

Broadband PLC for Smart Communication Infrastructure

Kyushu Institute of Technology
Mikio Mizutani

December 10th 2014

1. Introduction



PLC is used for Home-Network

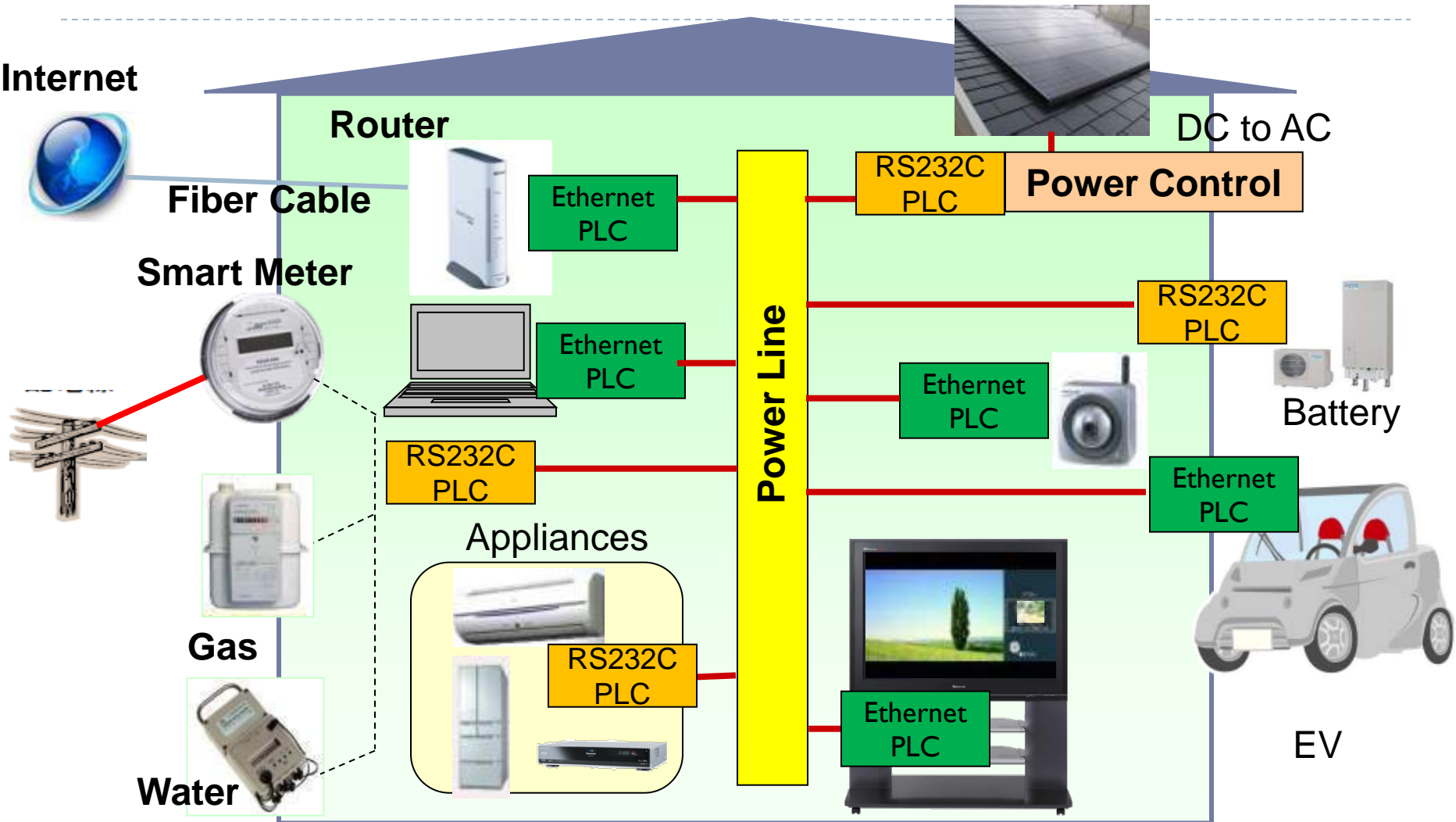
■ Nature of Power Line Communication

- # No new wiring=Power Line is ubiquitous
- # Connect to Power Supply Network
- # Over 100Mbps capability available

■ PLC application & required rate

- # Router to PC → 100Mbps required
- # Router to TV (Broadcast) → 24Mbps necessary
- # Router to Telephone → less than 100mS delay
- # Smart Meter to HEMS-GW → 1kbytes/minute
- # Auto-Meter-Reading → 100bytes/month

PLC applications

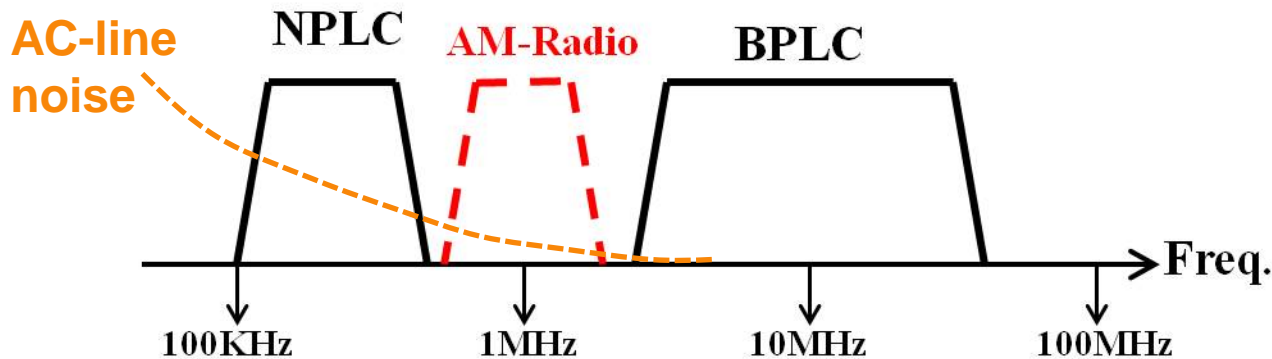


2 . Physical layer of PLC & Noise/Attenuation

Doctoral dissertations of Mikio Mizutani ;Kyushu Institute of Technology 2014
'Studies on Reinforcement of Power Line Communications on Home Networks'

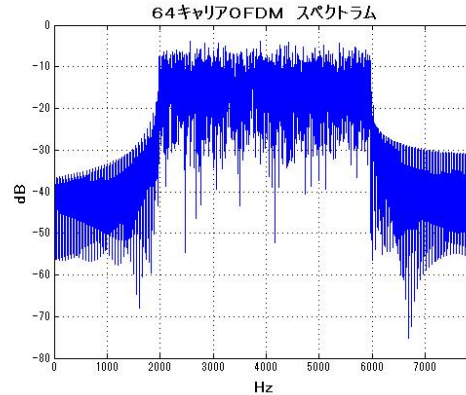
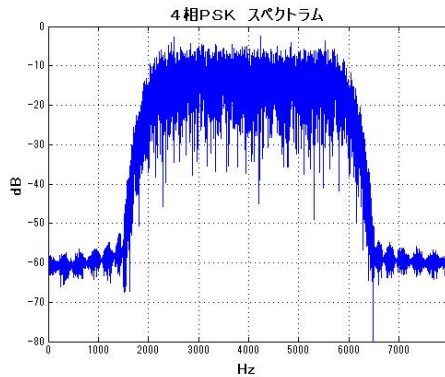
PLC-standards in Japan

- Broad-band PLC:BPLC \doteq 120Mbps
Narrow-band PLC:NPLC \doteq 30kbps

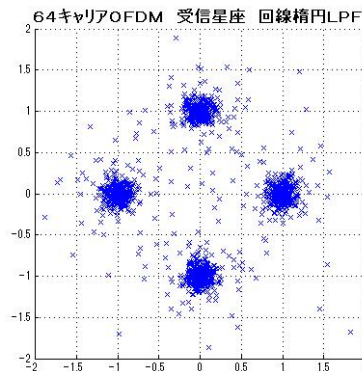
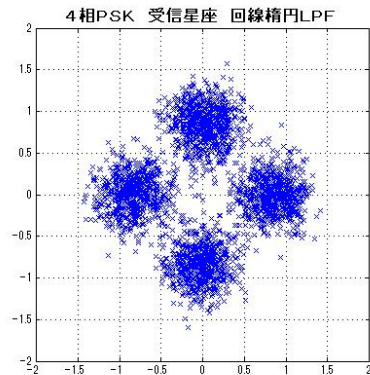
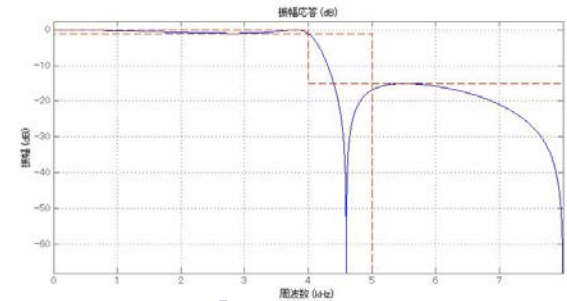


- **BPLC-standard IEEE1901,ITU-T G.9972 (2011)**
Application in Japan is limited to use only in-house
- **NPLC-standard IEEE1901.2,ITU-T G.9903-ARIB(2014)**
TEPCO start to use for Smart-Meter from 2015 Spring

OFDM Modulation is better for wideband



Line spectrum



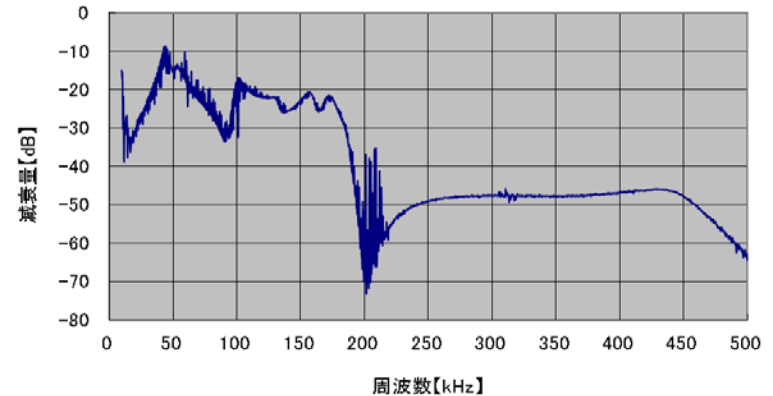
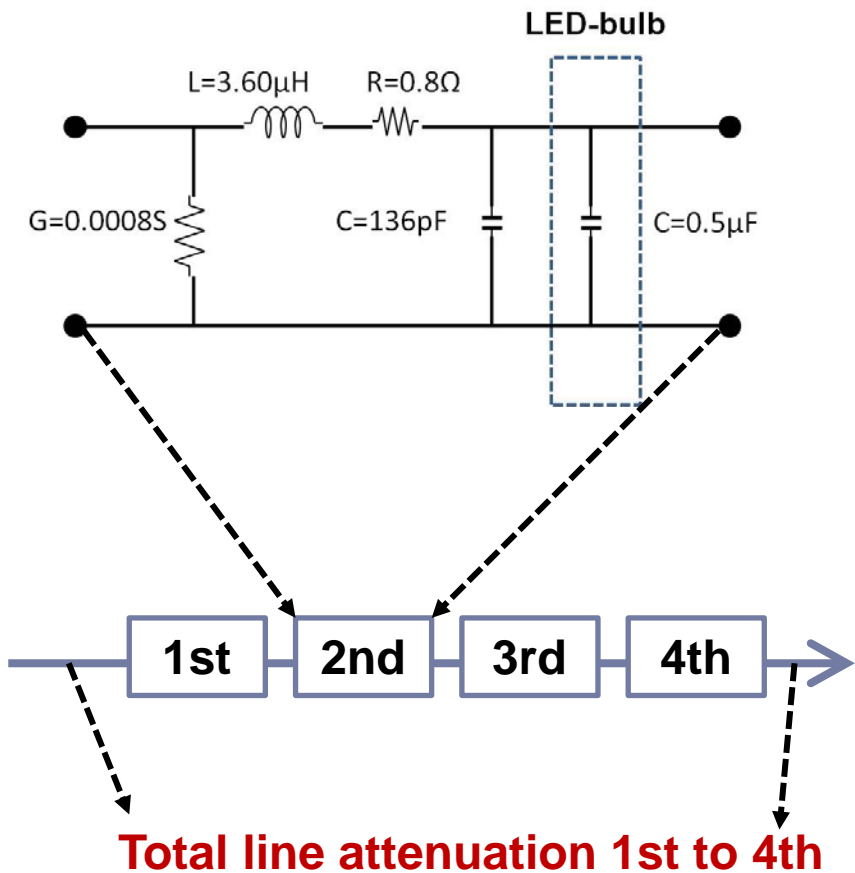
Single-Carrier-PSK

OFDM

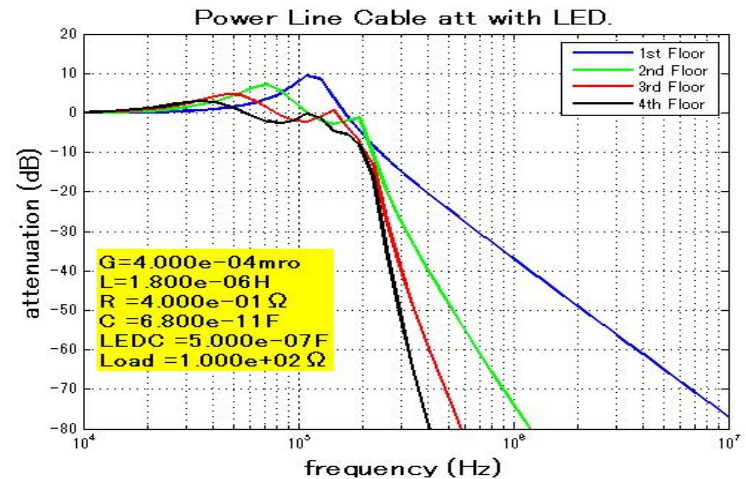
- In deeply-notched-spectrum-line, OFDM is less damaged than Single-Carrier system.

Typical Line-Attenuation is Low-Pass in high rise housing vertical cable.

25mm² cable model + LED-bulb

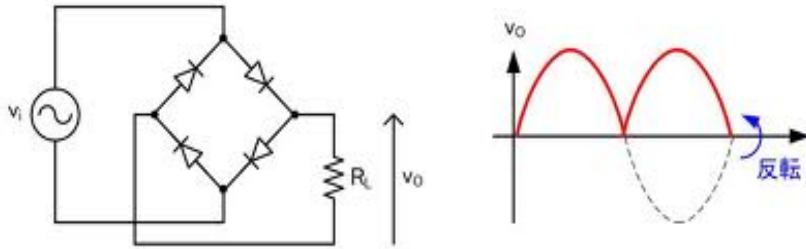


Observed line attenuation 1st to 4th

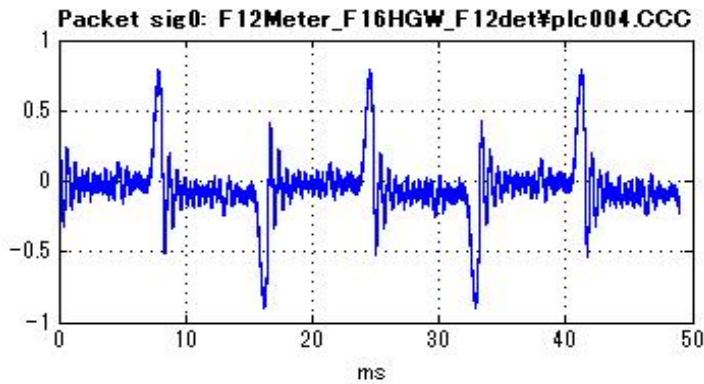


Simulated line attenuation

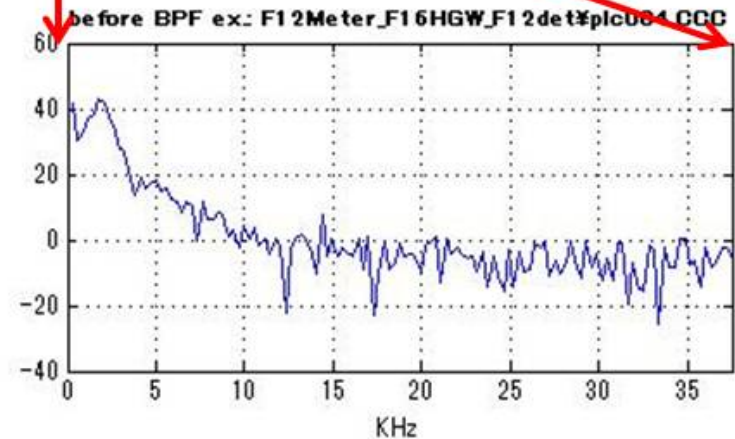
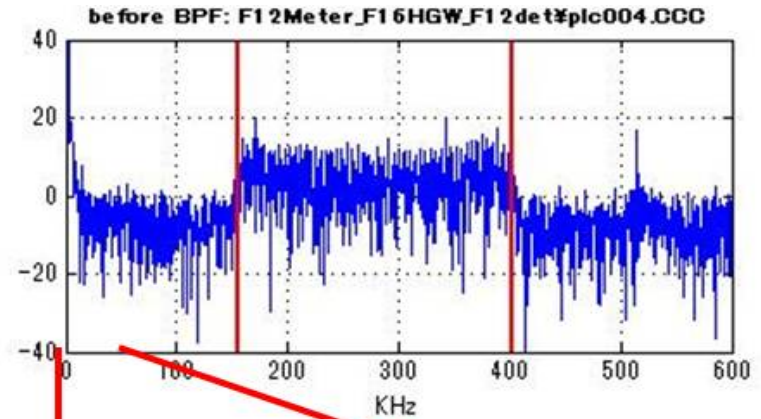
Diode bridge noise is limit under 10kHz.



Diode bridge in power-supply



■ Noise wave of Diode bridge

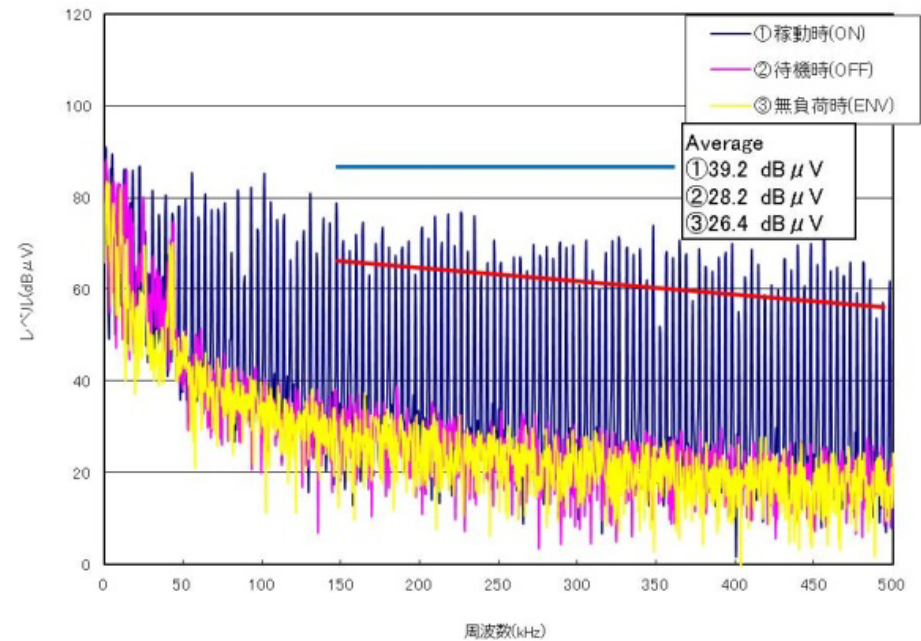
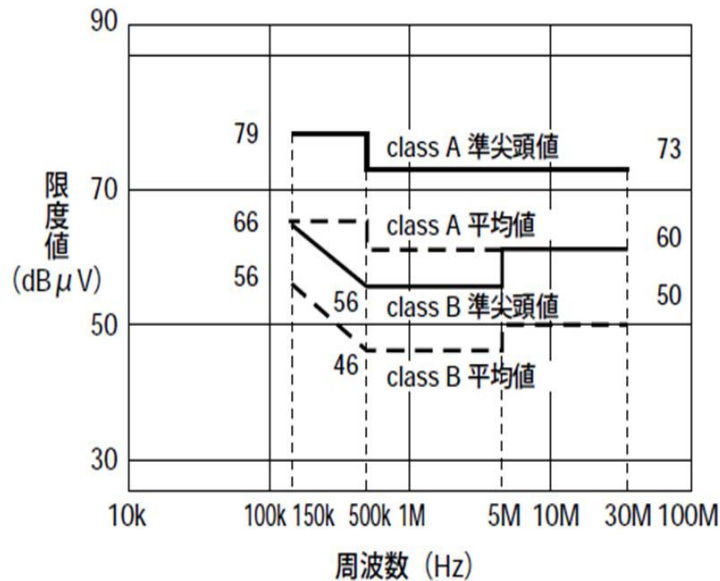


■ Diode bridge has no damage for NPLC

Equipment with dimmer has over 150kHz noise.

家電製品の雑音電力測定 (こたつ)

[雑音端子電圧 (電源)]



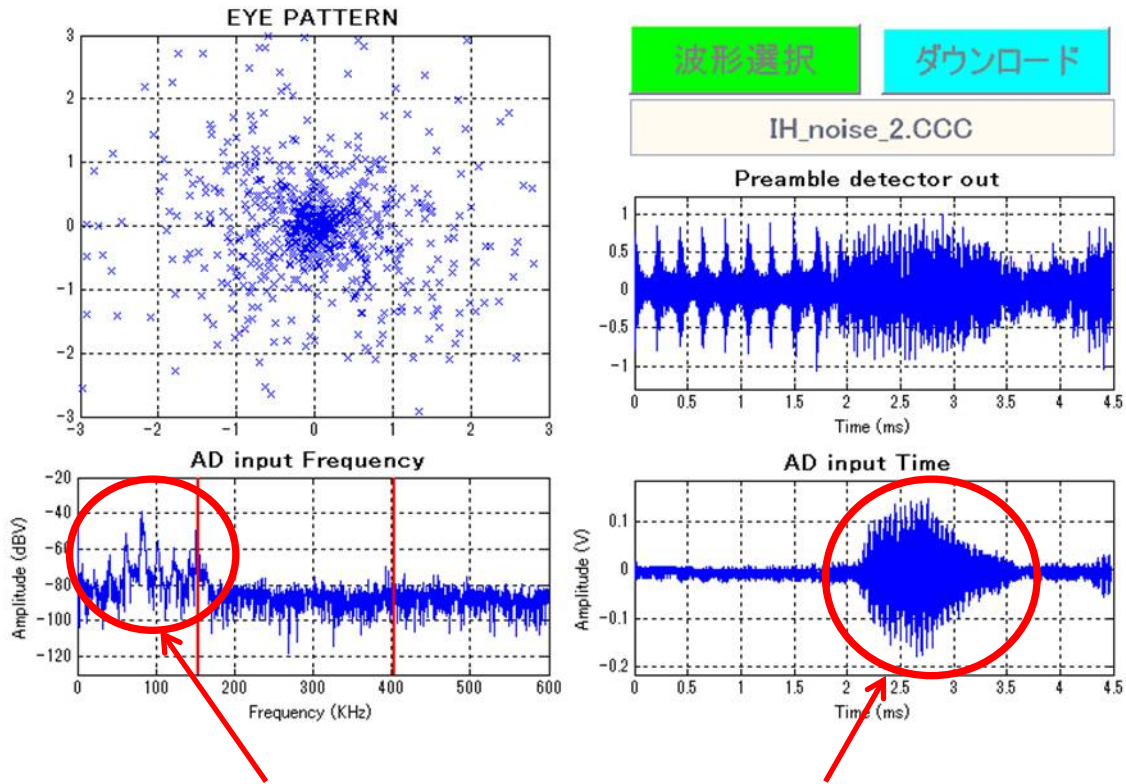
■ Japan regulation of AC-noise

■ Noise of KOTATSU with dimmer

■ Over 150kHz noise has damages for NPLC



IH-cooking-heater power-supply-burst-noise exceed 150kHz.

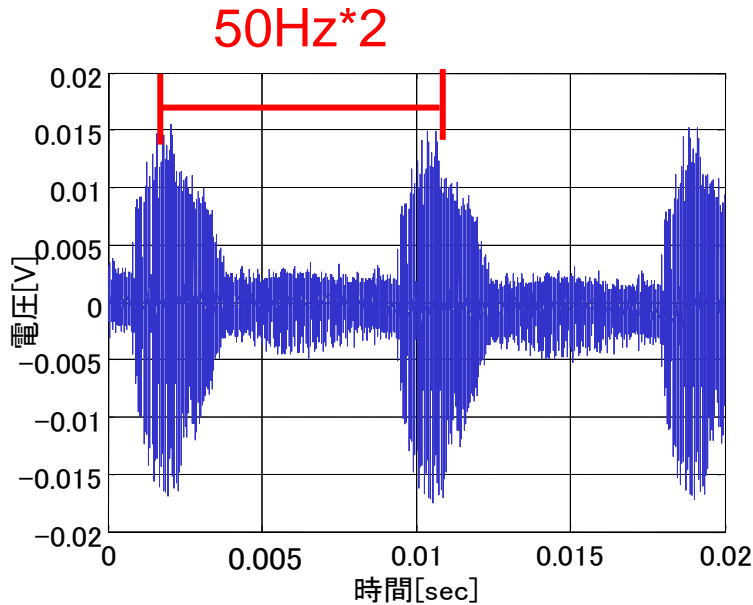


Display of G3plc_monitor By Egretcom

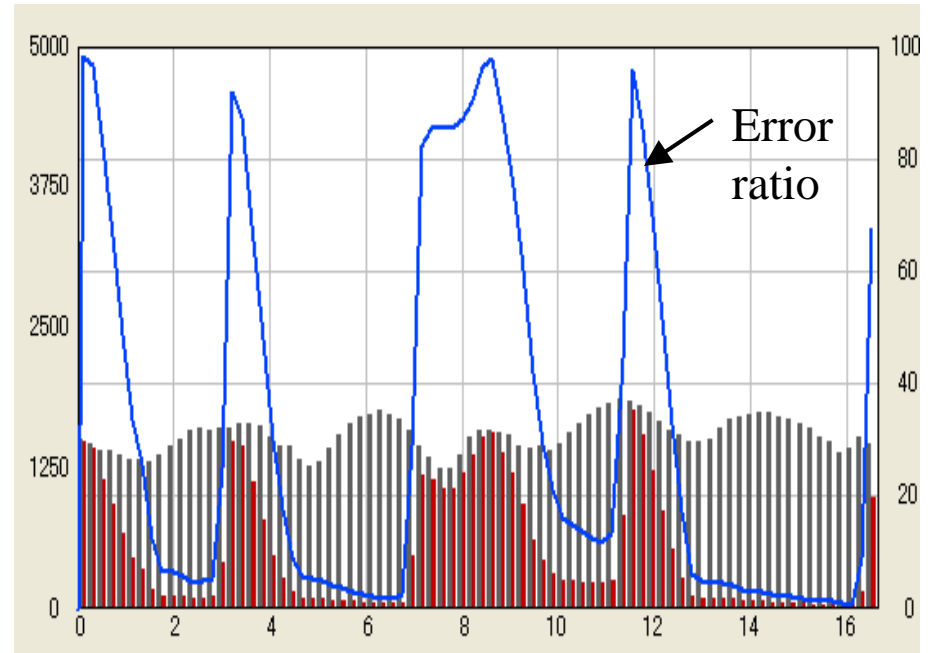
■ IH-cooking-heater-Noise

■ IH-noise is burst in every 20mS cause error in NPLC.

Impedance up/down by 50Hz



■ Wave of Impedance up/down



■ Packet-error-ratio vs. 0-cross of 50Hz

■ Packet-error-ratio varies from 0% to 100% depend on AC-wave zero-cross timing.

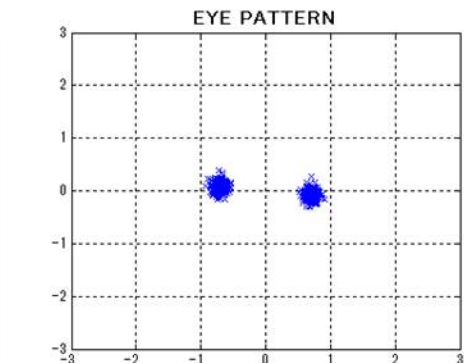
3. G3PLC & real environment



G3PLC-ARIB frame in real environment-1.

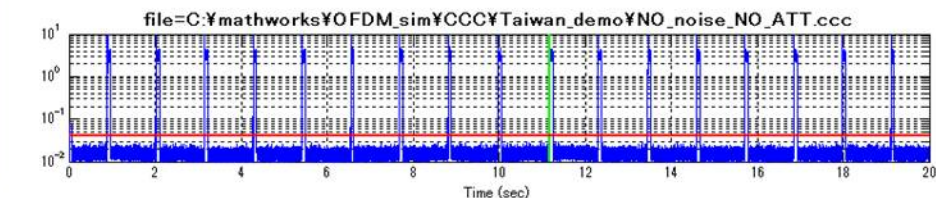
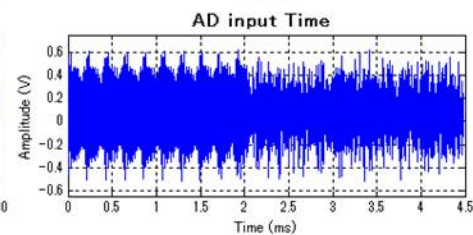
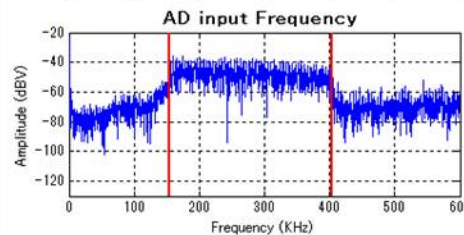
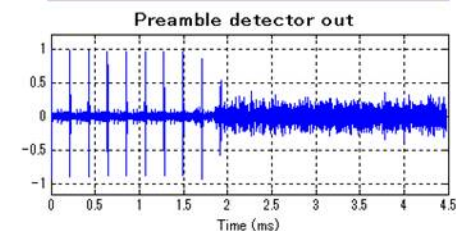
no-ATT & no-noise

Frame:NO_R:RB:FL=304:	Amp= 214.35mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.69mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.06mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.70mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.67mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.62mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.92mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.15mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.77mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.60mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 212.82mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.17mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.39mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 215.34mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.70mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 214.52mV:	EQM=0
Frame:NO_R:RB:FL=304:	Amp= 213.57mV:	EQM=0



波形観測 ダウンロード

NO_noise_NO_ATT.ccc



設定 0dB 画面保存

フレームシーケンス番号=10/17 sec=11.174
 Frame:NO_R:RB:FL=304: Amp= 213.60mV: EQM=0

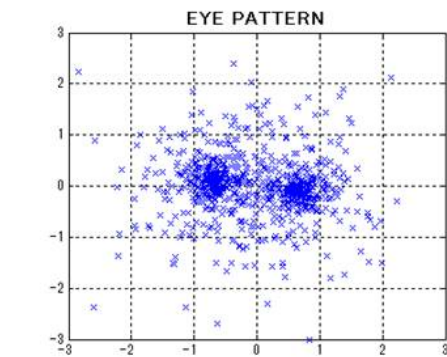
終了

■ FCH-no-error EQM=0

G3PLC-ARIB frame in real environment-2.

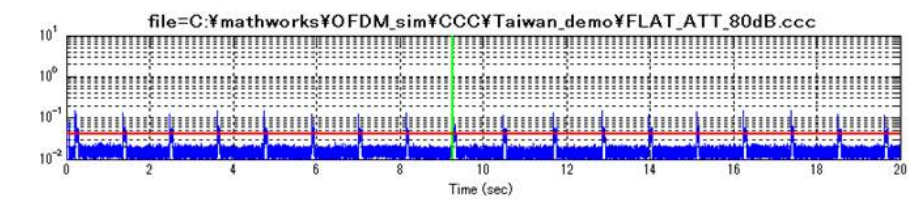
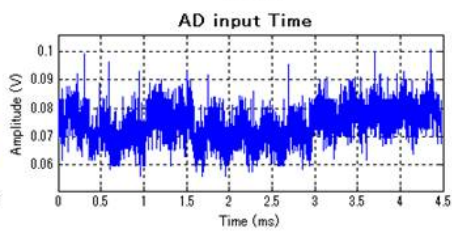
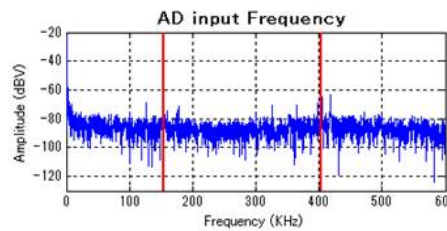
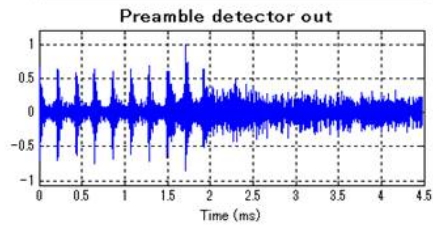
Flat-ATT 55dB=SN 0dB

ERROR 3AE4D3237823EE7240:	Amp=	4.03mV:	EQM=764
Frame:NO_R:RB:FL=304:	Amp=	3.95mV:	EQM=329
Frame:NO_R:RB:FL=304:	Amp=	3.98mV:	EQM=365
Frame:NO_R:RB:FL=304:	Amp=	3.93mV:	EQM=343
Frame:NO_R:RB:FL=304:	Amp=	4.13mV:	EQM=318
Frame:NO_R:RB:FL=304:	Amp=	4.05mV:	EQM=373
Frame:NO_R:RB:FL=304:	Amp=	3.82mV:	EQM=309
Frame:NO_R:RB:FL=304:	Amp=	3.62mV:	EQM=299
Frame:NO_R:RB:FL=304:	Amp=	3.79mV:	EQM=294
Frame:NO_R:RB:FL=304:	Amp=	3.78mV:	EQM=284
Frame:NO_R:RB:FL=304:	Amp=	3.76mV:	EQM=307
Frame:NO_R:RB:FL=304:	Amp=	3.83mV:	EQM=321
Frame:NO_R:RB:FL=304:	Amp=	3.91mV:	EQM=335
Frame:NO_R:RB:FL=304:	Amp=	3.82mV:	EQM=302
Frame:NO_R:RB:FL=304:	Amp=	3.96mV:	EQM=345
Frame:NO_R:RB:FL=304:	Amp=	4.01mV:	EQM=303
Frame:NO_R:RB:FL=304:	Amp=	3.87mV:	EQM=323
Frame:NO_R:RB:FL=304:	Amp=	4.05mV:	EQM=321



波形選択 ダウンロード

FLAT_ATT_80dB.ccc



設定 0dB 画面保存

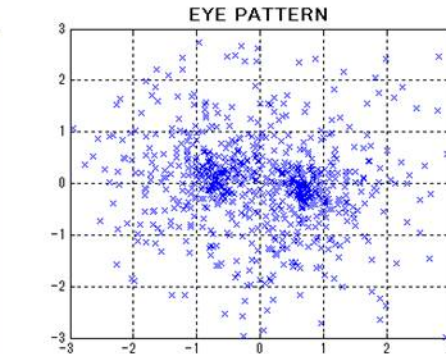
フレームシーケンス番号=9/18 sec=9.271
 Frame:NO_R:RB:FL=304: Amp= 3.79mV: EQM=294 終了

■ FCH-no-error EQM=294

G3PLC-ARIB frame in real environment-3.

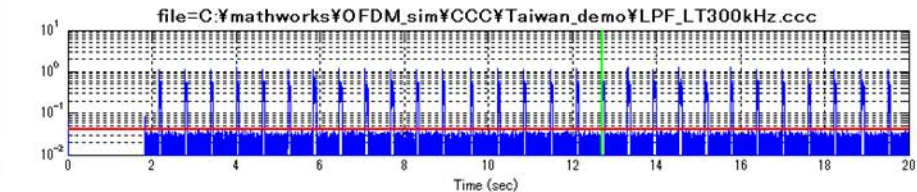
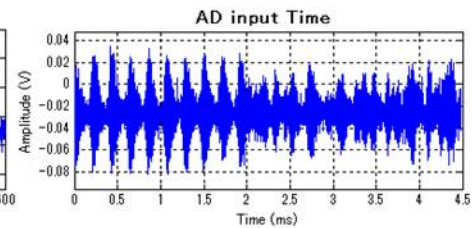
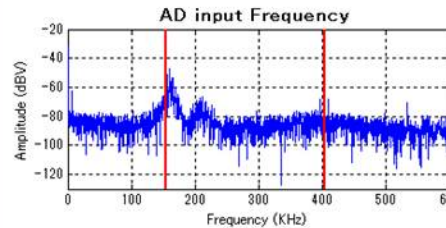
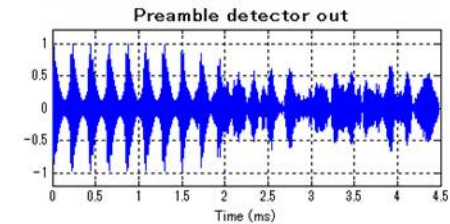
Line=180kHz low-pass

ERROR F70680BCC393002780:	Amp= 15.59mV:	EQM=709
Frame:NO_R:RB:FL=254:	Amp= 16.52mV:	EQM=445
ERROR F7587EFFFF03002780:	Amp= 16.27mV:	EQM=520
Frame:NO_R:RB:FL=254:	Amp= 16.14mV:	EQM=592
Frame:NO_R:RB:FL=254:	Amp= 16.19mV:	EQM=515
ERROR 4000EFFFF03002780:	Amp= 16.04mV:	EQM=640
Frame:NO_R:RB:FL=254:	Amp= 16.45mV:	EQM=582
ERROR 0000EFFFABDC89BC80:	Amp= 15.43mV:	EQM=714
Frame:NO_R:RB:FL=254:	Amp= 15.97mV:	EQM=537
Frame:NO_R:RB:FL=254:	Amp= 16.27mV:	EQM=459
ERROR 6D1936FFFF03002780:	Amp= 16.52mV:	EQM=568
Frame:NO_R:RB:FL=254:	Amp= 16.44mV:	EQM=463
ERROR 0000EFFF03C744380:	Amp= 15.86mV:	EQM=683
Frame:NO_R:RB:FL=254:	Amp= 16.11mV:	EQM=595
Frame:NO_R:RB:FL=254:	Amp= 16.18mV:	EQM=529
Frame:NO_R:RB:FL=254:	Amp= 16.16mV:	EQM=581
ERROR FDD77EFFFF03004380:	Amp= 15.84mV:	EQM=719
Frame:NO_R:RB:FL=254:	Amp= 16.35mV:	EQM=582
Frame:NO_R:RB:FL=254:	Amp= 16.14mV:	EQM=615
Frame:NO_R:RB:FL=254:	Amp= 16.48mV:	EQM=499
ERROR 472162B57603002780:	Amp= 16.11mV:	EQM=642
Frame:NO_R:RB:FL=254:	Amp= 16.26mV:	EQM=621
Frame:NO_R:RB:FL=254:	Amp= 15.96mV:	EQM=607
Frame:NO_R:RB:FL=254:	Amp= 16.40mV:	EQM=568
Frame:NO_R:RB:FL=254:	Amp= 16.13mV:	EQM=591
Frame:NO_R:RB:FL=254:	Amp= 16.29mV:	EQM=583
Frame:NO_R:RB:FL=254:	Amp= 16.42mV:	EQM=574
Frame:NO_R:RB:FL=254:	Amp= 15.67mV:	EQM=540
ERROR 0000EFFFF03004380:	Amp= 15.66mV:	EQM=591



波形選択 ダウンロード

LPF_LT300kHz.ccc



設定 0dB 画面保存

フレームシーケンス番号 = 18/29 sec=12.701
 Frame:NO_R:RB:FL=254: Amp= 16.35mV: EQM=582

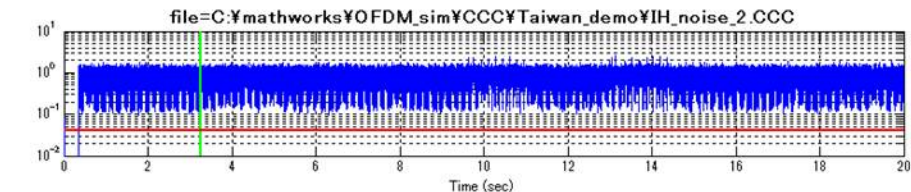
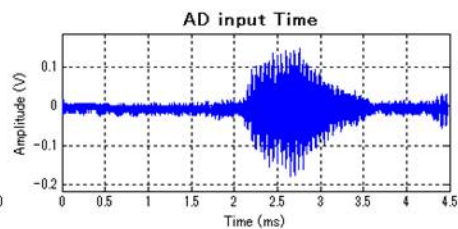
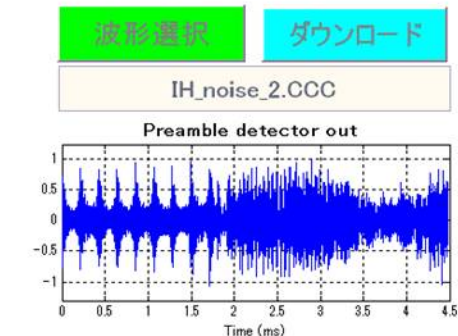
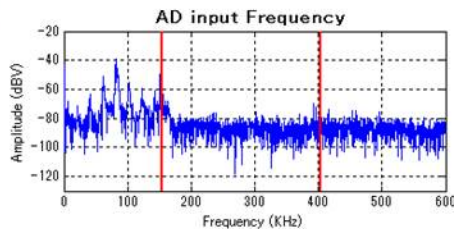
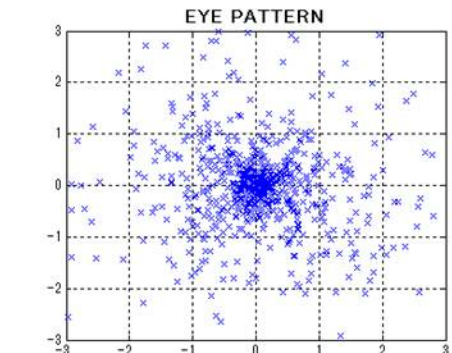
終了

■ FCH-no-error EQM=582

G3PLC-ARIB frame in real environment-4.

IH-cooking-heater-burst-noise

preamble miss	Amp= 7.49mV	
ERROR 1045A252EC4BD83240:	Amp= 7.89mV:	EQM=818
ERROR FAE6B9462162D5FB40:	Amp= 7.70mV:	EQM=789
ERROR 114010961CE8C05140:	Amp= 7.12mV:	EQM=765
ERROR B16460ED82D2962E40:	Amp= 6.60mV:	EQM=826
ERROR 356CD79A4F402A3F00:	Amp= 8.29mV:	EQM=791
preamble miss	Amp= 7.09mV	
ERROR 3ED104C0EEF4F5C480:	Amp= 8.03mV:	EQM=813
ERROR 88D55F56D5A4064540:	Amp= 7.39mV:	EQM=792
Frame: RQ_R:RB:FL=254:	Amp= 6.91mV:	EQM=430
ERROR 9D5A13A8D2359D9F00:	Amp= 7.40mV:	EQM=776
ERROR 76A394D03327B0A900:	Amp= 7.66mV:	EQM=759
ERROR 6E02FEF5982933D400:	Amp= 7.35mV:	EQM=731
ERROR 618A64B597FA0D9780:	Amp= 7.15mV:	EQM=745
preamble miss	Amp= 7.82mV	
preamble miss	Amp= 6.92mV	
ERROR BD02FEFFFF0300A700:	Amp= 6.56mV:	EQM=699
preamble miss	Amp= 7.28mV	
ERROR CA206BAEACB1E98B00:	Amp= 7.77mV:	EQM=815
ERROR 1FAFE9D4AC7F8A9180:	Amp= 7.76mV:	EQM=820
ERROR 9C37F1C15EFB9EB140:	Amp= 7.54mV:	EQM=788
Frame: RQ_R:RB:FL=254:	Amp= 7.58mV:	EQM=464
ERROR 4DAD092F52F877FA40:	Amp= 7.42mV:	EQM=827
preamble miss	Amp= 8.65mV	
preamble miss	Amp= 8.58mV	
ERROR 7B3217B9E11019E280:	Amp= 6.02mV:	EQM=802
ERROR 2D8A34B467897E7FC0:	Amp= 7.10mV:	EQM=790
preamble miss	Amp= 8.08mV	
ERROR 22C340D042C35AF7C0:	Amp= 7.92mV:	EQM=776
ERROR 3D07BA7FFF03001500:	Amp= 7.24mV:	EQM=762
ERROR D3B8B61DA0CE562540:	Amp= 7.47mV:	EQM=772
ERROR 76FC7527EDB9EE680:	Amp= 8.96mV:	EQM=806
preamble miss	Amp= 7.90mV	
ERROR 9F02FEA0448300F280:	Amp= 7.11mV:	EQM=662
preamble miss	Amp= 7.16mV	
ERROR 36531C929F33724C00:	Amp= 7.29mV:	EQM=796
ERROR 6AAF2B3E414BC1C780:	Amp= 8.11mV:	EQM=778
ERROR CC0817B08B0AE67CC0:	Amp= 7.43mV:	EQM=762
ERROR 7A5081832BD66A0D00:	Amp= 7.91mV:	EQM=777



設定 0dB 画面保存

フレームシーケンス番号=12/81 sec=3.256
 ERROR 76A394D03327B0A900: Amp= 7.66mV: EQM=759

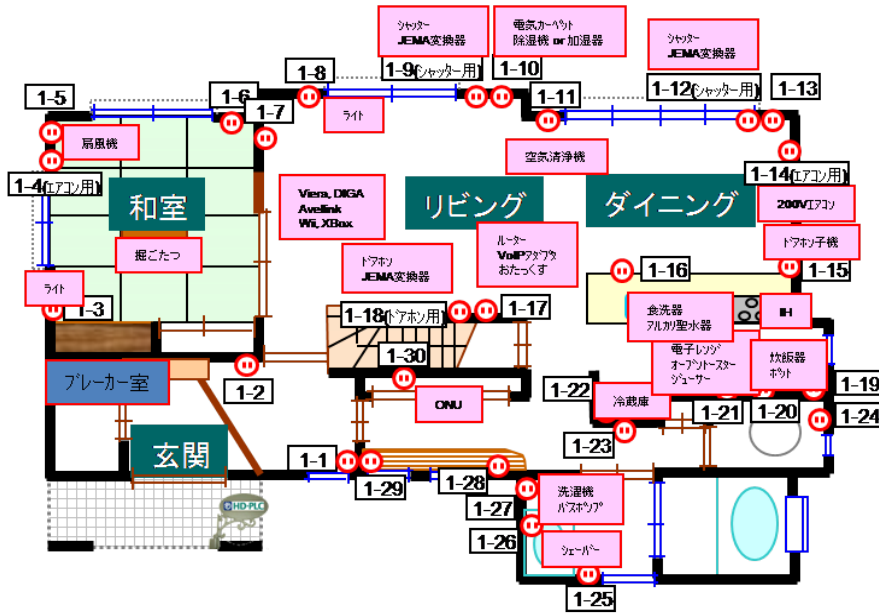
終了

■ FCH-FCS-error EQM=759.

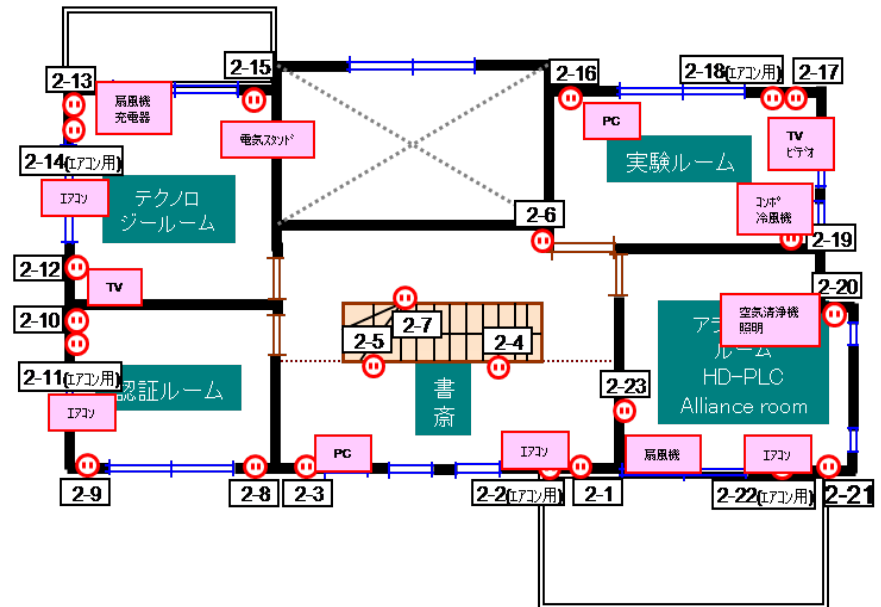
4. HD-PLC performance issue

Mikio Mizutani, Masato Tsuru, Yuji Oie, “New Performance Estimation Scheme and Applications for Broadband Communications Over Power Lines in the Home,” Proc. 2011 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM2011), pp. 578-583, August 2011.

Panasonic PLC house in Minoshima



1F



2F

■ Number of outlets is 84



Observed UDP-rate in PLC house

TX outlet	RX outlet	Bit rate [Mbps]	Att. [dB]	Layer
1-17 (2)	1-7 (2)	67.7	-13.2	same B
	1-20 (10)	36.9	-45.3	diff. L
	1-26 (4)	36.2	-39.3	same L
	2-1 (7)	30.2	-44.9	diff. L
	2-10 (5)	25.6	-49.6	diff. L
	2-17 (6)	19.7	-53.6	same L
2-1 (7)	1-5 (3)	12.9	-51.6	same L
	1-7 (2)	29.4	-45.3	diff. L
	2-5 (7)	67.8	-18.2	same B
	2-17 (6)	31.7	-50.1	diff. L
2-10 (5)	2-17(6)	39.1	-45.7	diff. L
	1-15 (1)	11.3	-48.8	same L
1-12 (2)	2-13 (5)	0.0	-63.7	diff. L

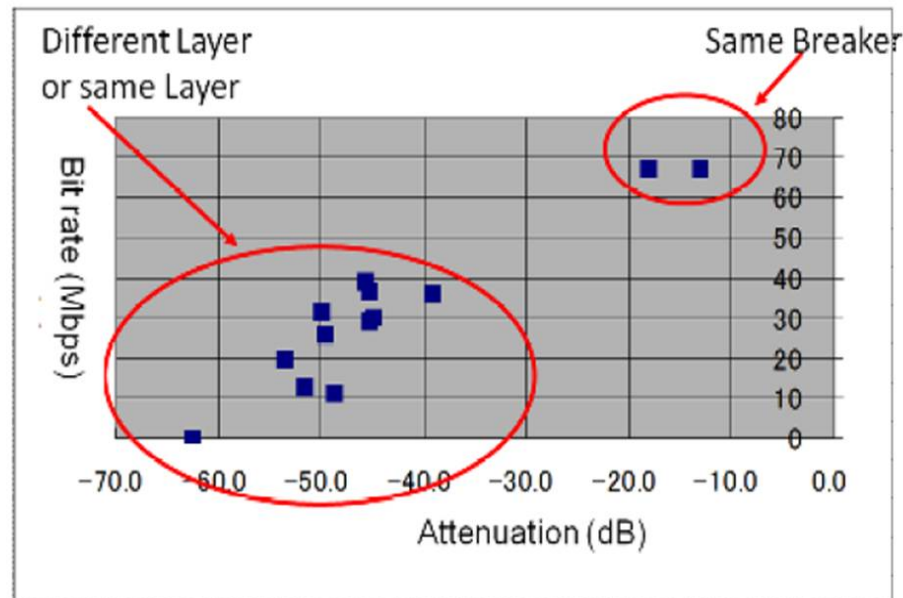
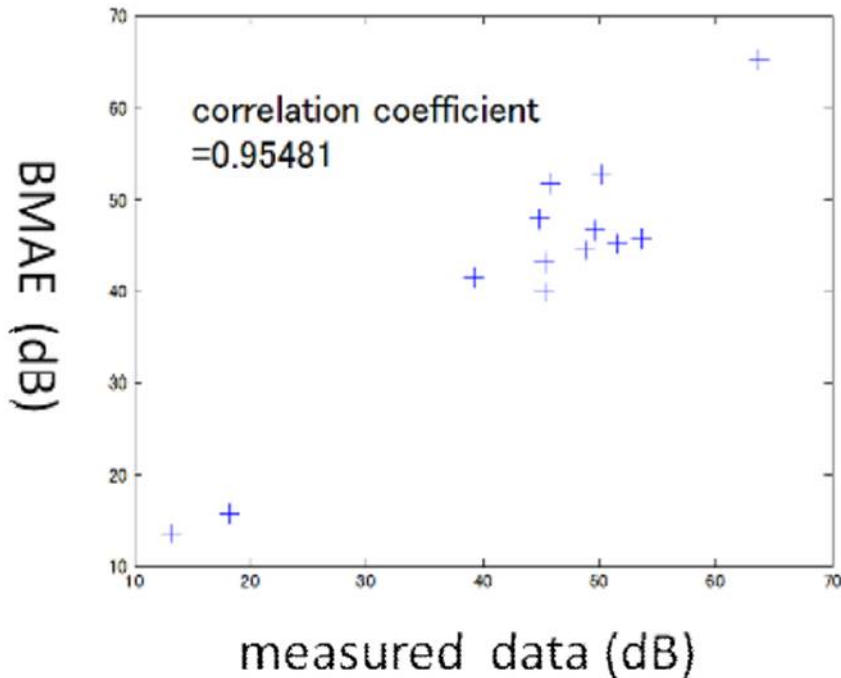


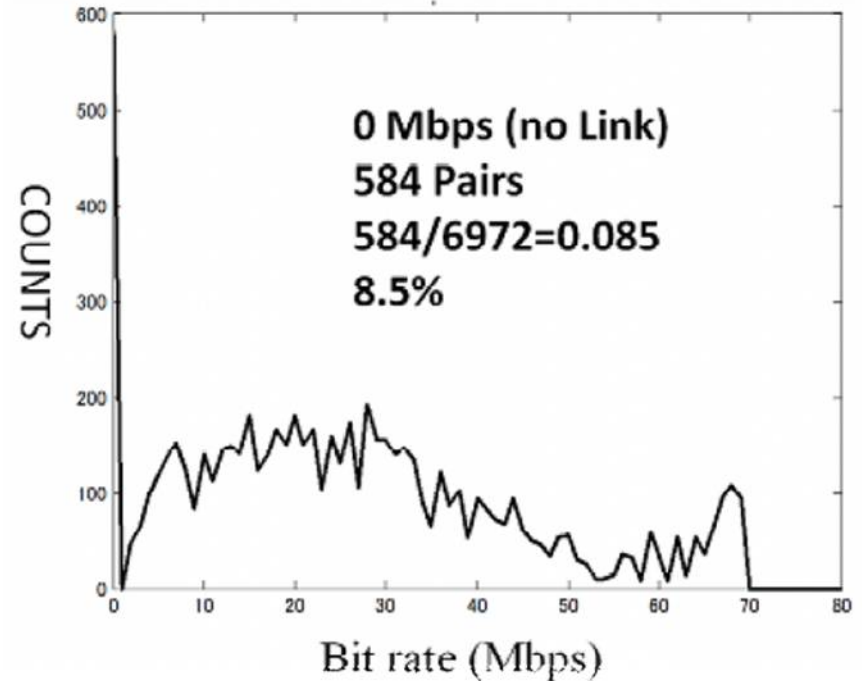
Table 1. Attenuation (dB) and bit rate (Mbps)

■ UDP-rate vs. Attenuation in each 13 pairs of outlet

UDP rate Estimation of every outlet pairs

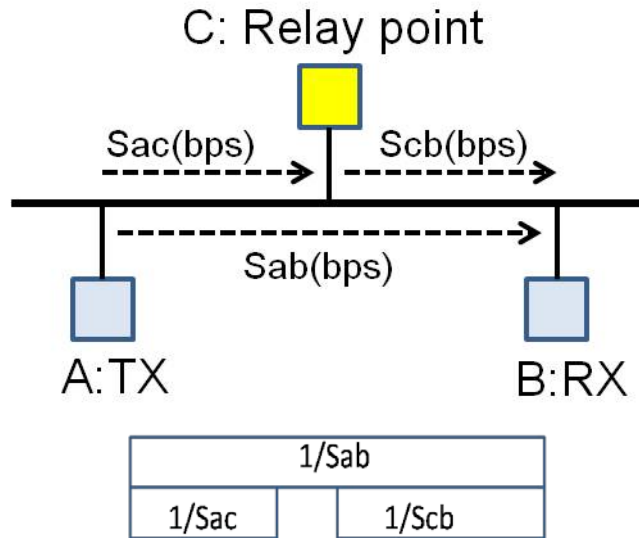


■ Attenuation estimation by BMAE

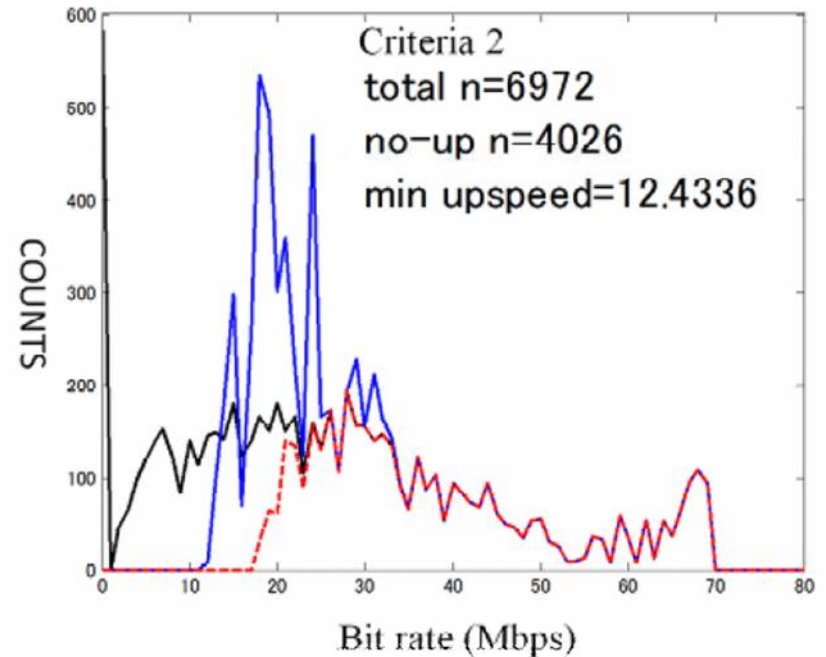


■ Estimated UDP rate of every outlet pairs

UDP rate up by relay transmission



- Rate up criteria
 $Sac > Sab * 2$ &
 $Scb > Sab * 2$



- UDP rate up by relay transmission
RED: no improve **Blue: Rate up**

■ Relay transmission improve UDP rate.

100% up-12Mbps : 95% up-20Mbps : 90% up-24Mbps

Thanks your corporation