HomePlug HF Propagation Model and Estimates (FAA Receiving)

Prepared for:
Radio Shack

Technical Contact:
Mr. Pete Griffin
Pete.Griffin@radioshack.com
817-919-0681

July 24, 2001

Prepared by:
Ed Joy, Ph.D., President
Joy Engineering Company
1450 Rembrandt Road
Boulder, Colorado 80302
303-776-5389
ed.joy@mindspring.com

This report supplements the Joy Engineering Report of June 24, 2001 and uses the methodology presented in that report. This report presents a simplified model of high frequency propagation of HomePlug equipped dwelling radiation from all such dwellings on the east side of North America to the FAA HF receiving site at South Hampton, Long Island, New York and compares that radiation to the signal from an aircraft inbound to North America from Europe received at the same FAA HF receiving site at South Hampton, Long Island, New York. Expected values for the FAA received voltages are then evaluated using the model.

List of Additional Symbols, Definitions and [values used in example calculation]

GFAA = Gain of FAA HF Antenna including ground reflection gain measured in dB above isotropic. [Antenna assumed to be a log periodic dipole array with 7 dBi gain plus a +6 dB ground reflection gain = 13 dBi] The gain as a power ratio is multiplied by the pattern of the antenna is given by:

GPFAAI = GFAA*COS^5(AZI)
for (AZI) angles –90 < AZ < 90 degrees (front lobe)
and equals
GPFAAI = GFAA*MAGNITUDE(0.01*COS^5(AZI))
for –180 < AZI <-90 and
90 < AZI < 180 degrees (back lobe).

Where COS is the cosine function, MAGNITUDE is the absolute (positive) value and AZI is the azimuth angle in degrees to each population center PCI with respect to the main beam of the FAA antenna.

The back lobe is seen to be 20 dB below the front lobe. The peak of the beam is pointed toward the incoming aircraft located approximately 200 miles east of St. Johns, Newfoundland, Canada.

VFAAAR = Voltage delivered by FAA antenna to FAA receiver on 50

Ohm transmission line in 9 KHz bandwidth due to Aircraft HF radiation measured in microvolts. [calculated]

DAFAALI = Distance from FAA Long Island HF Transmission Station to Aircraft along surface of earth measured in kilometers. [2,100 Km]

DAFAAA = Distance from FAA Long Island HF Transmission Station to Aircraft via one reflection from the ionosphere measured in kilometers given by the following equation:

$$DAFAAA = 2*SQRT\left((DAFAALI/2)^2 + HIONO^2\right) \qquad (Km)$$

Note the DAFAALI, DAFAAA and HIONO values are in Km.

DCIFAA = Distance along surface of earth from City I to FAA HF receiving site in South Hampton, Long Island, New York. Also shown is the Azimuth angle of the antenna pattern, AZI, to each City I and the FAA antenna power pattern factor, (COS^5(AZI) or 0.01*COS^5(AZI) depending main lobe or rear lobe reception respectively). [See list below]

City	**PCI**	**DCIFAA**	**AZI**	**COS^5(AZI)**
St. John's, NF	700,000	1,790	0^o	1.0
Halifax, NS	947,900	860	0^o	1.0
Moncton, NB	762,000	890	-12^o	0.89
Boston, MA	13,429,000	195	-13^o	0.87
Montreal, QB	18,828,000	520	-67^o	0.0091
New York, NY	26,290,000	135	-135^o	0.0059
Philadelphia, PA	13,812,000	285	-161^o	0.0076
Washington, DC	13,213,200	485	-168^o	0.009
Chicago, IL	48,131,000	1,290	-130^o	0.0011
Atlanta, GA	46,475,000	1,330	-173^o	0.0096
East Long Island*	60,000	10	0^o	1.0

*East Long Island is a group of the following small towns each of which is assumed to have a population of 10,000 each. This new population center was added for this analysis as it is close to the FAA Receiving site and in the main beam of the FAA receiving antenna. The individual towns are as follows:

Bridgehampton
East Hampton
Sag Harbor

North Haven
Montauk
Amagansett

DFAACI = Distance from City I to the FAA HF receiving via the Ionosphere measured in Kilometers. The equation for this distance is given for each City I by:

$$DFAACI = 2*SQRT\ (\ (DCIFAA/2)^2\ +\ HIONO^2\ )$$

Note: DCIFAA, DFAACI and HIONO values are in Km. There are NPC values: DCA1, DCA2, DCA3….;. and DCA11. Note that the signal from HomePlug radiation from East Long Island HomePlug equipped homes is a ground wave due to its close proximity to the FAA receiving site and does not utilize the ionosphere.

PRFAA = Total Power Received, in 9 KHz bandwidth, due to all HomePlug equipped dwellings at FAA measured in watts [calculated]

VFAAHP = Voltage delivered by FAA antenna to FAA receiver on 50 Ohm transmission line in 9 KHz bandwidth due to total HomePlug radiation measured in volts. [calculated]

Calculation of the FAA Received Voltage due to the Total of all HomePlug HF radiation.

The number of HomePlug dwellings which are simultaneously radiating for each population center, NHPI, is given in terms of the Population of each city, PCI (I from 1 to NPC), the percent of HomePlug equipped dwellings simultaneously radiating, PCTON, the number of people per dwelling, NPD, and the percentage of dwellings which are HomePlug equipped, PCTDHP as:

NHPI=SQRT(PCI*(PCTON/100)*(PCTDHP/100)/NPD)

NHPI is evaluated for each population center. Thus there NPC values for NHPI: NHP1, NHP2, NHP3……. and NHP11

The reason for the use of the square root is that the sum of the radiations is considered non coherent as the HomePlug radiation from a particular HomePlug equipped dwelling is not phased locked to the HomePlug radiation from any other HomePlug equipped dwelling. So the sum is a quadrature sum.

The power received by the FAA antenna due to the total HomePlug radiations, PRFAA, is given in terms of the electric field strength measured 1 meter above ground, 10 meters from an HomePlug equipped dwelling in a 9 KHz bandwidth, EHP10, the number of HomePlug dwellings which are simultaneously radiating for each population center, NHPI, and the distance from City I to the FAA receiving site at South Hampton, Long Island, New York via the ionosphere, DFAACI as:

PD10 = 10^{-12} *(10EXP (EHP10/20))^2 /377 [Power Density, watts/meter^2]

PRC = 10EXP (-LIONO/10) [Ionospheric Power Reflection Coefficient]

G = 10EXP (GFAA/10) (FAA Antenna Power Gain, Including Ground Reflection Gain)

GPFAAI = G*COS^5(AZI) or
G*0.01*MAGNITUDE(COS^5(AZI))
Depending on main lobe or back lobe reception respectively
(FAA Antenna Gain including Power Pattern Factor)

AEI = GPFAAI*(L^2 /(4*PI)) (Effective Area of FAA Antenna, m^2)

PRFAA = PD10*PRC*0.01^2 *(AE1*(NHP1/DFAAC1)^2 +
AE2*(NHP2/DFAAC2)^2 +
AE3*(NHP3/DFAAC3)^2 +
…………. +
AE11*(NHP11/DFAAC11)^2)

[Watts]

Note: In this equation the DFAACI values are in Km and PD10 is in watts/m^2.

The received voltage at the FAA input terminals on the 50 Ohm transmission line connecting the FAA antenna to the FAA receiver, VFAAHP due to HomePlug radiation is given in terms of the total power received by the FAA antenna, PRFAA is given as:

VFAAHP = SQRT (PRFAA*50) (volts)

Calculation of the FAA Voltage Received at FAA HF facility at South Hampton, Long Island, New York due to Aircraft HF Transmission.

The power density at the FAA antenna, PDFAA, due to aircraft HF transmission is given in terms of the aircraft transmitter power output, PA, the gain of the aircraft HF antenna, GA, and the distance from the FAA Long Island, NY receiving station to the aircraft via one reflection from the ionosphere, DAFAA as:

PG = 10EXP (GFAA/10)	[Gain of Aircraft Antenna]
ERP = PA*PG	[Effective Radiated Power, watts]
SS = 10^6 *4*PI*$DAFAALI^2$	[Surface of Sphere, m^2, where DAFAA is in Km]
IL = 10EXP (-LIONO/10)	[Ionospheric Power Loss Factor]
PDFAAA=ERP*IL/SS	[watts/m^2]

The received voltage at the FAA receiver input terminals on the 50 Ohm transmission line connecting the FAA antenna to the FAA receiver, VFAAAR, due to aircraft HF transmission is given in terms of the power density incident on the FAA antenna, PDFAAA, the gain of the FAA antenna including ground reflection gain, GFAA and the wavelength, L as:

G = 10EXP (GFAA/10)	(FAA Antenna Power Gain, FAA antenna pointed toward aircraft for maximum gain and including ground reflection gain)

$AE = G*(L^2 /(4*PI))$	(Effective Area of FAA Antenna, m^2)
$PR = PDFAAA*AE$	(Received Power, watts)
$VFAAAR = SQRT (PR*50)$	(volts)

Example Calculation:

The voltage received by the FAA HF communication center on Long Island, NY due to radiation by HomePlug equipped dwellings is calculated and compared to the received voltage from the transmission from an aircraft inbound from Europe. It is assumed that the aircraft is located approximately 200 miles east of St. John's, Newfoundland. Other assumed parameters of the communication paths are summarized as:

L = 40 meters
HIONO = 400 Km
LIONO = 6 dB
PA = 400 Watts
GFAA = 13 dBi
GAA = 4 dBi
DAFAALI = 2,100 Km
DAFAACI = Calculated = Km
EHP10 = 48.5 dBuV/m
PCTON = 2 percent
PCTDHP = 50 percent
NPD =2.3
NPC = 11

Calculated FAA received voltage due to HomePlug radiation.

PCI and DCIFAA values and Calculated DFAACI values:

DFAACI values calculated as:

$DFAACI = 2*SQRT((DCIFAA/2)^2 + HIONO^2)$

PC1 =700,000	DC1FAA = 1,790 Km	DFAAC1 = 1,960 Km
PC2 = 947,900	DC2FAA = 860 Km	DFAAC2 = 1,175 Km
PC3 = 762,000	DC3FAA = 890 Km	DFAAC3 = 1,197 Km

PC4 = 13,429,000	DC4FAA = 195 Km	DFAAC4 = 823 Km
PC5 = 18,828,000	DC5FAA = 520 Km	DFAAC5 = 954 Km
PC6 = 26,290,000	DC6FAA = 135 Km	DFAAC6 = 811 Km
PC7 = 13,812,000	DC7FAA = 285 Km	DFAAC7 = 849 Km
PC8 = 13,213,200	DC8FAA = 485 Km	DFAAC8 = 935 Km
PC9 = 48,131,000	DC9FAA = 1,290 Km	DFAAC9 = 1,518 Km
PC10 = 46,475,000	DC10FAA = 1,330 Km	DFAAC10 = 1,552 Km
PC11 = 60,000	DC11FAA = 10 Km	DFAAC11 = 10 Km

NHPI=SQRT(PCI*(PCTON/100)*(PCTDHP/100)/NPD)

Calculated Values
NHP1 = 55.2
NHP2 = 64.2
NHP3 = 57.6
NHP4 = 241.6
NHP5 = 286.1
NHP6 = 338.1
NHP7 = 245.1
NHP8 = 239.7
NHP9 = 457.5
NHP10 = 449.5
NHP11 = 16.2

PD10 = 10^{-12} *(10EXP(EHP10/20))^2/377 [Power Density, watts/meter^2]

PD10 =187.78*10^{-12} w/m^2

PRC = 10EXP(-LIONO/10) [Ionospheric Power Reflection Coefficient]

PRC = 0.25

G = 10EXP(GFAA/10) (FAA Antenna Power Gain, Including Ground Reflection Gain)

G = 20.0

GPFAAI = G*COS^5(AZI) (FAA Gain including Power Pattern Factor)

AEI = GPFAAI*(L^2 /(4*PI)) (Effective Area of FAA Antenna, m^2)

City	**AZI**	**$COS^5(AZI)$**	**GPFAAI**	**AEI**
St. John's, NF	0^o	1.0	20.0	2,546.0
Halifax, NS	0^o	1.0	20.0	2,546.0
Moncton, NB	-12^o	0.89	17.8	2,266.0
Boston, MA	-13^o	0.87	17.4	2,215.0
Montreal, QB	-67^o	0.0091	0.182	23.2
New York, NY	-135^o	0.0059	0.118	15.0
Philadelphia, PA	-161^o	0.0076	0.152	19.4
Washington, DC	-168^o	0.009	0.18	22.9
Chicago, IL	-130^o	0.0011	0.022	2.8
Atlanta, GA	-173^o	0.0096	0.192	24.4
East Long Island*	0^o	1.0	20.0	2,546.0

$$\begin{aligned}PRFAA = PD10*PRC*0.01^2*(&AE1*(NHP1/DFAAC1)^2 + \\ &AE2*(NHP2/DFAAC2)^2 + \\ &AE3*(NHP3/DFAAC3)^2 + \\ &\ldots\ldots\ldots\ldots. + \\ &AE11*(NHP11/DFAAC11)^2\ )\end{aligned}$$

[Watts]

Note: In this equation the DFAACI values are in Km.

$$\begin{aligned}PRFAA = 187.78\ 10^{-12}*0.25*10^{-4}*(&2,546.0\ (55.2/1,960)^2 + \\ &2,546.0(64.2/1,174)^2 + 2,266.0(57.6/1,197)^2 + \\ &2,215.0(241.6/823)^2 + 23.2(286.1/954)^2 + \\ &15.0(338.1/811)^2 + 19.4(245.1/849)^2 + \\ &22.9(239.7/935)^2 + 2.8(457.5/1,518)^2 + \\ &24.4(449.5/1552)^2 + 2,546.0\ (16.2/10)^2\ )\end{aligned}$$

$$\begin{aligned}PRFAA = 4.69\ 10^{-15}\ *(&2.02 + \\ &7.61 + 5.25 + \\ &190.9 + 2.09 + \\ &2.61 + 1.62 + \\ &1.51 + 0.254 + \\ &2.05 + 4124.5)\end{aligned}$$

$$PRFAA = 4.69\ 10^{-15}\ *4340.4$$

PRFAA= 20.4 10^{-12} Watts

VFAAHP = SQRT (PR*50) (volts)

VFAAHP = 31.9 10^{-6} Volts = 31.9 microvolts

Calculated Power Received by FAA Receiver Due to Aircraft Transmission

PG = 10EXP (GA/10) [Power Gain]
PG = 2.5

ERP = PA*PG [Effective Radiated Power, Watts]
ERP = 1,000 Watts

DAFAAA= 2*SQRT ((DAFAALI/2)^2 + HIONO^2) (Km)
DAFAAA = 1,442 Km

SS = 10^6*4*PI*DAFAAA^2 [Surface of Sphere, m^2]
Note in this equation DAFAAA has units of Km.
SS = 63.5 10^{12} m^2

IL = 10 EXP (-LIONO/10) [Ionospheric Power Loss Factor]
IL = 0.25

PDFAAA=ERP*IL/SS [watts/m^2]
PDFAAA = 3.94 10^{-12} watts/m^2

G = 10EXP (GFAA/10) (FAA Antenna Power Gain, Including Ground Reflection Gain)
G = 20

AE = G*(L^2 /(4*PI)) (Effective Area, m^2)

AE = 2,546 m^2 (Effective Area of FAA Antenna)

PR = PDFAAA*AE (Received Power, watts)
PR = 10.03 10^{-9} watts

VFAAAR =SQRT (PR*50) (volts)

VFAAAR = 708 10^{-6} volts = 708 microvolts

Comparison of the two received voltages:

Voltage due to HomePlug Radiation: 31.9 uV
Voltage due to Aircraft Transmission: 708 uV

The ratio of these two voltages is 22.2 dB.

Comment:

It is noted that the largest contributor to the HomePlug generated voltage at the FAA receiving site is due to the HomePlug equipped homes on the East End of Long Island. Without those homes, the HomePlug generated voltage would be:

$$\text{PRFAA} = 187.78\ 10^{-12}*0.25*10^{-4}*(2{,}546.0\ (55.2/1{,}960)^2 + 2{,}546.0(64.2/1{,}174)^2 + 2{,}266.0(57.6/1{,}197)^2 + 2{,}215.0(241.6/823)^2 + 23.2(286.1/954)^2 + 15.0(338.1/811)^2 + 19.4(245.1/849)^2 + 22.9(239.7/935)^2 + 2.8(457.5/1{,}518)^2 + 24.4(449.5/1552)^2)$$

$$\text{PRFAA} = 4.69\ 10^{-15} *(2.02 + 7.61 + 5.25 + 190.9 + 2.09 + 2.61 + 1.62 + 1.51 + 0.254 + 2.05)$$

$$\text{PRFAA} = 4.69\ 10^{-15} *215.9$$

PRFAA= 1.01 10^{-12} Watts

VFAAHP = SQRT (PR*50) (volts)

VFAAHP = 7.11 10^{-6} Volts = 7.11 microvolts

Comparison of the two received voltages:

Voltage due to HomePlug Radiation: 7.11 uV
Voltage due to Aircraft Transmission: 708 uV

The ratio of these two voltages is 40 dB. This is an improvement of 17.8 dB.