# 4-7-3 An OFDM Terminal for Experiment of a Satellite Audio Broadcasting

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An OFDM terminal, with sound quality equivalent to that of a compact disk, is used for experiments on satellite audio broadcasting using Engineering Test Satellite VIII (ETS-VIII).

The terminal consists of an OFDM signal generator, and a test receiver for estimating OFDM signals. The modulation method used is a multi-carrier OFDM system. A feature of this OFDM method is that good transmission characteristics are acquired even if a delay wave exists in a transmission path. It is suitable for reception of signals in urban areas where delay waves often exist as a result of reflections from buildings, etc. However, since it is a multi-carrier, when there are nonlinear characteristics in the transmission path, the transmission characteristic deteriorates due to the influence of inter-modulation. For this reason, when a satellite transponder designed to achieve electric-power efficiency is used, it is thought that a bit error rate may deteriorate under this influence.

This paper describes an outline of an OFDM terminal for satellite audio broadcasting experiments. The results of a ground test using an electric model of ETS-VIII (SEM) and an OFDM terminal are also reported.

***Keywords***

**ETS-VIII, Satellite audio broadcasting, OFDM**

## 1 Introduction

For Engineering Test Satellite VIII (ETS-VIII), the Communications Research Laboratory is planning high-quality digital audio broadcasting experiments for mobiles by OFDM (Orthogonal Frequency Division Multiplexing). Since OFDM provides excellent transmission characteristic even in the state where there is delay wave, it is used for high-quality digital audio broadcasting (DAB: Digital Audio Broadcasting) for mobiles in Europe. Moreover, OFDM has been adopted as a transmission system for digital TV broadcasting in Japan. One significant reason for this adoption is that the transmission system is effective against interference by delayed waves caused by multipath in environments such as urban areas, where high-rise buildings stand close together.

On the other hand, for satellite communication, since the equipment on board a satellite requires high electric power efficiency, amplifiers are often operated in their saturation region. Under these conditions, deterioration of transmission characteristics resulting from intermodulation, a drawback of the OFDM transmission system, may present problems.

This paper reports on the OFDM terminal equipment used for the high-quality satellite audio broadcasting experiments by an OFDM transmission system that uses ETS-VIII, and reports the performance results of a ground-test using an SEM (System Engineering Model) of the ETS-VIII.

## 2 Overview of satellite audio broadcasting experiments

Overview of the satellite audio broadcasting experiments is shown in Fig.1.

The OFDM signal transmitted from a Ka-band feeder-link earth station [1] is frequency converted to an S-band signal by the satellite and re-transmitted to the ground. On the ground, by receiving signals via the mobile station [2] or S-band earth station [3], we will obtain several types of data on the effects of multipath caused by structures, such as buildings, and the effects of nonlinear transmission paths.

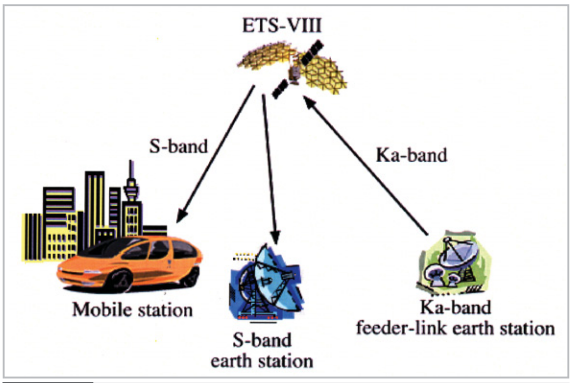


**Fig.1** Overview of satellite audio broadcasting experiments

## 3 Experimental system

The OFDM terminal for the audio broadcasting experiments consists of an OFDM signal generator in the transmission system and a test receiver for estimating an OFDM signal in the reception system.

The OFDM signal is transmitted from the Ka-band feeder-link earth station, converted into an S-band signal by the satellite, re-transmitted to the ground, and received by the mobile station and the S-band earth station. Therefore, the OFDM signal generator is installed in the Ka-band feeder-link earth station, and the test receiver for estimating an OFDM signal is installed in the mobile station and the S-band earth station.

Fig.2 shows the appearance of the OFDM signal generator.

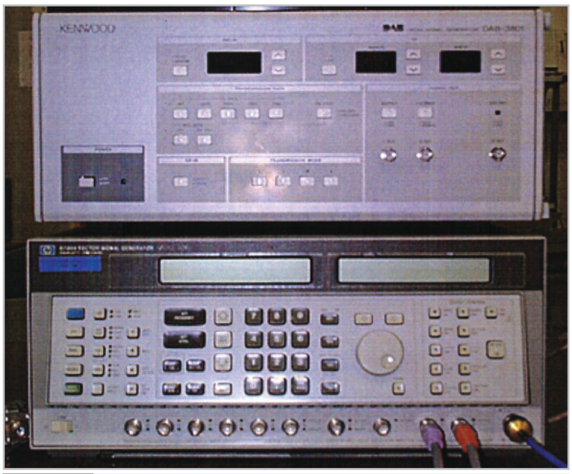

**Fig.2** Appearance of OFDM signal generator

The upper side is the OFDM signal generator and the lower side is the vector signal generator (vector SG). OFDM modulated I and Q signals which are output from the OFDM signal generator are quadrature modulated by the vector SG, and obtain the 140-MHz band IF signal.

Fig.3 is a block diagram of the OFDM signal generator.

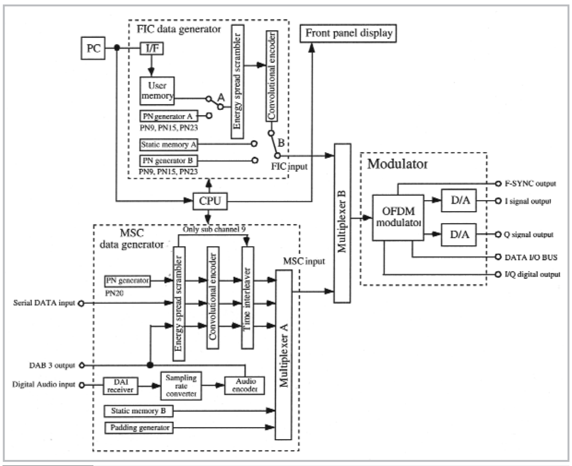


**Fig.3** Block diagram of OFDM signal generator

The OFDM signal generator consists of an FIC (First Information Channel) data generator, an MSC (Main Service Channel) data generator, and an OFDM modulator.

The FIC transmits additional information about the service. Its data generator can select and output fixed data prepared in advance, user-created data, and a pseudo noise code

(PN code). Moreover, it has rewritable memory for saving user-created data. For the PN code, the FIC data generation section has generators for three types of CCITT-compliant codes (PN9, PN15, and PN23).

The MSC is a channel through which actual service information is transmitted. Its data generator converts input digital audio interface data into DAB audio frames, and carries out predetermined scrambling, convolution coding and time interleaving together with external serial data and the PN code in an energy spread scrambler, a convolutional encoder, and a time interleaver. The data is then multiplexed with a data from the padding generator and a data in static memory B, by multiplexer A according to the contents of FIC, and output as MSC data.

In the modulator section, FIC and MSC data are multiplexed by Multiplexer B according to a transmission mode, and the multiplexed data is modulated with an OFDM modulator, and I - Q signals are output.

Although four transmission modes are prepared for OFDM, the ETS-VIII experiment uses MODE III. Table 1 shows the transmission parameters of the respective transmission modes. These modes are chosen according to the difference in the frequency band and the transmission method to be used, and MODE III is used for satellite broadcasting at 3 GHz or below.

**Table 1** Parameters of respective transmission modes

| | MODE I | MODE II | MODE III | MODE IV |
|---|---|---|---|---|
| Number of OFDM symbols (Except NULL) | 76 | 76 | 153 | 76 |
| Number of carriers | 1536 | 384 | 192 | 768 |
| Carrier interval | 1 KHz | 4 KHz | 8 KHz | 2 KHz |
| Frame length | 96 ms | 24 ms | 24 ms | 48 ms |
| NULL symbol length | 1.297 ms | 0.324 ms | 0.168 ms | 0.648 ms |
| OFDM symbol length | 1.246 ms | 0.312 ms | 0.156 ms | 0.623 ms |
| Effective symbol length | 1 ms | 0.250 ms | 0.125 ms | 0.5 ms |
| Guard interval length | 0.246 ms | 0.062 ms | 0.031 ms | 0.123 ms |
| Modulated wave bandwidth | 1536 KHz | | | |

Fig.4 shows a composition of a transmission frame.

The NULL symbol with $l$ = 0 is a section of signal off, and is used in order to adjust

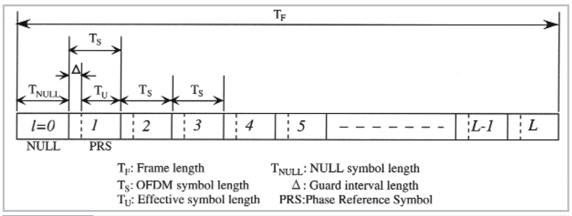


**Fig.4** Composition of transmission frame

timing on the reception side.

The symbol with $l$ = 1 is called PRS, and is fixed data. The reception side uses this symbol to estimate offset frequency and timing, and a reference phase signal in differential detection. The symbols of $l$ = 2 to L contain transmitted data.

Fig.5 shows the appearance of the test receiver for estimating an OFDM signal. The equipment can be mounted into a 19-inch rack.

Fig.6 is a block diagram of the test receiver for estimating an OFDM signal.


**Fig.5** Appearance of the OFDM signal estimation receiver

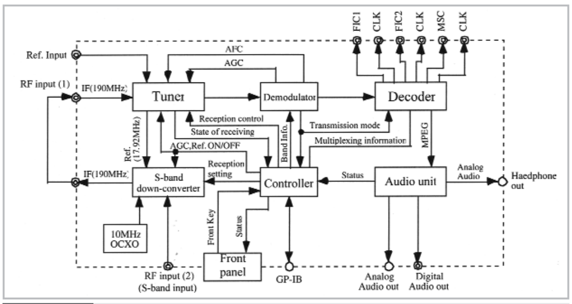


**Fig.6** Block diagram of OFDM signal estimation receiver

The received S-band RF signal is converted into the 190-MHz band IF signal by the S-band down-converter. This IF signal is input into the tuner unit through a U-link.

The IF signal input into the tuner unit is further converted into the 3.072-MHz IF signal, and converted into a baseband signal by quadrature detection in a demodulator. This signal is FFT transformed in an effective symbol period, and complex data transmitted on carriers of OFDM is subjected to differential detection to obtain demodulated data. This demodulated data undergoes frequency de-interleaving, time de-interleaving, error correction, and energy spread removal in the decoder to obtain service data.

If a service selected in the front panel is audio, the data is MPEG-decoded in the audio section and output as analog voice signals. In the case of the data, this is output in the form of data with clock to the outside.

Synchronization is performed so that coarse frame synchronization is established by a NULL symbol of a frame, its frequency deviation is detected based on PRS (Phase Reference Symbol), and the VCXO of the tuner section is controlled by AFC. AGC calculates the electric power of the OFDM symbol subjected to differential detection and outputs an AGC voltage to the tuner section so that its value coincides with the target value.

Table 2 shows the electrical performance for the test receiver for estimating an OFDM signal.

Fig.7 shows a BER characteristic (before error correction) of the loop test of this system in IF. The reception frequency is 176 MHz, and the signal is input into the test receiver at an RF input (1). BER measurement was performed in all transmission modes.

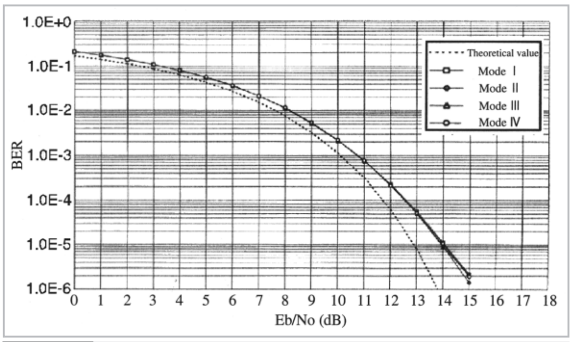


**Fig.7** Loop back BER characteristics in IF (before error correction)

Inherent deterioration of system to a theoretical value of BER up to 1.0 E-4 is 1 dB or less.

Fig.8 shows BER characteristics (before error correction) of a loop test with IF in the S-band. The signal was input into the test receiver at an RF input (2). In this measurement, noise was added to the output signal (190 MHz) from the S-band down-converter.

In the S-band, inherent deterioration of system to the theoretical value of a BER at 1.0E-4 is approximately 1.2 dB, indicating a result slightly worse than the measurement at 176 MHz.

**Table 2** Electrical performance

| Item | | Specification |
|---|---|---|
| RF input(1) | Frequency (BAND II) | 87.5～108.0 MHz |
| | (BAND III) | 175.0～250.0 MHz |
| | (L-BAND) | 1452～1492 MHz |
| | Frequency resolution | 1 KHz |
| | Input level (BAND II,III) | -94～10 dBm |
| | (L-BAND) | -91～0 dBm |
| | Noise figure (BAND II,III) | 8 dB |
| | (L-BAND) | 11 dB |
| RF input(2) | Frequency (S-BAND) | 2535～2540 MHz |
| | Frequency resolution | 500 KHz |
| | Input level | -130～-40 dBm |
| | Noise figure | 3 dB (Max) |
| IF output | Frequency | 190 MHz |
| | Output level | -10 dBm |
| BER output (1) (Before error correction FIC) | Data, Clock Output level | TTL |
| BER output (2) (After error correction FIC) | Data, Clock Output level | TTL |
| BER output (3) (After error correction MSC) | Data, Clock Output level | TTL |
| Analog audio output | Maximum output level | 2 V r.m.s |
| Digital audio output | Output level | 5 Vp-p |

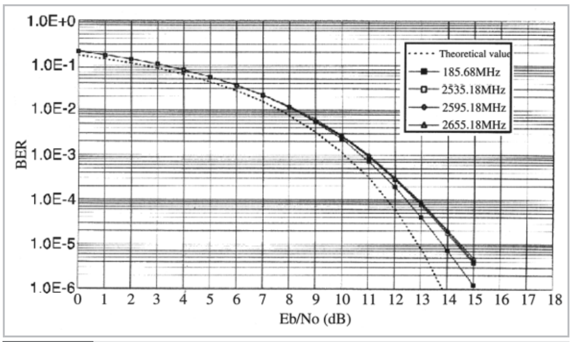


**Fig.8** Loop back BER characteristics in S-band (before error correction)

## 4 Ground test using SEM

The ground test was performed to measure deterioration of the transmission characteristics caused by the nonlinear characteristic of the transponder (especially a power amplifier) of the satellite [4].

In addition, the SEM (System Engineering Model) of ETS-VIII used for the examination consists of orbital flight models. Therefore, this experiment can be regarded as a verification of whether or not the audio broadcasting experiments can be conducted normally while in orbit.

Fig.9 shows an example of a system diagram of the ground test which used the SEM. Several routes inside the satellite can be selected for the audio broadcasting experiments. A typical system diagram is shown here.

Since the input frequency of the SEM is in the Ka band, the S-band OFDM signal output from the OFDM signal generator is converted into the Ka-band by an up-converter, and is input into the SEM.

In the SEM, the signal passes through an input circuit, a low noise amplifier, and a down-converter, and is converted into an IF frequency of the 140-MHz band. The signal then passes through an S-band up-converter, a beam-forming network, and an SSPA (Solid State Power Amplifier), which outputs a signal of the S band. The SEM has 31 SSPA systems, the combined outputs of which serves as a transmission signal in orbit. In this test, the one output of these SSPA systems is taken out to the outside.

Fig.10 is an input-output characteristic of the SEM.

The figure shows the input-output characteristics of the CW signal and the OFDM signal. The input-output characteristic of OFDM signal tend to exhibit lower gain than the CW signal at low input level. This is characteristic of cases in which multiple signal waves are common amplified. Since the OFDM signal is composed of 192 carriers, intermodulation effects are expected to become prominent.

In this test, the maximum input level is set

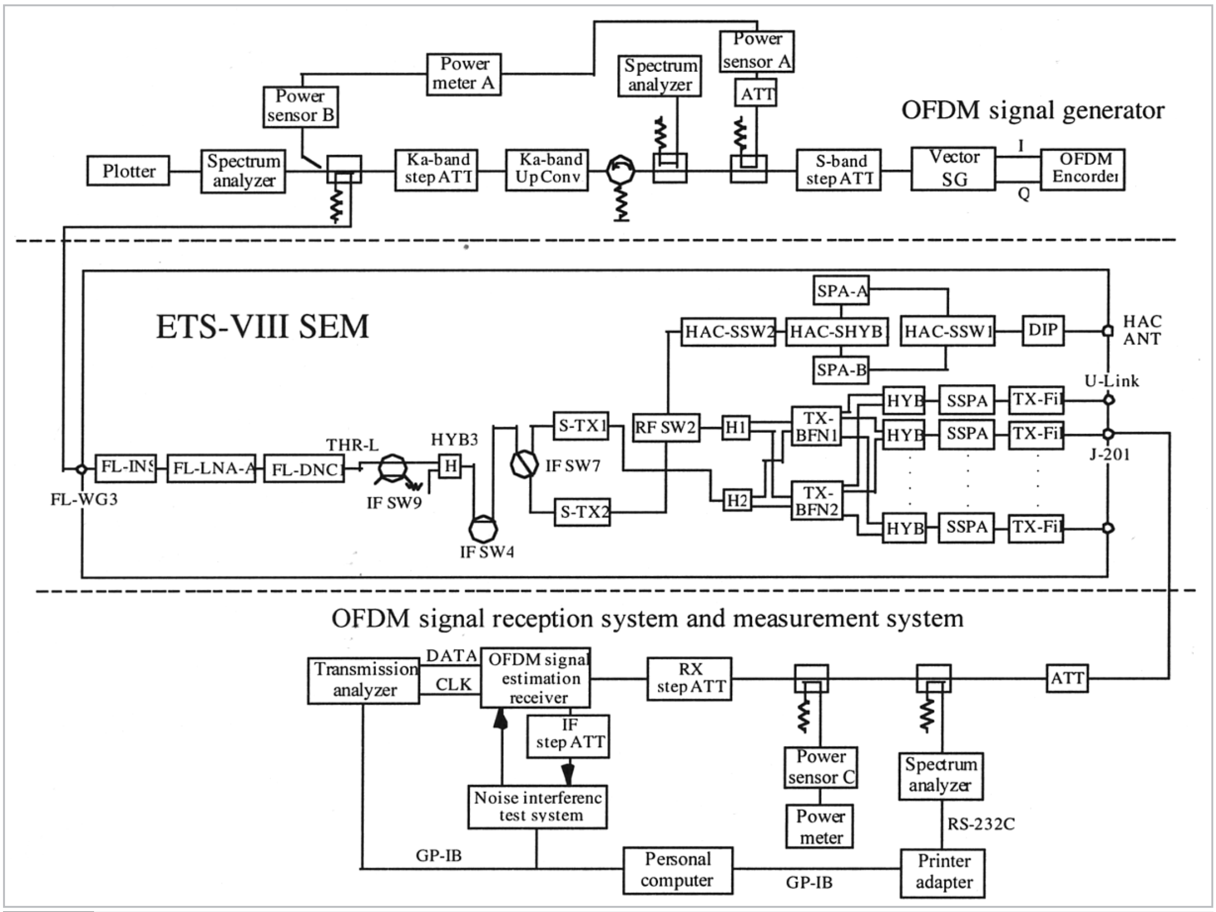


**Fig.9** *An example of an SEM test system diagram*

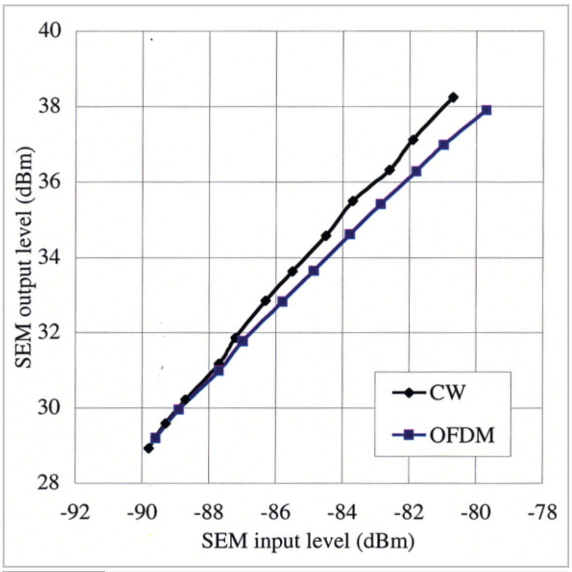


**Fig.10** An example of SEM input-output characteristics

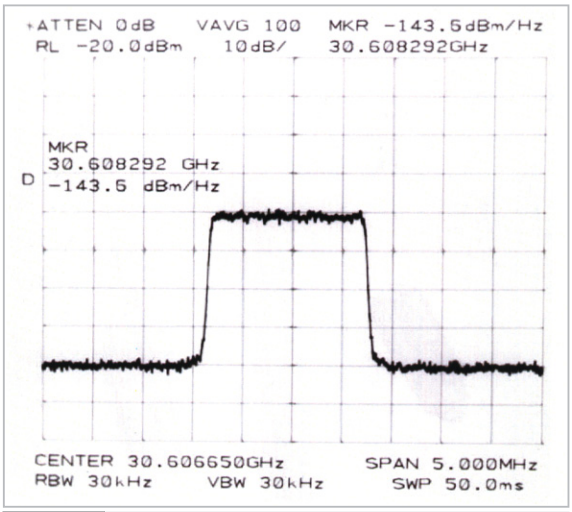


**Fig.11** Output spectrum of Ka-band up-converter

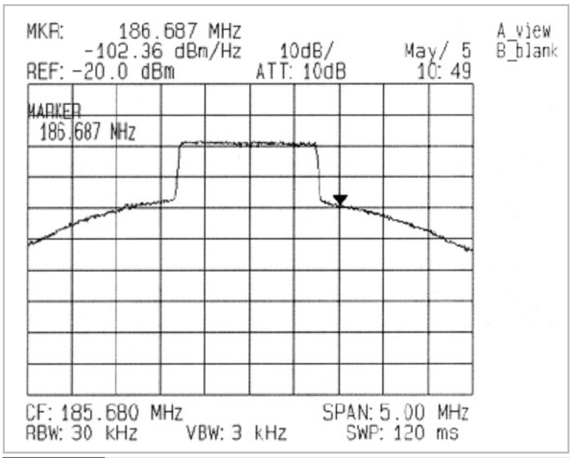


**Fig.12** SEM output spectrum (IBO = 0 dB)

to −79.6 dBm due to limitations of SEM. This input level is more or less identical to the input level (−78.9 dBm) at the same interface point, estimated from the link budget exemplified in Table 3.

**Table 3** An example of a link budget for audio broadcasting (good weather)

| Item | Unit | Audio broadcasting | |
|---|---|---|---|
| | | Earth station → Satellite | Satellite → Mobile station |
| EIRP | dBW | 60.9 | 61.8 |
| Pointing loss | dB | 0.0 | -2.0 |
| Path loss | dB | -213.7 | -192.1 |
| Atmospheric absorption loss | dB | -0.3 | 0.0 |
| Rain attenuation | dB | 0.0 | 0.0 |
| Polarization loss | dB | -0.3 | -0.5 |
| Fading loss | dB | 0.0 | 0.0 |
| Propagation loss | dB | -214.3 | -192.7 |
| Pointing loss | dB | 0.0 | 0.0 |
| G/T | dB/K | 13.1 | -21.6 |
| C/No | dBHz | 88.3 | 74.1 |
| C/No (2way) | dBHz | 74.0 | |
| Required C/No | dBHz | 74.4 (including the implementation loss) | |
| Margin | dB | -0.4 | |

Each characteristic was obtained using as a parameter the input-back-off (IBO) from the maximum input level of the SEM into a reference level.

Fig.11 shows the spectrum of an output of the Ka-band up-converter input into the SEM. In the transmission path from the OFDM signal generator to an SEM input, the signal is treated in a linear region so that it is not affected by intermodulation.

Fig.12 is an output spectrum of SEM at a reference input level (IBO = 0 dB). The spectrum was observed at an output of the S-band down-converter built into the test receiver for estimating an OFDM signal (in the 186-MHz band).

As shown in the figure, slopes exist in the noise level of the both sides of the OFDM signal. This is considered to be caused by intermodulation.

Figs.13 and 14 are SEM output spectrum when IBO was set to −3 dB and −6 dB, respectively.

The larger the IBO, the flatter the slope of the noise level becomes, indicating reduction of the influence of intermodulation. Incidentally, noise levels decrease on both sides of the spectrum in Fig.14, which is attributed to the characteristics of a band pass filter installed on

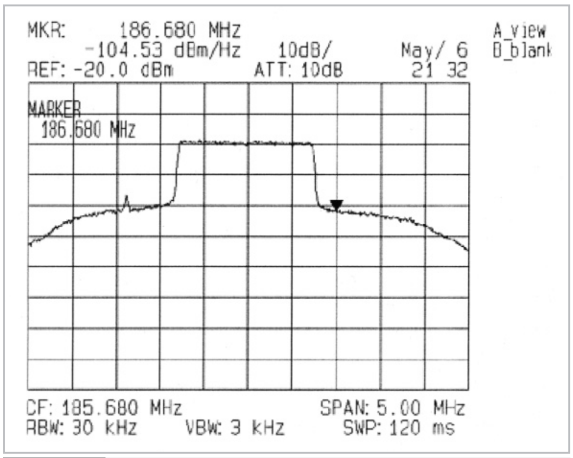


**Fig. 13** SEM output spectrum (IBO = −3 dB)

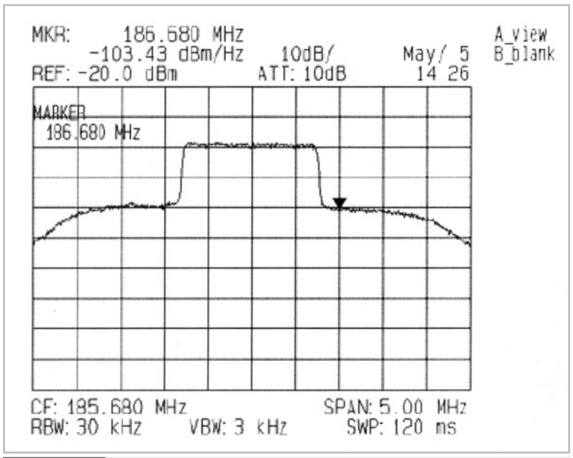


**Fig. 14** SEM output spectrum (IBO = −6 dB)

a signal route in the SEM.

Fig.15 shows the BER characteristics of several IBO (before error correction).

A tendency is observed in which BER somewhat improves for higher C/No with increasing IBO, but for lower C/No, no significant difference can be observed.

It is thought that the communication quality required in the audio broadcasting experiments is 1.E−4 or less in BER after error correction. The BER before error correction is 1.E−2 or less, and the overall C/No required for the link is 72.6 dBHz or more at IBO = 0 dB.

From one example of the link budget of the audio broadcasting experiments of Table 3,

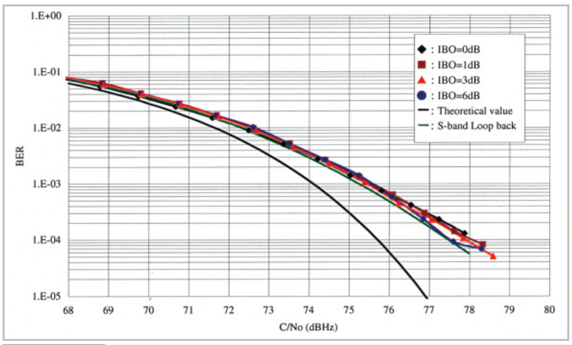


**Fig. 15** BER characteristics of several IBOs

although the required C/No is 74.4 dBHz, it includes a value of inherent deterioration. From the results of the SEM test, the required C/No becomes 72.6 dB or more, indicating that obtaining a margin of 1.4 dB is possible. Performance of the mobile station assumed in the link budget is an antenna gain of 6 dBi and a LAN NF (Noise Figure) of about 3 dB. This link budget assumes a state free of rain attenuation. Moreover, intermodulation noise and interference noise are assumed to be part of the inherent deterioration obtained in the test.

## 5 Concluding remarks

This report discussed the OFDM terminal used for the audio broadcasting experiments with the ETS-VIII. We have obtained BER characteristics using this terminal and the SEM of ETS-VIII, confirming the feasibility of experiment in orbit.

Although the electric power efficiency of the equipment on a satellite is important, in the satellite audio broadcasting which uses an OFDM, deterioration of the channel quality due to the nonlinear characteristic of on-board equipment poses a problem. However, it is thought that OFDM is effective in the measure of disturbance by the delay wave in environment with many multipass like ground broadcasting, and experimental results using ETS-VIII are expected.

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