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A Compact Two-Element HF Active Phased Array Antenna

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Abstract

One of the most vital issues regarding the installation of HF antennas is their sizable dimensions. This is because an HF antenna must be designed around the proper wavelengths to operate at a satisfactory efficiency, especially when a certain level of directivity is also a requirement. Although an HF short dipole's efficiency is lower than the half wave dipole, it can be enhanced by the use of active circuits for usable monitoring purposes. Directional HF antennas, like the Yagi, that employs passive elements such as reflectors and directors cannot be shorter than the proper dimensions and still function properly. A similar limitation applies for the dipoles of the Log Periodic antenna. This paper presents the design and preliminary testing results of a linear polarization HF monitoring very compact lightweight active phased array that produces a radiation pattern with a sufficient front-to-back ratio specially designed to be installed in locations where limited space imposes a limitation.

1 Introduction

The design of antenna has been implemented in the frames of a research project to perform a directional (azimuthal) investigation of interference at HF. The lack of affordable compact antennas to meet the project requirements was the incentive to develop a compact unidirectional antenna, with the maximum possible front-to-back ratio at frequencies $\leq$ 10 MHz where the dimensions of traditional passive antennas are enormous [1]. Therefore, the antenna has been designed and developed to meet the space limitations at the monitoring site which did not allow the deployment a traditional HF directional antenna that employs a very long boom and elements. As a result, the innovation of this phased array active antenna lies on the fact that it can be installed almost anywhere because it is very lightweight and compact. Further, it is very simple to be constructed, fairly wideband but most importantly, enables reception from horizontal or vertical polarization incoming signals because the dipoles' elements that employs are short and can be very easily arranged on vertical or horizontal direction on any mast. This compact directional antenna is particularly suitable for monitoring directional HF incoming signals due to limited space at a certain installation location.

2 Numerical Analysis and Simulation.

This phased array design is based on two HF short active dipoles mounted on a quarter-wavelength boom, with 90-degrees phase difference feed. Furthermore, it has been

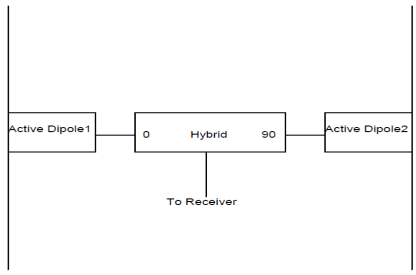

Figure 3. The basic sections of the HF active phased array.

taken into account that the radiation pattern of a short dipole is almost identical with that of a half wave dipole [2]. As a result, the radiation pattern of two equal amplitude end-fire short dipoles phased array does not depend on the length of the dipole's elements but strictly on the phase difference and the distance between them as shown by equations below [2][3][4]. The phase of the array in a given direction is given in equation 1:

$$\psi = \frac{2\pi S\lambda sin\theta}{\lambda} - \Delta\Phi \quad (1)$$

The array factor for N isotropic elements is given by equation 2:

$$A.F = \frac{\sin\left(\frac{N\Psi}{2}\right)}{N\sin\left(\frac{\Psi}{2}\right)} \quad (2)$$

where

ΔΦ: Phase difference between the elements
AF: Array Factor
N: Number of elements
Θ: The angle of radiation
Sλ:The distance between the elements in terms of λ
λ: wavelength

Table 1. Different distance of the two horizontal polarization short dipoles (L=3.2m) 90 degree phase difference feed, dipole elements' diameter 8mm simulated by Eznec.

Boom Length(Meters)	Frequency(MHz)	F/B (dB)	HPBW (Degrees)	HPBW (Degrees) H Plane	Directivity(dBi)
10	2	3.75	271.4	85.2	3.08
10	5	11.45	187	84	4.31
10	8	52	179.8	92.8	4.62
10	10	35	179.8	116	4.63
10	13	48	180	145	4.64
10	15	60	88	155	4.65
10	18	38	56	163	4.66
10	20	23	48.5	168	4.66
10	25	34	105	-77	4.72
10	30	31	29	174	4.76
Boom Length(Meters)	Frequency(MHz)	F/B (dB)	HPBW (Degrees)	HPBW (Degrees) H Plane	Directivity(dBi)
7.5	2	2.77	280	85	2.77
7.5	5	7.67	201	84	3.93
7.5	8	16	182	85	4.5
7.5	10	62	180	86	4.63
7.5	13	53	180	115	4.64
7.5	15	31	180	133	4.64
7.5	18	31	180	145	4.66
7.5	20	55	90	154	4.68
7.5	25	27	53	163	4.71
7.5	30	42	96	-71	4.77

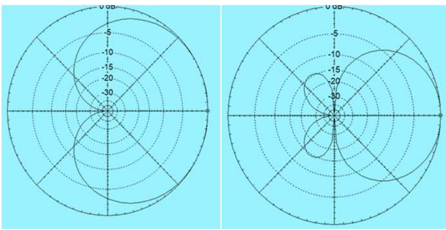

Figure 3. The E and H Plane radiation pattern of a λ/4 phased array at 10MHz 90^0 phase difference feed simulated using equations (1) and (2).

5 Active Dipoles Design and Simulation.

The dipoles' efficiency determines the sensitivity of the array, therefore it is an important parameter to be considered. The short dipole length determines the real and imaginary part of its output impedance. The efficiency of the dipole can be calculated then by equation 3 below:

$$\eta = \frac{Rr}{Rr+Rl} \tag{3}$$

where Rr is the radiation resistance and Rl the loss resistance. Using Eznec simulation, the theoretical output impedance of various short dipole lengths and the perspective coupling losses to a 50Ω receiver's input port is presented on table 2 below:

Table 2. The impedance of a short dipole as a function of frequency and losses.

Frequency	Impedance	Length of Dipole	Attenuation (dB)
2MHz	0.18-j9942Ω	λ/47	40
5MHz	0.7-j4415Ω	λ/19	32.8
10MHz	3.16-j2128Ω	λ/9	26.5
15MHz	7.17-j1330Ω	λ/6	22.5
20MHz	12.91-j903Ω	λ/4.5	19
25MHz	j20.49-j625Ω	λ/4	16
30MHz	j30.07-421Ω	λ/3	12.6.

The efficiency of a passive short dipole is expected to be very poor. In addition, coupling losses presented on table 2 are apparently due to the mismatch between the output impedance of the antenna and the 50Ω input impedance of the receiver. In order to minimize these losses, the high capacity reactive component should be eliminated using a high Q inductor but such an inductor occupies space, is narrowband as an L matching network and introduces additional losses [5]. Alternatively, a low noise amplifier has been adapted to solve the problem and is illustrated in Figure 2. It consists of two stages. The first stage which acts as an impedance transformer is a self-bias emitter follower JFET (2N3819) and the second stage is a robust low noise, 30dB gain, Mini Circuit's amplifier MAR-8A+. Instead of using the high Q inductor, the high input impedance of the JFET stage minimizes the effect of the high capacitive component of the short dipole's impedance preventing a significant voltage drop at the input of the LNA. Furthermore, the low output impedance of the emitter follower JFET buffer stage is almost matched to the 50Ω input impedance of the MAR-8A+. The MAR-8A+ is used because it is a high gain robust LNA that ensures a 50Ω output impedance to the 50Ω input port of the 90 degree hybrid (splitter/combiner PSCQ-2-51W+) at which both dipoles are connected to it. The two-stage LNA illustrated in Figure 2, has been designed to run at a low power consumption (≈35mA) and very reliable operation in order to withstand weather temperature changes.

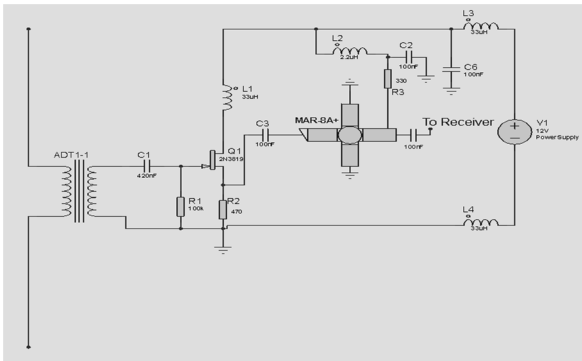

Figure 2. The schematic of the two-stage Low Noise Amplifier.

6 Design and Testing of the Active Dipole

The results of testing the first stage as a broadband active matching network are illustrated in Figure 3. The circuit has been tested at 2MHz which according to table 2 corresponded to the worst coupling losses of the short dipole as can be modelled to a source with a series impedance of 0.18-j9942Ω. The red sinusoidal waveform is the voltage produced from the signal generator, the blue is the voltage at the input of the 2N3819 that has been reduced because of the series impedance of the antenna and the yellow is the output voltage on the 50ohm load which is the input of the next stage that is MAR-8A+. According to the oscilloscope in Figure 3, the losses have been improved from -40dB to -10dB. Taking into account the gain of the MAR-8A+

compensates completely the coupling losses from the low output impedance from the dipole. Finally, the frequency response of the two-stage LNA from 2MHz to 110MHz has been tested by the use of a broadband noise generator and is illustrated in Figure 4. The small ripple that is observed at the spectrum analyser will not affect the performance of the active antenna because the LNA's gain is much higher than required, which can be used to compensate for long cable losses, connectors and hybrid losses as well. The Gain of the LNA can be controlled if necessary by varying the supply voltage from 5-15 V DC. The spectrum analyser used for testing the active dipole's LNA is an Advantest U3751. Testing the sensitivity of the active dipole on

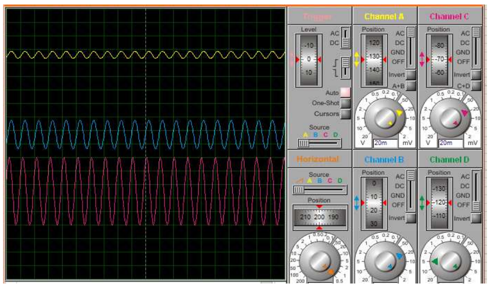

Figure 3. The results of testing the JFET as a broadband active matching network.

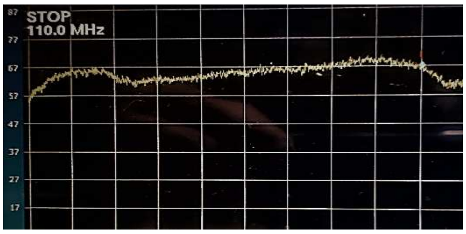

Figure 4. Testing the frequency response of the two stage LNA using the Advantest U3751 Spectrum Analyser.

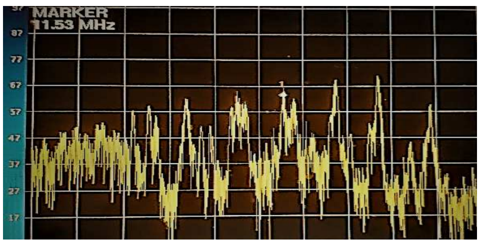

Figure 5. Testing free on air HF signals detected utilizing the active dipole antenna and the Advantest U3751 Spectrum Analyser.

real-world conditions has been implemented by monitoring free on air over the horizon HF incoming signals that can cause interference to the local network.The dipole has mounted on a temporary mast horizontally as illustrated in Figure 6. Firstly has been tested by removing the active circuit and connecting the passive dipole directly on the spectrum analyzer. As it has been justified from table 2 earler, the reception was very poor as it was expected.By connecting the active circuit back, the dipole's efficiency has enhanced dramatically and the results from Advantest U3751 are presented in Figure 5.

Figure 6. The active dipole as a single element.

7 Phased Array Test Results

Testing a prototype array in the lower HF band, according to Table 1, requires to begin with a boom ranging from 7 to10 meters long. A mast to be installed that is ideally above 15 meters is also required and a tower climber to elevate in order to optimize the antenna while it is mounted on the mast. Because the major target of this paper is to explore the array's front-to-back ratio versus bandwidth, it should be also tested in the far-field zone by installing a signal generator in a location for which $r \gg 2\lambda$ and by receiving free on air incoming signals as well. For all these reasons, it has been decided to optimize the array by constructing it first at a 10 times higher frequency by scaling the elements of the two active dipoles and the distance between them at the same wavelengths analogy, as it would operate at 10 MHz. As a result, an array with a short boom is much easier to be tested and optimized primarily mounted on a tripod given as follows. Scaling at 100 MHz the dipoles elements' diameter from 8mm it becomes 0.8mm, the length of the dipoles from 320cm becomes 32cm and the distance between them from 8 meters 80cm. The array has been installed at 1.7 meters above the ground (that corresponds to 17 meters mast for HF) in the middle of a temporary aluminium mast as illustrated in Figure 7.

Figure 7. The active array under test installed on a temporary mast.

First test was conducted by receiving random free on air signals transmitted from a known location in order to test the active array by rotating it in three angles as given below:

Table 3. Random free on air signal transmitted from a known location

Frequency MHz	0	90	180	Eurostick Omnidirectional
88.2MHz	45dBuV	27dBuV	20dBuV	45dBuV
94.8MHz	50dBuV	36dBuV	43dBuV	47dBuV
101.1MHz	46dBuV	40dBuV	30dBuV	37dBuV
104.8MHz	47dBuV	44dBuV	40dBuV	38dBuV

The readings were monitored using the Advantest U3751 spectrum analyser. The mentioned signals was also measured by replacing the array with a Eurostick broadband omnidirectional antenna in order to test the sensitivity of the array as is illustrated in Table 3 as well. From the first results was obvious that the array provides a good efficiency and a countable front-to-back ratio. The effect of rotating the array zero, hundred, and eighty

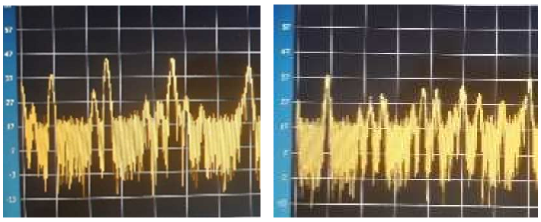

Figure 8. Free on air signals before and after rotating the array 180^0 using the Advantest U3751 Spectrum Analyser.

degrees is also given In Figure 8 where it presents the spectrum analyser recording of free on air signals. In addition, a second test was executed by installing a 10dBm signal generator connected to a Eurostick broadband omnidirectional antenna. The distance between the transmitter and the antenna was 15 meters far away. The readings were monitored using the Advantest U3751 spectrum analyser. The results by rotating the array zero, ninety and hundred eighty degrees are given in Table 4.

Table 4. Spectrum analyser's readings of rotating the array.

Frequency MHz	0	90	180
60	27dBuV	0	10dBuV
70	32dBuV	17dBuV	20dBuV
80	43dBuV	36dBuV	33dBuV
90	42dBuV	22dBuV	26dBuV
100	28dBuV	25dBuV	20dBuV
110	22dBuV	22dBuV	18dBuV
120	35dBuV	31dBuV	18dBuV
130	35dBuV	31dBuV	34dBuV
140	35dBuV	28dBuV	32dBuV
150	33dBuV	30dBuV	32dBuV

8 Conclusions

Based on these preliminary measurements, it has been justified that the array is operating satisfactorily in terms of efficiency but also provides a respectful front-to-back ratio within a bandwidth of $\pm$35%. Provided that the measurements that were conducted are applied at 10 times lower corresponding frequencies in the HF Band, then the antenna can operate with a good frond-to-back ratio between 6-12 MHz with center frequency of approximately 9 MHz. However, this issue requires to be further explored because, based on Eznec simulation that is given in table 1, the front-to-back ratio should be wider. In this respect, as a future research target is to increase the array's front-to-back ratio's bandwidth by investigating the installation of another one pair of active dipoles 90 degree phase difference feed on the same boom with different center frequency. The degree of the metallic mast's effect should be explored as well. However, the fundamental and most important factor is that the array discussed in this paper as it is presented, contributes to overcome a vital problem about the installation of traditional HF monitoring antennas in locations where limited space imposes a limitation. Particularly at frequencies lower than 10 MHz, a good front-to-back ratio can be obtained only by using antennas that their elements' dimensions are enormous. The aforementioned makes their installation very difficult especially for reception of vertically polarized waves. The important key benefit of this array is that employing short active dipoles makes it ideal for receiving vertical or horizontal polarization signals at very low frequencies in the HF band as can be very easily arranged on vertical or horizontal direction on any mast.

9 Acknowledgment

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