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A Compact Active Monitor Antenna for HF Spectral Occupancy Measurements

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Abstract

This paper presents a short dipole active HF monitor antenna which has been designed and developed during a Spectral Occupancy research project where limited space imposed a limitation. This short dipole is very lightweight and compact, as a result, it can be easily installed either vertically or horizontally on any mast. The active dipole's efficiency has been optimized based on a two-stage low noise amplifier. The first stage of this LNA cancels the high capacitive reactance of the antenna's impedance. The second stage operates as a common emitter amplifier in order to provide the required Gain to the receiver.

1. Introduction

A directional monitor antenna was to be built last year during a research project concerned HF Spectral Occupancy and azimuthal interference monitoring over the Eastern Mediterranean [1]. It had to be very compact with a high Front to Back ratio response between 20-30MHz. Finally, a phased array antenna consisting of two active dipoles has been constructed with very good results [2][3]. One of the key parameters to the success of the antenna was the single element's characteristics i.e. the active dipole which is analysed in depth in this paper below. From the test results presented in the following section, it has been confirmed that the dipole performs very well between 5-30MHz despite the fact that is short. As it is well known in shortwaves, the dimensions of a dipole antenna are very important since the wavelengths are huge. That is, as the dimensions of a dipole become smaller with respect to the wavelength, its radiation resistance decreases consistently. Further, the impedance of the short dipole is dominated by a high capacitive reactance which has the effect of reducing its efficiency. One way to increase the efficiency of a short antenna is to cool it as to become superconductive [4]. Since this method is not of great practical use, different other ways should be explored. As a good begging in this research is to investigate the efficiency of a short dipole when is matched to 50Ω. To design a matching network for a shortwaves passive short dipole antenna like for instance, the reactive L low pass illustrated in figure 1, it would be require an inductor with very high reactance since there is a large capacitance that must be cancelled. Such a highly inductive coil must be wound on a core which exhibits losses. Other losses will also result from the copper's resistance and the A.C resistance of the inductor's wire as well. All these losses added up to an overall significant resultant loss that deem the importance of the matching network questionable. This is one of the main reasons that a passive small antenna is of low efficiency. To clarify these aspects in the subsequent sections we analyse such an approach along with other considerations affecting the antenna efficiency.

2. The Passive Short Dipole Analysis

As the first step, the Eznec antenna software has been used to simulate the impedance of a dipole λ/12. The simulated impedance of the mentioned dipole at 5MHz is around Z= 1.2-j3659Ω. Without incorporating a matching network the coupling loss of this dipole when is connected directly to the 50Ω input port of a receiver is around 31dB over to a corresponding half-wave dipole which is fully matched and has no return loss. The equivalent circuit of the dipole is composed by the source V1 in series with the resistor R1 and the capacitor C1 as illustrated in Figure 1. The loss resistance of the dipole is not yet taken into account.

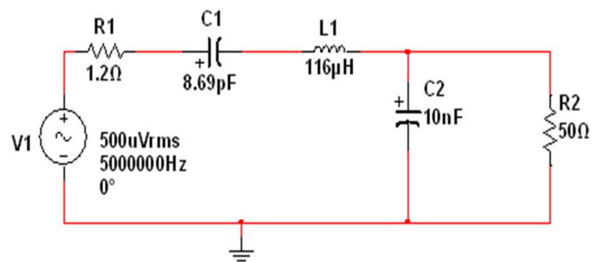

Figure 1. The Output Impedance of the Short Dipole Matched to 50Ω

According to Figure 1, R1 represents the radiation resistance of the short dipole and C1 is its capacitive reactance. L1 and C2 constitute a typical LC network which matches the antenna impedance to 50Ω. The frequency response of the matching network has been simulated by Multisim and is given in Figure 2. Based on the simulation results below, the short dipole presents a very narrow bandwidth. This is because the discussed network has an extremely high Q, therefore, can operate properly only at the frequency which is tuned.

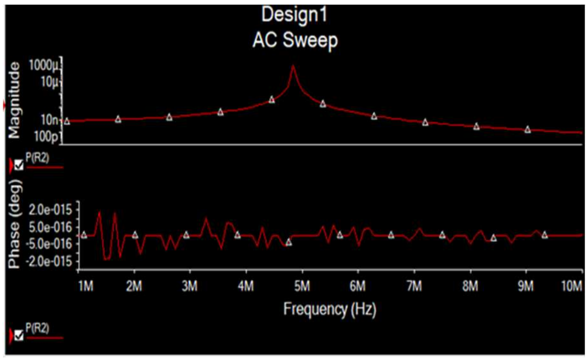

Figure 2. The Frequency Response of the Short Dipole's Matching Network

Other broadband matching networks cannot be applied due to the high capacitive reactance and the very low radiation resistance of the dipole's impedance. In this respect, a very important factor that must be discussed regarding the dipole's efficiency is the inductor's resistive loss of the matching network in Figure 1.

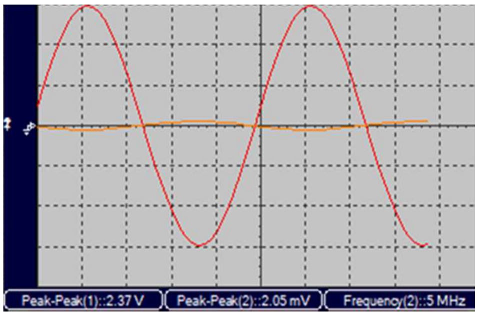

Figure 3. Potential Difference across the Inductor L1 based on Oscilloscope's Measurements.

Figure 3 presents a two-channel oscilloscope which its probes connected across the inductor L1. The potential difference across the inductor is 2.36V i.e. 4720 times higher than the reference source's voltage, which is 500uV. In this respect, the current flowing through the inductor L1 is therefore 42 times higher than the current of a 50Ω dipole antenna that is matched to a 50Ω load. The power loss of the inductor L1 certainly depends on its quality factor but is very high. It is expressed as the current squared times the inductor's resistance. The analysis above is still incomplete since it only considers the coupling loss between the antenna and the receiver. It is worth noting that beyond the coupling losses mentioned above the efficiency of the dipole depends also on its radiation resistance as well as the resistive loss of the material which has been constructed as is given in equation 1 [5]. Having as reference a traditional fully matched 50Ω half wave dipole of efficiency around 98%, its resistive loss as calculated by equation 1 is 1Ω. In this respect, using equation 1, the λ/12 dipole's efficiency is computed 54% assuming that the resistive loss of the short dipole remains identical to that of a half-wavelength dipole.

$$\text{Efficiency} = \frac{Rr}{Rr+Rl} \qquad (1)$$

Where:
Rr is the radiation resistance of the dipole.
Rl: is the resistive loss of the antenna.

Without taking into account the matching network loss which has been analysed previously, the Gain of a short dipole antenna can be computed based on equation 2 below:

GAIN=DIRECTIVITY X EFFICIENCY (2)

The Gain of a λ/12 short dipole using eq.2 has been claculated as -0.62dBi over the Gain of the half-wave dipole which is 2.12dBi. In other words, summarizing all of the above mentioned key parameters, the overall Gain of the passive short dipole discussed in this paper, including all losses expressed in a single equation is given as follows:

Final Gain(dBi):2.15dB-(Le+Lind+Lg) (3)

Where:
Le: Efficiency loss (dB)
Lind: Coupling loss between antenna and receiver (dB)
Lg: General losses (dB) - cables connectors etc.

3. The Active Short Dipole Analysis

For a short dipole monitor antenna to be efficient and broadband is vital. Alternatively, its efficiency and bandwidth can be enhanced by the use of a built in active circuit. The success of this approach lies on the proper interface between the antenna with the active circuit which is intended to be an integrated part of the dipole. For instance, a key point is the compensation of antenna losses analysed earlier. For the proper design of this active compensator circuit, the impedance of the dipole must be computed at the low, middle and high frequency range of the HF band. However, to simulate the impedance values the optimum dimensions of the dipole must first be determined based on the principle that as the size of the dipole decreases, so does its efficiency. On the other hand, the length of the HF dipole cannot be very long as this will not be practically feasible. A good trade-off between the size and performance of the dipole, is to be constructed at half-wavelength at 30MHz, i.e. five meters long using 8mm diameter aluminium round tubes in order to be very light in weight. Finally, a dipole of this size can easily be installed vertically or horizontally on any mast. Since the length of the dipole has been determined the impedance was simulated as shown in Table 1. In this respect, a very important factor that has been taken into account for the next step of the active dipole's design concerns the LNA properties. For instance, if the signal generated by the dipole at the LNA's input, is weak and noisy, noise will also be amplified. Therefore, a traditional 50Ω LNA will not provide any significant benefit to the performance of this active antenna especially below 15MHz. It is because of the losses which will be caused due to the high capacitive reactance of the dipole's impedance loaded by the low input impedance of the amplifier. Alternatively, a very high impedance amplifier can provide an excellent compensation of the high reactive component of the dipole's impedance in order to significantly improve the performance of the short dipole.

Table 1. Short Dipole Parameters Versus Wavelength

Frequency	Impedance	Coupling Loss (50Ω)	Efficiency	Dipole Length	Total Gain
30MHz	74+j5.4	-1.87dB	98%	λ/2	0.21dB
15MHz	18-j764	-17.7dB	94%	λ/4	-15.7dB
10MHz	7.58-j1409	-23dB	88%	λ/6	-21.3dB
5MHz	1.2-J3659Ω	-31dB	54%	λ/12	-31.4dB
1.8MHz	0.29-j8595	-58dB	22%	λ/33	-62dB

A common drain JFET amplifier as illustrated in Figure 4 can be a very good solution. As it is well known, the JFET is a semiconductor device that inherently has a very high input impedance especially when operating as a common drain amplifier [6]. A common drain amplifier exhibits a very limited Miller capacitance effect especially when operating in the HF Band.

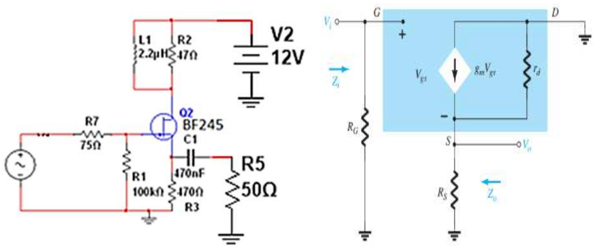

Figure 4. The circuit diagram of a Common Drain Amplifier and the Equivalent Model

This means that the input impedance of the JFET amplifier will be very high across the entire HF band. In this respect, the bode plot diagram of the single stage common drain amplifier simulated using the dipole impedance values of Table 1 is presented in Figure 5. It is justified by figure 5 that its response is almost constant across the entire HF Band. As a result, the high capacitive reactance of the dipole impedance has no influence on the amplifier performance. The complete two-stage amplifier is presented in Figure 6. Because the dipole is a balanced antenna, a 1:1 impedance ratio transformer is used to convert it to unbalance. The resistor R7 is used to discharge the dipole. Since the common drain is a unity voltage gain amplifier, a common emitter amplifier is used to amplify the signal at the desired level as shown in Figure 6. The output of the two stage LNA is illustrated in Figure 7.

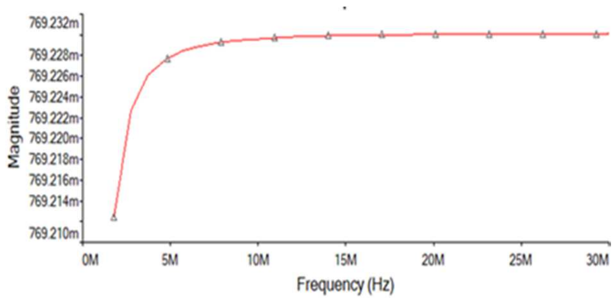

Figure 5. The Frequency Response of the Common Drain Amplifier Simulated Based on the Impedance Values of Table 1

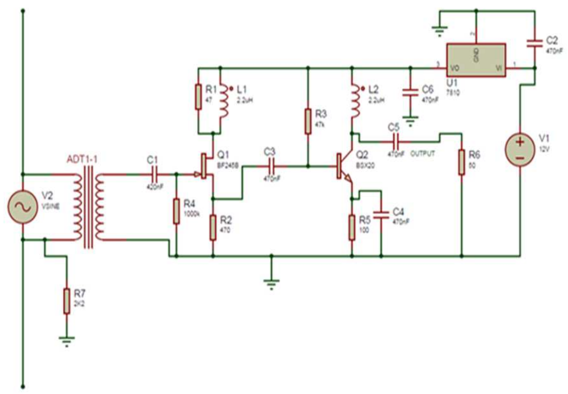

Figure 6. The Completed Two Stage LNA

Although the Gain of the amplifier is decreasing consistently due to the Miller effect on the second stage, this will not affect the performance of the dipole. That is, the efficiency of the dipole is proportional to the increase in frequency resulting in lower compensation being needed.

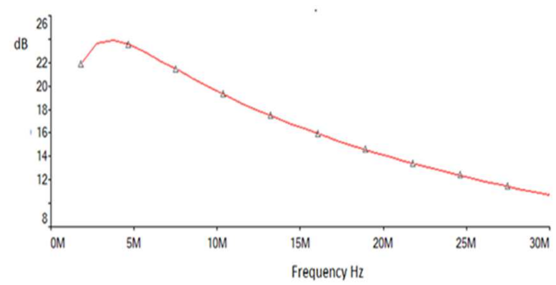

Figure 7. The Output Response of the Two stage LNA

4. Test results

To validate the HF dipole active antenna as illustrated in Figure 8, we used a Rohde & Schwarz (R&S) EM510 HF digital wideband receiver and dual polarization (HE016) active antenna[7][8]. Since the short dipole under test has been mounted horizontally polarized as illustrated in

Figure 8 the omnidirectional turnstile component of the R&S HE016 antenna, capable of receiving HF signals at high incident angles, was used. It is evident that the active dipole antenna presents a very good performance in terms of receiving signals from 5-30 MHz as illustrated in Figure 9. Figures 9 (a) and (b) present the display of the Rohde & Schwarz (R&S) EM 510 HF digital wideband receiver when connected to the turnstile component of the R&S HE016 antenna and the short dipole antenna examined in this respectively. The results between the two antennas cannot be 100% identical since the (HE016) is an omnidirectional antenna whereas the short dipole's pattern is bidirectional. However, based on the incoming signals from the same direction which appear in both charts in common, the short dipole's response is very satisfactory.

Figure 8. The active array under test installed on a temporary mast.

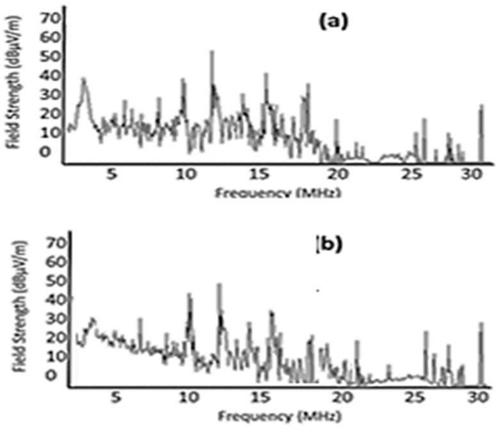

Figure 9. a) Test Results of the HE016 b) Test results of the active dipole

5. Conclusion and Future Research

The dimensions of a dipole antenna is a very crucial design factor for any band. Particularly, in the HF band is much more important because the length of the dipole elements must be very long in order to achieve a good performance. This factor becomes even more crucial for frequencies lower than 15MHz. Therefore, a future research direction will be to upgrade the efficiency of the short active dipole monitor antenna based on two vital key parameters. That is, by using the minimum loss materials for antenna elements and by optimizing a new ultra-high input impedance flat frequency response LNA. The noise figure of this LNA is a very important aspect that must also be considered.

6. Acknowledgment

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