Effective Microstrip Feed Line Length in Ultra-Wideband Responses and Wireless Applications

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Abstract: In this article, an effective feed line technique is used instead of DGS (Defected Ground Structure) and CSRR (Complimentary Split Ring Resonator) which are commonly used for achieving UWB (Ultra-Wideband Applications) responses. A classical antenna is designed for 2.4GHz frequency with a feedline of 180° electrical length. The resonance of proposed antenna responses as UWB and it has interesting current distributions through the patch antenna. This paper avoided all aspects of existing techniques which are proposed to achieve UWB.

1. Introduction

Microstrip patch antennas are widely used for wireless communication in MM wave applications [1]. The design theory of antenna is studied by various researchers and different types of geometry models are invented with respect to their knowledge and applications [2] [3] [4]. Among them, widely used is the rectangular patch antenna, which is having impressive characteristics like narrow bandwidth, basic positive radiation pattern in terms of dB, horizontal polarization with respect to design axis, etc. It is being appreciated for its design aspects that include easy sketch, feeding techniques, fabrication, etc [5].

There are different types of feeding techniques used for exciting the rectangular patch antenna [6] [7] [8]. One of the most used feeding methods is microstrip feed line, whereas the other feeding techniques like coaxial feed and aperture coupled feed have design challenge aspects [5]. The feed line is a conducting strip to the patch antenna with smaller width (fW) when compared to patch (pw), i.e. fW <<pw. This feeding technique is easy to position to the proposed model of patch. This type of feed line is easy to fabricate by controlling impedance matching with the patch [9] [10] [11].

The patch antenna naturally has narrow bandwidth. The conditions to design these types of patches are substrate thickness (H) which varies from 2.2 to 12, Thickness of the patch (t≤λo). λo is free space wavelength with respect to design frequency. The proposed antenna has a design frequency of 2.4GHz which is used for well-known wireless devices. Further, the antenna is optimized to generate dual and multiband responses. To achieve multiband responses, different techniques are proposed [12] [13] [14] [15] [16]. This paper proposed changes in the electrical length of feed line to match with antenna load. We used 180° electrical length (fω) to provide maximum matched feed line to antenna as per transmission line theory.
concept, i.e. the load (antenna) is matched with input impedance (excitation) and transmission line (feed line) [5][10][11].

So, this paper proposes effective feed line length (FL) which gives Ultra-Wide Band (UWB) responses, and the parameters of antenna are compared with previous works which are useful to study about UWB technology design aspects.

2. Design of effective electrical length antenna
The rectangular patch antenna is designed for $f_0$=2.4GHz, with the following design equations. The geometry design of the patch depends on dielectric constant. The patch and feedline are placed on the dielectric material consisting electrical characteristics.

$$
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + 12 \frac{h}{W} \right]^{-\frac{1}{2}}
$$

where:

- $\varepsilon_{\text{eff}}$ = Effective Dielectric constant.
- $\varepsilon_r$ = Relative permittivity of the substrate.
- $h$ = Substrate height.
- $W$ = Width of the microstrip.

The normalized extension of patch length ($\Delta L$) is calculated by,

$$
\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{\text{eff}} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{\text{eff}} - 0.258)(\frac{W}{h} + 0.8)}
$$

Here,

- $\frac{W}{h} < 1$ gives narrow strip line
- $\frac{W}{h} >> 1$ & $\varepsilon_r > 1$ gives wider transmission line.

Electrically, the microstrip patch antenna looks greater than its physical dimension due to fringing effect. Figure 1 shows the top view dimension of microstrip patch antenna with geometrical calculations for $\varepsilon_r$=4.4 and substrate thickness 0.5mm.
The resonant frequency of this model is defined by TM010. The length of the patch can be calculated by

\[
\frac{1}{f_0} = \frac{1}{2L\sqrt{\varepsilon_r\mu_0\varepsilon_0}} = \frac{c_0}{2L\sqrt{\varepsilon_r}}
\]

(2.3)

Where,
- \(f_0\) = Resonant frequency.
- \(\varepsilon_r\) = Relative permittivity of the substrate.
- \(\mu_0\) = Permeability of free space in vacuum.
- \(\varepsilon_0\) = Permittivity of free space.
- \(c_0\) = Free space velocity of light.
- \(L\) = Length of patch.

Eq. (2.3) is done for the cavity model of rectangular patch. If the fringing effects are present in the same patch, then Eq. (2.3) can be modified as,

\[
\frac{1}{f_{rc}} = \frac{1}{2L\sqrt{\varepsilon_r\mu_0\varepsilon_0}} = \frac{1}{2(L + 2\Delta L)\sqrt{\varepsilon_r\mu_0\varepsilon_0}}
\]

(2.4)

The width of the patch for same resonant mode,

\[
\frac{1}{f_{rc}} = \frac{1}{2L\sqrt{\varepsilon_r\mu_0\varepsilon_0}} = \frac{1}{2(L + 2\Delta L)\sqrt{\varepsilon_r\mu_0\varepsilon_0}}
\]

(2.5)

By using Eq. (2.4) and Eq. (2.5), the patch dimensions are calculated. So, the length and width of the patch are \(L= 27.9\)mm and \(W=38\)mm.

The return loss of 2.4GHz patch antenna is as shown in Figure 1.
Figure 2. Return loss of inset feed for 2.4GHz

Figure 3 shows the corresponding radiation pattern of the antenna with normal edge excitation near boundary radiation in HFSS (High Frequency Structure Simulator tool).

The return loss responses are observed with 90° electrical length of inset feed line, width as per resonant frequency and same phase.

Figure 3. Polar plot of inset feed radiation pattern

Figure 4. Corresponding 3D pattern
The electrical length of antenna is increased from 90° to 180° for exciting the antenna to obtain the response in wide band frequency range. The inset feed method is removed for better bandwidth. So, the following figure 5 shows the physical dimension of patch antenna

![Physical Dimension of Patch Antenna](image)

**Figure 5.** Effective electrical length of 180° feed line with same properties of microstrip patch antenna for 2.4GHz.

3. Results and Discussion for Effective Feedline Technique.

Figure 6 shows the return loss of effective length introduced in the patch antenna and inset feed technique is removed without disturbing the dimensions of the patch with respect to 2.4GHz.

![Return Loss Graph](image)

**Figure 6.** Return loss of Effective electrical length of 180° feed line with same properties of microstrip patch antenna for 2.4GHz

The proposed design explored in Figure 5 achieved UWB frequency responses. The bandwidth of an antenna depends on SWR (Standing Wave Ratio) where 2:1 is the lossless transmission line.

So, the antenna is fed with lossless transmission line of 180° electrical length feed line. Basically, microstrip patches respond with narrow bandwidth. In this proposed design, the antenna dimension is not optimized and is designed at a frequency of 2.4GHz. The feeding techniques are studied very deeply with mode analysis. TM010 mode analysis is used achieve this response.
The current distribution of UWB antenna voltage of 0.697V is noted. Most of the voltage/current is distributed through the antenna due to lossless transmission line called feed line. Typically, 2% to 5% of bandwidth is achieved by increasing substrate thickness. If the thickness increases, surface wave and spurious feed radiation increase.

These are the works proposed by various authors in recent years [14]-[21] with different technologies to achieve UWB.

This article proposes the novel work of electrical length. It also decides the reflection loss of antenna to get UWB.

4. Achieving UWB with DGS

Employing defects on the ground plane to enhance antenna parameters like Input Impedance, Radiation Pattern, Gain, Efficiency, return loss is proved to be a complex yet useful technique to obtain the desired characteristics. This method of sliding defects such as slots, stubs on the ground plane along with periodic and aperiodic structures is called DGS (Defected Ground Structures) [26]-[30]. Compared to other techniques like EBG (Electromagnetic Band Gap), PBG (Photonic Band Gap), FSS (Frequency Selective Structures), DGS is proven to be most effective. In this paper, we will be comparing the results obtained by the proposed work with the results generated by employing DGS in the antenna design. [21]-[25]

For this evaluation, we designed a concentric circular patch antenna at 2.4GHz (Figure 7) This is further extended to UWB frequency range by using partial ground plane method followed by dimensional optimization of the design parameters. Defects are later introduced on the ground plane in form of small slots across the edge and directly under the feedline.

![Figure 7. Concentric Circular patch antenna with DGS.](image)

The DGS on the ground plane increases fringing field which introduces parasitic capacitance. This parasitic capacitance increases the coupling between the conducting patch and the ground plane which is responsible for the enhancement of the bandwidth. The performance of the antenna depends on the physical dimension of the antenna as well as location and shape of the DGS. The parameters that effect the operating band characteristics of the antenna such as the position of DGS slots and horizontal slot are parametrically analysed.[21]-[25].

The working of the antenna is analysed by varying the radius of the concentric circular patch, along with length and width of the slots on the ground plane.
This design achieved return loss less than -10dB at application frequencies as proposed in the paper and exhibits good gain and radiation properties.

**Figure 8.** Return loss of Concentric Circular Patch Antenna

**Figure 9.** Radiation Pattern of DGS based designed Geometry.

**Figure 10.** Obtained 3D Pattern
5. Result

While comparing the gain, return loss and radiation pattern parameters of both feedline simulated and DGS simulated designs, we can observe that the effective feedline technique resonates at desired application frequencies with dual and multiband operations thus building high gain and return loss values. Whereas DGS outputs do obtain the desired characteristics, but for optimum results, design modifications are to be done which results in complexity. Here, the term design modifications highlight the fact of introducing more defects on the ground plane.

6. Conclusion

The direct feeding method gives more affable response when compared to inset feed technique due to the changes in electrical length of antenna. The proposed antenna responded at the given application frequency ranges.

1. Wireless Local Area Networks (WLAN) operating at 2.45 GHz (2.4–2.484 GHz), 5.25 GHz (5.15–5.35 GHz), 5.75 GHz (5.725–5.825 GHz) bands.
2. Wi-MAX operating at 3.3–3.7 GHz band.
3. C-band satellite communication
   Downlink band (3.9–4.2 GHz)
   Uplink band (5.9–6.2 GHz).
4. X-band satellite communication
   Uplink band (7.92–8.395 GHz)
   Downlink band (7.252–7.75 GHz).

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