Study on Impedance Matching of 2.4 GHz Dipole Antenna

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Abstract. Understanding on matching impedance between feedline and load is important in many application. Theoretically, matching impedance can be calculated easily if characteristic impedances both load and line is known. Practically, when we do impedance matching at certain frequency we face a problem if the impedance of the feedline and antenna are unknown. By using vector network analyzer and anechoic chamber we tried to study and to approach the impedance match through measurement of return loss, VSWR, and antenna radiation pattern. The results of studies have shown that adjusting dipole antennas to lines can be done by optimizing antenna and lines length and subsequently optimizing the use of balun. In this research we optimized 2.4 GHz dipole antenna and matched it to feedline by using bazooka and balun 1:1. To achieve good matching, the antenna length is 0.35 λ and the feedline length multiplies 0.5 λ. The length of the bazooka and balun for the best impedance adjustment are 0.25 λ and 0.2 λ.

1. Introduction

The characteristic of impedance feedline and load are very sensitive to frequency. Furthermore, the impedance matching technique needs to be performed accurately in various applications such as antenna design. Theoretically, fundamental design of the antenna can be studied on [1], [2]. On High Frequency (HF) band antenna design and impedance matching can be practically studied on [3] But for higher frequencies base on our knowledge there are no practical references available. In this study we focus on design and matching line and dipole antenna. Some literature about dipole antenna can be found as in [4]–[7]. A calculable dipole antenna for frequencies 1-3 GHz using the moment method with the hybrid balun derived in [4] but no empirical testing of the antenna. Optimization of printed dipole antennas with integrated balun is done in [5] by using an algorithm that is able to optimize antenna geometry with a faster time compared to conventional parametric studies. The integrated dual band balun antenna at the 2.4 GHz frequency was designed at [6] but produced a complex antenna design making it more difficult in application. The various crossed dipole applications discussed in [7] are very readable to increase understanding of dipole antenna applications and matching networks. In this paper we conduct a design study and match of the dipole antenna impedance at higher frequencies with practical testing which was not done in the previous literature. In the early part of the study we tested 500 MHz standard dipole antenna to study the concept of impedance adjustment and then tried to design dipole antennas for higher frequencies. In this paper we report the results of a study of dipole antenna design at a frequency of 2.4 GHz. The choice of 2.4 GHz frequency because standard dipole antennas for 2.4 GHz or higher does not available on the laboratorium telecommunications. The results of this study can be used as a reference for designing standard dipole antennas for higher frequencies.
2. Methodology

Dipole antenna is a wire antenna that consists of two conductor rods with a half-wavelength long that is feeded at center. Dipole antenna has omnidirectional pattern as shown at Figure 1[1]. Matematically pattern at Figure 1 can be written as \( U = \sin(\theta) \).

![Figure 1. Half wavelength Dipole and pattern[1]](image1)

This omnidirectional pattern is formed by the current distribution for a halfwave dipole antenna that maximum at the center tap and minimum at both ends. For balance lines that are flared at both ends, current distribution will be generated as in Figure 2. Standing waves do not eliminate each other on the wire because a current distribution is also formed on the part of the flare (dipole) so that the current flows from one end to the other as in Figure 2(a). Dipole antennas with half wave length the current distribution is as shown in Figure 2(b). maximum current is distributed at the center tap and minimum at both ends. So that the radiation pattern of the signal radiated by the antenna is as in Figure 1.

![Figure 2. A dipole construction and it equivalent circuit[1]](image2)

The problem in dipole antenna design and antennas in general is to match the antenna impedance with the feedline. Antenna is usually fed with coaxial cable which is unbalanced line while dipole antenna is balance line. For this reason, it is necessary to match the unbalance line with the dipole. There are several ways that we can do to adjust the dipole antenna with the feed line. In this study two methods will be used, namely bazooka balun (Figure 2a) and \( \lambda / 4 \) coaxial balun (Figure 2b.). Before we design the antenna at the 2.4 GHz frequency, we tested the standard dipole antenna that available in the Antenna and Propagation laboratory of the Padang State Polytechnic Department. The antenna is 500 MHz dipole that has two handle without and with balun. We measured antenna pattern, VSWR and return loss of the antenna for this two balun. By conduct this measurement we can have best knowledge of matching impedance of dipole antenna. Furthermore, we created a 2.4 GHz dipole antenna with length of \( \frac{1}{2} \lambda \) by using conductor with diameter is 1 mm and fed it using a standard 2.4 GHz coaxial cable. The dipole antenna is shown in Figure 5.
The methodology of our research is to do a direct measurement of return loss and VSWR antenna using the Vector Network Analyzer to observe whether the 2.4 GHz antenna working frequency has been reached. Antenna was optimized by varying the length of the antenna and feedline and observing its return loss and SWR measurements. The dipole antenna is not exactly $1.5 \lambda$ length so the antenna length is reduced slowly to get the 2.4 GHz frequency. If a 2.4 GHz working frequency is achieved then an impedance adjustment is mounted as in Figure 2. Then measurements are taken to optimize the antenna impedance adjustment. Optimization is done by slowly changing the balun length and observing the value of return loss and VSWR and antenna polarization so that the antenna with VSWR and minimum return loss is obtained. Antenna pattern is also observed to obtain omnidirectional pattern which are closer to pattern in theory as in Figure 1.

### 3. Result and Discussion

The measurement of dipole 500 MHz antenna pattern is depicted in Figure 4. The type of balun used on this antenna is 1:1 balun as in Figure 2b. Pattern of the antenna without balun is not symmetrical as depicted in figure 4a (blue line). This shows the unequal current between the two dipole arms due to unmatching between the dipole and the feedline. Unlike conditions without balun, the antenna pattern looks balanced between the two poles due to match conditions as shown in red line in Figure 4(a). It means that the use of balun on a dipole antenna can effectively increase the antenna impedance matching. The pattern with balun was compared to theoretically omnidirectional pattern $U = \sin (\theta)$ as depicted in figure 4(b). It shown good agreement between measurement and theory. Figure 4(c) is photograph of 500 MHz antenna.

After testing the 500 MHz dipole antenna, we designed the dipole antenna for the 2.4 GHz. The antenna is made of wire with a diameter of 1 mm as in Figure 5. dipole is $0.5 \lambda$ length (3.1 cm) and fed by 1.5 $\lambda$ coaxial. The antenna length is gradually reduced and its effect is observed on the frequency response. The measurement result is shown in Figure 6. An antenna with a length of $0.5 \lambda$ is very good on the 1.58 GHz. This shows that the actual length of the dipole antenna is shorter than $0.5 \lambda$. The 2.4

![Figure 3. Balun Configuration that used in this study][1]

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frequency is obtained at $0.35\lambda$ dipole length. Figure 4b. Shows the frequency response to VSWR which results are linear to return loss. To observe the effect of the dipole length on the antenna working frequency, the minimum return loss value to dipole length is displayed in Figure 7. by changing the dipole length from 0.5 to 0.35, slowly decreases to -45 dB (0.42 $\lambda$). Similar results are shown in the SWR curve of Figure 5b. Using a length of 0.35 $\lambda$, we then observe the change in feedline length. The previous line with a length of $1.5\lambda$ was cut by step 0.2 $\lambda$ and observed it return loss. Changes in feedline length result in slight changes in frequency as in Figure 6a, But for 0.5, 1, and 1.5 $\lambda$ the antenna still produces the center frequency response at 2.4 GHz as in Figure 6(b). It can be seen that the size of the feed must be a multiple of 0.5 $\lambda$, the antenna response for 0.5 $\lambda$ as good as 1.5 $\lambda$ length.

![Figure 5 Dipole antenna for 2.4 GHz](image)

**Figure 5** Dipole antenna for 2.4 GHz

![Figure 6. Influence of length dipole on antenna frequency (a) Return Loss (b) VSWR.](image)

**Figure 6.** Influence of length dipole on antenna frequency (a) Return Loss (b) VSWR.

![Figure 7. Minimum Return Loss vs dipole length](image)

**Figure 7.** Minimum Return Loss vs dipole length
Figure 8. The variation of line length vs antenna impedance

Figure 9. Variation of bazooka and balun length vs antenna pattern. (a) Bazooka (blue line = 0.25 λ, red line = 0.2 λ, magenta line = 0.16 λ.) (b) Balun 1:1. (blue line = 0.5 λ, red line = 0.25 λ, magenta line = 0.16 λ. Cyan line = 0.2 λ)

by keeping the cable length of 1.5 λ and a dipole length of 0.35 λ, then the bazooka and balun are mounted to the antenna as in Figure 2. Each balun and bazooka were measured in varying lengths. The pattern is observed to see the impedance matching. It can be seen that the most symmetrical radiation pattern is obtained for the bazooka size ¼ λ. Whereas for balun 1:1, the most symmetrical pattern is obtained for balun length of 0.16 λ.

4. Conclusion
Impedance matching and optimization of dipole antenna for 2.4 GHz is presented. In Optimizing the dipole antenna, the antenna length is optimized first to achieve the required frequency. When frequency was reached, the line feed is cut 0.5 λ length or multiple of 0.5 λ. And the last step is to optimize the impedance balancing device. We found that the length of the dipole antenna for the 2.4 GHz frequency is 0.35 λ, and the balun length is 0.25λ for the bazooka and 0.2 λ for the 1:1 balun.
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