

Smart Notching – New concepts for EMC coordination

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Abstract

From an EMC point of view a device is compliant if it works in its environment without causing any unwanted interferences. The classical coordination of EMC requires constant emission and immunity limits against high frequency signals. The emission limit of all devices and the own immunity threshold defines the operating range. Devices working within this range run without any interference in their environment. The classical concept to guarantee EMC has the drawback of unused resources. Furthermore devices have costly shielding, even though often there are no disturbing signals. That is all frequencies are shielded by the device independent of where and when the device is operated. In short, resources are not used efficiently.

In some cases the reception of a low power signal is disturbed despite the fact that surrounding devices are EMC compliant. From an economical as well as from a technical point of view this is not satisfactory. Here stricter limits should have been chosen.

Modern communication systems are able to integrate EMC measures into their design.

For example the next generation Powerline Telecommunication (PLT) modems described here, use this approach. Compared to conventional PLT modems which might interfere with short wave (SW) radio services, the modems which use the concept of ‘Smart Notching’ are less likely to disturb radio receivers.

Due to the antenna properties of the low voltage distribution grid, the electricity cables in a building receive signals from radio broadcast services. PLT modems equipped with Smart Notching detect the existence of such radio services by measuring the spectrum of the signals on the mains network. After an analysis of this spectrum the PLT modem excludes frequencies used by radio services. This process is called ‘notching’. Thanks to the adaptive OFDM transmission with a high number of carriers, ‘smart notching’ only causes a minor decrease in the transmission bit-rate because only low SNR carriers are lost. Continuous analysis allows the system to minimize interference and optimize throughput depending on the current conditions. Electromagnetic compliance is achieved in a different way: instead of rigid constraints ‘smart notching’ devices can comply and improve EMC.

1. Introduction

Home Networking targets to connect all digital consumer electronic devices within a single house or a flat. The consumer will be able to access all services and data at any time and any place in his home, independent of the location of the electronic devices that host these services and data. Powerline communication will enable this application without requiring new networks.

The frequency range of conventional PLT modems (2 MHz to 30 MHz) overlap with SW radio broadcast frequencies defined by ITU-R [1]. Powerline wires in private homes are not shielded and are structured with a certain amount of asymmetry. If a SW radio receiver (AM or DRM) is operated indoor where a powerline communication is active the radio reception quality might suffer. This paper describes a concept called 'Smart Notching'. This is an adaptive mechanism for avoiding radio broadcast frequencies by PLT modems.

There are two main requirements for this concept:

- Minimize interference between PLT and SW radio broadcast;
- Maximize data throughput and QoS requirements of PLT.

The presence of broadcasting signals must be detected by PLT modems by sensing the 'noise' at an electrical socket. Frequencies, where SW Radio broadcasting signals are identified, must be omitted from the transmitted signal by inserting a notch into the spectrum of the transmission signal.

This paper includes descriptions of the:

- Measurements of the signal spectrum on low voltage distribution networks,
- Automatic mechanism for the detection of receivable radio services,
- Impact on AM and DRM radio reception indoor,
- Implementation of notches, which is proven by a feasibility study of a PLT modem,
- Impact on PLT transmission throughput.

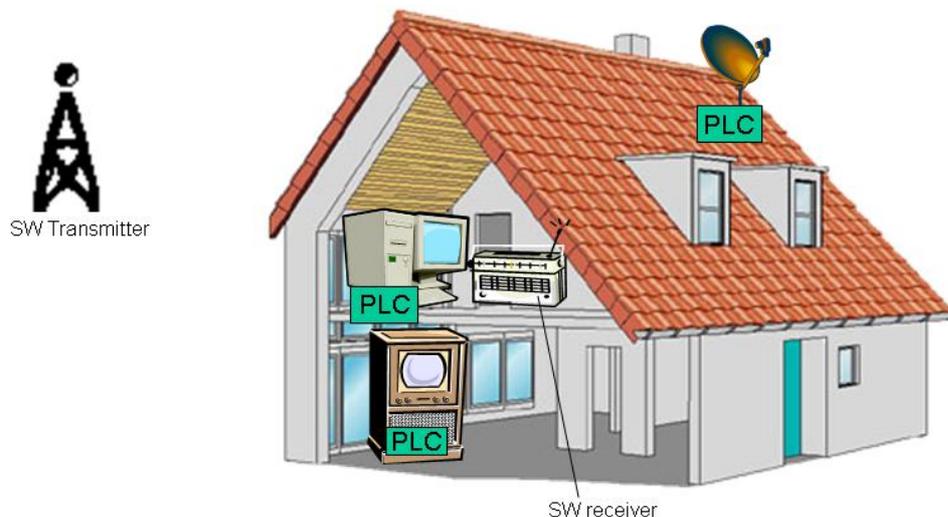


Figure 1. PLT application and SW reception scenario

2. EMC Coordination

According to the definition of the International Electrotechnical Vocabulary (IEV) a product is called electromagnetic compatible, if it works satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in its environment. Since radio systems receive a large range of signal amplitudes, they are typically the most sensitive devices in the home environment. Therefore, radio signal protection dominates the process of EMC

coordination in the area of high frequency signals. EMC coordination has been done for several decades by simply defining limits for electromagnetic emissions produced by equipment. In the past this simple approach was adequate. Classical disturbance sources like commutator machines or switched power supplies produce emissions in a wide frequency band. A selective and at the same time flexible suppression is not possible. Therefore suppression is designed by limiting the maximum emission to a value a few dB below the limit line. More and more the established limits are discussed by the radio people since the limits once were designed under certain conditions regarding spatial, time and frequency probability of disturbance sources. A large number of modern disturbance sources produce in a broad band continuous emissions, so that the original preconditions not necessarily are met. In addition to that new radio systems show up. In former times (when the limits were once defined) an external antenna and a separate earthing of the receiver was common practise. Nowadays the same reception quality is expected from radio receivers without any earth connection and using only an internal (whip) antenna. Furthermore new digital radio services (e.g. DRM) tend to be more sensitive to disturbances, because the spectral information density is higher and/or the transmission power is reduced.

On the other hand new wired communication systems based on OFDM technology (e.g. ADSL, VDSL, PLT) have been introduced, which can use the spectrum in a very flexible way.

Unfortunately, the lines act as antennas, so that there is a coupling between wired and wireless communication working in the same frequency bands. Disturbance situations are therefore inevitable.

It is obvious that all aspects can be addressed by a more flexible spectrum usage by the wired systems. By design they can adapt themselves to the electromagnetic environment in order to protect radio services. Discussions in some standardisation committees show that the way towards this new paradigm is very stony. Traditionally there are inflexible limits. Lively discussions to find a consensus between the concerned parties can be expected. To achieve technical and economic progress we need fresh thinking. The smart notching mechanism for PLT modems presented in this paper is an example for new ways of EMC coordination.

Further examples of adaptive coexistence or EMC with other applications are:

- OFDM overlay systems
- Cognitive Radio
- Frequency Management with Mobile Satellite Services

These state of the art technologies demonstrate the feasibility of this design.

3. Signal Spectrum on Power Lines

In addition to the noise of devices that are connected to low voltage distribution networks, the signals of radio broadcast stations are detectable on the powerlines. The effectivity of electromagnetic coupling of radio signals to powerlines can be described by an 'antenna gain' of the power grid. The mains network acts as a passive antenna: On one hand, received broadcast signals disturb the PLT network. On the other hand, PLT systems transmit signals that may disturb the broadcast reception. Strong radio signals that are receivable by a radio receiver can therefore

be identified by monitoring the spectrum on powerlines. The amplitude of the radio signals on the powerline in relation to their field strength gives the antenna factor. Sensing the ingress magnitude at a socket, where a PLT modem is connected to, enables a PLT modem to identify the presence of radio broadcast signals that are receivable by a typical consumer electronic (CE) radio receiver. Figure 2 shows a snapshot of a measurement (in 49m Band) of the noise between live and neutral at a socket using a spectrum analyzer. Each 'peak' (e.g. at 5 954 kHz or 6 075 kHz), shows the presence of an AM - SW Radio broadcast signal. Each 'plateau' (e.g. around 5 990 kHz, marked in red dashed ellipse) shows the presence of a DRM radio station. The AM - SW Radio broadcast signals marked with the green dotted ellipses show acceptable reception quality using a typical consumer electronics SW radio receiver. These signals were compared with the spectrum measured using a calibrated antenna at the same time at the same location. As the two spectra look basically identical, the measurement result using the calibrated antenna is not shown here. All radio signals in the air that are stronger than 20 dB(μ V/m) (Resolution Bandwidth (ResBw) = 9 kHz) increase significantly the noise floor on power lines.

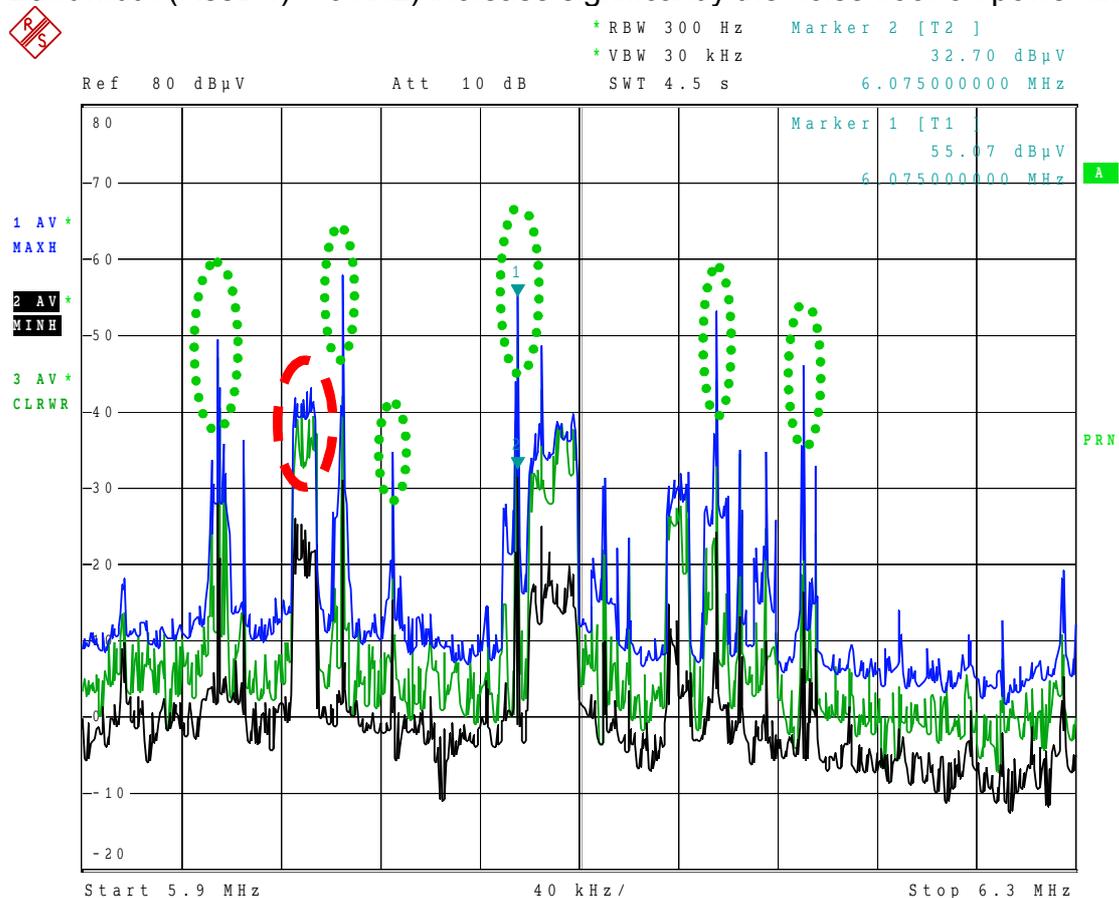


Figure 2: Measured signal spectrum on Powerline in a residential building

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3. Automatic Detection of Receivable Radio Services

PLT modems are connected to the mains grid at a socket to feed and receive signals between live and neutral line. Today's PLT modems are equipped with a very sensitive analog frontend. Typically, modems use OFDM transmission with hundreds or even over a thousand carriers. To demodulate the OFDM signals, an FFT module is needed which is realized in hardware on the PLT PHY layer silicon. This FFT

module can also be used to calculate the frequency spectrum of any noise signal received by the modem. Comparing the noise spectrum with a threshold enables a PLT modem to identify the presence of radio broadcast signals that are receivable by typical CE radio receivers.

The threshold when to omit an OFDM carrier was defined on the basis of many field measurements inside residential buildings. Within these measurements three main parameters were compared:

- Reception quality of broadcast services using SW radio devices
- Signal levels in the air, measured with a calibrated antenna
- Level of signal ingress at the mains sockets

This threshold was set to -85 dBm for $f < 9$ MHz and to -95 dBm for $f > 9$ MHz.

Any device that is connected to the mains may feed unintended noise to the power lines. The noise from connected devices and noise from other radiating devices raise the noise floor. Consequently the reception quality of SW radio services declines and the noise floor level on the mains grid increases. As a result the receivability of SW radio signals can't be detected by comparing the noise signal to a fixed threshold any more. The SW radio carriers get lost in the noise signals. Trials were performed in an anechoic chamber where an AM transmission plus noise was set up. Subjective assessment of the sound quality from a CE AM radio was done. A speaking voice is no longer understandable when the AM signal becomes weaker than 17 dB above the noise floor in the HF range. To guarantee robust DRM receptions it was determined that the 'needle' of the radio signal ingress should exceed the noise floor by more than 12 dB. The Noise Floor was measured as required in.

If a receivable radio signal has been detected, its frequency should be avoided by PLT modems within 10 seconds. The system takes the strong fading behaviour of the SW radio transmission channels into account and reuses frequencies if no radio services were detected within the last 60 seconds.

Today's OFDM PLT modems adapt the constellation of each carrier depending on the SNR available on each frequency. Therefore modems have to monitor channel and noise characteristics quite frequently. Existing components can be reused to evaluate the spectrum.

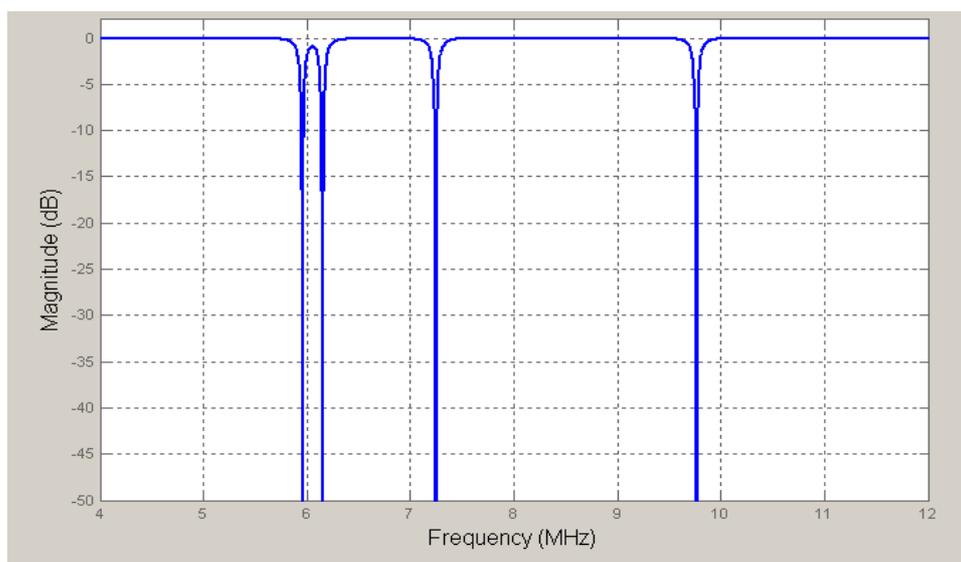


Figure 3: Multiple notch filters

The lower level of the notch must not exceed -68 dBm, measured at a power outlet using a spectrum analyzer with ResBw = 300Hz, Average Detector and 9 seconds Max Hold view. The value of -68 dBm was found by field measurements in many buildings and it guarantees undisturbed reception of radio services. If the radio device is operated by battery or if the power supply is not connected very close to the socket where the PLT modem feeds its transmission signals, no interferences from PLT could be heard using an AM receiver. The benefit for the radio reception side is that this value is more stringent than the limits defined in EN55022 (5-30 MHz: 50 dB(μV) for class B device, measured with an AMN at 9 kHz bandwidth, Average). The benefit for PLT is to reuse free frequencies and maximize data transmission rate. Today's ETSI draft TS [2] defines the verification of this concept. This document describes an impedance stabilisation network to connect PLT modems and measurement devices, as well an artificial (ingress) signal to stress the modems. Figure 4 shows a measurement with signal ingress (blue, lower line) and feeding level of a dynamic notching system. Notches were activated (black line) and disabled (green, top line).

5. Impact of 'Smart Notching' on PLT Transmission Throughput

To evaluate the impact of smart frequency notching on the performance of PLT, following assumptions of the PLT modem and the channel characteristics are done, which are based on measurements in private flats:

- Design of PLT modem is optimized to realize Smart Notching.
E.g. OFDM Carrier spacing: 10 kHz. Used frequency range: $2 \text{ MHz} < f < 30 \text{ MHz}$
- Number of radio services to be protected: 22
consequently 22 times 10 kHz are not available for communication (220 kHz)
- Level ingress at these carriers: 35 dB(μV)
(ResBw = 9kHz, readout values of figure 2 must be corrected by 14 dB(Hz))
- Median Attenuation of a PLT channel: 42 dB
- Median Noise Floor at an outlet: $N_{\text{receive}} = 12 \text{ dB}(\mu\text{V})$ (ResBw=9 kHz)
- Feeding Level of PLT modem: $P_{\text{feed}} = -64 \text{ dBm/Hz}$ (AvgDet) -> 86 dB(μV)
(ResBw=9 kHz)

The Signal to Noise Ratio SNR is: $\text{SNR} = P_{\text{feed}} - \text{Attenuation} - N_{\text{receive}}$

The theoretical channel capacity is defined by Shannon : $C = \int_{f_{\text{Start}}}^{f_{\text{Stop}}} \log_2(1 + \text{SNR}) df$

With $\text{SNR} = 86 \text{ dB}(\mu\text{V}) - 42 \text{ dB} - 12 \text{ dB}(\mu\text{V}) = 32 \text{ dB}$

$C_{\text{all}} = 28 \text{ MHz} * \log_2(1+10^{3.2}) = 297,7 \text{ Mbps}$

For simplification the capacity C_{all} includes the communication resources that are lost due to the noise ingress.

Lost Channel Capability due to Dynamic Notching:

Remaining SNR at carriers where SW-radio ingress:

$\text{SNR} = 86 \text{ dB}(\mu\text{V}) - 42 \text{ dB} - 35 \text{ dB}(\mu\text{V}) = 9 \text{ dB}$

Lost throughput: $C = 220 \text{ kHz} * \log_2(1+10^{0.9}) = 695 \text{ kbps}$

Theoretically lost throughput resources due to Smart Notching:

$0.7/300 * 100\% = 0.23\%$

Due to the fact that only carriers with low SNR are omitted, the impact on the throughput will be significantly less than 1%, if PLT modems implement Smart Notching properly.

6. Outlook

The development of this technology is at an early stage. First laboratory prototypes of smart notching PLT devices with a 200 MBit/s throughput have been realized and tested in typical residences.

Another solution to avoid coexistence problems with SW radio broadcast would be to go to higher frequencies. The frequency range from 30 MHz to 80 MHz shows better performance for In-House PLT than today's frequency range which ends at 30 MHz .

7. Conclusions

PLT modems equipped with Smart Notching significantly reduce the interference to radio services. If the proposed thresholds to detect a radio service and the lower level of the notch are respected by PLT modems, indoor reception of SW radio services is possible without any interference.

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