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# White Paper

## Smart Grid - Power Line Communication


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## 1.0 Introduction

With the rise of smart metering it has become commonplace to transmit critical data over electrical power lines using Power Line Communication (PLC). Although the transport medium can be considered unconventional for radio communication, PLC is a form of radio frequency (RF) communication. PLC utilises a modulated carrier, typically at low frequencies comparing to most commercial radio systems working over an air interface.

The reliability and functionality of any RF link is based on transmitting and receiving data with some specified bit-error-rate at optimum signal conditions, usually for a specified carrier-to-interference (C/I) ratio. The system will also have to be designed with less-than-ideal signal conditions due to a large distance between the transmitter and receiver. Better signal conditions in the transmission line result in greater signal range and - in the case of PLC – longer lines being usable for transmission of metered data.

So, a key factor in building any reliable radio frequency system is establishing a good signal path with low interference. What does interference have to do with PLC? After all, there should be no other RF signal that is being transmitted in the power line which means there should be no interfering signals, right?

In this article we will look at examples of RF interference in specifically PLC as well as how to localise the sources of interference. Anritsu has also produced a number of application notes regarding interference in RF environments which also offer a great resource of complementary information for any person interested in getting to know this phenomenon a bit deeper

## 2.0 What causes Interference in PLC?

Interference in itself is quite easy to comprehend. Let's take an example of two persons having a conversation. In order for the speech to be intelligible the signal (the voice of the person one is listening to) has to be high enough to reach the receiver (one's ears) so that any possible noise is overcome by a reasonable margin. The interference can be wideband noise like the rumble of traffic or narrowband like a jackhammer or a police siren, but in any case when the noise level is high enough the signal will become unintelligible.

The same simple principle holds true to any RF system. If the interference level is too high the receiver will not be able to "hear" the transmitter and the link between them will not function. The signal level vs. the amount of interference at the receiver is the key factor: this is the C/I ratio.

Different receivers will also act in different ways. Some receivers will have been designed with interference suppression in mind and will be very narrow-band, meaning they will not "hear" anything far away from their own carrier frequency. For this kind of receiver the interference outside of the signal band is all but meaningless but interference within the signal band will be a problem. If, on the other hand, the receiver has no filtering of out-of-band signals and thus works on a relatively high bandwidth it will "hear" almost everything that's thrown at it. In this case a strong interfering signal may block communication even if it is seemingly far away from the system's carrier frequency.

## 2.1 PLC system principles

A normal PLC metering system will look like something in the picture below. Each user will have their own energy meter which will communicate with a hub, usually located at the transformer. The PLC communication used for this is described as the blue lines. The hub will then use a radio modem (ex. GPRS) to transmit the data to the utility company via the air interface. The amount of installed meters per hub can be in the order of hundreds where as a single utility may have anywhere between thousands to millions of metering units installed in the field.

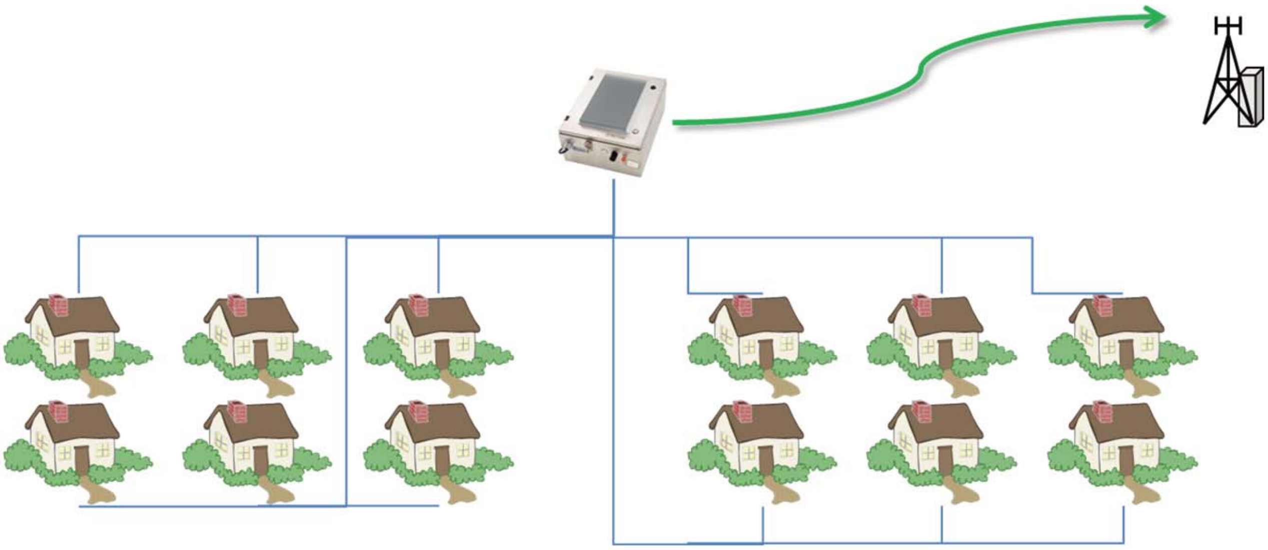

*Figure 1: Diagram of a PLC system*

There are many standards implemented for PLC around the world but most technologies employed use a frequency range of about 10 – 150 kHz (Europe), or 150 – 400/500 kHz (Japan/USA) .

As the air interface is usually the concern of a mobile operator most utilities will not have to worry about interference over the air. If this is not the case we recommend also reading the aforementioned documents related to finding interference in radio networks.

However interference in the power line may, and often will, become an issue especially when the amount of installed meters is large. So what will cause interference in the power line? The sources of interference are many but the most common sources include but are not limited to:

1. Switch-mode power supplies
2. Electrical engines and their drives such as frequency converters
3. Other types of switching and dimming devices

Many other devices, especially failing/broken ones or poorly designed ones can cause interference.

The interference can be a signal at a particular frequency or a number of frequencies (usually switch-mode power supplies will exhibit this behaviour) or wideband noise (often the case with frequency converters) or even a combination of both.

## 2.1 PLC vs. EMC

Electromagnetic Compatibility (EMC) regulation normally limits interfering emissions from electronic devices but most EMC standards have a lower frequency limit of 150 kHz. This means that especially the European PLC frequency band is largely uncontrolled when it comes to conducted emissions of connected equipment.

## 3.0 Recognizing the interference

So what does interference look like? The frequency of an interfering signal is the most common parameter leading to the identification of the interfering source. Thus, an interference problem can often be categorized by its frequency characteristics.

It should be noted that whether the interfering signal is in-band or out-of-band, the signal is almost certainly coming through the antenna, down the cable, and into the affected receiver. Therefore, a spectrum analyzer connected to the operating system antenna will serve as a substitute measuring receiver which will display and help identify unwanted signals. Remember that the system's band pre-selection filters are inside its receiver, so many out-of-band signals are naturally present at its antenna input connector.

Interference generally only affects receiver performance. Although it is possible that a source of interference can be physically close to a transmitter, the characteristics of the transmitted signal will not be affected. Thus, the first step in recognizing if interference has corrupted a receiver is to learn the characteristics of the signal that the affected system is intended to receive.

By analyzing the frequency domain using a spectrum analyzer the signal frequency, power, harmonic content, modulation quality, distortion and noise or interference can easily be measured. If interference is overlapping the intended receiver signal, it will be relatively obvious on the spectrum analyzer display.

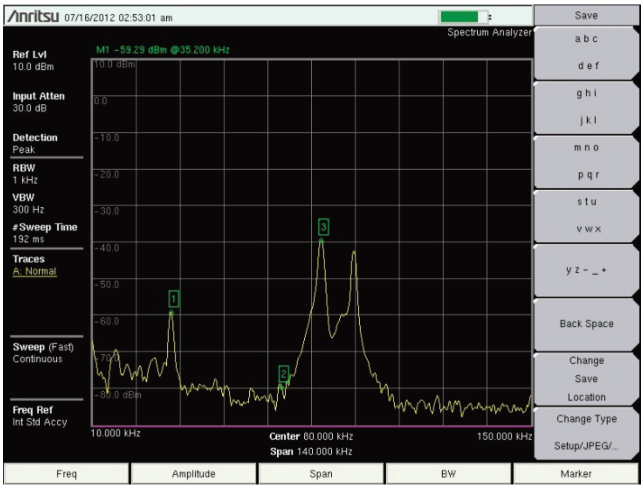


*Figure 2: PLC signal spectrum*

In figure 2 the transmitted spectrum of a PLC system is displayed. The actual signal is the saddle shape pointed out with the red arrow.

A displayed interference "fingerprint" contains important identification characteristics. As mentioned above different causes of interference will typically have a different kind of spectrum.

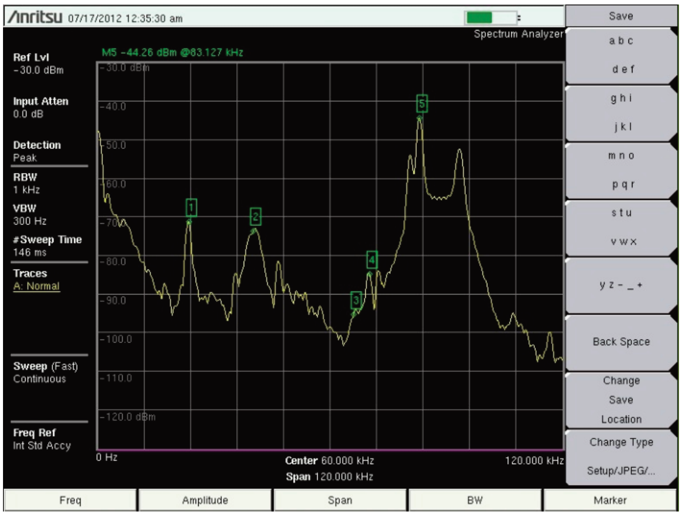


*Figure 3: PLC signal with interference*

Let's look at figure 3 as one example In the picture above a spectrum measured from a power line feed at a transformer station is displayed. It is easy to differentiate the saddle shape of the PLC hub trying to communicate with the energy meters but as can be seen there is also plenty of interference present. The highest amplitude interferer is right on top of the PLC signal, represented wit marker 5. Without the PLC present the signal environment looks like this:

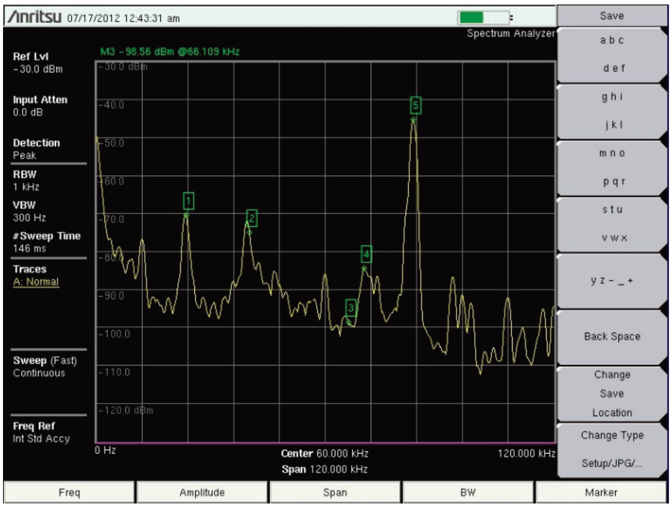


*Figure 4: interference spectrum*

In figure 4 we can see that the strongest interference is a single frequency peak which leads us to the conclusion that it may be a switch-mode power supply operating somewhere close. In this case it was found that in an adjacent building there was a mobile base station with a large power supply running it. The power supply was turned off in order to verify the signal source and the result was a somewhat cleaner spectrum.

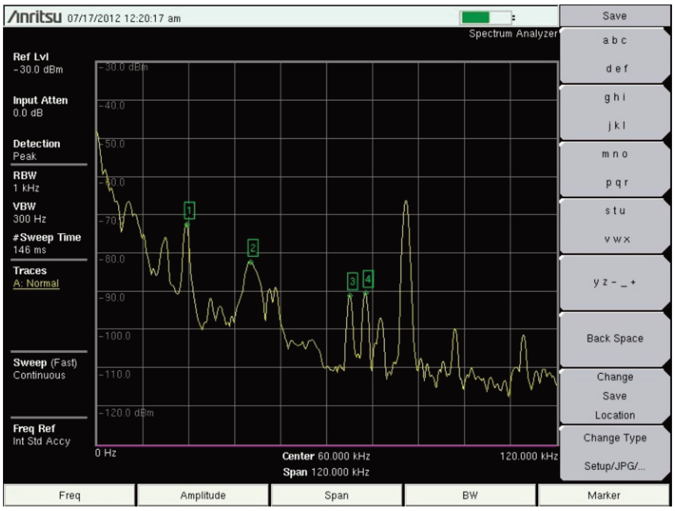


*Figure 5: Resultant spectrum*

The resultant spectrum is cleaner as the overall noise floor at the operating frequency of the system is considerably lower (by about 10 – 20 dB) but also the main interfering signal is removed. However it was found that under the main interferer there was additional interference at a slightly lower frequency. The diagnostics continued to make sure this interference was also found.

### 4.0 Selecting the Appropriate Test Equipment

The most useful and accurate tool for qualitative and quantitative analysis of RF and interference in the field is the broadband, hand held spectrum analyzer. The Anritsu Spectrum Master handheld spectrum analyzer is such a tool that features powerful user-convenience parameters (soft keys), data manipulation and storage capabilities.

The spectrum analyser to be chosen should deliver a few key features to be effective in hunting down the interference:

### 4.1 Spectrum Analyzer features

What do we need to know about a spectrum analyzer to make sure that we can measure the signal environment adequately? Very basically, we need to know the frequency range, sensitivity, dynamic range, frequency resolution and accuracy.

**Frequency Range –** Frequency range should be the easiest criteria, since you have a good idea of your system's frequency band and hence the spectrum span you want to observe. For PLC measurements you will need a lower frequency limit of 10 kHz or below. The higher frequency limit is usually not a concern as most modern handheld spectrum analyzers cover a range of up to 3 GHz at minimum but if one desires also to measure wireless RF links it is beneficial to have the frequency coverage to allow for it.

**Sensitivity –** As the attenuation of power lines is quite high you will need a very sensitive instrument to be able to measure the PLC communication and interference when they are far from the measurement point. This is especially important as the technique to "hunt" for the interference is based on physically following the interfering signal along the power line cabling.

**Frequency Resolution, Dynamic Range, and Sweep Time –** Frequency resolution, dynamic range, and sweep time are inter-related. Think of resolution as the shape of a scanning "window" which sweeps across an unknown band of signals. Spectrum analyzers provide for selectable resolutions, and call it resolution bandwidth (RBW). Resolution becomes important when you are trying to measure signals that occur close together in frequency, and you need to be able to distinguish one from the other. Basically the narrower the lowest resolution bandwidth available, the better.

**Selectivity –** In some interference applications, there will be signals that have amplitudes that are quite unequal. In this case, "selectivity" becomes an important criteria. It is very possible for the smaller of the two signals to become buried under the filter skirt of the larger signal.

**Measurement and trace features –** Additional processing for the signals may be needed in order to differentiate the source of the interference. The following features are desirable additions to a spectrum analyser that is used for hunting interference in power lines.

- Multiple traces, trace math and trace operations such as max hold will enable the user to easily detect changes in signal conditions between different cables and, for example, when switching off possible sources of interference (see figure 6 below)
- Zero Span mode will allow the user to look at the interfering signal in time domain, thus making it possible to differentiate a switch-mode power supply (having a particular duty cycle) from other types of narrow-band interference (being continuous in nature)
- Multiple markers and marker tabling will allow the user to continuously monitor several frequency points as the measurements are being made
- A Spectrogram display (displaying spectrum over time) will allow the user to monitor changes in the signal over a longer period of time.

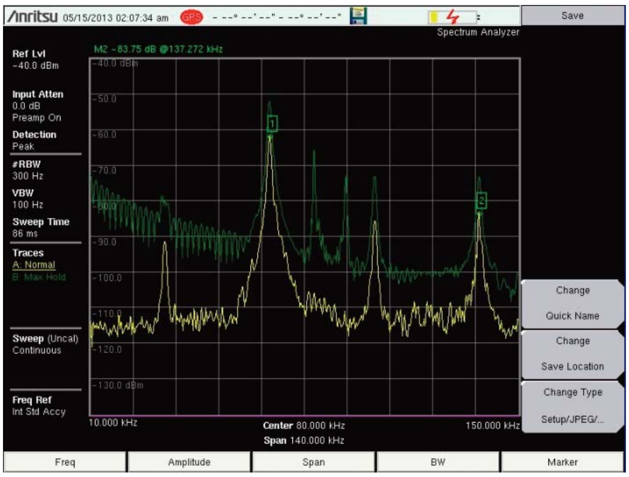


*Figure 6: Max hold trace vs. Live trace*

### 4.1 Probes

The spectrum analyser will need to have a means of coupling to the power line in order to feed the signal to its receiver. There are 3 main types of probes that can be used to make that coupling.


*Figure 7:Anritsu 2000-1689 probe kit*

**Near field probes –** Near field probes are the most universal of the probes and also the type of probe to offer the highest diagnostic power. Especially the loop type probes, designed to couple with magnetic fields, are particularly powerful. This is because in many cases the interference can be seen in the spectrum of the current that the interfering device draws from the network. The loop type probes couple to this magnetic field and can isolate the cable feeding the interfering instrument from other cables. This makes it possible to "follow the lead" and find the interfering device. The near field probes are also very fast in diagnosing a particular site as they require no physical connection to the cable or the voltage buses. It is easy and quick to take the probe close to a cable and see what's happening. The drawback is the lower sensitivity of these types of probes when comparing to a clamp type current probe or a contacted voltage probe.

*Figure 8: Using a loop probe to measure interference*

**Clamp type current probes–** Clamp type probes differ from the above mentioned near-field probes in that they are clamped onto the cable being measured. Because the cable, and thus all of the current that it carries, passes through the clamp it offers better coupling to the signal and thus greater sensitivity (about 10 – 20 dB) than the near field loop probe. However using the clamp type probe is sometimes slow, cumbersome and often even dangerous as it needs to be clamped onto live electrical feeds.

**Contacted voltage probes –** This probe type is contacted directly onto the voltage bus of the power station and is thus probably the most dangerous probe type and requires extreme caution and expertise. However when used properly it gives a very good look at everything that is happening in that particular voltage bus and offers high sensitivity. However the voltage probe cannot differentiate between the cables as the voltage will be exactly the same at a given point and thus has less diagnostic power than the current probes mentioned above

### 5.0 Interference hunting in PLC

In normal over-the-air Radio Frequency telecommunication finding and localising the interference is often very time consuming. The interferer may be intermittent and there is no physical connection between the receiver and the interference. In PLC communication the situation is simplified because there is always a wired connection between the receiver and the transmitter. It is at the end of one of these wires where the cause of the interference must be.

In a typical case there will be a number of smart meters down in a particular area. Next we will introduce a basic method to find the source of interference.

### 5.1 Start at the root – follow the current

The typical simplified PLC grid topology will look something like a tree. The PLC hub will be located at the transformer station where the power lines will be distributed to different areas. The lines will again be split at distribution boxes to different buildings and possibly again to different apartments inside the buildings.

The most effective way to find the interferer is to measure the spectrum from the current - not the voltage – of the circuits. The voltage at a given point will be essentially the same in all of the circuit but the currents will vary. The current draw of the interferer will in most cases contain the interference spectrum and can thus be pinpointed.

So, start your hunt at the transformer and measure each line (phase) with a current probe, i.e. a loop or a clamp as described above. When you find the line with the highest amplitude of the interfering signal you will know where to go next. Follow the line (and the current) down to the next junction where it is split and repeat the above procedure. Repeat until you know which building the interference is coming from.

Once you are in the building things get slightly more challenging but still the same methodology applies: Scan the lines with the loop probe to see where the signal is coming from. Take the loop close to the power supply or the supply line of different devices. You will be able to see quite clearly if the interference comes from that particular device. When you have filtered the source down to a manageable amount of possibilities you can start trying to shut devices down to see what kind of an effect it has on the interference levels. This will allow you to verify which device/devices are causing the interference and what could be done to minimise or remove it altogether.

### 6.0 Conclusion

PLC communication is a robust and easily deployable system for smart metering. However, as all RF communication systems it is susceptible to interference. What's more, the frequency range where PLC most commonly operates is commonly not specified in EMC regulation. This adds to the probability of finding interfering components being connected into the power grid. It is important for the utility company to be able to diagnose the sources of interference in their smart metering network in a fast and efficient manner in order to avoid the cost of not being able to monitor the grid. Anritsu's lineup of handheld spectrum analyzers, when used with the correct type of probe, provide a simple and economical tool that makes it possible for engineers to pinpoint the sources of interference in their network.

Specifications are subject to change without notice.


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