Interference Measurements in HF and UHF Bands Caused by Extension of Power Line Communication Bandwidth for Astronomical purpose

Fuminori Tsuchiya[1*], Hiroaki Misawa[1], Tomoyuki Nakajo[1], Ichiro Tomizawa[2], Junichi Nakajima[3], Masatoshi Ohishi[4], Munetoshi Tokumaru[5], Takayuki Ono[1], and Akira Morioka[1]

[1] Graduate School of Science, Tohoku Univ., Aramaki Aza Aoba, Aoba-ku, Sendai, 980-8578, Japan
[2] Univ. of Electro-Communications, 1-5-1 Chofugaoka, Chofu-shi, Tokyo 182-8585, Japan
[3] Kashima Space Research Center Communications Research Laboratory, 893-1 Hirai, Kashima, Ibaraki, 314-0012, Japan
[4] National Astronomical Observatory, 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan
[5] Solar Terrestrial Environment Laboratory, Nagoya Univ. 3-13 Honohara, Toyokawa-shi, 442-8507, Japan

* E-mail: tsuchiya@pparc.geophys.tohoku.ac.jp, Phone : +81-22-217-6738, Fax: +81-22-217-6406

Abstract

Power line communication (PLC) system which extends the available frequency bandwidth up to 30 MHz has been proposed in Japan. The electromagnetic interference (EMI) problems on PLC had been investigated by the PLC study group organized by the Ministry of Public Management, Home Affaires, Post and Telecommunications (MPHPT). The study group held collaborated field experiments of the PLC facility and we measured interferences caused by the PLC facility in HF and UHF bands in order to evaluate influences of the expansion of PLC bandwidth on radio astronomical observations. In the field experiment, two sets of PLC modems (SS and OFDM) were tested as an access system. During the PLC modems were on, the HF spectra observed showed strong increase of the noise floor level, and it was found that the PLC noise exceeded the level of the galactic noise by more than 30 dB. In UHF band, spurious emission around 327MHz was identified. In both HF and UHF bands, the interferences exceeded the limit of harmful interference level for radio astronomical observation which is given in Recommendation ITU-R RA769-1. Safety distances where the Recommendation was satisfied are estimated to be 219 km and 12 km at 9.2 MHz and 327 MHz, respectively. PLC seems to be a harmful interference source for the radio astronomical observation in both HF and UHF bands.

1. Introduction

In Japan, PLC has become available for a low bit rate network which is permitted to use the frequency range from 10 kHz to 450 kHz. Recently, the fast power line telecommunication equipments to archive data rates of several Mbit/s are developed, and the broadband PLC system by extending the available frequency bandwidth up to 30 MHz is proposed. However, because power lines are designed not for telecommunication line but 50 Hz power distribution, high power transmission is required and the power lines emit substantial level of electromagnetic noise in HF. In HF band, there are a lot of radio stations for broadcasting, amateurs, air-traffic control, and so on. If the PLC using HF band becomes operational, large portion of HF spectrum may become unusable for them. HF band is also worth for scientific observations to research the earth's environments and astronomical objects. Because the received signal level is usually very weak in these observations, it is feared that interferences from the power lines make impossible them.

The EMI problems described above had been investigated from April to July in 2002 by the PLC study group organized by the MPHPT in Japan. The study group held a working group on the field experiments and executed collaborated field experiments of the PLC facility. In July 8-9 and 22-23, field experiments were carried out at Mt. Akagi in Gunma Prefecture, Japan. In the experiments, we measured interferences leaked from the PLC facility in HF and UHF bands in order to evaluate influences of the expansion of PLC bandwidth on the radio astronomical observations and examine the presence of spurious emissions over higher frequency. In this paper, we report the experimental results in the field experiments, and compare the PLC noise with the limit of harmful interference for radio astronomical observation which is given in Recommendation ITU-R RA769-1.

2. Field Experiment at Mt. Akagi in July 23, 2002

Figure 1 shows the configuration of the field experiment of the PLC facility. Power lines used for the experiment were extended between electric poles (poles #1, #2, and #3 in Figure 1) and a model house. In July 23, five pairs of PLC modems listed in Table 1 were tested and we carried out measurements of the interferences in HF and UHF bands. A in-house PLC system was set up inside the model house. Three pairs of laptop-type personal computers were connected into wall sockets by way of the PLC modems (No. 5/6, 7/8, and 9/10 in Table 1). An access system was set up between the model house and the electric poles. Two pairs of modems were tested as the access system (No. 1/2 and 3/4). The modems and the computers connected at the outdoor side of power lines were set on the pole #2. In this experiment, the interference caused by the in-house system was difficult to examine because the model house was electromagnetically shielded by wire meshes which significantly prevent radio waves from transmitting outside the model house.

For the purpose of the experiment in HF band, two sets of equivalent T2FD antennas of 25 m long were set up at distances of 57 m and 180 m apart from the pole #2 (T2FD #1 and #2 in Figure 1, respectively). Height of each antenna from the ground was about 5 m. It is noted that the T2FD were not sensitive to a vertically polarized component of electric waves because they were set up parallel to the ground level. Therefore, the T2FD may not receive the total power of the PLC noise. Output from the T2FD antennas were directly connected with spectrum analyzers which measured electric power up to 30 MHz. For the quantitative measurements, we obtained 10 spectral traces for one spectrum measurement then evaluated the deviations of the measurements.

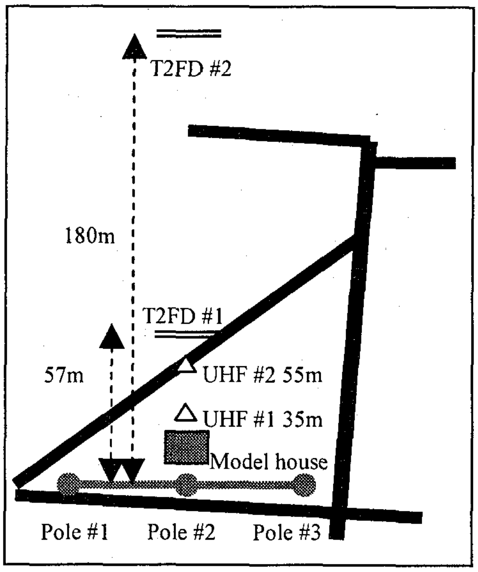

Fig.1: Map of the experiment site. Details are described in the text.

Table 1: PLC modems used for the field experiment.

No.	Modulation Principal	Freq. Range [MHz]	System Type
1/2	OFDM	4.3-20.9	access
3/4	SS	4.0-20.0	access
5/6	Multi-Carrier	2.622-11.202	in-house
7/8	OFDM	3.8-11.8	in-house
9/10	OFDM	7.9-22.8/3.8-17.0	in-house

In order to examine the spurious emission from the PLC facility, a log-periodic antenna (Create Design, CLP-5130-1) and a receiver were set up at a distance of 55 m apart from the pole #2 (UHF #2 in Figure 1), and sometimes moved at a distance of 35 m (UHF #1). The receiver consisted of a high pass filter, a low noise pre-amplifier, and a wide band amplifier. The pre-amplifier had a power gain of 40 dB at the center frequency of 327 MHz, the bandwidth of about 20 MHz, and the minimum noise figure of 0.8 dB. The high pass filter which had a cut off frequency at 260 MHz prevented saturation of the pre-amplifier by strong broadcasting signals in VHF range. Spectra around 327 MHz were measured by spectrum analyzers, and automatically recorded by a personal computer via GPIB interface. In order to check that the spurious emissions were actually originated from the PLC facility, we measured the HF spectra simultaneously and examined dependences of spurious emission on distance and direction from the PLC facility.

3. Interferences in HF Band

Figure 2 shows the results of the spectral measurements. When the PLC modem was not in operation, a lot of broadcasting bands were appeared over a flat noise floor which represented a noise level of the spectrum analyzer. After the modems were turned on, the noise floor level significantly increased in the frequency range from 4 to 20 MHz. There were some narrow drops in the increased noise floor at frequencies of 7, 10, 14, and 18 MHz, which were identical with frequencies of notch filters in the modem unit. These characteristics indicated that the increased noise level was caused by the PLC facility. Both SS (No. 3/4) and OFDM (No. 1/2) modems caused strong increases of the noise floor and the noise level of the SS modem was about 5 dB larger than that of the OFDM modem. As shown in the figure, many broadcasting signals were interfered and some of them were completely masked by the PLC noise.

Distance dependence of the PLC noise level was examined assuming that the leakage electric field E is proportional to the power low of distance r, that is,

$$E \propto r^{-\alpha}, \quad (1)$$

where, α is an attenuation coefficient. The coefficients were calculated based on the measurements with two T2FD

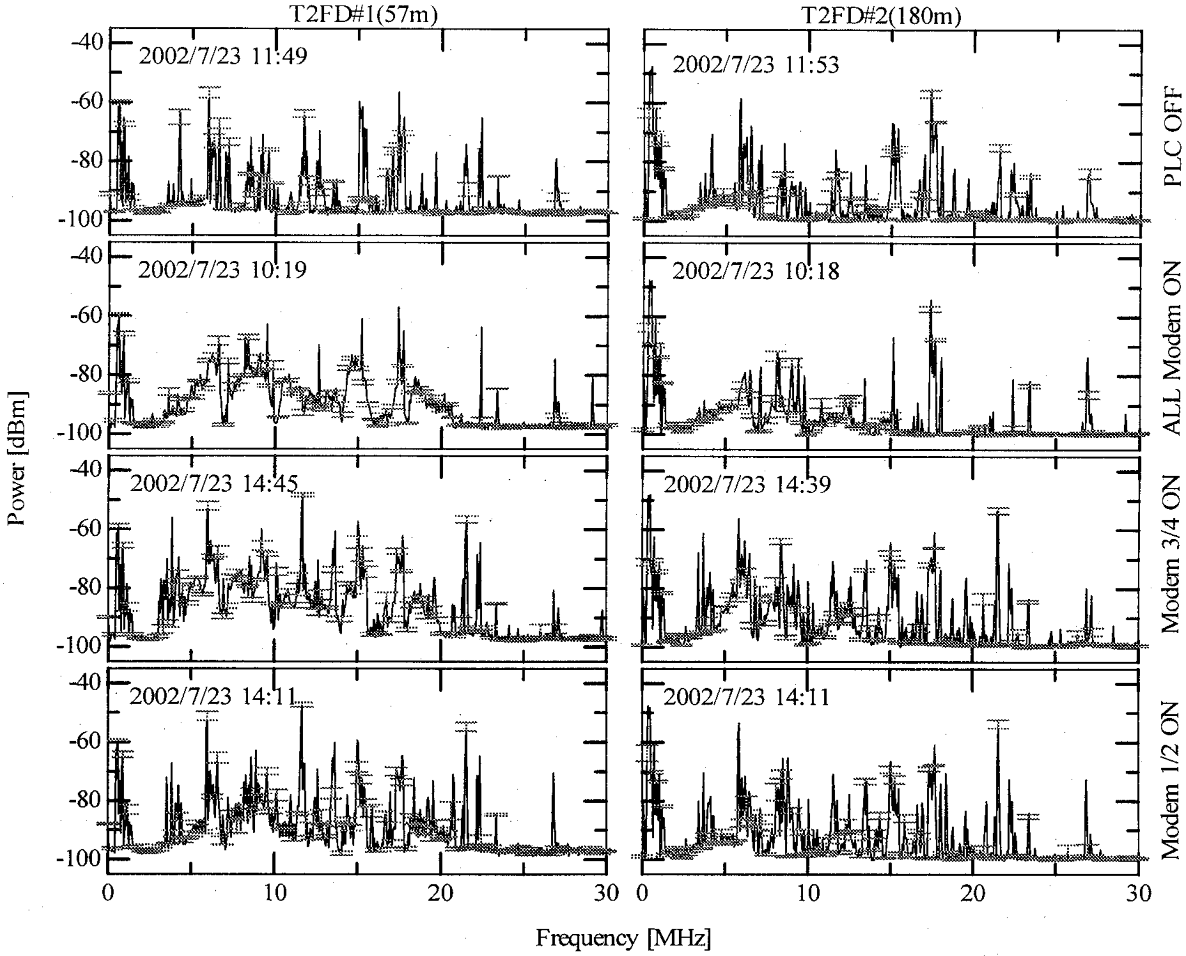

Fig.2: HF spectra measured by T2FD #1(left) and #2 (right) when the PLC system was not in operation (top panels), all modems were turned on (second panels), only model 3/4 was running (third panels), and only modem 1/2 was running (bottom panels) . Error bars represent the standard deviation.

antennas. The calculated coefficients scattered depending on frequency but distributed around 1.0.

In order to evaluate the interference level quantitatively, the T2FD antennas were calibrated. A standard loop antenna (Antitsu MP414B) was set just below the T2FD antenna, and we measured electric field intensities of some broadcasting frequencies simultaneously. An antenna factor K of T2FD was calculated by

$$K = E / V, \qquad (2)$$

where, V [μV] and E [$\mu V / m$] were output from the T2FD antenna and the standard loop, respectively. For example, the antenna factor of the T2FD antenna at the frequency of 9.6 MHz was derived to be -8.0 ± 2.5 dB. The T2FD antenna was also analyzed based on the moment method and an antenna gain Ga was calculated to be 2.3 dBi at 9.6 MHz. The antenna factor is also derived from the antenna gain by

$$K = \sqrt{\frac{4\pi\eta_0}{Z_0 G_a \lambda^2}}, \qquad (3)$$

where, η_0 is wave impedance and equal to 120π, Z_0 is 50Ω, and λ is wave length. By using Eq.3 and considering a transmission loss through a co-axial cable of 0.8 dB, the antenna factor was calculated to be -5.8 dB, which is consistent with the value estimated by the calibration.

Figure 3 shows a comparison between the PLC noise and the galactic level calculated by referring known galactic spectra [1] and the calibrated antenna factors. The PLC noise exceeded the level of galactic noise with more than 30 dB.

4. Spurious Emission in UHF Band

UHF band is an earth-based window for the radio astronomical observation and high sensitive measurements of weak radio sources are possible. Although the broadband PLC system dose not use such a higher frequency band, it is necessary to confirm the level of spurious emissions from the PLC facility. Figure 4 shows a dynamic spectrum in the frequency range from 297 to 357 MHz during an operation of the modem 3/4. When the modem was turned off at 15:04, disappearances of a broadband noise and some narrow band emissions were clearly observed. Figure 5 shows dependence of the spurious level on the distance and direction of the log-periodic antenna with respect to the PLC facility. When the all modems were turned off or the antenna did not direct to the PLC facility, no spurious emission was detected. On the other hand, the strong spurious emission was received when the antenna direction and position were close to the facility. At the position of UHF #1, the increase of the noise floor reached about 4 dB. These results indicate the presence of spurious emissions from the PLC facility in UHF band.

Distance dependence of the PLC noise level was also evaluated in UHF band. By using Eq.1, the attenuation coefficient was calculated to be 1.3, which was close to but somewhat larger than the far field value.

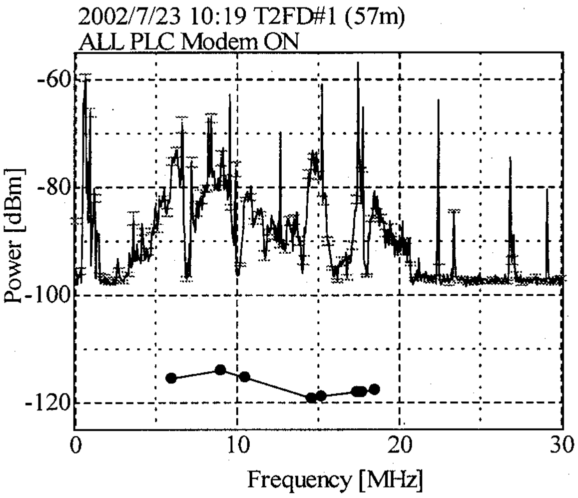

Fig.3: Comparison plot for a HF spectrum measured by T2FD #1 during all the PLC modems were running (upper line) and estimated galactic level (lower line).

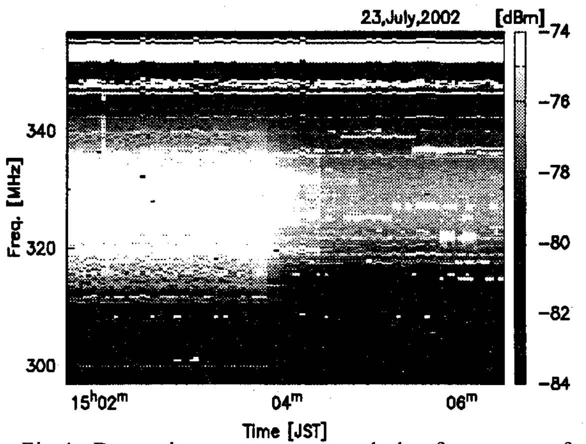

Fig.4: Dynamic spectrum around the frequency of 327 MHz. Corresponding to the turning off of the modem 3/4 at 15:04, the broadband noise and some narrow band emissions were disappeared.

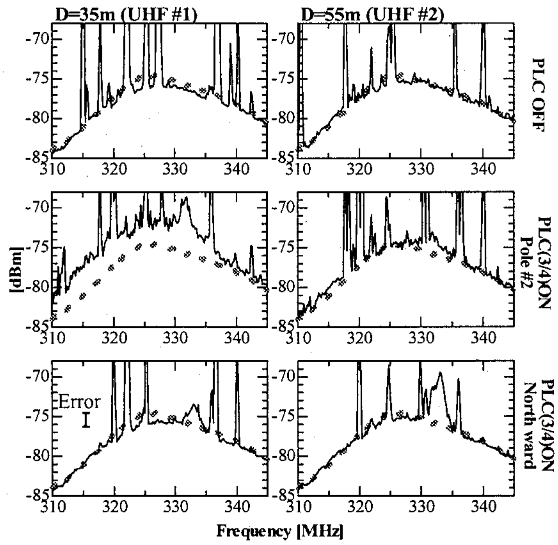

Fig.5: Dependence of spurious emissions on the distance and direction of the log-periodic antenna with respect to the PLC facility measured at 35m point (left) and at 55m point (right). Top: PLC was not operational. Middle: PLC modem 3/4 was running and the antenna was directed to the pole #2. Bottom: Same as middle panels but the antenna pointed the opposite direction. In each panel, solid lines are averaged spectra around the frequency of 327 MHz and gray dotted line shows a spectrum when input of the receiver was terminated. Some environmental noises which were not related to PLC were also identified as narrow band emissions which were received when the PLC was turned off and the antenna directed northward. A typical error bar in the measurements is indicated in left-bottom panel.

5. Comparison of the PLC Noise Level with Recommendation ITU-R RA 769-1

Threshold levels for interference detrimental to the radio astronomy service are given in Recommendation ITU-R RA 769-1. We selected two frequencies, 9.2 and 327 MHz where strong PLC noises were detected, estimated interference level from the PLC facility at both frequencies, and compared them with the threshold levels.

From Fig. 2, the interference levels measured by the T2FD antenna at T2FD #1 and #2 were -79.4 ± 0.5 and -90.9 ± 0.4 dBm, respectively, when all modems were turned on. Considering a loss through the transmission line of 0.8 dB and measured bandwidth of 10 kHz, and assuming that the antenna factor at 9.2 MHz was same as that at 9.6 MHz, the spectral power flux densities of the PLC noise at each antenna position were -173 and -185 dBW/m^2/Hz, respectively. The attenuation coefficient at 9.2 MHz was calculated by Eq.1 and was 1.15 ± 0.15, which was consistent with the far field value of 1.0.

From Fig. 5, the noise floor levels at the UHF #1 around the frequency of 327 MHz were -72.1 dBm when the modem 3/4 was operational and -75.9 dBm when they turned off. Considering the system gain of 51.2 dB, measured bandwidth of 100 kHz, and the antenna gain of 12 dBi, the spectral power flux density of the spurious emission was estimated to be -206 dBW/m^2/Hz.

On the other hand, the threshold level of harmful interferences for a continuum observation was calculated according to Recommendation ITU-R RA 796-1. At 9.2 MHz, considering a typical antenna noise temperature of 78000 K, receiver noise temperature of 100 K, and receiver bandwidth of 10 kHz, the spectral power flux density of the threshold level was calculated to be -245 dBW/m^2/Hz. The bandwidth of 10 kHz is generally needed for radio astronomical observation in HF band [2]. The frequency around 327 MHz is one of radio astronomy bands and the threshold level of -258 dBW/m^2/Hz is given in the Recommendation. In both frequencies the threshold levels were much smaller than the interferences. Applying the far field attenuation coefficient of 1.0, the safety distances for the radio astronomical observation were estimated and shown in Table 2. The result shows that it seems to be quite difficult for the radio astronomical observation to prevent harmful interference in HF band. In UHF band, the safety distance of 12 km is also not short because a distance between a radio observatory and the closest residential area to the observatory will be generally less than 12 km in Japan.

6. Conclusions

From the spectral measurements in HF band, it was confirmed that the noise floor level significantly increased in the frequency range which was used by the operational PLC modem. The intensity of the interference was much stronger than that of radio astronomical signals. From the experiments in UHF band, it was found that the spurious emissions were leaked from the PLC facility. In both frequency bands, the interferences from the PLC facility were grater than the limit of interference level given by Recommendation ITU-R RA 769-1. The safety distance for the radio astronomical observatory of 219 km means that PLC seems to be a harmful interference source for the radio astronomical observation. If PLC is widely operated, interference level will further increase and the safety distance will become large. Furthermore, because the radio waves in HF band are reflected from the ionosphere and can propagate over long distance, it becomes difficult to prevent the harmful interferences of PLC.

It is noted that the measurements reported in this paper were carried out under a specific environment; only a few PLC modems were running in the rural area, the model house was electromagnetically shielded, and there was no home electronics plugged in the model house. These situations were quite different from that the general persons would use the PLC modems for actually. A more realistic environment and elaborated measurement are necessary in the future experiments.

Table 2: Safety Distance against PLC Interference

	HF	UHF
Frequency [MHz]	9.2	327
Threshold Level [dBW/m^2/Hz]	-245	-258
Interference of PLC [dBW/m^2/Hz]	-173	-206
Distance from pole#2 [m]	57	35
Safety Distance [km]	219	12

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