}$$

$$= \frac{1}{2}\left|1+\exp(j\frac{2\pi d}{\lambda}\sin\theta)\right|$$

$$= \frac{1}{2}\left|1+\cos(\frac{2\pi d}{\lambda}\sin\theta)\ +j\sin(\frac{2\pi d}{\lambda}\sin\theta)\right|$$

$$= \frac{1}{2}\sqrt{\left\{1+\cos(\frac{2\pi d}{\lambda}\sin\theta)\right\}^2+\left\{\sin(\frac{2\pi d}{\lambda}\sin\theta)\right\}^2} \qquad (36)$$

$$= \frac{1}{2}\sqrt{1+2\cos(\frac{2\pi d}{\lambda}\sin\theta)+\cos^2(\frac{2\pi d}{\lambda}\sin\theta)+\sin^2(\frac{2\pi d}{\lambda}\sin\theta)}$$

$$= \frac{1}{2}\sqrt{2+2\cos(\frac{2\pi d}{\lambda}\sin\theta)}$$

$$= \sqrt{\frac{1+\cos(\frac{2\pi d}{\lambda}\sin\theta)}{2}}$$

If the antenna space d is half the wavelength ($d = \lambda/2$), equation (30) in § 6.4.7 is obtained.

6.4.10 Coupling loop canceller

Coupling loop cancellers provide the following three capabilities:

Capability	Description
Coupling loop cancellation	Cancels the coupling loop radio waves from itself. It covers all coupling loop waves in the target range.
Multipath equalization	Compensates for the frequency response distortion of the received signals caused by multipath interference.
Oscillation detection	Detects oscillation before it generates an out-of-band component, stops output, and restarts the system.

Figure 6.4.9 shows the mechanism of a coupling loop canceller.

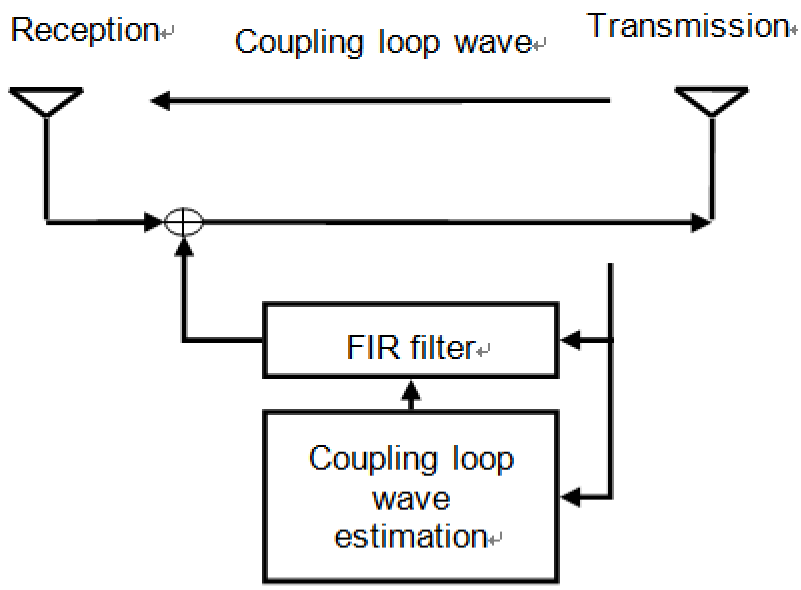
For SFN broadcast wave relaying, the station uses the same channel as the upper-node station, and therefore the transmission waves from itself may couple, causing signal deterioration and/or oscillation.

The coupling loop canceller replicates coupling loop waves from the station included in the received signals to cancel them.

The delay device provides delay of more than 10 µs.

FIGURE 6.4.9

Mechanism of coupling loop canceller



6.5 Design of equalizers and reception systems

6.5.1 Design of space diversity

6.5.1.1 Concept

For a system with large fading, space diversity (hereafter referred to as SD) reception is used to relax the fading margin. SD reception uses two SD reception antennas vertically separated from each other; the important point is to space them properly. According to the propagation path, they must be properly spaced to provide desired improvement.

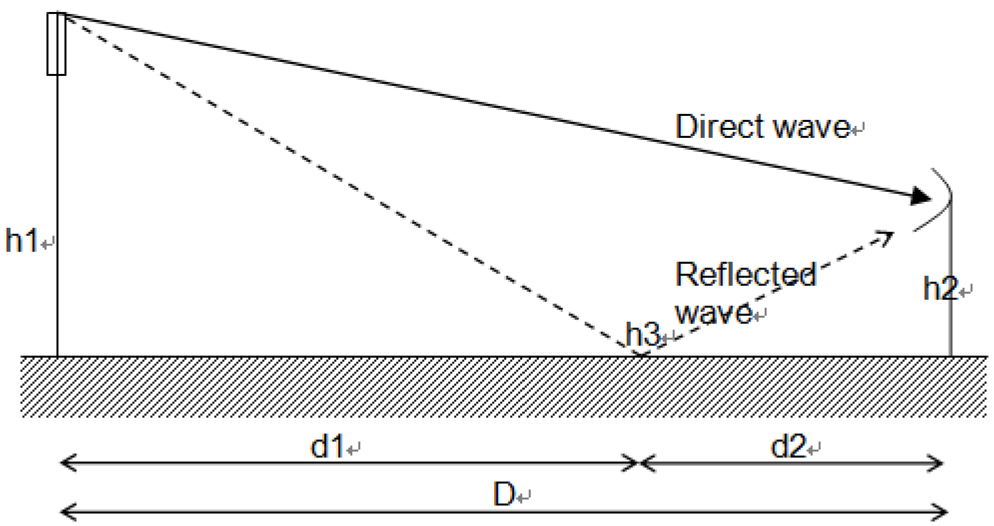
A system with large fading also experiences deterioration in frequency response in many cases. In some cases, it is difficult for a multipath equalizer to sufficiently improve the reception *C*/*N* of a particular sub-carrier decreased by fading. SD reception can perform optimum syntheses on a per sub-carrier basis, and hence has an effect of ensuring quality for this type of system.

From past experience, SD reception is often required for links with fading margin of more than 15 dB or marine propagation links.

In general, SD antenna spacing should be so designed as to be half the pitch of the reception height pattern. This calculating formula is predicated that the propagation path is a two-wave model based on ground reflection. This model receives two waves – direct and reflected waves – that interfere with each other as indicated in Fig. 6.5.1, where reflected waves mainly cause fading. In many cases, actual propagation paths are not ideal as a two-wave model based on ground reflection because, for example, direct and/or reflected waves are interrupted by mountains or other objects. In this case, they do not always achieve required values as calculated, and therefore measurements are required as a rule.

FIGURE 6.5.1

Two-wave model based on ground reflection



Design of SD antenna spacing is reviewed in the investigating and review Report by ARIB in the course of institutionalization of UHF-band TTLs. This is, however, also based on a technique verified using a typical experimental system built around a two-wave model based on ground reflection; the calculating formula cannot apply to all systems under present circumstances.

With attention paid to the points noted above, the improvement provided by SD reception should be desirably verified based on measurements as a rule. Specifically, the height pattern pitch should be measured to determine the antenna locations, and then the long-term electric field should be measured to verify the improvement provided by SD reception.

For diversity reception, the reception status of each antenna should desirably be uncorrelated with that of the others. A two-wave model based on ground reflection as a propagation path intends to provide a lower correlation by placing antennas at the pitch which is half the pitch of the height pattern to change the phase relation of each antenna.

This does not completely cover everything about fading occurrence, however. Proper SD spacing for each system requires verification based on measurements.

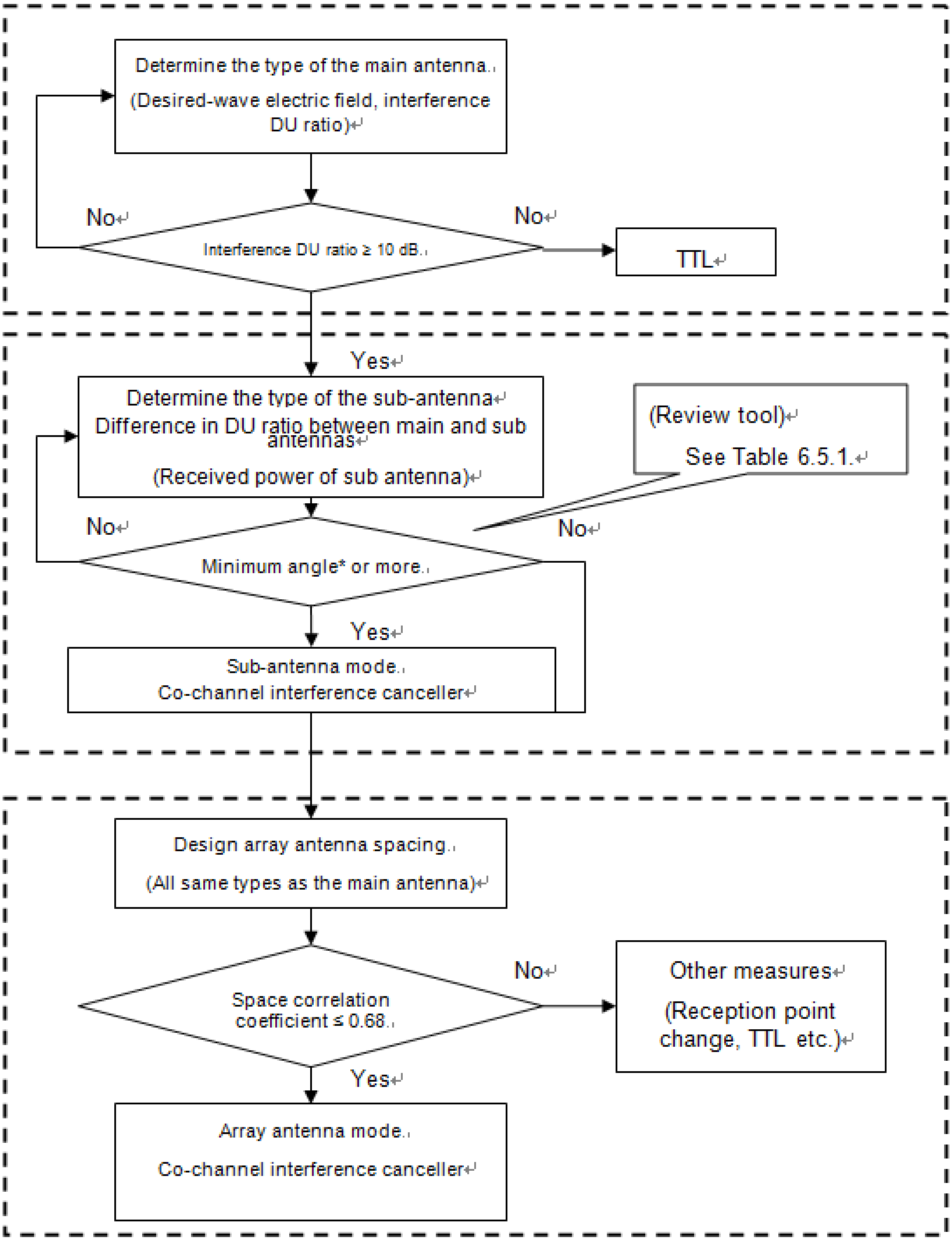
6.5.2 Design of reception antennas for co-channel interference canceller

6.5.2.1 Concept

Figure 6.5.2 shows the procedure for designing reception antennas.

FIGURE 6.5.2

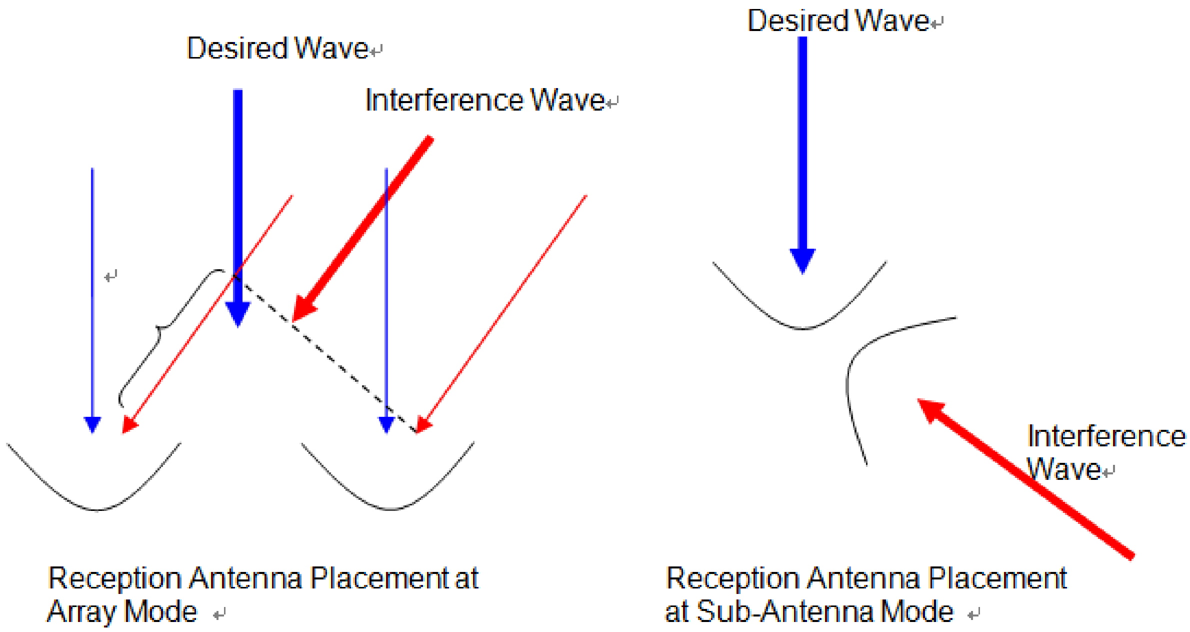
Co-channel interference canceller and design of reception antennas



A co-channel interference canceller operates in one of the two modes shown in Fig. 6.5.3: array-antenna and sub-antenna modes. In either mode, the reception antennas must be designed so that the difference in arrival angle between the desired and interference waves, *D*/*U* ratio of interference waves, and antenna installation condition will satisfy the operation requirements. In sub-antenna mode, both of the main and sub-antennas can be installed at one steel tower, which can downsize the facilities. For this reason, the reception antennas should be so designed as to allow this scheme to be applied where possible.

FIGURE 6.5.3

Array-antenna and sub-antenna modes



6.5.2.2 Requirements

6.5.2.2.1 Array-antenna mode

This mode is used to remove interference when the difference in arrival angle between the desired and interference waves is small.

As Fig. 6.5.3(a) shows, reception antennas of the same type are placed so that they will be oriented to the desired waves. In array-antenna mode, the phase difference between the interference waves that arrive at one antenna and those that arrive at another is used to remove interference waves. Depending on the arrival angle of the interference waves and antenna spacing, the desired waves are in phase with the interference waves in some regions, where interference waves cannot be removed. The operation requirements require that the antennas should be so placed as to ensure that the space correlation coefficient is not more than 0.68. The antenna placement is reviewed with the array-antenna spacing design tool.

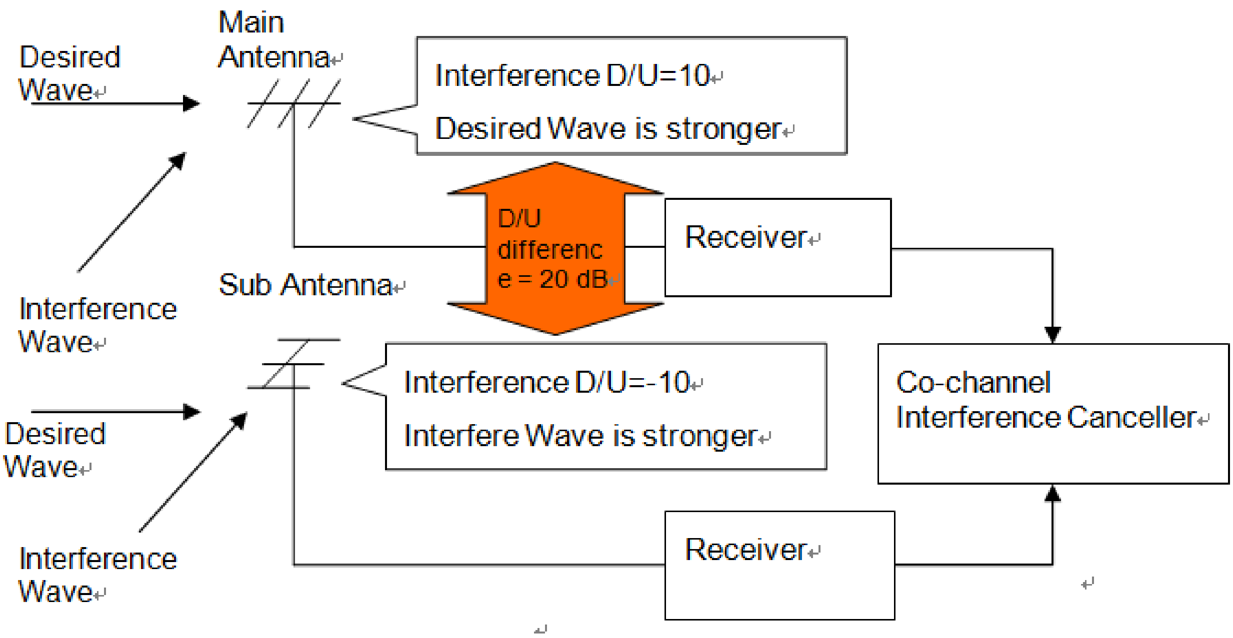
• Sub-antenna mode

This mode is used to remove interference when the difference in arrival angle between the desired and interference waves is large.

As Fig. 6.5.3(b) shows, the main antenna and sub-antennas are placed so that they will be oriented to desired and interference waves, respectively. In sub-antenna mode, the difference in *D*/*U* ratio between the desired and interference waves received by the main and sub-antennas is used to remove interference waves. As Fig. 6.5.4 shows, the difference in *D*/*U* ratio must be at least 20 dB; the types of the main and sub-antennas must be selected so that this requirement will be satisfied. It is also required to secure the received power of the sub-antenna with consideration given to the fading of the interference waves. In sub-antenna mode, the main and sub-antennas can be different in type in some cases unlike in array-antenna mode.

FIGURE 6.5.4

Difference in *D*/*U* ratio between main and sub-antennas

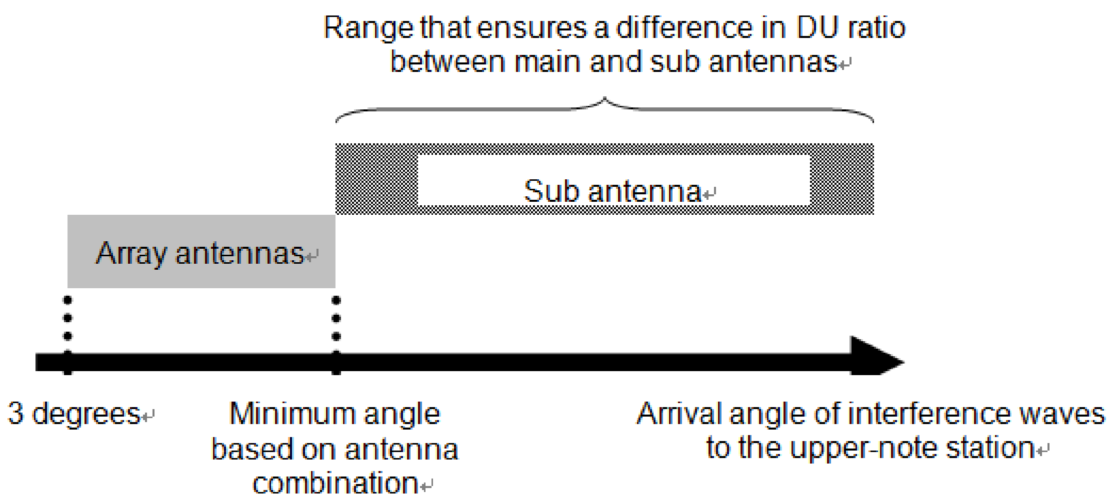


6.5.2.2.2 Application scopes of the array-antenna and sub-antenna modes

Figure 6.5.5 indicates the application scopes of the two modes. As a general rule, the sub-antenna mode should be used. When it is not possible to secure a difference in *D*/*U* ratio between the main and sub-antennas, the sub-antenna mode is used.

FIGURE 6.5.5

Application scopes of the array-antenna and sub-antenna modes



6.5.2.2.3 Array-antenna spacing in array-antenna mode

A co-channel interference canceller performs electric signal processing to cancel the interference waves received by the antennas. Depending on the array antenna spacing, however, it cannot effectively remove interference waves.

The removal of interference waves is less effective when the antennas are spaced so that the space correlation between the desired and interference waves will be positive, with a space correlation coefficient of approximately 1. The range where the space correlation coefficient is approximately 1 is called a grating lobe. Figure 6.5.6 shows an example of antenna spacing along with a space correlation coefficient.

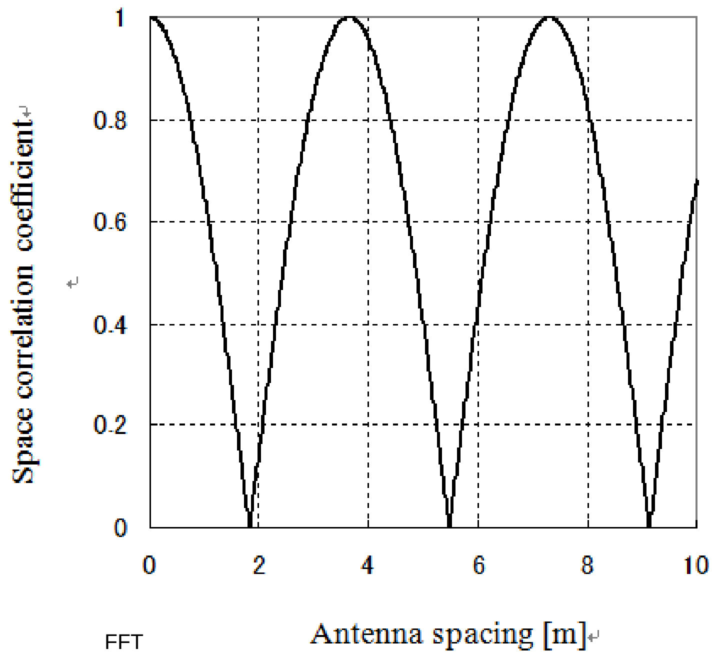
As a rule, when a co-channel interference canceller is used, the antenna spacing must ensure that the space correlation coefficient is not more than 0.68. If the reception antennas are shared by multiple media, all media must satisfy this requirement.

In actual antenna placement, the space correlation coefficient is calculated using the array-antenna spacing design tool to design proper design spacing.

FIGURE 6.5.6

Example of relation between antenna spacing and space correlation coefficient

[Channel 13 (with a wavelength of 0.63 m), interference-wave arrival angle of 10 degrees, and two antennas]



6.5.2.2.4 Difference in *D*/*U* ratio between the main and sub-antennas in sub-antenna mode

The operation requirements require that the difference in *D*/*U* ratio between the main and sub-antennas should be at least 20 dB. This requirement is based on the fact that co-channel interference canceller in sub-antenna mode perform signal processing intended to replicate the interference waves from the sub-antenna for interference cancellation.

The difference in *D*/*U* ratio between the main and sub-antennas is basically determined only by the directivity of the antennas used. Table 6.5.1 shows antenna combinations along with their corresponding minimum angles that allow the use of the sub-antenna mode. In case where SFN waves come, however, attention should be paid. If SFN waves are received by the sub-antenna, in particular, then the difference in *D*/*U* ratio between main and sub-antennas must be at least 20 dB for desired or SFN waves, whichever exhibit larger received power.

TABLE 6.5.1

Minimum angles that allow the use of sub-antenna mode

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="10">Sub-antenna types</th></tr>
<tr><th>40DPU-12</th><th>40DGU-12</th><th>30DPU-12</th><th>30DGU-12</th><th>30DGU-11</th><th>24DGU-12</th><th>24DGU-11</th><th>20DPU-12</th><th>18DGU-12</th><th>18DGU-11</th></tr>
<tr><td rowspan="10">Main antenna types</td><td>40DPU-12</td><td colspan="4">18 degrees</td><td>17 degrees</td><td>20 degrees</td><td>18 degrees</td><td colspan="2">20 degrees</td><td>21 degrees</td></tr>
<tr><td>40DGU-12</td><td>18 degrees</td><td>16 degrees</td><td colspan="2">18 degrees</td><td>17 degrees</td><td>19 degrees</td><td>17 degrees</td><td colspan="3">19 degrees</td></tr>
<tr><td>30DPU-12</td><td>*</td><td>*</td><td colspan="2">18 degrees</td><td>17 degrees</td><td>20 degrees</td><td>18 degrees</td><td colspan="2">20 degrees</td><td>21 degrees</td></tr>
<tr><td>30DGU-12</td><td>*</td><td>*</td><td colspan="2">18 degrees</td><td>17 degrees</td><td>20 degrees</td><td>18 degrees</td><td colspan="2">20 degrees</td><td>21 degrees</td></tr>
<tr><td>30DGU-11</td><td>*</td><td>*</td><td colspan="8">17 degrees</td></tr>
<tr><td>24DGU-12</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td colspan="5">22 degrees</td></tr>
<tr><td>24DGU-11</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>22</td><td>17</td><td colspan="3">22 degrees</td></tr>
<tr><td>20DPU-12</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td colspan="3">22 degrees</td></tr>
<tr><td>18DGU-12</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td colspan="2">22 degrees</td></tr>
<tr><td>18DGU-11</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td>*</td><td colspan="2">22 degrees</td></tr>
</table>

NOTE – Attention should be cases where SFN waves come.

The sub-antenna is required to have a diameter smaller than that of the main antenna. With an error of 2 degrees allowed for as the antenna orientation adjustment, the antenna directivity was calculated based on the standard pattern used for the station-to-station calculation result form.

6.5.2.2.5 Sub-antenna selection in sub-antenna mode

In the selection of the equalizer, the rule is that a co-channel interference canceller should be selected if the *D*/*U* ratios of interference waves are less than 28 dB for digital and analogue waves. This means that the selected co-channel interference canceller must be able to successfully remove interference waves having *D*/*U* ratios between 10 dB (according to the operation requirements for co-channel interference canceller) and 28 dB.

The sub-antenna must be so selected as to satisfy this requirement as well. Specifically, the *D*/*U* ratio of the interference waves must be between 10 dB and 28 dB and the received power of the sub-antenna must be included in the squelch setting range and in the AGC response range.

6.5.2.3 Base of consideration

6.5.2.3.1 Minimum arrival-angle difference

The minimum angle difference that satisfies the following requirements was defined to be 3 degrees.

TABLE 6.5.2

Conditions of sub-antenna

Characteristics	Requirements
Antenna to be used	1.8-m grid parabolic antenna (Envisioned as the smallest antenna to be used at typical relay stations)
Antenna spacing	5 λ (This spacing should not require inter-antenna coupling)
Number of antennas	2 (Based on the assumption that the number of interference waves is one)
Directivity attenuation of desired waves	The directivity attenuation of the desired waves after array combination must be less than 3 dB.

6.5.2.3.2 Space correlation coefficient

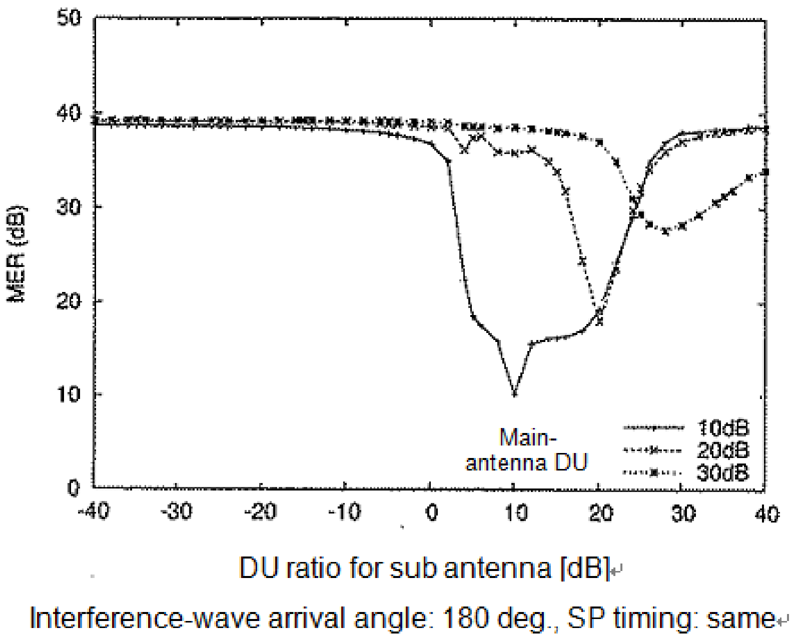
For the purpose of generally evaluating the antenna installation conditions, the space correlation coefficient is determined. The space correlation coefficient for the conditions for which the minimum arrival angle is set is 0.68. For this reason, when the antenna installation requirements were designed, it was defined that the space correlation coefficient should be less than 0.68.

6.5.2.3.3 Difference in *D*/*U* ratio between the main and sub-antennas

Figure 6.5.7 shows the simulation result for the sub-antenna mode. In an environment where the *D*/*U* ratios for the main and sub-antennas are 10 dB, the MER is 10 dB, meaning that the interference waves are removed. When the *D*/*U* ratio for the sub-antenna is –10 dB (meaning that strong interference waves are received), the MER is improved to around 40 dB, producing a sufficient effect. Similarly, even in a case where the *D*/*U* ratio for the main antenna is 20 dB or 30 dB, it is possible to stably remove interference waves by ensuring that the difference in *D*/*U* ratio between the main and sub-antennas is 20 dB or more.

FIGURE 6.5.7

Sub-antenna *D*/*U* ratios and their corresponding MER characteristics



6.5.2.3.4 Received power of sub-antenna

The required received power of the sub-antenna is given by the following equation:

Required received power of sub-antenna

$\geq$ squelch setting for reception transformation + 28 dB – main-antenna *D*/*U* ratio (99.9%) (37)

Japan digital TV requires that the squelch setting for reception transformation should be between –80 dBm and –67 dBm (the AGC response should be between –80 dBm and –27 dBm). If –80 dBm is substituted to equation (37) as the squelch setting for reception transformation,

Required received power of sub-antenna

$\geq$ –80 dBm + 28 dB – main-antenna *D*/*U* ratio (99.9%) (38)

Supposing that the main-antenna *D*/*U* ratio (99.9%) is 10 dB,

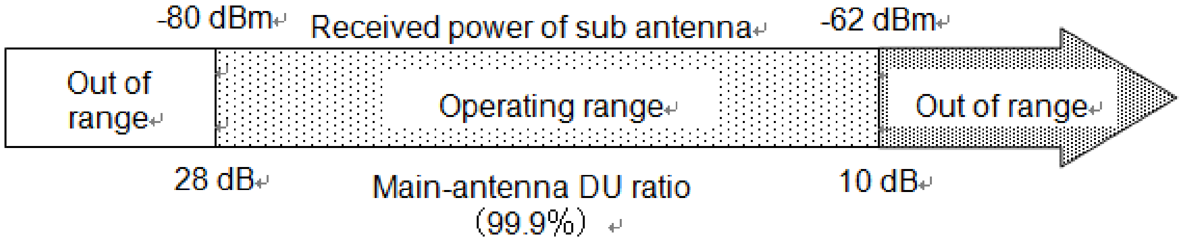
Required received power of sub-antenna

$\geq$ –80 dBm + 28 dB – 10 dB = –62 dBm (39)

Figure 6.5.8 illustrates the statements above.

FIGURE 6.5.8

Received power of sub-antenna and *D*/*U* ratio of main antenna



On the other hand, the relation between the reception antenna and its received power is given by the following equation:

Received power of sub-antenna (dBm)

$$= Eu\,(50\%) + fm + G - 2.1 - 1.6 + he - L - 6 - 107 \quad (40)$$

where:

- *Eu* (50%): Electric field strength of interference waves with a time percentage of 50% (dBμV/m)
- *fm*: Fading margin (interference wave) for a time percentage of 99.9% (dB)
- G – 2.1: Relative gain (dB)
- –1.6: Radiation resistance conversion (dB)
  10 log (50/73.13) (for a feeder impedance of 50 Ω)
- *he*: 20 log (λ/π) (dB)
- *L*: Cable loss (dB)
- –6: Termination voltage conversion (dB)
- –107: dBm conversion (for a feeder impedance of 50 Ω) (dB)

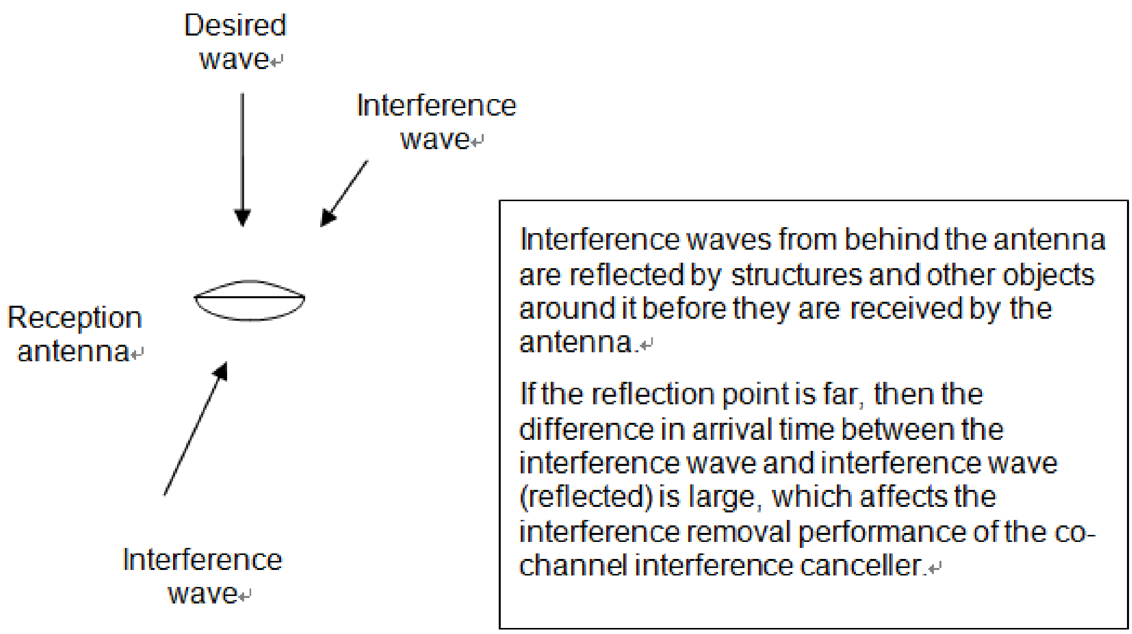
Based on the above equation, the sub-antenna should be selected so that the value of equation (40) will be higher than that of equation (38).

6.5.2.3.5 Effect of the multipath interference

If interference is multipath as shown in Fig. 6.5.9, a longer delay time of the waves degrades the inference-wave removal performance. For an environment where reflected waves are expected to come or for a propagation path where interference waves are diffracted, the network planning team must be individually consulted.

FIGURE 6.5.9

Example of multipath interference



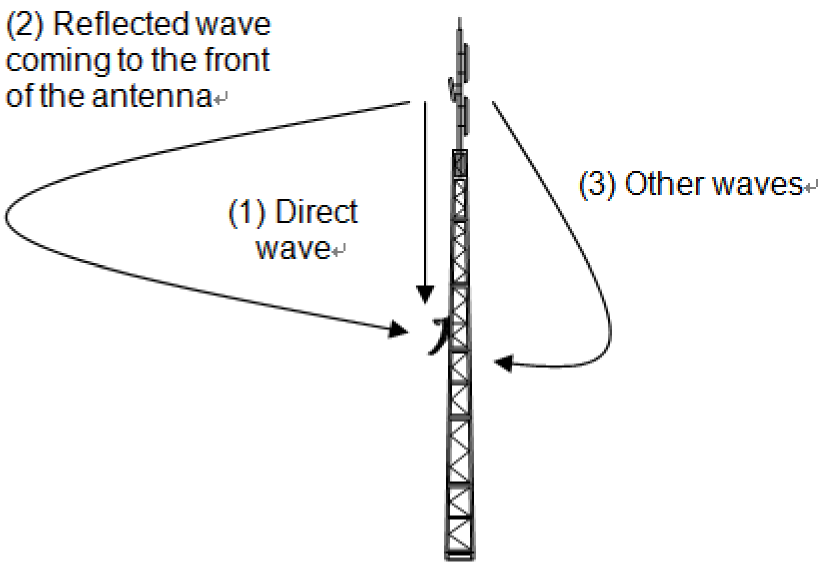
6.6 Coupling loops of self-transmitted waves and design of reception antennas

6.6.1 Concept

Coupling loops of self-transmitted waves are an important factor in reviewing SFN broadcast wave relaying, adjacent-channel interference, and image interference. They involve (1) direct waves, (2) reflected waves coming to the front of the reception antenna, and (3) the other reflected waves as shown in Fig. 6.6.1.

FIGURE 6.6.1

Coupling loops of self-transmitted waves



The strength of coupling loop waves is expressed in equation (41).

$$P_l = P_t + C_{tr} \tag{41}$$

where:

- P_l: Strength of coupling loop waves (dBm)
- P_t: Transmitter output (dBm)
- C_{tr}: Combined amount (dB).

Normally, C_{tr} is a negative value.

The combined amount C of (1) direct waves is determined from equation (42).

$$C = (G_t + D_t + L_{ft}) + 20\log\frac{\lambda}{4\pi d} + (G_r + D_r + L_{ft}) \tag{42}$$

where:

- G_t: Maximum gain of reception antenna (dBi)
- D_t: Reception-antenna directivity attenuation of transmission antenna (dB)
- L_{ft}: Transmission feeder loss (dB)
- G_r: Maximum gain of reception antenna (dBi)
- D_r: Reception-antenna directivity attenuation of transmission antenna (dB)
- L_{fr}: Transmission feeder loss (dB)
- D: Distance between transmission and reception antennas (m)
- λ: Wavelength (m).

Reflected waves (2) and (3), however, are difficult to determine by calculation, and therefore must be measured.

6.6.2 Estimated coupling loops of self-transmitted waves in unseparated reception

Past experiments have revealed that the combined amount in unseparated reception is around –60 dB and never exceeds about –80 dB. This combined amount covers direct waves and many other reflected waves. Table 6.6.1 shows the strength of the coupling loop waves when the combined amount is –80 dB.

TABLE 6.6.1

Coupling loops of self-transmitted waves in unseparated reception (combined amount: –80 dB)

Transmitter output	10 W	3 W	1 W	0.3 W	0.1 W
P_l	–40 dBm	–45 dBm	–50 dBm	–55 dBm	–60 dBm

The received power for reception antenna output does not include the reception feeder loss.

6.6.3 Consideration of the combined amount

6.6.3.1 Direct waves

The combined amount of the direct waves almost agrees with the value given by equation (42) if there is no structure between the transmission and reception antennas. G_t, L_{ft}, G_r, and L_{fr} are uniquely determined by the specifications of the relay station. D_t is more than 20 dB or so in the region where the depression angle of the transmission is 30 degrees or more. For this reason, considering that D_t = –20 dB, D_r can be determined by calculation, by having the reception antenna to be used; refer to the directivity for consideration. If there is a parabolic antenna or any other structure between the transmission and reception antennas, D_r must be measured because it is not expected to agree with the calculated value. Here is an example of combined amount calculation:

(a) Transmission antenna: one face at Tier 4L1, reception antenna: 13FLU-11, distance between the transmission and reception antennas: 10 m

When the frequency is 500 MHz:

$$C_{tr} = (G_t + D_t + L_{ft}) + 20\log\frac{\lambda}{4\pi d} + (G_r + D_r + L_{ft})$$

$$= (12.7 - 20 - 1) + (-46.4) + (13 - 38 - 1) = -80.7 \text{ (dB)} \qquad (43)$$

(b) Transmission antenna: one face at Tier 6L1, reception antenna: 30DGU-11, distance between the transmission and reception antennas: 10 m

When the frequency is 500 MHz:

$$C_{tr} = (G_t + D_t + L_{ft}) + 20\log\frac{\lambda}{4\pi d} + (G_r + D_r + L_{ft})$$

$$= (14.5 - 20 - 1) + (-46.4) + (20 - 31 - 1) = -64.9 \text{ (dB)} \qquad (44)$$

6.6.3.2 Consideration of reflected waves

Basically, reflected waves cannot be determined by calculation, and therefore must be measured at the location where the reception antenna will be installed. In making measurements, it is important to identify the trees, structures, and other objects that may reflect radio waves. It is recommended to take pictures of all areas around the reception point so that the surroundings can be checked later. Extra attention should be paid to reflectors located in front of the reception antenna because they cannot be controlled. Here are reflectors that require attention:

– steel tower;

– electric wire and power pole;

– building (a building located in front of the reception antenna may have an effect even if it is several kilometres away);

– trees;

– topographic objects (such as mountains).

As noted above, the coupling loop of self-transmitted waves should be largely considered based on measurements. It is important to conduct a solid field study, with the consideration on the desk limited to the determination of the estimated D/U ratio that can be ensured. In the field study, a location should be selected that provides sufficient electric field strength of the upper-node station and receives less reflection from the surroundings. It is desirable that after the study, a long test radio-wave period (about 2-month period) should be set aside, during which adjustments can be made after the setup.