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# AN58825

## Cypress Powerline Communication Debugging Tools

**Associated Project: No**
**Associated Part Family: CY8CPLC10/CY8CPLC20/CY8C29x66**
**Software Version: None**
**Related Application Notes: AN54416, AN52478**

**If you have a question, or need help with this application note, contact the author at adiy@cypress.com.**

Powerlines are a widely available communication medium all over the world for Powerline Communication (PLC) technology. The pervasiveness of powerlines also makes it difficult to predict the characteristics and operation of PLC products. Because of the variable quality of powerlines around the world, implementing robust communication over powerline has been an engineering challenge for years. This application note describes these challenges, explains how to identify the cause for poor PLC performance, and provides solutions to ensure successful communication.

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## Introduction

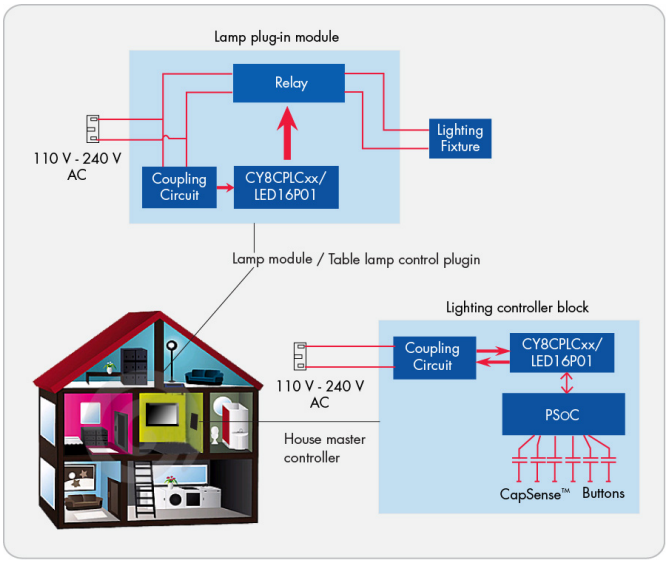
Powerline communication has received tremendous attention in recent years as an alternative and cost-effective last-mile-access technology. There are powerline outlets everywhere, making it an all-encompassing network and the largest infrastructure which can be used for data communication. However, even today it has remained an engineering challenge to communicate data on the powerline due to the varying nature of the powerline itself and the loads (such as electrical appliances, motors) connected to the powerline.

This application note discusses the various issues faced in powerline communication and how they can be detected and debugged in a real life implementation.

## System Diagram

Figure 1 illustrates an example where PLC is used for residential lighting control. This example consists of a lamp plug-in module controlled over powerline by a House Master Controller. There can also be similar modules for electrical appliances other than lighting, to be controlled or automated with PLC. Though Figure 1 shows a residential application, PLC can be used for command and control in commercial applications as well.

.Figure 1. PLC in Residential Lighting Control




## Challenges for Powerline Communication

This section discusses the reasons why powerline communication might fail in a real life environment. The three common causes of failure are:

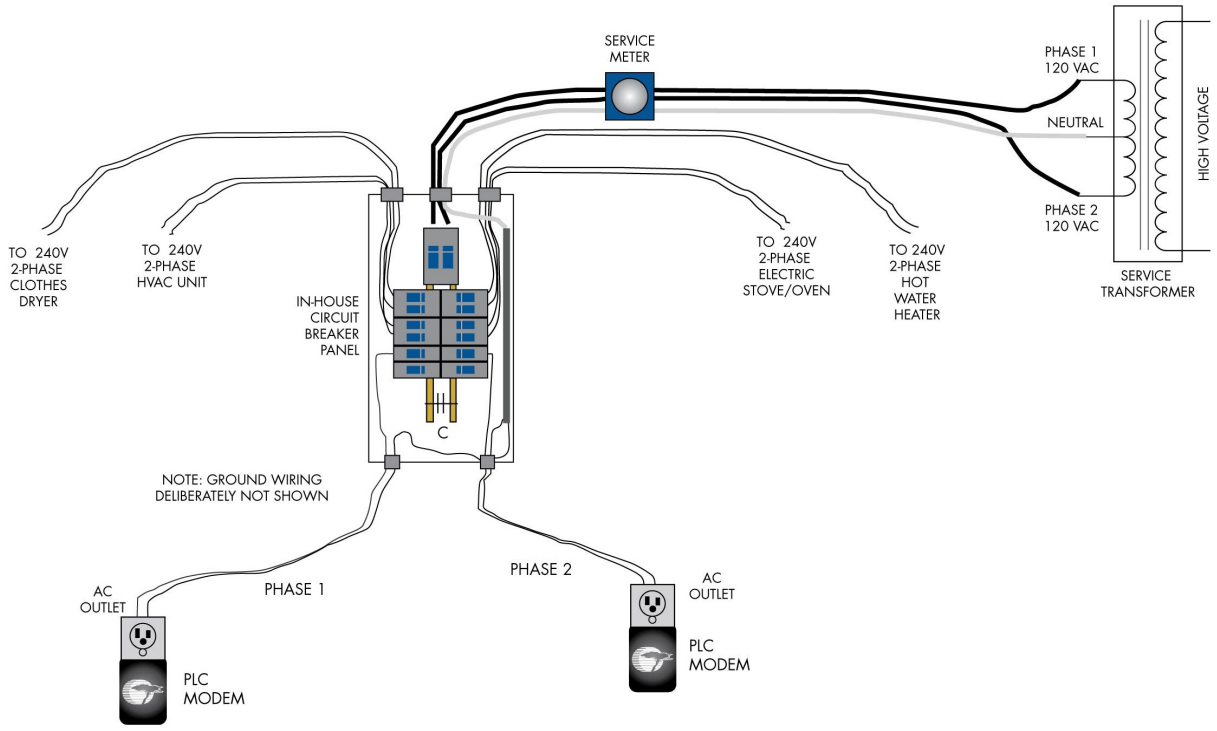
- Different electrical phases
- Noisy environments
- Impedance and distance

## Different Electrical Phases

*Problem Description*

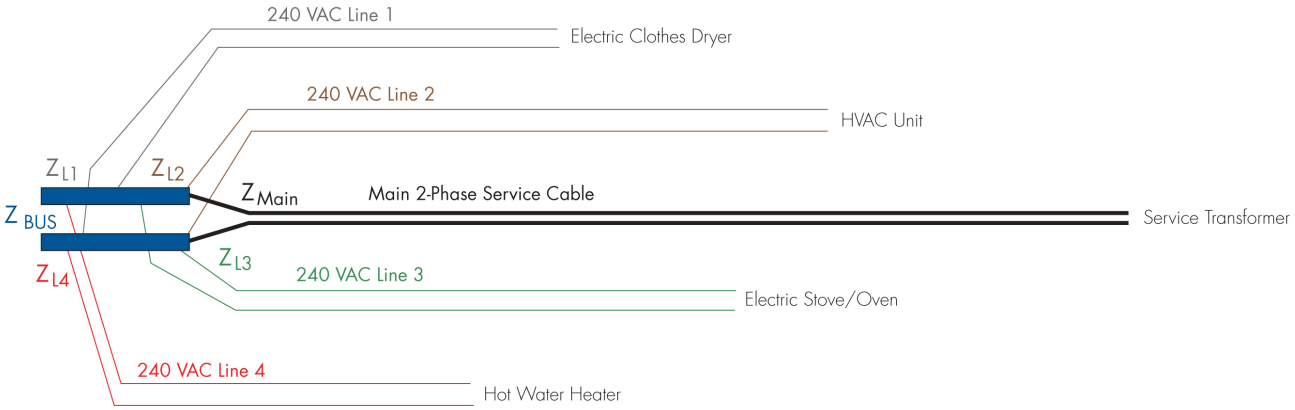
Some countries provide only a single phase of AC power to a dwelling (home or apartment). This is common throughout the UK and across Asia. It is also true for many countries in Europe. When only one phase is employed, the problem of communication across phases does not exist. However, homes in Canada, the Americas, Germany, and other parts of Europe are supplied with multiple AC phases or service lines where multiple phases separate AC circuits. Figure 2 shows an example of a generic two-phase electrical distribution system.

Figure 2. Two-phase Electrical Distribution System




The reason why the communication signal is usually not able to get across different electrical phases is the high impedance between the phases in the frequency band of interest. The impedance across the phases can be modeled from Figure 2 as shown in Figure 3.

Figure 3. Impedance Model for a Two-Phase System




$$Z_{BUS} = Z_{L1} \,||\, Z_{L2} \,||\, Z_{L3} \,||\, Z_{L4} \,||\, Z_{Main}$$

As shown in Figure 3, the overall impedance is always lower than the individual impedances because it is the parallel combination of different impedances. However, it is not always sufficiently low to bridge the communication signals across different phases.

Also, sometimes communication fails across different circuits out of the breaker box, even though these circuits belong to the same phase. This is usually due to the breaker box being far away from the sockets and the signal having to travel a long distance to get to the other

circuit. If the distance between the two sockets from the two different circuits (of the same phase) is within the limits, then communication should not fail. For distance limitations, refer to the Impedance and Distance section.

### *How to Detect Phases*

There are various phase detectors available in the market which can be used to detect the different electrical phases in the network. Figure 4 shows the 3129 series phase detector from Hioki, which is used for phase detection and checking phase sequence.

Figure 4. Hioki 3129 Series Phase Detector



Another approach is to use a generic multimeter to detect the voltage/impedance across different sockets. The multimeter readings indicate whether the sockets are on the same phase or not. For example, in a typical US residential two-phase system, the voltage between the two hot phases is 220V with 110V from either hot to neutral. This approach can involve hooking the multimeter with cables that can handle the powerline voltages. Also, extreme precaution should be taken with any bare conductors and exposed metallic parts.

### *Solution*

Any medium that can couple the signal across different phases is a solution to this problem. As shown in Figure 3, when any impedance is lowered, the overall impedance goes down because it is the parallel combination of all impedances. Thus a capacitor of appropriate value, either at one of the polyphase 240 VAC appliance ends or the breaker box (Mains) end, couples the signal across phases.

There are also digital ways of phase coupling. An example is a powerline-to-wireless bridge that is connected to each phase and wirelessly couples the signals across the different phases.

## Noisy Environment

### *Problem Description*

A non-Cypress-PLC signal in the communication bandwidth is considered to be noise. The PLC receiver filters out the noise outside the communication bandwidth and so the noise inside this band is the most destructive.

When the signal-to-noise ratio (SNR) becomes too small, the PLC data signal is not picked up by the receiver, leading to unsuccessful communication. The plot in Figure 5 shows the Packet Error Rate (PER) of the modem versus the Signal-to-Noise Ratio (SNR) to demonstrate how communication is affected by noise on the channel. The noise in this test is white noise (all frequencies).

Figure 5. PER Vs SNR (with SNR on X-axis and PER on Y-axis)

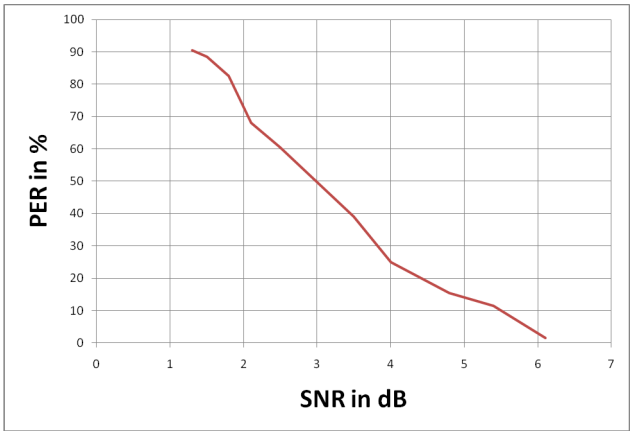
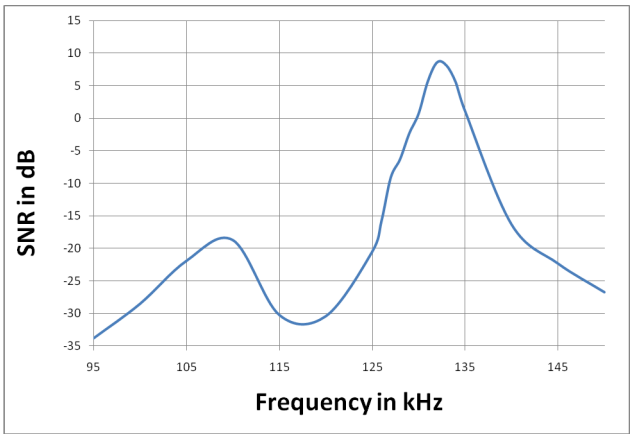



Figure 6 shows the variation of SNR with the frequency of the interfering noise for the Cypress PLC filter (PER = 1%). As expected, the SNR peaks at the communication frequency of 132 kHz.

Figure 6. SNR Vs Noise Frequency




The noise in PLC systems is mainly caused by electrical appliances connected to the powerline. These devices are not only sources of noise, but also cause fluctuations in the line impedance. The major noise sources include CRT color televisions, fluorescent lamps, light dimmers, vacuum cleaners with a brush motor, and switch mode power supplies. Noise waveforms generated by some of these appliances are shown in the following figures.

Figure 7. Noise Waveform by a CRT Color Television

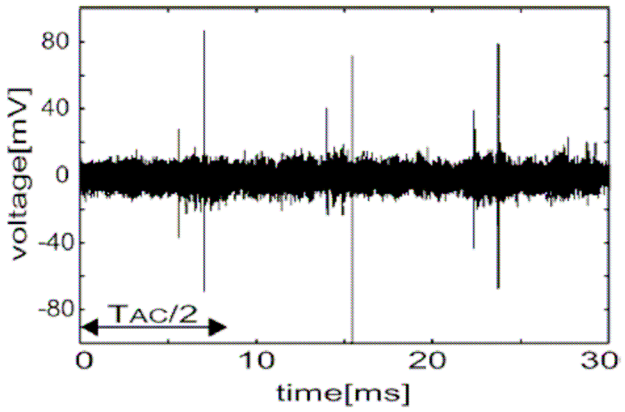



Figure 8. Noise Waveform by an Inverter Driven Fluorescent Lamp (30W)

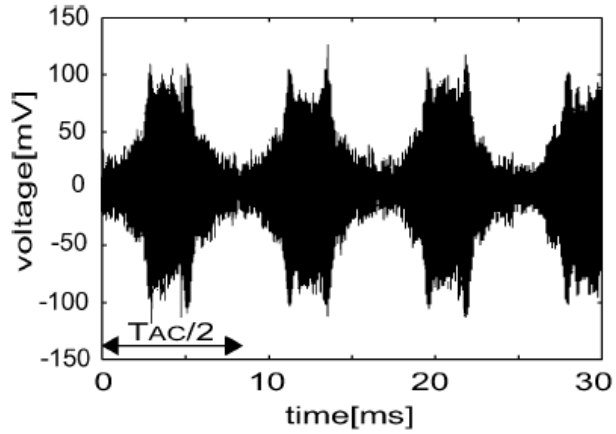
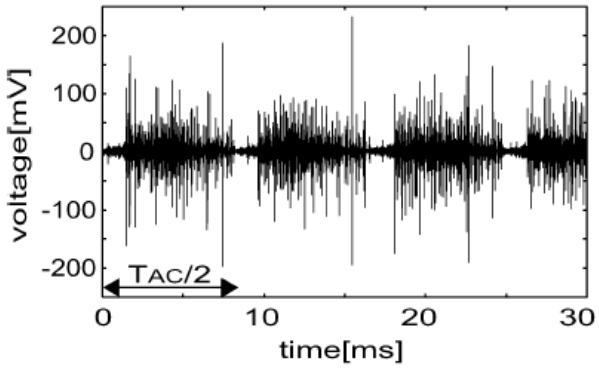



Figure 9. Noise Waveform by a Vacuum Cleaner with Brush Motor




Apart from electrical appliances, there can be alien PLC modems injecting communication signals in the same frequency bandwidth. If these alien PLC nodes comply with the CSMA protocol according to the European CENELEC standard, then they can co-exist with the Cypress PLC nodes. This is because the CENELEC standard mandates all compliant CSMA nodes to co-exist on the same line. However, if the alien nodes do not comply with the CENELEC standard, then their communication signal is also treated as noise for Cypress PLC.

### *How to Detect Noise*

The first indication is if the communication success rate is mid-range. This can be around 40 to 70% (neither 0% nor 90 to100%); it is most likely due to noisy environments. However, note that the success rate can also be 0% due to noisy environments, but a 40 to 70% success rate implies a noisy line.

Cypress has developed a Noise Measurement Application GUI to scan the noise for a given time period to understand the noise levels on the powerline for a particular time interval. This GUI is available as one of the tabs in the Cypress Control Panel Application V1.1 available at www.cypress.com/go/plc. The instructions on how to use this GUI are provided in the Appendix.

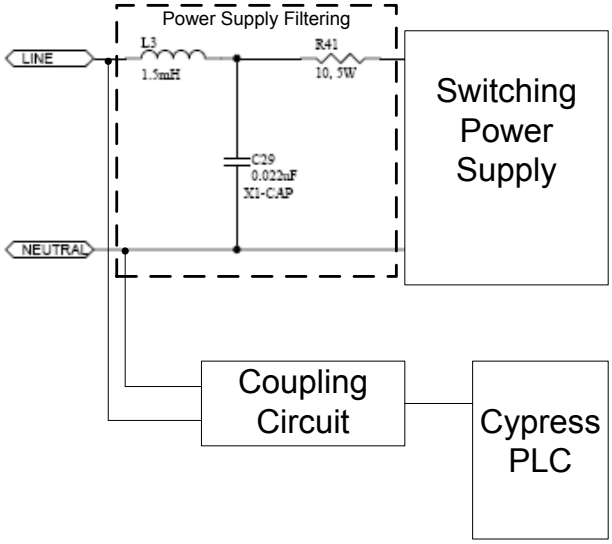
The noise levels (in dBuV) obtained for a particular time interval can be constant or varying with time. A constant low value indicates that it is a clean noise-free line and should have high SNR leading to reliable communication. A constant high noise level indicates static noise which is present at all instants of time, thus decreasing the SNR. The graph in Figure 6 shows how the communication success goes down with decreasing SNR. The third kind of results is when the noise level fluctuates with time, for example, a noise spike for a 5 ms interval. In such a case, the communication packet is dropped if it clashes with the noise spike. However, the protocol compensates for the packet loss with features such as Acknowledgements and Transmit retries to regain the communication success rate.

It is recommended that the Noise Measurement GUI is run with no Cypress PLC node transmitting on the same line so that the GUI does not pick up the Cypress signal and interpret it as noise as well. In case of multiple Cypress PLC nodes on the line, ‘Transmit To Clear’ functionality can be used to keep the line free for at least the minimum BIU interval. The GUI gives eight different levels of noise. If the noise in the GUI is at the highest level, it means that the actual noise is at this level or even higher. In such a case, a transmit attempt should be made, in which BIU timeout indicates whether the noise level is higher than the signal level, that is, negative SNR and no communication is possible in such a scenario.

### *Solution*

In a noisy environment, it is recommended to increase the transmit gain to have maximum signal output to maximize SNR. If the noise level is beyond the maximum according to the GUI, then try disabling BIU and set up the network accordingly. Make sure switching frequency and harmonics of the onboard power supply are not in the sensitive frequency range of the PLC device. To reduce the effect of the power supply noise, an LC filter can be added between the line and the power supply. Figure 10 shows the on-board power supply filter in the Cypress High Voltage kits CY3272/74/76.

Figure 10. Power Supply Input FIlter




The frequency response of this filter is shown in the following figure.

Figure 11. Frequency Response for Power Supply Filter

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As shown, the power supply filter has an attenuation of 28 dB at the communication frequency of 132 kHz.

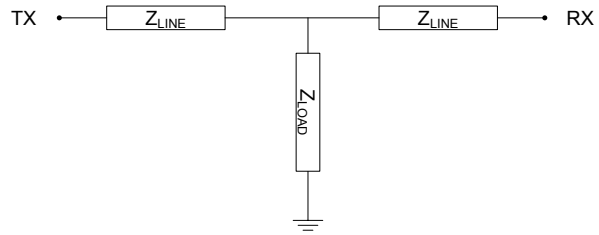
## Impedance and Distance

*Problem Description*

Distance and impedance are two related parameters in powerline communication. Every PLC solution has a distance limitation based on the signal strength of the transmission signal. The maximum communication distance depends on the specific powerline network used. The network impedance and noise as well as the signal distortion and attenuation are affected by the network topology and by other devices connected to the same network at a given time. As a consequence, the maximum communication distance can widely vary from one network to another or even from one time to another on the same network.

The impedance of the powerline can be categorized into line impedance and load impedance. Figure 12 shows how the powerline can be modeled into these two kinds of impedances.

Figure 12. Impedance Model for a Powerline



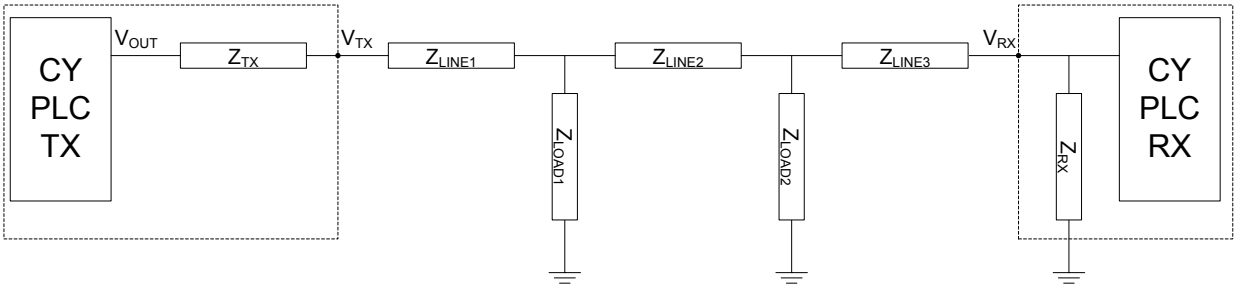

The line impedance directly impacts the maximum communication distance with an inverse relationship. This means, the lower the line impedance, the lower the voltage drop across the line and hence better distance. However, the line impedance in most powerline networks is a small value on the order of few ohms (around 10 ohms at the communication frequency of 132 kHz) and does not change with time. Therefore, unless there is a really long distance (for example, more than 100 meters) to be covered, line impedance is usually negligible.

On the other hand, even though the load impedance does not directly impact the maximum communication distance, it is the more dominant factor in determining communication success. The load impedance comes from different electrical appliances or PLC nodes that are plugged onto the same powerline. If the load impedance is significantly lower than the transmit output impedance, the communication signal gets grounded through this load, leading to significant attenuation of the signal. The mathematical relations of the different signal levels to the various impedances are discussed later in this section. Also, the load impedance can vary with time, depending on the appliances that are plugged in at that time. This ambiguity adds to the unreliability of communication.

As discussed earlier, though the maximum communication distance is considered to be a standard specification for any PLC system, it varies drastically depending on several factors such as network topology and the varying load impedance of the line. Hence, powerline impedance is a better parameter to gauge communication success. The maximum distance is generally considered for a clean powerline network with no other devices connected to it. For example, communication distances of 500m using CY3272/74/76 have been demonstrated in an undisturbed powerline environment.

To summarize, the line impedance of a powerline is usually small and hence does not attenuate the signal to a large extent. However, load impedance plays an important role in determining performance. Let us consider the different relations between signal levels and impedances. Figure 13 shows the powerline impedance model and two PLC nodes connected on the line.

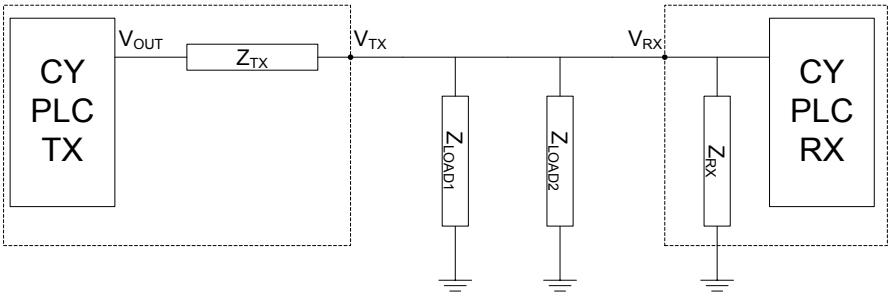
Figure 13. Two PLC Nodes Connected on the Powerline




In Figure 13, $Z_{TX}$ is the output line impedance of the transmitter and $Z_{RX}$ is the input load impedance of the receiver. $V_{OUT}$ is the voltage signal from the power amplifier, before it gets coupled on to the line through $Z_{TX}$. $V_{TX}$ is the voltage signal after the transmit line impedance stage and $V_{RX}$ is the voltage signal at the receive input. In a low noise environment, if $V_{RX}$ is higher than the receive sensitivity of the modem that can be varied from 150 uVrms to 5Vrms, then the signal is picked up by the modem receiver leading to successful communication. In noisier environments, the SNR of the signal at the receiver input needs to be considered. Earlier in the document, Figure 5 shows how the packet error rate increases with decreasing SNR for the same reason. Now $V_{RX}$ can be obtained from $V_{TX}$ by applying the voltage divider theorem with all the impedances. However, as discussed earlier, the line impedance of a powerline is negligible for not very long distances, for example, distances less than 100 meters. We will consider the case for longer distances (more than 100 meters) later in the document. So neglecting all line impedances, we get the following from Figure 14.

$$V_{RX} \cong V_{TX} \qquad \text{Equation 1}$$

Figure 14. Powerline Impedance Model (after neglecting all line impedances)




The effective load impedance of the line from Figure 14 is

$$Z_{EFF} = Z_{LOAD}1 \,||\, Z_{LOAD}2 \,||\, Z_{RX} \qquad \text{Equation 2}$$

Because $V_{OUT}$ is the actual transmit output signal level off the power amplification stage, there is a relation between $V_{OUT}$ and $V_{TX}$ (which is also $V_{RX}$).

$$\frac{V_{TX}}{V_{OUT}} = \frac{Z_{EFF}}{(Z_{EFF} + Z_{TX})} \qquad \text{Equation 3}$$

Consider the case where $Z_{LOAD}$ is much greater than $Z_{RX}$; the effective load impedance is then $Z_{RX}$. So Equation 3 becomes:

$$\frac{V_{TX}}{V_{OUT}} = \frac{Z_{RX}}{(Z_{RX} + Z_{TX})} \qquad \text{Equation 4}$$

From Equation 4, if $Z_{RX} > Z_{TX}$ (as is the case of all the Cypress boards), $V_{TX}$ is comparable to $V_{OUT}$. Also, because $V_{RX}$ is equal to $V_{TX}$ (from Equation 1), $V_{RX}$ is sufficiently higher than the receiver sensitivity in this case which leads to successful and reliable communication. Therefore, a network where $Z_{LOAD} >> Z_{RX}$ is considered to be a good powerline for communication.

The problem arises when $Z_{LOAD}$ is a smaller value (of the order of a few ohms). Let us consider the case when $Z_{LOAD} << Z_{RX}$. So neglecting $Z_{RX}$ in Equation 2:

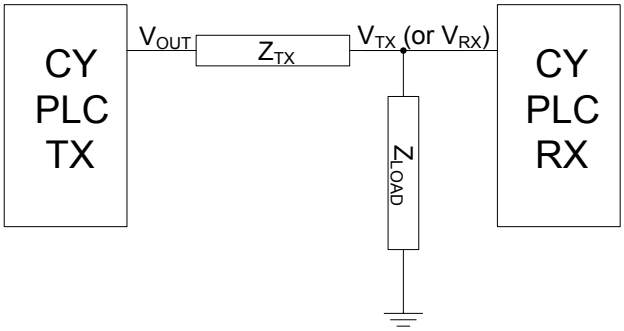
$$Z_{EFF} = Z_{LOAD}1 \,||\, Z_{LOAD}2 = Z_{LOAD} \qquad \text{Equation 5}$$

$Z_{LOAD}1 \,||\, Z_{LOAD}2$ is denoted as $Z_{LOAD}$ for this example. This makes Equation 3:

$$\frac{V_{TX}}{V_{OUT}} = \frac{Z_{LOAD}}{(Z_{LOAD} + Z_{TX})} \qquad \text{Equation 6}$$

Figure 15 shows the simplified diagram for calculating $V_{TX}$ and $V_{RX}$ from $V_{OUT}$ using Equation 6.

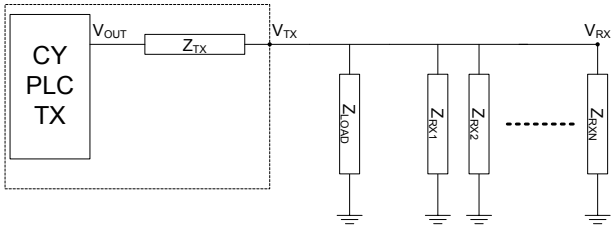
Figure 15. Relation between VOUT and VTX (or VRX)




As shown, the value of $V_{TX}$ is largely dependent on the $Z_{TX}$ and $Z_{LOAD}$ values. Because we do not have any control over $Z_{LOAD}$, it is recommended that $Z_{TX}$ should be as low as possible to make it lower than the time-variant $Z_{LOAD}$ value. On the other hand, if $Z_{LOAD}$ is much lower than $Z_{TX}$, then there is a big potential drop across $Z_{TX}$, leading to signal attenuation and hence unreliable communication.

Now consider a case when there are multiple PLC nodes on the network. Figure 16 shows such a case with multiple receivers on the line adding to the load impedance of the line.

Figure 16. Multiple PLC Receivers on the Line




In such a case, the effective load impedance from Equation 2 becomes:

$Zeff = Z_{LOAD} \,||\, Z_{RX1} \,||\, Z_{RX2} \,||\, \ldots. \,||\, Z_{RXN}$

Therefore,

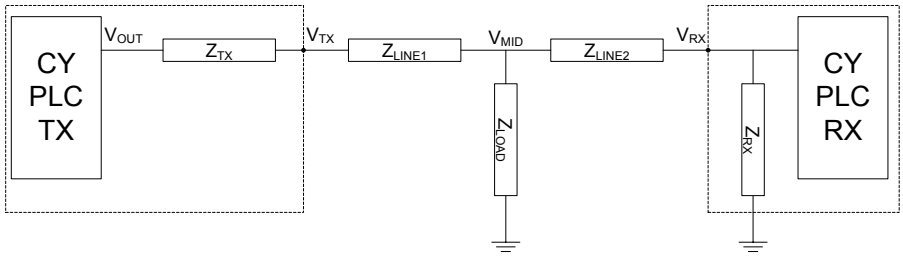
$$Zeff = Z_{LOAD} \,||\, (Z_{RX} / N) \qquad \text{Equation 7}$$

This equation assumes that the impedances of the boards are approximately equal ($Z_{RX1}$ = $Z_{RX2}$ = $Z_{RXN}$). As N becomes large, $Z_{RX}/N$ dominates $Z_{LOAD}$ and becomes the limiting factor. This gives a clear idea on the maximum number of PLC nodes that can be present on the line without lowering the effective load impedance to a level where the SNR is lower than the minimum sensitivity of the receiver.

As an example, assume that the load on the network is 10 ohms and the average PLC board impedance is 1000 ohms. If there are only two boards on the network, the effective impedance is Zeff = 10 || (1000 / 2) = ~10 ohms. The board impedance has almost no effect. However, if there are 1000 boards on the network, the effective impedance is Zeff = 10 || (1000 / 1000) = ~1 ohms. In this case, the board impedances have a large effect. If the transmit impedance $Z_{TX}$ is 3 ohms, the signal is 25% of the original voltage. (Zeff / (Zeff + $Z_{TX}$) = 1 / (1 + 3)).

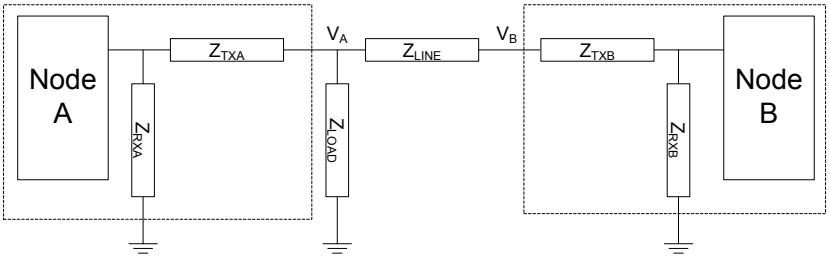
Now, consider a case of the longer cable (distances more than 100 meters) where the $Z_{LINE}$ comes into play. Figure 17 shows a generic distribution on the line impedance with the load impedance placed around the centre of the two communicating nodes.

Figure 17. Line Impedance with Load at Centre




In such a case, $V_{TX}$ drops to a voltage $V_{MID}$ due to the combined effect of $Z_{LINE1}$ and $Z_{LOAD}$. This voltage drops further due to $Z_{LINE2}$ by the time the signal reaches the receiver. However, the situation becomes a little tricky when the $Z_{LOAD}$ is closer to one of the two communicating nodes. Let us consider two PLC nodes as shows in Figure 18 with the load being closer to Node A.

Figure 18. Load Impedance Closer to one Node




In such a case, when Node A is transmitting, the voltage divider does not attenuate the signal as much as when Node B is transmitting. This is because the signal at $V_A$ sees a lower total transmit series impedance ($Z_{TXA}$) when Node A is transmitting as compared to when Node B is transmitting as the $Z_{LINE}$ gets added to $Z_{TXB}$ in the later case, making the total transmit series impedance as $Z_{LINE}$ + $Z_{TXB}$. Let us consider some impedance values to understand this better. Assume that both $Z_{TXA}$ and $Z_{TXB}$ are very small (~3 ohms) and both $Z_{RXA}$ and $Z_{RXB}$ are large (~1000 ohms). Also, assume $Z_{LOAD}$ is 10 ohms and $Z_{LINE}$ is approximately 50 ohms for longer distances (more than 100 meters). Now when Node A transmits, the voltage at $V_A$ is ~75% [$Z_{LOAD}$ / ($Z_{LOAD}$ + $Z_{TXA}$) = 10/(10+3)] of the original transmit voltage and the voltage at $V_B$ is ~95% [$Z_{RX}$ / ($Z_{RX}$ + $Z_{LINE}$) = 1000 / (1000 + 50)] of $V_A$. On the other hand, when Node B transmits, the voltage at $V_A$ is ~15% [$Z_{LOAD}$ / ($Z_{LOAD}$ + $Z_{TXB}$ + $Z_{LINE}$) = 10/(10+3+50)) of the original transmit voltage. This implies that the voltages at both $V_A$ and $V_B$ change depending on which node is transmitting. They are higher when the node closer to the load impedance is transmitting. Also, this is in agreement with Equation 6 which says the higher the value of total $Z_{TX}$, the higher the signal attenuation for the same value of $Z_{LOAD}$. This means that it is better to have loads near the transmitter than the receiver. Also, this can sometimes lead to a situation where communication fails in the direction which has higher attenuation but it still works in the other direction which has considerably lesser attenuation. In such a case, bidirectional communication will fail and so the network should be set up for unidirectional communication, if possible.

### *How to Detect Impedance*

The first indication is if the success rate is around 0 to 10%. It is most likely due to distance/impedance issues unless the impedance is varying on the line.

The next step is to consider if there is a distance (line impedance) or load impedance problem. To do this, measure the signal levels at the transmit and receive ends: $V_{TX}$ and $V_{RX}$. If there is a significant difference between the $V_{TX}$ and $V_{RX}$ signal levels, the communication failure is because the distance between the two nodes is more than the maximum communication distance. The difference between the $V_{TX}$ and $V_{RX}$ level is due to the voltage drop across the series line impedance, which has a significant value for longer distances.

If the voltage signal levels at $V_{TX}$ and $V_{RX}$ are approximately the same and both values are considerably low, then it is due to the load impedance of the line. As seen previously, when it is a problem with load impedance (low $Z_{LOAD}$ value), the voltage level at the transmitter ($V_{TX}$) drops down. This is because of the considerable voltage drop between $V_{OUT}$ and $V_{TX}$.

In both distance and load impedance issues, compare the $V_{RX}$ value with the sensitivity and SNR performance of the receiver and accordingly adjust its value for successful communication. If the receive signal level ($V_{RX}$) is lower than the minimum receive sensitivity of the modem, then communication is not possible.

Table 1 summarizes the discussion in three cases.

Table 1. PLC Distance and Impedance

| Case | $V_{TX}$ | $V_{RX}$ | Result |
|---|---|---|---|
| #1 | High | High | Successful communication |
| #2 | High | Low | Unsuccessful communication due to long distance |
| #3 | Low | Low | Unsuccessful communication due to low load impedance. |

### *Solution*

In this situation, it is always recommended to increase the transmit gain to have maximum signal output ($V_{OUT}$). Also, the circuit design should ensure a minimum possible transmit impedance ($Z_{TX}$) for maximum output voltage transfer. If CENELEC compliance is not needed, then the circuit can be modified to further lower the output impedance of the circuit. If there are capacitive loads which are pulling down the impedance of the powerline (including potentially the on-board power supply), an inductor can be used in series to increase the impedance of the loads. Ensure that the receiver's load impedance ($Z_{RX}$) is high by making sure that the transmit amplifier section is disabled or disconnected when not transmitting. Also, the inductor at the power supply input stage as shown in Figure 10 might impose a low impedance onto the powerline in the communication frequency range. Hence, the value of this inductor should be chosen so that there is no impedance reduction on the line.

# Appendix

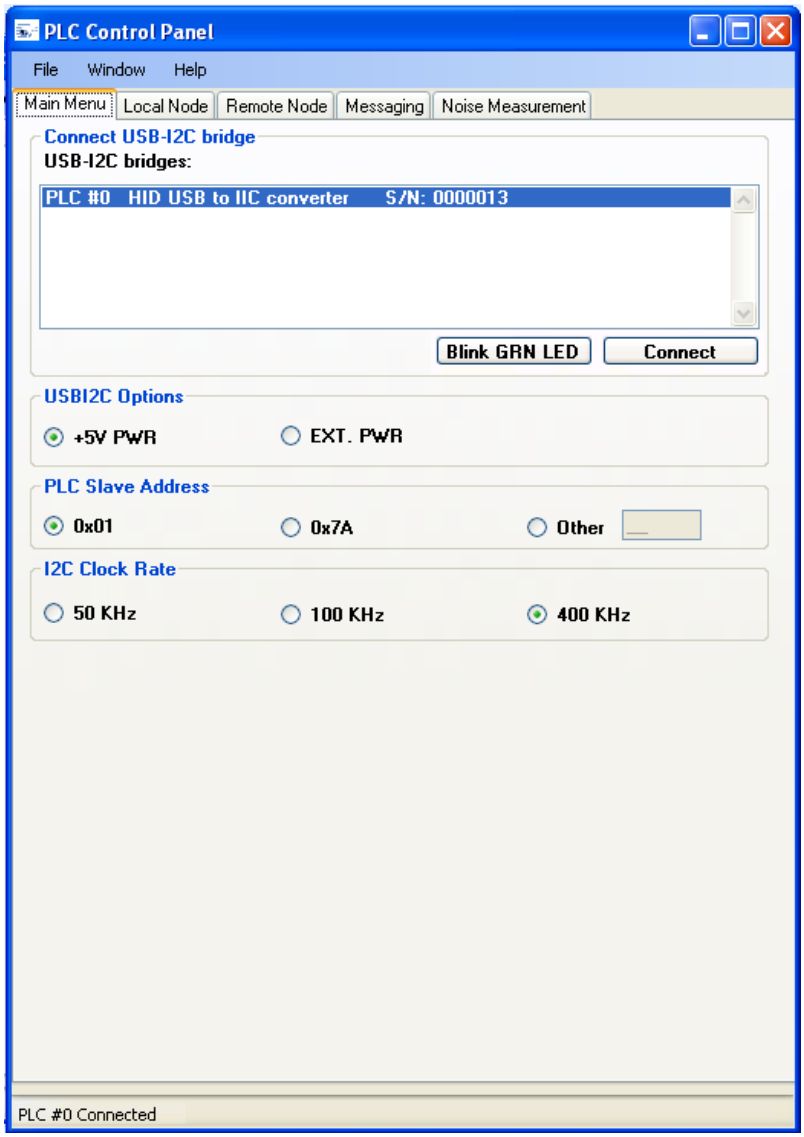
This section provides instructions on using the Cypress Noise Measurement tab of the PLC Control Panel GUI for real time noise measurement on the powerline.

This GUI can be used with any of the Cypress PLC kits (CY3272/3/4/5/6/7). The GUI also needs the CY3240 USB-I2C Bridge, which connects the I2C port of the PLC board to the USB port of the PC where the GUI is running. Refer to the Control Panel GUI User's Guide for installation and setup instructions.

## Main Menu

When the CY3240 USB-I2C Bridge device is connected to the PC, it appears in the list. You can connect to any of the listed devices.

Figure 19. Main Menu Tab



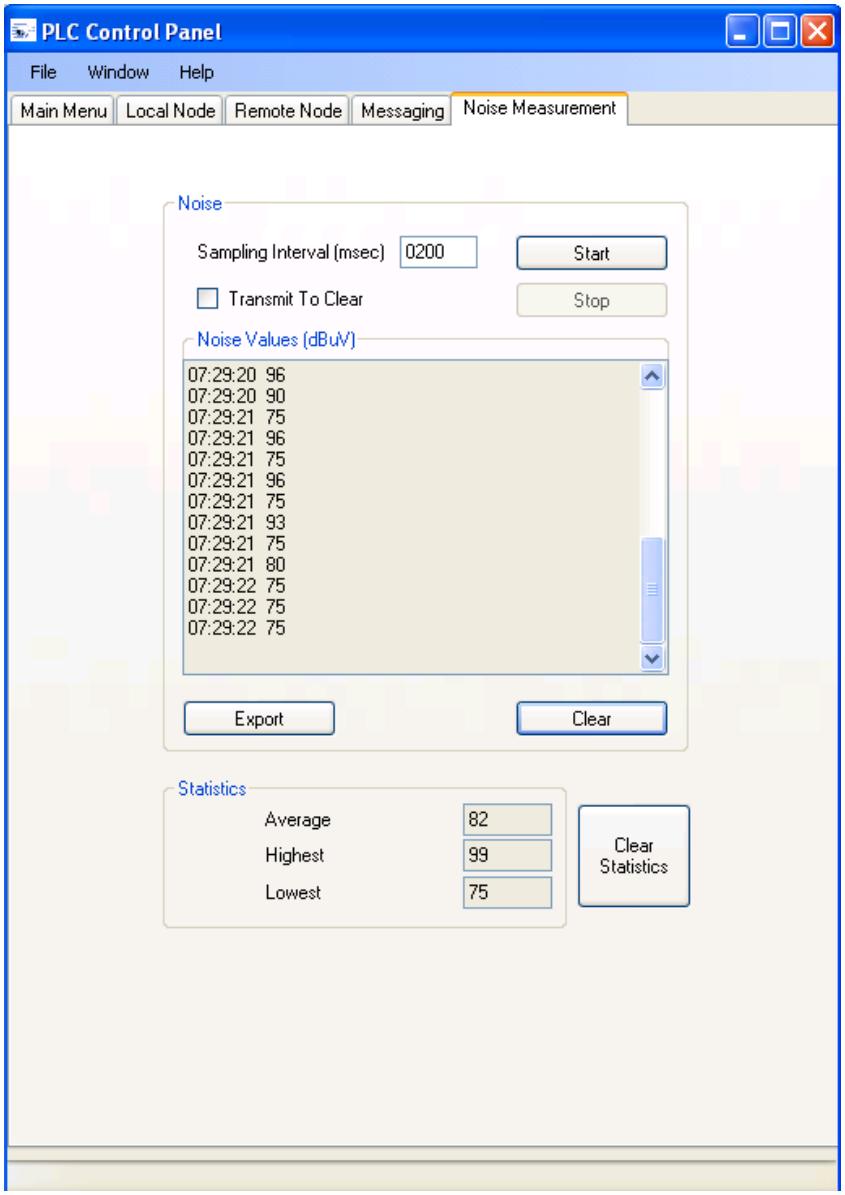

**Blink GRN LED:** This button blinks the green LED on the bridge to help identify which bridge is currently selected.

**Connect:** Click this button to connect the PLC device to the computer. If you try to connect to a bridge that is not connected to a PLC device, you see an error message. The power mode, slave address, and clock rate are set according to the selections made in the radio buttons.

**Note** If the USB-I2C bridge is powered by external power (that is, a jumper is connected across the 'PWR' pin on the PLC board), do not select +5V power as the power mode.

## Noise Measurement

Figure 20. Noise Level Tab




Noise

**Start:** When this button is pressed, the PLC node starts scanning the powerline.

**Stop:** When this button is pressed, the PLC node stops scanning the powerline.

- **Sampling Interval (msec):** This field specifies the duration between two consecutive samples. The minimum value required is 200 msec and maximum is 2000 msec.
- **Transmit To Clear:** When this option is checked, the PLC device transmits a packet in unacknowledgement mode so that the other nodes do not transmit any packet for at least the minimum BIU interval. For correct operation, the minimum BIU Time Interval should be at least 50 msec.
- **Noise Values (dBuV):** This window displays the noise values sampled.
- **Export:** When this button is pressed, the noise values are exported to an MS Excel Spreadsheet.
- **Clear:** This button clears the noise values window.

Statistics

**Average:** This field shows the average of the noise values.

**Highest:** This field shows the highest noise value sampled.

**Lowest:** This field shows the lowest noise value sampled.

**Clear Statistics:** When this button is pressed, the statistics are reset.

# Document History

**Document Title**: Cypress Powerline Communication Debugging Tools

Document Number: 001-58825

| Revision | ECN | Orig. of Change | Submission Date | Description of Change |
|---|---|---|---|---|
| ** | 2901617 | GHH | 03/30/10 | New application note |
| *A | 3974061 | ADIY | 4/19/2013 | Updated Template |

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