

DESIGN OF BROADBAND COUPLING CIRCUITS FOR POWER-LINE COMMUNICATION

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Abstract

One of the most critical components of any Power Line Communication (PLC) system is its interface circuit (or coupling circuit) with the power distribution network. This is by no means a simple unit considering the challenging characteristics of the PLC channel. Due to high voltages, varying impedances, high amplitudes and time dependent disturbances, coupling circuits need to be carefully designed to provide both the specific signal transmission with the appropriate bandwidth, and the safety level required by the applicable domestic or international standard. This paper presents various aspects on practical coupling circuit design. We investigate inductive coupling, capacitive coupling and some hybrid designs. We present measurements of the coupling circuits in terms of transfer function and PLC channel measurements under practical power line noise and impedance loading. We demonstrate the influence of coupling circuit in measurements and show how to compensate its effects in order to measure the actual scattering parameters of the power lines. We compare and comment the various coupling circuit designs in order to define their applicability in practical power line communication systems.

1. Introduction

The superimposing of a PLC signal on a power waveform implies that the coupler circuitry and power circuitry would have to be carefully designed and interfaced for optimal compatibility between the two systems. Power system and the communication system operate at the two extremes – power system at very low frequency and very high power, current and voltages levels and communication systems at much higher frequencies and very low power, current and voltage levels. To be able to design PLC systems as well as to supply a proper interface between power and communication

system the coupling circuitry must be clearly understood. Coupling of the communication signal on the PLC channel can be achieved using several closed current paths [1]:

- Differential mode coupling: In this case the ‘line’ wire is used as one terminal and the ‘neutral’ wire is used as the second terminal.
- Common mode coupling: In this case the ‘line’ and ‘neutral’ wires are used together, forming one terminal, and the ‘ground’ wire serves as the second terminal. This coupling mode is known to yield up to 30 dB better coupling than the differential coupling. In some countries, common mode coupling is not allowed on the low voltage networks, due to potential danger for the customers.

Coupling circuit has to provide the necessary galvanic isolation of the PLC system from the power line, which can be achieved through inductive or capacitive coupling. Inductive coupling is known to be rather lossy up to several decibels. However, it avoids physical connection to the network, which makes it safer and often easier to install than the capacitive coupling. Capacitive coupling, on the other hand, realizes the required high-pass filtering with a straight-forward electronics that is easy and compact to design. Practical coupling circuits often apply a combination of both techniques.

2. Coupling Circuit Components

To be able to design an optimum coupling circuit, appropriate components must be chosen and their operation must be understood:

- Coupling capacitors: These are extensively used in power line communications, most

commonly to couple the PLC signal to the power line [6], but also as a part of more sophisticated, higher-order filters [5]. The requirements and essential characteristics of coupling capacitors have been standardized in ANSI C93.1-1972, [7]. Coupling capacitors carry the communication current and thus have to be high-frequency capacitors (self-resonant frequency has to be higher than the modulation frequency [4]). Conversely, they have to filter the power voltage (dropped across the component), as well as voltage surges and therefore need to be high-voltage capacitors. The filtering characteristics of the coupling capacitors are quite dependent on the load onto which the waveform terminates [3].

- Coupling transformers: The main function of the coupling transformers is to provide galvanic isolation and impedance adaptation, but the coupling transformer has also to pass the high-frequency communication signal and it has to be designed as such. The power waveform has a much lower frequency and much higher voltage level, and the power waveform has a saturating influence in the order of at least 10^5 compared to the communication waveform [4]. Therefore, the power waveform is typically first lowpass filtered before entering the coupling transformer.
- Blocking inductors: These have to be designed for the power frequency (to prevent saturation) and for the power current (to prevent voltage-drops). Blocking inductors need to block the modulation frequency, and therefore the self-resonant point needs to be above that frequency [4]. Air-core inductors are well suited to this application.
- Resistors: For power-line coupler circuits, in general, one strives to avoid using resistors, as a resistor, in essence, implies a loss of power, either of the communication signal or the power waveform.

3. Coupling Circuit Example

A typical coupling circuit employs generally both coupling capacitors and a coupling transformer. Fig. 1 shows a circuit diagram of a broadband coupling circuit designed for our

PLC channel measurements. The circuit employs high voltage capacitors to filter out the 50/60 Hz high voltage waveform, a broadband transformer, and a combination of diodes for over voltage protection.

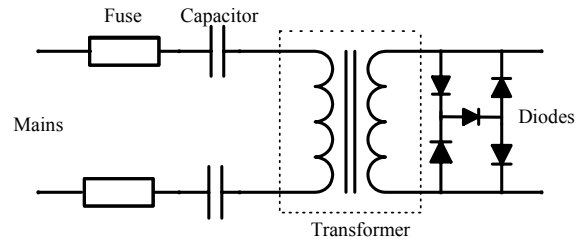


Figure-1. A broadband coupling circuit.

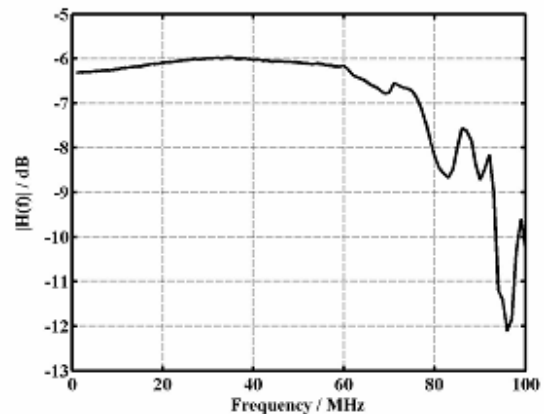


Figure-2. Transfer function of the coupling circuit of Fig. 1.

Fig.2 presents the transfer function of this coupling circuit. The coupling circuit should not influence the actual scattering parameters of the PLC channel during measurements. The effect of coupling circuit needs to be compensated in the measured data. This can be done by post processing of the measurement data, once the transfer function of the coupling circuit is known. Another way is by calibrating the measuring equipment (in our case Network Analyser S200) in such a way that the effect of coupling circuit is compensated. Fig. 3 and 4 present a sample of PLC-channel measurements obtained by using this coupling circuit. Fig. 3 presents the measured frequency response of a power cable with a length of approximately 20 m and Fig. 4 shows the frequency response of the PLC channel under practical power line noise and impedance loading.

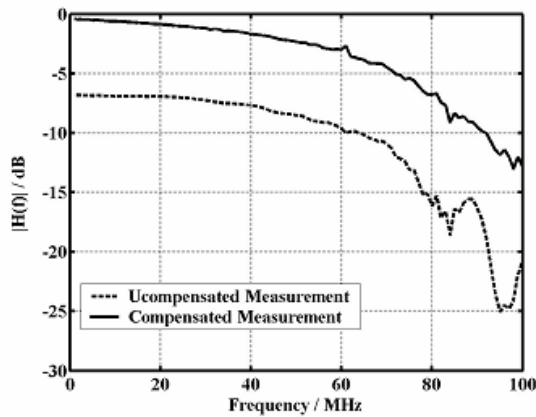


Figure-3. Attenuation in the 20 m power cable.

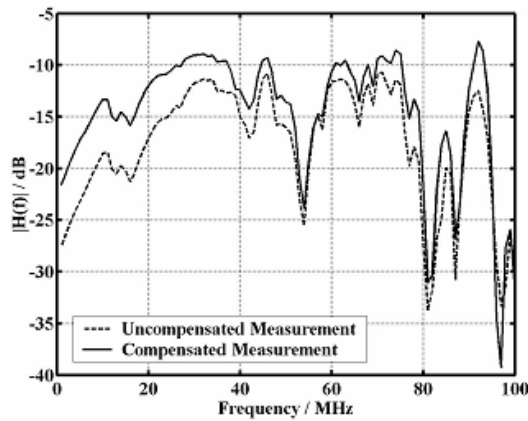


Figure-4. Frequency response of PLC channel.

4. Inductive Coupling

In the inductive coupling, PLC signal current is injected into the power distribution lines. This is achieved through an inductive transformer coupler using appropriate high-frequency ferrites. The inductive injection method is most effective when the mains impedance is low at the signal injection point. This is typically the case when injecting the signal into a bus network where several power cables are connected together. Connecting several power cables to a single point or bus effectively results in a parallel connection of the individual cable impedances. This results in low input impedance.

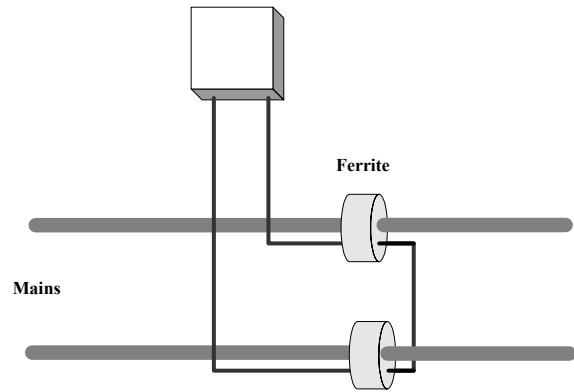


Figure-5. Inductive coupling using ferrites.

The inductive coupling is often the preferred method for coupling due to its better performance in low impedance situations, lower radiation from power mains and its simplicity to use [2]. Inductive coupling employs ferrite rings (acting as transformers) to inject the communication signal into the mains. In this case, there is no galvanic connection between the power grid and the PLC equipment, which is handy, and also safe from the practical point of view. Selection of the ferrite depends on:

- The cut-off frequencies of the ferrite. (Fig. 6 shows the frequency response of the applied ferrite.)
- The current rating of the ferrite ring. (The current in the conductor, which passes through the ferrite, should not exceed this current rating.)
- Choose the ferrite with a smaller diameter that can alleviate installation work.

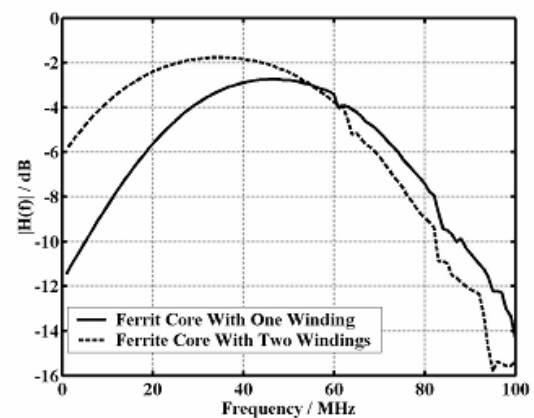


Figure-6. Frequency response of the ferrite.

The coupling capacitors are used to lower the impedance at the coupling point, resulting in

increased coupling efficiency, and also to limit signal propagation in an unwanted direction. The coupling capacitors act as a signal shortcut for the injected communication signal. Therefore, the signal current flows mainly through the coupling capacitors. Two schemes can be used to inject the PLC signal on the power distribution lines as shown in Fig.7. The first scheme uses one ferrite and the second scheme uses two ferrites. The second method enhances coupling efficiency. Fig. 8 presents a measurement of a 20 m power cable with the 50 ohm termination at both ends, employing inductive coupling with ferrites. The second scheme, employing two ferrites (Fig. 7b), yields an improved coupling of up to 8 dB (Fig. 8).

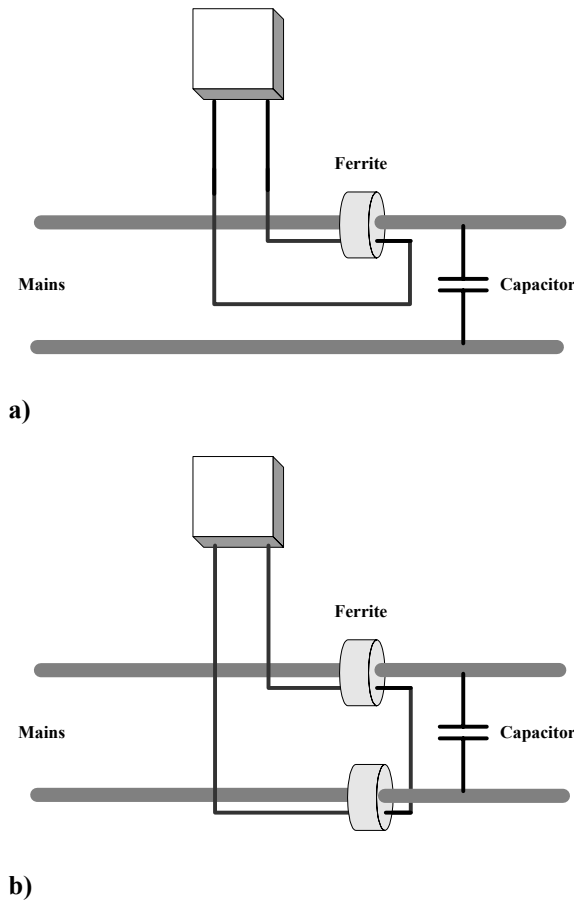


Figure-7. Inductive coupling schemes.

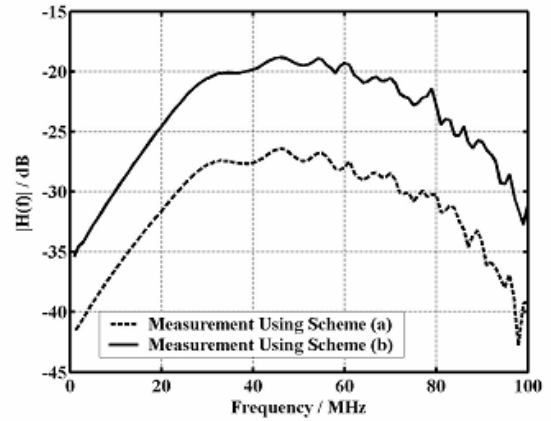


Figure-8. Cable measurements using ferrites.

5. Conclusion

Coupling circuit is an important component in power line communication systems. To be able to design an optimised interface between the power and PLC system, the components of the circuitry must be carefully chosen.

In this paper, we have presented a generic design for a broadband coupling circuit suitable for PLC channel measurements, and included a set of measurements of PLC channel under practical power line noise and impedance loading. We have also investigated inductive coupling using ferrites, and pointed some practical guidelines for their design practises.

Acknowledgement

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