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Interference to power-line communications by amateur LF/MF transmitters

by

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Abstract

Measurements of the electric field produced by carrier communication on power-transmission lines are available from a number of investigations of potential interference. These measurements are used to determine the signal introduced into the line by a nearby LF/MF amateur-radio transmitter. First, the line is treated as a transmitting antenna and its gain is determined from the measured field strength, PLC power, and measurement distance. Then the gain and frequency are used to determine the capture area of the line as a receiving antenna. The power received from the amateur station is then computed. The minimum signal-to-interference ratio is 41 dB for an amateur station with 1 W EIRP at a distance of 1 km. Numerous experimental stations have operated in close proximity to power-transmission lines without interference problems. Consequently, no harmful interference to a PLC system is expected for an amateur station with an EIRP of 5 W that is located as close as 300 m to a power-transmission line.

Indexing Terms

Radio, amateur
Communication, power-line-carrier
LF/MF

1. INTRODUCTION

The power industry has for some time used power-line carrier (PLC) communications for protective relaying and other purposes [1]. These systems operate in the range of 10 to 490 kHz with power levels from 1 to 100 W [2]. In accordance with the resolutions of the WRC-12 conference, the FCC has proposed opening the 2200 and 630 meter bands to US amateurs:

- 135.5 - 137.5 kHz with 1 W EIRP, and
- 472 - 479 kHz with 5 W EIRP except 1 W EIRP in parts of Alaska.

A key element in the FCC's concept for allowing both amateurs and power-line communication to co-exist in parts of the LF and MF spectrum is a "restriction/coordination distance" (RCD). Basically

- An amateur who is further than the RCD from a power-transmission line (PTL) can operate with full permitted power without any special concerns.

- An amateur who is within the RCD from a power-transmission line is restricted to a lower power, or must undergo frequency or other coordination.

Establishing a realistic RCD is therefore essential for this strategy. Setting the RCD too large will unnecessarily restrict and encumber amateur use of the proposed bands. Setting the RCD too small invites interference to the power-line carrier systems.

The author has found little useful information that explicitly addresses how much signal power from a nearby radio transmitter is picked-up by a power-transmission line. However, a number of papers and reports are concerned with interference from power-line PLCs to other services such as Loran-C radionavigation, GWEN (Ground-Wave Emergency Network, now decomissioned), and NDBs (non-directional navigation beacons). Consequently, there are a number of measurements of the fields produced by various PLC systems.

This note therefore determines the amount of power picked-up by a PTL by regarding it as a radio antenna:

- The gain of the PTL as a transmitting antenna is determined from the measured field strength, measurement distance, and PLC power.

- The capture area of the PTL as a receiving antenna is determined from the gain and frequency.

- The power picked-up (received) by the PTL is determined from the capture area and power density of the signal from the amateur station.

This methodology is similar to the "coupling-factor" approach and is explained in detail subsequently. A number of measurements are then processed to calculate the amount of power received by the power line from an amateur transmitter with 1 W EIRP at a distance of 1 km. The received power is then compared to the PLC power to determine the signal-to-interference (*S/I*) ratio. Finally, the implications for the restriction/coordination distance are reviewed.

2. SIGNAL PRODUCED BY ISOTROPIC ANTENNA

Effective Isotropic Radiated Power (EIRP) is defined as the signal that would would be produced by an ideal lossless isotropic radiator fed with the specified power.

The "ideal" isotropic radiator transmits power uniformly in all directions. As a result, as a distance *d*, the power is spread uniformly over a spherical surface with area $4\pi d^2$. For a transmit power P_t, the power density at a distance d is therefore

$$W = \frac{P_t}{4\pi d^2} \quad \text{W/m}^2 \quad . \qquad (1)$$

The power density W and the electric field E in V/m are related by

$$W = \frac{E^2}{2\,\eta_0} \quad , \qquad (2)$$

where $\eta_0 \approx 377\ \Omega$ is the impedance of free space. Note that E is a peak value, not rms. Thus for $P_t = 1$ W of transmit power the power density at $d = 1$ km is

$$W = 1 / (4\pi \times 1000^2) = 7.96.10^{-8} \ \text{W/m}^2 \quad , \qquad (3)$$

and the corresponding electric field is

$$E = (2 \times 377 \times 7.96\text{x}10^{-8})^{1/2} = 7.75 \ \text{mV/m} \quad . \qquad (4)$$

3. MEASUREMENT DISTANCE

The electric field produced by the PLC system is measured at some distance from the lines. In order to make accurate predictions, the distance d must satisfy two criteria:

- Distance *d* must be significantly larger than the height and width of the PLT, and
- Distance *d* must be significantly smaller than the distance at which propagation transitions from free-space to ground-wave.

Distance from Power-Transmission Lines

An example geometry of a PLT is shown in Figure 1. The PLC signal may be applied from one or more lines (phases) to ground, or from one line to another. Phase-to-ground PLC has a relatively high loss [1], hence a limited useable distance (< 10 mi).

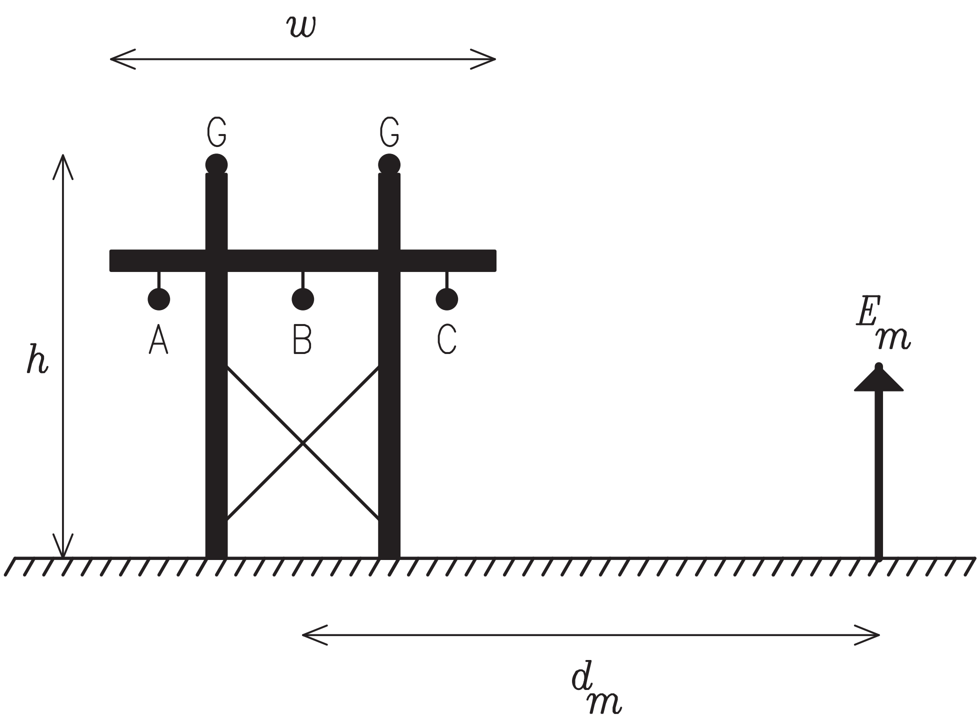

Figure 1. Example geometry of power-transmission line.

If signals are observed close to the line, the fields of individual lines can be dominant. In this "induction-field" region, the amplitude of the electric field decreases as $1/d^2$. At larger "far-field" distances, the fields take on the characteristics of a propagating signal and decrease as $1/d$. The distance of the transition between the induction-field and far-field characteristics depends upon line height and width. Madge [3] gives 150 m as a typical distance (Figure 2).

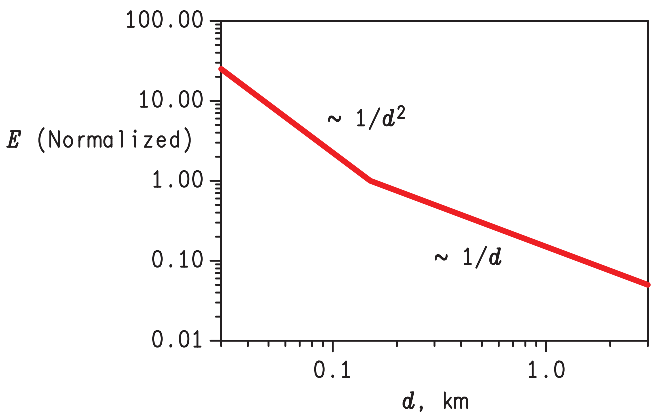

Figure 2. Illustration of induction-field and far-field regions near a PLT.

Consequently, the distance at which the field is measured should be significantly larger than the transition distance. The signal strength must also be sufficiently larger than the noise level. Distances of 500 m to 1 km are well suited for these measurements.

Ground-Wave Region

As distance increases further, the variation of field strength with distance transitions from $1/d$ for free space to $1/d^2$ for a flat-earth surface wave. To ensure useable measurements, the distance must be less than the distance of this transition.

The surface-wave attenuation factor (Figure 3) for ground of conductivity σ and permittivity ε_r is given approximately (208a) of [4] as

$$A = \frac{2 + 0.3p}{2 + p + 0.6p^2} - (p/2)^{1/2} \exp(-5p/8) \sin b \,, \tag{5}$$

where

$$x = 60\,\sigma\,\lambda \,, \tag{6}$$

$$b = \arctan[(\varepsilon_r + 1)/x] \,, \tag{7}$$

and

$$p = (\pi d / \lambda x) \cos b \tag{8}$$

is the numerical distance. Basically, $p << 1$ for free-space $1/d$ attenuation and $p >> 1$ for for surface-wave $1/d^2$ attenuation. For typical ground conductivities of 0.01 to 0.001 S/m, the transition from $1/d$ to $1/d^2$ attenuation occurs at 3 to 30 km. At 135 kHz, the transition to ground wave occurs at even larger distances.

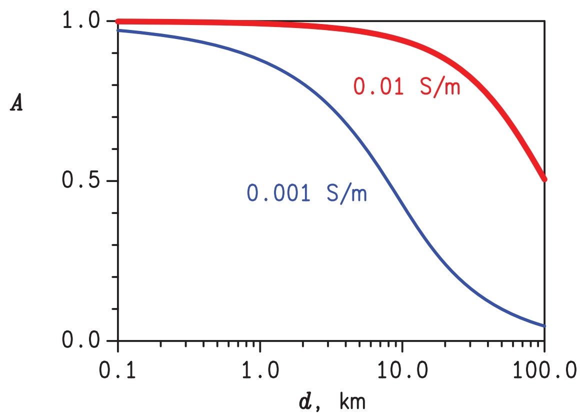

Figure 3. Surface-wave attenuation factor for 500 kHz.

Overall, a distance of about 0.5 to 1 km is best for field-strength measurement so that the effects of surface-wave propagation cause no more than a 12-percent error.

Best Measurement Distance

Avoidance of both the induction-field/far-field and the far-field/ground-wave transitions favors measurements at a distance of 0.5 to 1 km..

4. POWER LINE AS A TRANSMITTING ANTENNA

The electric power-transmission line may be regarded as an antenna that radiates a small part of the PLC signal into space. The power gain of a transmitting antenna relative to an isotropic radiator multiplies the transmit power in (1), thus the power density is

$$W = \frac{G P_t}{4\pi d^2} = \frac{E^2}{2\,\eta_0} \quad \text{W/m}^2 \quad . \tag{9}$$

The gain can be determined by measuring the electric field produced at a distance d by power P_t and comparing it to the field produced by an isotropic radiator. This is done by inserting the field, power, and distance into (9) and using the power density or field of an isotropic radiator from (3) or (4). It follows that gain can also be determined by comparing the measured electric field E_m to the field E_i of an isotropic radiator. Thus

$$G = E_m^2 / E_i^2 \quad . \tag{10}$$

Gain is usually converted into decibels via

$$G_{dB} = 10 \log (G) \quad . \tag{11}$$

For example, suppose the electric field at 1 km is measured as 40 dB relative to 1 μV/m or 100 μV/m. If the PLC power is 1 W, the power gain is then

$$G = (100\ \mu V/m\ /\ 7.75\ mV/m)^2 = 1.67 \times 10^{-4} = -37.8\ dB \quad . \tag{12}$$

5. POWER LINE AS A RECEIVING ANTENNA

According to the principle of reciprocity, the gain of an antenna is the same when transmitting or receiving. In this case, the received power is the power coupled into the line by a nearby amateur station.

The capture area *A* of an antenna s related to its gain [5] by

$$A = \frac{G\lambda^2}{4\pi} \quad , \tag{13}$$

hence the received power is

$$P_r = A\,W = \frac{G\lambda^2}{4\pi}\ W \quad . \tag{14}$$

In the previous example, suppose that the frequency is 137 kHz, for which λ = 2188 m. The capture area is then

$$A = \frac{0.000167 \times (2188)^2}{4\pi} = 63.5\ m^2 \quad . \tag{15}$$

Further suppose that the amateur station is located 1 km from the line and has an EIRP of 1 W. The power density is then given by (3) above. Multiplying (15) by (3) gives the received power

$$P_r = 63.5 \times 7.96 \times 10^{-8} = 5.06\ \mu W \quad . \tag{16}$$

Comparison of this to the 1-W transmit power of the PLC gives a signal-to-interference ratio of +53 dB.

6. RESULTS

Measurements of the fields produced by PLC system have been made in connection with a number of evaluations of potential interference. The required data are frequency, PLC power, measurement distance, and measured electric field. When available, both minimum and maximum values of field strength are included. These four parameters are processed by the equations in the previous sections to produce the received powers Pr given in Table A. These values of received power are based upon the amateur station radiating 1 W EIRP and being 1 km from the power-transmission line.

The signal-to-interference (*S/I*) ratio is then computed by comparing the PLC power to the power received from the amateur station, i.e.,

$$S/I \quad = \quad P_{\mathrm{PLC}} \,/\, P_r \quad . \qquad (17)$$

As shown in Table 1, the minimum *S/I* is 41 dB, while the average is 63 dB. The field-strength data are said to be typical, hence the derived *S/I* ratios should likewise be typical.

f kHz	P_{PLC} W	E_m dBμV	d_m m	*G* dB	*A* m²	P_r μW	*S/I* dB	REFERENCE
152	1	18	1000	-59.8	0.3	0.0259	75.9	[2], [3]
152	1	25	1000	-52.8	1.6	0.130	68.9	
200	1	26	1000	-51.8	1.2	0.0944	70.2	[2], [6]
200	1	35	1000	-42.8	9.4	0.750	61.2	
284	1	26	1000	-51.8	0.6	0.0468	73.3	
284	1	35	1000	-42.8	4.7	0.372	64.3	
284	1	34	1000	-43.8	3.7	0.295	65.3	[2], [6]
284	1	37	1000	-40.8	7.4	0.589	62.3	
400	1	34	1000	-43.8	1.9	0.149	68.3	
400	1	37	1000	-40.8	3.7	0.297	65.3	
283	1	37	1000	-40.8	7.5	0.594	62.3	[2], [3]
283	1	41	1000	-36.8	18.7	1.49	58.3	
200	1	30	1000	-47.8	3.0	0.237	66.2	[2], [7]
204	1	61	150	-33.1	85.0	6.76	51.7	[2]
205	1	57	150	-37.3	32.0	2.55	55.9	
207	1	53	150	-41.2	12.8	1.02	59.9	
204	1	55	100	-42.0	10.9	0.867	60.6	[2]
205	1	52	100	-45.3	5.0	0.401	64.0	
207	1	57	100	-40.8	13.9	1.11	59.5	
95	1	60	265	-29.3	927.5	73.8	41.3	[8]
95	1	53	280	-35.8	206.6	1.64	47.8	
85	1	43	265	-46.3	23.1	1.84	57.4	
85	1	41	265	-48.3	14.6	1.16	59.4	
172	10	32	1000	-55.8	0.6	0.0508	82.9	[9]
183	10	47	300	-51.2	1.6	0.128	78.9	
183	10	45	1000	-42.8	11.3	0.896	70.5	
170	8	47	455	-46.7	5.3	0.426	72.7	
137	1	40	1000	-37.8	63.5	5.05	53.0	Example
Minimum								41.3
Average								63.9

Table 1. *S/I* ratios derived from measurements of PLC fields.

7. EXPERIMENTAL OPERATIONS

The ARRL experimental license WD2XSH has 45 transmit sites located across the continental USA as well as Alaska and Hawaii. Since beginning operations in 2006, WD2XSH operators have logged over 180,000 transmitting hours in the 600 and 630 meter bands. Many other experimental stations have also been operating in this band, and many with higher power than the 20 W ERP that WD2XSH is allowed. To date, there have been no interference complaints from any source, PLC or otherwise.

As shown in Appendix A, a number of the experimental stations operating in the 630 and 2200-meter bands are quite close (well under 1 km) to power-transmission lines. Some of these are known to have power-line carrier (PLC) communications. There have been no reports of interference to the PLC systems.

8. IMPLICATIONS FOR AMATEUR LF AND MF OPERATION

The S/I ratios from Table 1 are based upon an EIRP of 1 W and a distance of 1 km from the power-transmission line. They are easily adjusted for 5 W EIRP (-7 dB), a distance of 316 m (-10 dB), and/or a distance of 100 m (-20 dB). The results are presented in Table 2.

d, km	WORST CASE		AVERAGE	
	1 W	5 W	1 W	5 W
1.0	41.3	34.3	63.9	56.9
0.316	31.3	24.3	53.9	46.9
0.1	21.3	14.3	43.9	36.9

Table 2. *S/I* ratios for various distances and EIRPs of amateur transmitter.

As the PLC and amateur signals propagate along the power line, they are attenuated equally. Consequently, the signal-to-interference ratio near the amateur transmitter is preserved all the way to the receiver.

The following conclusions can now be drawn from these data:

- In the vast majority of cases, amateur operation will cause no harmful interference to PLC operation.
- The minimum *S/I* ratio is 24.3 dB for an amateur transmitter with 5 W EIRP at a distance of 316 m. This is a very good *S/I* ratio and any properly functioning modem should decode its intended signal properly.
- At a distance of only 100 m, the *S/I* is 21.3 dB for a 1-W EIRP amateur signal, hence no disruption of reception should occur.

- For a distance of 100 m and an EIRP of 5 W, the *S/I* drops to 14.3 dB. A good quality modem should nonetheless work properly at this *S/I* level. However, there may be some problems with older modems and in cases of already marginal signal-to-noise ratio.

- Within the induction-field region, the signal pick-up may increase rapidly. Operation at distances of 100 m should therefore be approached cautiously, preferably with measurement of the actual signal-to-interference level.

- A restriction/coordination distance of 300 m will provide more than adequate protection of the PLC systems operating on a frequency in the amateur band.

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APPENDIX A. EXPERIMENTAL STATIONS NEAR POWER-TRANSMISSION LINES

STATION	BAND	ERP, W	D, km	COMMENTS
WD2XDW	2200	3	1.6	138 kV
WD2XSH/6	630	15	1.6	Lines to Navy base
WD2XSH/12	630	1	0.4	Xcel Energy
WD2XSH/14	630	2	0.93	
WD2XSH/15	630	2	3.2	Major N-S line, Entergy
WD2XSH/16	630	1	0.30	
WD2XSH/19	630	0.25	0.61	
WD2XSH/23	630	5	0.27	PLC 196 kHz
WD2XGJ	2200	4		
WE2XEB/2				
WE2XGR/1				
WD2XSH/26	630	0.01	0.015	Comm. distrib., local grid
WD2XSH/31	630	20	0.77	128 kV CW
WG2XFQ	630	20	0.77	Full-carrier AM
WD2XSH/33	630	0	1.25	161 kV
WD2XSH/44 WA	630	0	0.61	
WD2XSH/45	630	1.7	1.44	100-ft poles
WE2XPQ Wasalia/Palmer	630	30	5.26	Multiple LF/MF PLCs
	2200	1		Interconnector
WE2XPQ Anchorage	2200	3	0.06	Buried
		2.1		Main generator Chugach
WG2XKA	630	5	2.0	Substation, hydro, solar
WG2XPJ	630	1	0.8	
WG2XSV UT	630	1	0.13	
WG2XSV WA	630	1	0.33	
WH2XGP	630	10	1.6	DoI Columbia Grand Coulee
			2.0	Pair, Grant County PUD
VE7BDQ	630	5	0.56	
	2200	0.2		