Variation of Input Impedance with Feeding Position in Probe and inset-Fed Microstrip Patch Antenna

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Abstract

Proper impedance matching of a microstrip patch antenna to the feed line is paramount for efficient radiation. However, impedance matching in such a system is not easy and consequently most systems suffer from return losses. The variation of the input impedance of a probe-fed and inset-fed rectangular microstrip patch antennas along the longitudinal and transverse lengths is investigated on probe-fed and microstrip-fed antenna operating at 2.4GHz and 2.0GHz respectively. FEKO simulation software is used to evaluate and characterize the behaviour of the input resistance for varying values of feeding position. It is observed that the transverse variation in the input resistance is very minimal. The conclusion drawn here is that a cosine squared and shifted cosine squared function can be used to exactly locate the feed point in a probe and inset fed antennas respectively for an impedance matched antenna system.

Keywords: Longitudinal feeding position, FEKO, probe feeding, inset feeding, input impedance, return loss.

1. Introduction

Modern communication systems require low profile, light weight, high gain and simple antenna structures to go along with the research in miniaturization of system devices being undertaken e.g. in the design of mobile phones (G. Sharma, 2011). These antennas should also possess reliable propagation characteristics as well as high efficiency. Microstrip antennas depicts such characteristics as characterized by relative ease of construction, light weight, low cost, conformability to the mounting surface and extremely thin protrusion from the surface (T. Huque, 2011), (Rathod, 2010), (Sayeed, 2010) (Reddy, 2009) and (M. F. Bendahmane, 2010).

To enjoy the aforementioned advantages, return losses must be mitigated during the design phase in a particular antenna system (D.D. Sandu, 2006). These losses are attributed to impedance mismatch between the radiating patch and the feed line for the contacting feeding techniques outlined below.

Numerous methods of analyzing the performance of a microstrip antenna exist. Among these are; Transmission line model, Cavity model and those methods based on numerical calculations e.g. MoM, FETD e.t.c (P. Jsoh, 2005). The antennas designed in this paper are based on the transmission line model where the patch is considered as a section of a transmission line radiating from its two extremities.

There are two common contacting microstrip feeding schemes: probe and edge feeding techniques. In the former method, (V. Rajeshkumar K. Priyadarshini, 2012), the inner conductor of a coaxial cable penetrates through the substrate and is soldered to the radiating patch while the outer conductor is connected to the ground plane. Matching in this technique is achieved by placing the probe at an appropriate longitudinal position. In the edge feeding method, a conducting strip is connected directly to the edge of the radiating patch. Impedance matching in this technique, however, is a challenge since the edge impedance is very high varying between 150Ω-250Ω. However, it decreases as the feed point approaches the center of the patch. A variation to this scheme is the inset feeding where an inset notch is cut in the patch to enhance matching. Matching is achieved by controlling the longitudinal length of the notch thus controlling input impedance level.

Appropriate positioning of a coaxial probe and determining the appropriate notch length in the probe and inset-fed antennas respectively, is not easy. The main challenge therefore facing the designers of microstrip antennas is how to exactly position these feed lines for matched microstrip antenna systems. As noted in (G. Sharma, 2011), (Balanis, 2005), (Peters, 2010) designers have been using cosine squared functions for both feeding schemes and it's the authors' objective to further explore the behaviour of the input resistance in both schemes for various feeding positions.

In this paper, the effects of varying the longitudinal and transversal feeding position on the input resistance of both probe-fed and inset-fed microstrip antennas is investigated. Resulting curves; input resistance as a function of feed length are compared with typical functions. The investigation was carried out using FEKO Electromagnetic software. The design involves a probe-fed and inset-fed Microstrip Patch antenna operating at 2.4GHz and 2.0GHz frequency respectively, with the theory behind probe and inset feeding technique discussed in section 2. The design of the above described antennas and simulations are presented in Section 3 of this paper. Simulation results are presented and discussed in section 4. Section 5 gives a detailed conclusion and deduction of the investigation and comparison.

2.Contacting feeding techniques

Patch feeding can broadly be classified as either contacting or non-contacting. In the contacting method, either a microstrip line or coaxial cable is used to directly excite the radiating patch. This makes this techniques easy to fabricate and simple to model. The main advantage of these techniques is that impedance matching is relatively easy since the probe or microstrip line can be placed at any desired position.

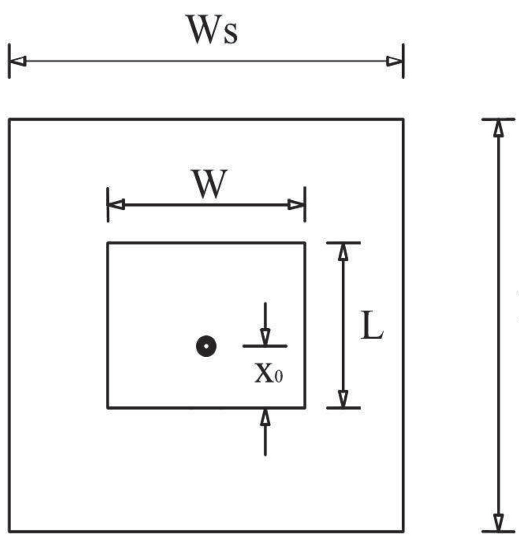


Fig. 1: Probe feeding scheme

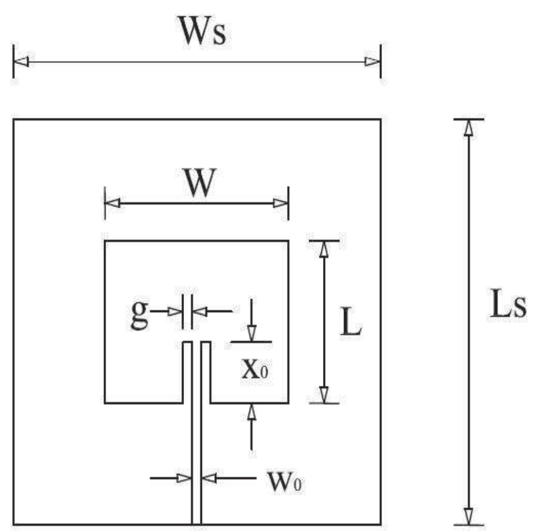


Fig. 2: Inset feeding scheme

2.1 Probe feeding

This scheme involves drilling a hole through the ground plane and the substrate and extending the inner conductor of a coax through the hole. This conductor is then soldered to the radiating patch while the outer conductor of the coax is connected to the ground plane. Control of the input impedance is achieved by positioning of the probe. This method result in minimal spurious radiation but is very complicated since it involves precise drilling both on the ground plane and the substrate in terms of position and size.

2.2 Inset feeding

This is a variation of the edge feeding where the fed line is in direct contact with one of the radiating edges of the patch. Impedance control is achieved by cutting out a notch from the radiating edge and extending the feed line into the notch. This scheme has the advantage that the feed line and the radiating patch can be etched on the same substrate making design and realization easier and highly suited for array design. However, conflicting substrate requirement for feed line and radiating element results in reduced system efficiency.

Figures 1 and 2 show both probe and inset fed microstrip antenna configuration. For efficient radiation, the dimensions of the patch as captured in the figures are governed by the following relations derived from the transmission line model.

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \tag{1}$$

$$\mathrm{L} = \frac{\mathrm{c}}{2\mathrm{f_r}\sqrt{\epsilon_{\mathrm{eff}}+1}} - 2\Delta\mathrm{L} \tag{2}$$

Where

$$\Delta\mathrm{L} = 0.412h\,\frac{\epsilon_{\mathrm{eff}}+0.3}{\epsilon_{\mathrm{eff}}-0.258}\left[\frac{\frac{w}{h}+0.264}{\frac{w}{h}+0.8}\right] \tag{3}$$

$$\epsilon_{\mathrm{eff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{4}$$

The feedline width w_0 is evaluated from equation 5 below

$$z = \frac{120\pi}{\sqrt{\epsilon_r}\left[\frac{h}{w}+1.393+0.667\ln\left(\frac{h}{w}+1.444\right)\right]} \tag{5}$$

Table 1: Patch antenna dimensions

S. No	Symbol	Parameter	Probe-fed	Inset-fed
1.	Ls	Substrate length	100mm	100mm
2.	Ws	Substrate width	100mm	100mm
3.	H	Substrate thickness	3.175mm	3.81mm
4.	L	Patch length	31.778	33.28mm
5.	W	Patch width	42.7540	42.3050mm
6.	w0	Feedline width		9.0273mm

Substrate dimensions as well as those obtained from the above equations are tabulated in Table 1 above for a frequency of 2.0GHz for the inset feeding and 2.4GHz for the probe feeding. The substrate employed in this design is Rogers TMM3 with a dielectric constant ϵ_r=3.27, loss tangent tanδ=0.004.

2. Simulation procedures

Below is a brief description of how the simulations were carried out for both feeding schemes.

2.1. Probe-fed microstrip patch antenna

A probe-fed microstrip antenna was designed in FEKO with dimensions as tabulated in Table 1. Starting from one of the radiating edge of the patch and sequentially changing the feed position in definite steps along the center line all the way to the opposite edge, and for each position the input resistance was evaluated. The procedure above was repeated but this time along 5mm, 10mm and 15mm offset of the center line with the input resistance being evaluated for each case.

Again stating from one of the non-radiating edges and at 5mm from the one radiating edge, probe feeding positions were sequentially moved in a transversal manner from one edge to the other. This was repeated along a line 10mm and 15mm from the radiating edge.

2.2. Inset feeding technique

Simulation in this scheme involved extending the feed line to the edge where the notch has been cut out. This way, the simulated input resistance is that of the edge where the notch has been cut out. For values of the longitudinal notch length varying from zero to L/2 , the procedure above was again used to evaluate the input resistance along the center line. This was repeated along a line 5mm, 10mm and 15mm offset of the center line.

Starting from one of the non-radiating edges with the notch length set to 0mm, the feed position was changed transversally to the opposite edge with the input resistance being evaluated for each position. This was repeated feed position 4mm, 8mm, and 12mm from the radiating edge and along the transverse centerline.

To characterize the behaviour of the input resistance with notch gap, simulation was repeated along the longitudinal centerline for the following notch gap *g* (as a fraction of the feedline width w0): g=0.3w_0, 0.5w_0, 0.7w_0 and w_0.

3. Results and discussion

4.1 Longitudinal and transverse variations

Figures 3 and 4 shows the longitudinal and transverse variations of input resistance in both probe-fed and inset-fed scheme. In both figures agreement in the longitudinal and transverse variations can be clearly observed. In figure 3b, it can be seen that the transverse variations are minimal especially at the center but deviates from this behaviour as the probe approaches the radiating edges. For the inset-fed antenna, from figure 4b, the transverse variations are not constant and the input resistance reduces as the feedline approach the center.

4.2 Characterization of input resistance in probe and inset feeding schemes

The simulation results are as captured in Fig. 5 for the probe-fed antenna and Fig. 6 for the inset-fed antennas for varying values of notch gap *g*. From figure 5a, the simulated input resistance exactly follows the cosine squared function. As the probe feed approach edge edges of the patch however, the curve deviates from the cosine squared behaviour. Defining the resonant frequency as the frequency at which S_{11} is minimum, figure 5b shows the variation in the resonant frequency with feeding position. It can be seen that the variation in frequency with feed position is very minimal as the probe approaches the center of the radiating patch.

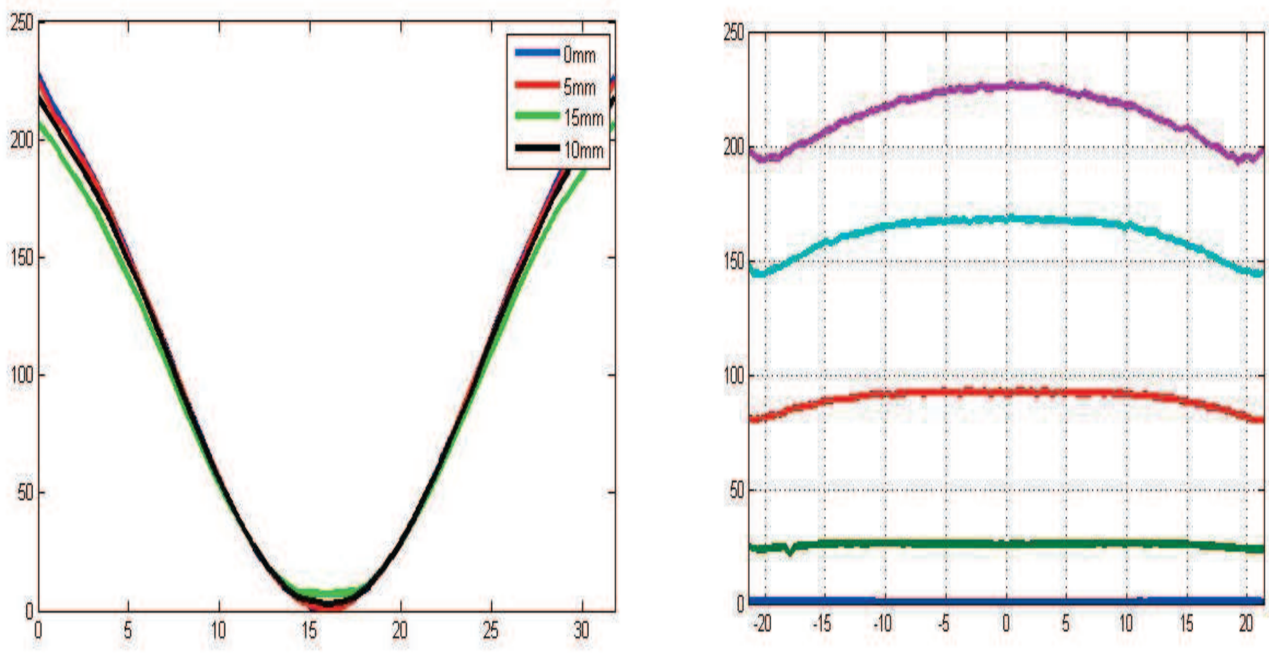
For inset-fed antenna, results show that the trace follows cosine squared behaviour. However, the minima are not at the center but shifted towards the feeding edge which is not the case with cosine squared function. It is also observed that the shift is a function of the gap width as depicted in figures 6a-6d. Figure 7 captures all traces for various values of *g* from $0.3w_0$ to w_0. From this, it can be observed how the degree of the shift increases with the notch gap. From this, the input resistance therefore, can be modeled as

$$R_{in(x=x_0)} = R_{in(x=0)} cos^2\left[\frac{\pi}{L}(x_0 - x_g)\right] \tag{6}$$

Where x_g is the notch-gap dependent variable. Tabulated below in Table 2 are values of gap width *g* and the corresponding values of x_g.

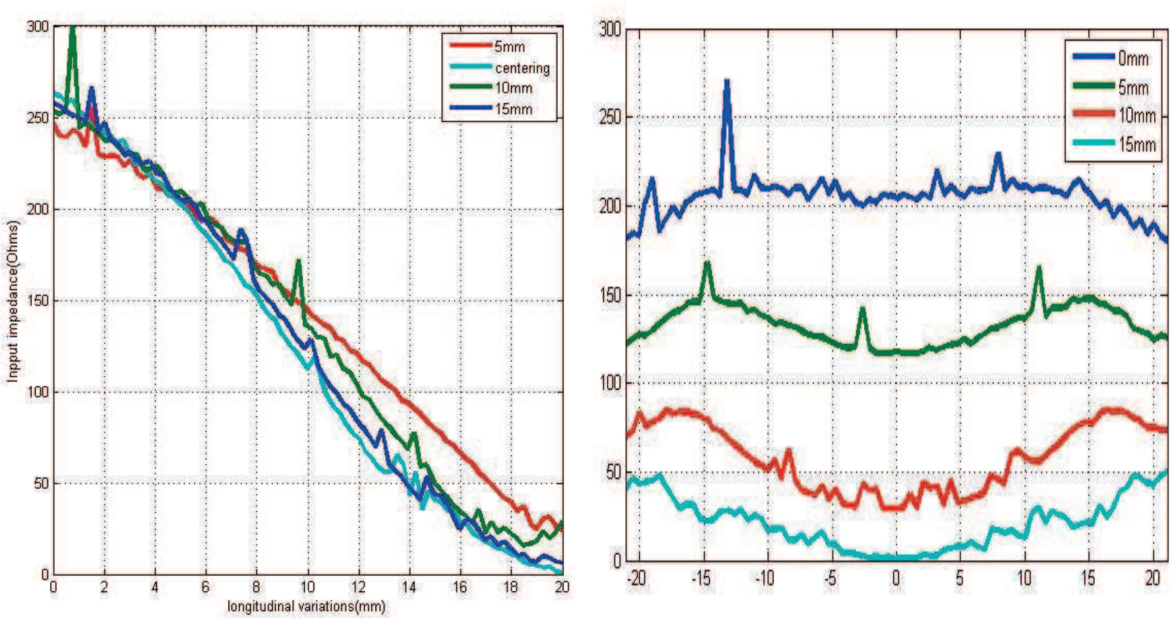
Table 2: Variation of notch length with gap

S. No	g(in terms of w_0)	g(mm)	Xg
1.	0.3	2.7390mm	1.5271mm
2.	0.5	4.5650mm	2.2906mm
3.	0.7	6.3910mm	2.5451mm
4.	1	9.1299mm	3.1814mm



a) Longitudinal variations of input resistance b) Transversal variations of input resistance

Figure 3: Variation of input resistance in a probe-fed antenna



a) Longitudinal variations of input resistance b) Transversal variations of input resistance

Figure 4: Variation of input resistance in an inset-fed antenna

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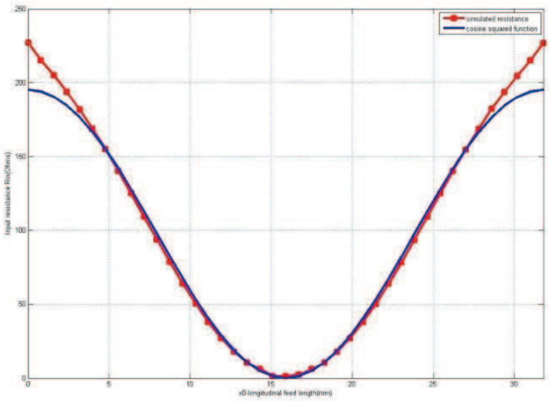
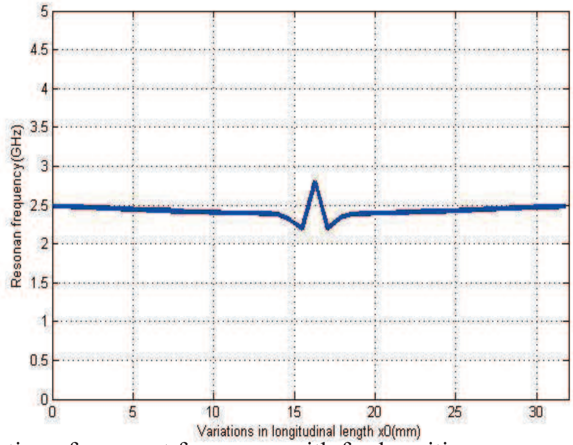
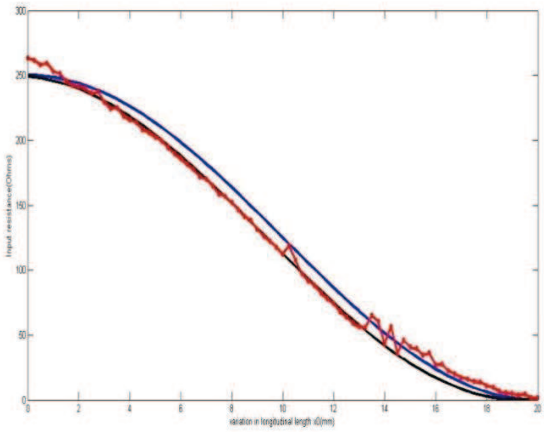


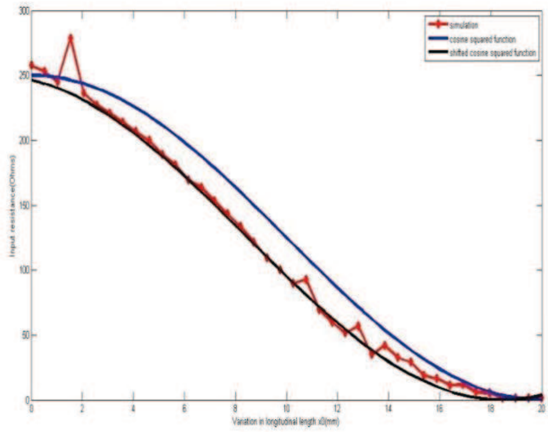


a) Variation of input resistance with feed position b) Variation of resonant frequency with feed position

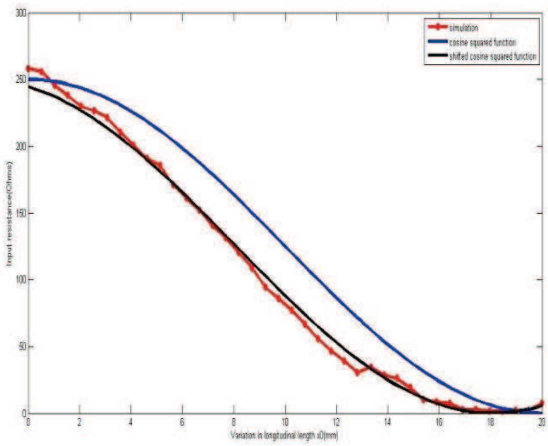
Fig. 5: Characterization in a probe-fed antenna

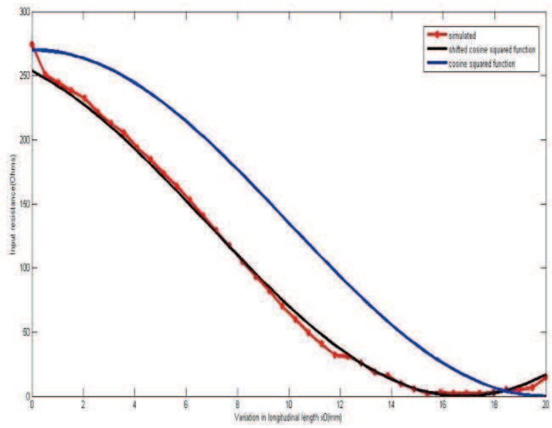


a) $g=0.3w_0$



b) $g=0.5w_0$





c) $g=0.7w_0$ d) $g=w_0$

Fig. 6: Characterization in an inset-fed antenna

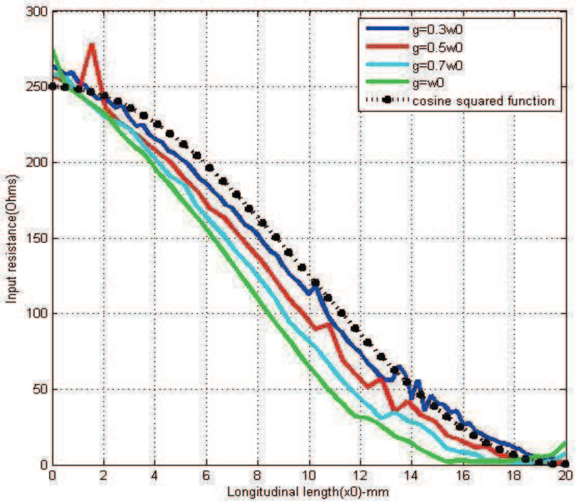


Fig. 7: Variation of input resistance with notch gap.

4. Conclusion

The behaviour of the input resistance of a rectangular microstrip patch antenna with contacting feeding techniques was investigated. For coaxial feeding scheme, it was concluded that cosine squared function fully characterize the variation of the input resistance along the resonant length of the patch. Variation of the input resistance in an inset-fed though following cosine squared behaviour, was shifted towards the feeding edge. The phase shift was found to vary with the gap between the feed line and the radiating patch.

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