A Small Antenna for a Temporary Short Range Loran System

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Abstract
Exciting new technology developed by Nautel offers greatly improved accuracy and efficiency for Loran transmission equipment. Due to the 3000m wavelength of the radiated signal, Loran transmissions have traditionally used extremely large antenna systems. Installations with peak power levels up to 400 kW typically use 625 ft or 1350 ft top loaded towers. Loran transmissions with peak radiated power levels between 4 and 40 KW have successfully used tower heights between 200 and 400 ft. This paper describes a brief study that was initiated to explore the possibility of creating a temporary Loran system with a range of 25 nautical miles (46.3 km) using a much smaller antenna. This antenna should be capable of erection in a few hours without the use of concrete foundations, highly skilled riggers or the specialized equipment that is normally required for tower construction. An evaluation of four alternative structures, commonly used in the LF/MF frequency band, rapidly eliminated all but one possible solution. Field trials of the system are planned in October 2009.

Required Level of Radiated Power
A field strength of +55dBuv/m (562uv/m) was selected as the target over the coverage area. Publications by the ITU Radiocommunication Assembly are a widely accepted source of data used for ground wave propagation studies at frequencies from 10kHz to 10MHz. ITU-R P832-2 contains maps of ground conductivity in units of mS/m for many countries throughout the world. Figure 1 (ITU Fig 35) depicts the variation of soil conductivity throughout North America (excluding Canada). It shows that a conductivity of 3 mS/m exists throughout most of the East coast of U.S.A. ITU-R P368 presents ground wave propagation data, normalized to a radiated power level of 1 KW, showing the field strength versus distance, for various soil conductivities and operating frequencies. Figure 2 (ITU Figure 6) applies to conductivities of 3 mS/m. for various operating frequencies. The 100 kHz curve indicates a field strength of +76dBuv/m at a range 46 km. Hence the necessary radiated power for a field strength of +55dBuv/m is equal to 76-55dBuv/m or 21dB below 1KW. This is equivalent to only 7.94watts (rms values) or a peak power level of 31.76 watts. Figure 2 also shows that signal attenuation to a range of 46.5 km closely follows the linear inverse distance curve. Figures 3 and 4 (ITU Figures 16 and 17) present this same signal propagation data at specific frequencies of 90 kHz and 120 kHz for various soil conductivities. They clearly indicate that at the short range of 46.5 km, a difference of soil conductivity of 5000:1 i.e. between 5 S/m and 1 mS/m causes less than a 1 dB change in field strength. In summary, our task is to produce a peak radiated power level of 32 watts to achieve a 25nm operating range.

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Choosing an optimum Configuration of Radiating Element

Designers of low frequency antennas with heights that are a small fraction of the wavelength have sought the optimal configuration since the dawn of radio communications. The use of base insulated vertical radiating towers was initially ruled out due to their excessive weight, the requirement for concrete foundations and difficulty of rapid deployment and relocation. In recognition of the importance of effective height, (radiation resistance is proportional to the square of the effective height) we looked for lightweight vertical structures that could be rapidly erected without cranes or other mechanical devices. It was decided to investigate two commonly used arrangements. The results led us to create a new configuration that optimized the effective height and antenna reactance within the restraints of available mechanical structures. Results were thus compared for the following configurations.

1. A 75 ft fiberglass whip, modified to include six 70 ft. top loading guy elements (TLE's) with a ground plane comprising 60 x 60 ft radials. This is illustrated in Figure 6.

2. A T antenna comprising two 150 ft horizontal wires, spaced 4 ft apart fed at the center by a single vertical wire. The horizontal wires are suspended by insulators between two 60 ft masts. A ground plane of 26 x 90ft radials and 18 x 135 radials was used. Figure 7 shows the basic configuration.

3. Four 60 ft masts supporting an arrangement of wires resembling a 60 ft square inverted cone (upside down pyramid). This configuration is shown in Figure 8. A ground plane comprising 36 x 60ft radials was used. The model was subsequently scaled up to 70 x 70 x 70 ft inverted cone with 36 x 70 ft ground radials.

Antenna Equivalent Circuit

All antennas that are very short compared to the signal wavelength may be represented by the equivalent circuit shown in Figure 9. It comprises a series connection of an inductance, a capacitor and three resistors. The reactance of the capacitor (Xc) is much higher than the reactance of the inductor (Xl), resulting in a net capacitive input impedance in series with the total resistance. The resistors represent the antenna radiation resistance, the antenna loss resistance and the ground loss resistance. The radiation resistance which is dependent on the effective height, represents the degree to which the antenna is able to couple to the 377 ohm resistance of free space and is typically very small. The antenna resistance is normally insignificant but can increase to a significant value when insulator leakage currents occur in highly saline environments. The ground loss resistance, usually the largest of the three, is dependent on soil conductivity immediately beneath the antenna. An arrangement of radial wires buried just below the ground surface is normally used to minimize the ground loss resistance.

Matching the Antenna to the impedance required by the transmitter

Figure 10 illustrates a common method of tuning the antenna using a series connected variable loading coil to resonate the capacitive input impedance. This adds a fourth resistor (Rc) to the circuit as the loss resistance of the coil. At resonance, the antenna current (Ia) achieves a maximum value determined by the input voltage.

The radiated power (Pr) is given by $Pr = Ia^2\ Rr$

The power lost as heat = $Ia^2\ (Ra+Rg+Rc)$

Efficiency = Rr / Rt

Where Rt= Rr+Ra+Rg+Rc

Rr is usually very small compared to Rt hence the overall efficiency is very low.

The Q value of this resonant circuit = Xc/Rt where $Xc=10^6 /(0.2\text{pi}\ C_{pf})$

Where C_{pf} =antenna Capacitance in picofarads

And antenna bandwidth at 100 kHz = 10^5 / Q

Comparing the four Antenna Configurations

The powerful NEC-4 Antenna Analysis software was used to analyze the four configurations. Each was modeled by inputting the detail of the radiating structure and the associated ground plane together with a soil conductivity of 1 mS/m.

The antenna input impedance of each antenna was measured at 100 kHz, and a loading coil with a Q of 1000 was added to tune the model.

The Antenna Excitation level was then adjusted to provide a field strength of +55dBuv/m on the ground at a range of 46.5 km.

The following values were recorded

Field strength at 10km

Antenna Current (Ia)

Antenna reactance (Xl)

The radiated power (Pr) was calculated from $Pr= 1.33\text{pi}\ e^2 d^2 / 377$ watts

And the radiation resistance (Rr) from $Rr = Pr/Ia^2$

Peak antenna input voltage (2IaXl)

The results tabulated in Table 1 indicate that the requirement to keep the peak antenna voltage below 50 kilovolts is achieved only with the 70 ft inverted cone. Further investigation was therefore restricted to this model.

Table 1 Antenna Parameters for a Radiated Power level of 7.94watts

Antenna	Loading Coil Inductance µH	Antenna Reactance Xl ohms	Antenna Current Ia amps	Radiation Resistance Rr ohms	Peak Antenna Voltage Vp KV
75' Top loaded whip	3741.8	2351	16.63	0.0287	76.66
60' x 150' T antenna	4464	2805	14.09	0.04	79.1
60' Inverted cone	2957	1858	15.82	0.0317	58.7
70' Inverted cone	2488	1563	13.37	0.0431	41.8

Operating Parameters of the 70 ft Inverted Cone

The model was changed for a soil conductivity of 3 mS/m.
Input Impedance was measured as 1.657 –j 1585.8 ohms
The reactance slope at 100 kHz was measured as 15.75 ohms per kHz.

The real values of antenna inductance and capacitance were calculated as described in Reference 1.

$$L = \frac{1}{2}\left[\frac{dx}{dw} + \frac{x}{w}\right] = 13.5 \text{ uH}$$

$$C = \frac{2}{w^2 \frac{dx}{dw} - wx} = 1015 \text{ pf}$$

The required tuning coil is therefore equal to 2488.6 uH and would have a loss resistance of 1.6 ohms. The resulting equivalent circuit is shown in Figure 11. It has a Q value of Xt/Rt = 1572/3.257 or 482.7. This is much higher than that of typical Loran antennas, requiring a much higher input voltage to achieve the required pulse rise-time.

Figure 12 shows that this Q value, an input voltage 41 times greater than that of a CW signal is necessary.

Laboratory experiments have demonstrated that operation with this impedance and Q value is achievable.

Searching For Suitable Supporting Masts

Four lightweight masts that could be easily erected were required to support the wires of the inverted V antenna. A telescopic fiberglass whip with a mechanical crank handle was an initial favorite, until it was revealed to be made from carbon fiber which burns when exposed to high intensity electric fields. 70 ft. telescopic masts, made from aluminum alloy were subsequently selected. These are available at heights up to 82 ft. using multiple telescopic sections that are extended pneumatically using a small 12 volt air compressor. As the mast is extended, locking rings at the top of each section, secure the mast in its erect position. The 70 ft mast which has seven sections and measures 12 ft when fully retracted is guyed at three heights using three pre-stretched 6 mm polyester ropes connected to 30 inch anchors hammered into the ground. The maximum head-load for this mast is 44 lbs. Each is required to support one quarter of the total weight of the antenna wires and insulators together with the necessary guy strain to minimize sag in the wires to an acceptable level. 1/8 inch diameter stainless steel wires weighing a total of 17 lbs and insulators weighing 5.7 lbs were selected as a compromise between weight and maximum workable voltage. This produced a sag of about five feet at the center of the array. Figure 5 show the mast in its retracted position

Exposure of Personnel to Hazardous RF Electromagnetic Fields

IEEE Standard C95.1 -2005 recommends Safety Levels for the maximum exposure of the general public to electromagnetic fields. Table 9 on page 25 specifies these limits for a frequency of 0.1 MHz. as 614 v/m and 163 A/m for the maximum E and H fields when averaged over a period of 6 minutes.

The intensities of the near E and H fields were measured using the model to ensure the safety of personnel in close proximity to the antenna.
The measured peak values for the electric and magnetic fields are shown in Fig 12. The duty cycle of the loran pulse is in the order of 6%. Hence the indicated peak values could be safely reduced by a factor of 10. Consequently it is evident that the proposed system does not represent a safety hazard at any point close to the antenna.

Summary

The study suggests that it is possible to provide an antenna structure that can be erected by untrained personnel in a few hours, capable of achieving a useable Loran signal at a range of 25 nautical miles. Field trials are scheduled to be carried out late in October 2009.

References:

1. Next Generation LF Transmitter Technology for (e)LORAN systems – Tim Hardy

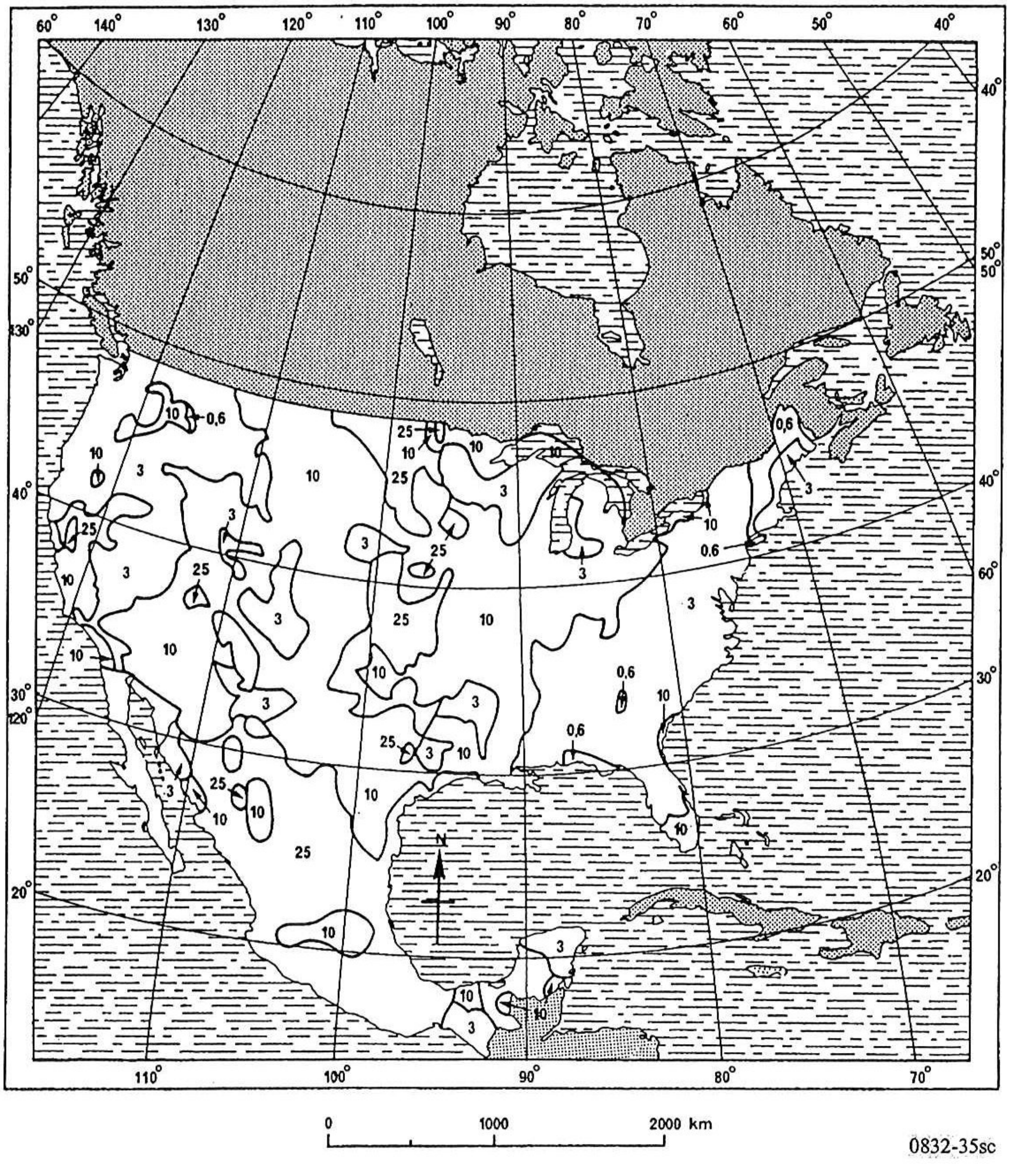


Figure 1.
Soil Conductivity in USA

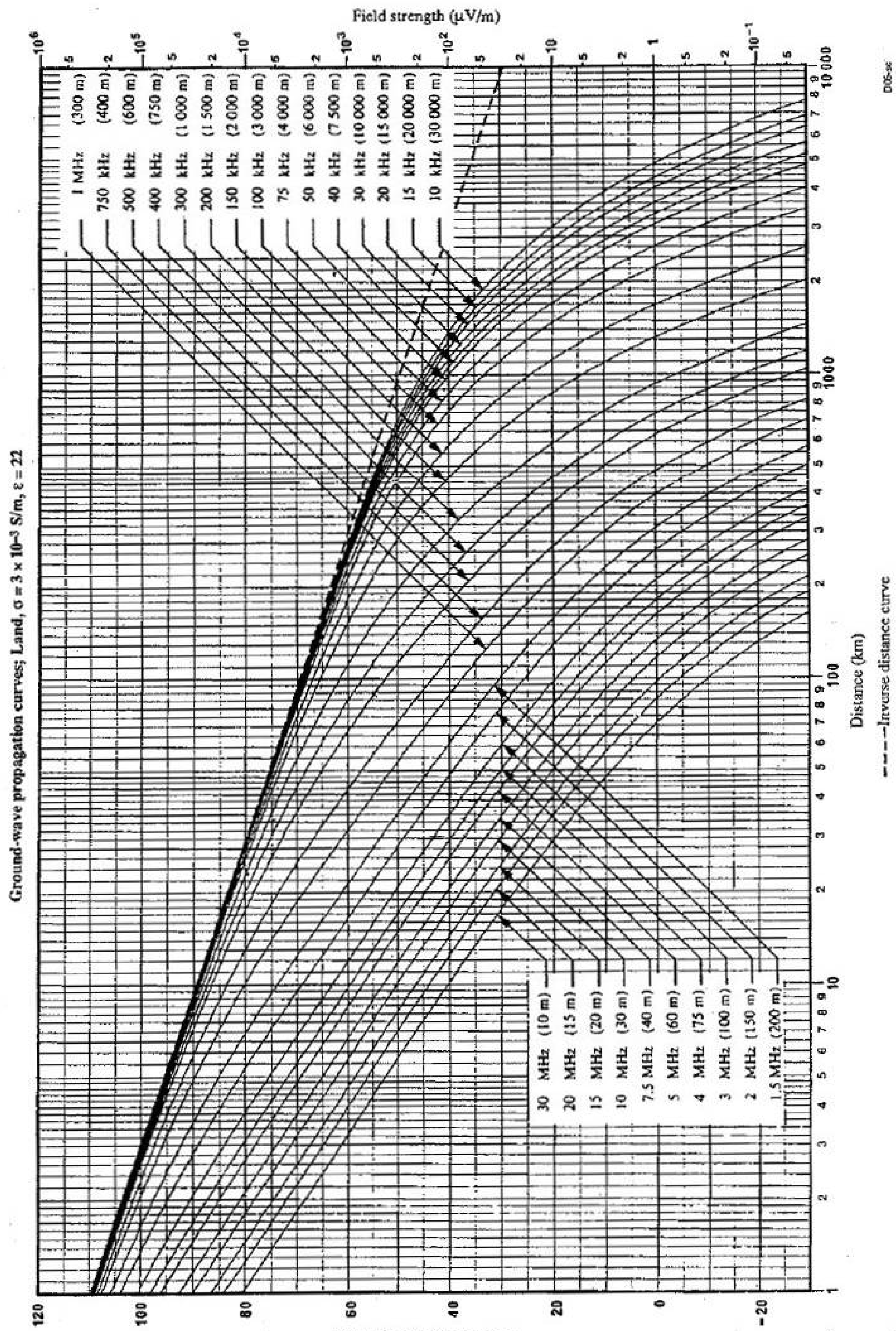


Figure 2
Grounding Propagation with 3mS/m Soil

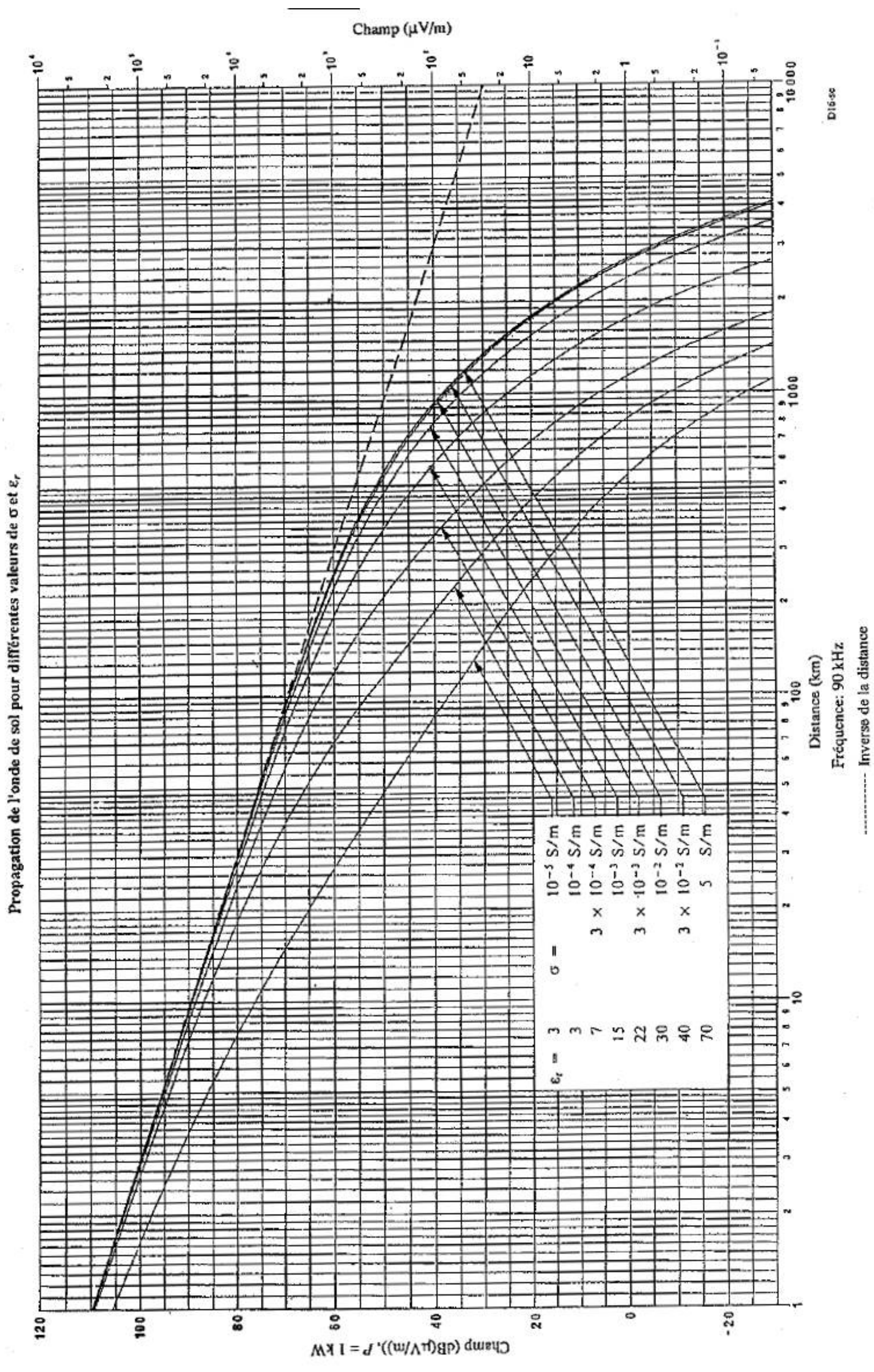


Figure 3
Grounding Propagation for Various Soil types at 90KHz

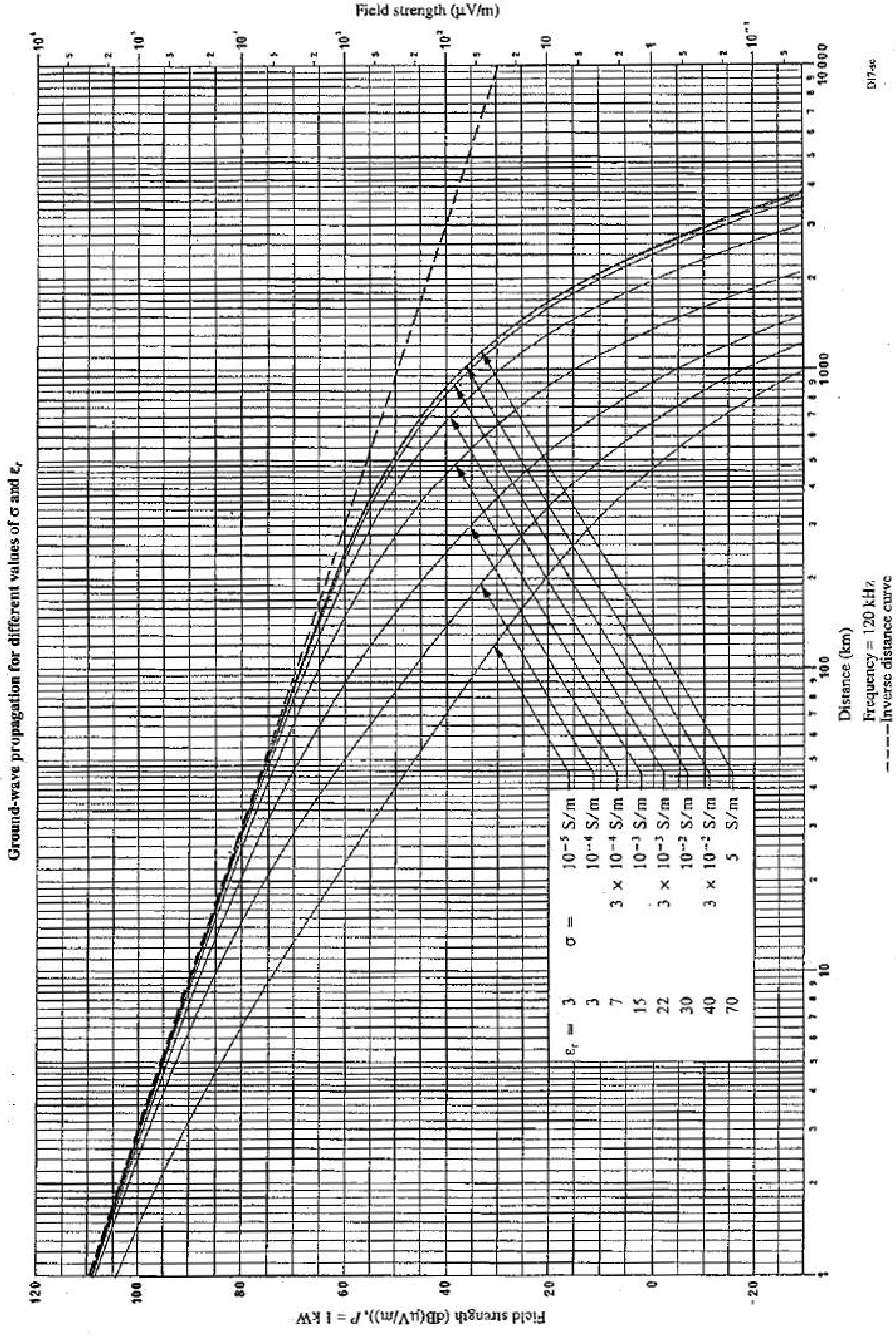


Figure 4
Grounding Propagation for Various Soil types at 120KHz

Figure 5
Telescopic mast in its retracted position

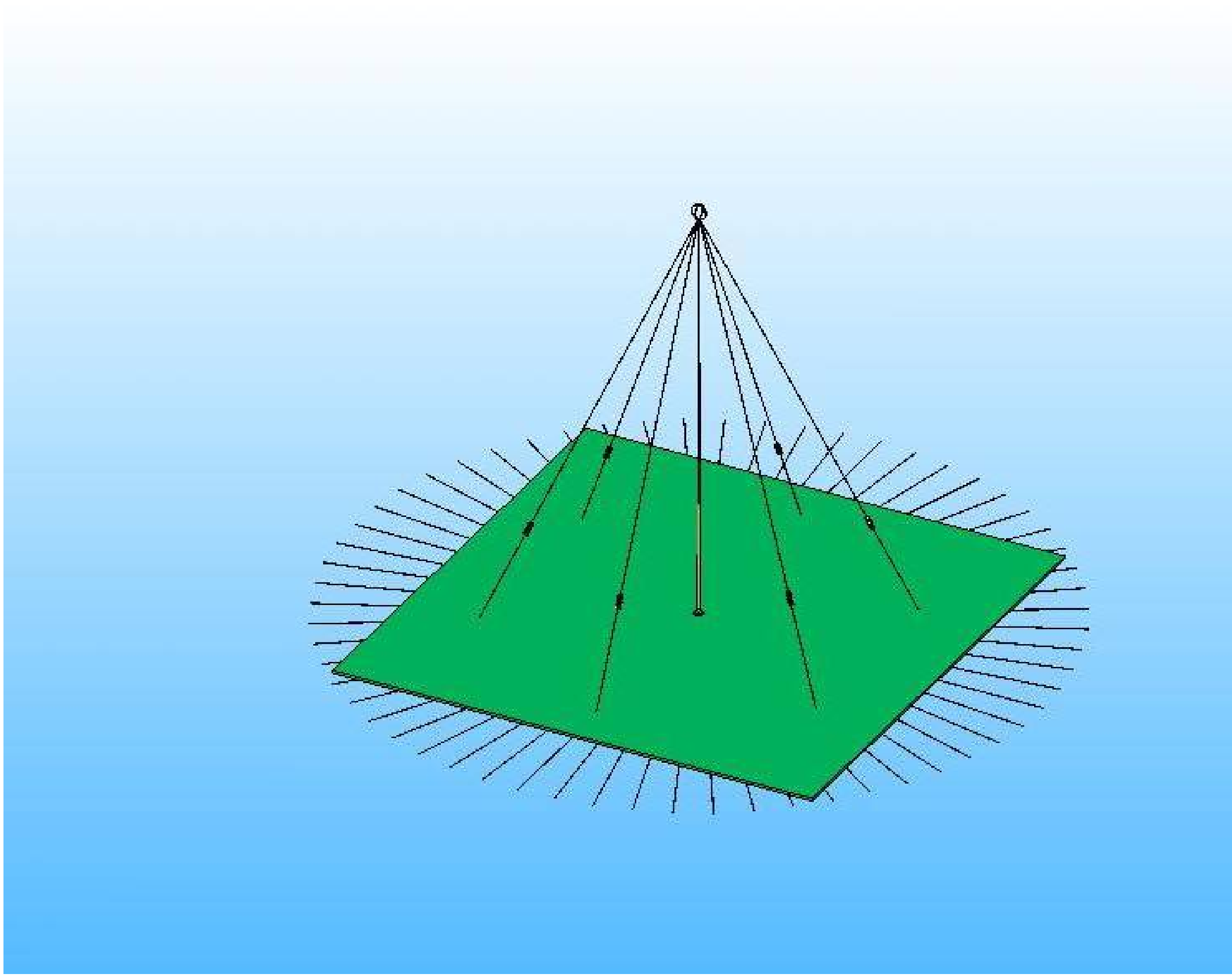


Figure 6
75' Fiberglass Whip with 6 TLEs

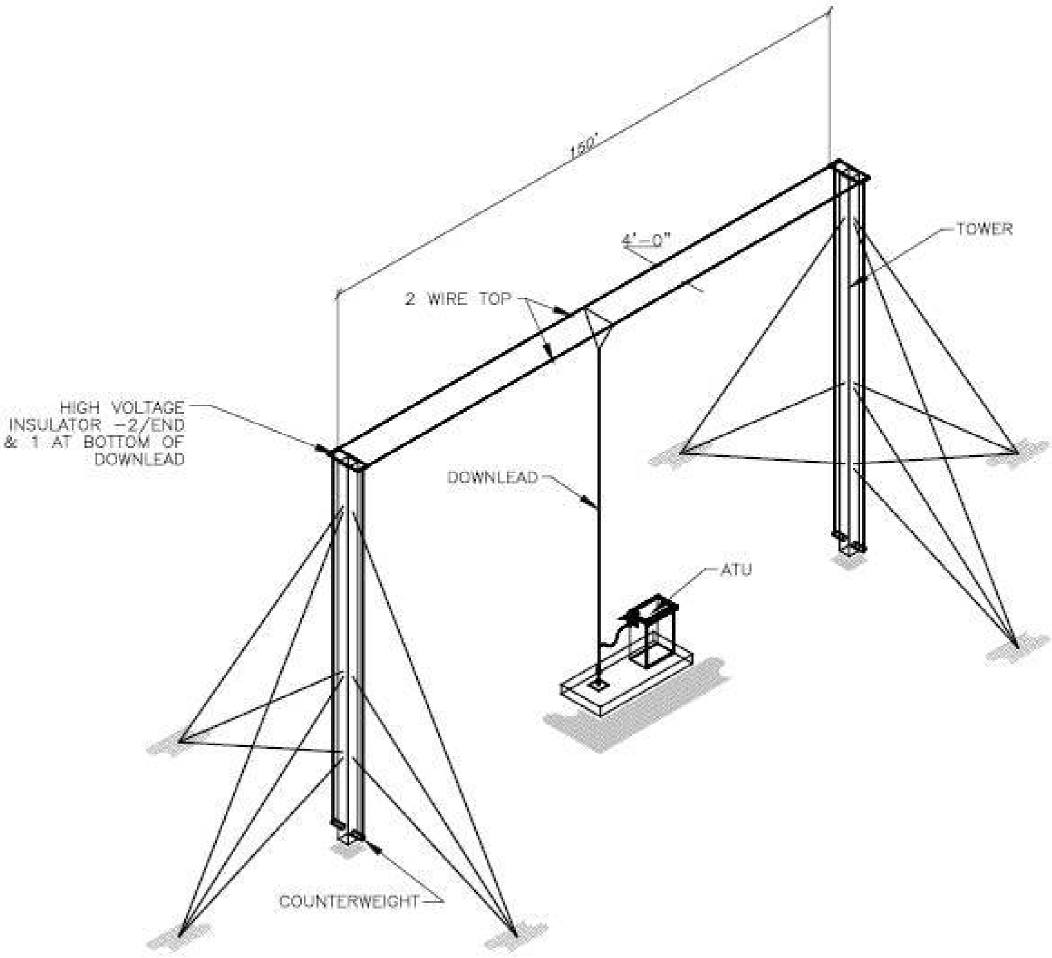


Figure 7
60’ x 150’ Antenna

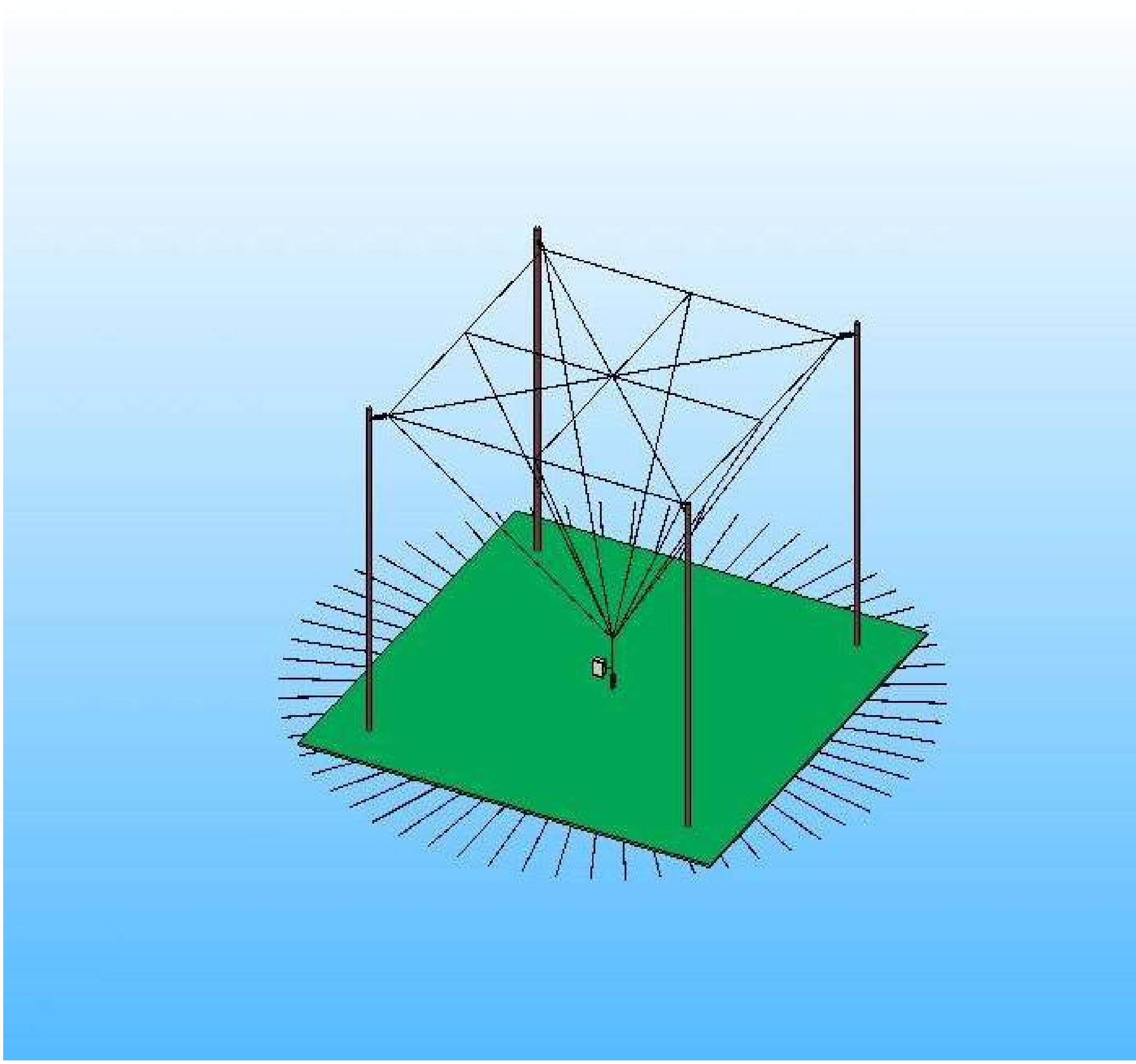
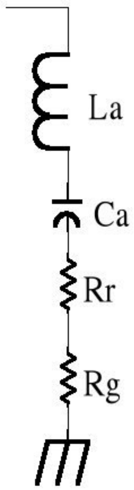


Figure 8
Inverted Square Cone Antenna

Antenna Equivalent Circuit



WHERE:

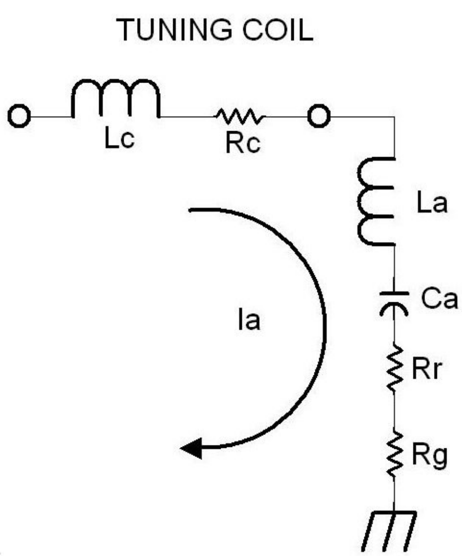
La = ANTENNA INDUCTANCE

Ca = ANTENNA CAPACITANCE

Rr = RADIATION RESISTANCE

Rg = GROUND LOSS RESISTANCE

Figure 9



WHERE:

Lc = TUNING COIL INDUCTANCE

Rc = TUNING COIL LOSS RESISTANCE

La = ANTENNA INDUCTANCE

Ca = ANTENNA CAPACITANCE

Rr = RADIATION RESISTANCE

Rg = GROUND LOSS RESISTANCE

Ia = ANTENNA CURRENT

Figure 10
Equivalent Circuit of Tuned Antenna

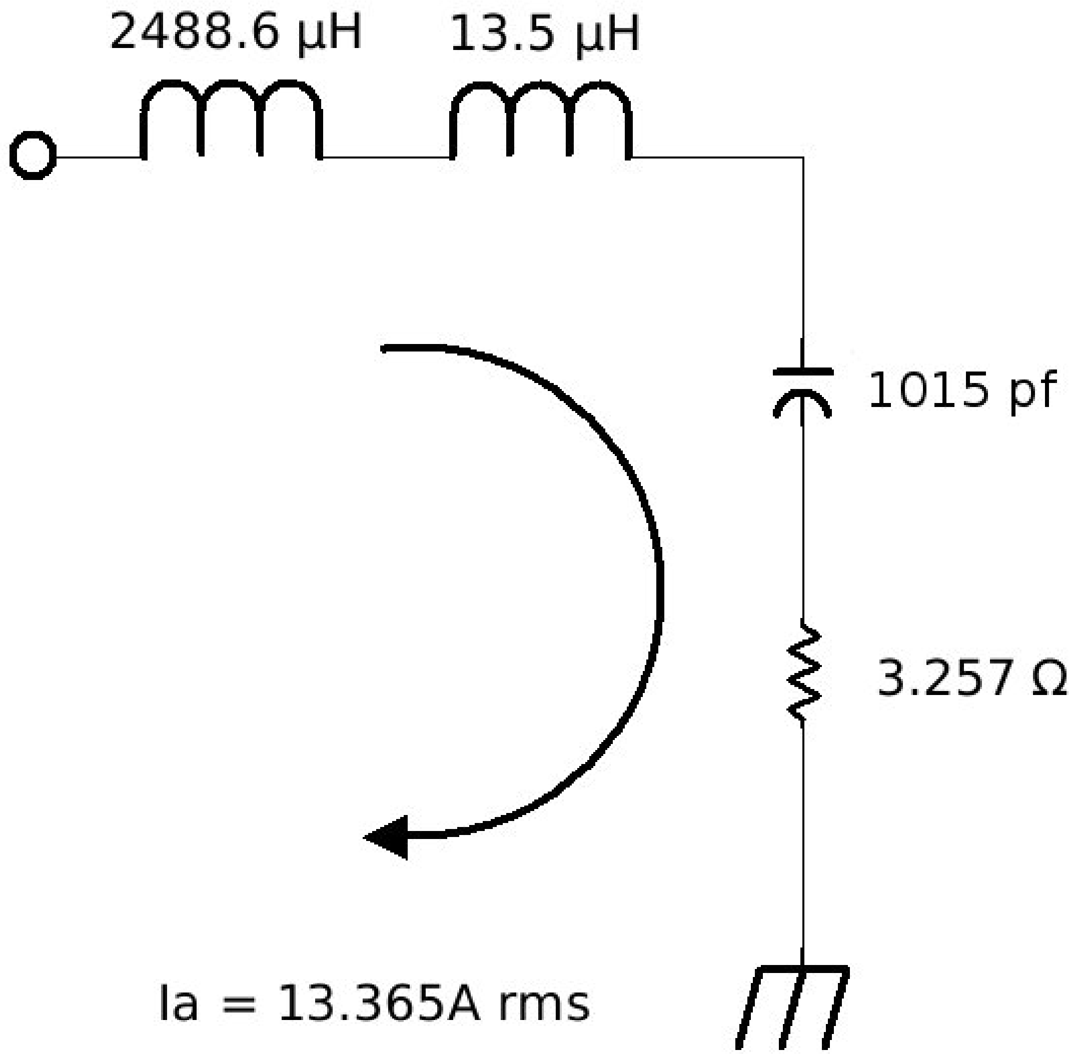


Figure 11
Equivalent Circuit of 70' inverted cone antenna

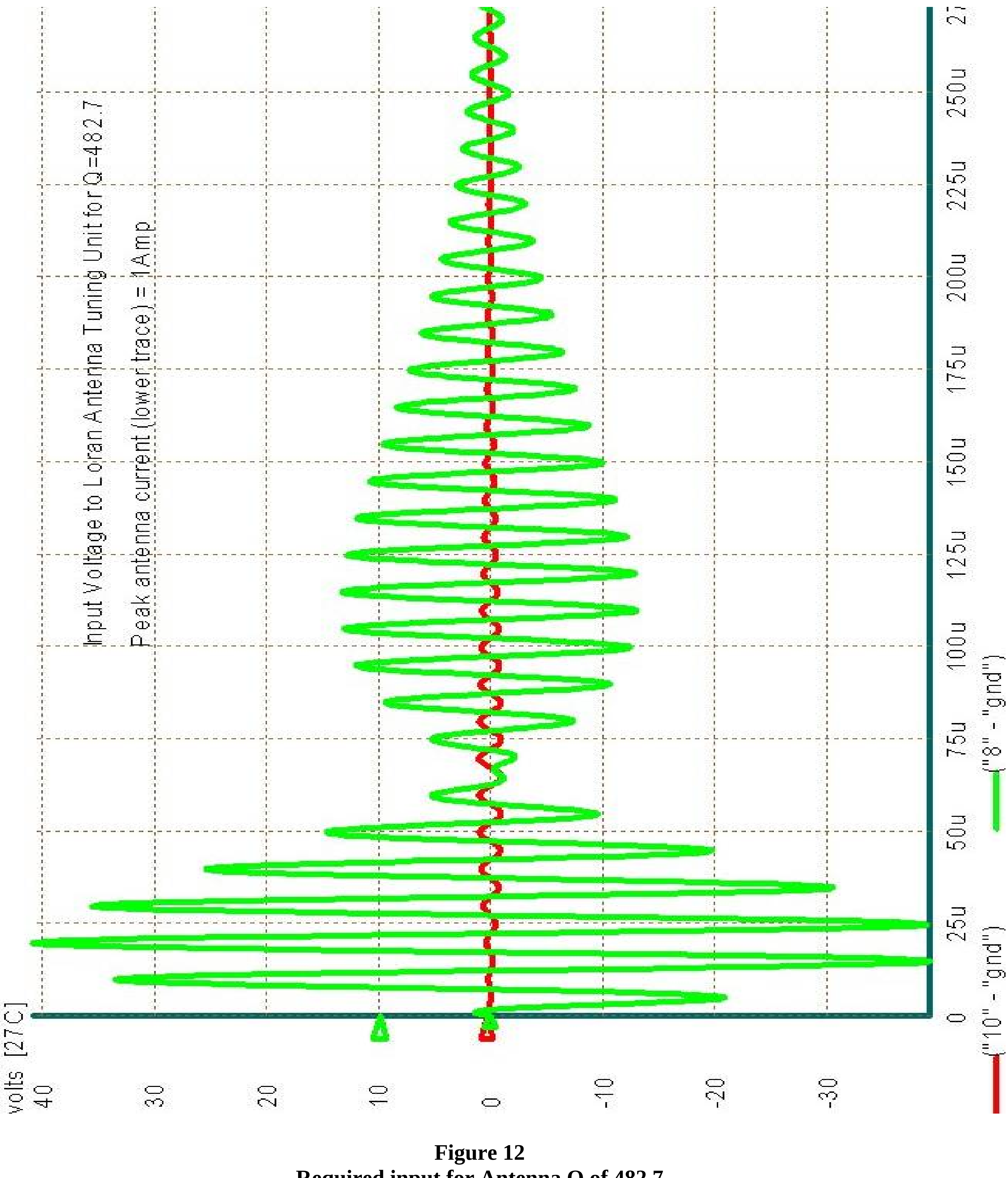


Figure 12
Required input for Antenna Q of 482.7