

HomePlug
HF Propagation
Model and Estimates

Prepared for:
Radio Shack

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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 an aircraft inbound to North America from Europe and compares that radiation to the FAA transmission signal from Long Island, NY. A many parameter model used to estimate the values of the aircraft received voltage is present along with typical values for the many parameters of the model. Expected values for the received voltages are then evaluated using the model.

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

PI = Pi = [3.141592654]

SQRT = Square Root Operation

10 EXP (A) = 10 raised to the power A

L = Wavelength of HF frequency measured in meters. The wavelength over the span of HomePlug frequencies: 4-21 MHz, ranges from 14.29 to 75 meters. I have chosen 7.5 MHz as a typical single-skip short distance (up to approximately 2,500 mile) ionospheric path frequency. [40 meters]

HIONO = Height of the ionosphere in Km. [400 Km]

LIONO = Loss due to single ionospheric reflection measured in decibels. [6 dB]

PFAA = Power measured in watts into antenna at FAA HF transmitting site located on South Hampton, Long Island, NY. [400 Watts]

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]

PDFAA = Power density at aircraft in 9 KHz bandwidth measured in Watts/m² due to FAA transmission from Long Island to a point 200 miles east of St. John's, NF. [calculated]

VARFAA = Voltage delivered by aircraft antenna to aircraft receiver on 50 Ohm transmission line in 9 KHz bandwidth due to FAA HF radiation measured in microvolts. [calculated]

DAFAALI = Distance from FAA Long Island HF Transmission Station to Aircraft along surface of earth measured in kilometers. [1,100 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:

$$DAFAA = 2 * \text{SQRT} \left((DAFAALI/2)^2 + \text{HIONO}^2 \right) \quad (\text{Km})$$

Note the DAFAALI value and the HIONO value are in Km.

EHP10 = Field strength, including effects of any ground reflection gain, of HomePlug equipped dwelling measured 10 meters in 9 KHz bandwidth from dwelling measured in decibels above 1 microvolt per meter. [48.5 dBuV/m]

PCTON = Percentage of HomePlug equipped dwellings which are transmitting simultaneously measured as a percent (0 – 100). [2 percent]

PCTDHP = Percentage of dwellings which are HomePlug equipped measured as a percent (0-100). [50 percent]

NPD = number of people per dwelling. [2.3]

NPC = Number of population centers (cities). [10]

PCI = Population of City I. (Where I ranges from 1 to NPC) [See list below]

DCI = Distance along surface of earth from City I to an inbound aircraft 200 miles (320 Km) east of St. John’s, NF measured in kilometers. [See list below]

City	Population (PCI)	Distance to Aircraft (Km) (DCI)
St. John’s, NF	700,000	320
Halifax, NS	947,900	1,220
Moncton, NB	762,000	1,250
Boston, MA	13,429,000	1,830
Montreal, QB	18,828,000	1,960
New York, NY	26,290,000	2,120
Philadelphia, PA	13,812,000	2,300
Washington, DC	13,213,200	2,500
Chicago, IL	48,131,000	3,130
Atlanta, GA	46,475,000	3,340

Notes on Cities, Population and Distance to Aircraft: These 10 population centers (cities) were chosen to represent the population of the east coast of North America. Flights inbound to North America from Europe (mostly) make their first land based VHF/UHF contact near St. John's, Newfoundland. The population of the cities is inflated to include all the population in the region of the cities. The regions are small near St. John's, NF and increase with increasing distance from St. John's, NF. A similar approach would be taken for other inbound routes to North America (such as from Asia and South America). The population of the 10 cities includes the following populations listed in order of increasing distance (in kilometers) from the city to a point approximately 200 miles [320 kilometers] east of St. John's, NF:

Cities	Included Populations (Provinces/States)
St. John's, NF	Newfoundland Prince Edward Island
Halifax, NS	Nova Scotia
Moncton, NB	New Brunswick
Boston, MA	Massachusetts Maine New Hampshire Vermont Rhode Island Connecticut
Montreal, QB	Quebec Ontario
New York, NY	New York New Jersey
Philadelphia, PA	Pennsylvania West Virginia
Washington, DC	District of Columbia Maryland Delaware Virginia
Chicago, IL	Illinois Michigan Wisconsin Indiana Ohio

Atlanta, GA

Kentucky
Georgia
North Carolina
South Carolina
Florida
Tennessee
Alabama
Mississippi

DACI = Distance from City I to the Aircraft via the Ionosphere measured in Kilometers. The equation for this distance is given for each City I by:

$$DACI = 2 * \text{SQRT} ((DCI/2)^2 + HIONO^2)$$

Note: DCI and HIONO values are in Km. There are NPC values: DCA1, DCA2, DCA3.....; and DCA10

ETA = Total electric field, in 9 KHz bandwidth, due to all HomePlug equipped dwellings at aircraft measured in microvolts/meter [calculated]

GAA = Gain of aircraft antenna measured in decibels above isotropic. The gain of the aircraft HF antenna should approach the gain of a monopole, which is approximately 5.15 dBi, however, due to matching losses, is probably only 80 percent efficient. [4 dBi]

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

Discussion of high frequency HF (3 – 30 MHz) propagation via the ionosphere over short distances (up to 2,500 miles).

Communication beyond line-of-sight is possible at HF frequencies due to reflection from the ionosphere. The ionosphere is a partially reflecting layer above the earth's atmosphere. The height of the ionosphere varies from approximately 60 to 600 Km, being low during the day and high during the night. The higher the ionosphere the fewer earth-ionosphere reflections are required to span a desired communication path. The ionosphere is also frequency dependent. Higher frequencies tend to pierce

the ionosphere and are not reflected as well as lower frequencies. The lower frequencies are, however, absorbed more than the higher frequencies. Thus time of day and choice of frequency are important to optimize the communication via the ionosphere. Optimum communication is normally associated with minimizing the number of earth-ionospheric reflections. It is often possible to communicate over a distance up to 2,500 miles with a single ionospheric reflection with the proper choice of frequency. It is noted that all the distances from the population centers to the inbound aircraft are less than 2,075 miles (3,340 Km). The frequency for such short distance communication is normally at the lower frequency end of the HF frequency band. Typically 3 to 10 MHz depending on the time of day. In the example to follow I have assumed an ionosphere height of 400 Km, a single reflection case at a frequency of 7.5 MHz with an associated 6 dB ionospheric reflection loss.

The angle of launch and reception for a single ionospheric reflection with respect to a flat earth over a distance of 3,000 Km with an ionospheric height of 400 kilometers is given by:

Angle = Inverse Tangent of (400/1500) = 15 degrees from the horizon. Thus most of the HomePlug radiation for this HF path would propagate through the walls of the dwelling.

Calculation of the Aircraft 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:

$$NHPI = \text{SQRT}(PCI * (PCTON/100) * (PCTDHP/100) / NPD)$$

NHPI is evaluated for each population center. Thus there are NPC values for NHPI: NHP1, NHP2, NHP3..... and NHP10

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 electric field strength at the aircraft due to the total HomePlug radiations, ETA, 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 Aircraft via the ionosphere, DACI as:

$$EF = 10 \text{ EXP } (EHP10/20) \quad \text{[Electric Field Strength, microvolts/meter]}$$

$$RC = 10 \text{ EXP } (-LIONO/20) \quad \text{[Ionospheric Voltage Reflection Coefficient]}$$

$$ETA = EF * RC * 1000 * 10 * \text{SQRT}((NHP1/DAC1)^2 + (NHP2/DAC2)^2 + (NHP3/DAC3)^2 + \dots + (NHP10/DAC10)^2)$$

[microvolts/meter]

Note: In this equation the DACI values are in Km and EF is in uV/m.

The received voltage at the aircraft input terminals on the 50 Ohm transmission line connecting the aircraft antenna to the aircraft receiver, VARHP due to HomePlug transmission is given in terms of the total electric field strength incident on the aircraft antenna, ETA, the gain of the aircraft antenna, GAA and the wavelength, L as:

$$G = 10 \text{ EXP } (GAA/10) \quad \text{(Aircraft Antenna Power Gain)}$$

$$AE = G * (L^2 / (4 * PI)) \quad \text{(Effective Area of Aircraft Antenna, m}^2\text{)}$$

$$PR = \text{ETA}^2 / 377 \quad (\text{Received Power, } 10^{-12} \text{ W/m}^2)$$

$$\text{VARHP} = \text{SQRT} (PR * 50) \quad (\text{microvolts})$$

Calculation of the Aircraft Voltage Received due to FAA HF Transmission from Long Island.

The electric field strength at the aircraft due to FAA HF transmission is given in terms of the FAA transmitter power output, PFAA, the gain of the FAA HF antenna including ground reflection gain, GFAA, and the distance from the FAA Long Island, NY transmission station to the aircraft via one reflection from the ionosphere, DAFAA as:

$$PG = 10 \text{ EXP} (GFAA/10) \quad [\text{Power Gain}]$$

$$ERP = PFAA * PG \quad [\text{Effective Radiated Power, watts}]$$

$$SS = 4 * \text{PI} * \text{DAFAA}^2 \quad [\text{Surface of Sphere, } \text{Km}^2 = \text{m}^6]$$

$$IL = 10 \text{ EXP} (-LIONO/10) \quad [\text{Ionospheric Power Loss Factor}]$$

$$\text{PDFAAA} = ERP * IL / SS \quad [\text{microwatts/m}^2]$$

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

$$G = 10 \text{ EXP} (GAA/10) \quad (\text{Aircraft Antenna Power Gain})$$

$$AE = G * (L^2 / (4 * \text{PI})) \quad (\text{Effective Area of Aircraft Antenna, } \text{m}^2)$$

$$PR = \text{PDFAAA} * AE \quad (\text{Received Power, microwatts})$$

$$\text{VARFAA} = 1,000 * \text{SQRT} (PR * 50) \quad (\text{microvolts})$$

Example Calculation:

The voltage received by an aircraft inbound from Europe due to radiation by HomePlug equipped dwellings is calculated and compared to the voltage received by the same aircraft due to the FAA HF communication center on Long Island, NY. 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

PFAA = 400 Watts

GFAA = 13 dBi

GAA = 4 dBi

DAFAALI = 1,100 Km

DAFAA = Calculated = 1,360 Km

EHP10 = 48.5 dBuV/m

PCTON 2 percent

PCTDHP = 50 percent

NPD = 2.3

NPC = 10

PCI and DCI values and Calculated DACI values:

DACI values calculated as:

$$\text{DACI} = 2 * \text{SQRT} ((\text{DCI}/2)^2 + \text{HIONO}^2)$$

PC1 = 700,000

DC1 = 320 Km Calculated, DAC1 = 862 Km

PC2 = 947,900

DC2 = 1,220 Km Calculated, DAC2 = 1,459 Km

PC3 = 762,000

DC3 = 1,250 Km Calculated, DAC3 = 1,484 Km

PC4 = 13,429,000

DC4 = 1,830 Km Calculated, DAC4 = 1,997 Km

PC5 = 18,828,000

DC5 = 1,960 Km Calculated, DAC5 = 2,117 Km

PC6 = 26,290,000

DC6 = 2,120 Km Calculated, DAC6 = 2,266 Km

PC7 = 13,812,000

DC7 = 2,300 Km Calculated, DAC7 = 2,435 Km

PC8 = 13,213,200

DC8 = 2,500 Km Calculated, DAC8 = 2,625 Km

PC9 = 48,131,000

DC9 = 3,130 Km Calculated, DAC9 = 3,231 Km

PC10 = 46,475,000

DC10 = 3,340 Km Calculated, DAC10 = 3,434 Km

$$\text{NHPI} = \text{SQRT}(\text{PCI} * (\text{PCTON}/100) * (\text{PCTDHP}/100) / \text{NPD})$$

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

EF = 10 EXP (EHP10/20) [Electric Field Strength,
 microvolts/meter]

EF = 266.1 uV/m

RC = 10 EXP (-LIONO/20) [Ionospheric Voltage
 Reflection Coefficient]

RC = 0.50

ETA = EF*RC*1000*10*SQRT((NHP1/DAC1)*(NHP1/DAC1)+
 (NHP2/DAC2)*(NHP3/DAC3)+
 (NHP3/DAC3)*(NHP3/DAC3)+
 +
 (NHP10/DAC10)*(NHP10/DAC10))

[microvolts/meter]

Note: In this equation the DACI values are Km and EF has the units of uV/m.

ETA = 266.1*0.50*1000*10*SQRT((0.064)² + (0.044)² + (0.0388)²
 + (0.121)² + (0.135)² + (0.149)² + (0.101)² + (0.091)²
 + (0.142)² + (0.131)²)

ETA = 0.458 uV/m

G = 10 EXP (GAA/10) (Aircraft Antenna Power Gain)

G = 2.51

AE = G*(L²)/(4*PI) (Effective Area of Aircraft Antenna, m²)

$$AE = 319.6 \text{ m}^2$$

$$PR = AE * \text{ETA}^2 / 377 \quad (\text{Received Power, Watts})$$

$$PR = 0.1778 * 10^{-12} \text{ watts}$$

$$\text{VARHP} = \text{SQRT} (PR * 50) \quad (\text{microvolts})$$

$$\text{VARHP} = 2.98 \text{ uV}$$

$$PG = 10 \text{ EXP} (G\text{FAA}/10) \quad [\text{Power Gain}]$$

$$PG = 20.0$$

$$\text{ERP} = P\text{FAA} * PG \quad [\text{Effective Radiated Power, Watts}]$$

$$\text{ERP} = 8,000 \text{ Watts}$$

$$SS = 4 * \text{PI} * D\text{AFAA}^2 \quad [\text{Surface of Sphere, Km}^2 = \text{m}^6]$$

Note in this equation DAFAA has units of Km.

$$SS = 23,242,759 \text{ Km}^2$$

$$\text{IL} = 10 \text{ EXP} (-L\text{IONO}/10) \quad [\text{Ionospheric Power Loss Factor}]$$

$$\text{IL} = 0.25$$

$$\text{PDFAAA} = \text{ERP} * \text{IL} / SS \quad [\text{microwatts/m}^2]$$

$$\text{PDFAAA} = 86.0 * 10^{-6} \text{ microwatts/m}^2$$

$$G = 10 \text{ EXP} (G\text{AA}/10) \quad (\text{Aircraft Antenna Power Gain})$$

$$G = 2.51$$

$$AE = G * (L^2 / (4 * \text{PI})) \quad (\text{Effective Area of Aircraft Antenna, m}^2)$$

$$AE = 319.6 \text{ m}^2$$

$$PR = \text{PDFAAA} * AE \quad (\text{Received Power, microwatts})$$

$$PR = 0.0275 \text{ microwatts}$$

$$\text{VARFAA} = 1,000 * \text{SQRT} (PR * 50) \quad (\text{microvolts})$$

$$\text{VARFAA} = 1,172 \text{ uV}$$

Comparison of the two received voltages:

Voltage due to HomePlug Radiation: 2.98 uV

Voltage due to FAA Transmission: 1,172 uV

The ratio of these two voltages is 51.9 dB.