Power Line Communication and dirty electricity turn electrical wires into radiating antennas

Power line communication uses existing power lines and household wiring for communication. Dirty electricity is high-frequency waves added to electrical wires. An unintended consequence of these systems is that they turn the power lines into antennas that radiate into homes from the outside, and also from the wires within a home.

Keywords: power line communication, power line carrier, power line telecom, broadband over power lines, power line network, BPL, PLT, HomePlug, ripple control, EMC, EMI, PLC, dirty electricity, interference, radiation, FCC, regulation

What is power line communication?

Power line communication (PLC) uses existing power lines and household wiring for communication. It is used for a variety of functions, such as computer networking, utility control systems and smart grid.

The frequencies added to the wires is also referred to as dirty electricity.

In some areas, PLC is used to provide internet services to households and small businesses. This is often referred to as Broadband over Powerlines, BPL or BB-PLC. One home-use product is called HomePlug.

Some utilities use PLC to remotely read their electrical meters and are experimenting with various smart grid functions to control appliances in the household, sometimes also using PLC.

Power companies have used PLC for decades to control remote switching stations and other equipment, by sending PLC signals over long distances on their high-voltage transmission lines. The utilities refer to their use of PLC as Power Line Carrier (also PLC).

PLC is called PLT (Power Line Telecommunication) in some countries.

What is dirty electricity

Dirty electricity is any frequency added to electrical systems, other than the power frequency. In North America the power frequency is 60 hertz, in most of the world it is 50 hertz.

Dirty electricity is produced by many types of electrical equipment, such as energy efficient light bulbs, light dimmers, home electronics, computers, solar inverters, battery chargers and variable-speed motors. PLC is a particularly potent source of dirty electricity.

Unintentional antennas

All types of PLC systems turn the electrical wires into unintentional antennas. Since the PLC users continue to maintain that it is not true, this document goes to great lengths to refute them.

When electrical signals travel along a wire, that wire will radiate the signals into the air. This can sometimes make electronic equipment malfunction, which is referred to as Electromagnetic Interference (EMI). The engineering specialty that deals with these kinds of problems is called EMC (Electromagnetic Compatibility).[1, 2,3]

Cables intended for data communication such as coax, telephone wires and twisted-pair are all designed to limit the antenna effect.

The electrical wires inside a house and along the street were not designed this way, as they were never intended to carry communication signals. It is even common for wires on poles to be separated from each other, which enhances the antenna effect. The miles of electrical wires in a neighborhood can act as a very large antenna.

We refer engineers and other technical people to the appendix for more details.

Using household wires as antennas

In a few cases, the wires in a home are used as intentional antennas. The most common use is by electricians who need to locate hidden wires. They plug a small device into an outlet, which sends signals out onto the household wires (usually in the lower kilohertz range). The electrician then uses a small handheld wireless receiver to locate the wires.

Another use is PowerLine Positioning (PLP).4 This can be used to locate people in a building, if they wear special tags which receive the signals from the wiring in the walls.

Household wires have been used to transmit the wireless signals of an AM radio station serving a small area, such as student housing on a college campus. These are called carrier current stations.[5]

PLC systems as transmitters

The early PLC systems used low frequencies, which were not a problem for telecommunication. As faster PLC systems were introduced, they started using higher frequencies that were getting close to those used for telecommunication.

Users of short wave radio (HAM radio), emergency services and radio astronomy became concerned that the PLC signals would spill up into the bands they were using, causing interference.

Radio amateurs started complaining about interferences with their radios. The PLC industry responded by denying there were any problems at all.[6]

A spokesperson for a PLC vendor with operations in Ohio and Maryland stated that:

> [Interference] just doesn't exist.[7]

However, an IEEE engineering paper on the subject states:

> Power cables can be considered linear antennas . . . Whenever PLC signals overlay frequency ranges of wireless services, interference may occur.[8]

Another research paper, published by the British Broadcasting Corporation, states:

> there is the difficulty for radio-system users that the signals [PLC] injects do not simply travel from point to point along the wiring, they also escape as radiated emissions [emphasis in original][6]

The trade magazine Compliance Engineering published an article about PLC systems interfering with various wireless technologies, such as anti-shoplifting devices.[29]

The authorities get involved

The British Broadcasting Corporation (BBC) got concerned and started looking into the issue. The BBC World Service broadcasts shortwave radio world wide in many languages, especially to countries which do not have a free press. PLC could hamper the reception of these broadcasts.

Since the PLC industry continued to claim that there was no antenna effect, a BBC engineer produced a very elegant demonstration that a widely available PLC system (HomePlug) could be used as a wireless network.[6, 9]

The Federal Communications Commission (FCC) in the United States looked into PLC after receiving complaints from radio amateurs. The FCC Laboratory measured the radiation from seven PLC/BPL systems. All seven systems radiated unintended wireless signals. One system exceeded the FCC radiation limit, while two others reached the limit..[10, 11.]

The FCC Laboratory engineers also produced a video.[12] It demonstrates how the radiation from the power lines interferes with a shortwave radio, as they drive in and out of an area with a PLC/BPL system.

The NATO military alliance became concerned that PLC may interfere with military communication and intelligence gathering. A research task group was assigned to study the issue. The group found that the radiation from both the power lines, as well as in-home wiring could become a problem:

> These increased [RF] levels would have an adverse effect on military communications and COMINT [intelligence] systems . . .[13]

The Japanese government funded a study to determine if PLC systems would interfere with civilian and military communications, as well as with radio astronomy. An elaborate test was created, with a power line dedicated to the experiment. Wireless receivers were then used to detect the signals at various distances from the power line.[14] The Japanese scientists found significant radio interference from the test site and recommended that the government disallow PLC systems to operate at higher frequencies. The government agency concurred, and PLC was prohibited in Japan for frequencies above 450 kHz.[8, 15]

The Swiss Federal Office of Communication investigated the radiation from a commercial PLC system that brought internet service to the city of Fribourg.[16, 17] They found that the radiation levels were above the German NB30 limit.

The telecommunication authority of Austria investigated complaints from emergency services and radio amateurs in the city of Linz. They found that the PLC system providing internet service there exceeded the radiation guidelines and that even the street lights acted as antennas.[18, 19]

These examples of controlled studies in laboratories and measurements on installed PLC systems clearly demonstrate the PLC antenna effect.

The British Electromagnetic Compatibility Industry Association (EMCIA) asked the British authorities to disallow broadband PLC in Great Britain, citing wireless interference.[20] Other parties also weighed in.[13, 21] PLC was allowed in Great Britain, but with significant restrictions. The situation is similar in several other countries in Europe.

Low frequency PLC

Low frequency PLC systems are mostly used to communicate with remotely read electrical meters (i.e. AMR and smart meters). Some of these systems use frequencies around or below 1 kHz (such as TWACS and TS1/TS2), while newer metering systems tend to use the CENELECT bands (3-95 kHz and 125-140 kHz).[28]

Some of the older PLC systems for controlling street lighting, and remotely turn off large irrigation pumps, use a system called "ripple control," which also uses frequencies around 1 kHz.

Some utilities do not appear to understand their own technologies, as the following statement illustrates. It is from a 2011 response from Idaho Power to a complaint about their TWACS PLC system:

> *Our AMI system does not generate any frequency, we simply modulate the electrical 60Hz voltage and current wave form to communicate. Since there is no frequency produced by the communication there is no frequency to filter or cause a potential health issue.*

The antenna effect is there regardless of the frequency. It is not only in the higher radio frequency bands that power lines act as unintentional antennas. But, it is only at the higher frequencies that there is a problem for commercial and military communications, as well as for radio astronomy, so that is the area that is studied and regulated.

The lower frequencies are not used much for telecommunication any more. One of the earliest experiments with radio broadcasting (by Riginald Fessenden in 1906) used a 50 kHz transmitter, which was also the frequency the U.S. Navy used at the time.[27] Because of the poor sound quality at these low frequencies, the experimenters quickly moved to higher frequencies for their broadcasts.

Today, the lowest frequencies used for broadcasting is the long wave band (153-279 kHz), which is used by some AM stations in Europe, Africa and Asia.[27]

The low frequencies are used to transmit over great distances, as they can reach further. This makes them useful for communication with ships and submarines. The civilian marine radio and navigation go as low as 9 and 10 kHz.[22] The U.S. Navy communicates with its submerged submarines at frequencies around 20 kHz and even as low as 76 hertz.[22]

These marine users do not appear to be concerned about PLC systems, perhaps because of the distances to ships at sea.

There are various examples where electrical wires carrying extremely low frequencies can be picked up wirelessly:

During World War II, scientists considered using the emissions from the 50 Hertz power lines in Nazi Germany as navigational beacons for Allied bombers, but better systems were developed.[23]

A military listening station found that they could pick up ultra low frequency emissions (about 17 hertz) from electric trains several miles away.[24]

Electric fences to enclose horses and livestock send out pulses at an extremely low frequency, but it can still be picked up as clicks by an AM radio receiver.

A research institute under the Italian Ministry of Health did look at some of the early PLC systems.[25] They found that the systems operated in the frequency bands from 112 kHz to 370 kHz and could be clearly detected 100 meters (300 ft) from power lines. The authors wondered if the presence of a PLC system or not could explain why some studies showed health effects from living near a power line, while others showed no effect.

Other PLC antennas

Investigators in Austria found that street lights were better antennas for PLC radiation than the electrical lines themselves.[18, 19]

It may be that various electrical equipment in a house can work as antennas as well. This has not been studied, but likely candidates are electric stoves, electric space heaters, electric water heaters, light bulbs and track lighting.

Espionage using the antenna effect

The United States and the Soviet Union both started on preventing snooping by wireless means on their teleprinters, cryptosystems and computers in the 1950s. Even though these machines are not considered wireless transmitters, they have unintended wireless emissions and create dirty electricity, which can be used to decipher the secret messages.

The United States created the TEMPEST program to prevent such spying. Their methods include line filters and shielding conduits to prevent the antenna effect on the power cables.[26]

Regulation of PLC radiation

Following various investigations and recommendations by scientists, government agencies, the military and other interests, the governments in Europe and Japan have put restrictions on the amount of radiation that is acceptable from PLC systems.[8, 13, 15] These restrictions are only for the frequencies that are also used for wireless communication.

In the United States, there are presently few restrictions for PLC systems. The situation in the U.S. is characterized in one industry paper as:

> FCC . . . can be regarded as highly generous for high speed PLC and in no way obstructing the spreading of PLC technology.[8]

The FCC is the Federal Communications Commission, which has the legal authority to regulate wireless transmissions in the United States. That the FCC is much more lenient towards PLC radiation than other entities is demonstrated by various graphical comparisons.[8, 13]

Following complaints from the American radio amateurs, the FCC required operators of BPL/PLC systems to lower their emissions by 10 to 20 dB below the general limit.[30] The FCC also granted BPL exclusion zones around some radio astronomy laboratories.[30]

As there have been almost no studies of the biological effects of PLC and dirty electricity, there are not really any standards addressing the potential health effects.

Public listing of PLC systems

One of the few concessions the U.S. FCC made was to require the industry to maintain a public database of all proposed and operational BPL systems. The database is available at www.bpldatabase.org.

It lists only BPL type PLC systems in the USA, and only by ZIP code. Complaints have been logged with the FCC that the database is not maintained.

How far does the PLC radiation reach?

The radiation level drops with the distance to the antenna. Since virtually every wire in a house and near a house can become a PLC antenna, it can be difficult to get some distance from all sources.

It is possible to measure the PLC radiation quite some distance from the wires. The Italian study25 lists measurements up to 100 meters (310 ft) from the power line, while the Japanese study14 measured up to 180 meters (550 ft) away.

The NATO study used a model that went beyond 200 meters (600 ft).[13]

The Swiss study[17] was not able to detect any PLC signals from a city, when 500 meters (1500 ft) outside the city. However, the Swiss power lines were possibly buried, which would reduce the reach of the signals.[13]

The carrier current systems serving college campuses are said to have an effective reach of about 60 meters (200 ft) from the wiring.[5]

The American radio amateurs who complained about interference were up to 1100 meters (0.7 miles) from the power lines carrying the PLC signals.[11] Radio observatories, however, would need to be miles away.[14]

Different brands of PLC systems will radiate differently, and the radiation will also greatly depend on the specific place. Some of these factors are discussed next.

The antenna effect depends on the situation

Antenna systems are complicated; the radiated effect depends on the frequencies, the current and the exact dimensions of the antenna. The electrical system of just a single home is complex. There are several branches of wires, which vary in length, change direction and have various equipment attached to them. The radiation can thus be expected to vary with the house, even in the same neighborhood.

The electrical distribution system for an area is also very complex. There are substations, power lines on poles or in the ground, which branch off in various directions. Older systems are also likely to have corroded connectors, which can generate arcing. Stray voltages travelling on steel pipes and through the ground are very common, and further complicate the picture.

Whether the power lines are individual wires on poles, cables on poles or buried cables can also greatly influence the radiation levels.

The general wiring practices are another factor which vary by country. Some parts of continental Europe use three-phase feeds to households, while Great Britain, Japan and the United States use single-phase. In the United States, each transformer typically serves just a few households, while in Europe well over a hundred households are commonly served by one transformer.

An IEEE article points out one country-specific issue:

> In Great Britain [and North America] . . . only one phase and the neutral supply a building. Consequently, PLC signals must be injected between a phase and the neutral supply [of] a building. . . . this is a disadvantageous configuration regarding EMC [i.e. worse antenna effect].[8]

The voltages vary, with higher voltages used on power distribution lines in the United States. Higher voltages may enhance the antenna effect.

There are several kinds of PLC systems available. Some are better suited to a certain wiring practice than others. The different PLC systems also produce different signals, and thus different radiation from the electrical system.

There are additional factors than these mentioned. For further discussion of this topic, see [8, 13].

Reducing PLC radiation

There are technical measures available for reducing the radiation from wiring carrying PLC signals. Examples include filtering[8], buried power lines[13] and other measures that are all costly. However:

> complete avoidance of unwanted radiation is simply infeasible.[8]

Conclusion

There is much theoretical and practical evidence that PLC systems and dirty electricity radiate wirelessly. This effect has been demonstrated both by laboratory studies as well as measurements on city-wide PLC systems. The effect has been demonstrated for many frequency bands and is not limited to particular PLC systems.

That PLC systems turn power lines and household wiring into de facto antennas is well established, though the strength of the emissions will depend on the specific situation.

Further information

There are two excellent and readable books on this general topic, The *AC Power Interference Manual* is written by Marv Loftness, who specialized in mitigating interference from power lines. The *Designer's Guide to Electromagnetic Compatibility* is by Daryl Gerke and William Kimmel who specializes in all sorts of interference problems.

For more information on PLC systems and their public health issues, see www.eiwellspring.org/plc.html and www.eiwellspring.org/smartmeter.html.

For other aspects of dirty electricity, see www.eiwellspring.org/demenu.html

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Appendix: Technical comments

The antenna effect is a basic EMC problem with various versions of a dipole antenna. As an example, let us look at a typical residential power distribution line in America, carrying a single phase:

The neutral and phase wires are separated by an air gap and the neutral wire is grounded at regular intervals, perhaps at every pole. The PLC signal is injected between the phase and neutral. The phase and neutral wires are then each halves of a very long dipole antenna, with one dipole also connected to a ground plane.

This setup is not much different from a broadcast AM radio station, which also uses a ground plane to enhance the transmitted power. If one looked at a photo of a long-wave AM radio station's antenna, the similarity to a power line will be obvious.

The story about the Swedish trains[24] is a similar example, where the aerial line over the tracks is one dipole, while the tracks (and the earth they are grounded to) is the other dipole/groundplane.

The household wiring is another example of a dipole, but with different characteristics. If we consider a typical cable, it will have two conductors (phase and neutral) and a ground wire, all insulated from each other and encapsulated in a plastic sleeve. The neutral wire is connected to the grounding wire as well as the earth plane (via the bonding at the service entrance).

Here we have a very small gap between the two dipoles (wires), which is just the thickness of the insulation. For our purposes, it doesn't matter whether the insulation is plastic or an air gap.

If the gap was zero, there would be no radiated power, but the very small distance greatly reduces the magnetic radiation, compared to the larger gaps on power poles. The magnetic fields could further be reduced by twisting the wires (standard for cable-borne computer networks) or the use of coaxial cables (where one "wire" fully encloses the other).

Household wiring and cords are weak transmitters, but since they are so much closer to humans than power lines typically are, they can still be an important source of exposure.

In places where the two dipoles (wires) are more separated, the magnetic radiation will be higher. Examples are the bus bars in a power panel, wires in a wall box, and especially where there are unbalanced circuits and stray currents due to wiring errors (which are very common).

Then there is the ground plane. Whether it is relevant or not in a perfectly balanced electrical system does not appear to be known, but most houses have stray currents running in the soil (between grounding rods) as an alternate path for the neutral current. This means that for a part of the current (net current) the dipole gap is between the phase wire and the soil, not between the phase and neutral wires in the cable, so even a very small current can create a significant magnetic field.

The EMC engineers Gerke and Kimmel have a rule of thumb that a wire longer than 1/20th wavelength is an efficient antenna.[31] This means for a 100 kHz signal it takes a minimum 150 meter (450 feet) wire, which is everywhere in neighborhoods. For a 1 MHz signal, the efficient minimum length shrinks to 15 meters (45 feet).

Due to the large dimensions and the rather short distances inside a home or office, the electrical wiring and power lines can be considered line sources. This means that the radiation level will diminish less by distance compared to a typical antenna source (point source).

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