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Horizontal HF - Recommended Transmit Power

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1 Introduction

Data were collected at two frequencies, limited by allowable bandwidths for an amateur radio general license holder (shown in figure 1). These frequencies were 21.448MHz and 24.930MHz.

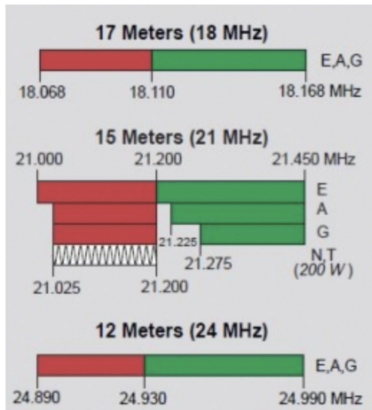

Figure 1: Applicable allowable frequencies for General License

Collected data demonstrated the feasibility of using this antenna to generate a 40ft by 6ft area with a ±3dB uniform electric field.

The purpose of this document is to demonstrate the derivation of the recommended transmit power to achieve 200V/m (±3dB) over a 6x40x6 foot volume using a similar antenna.

2 Measured Data

Simulated (EZNEC) radiation pattern and VSWR for this antenna based on physical measurements of the antenna's dimensions are shown below. These graphics are for 26.875MHz, but the radiation patterns were comparable for other target frequencies.

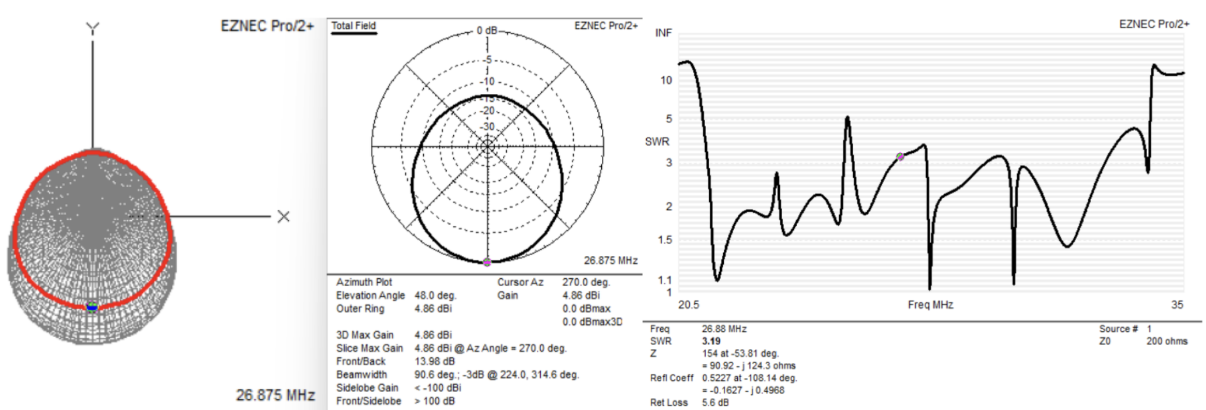

Figure 2: Radiation Pattern and SWR for 26.875MHz

The measured S11 and VSWR for the 20-30MHz bandwidth LPDA are shown plotted below.

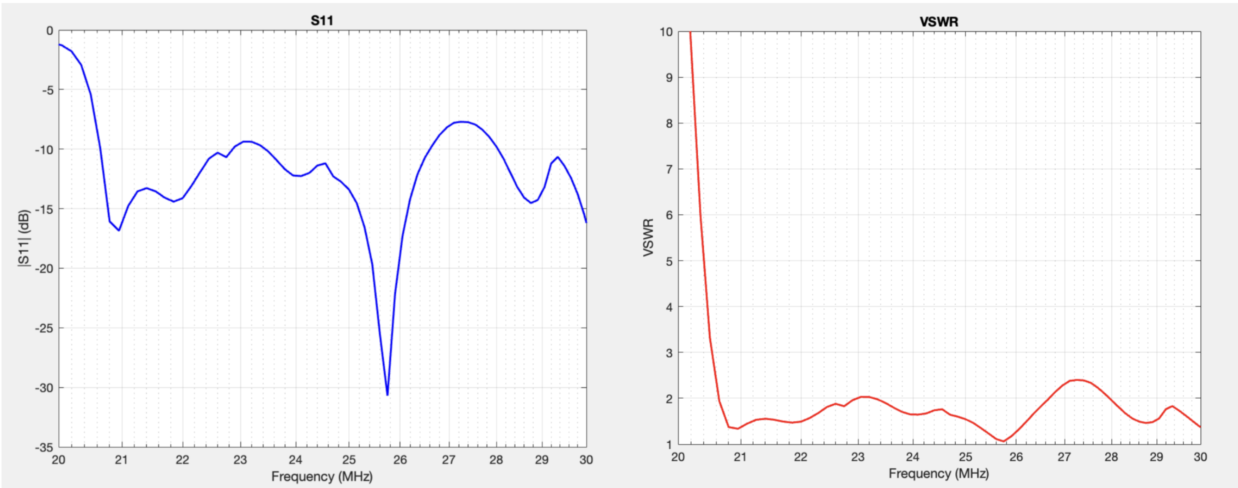

Figure 3: Measured S11 and VSWR using FieldFox

Resulting E-field measurements using the LumiLoop E-field probe are demonstrated below.

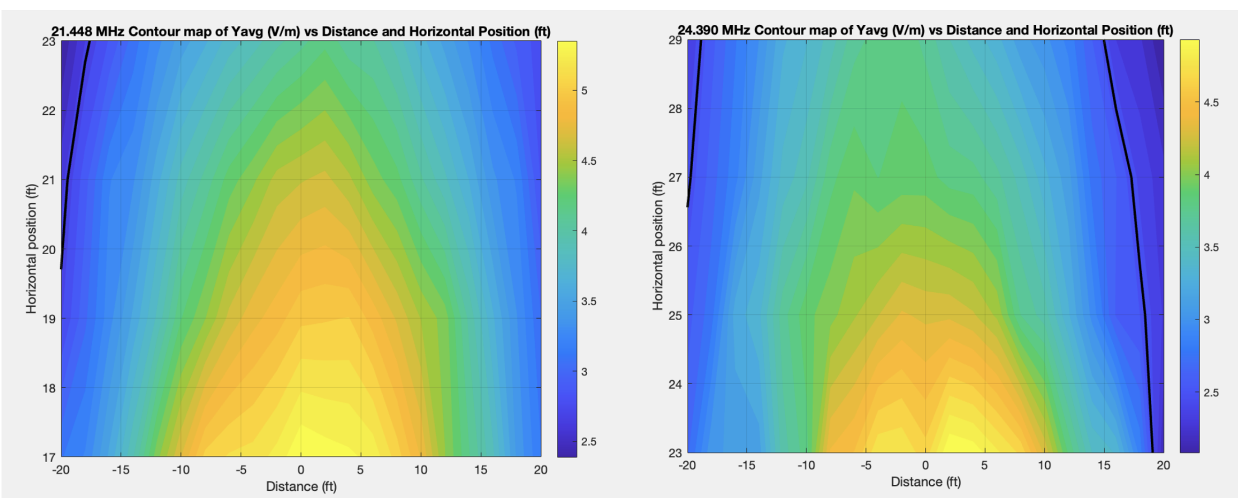

Figure 4: LumiLoop E-field measurements for 21.448MHz and 24.930MHz

3 Theory and Derivation

The derivation of the recommended transmit power to achieve the desired received power is not as straightforward as simply utilizing the Friis transmission equation (equation 1). There are several sources of loss between transmitter and near-field test region.

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi R})^2 \quad (1)$$

3.1 Transmitter to System

To begin, let us derive the amount of power being delivered to the antenna system from the balun. To do this, we will utilize the S11 parameters we captured using the Keysight FieldFox. Using equation 2, we can model a 20-30MHz frequency sweep for the power actually seen by the system. In this case, incident power is 25W being transmitted from a radio transceiver and Γ is S11.

$$P_t = (1 - |\Gamma|^2)P_i = (1 - |S_{11}|^2)25 \quad (2)$$

The resulting plot is shown below in figure 5, with P_t having been converted from W to dBm using the following formula:

$$P_{t_{dBm}} = 10 \log_{10}(1000 P_t) \quad (3)$$

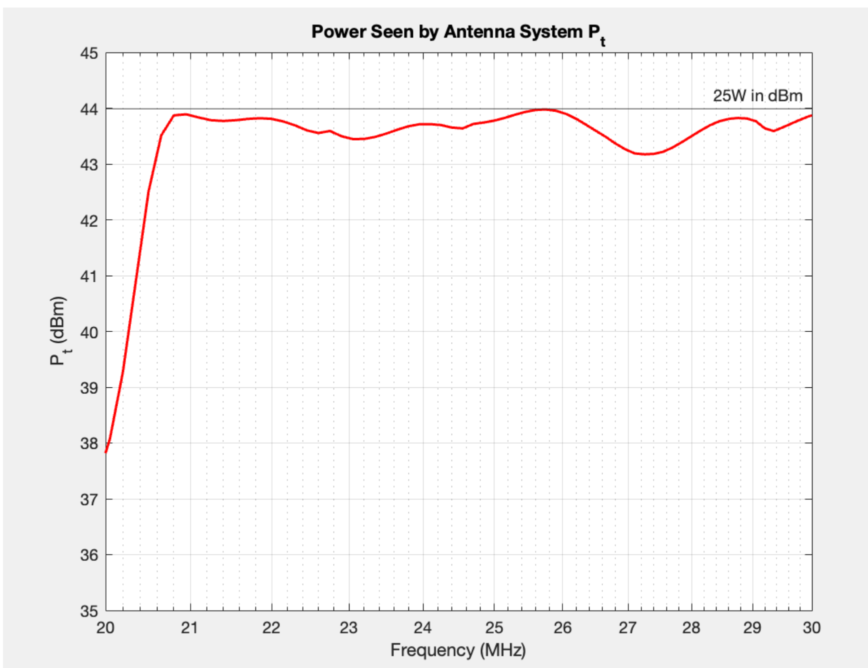

Figure 5: Power Seen by Antenna System based on S11

3.2 Balun Loss

A significant source of loss in this system is the 4:1 balun. The balun also introduces a significant challenge that must be discussed in conjunction with deriving the loss it causes.

In this case, a 4:1 ferrite-core balun was used to match the impedance of the load to a 50Ω system and eliminate common-mode currents. Unfortunately, a ferrite-core balun can only withstand 500W CW (continuous wave) power or 1500W SSB (single sideband) power before overheating. If the recommended transmit power exceeds these limits, alternatives must be investigated.

One option is to use an air-choke balun. This would also be a 4:1 balun, introduce the same losses, and eliminate common-mode currents, all while being able to withstand higher power due to the nature of its construction.

Alternatively, steps could be taken to match the impedance of the entire system to 75Ω. Each dipole naturally has an impedance of roughly 73Ω, though this can be tweaked by adjusting the length of the dipole. The center transmission line (antenna boom) can be built in such a way that its characteristic impedance is also 75Ω. By creating a system that is fully matched at 75Ω, the need for a balun is eliminated, and consequently the loss it incurs.

To calculate the loss incurred by the balun, a voltage divider can be used:

$$P_{balun} = P_t \frac{Z_S}{Z_S + Z_{antenna}} \tag{4}$$

in this case, Z_S is the impedance of the 4:1 balun, which is converting 200Ω to 50Ω. Thus, its impedance is 200Ω. The antenna itself is also 200Ω, hence the conversion. Using equation 5, we find:

$$P_{balun} = P_t \frac{200}{200 + 200} = \frac{P_t}{2} \tag{5}$$

The power after these balun losses is shown in figure 6:

Figure 6: Power after Balun Loss

Shown overlaid with the power seen by the system:

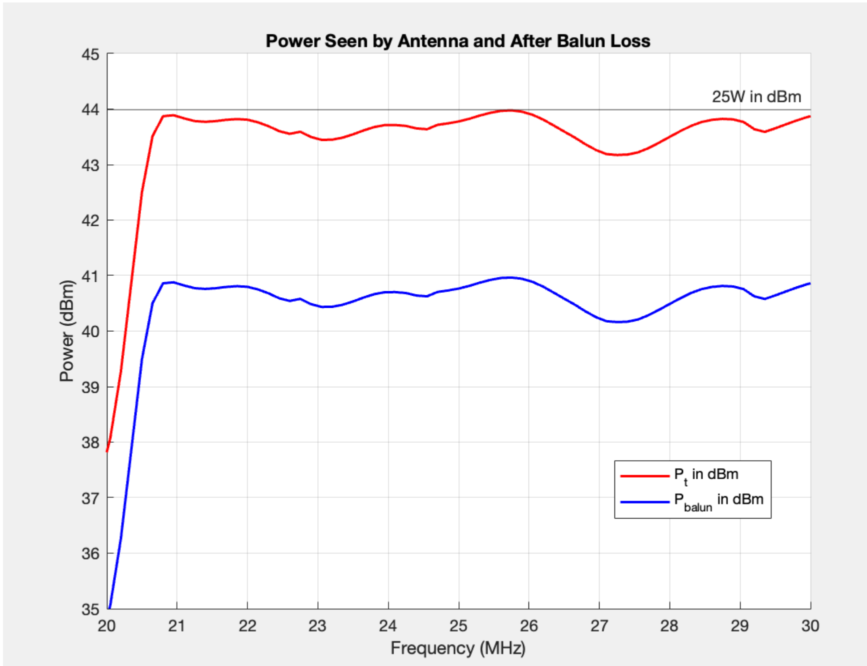

Figure 7: Power after Balun Loss

3.3 Propagation Loss

Finally, there will be propagation loss. We have experimentally determined the power received in the near field for two conditions:

At 21.448MHz, it was determined that the requested 40x6ft area could be achieved at a distance of 6m from the feed point. At 24.930MHz, it was determined that the requested 40x6ft area could be achieved at a distance of 8m from the feed point.

Because we are operating in the radiating near field, the impedance will need to be calculated using the following equation:

$$\eta = 120\pi \frac{(1 + \frac{1}{(jkD)^2})}{(1 + \frac{1}{jkD})} \tag{6}$$

where

$$k = \frac{2\pi f}{c} \tag{7}$$

thus, $|\eta| = 285.757\Omega$ for 21.448MHz and $|\eta| = 336.120\Omega$ for 24.930MHz. Plots for the impedance at each frequency as a function of distance are shown below:

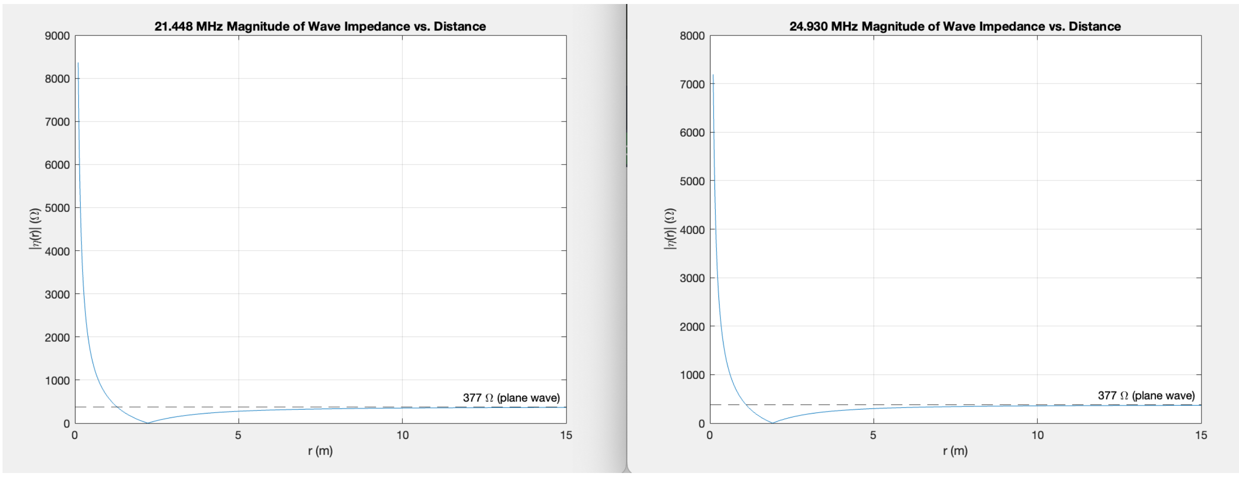

Figure 8: Wave Impedance as Function of Distance

Power flux density can be found as such:

$$S = \frac{|E|^2}{\eta} \tag{8}$$

Power flux density is measured in W/m^2, so finding power requires multiplying by area. Applying to equation 8,

$$P = SA = \frac{|E|^2}{\eta} A \tag{9}$$

In this case, the important value is the maximum electric field intensity measurement, knowing that it reflects a ±3dB change in that area. For 21.448MHz, this is 5.450820792079210 V/m and for 24.930MHz, this is 5.027207623762377. 240sqft is 22.2967m^2. Thus, equation 9 can be employed as follows:

$$P_{r_{21.4MHz}} = \frac{|5.45082|^2}{285.757}(22.2967) = 2.3183W \tag{10}$$

$$P_{r_{24.9MHz}} = \frac{|5.02721|^2}{336.120}(22.2967) = 1.6765W \tag{11}$$

Similarly, this can be found for the desired 200V/m:

$$P_{r_{21.4MHz}} = \frac{|200|^2}{285.757}(22.2967) = 3121.1W \tag{12}$$

$$P_{r_{24.9MHz}} = \frac{|200|^2}{336.120}(22.2967) = 2653.4W \tag{13}$$

4 Summary

If all other conditions are kept the same, it would be expected that 3.1211kW would be required to achieve 200V/m (±3dB) in a 40x6ft area at 21.448MHz. 2.6534kW would be required to achieve 200V/m (±3dB) in a 40x6ft area at 24.930MHz.

The losses due to reflection are very small because the VSWR is so low at all frequencies, but the balun loss is significant. Balun losses could be eliminated by employing a 75Ω matched system, and the transmit power required would halve.

When discussing scalability to up to 10kW transmit power, these are very promising results. Even with the balun, only 3.5kW would be necessary to ensure at least 200V/m is delivered in this 40x6ft area. Without the balun, only 2kW transmit power would be necessary.