STUDY OF ARRAY BI-CONICAL ANTENNA FOR DME APPLICATIONS

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ABSTRACT

This paper introduces a new configuration of array bi-conical antenna to enhance the gain of an antenna for Distance Measuring Equipment (DME) avionic system. Due to its large size, the antenna can be placed in terrestrials DME stations. The antenna consists of the bi-conical elements placed in a linear configuration. The simulated maximum gain is 10.2dB, the antenna operates in the DME band (960 – 1215 MHz). Al the simulations are performed with CADFEKO a Method of Moments based Solver.

KEYWORDS

DME, Array antennas, Bi-conical Antennas

1. INTRODUCTION

Distance Measuring Equipment (DME) is a Radio Navigation technology that measures the slant range (distance) between an aircraft and a ground station by timing the propagation delay of radio signals in the frequency band between 960 and 1215MHz. Line-of-visibility between the aircraft and ground station is required. An interrogator (airborne) initiates an exchange by transmitting a pulse pair, on an assigned ‘channel’, to the transponder ground station. The channel assignment specifies the carrier frequency and the spacing between the pulses. After a known delay, the transponder replies by transmitting a pulse pair on a frequency that is offset from the interrogation frequency by 63 MHz and having specified separation. The DME consists of two parts, the first one is embedded on the aircraft and the other is installed in ground stations [1-5]. The design of a DME system encounters several challenges among which: the development of signal analysis algorithms for signals coming from aircrafts and the design of antennas with very high gains in order to cover a long range. The purpose of this paper is the design of an operational array antenna for DME ground stations.

2. DISTANCE MEASURING EQUIPMENT PRESENTATION

DME is an international, standardized navigation system. It allows an aircraft to automatically measure its physical line of sight distance (in nautical miles) from a selected ground-based beacon (Figure 1).

DME systems are used throughout the world by all airliners, most military aircraft, and a large number of general-aviation aircraft. The range of service is most often up to 300 land miles (480

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km). System accuracy is usually 0.1 nautical miles (185 m) but precision equipment, intended for use during landing, has accuracy up to 100 ft (30 m). The airborne equipment, called an interrogator, transmits pulses of 1 kW peak power on 1 of 126 frequencies. These frequencies are in the 1025–1150-MHz band and are spaced 1 MHz apart (Figure 2). Each pulse has a duration of 3.5 µs and is paired with another, spaced 12 µs (X Mode) or 36 µs (Y Mode) (i.e. “delayed” by either 12 or 36 µs) (Figure 3).

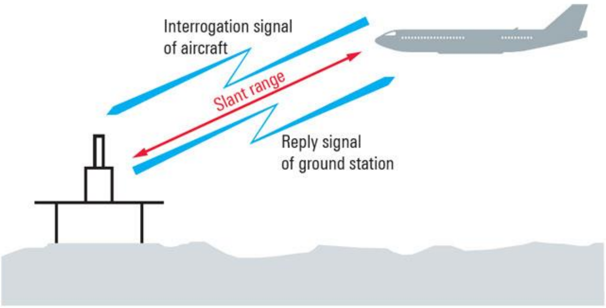


Figure 1. DME System

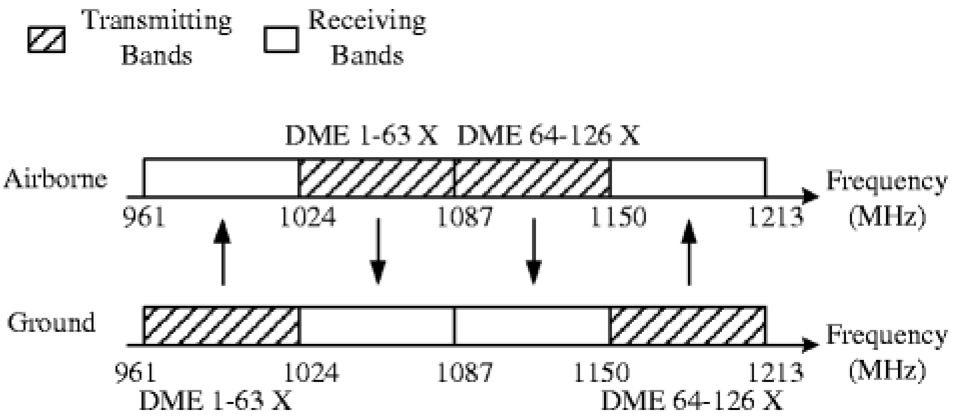


Figure 2. Frequency band and channels

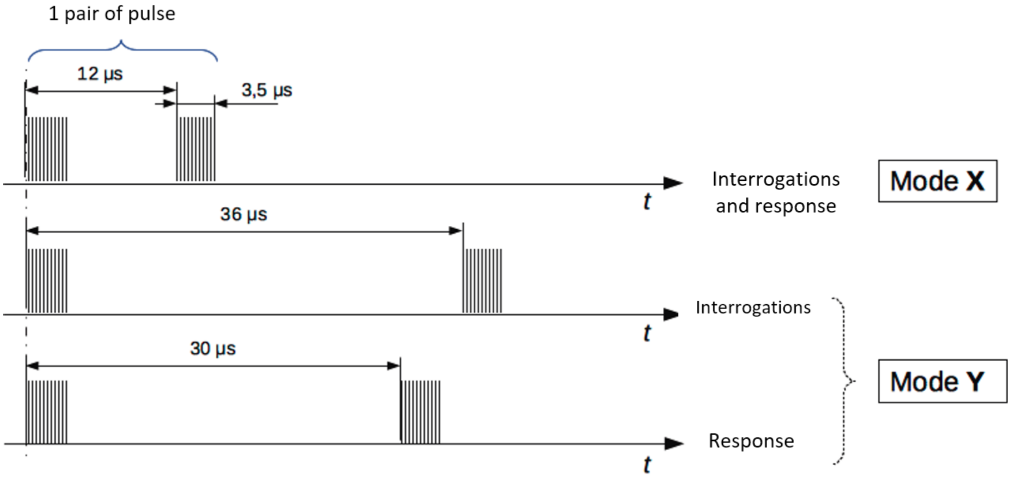


Figure 3. The two DME Modes X and Y

The combination of frequencies and pulse spacing therefore provides 252 operating channels in the system. The beacon equipment on the ground is called a transponder. It receives these pulses, delays them by 50µs, and then retransmits them, usually with a power of 1 kW, on 252 frequencies lying between 962 and 1213 MHz. The pulse-pair spacing is 12µs on those frequencies not used by the interrogator (X Mode), and 36µs on those frequencies shared with the interrogator (Y Mode) (Figure 3). The transponder transmission is called the reply. The frequency difference between interrogation and reply is always 63MHz. This arrangement allows each transmitter frequency to act as the local oscillator for its associated receiver, the intermediate frequency of which is 63MHz. For landing purposes, some transponders have powers as low as 100W. In the aircraft the replies to its own interrogations are recognized by their phase coherence with their own transmissions, and by the elapsed time measured between transmissions and reception (minus the 50µs transponder delay), usually by means of a crystal clock. This elapsed time is about 12.36µs for each nautical mile, and the measured distance is displayed in the cockpit on a digital meter, which is usually calibrated in nautical miles and tenths of nautical miles (Figure 4). We can find one or more DME system in an airplane [1-5].

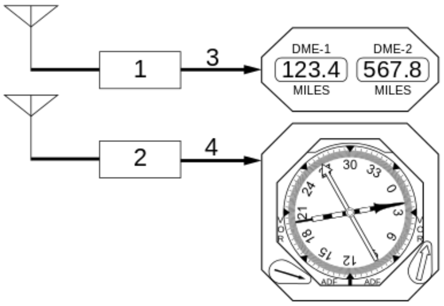


Figure 4. DME meter

3. BI-CONICAL ANTENNA ANALYSIS

The bi-conical antennas can be divided into two types according to their cone length (l), one is infinite length bi-conical antenna, and another is finite one, as illustrated in Figure 5. When the half-cone angles $\theta_1=\theta_2$, the bi-conical antenna is called symmetrical bi-conical, otherwise the antenna is asymmetrical bi-conical [6-8].

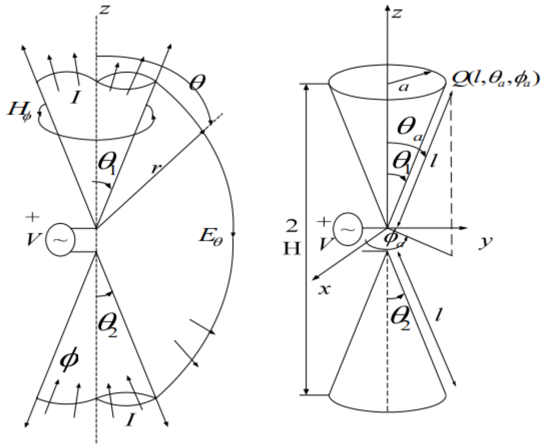


Figure 5. Infinite length and finite length bi-conical antenna [2-3]

The bi-conical antenna is most readily handled in spherical coordinates. If the dominant fields are satisfied for a spherical TEM mode condition with respect to the r-direction, the fields E_θ and H_φ in the infinite bi-conical horn antenna are:

$$E_\theta = \frac{V_0 e^{-jkr}}{r\sin\theta \cdot \ln\left\{\left(\cot\frac{\theta_1}{2}\right)\left(\cot\frac{\theta_2}{2}\right)\right\}} \qquad (1)$$

$$H_\varphi = \frac{V_0 e^{-jkr}}{\eta \cdot r \cdot \sin\theta \cdot \ln\{(\cot\frac{\theta_1}{2})(\cot\frac{\theta_2}{2})\}} \qquad (2)$$

At point Q(l, θ_a, φ_a) , when driving voltage is V_0, from the equivalent Huygens source and the wavefront field given by (l), the radiation field dE_θ of the infinitesimal aperture is :

$$\begin{aligned} dE_\theta = {} & \frac{-jkl^2 e^{-jkr}}{4\pi r} \\ & \cdot \exp\left\{-jkl\left[\sin\theta\sin\theta_a\cos(\phi-\phi_a)+\cos\cos\theta_a\right]\right. \qquad (3) \\ & \cdot E_{\theta_1}\left\{\sin\theta\sin^2\theta_a+\cos\theta\cos\theta_a\sin\theta_a\cos\left(\phi-\phi_a\right)\right\} \\ & +\sin\theta_a\cos\left(\phi-\phi_a\right)d\theta_a d\phi_a \end{aligned}$$

Where the field $E_{\theta 1}$, is the same field as the infinite bi-conical horn antenna at the cone length *l* (along the surface), and the $E_{\theta 1}$ is from (1)

$$E_{\theta_1} = \frac{V_0 e^{-jkl}}{l\sin\theta \cdot \ln\left\{\left(\cot\frac{\theta_1}{2}\right)\left(\cot\frac{\theta_2}{2}\right)\right\}}\,. \qquad (4)$$

Therefore, radiation field E_θ of the asymmetrical bi-conical horn antenna from (2) and (3) reduces to

$$\begin{aligned} E_\theta = {} & \int_0^{2\pi} d\phi_a \int_{\theta_1}^{\pi-\theta_2} dE_\theta d\theta_a \\ & \frac{jklV_0 e^{-jk(r+l)}}{2\cdot r\cdot \ln\left\{\left(\cot\frac{\theta_1}{2}\right)\left(\cot\frac{\theta_2}{2}\right)\right\}} \cdot \left[\int_{\theta_1}^{\pi-\theta_2} e^{jkl\cdot\cos\theta\cdot\cos\theta_a}\right. \qquad (5) \\ & \cdot\{\sin\theta\sin\theta_a J_0(kl\sin\theta\sin\theta_a) \\ & \left. +j(1+\cos\theta\cos\theta_a)J_1(ka\sin\theta\sin\theta_a)\}\,d\theta_a\right] \end{aligned}$$

Where J_n (n=0, 1) is first kind of Bessel function.

By numerically integrating over the antenna aperture, the radiation patterns are obtained for an asymmetrical bi-conical horn antenna. The total field of the array is determined by the vector sum of the fields radiated by the individual elements.

The input impedance of single finite length symmetry bi-conical antenna is [5]

$$Z_0 = \frac{\eta}{\pi}\ln\left(\cot\frac{\theta_1}{2}\right) \qquad (6)$$

In addition, the input impedance of single finite length asymmetry bi-conical antenna is [5]

$$Z_1 = \frac{\eta}{2\pi}\ln\left[\left(\cot\frac{\theta_1}{2}\right)\left(\cot\frac{\theta_2}{2}\right)\right] \qquad (7)$$

Where η is transmission medium impedance, and when medium is free space, η=367.7Ω≈120πΩ.

The total antenna array impedance at a driving point is the parallel combination of terminal impedances as described in (7).

$$Z_{array} = \frac{1}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_3}+\ldots+\frac{1}{Z_N}} \qquad (8)$$

Where N is the number of bi-conical linear array element. All the impedance in this paper is set according to (8).

4. DESIGN OF LINEAR ARRAY BI-CONICAL ANTENNA

4.1. The single element bi-conical antenna

As shown in figure 6, the single element bi-conical antenna is composed of two cones each one have a height (H) and a radius (R). (Figure 6). After design and optimisation with CADFEKO a Method of Moments (MoM) based solver [14], the values of H=44mm and R=15mm. As shown in figure 7, the antenna operates in the band of 960-1215MHz which can make it an adequate solution for the DME system. But as show in figure 7(b), the gain is not big enough.

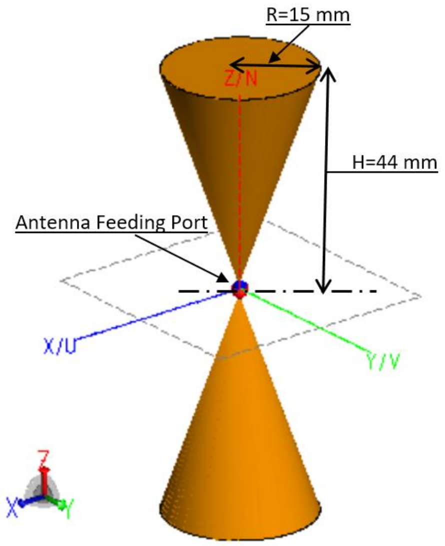
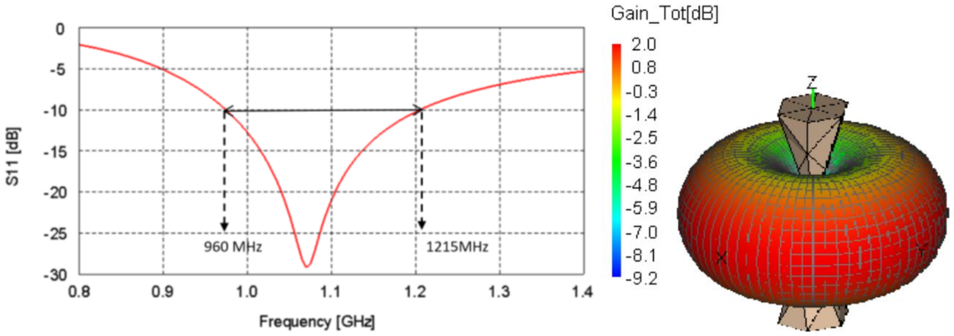


Figure 6. The geometry of single bi-conical antenna



(a) S_{11} parameter (b) 3D gain pattern

Figure 7. The Simulated S_{11} parameter (a) and the simulated 3D gain pattern of single bi-conical antenna (b)

4.2. Two elements bi-conical antenna

After optimisation with CADFEKO, the two elements of bi-conical antenna is composed of two bi-conical elements separated by D=0.75*λ=204mm (λ for the resonance frequency f=1.07GHz) (Figure 8). Figure 9 shows the S_{11} and S_{21} parameters versus frequencies, the antenna operates in the band of 960-1215MHz which can make it an adequate solution for the DME system. The S_{22} and S_{12} parameters are respectively the same as the S_{11} and S_{21} parameters. We observe that the gain increases from 2dB to 2.9dB.

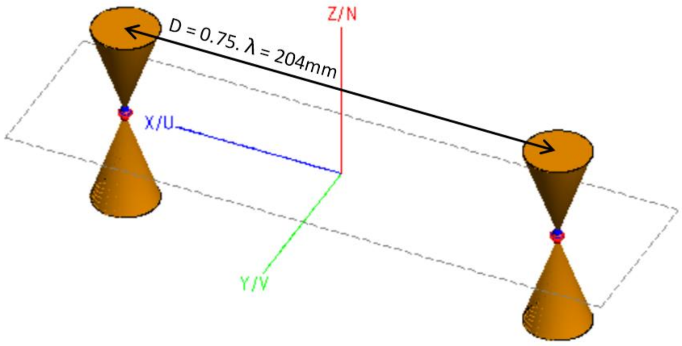
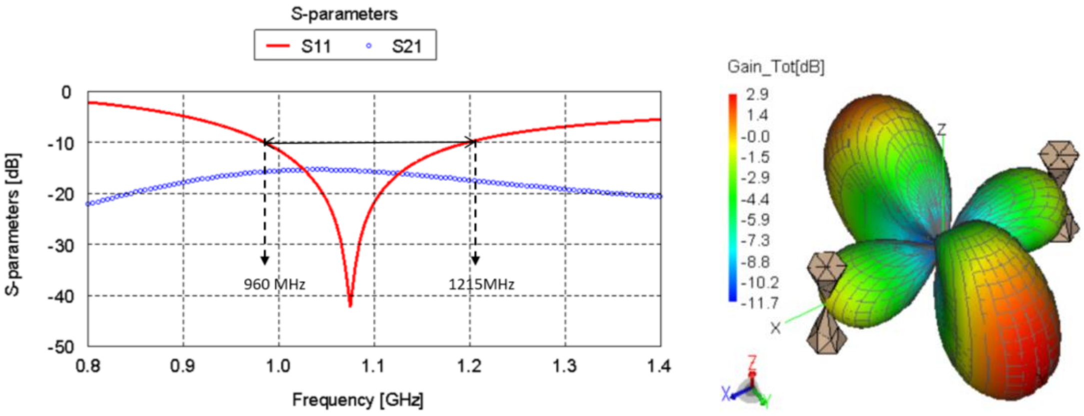


Figure 8. The geometry of two elements bi-conical antenna

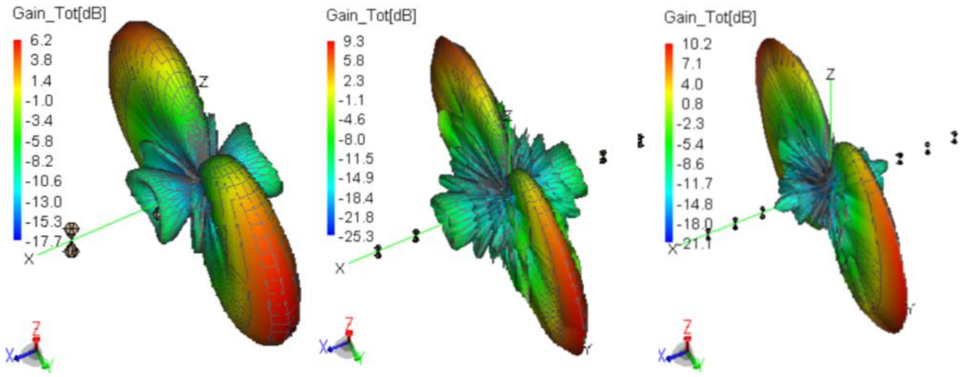


(a) S_{11} parameter (b) 3D gain pattern

Figure 9. The Simulated S_{11} parameter (a) and the simulated 3D gain pattern of two elements bi-conical antenna (b)

4.3. Four, eight and ten elements bi-conical antenna

When we increase the number of elements, we observe that the gain increases. For the four, eight and ten elements antenna the maximum gains are respectively 6.2 dB, 9.3 dB and 10.2 dB. The main lobe becomes very narrow so the antenna becomes more directive (figure 10).

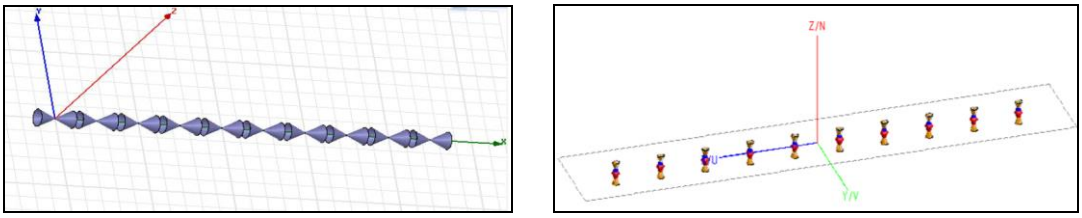


(a) Four elements (b) Eight elements (c) Ten elements

Figure 10. The simulated 3D gain pattern of four (a), eight (b) and ten (c) elements bi-conical antenna at the resonance frequency (1.07GHz)

5. COMPARISON WITH OTHER WORKS

The comparison with the results found by Qiuyuan Pang and Yude Ni [6][11] shows that this configuration allows to obtain a higher gain 10.2 dB for 10 elements versus 9.38 dB for the same number of elements. The difference between the two works is: in [6][11], the ten elements are place as shown in figure 11(a), but in our work these elements are placed as shown in figure 11(b).



(a) Qiuyuan Pang work [6][11] (b) our work

Figure 11. The comparison between Qiuyuan Pang work (a) and our work (b)

In 2014, Amna Ikram et Al, studied a Low Profile Aircraft Antenna with gains less than 4dB [9]. Mabrouk designed an inverted L-shaped antenna with omni directional gain pattern and the gain that varies between 2 and 5dB [12].

In 2016, Icev has studied the state of the art of embedded antennas on aircrafts. All the studied antennas are miniaturized and have the maximum gains varied between 17 and 80 dB [10]. Bhavya designed a Conformal Printed sleeve dipole antenna operating in 800MHz to 3000MHz with gains between 0.4 and 2.26dB [13].

6. CONCLUSION

A new configuration of array bi-conical antenna to enhance the gain of an antenna for DME avionic system has been studied. The antenna operates in the DME band (960 – 1215 MHz), the simulated maximum gain reaches the value of 10.2 dB. Due to its large size, the antenna can be placed in terrestrials DME stations.

In the next work, fabrication and measurement should be done to confirm the simulated results. Also, more refinements should be done to enhance the gain of the antenna.

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