# Formant Analysis System for Realtime Electromagnetic Interference Source Discrimination

Fumihiko Ishiyama†, Kazuo Murakawa, and Hiroshi Yamane


## Abstract

We studied a formant analysis system that extracts characteristic frequencies of acoustic noise generated by telecommunication equipment as a result of electromagnetic interference. Our realtime formant analysis system is based on linear predictive coding and digital signal processors. We checked the system's technical conditions for formant analysis and found that characteristic frequencies could be obtained even when the signal-to-noise ratio of the waveform was –5 dB.


## 1. Introduction

Malfunctions of telecommunication equipment caused by electromagnetic interference (EMI) are increasing along with the trend of saving power and operating telecommunications equipment at low voltages. In the countermeasures against equipment malfunction, it takes time to identify the EMI source causing the malfunction. Methodologies for characterizing EMI sources have not been established. Therefore, engineers need intuition and experience to discriminate EMI sources. Thus, there is a need to establish a quantitative method of discriminating EMI sources.

EMI waves invade equipment through its power supply wire or the communications line, or directly as electromagnetic waves. As a result, there are equipment malfunctions or problems such as audible acoustic noise being emitted from the equipment. For instance, the envelope of the EMI wave is detected at the rectification circuit of the power unit, and acoustic noise is generated.

We applied formant analysis based on linear predictive coding (LPC) [1]-[5] to the time series signal of acoustic noise to discriminate EMI sources because the EMI wave is thought to contain characteristic information. We clarified that the EMI wave is characterized by the distribution diagram of the formant frequencies [6].

The analysis system should preferably work in realtime considering practical use of the system in real applications. Therefore, we developed an EMI source discrimination system that uses LPC-based formant analysis and examined its realtime operation.

† NTT Energy and Environment Systems Laboratories
Musashino-shi, 180-8585 Japan
E-mail: ishiyama.fumihiko@lab.ntt.co.jp

## 2. Formant analysis system

### 2.1 Development environment

In developing a system based on digital signal processors (DSPs), we can describe the system in C/C++ language or describe it using a development environment. The main development environments are shown in **Table 1**. We chose Hypersignal RIDE [7] because it was the most suitable for developing our realtime LPC-based formant analysis system based on DSPs.

### 2.2 System configuration

The system's processing blocks are shown in **Fig. 1** and its display blocks in **Fig. 2**.

In Fig. 1, the upper left is the signal generation part. The signal $u(t)$ given here is:

$$u(t) = u_1(t)u_2(t) + u_3(t), \quad (1)$$

$$u_1(t) = \sin(2\pi f_1(t)t) + \sin(2\pi f_2(t)t), \quad (2)$$

$$f_1(t) = f_{a1} + f_{b1}|v(c_1t)|, \quad (3)$$

$$f_2(t) = f_{a2} + f_{b2}|v(c_2t)|, \quad (4)$$

Table 1. Development environments.

| Manufacturers/products | Main purpose | Main benefits | Assessment |
|---|---|---|---|
| The MathWorks, Inc. MATLAB | General | Widely used | Good |
| National Instruments Corp. LabVIEW | Measurement | Supports GP-IB, CAMAC, etc. | Fair |
| Elanix, Inc. SystemView | System analysis of wireless communication systems | W-CDMA, Bluetooth emulation | Fair |
| Hyperception, Inc. Hypersignal RIDE | DSP system development | Realtime audio/visual analysis | Excellent |

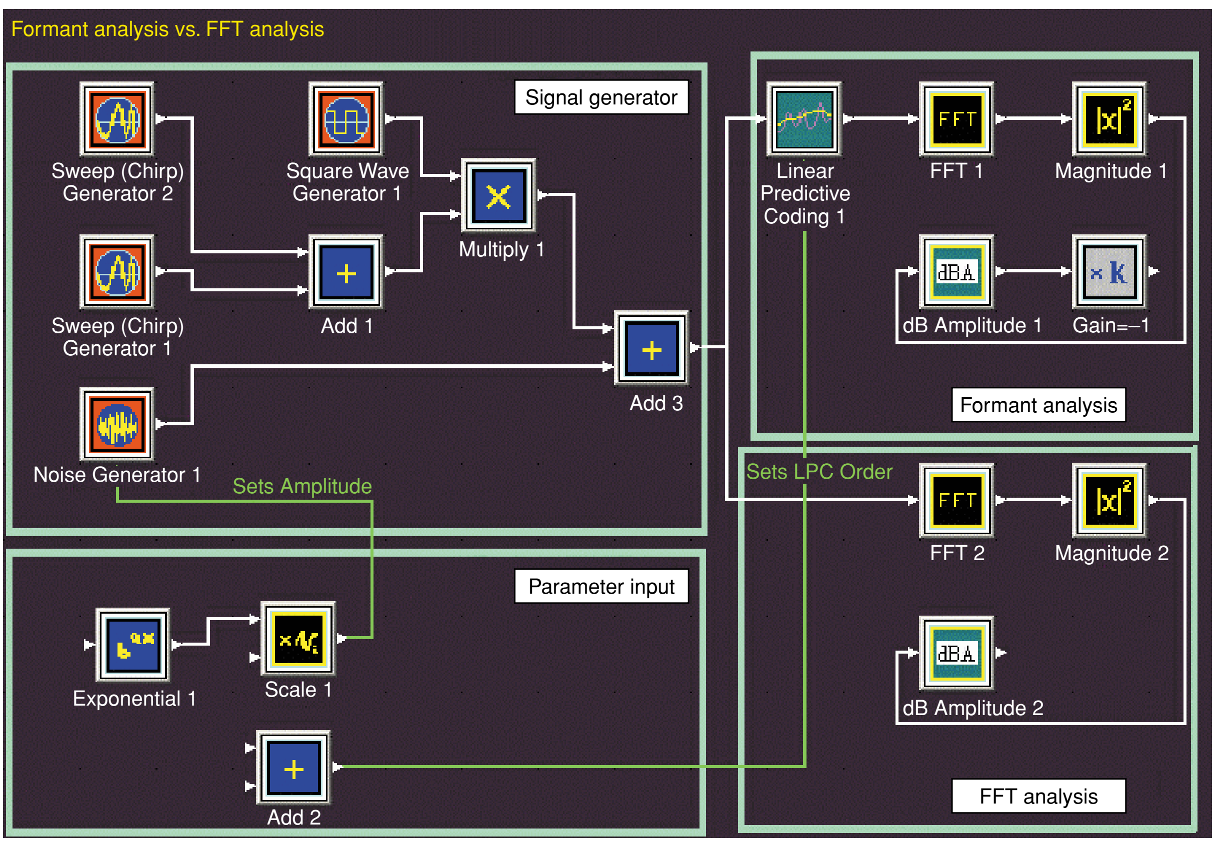


Fig. 1. Processing blocks of the system.

$$u_2(t) = \mathrm{sgn}(v(c_3 t)), \qquad (5)$$
$$u_3(t) = d \cdot rand, \qquad (6)$$
$$v(x) = x - 2\left\lfloor \frac{x}{2} \right\rfloor - 1. \qquad (7)$$

Here, $u_1(t)$ consists of two chirp frequencies, where the frequencies change from $f_{a1}$ to $f_{a1} + f_{b1}$ and from $f_{a2}$ to $f_{a2} + f_{b2}$. The periods of these frequency chirps are $2/c_1$ and $2/c_2$. The $u_2(t)$ is the modulation term of a rectangular wave with period $2/c_3$ on $u_1(t)$ to consider a pseudo-random number pattern of the spread spectrum. The $u_3(t)$ is the random noise term. The parameters are set as follows: $f_{a1} = 300$ Hz, $f_{b1} = 3300$ Hz, $c_1 = 1/60$ Hz, $f_{a2} = 500$ Hz, $f_{b2} = 2500$ Hz, and $c_2 = 1/7$ Hz. The $c_3$ is obtained from the “Wave form” bar in Fig. 2. The $d$ is the amplitude of the random noise obtained from the “Noise intensity” bar in Fig. 2.

The lower left of Fig. 1 is the parameter control part for the signal generation and formant analysis parts. It contains blocks giving the strength of the random noise imposed on the signal in the signal generation

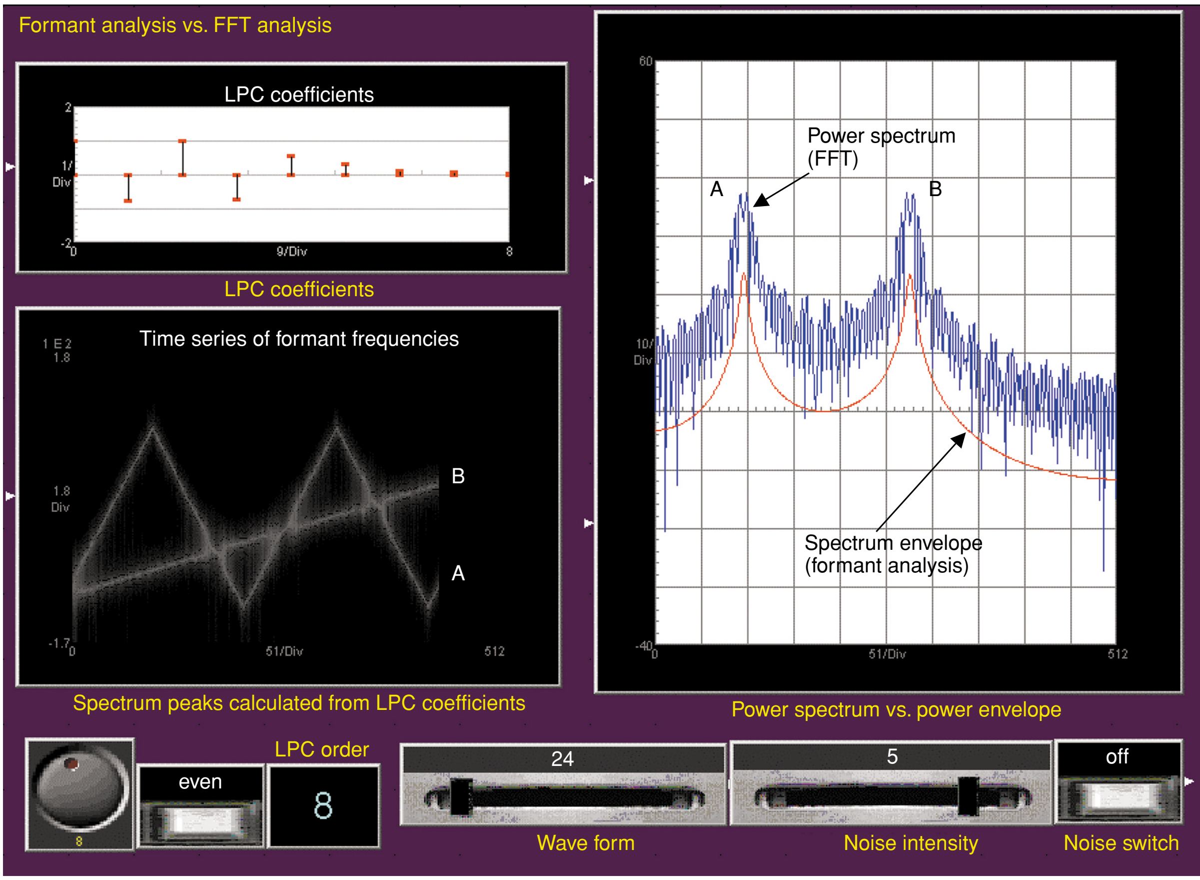


Fig. 2. Display blocks of the system.

part and blocks giving the analytical degree of formant analysis. We obtained the strength of the random noise in units of dB. The index is converted in the "Exponential 1" block and fed to the "Noise Generator 1" block. The "Scale 1" block is used as a switch that imposes the random noise. The analytical degree of LPC-based formant analysis, which is usually an even number, is obtained from the output of the "Add 2" block. Then, the output of the dial block, which is showing an even number (8) in Fig. 2, is added to the output of the block where either 0 and 1 is taken (also shown in Fig. 2), and the combined value is passed to the "Linear Predictive Coding 1" block, where the formant is analyzed.

The upper right of Fig. 1 is the formant analysis part. Here, the spectrum envelope is calculated using the LPC coefficients obtained from the time series signal [1]-[5]. The procedure is as follows. The LPC coefficients are obtained in the "Linear Predictive Coding 1" block. The result is passed to the "FFT (fast Fourier transform) 1" block and Fourier transformation is performed. The result is passed to the "Magnitude 1" block, which is usually used to calculate the power spectrum from the result of the "FFT" block. The spectrum envelope is obtained by taking the logarithm of the output of the "Magnitude 1" block in the "dB Amplitude 1" block and taking the reciprocal in the "Gain = –1" block. It is passed to the display panel in Fig. 2.

The lower right in Fig. 1 is the Fourier analysis part. It is provided for comparison with formant analysis. Here, the power spectrum is given by Fourier transform in the "FFT 2" block, and the result is passed to the "Magnitude 2" block. The logarithm of the power spectrum is taken in the "dB Amplitude 2" block. The result is passed to the display panel in Fig. 2.

### 2.3 LPC-based formant analysis and Fourier analysis

The lower left of Fig. 2 is the operation panel for giving the LPC order of the LPC-based formant analysis; in this example, the eighth degree of the order is set here [6]. The lower right is the operation panel to control the parameters for the signal genera-

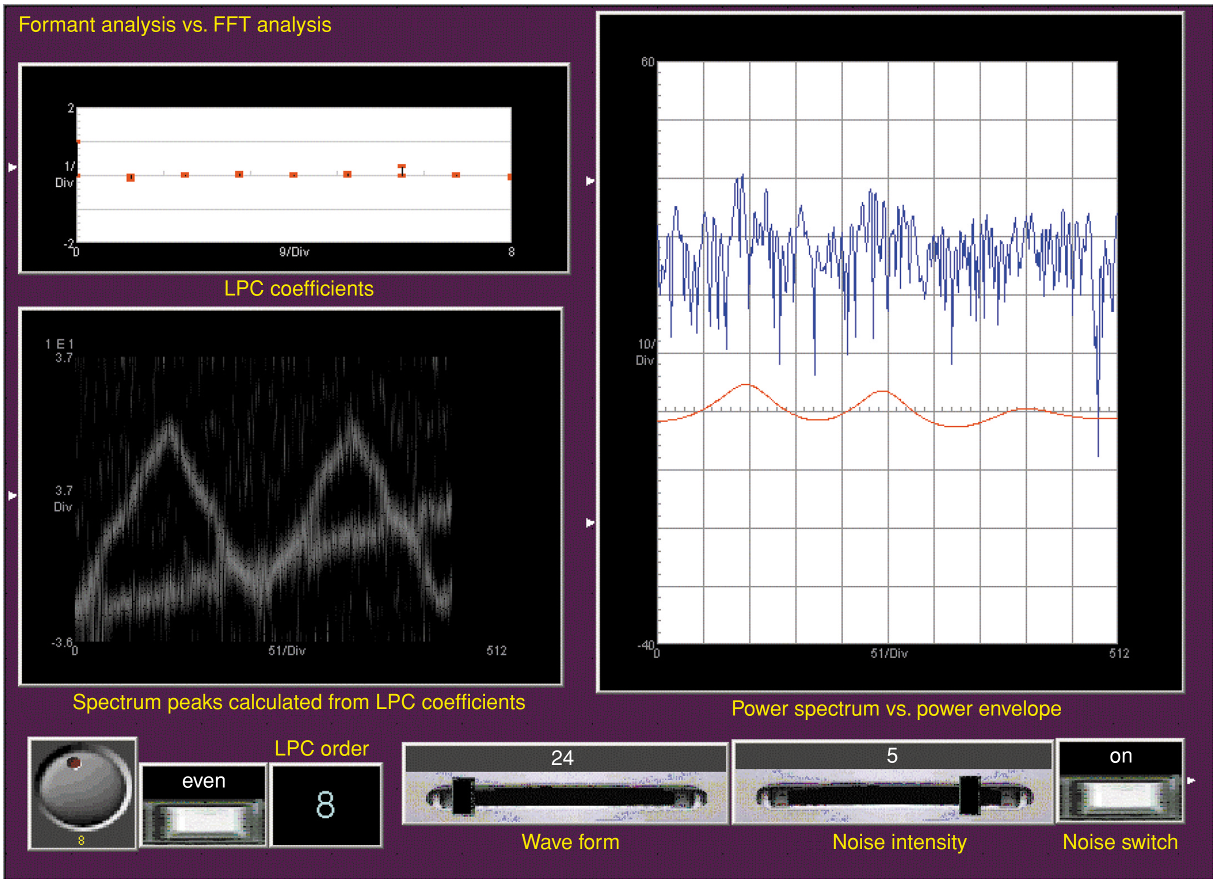


Fig. 3. Displays for SNR = –5 dB.

tion part. The value of twenty-four is given to the "Wave form" bar, which corresponds to $c_3$ in Eq. (5). The noise intensity is set to 5 dB, but it is disabled by the "Noise switch" (indicated by "off" on the display panel).

There are three display windows in the upper part of Fig. 2. The upper-left window displays the LPC coefficients obtained by the LPC method. The right window shows the spectrum envelope obtained by formant analysis and the power spectrum obtained by Fourier transform. The change in the temporal position of the peak frequency of the spectrum envelope is shown in the lower window on the left, where the horizontal axis is time and the vertical axis is frequency.

Two spectra are displayed in the window on the right of Fig. 2. The spectrum with lots of fine peak structure is the power spectrum obtained by Fourier analysis, and the spectrum with two peaks shown in a smooth line is the spectrum envelope obtained by LPC-based formant analysis.

As a result, we found that the outline of the peak structure of the power spectrum (peaks A and B in the window) was detected by LPC-based formant analysis, and the signal could be characterized by the frequencies. The lines correspond to two frequencies $f_1(t)$ and $f_2(t)$, which are functions of the frequency chirp of the sinusoidal signals given in the signal generation part, appearing in the lower left window. The A and B in this window correspond to A and B in the right window.

We found that LPC-based formant analysis could extract the main frequency information of the time series data of the signal, and the input signal could be characterized by that frequency information.

**Figure 3** shows the case when random noise was introduced.

The signal-to-noise ratio (SNR) was chosen to be –5 dB, so the signal was completely buried in the random noise. In this case, the characteristic frequencies of the original signal could not be read from the power spectrum by Fourier analysis. On the other hand, the spectrum envelope obtained from LPC-based formant analysis was not affected, and the

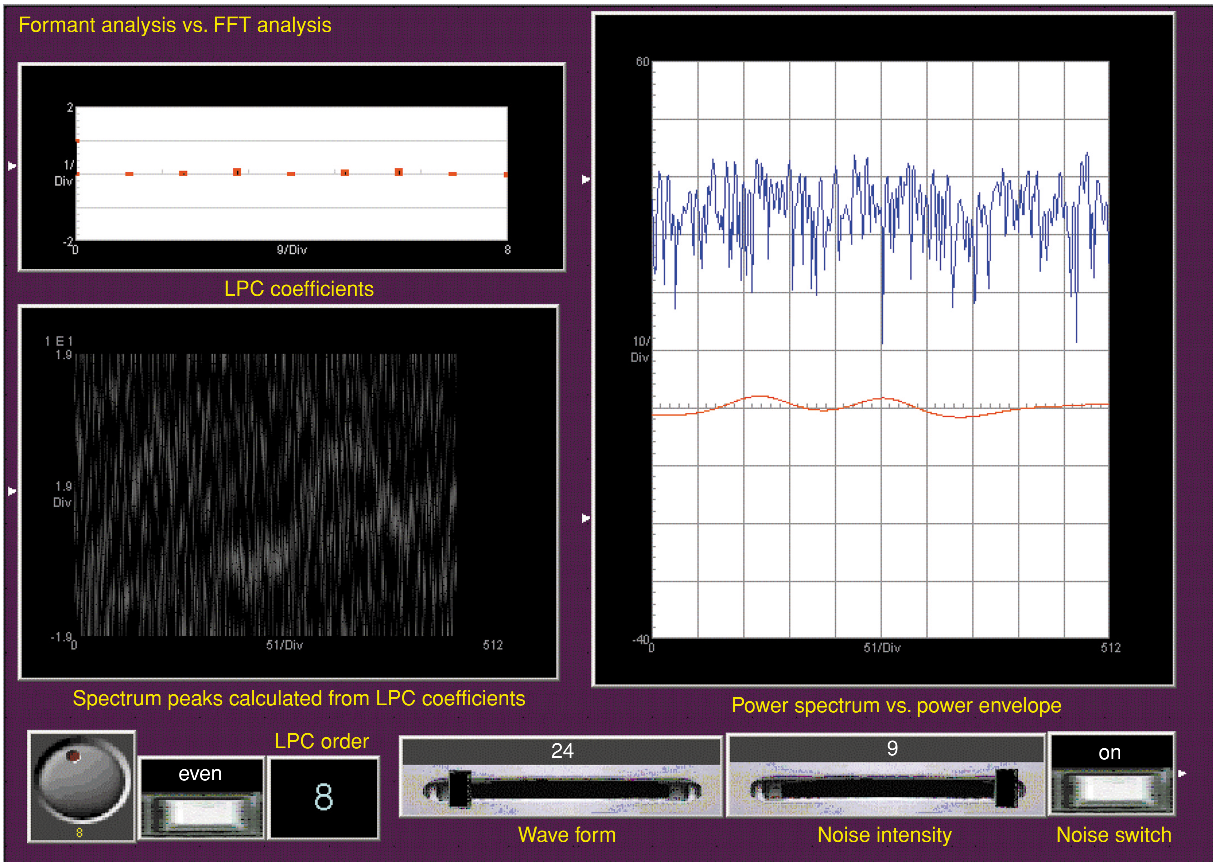


Fig. 4. Displays for SNR = –9 dB.

characteristic frequencies of the original signal were extracted. The peak frequency of the spectrum envelope displayed in the lower left window was almost the same as that obtained when random noise was not introduced (Fig. 2). Thus, we think that LPC-based formant analysis can cope with severe measurement conditions because it is more robust than Fourier analysis.

**Figure 4** shows the case where the intensity of the random noise was chosen to be 9 dB.

In this case, even when LPC-based formant analysis was used, the target signal was buried in the random noise. However, we could recognize signs of the target signal from the time series of the peak frequency of the spectrum envelope displayed in the lower-left window.

## 3. Conclusion

We developed an LPC-based formant analysis system to investigate how to discriminate EMI sources from the acoustic noise generated in telecommunications equipment by EMI waves. We chose to use Hypersignal RIDE to develop the system.

We found that LPC-based formant analysis was more robust than Fourier analysis for random noise and gave an analytical result equal to the case without the noise even in a situation that is hard to analyze by Fourier analysis. We could find characteristic frequencies even when the SNR was –5 dB. Therefore, we believe that LPC-based formant analysis is more effective than Fourier analysis.

Further studies are needed to improve the formant analysis system, construct a formant database system that presents candidate EMI sources in cooperation with the formant analysis system, and expand the application to the high frequency region.

## References

[1] J. Makhoul, “Linear prediction, a tutorial review,” Proc. IEEE, Vol. 63, pp. 561-580, 1975.
[2] A. Acero, “Acoustical and Environmental Robustness in Automatic Speech Recognition,” Kluwer Academic Publishers, Boston, 1992.
[3] S. Furui, “Digital Speech Processing, Synthesis, and Recognition,”

Marcel Dekker, Inc., New York, 1989.
[4] J. D. Markel and A. H. Gray Jr., "Linear Prediction of Speech, Springer-Verlag," New York, 1976.
[5] R. W. Schafer and J. D. Markel, "Speech Analysis," IEEE press, New York, 1979.
[6] F. Ishiyama and H. Yamane, "Identification of the source of acoustic noise caused by electromagnetic disturbances using formant analysis," IEEE Int. Sym. on EMC, Vol. 2, pp. 696-700, Aug. 2002.
[7] http://www.hyperception.com/RIDE/

**Fumihiko Ishiyama**
Research Engineer, Energy Systems Project, NTT Energy and Environment Systems Laboratories.
He received the B.S. and M.S. degrees in physics from Tohoku University, Sendai, Miyagi in 1988 and 1990, respectively. In 1990, he joined NTT Telecommunication Networks Laboratories, Kanagawa. He has been researching techniques for analyzing audible acoustic noise in telecommunication equipment caused by electromagnetic interference. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE).

**Kazuo Murakawa**
Senior Manager, Intellectual Property Strategy Planning Group, Intellectual Property Center.
He received the B.E., M.E., and D.E. degrees in electrical engineering from Kumamoto University, Kumamoto in 1983, 1985, and 2001, respectively. In 1985, he joined the Electrical Communication Laboratories, NTT, Ibaraki. He has been researching and developing electric field measurement and estimation systems for electromagnetic interference. In 2004, he moved to Intellectual Property Center. He is the rapporteur of ITU-T SG5 question 10. He is a member of IEICE and the Institute of Electrical Engineers of Japan.

**Hiroshi Yamane**
Senior Research Engineer, Supervisor, Energy Systems Project, NTT Energy and Environment Systems Laboratories.
He received the B.E., M.E., and D.E. degrees in electronic engineering from Ibaraki University, Hitachi, Ibaraki in 1980, 1982, and 1997, respectively. In 1982, he joined the Electrical Communication Laboratories, Nippon Telegraph and Telephone Public Corporation (now NTT), Ibaraki. He has been researching lightning surge and overvoltage protection for telecommunications systems. He is a member of IEICE.