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Comparative Radiation Performance of Different Feeding Techniques for a Microstrip Patch Antenna

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Abstract – One of the important aspects of a microstrip patch antennas is the variety of feeding technique applicable to them. A good impedance matching condition between the line and patch without any additional matching elements depends heavily on feeding techniques used. This work is an effort to model and simulate three different types of microstrip antenna's feeding methods on a rectangular patch. Simulation is done using the circuit model derived from the Transmission Line Model (TLM), and is compared with another simulation set of feeding methods produced using the Method of Moments (MoM). Both methods are simulated on Microwave Office. This design intends to focus on designing the patch and its respective feeds, simulate it using Method-of-Moments (MoM), and fabricate it. Radiation measurements are also presented. Designs for each feeding technique achieved the best return loss at the desired frequency range, which is 2.4 GHz. The fabricated hardware produces good return loss and comparable radiative performance with simulation using MoM.

Index Terms: Circuit Simulation, Microstrip Antennas, Moment Methods, Transmission Line Matrix Methods

1. Introduction

Microstrip patch antennas have several well-known advantages over other antenna structures, including their low profile and hence conformal nature, light weight, low cost of production, robust nature, and compatibility with microwave monolithic integrated circuits (MMICs) and optoelectronic integrated circuits (OEICs) technologies.

Various numerical methods have been developed by a number of researchers to ease computational efforts when designing microstrip patch antennas [1], [2], [3], [4], [5] which includes TLM and MoM. TLM is a numerical technique for solving Maxwell's equation in the presence of complex environment [6], while MoM involves the use of the Sommerfeld-type integrals to solve the dielectric slab Green's function [7].

TLM is regarded as most practical for its analysis and design, while MoM is applicable to many antenna types. TLM has been popular in the construction of an equivalent circuit model, especially for computer-aided design (CAD), due to its accuracy and numerical efficiency. MoM can handle antennas with small or large dimensions.

2. Types of Feed

2.1 Coaxial Probe Feed

A coaxial inner conductor of radius r_0 extends through the ground plane and is connected to the patch conductor. The probe position provides the impedance control in a similar manner to inserting the feed for an edge-fed patch.

Probe feed mechanism is in direct contact with the antenna and most of the feed network is isolated from the patch which provides an efficient feeding and minimizes spurious radiation [6]. However it is more complicated to manufacture.

Probe-fed patches have small bandwidth and are difficult to accurately analyze. The probe used to couple power to the patch can generate somewhat high cross-polarized fields if electrically thick substrates are used [4].

2.2 Microstrip Line Feed

A microstrip feed line of width w_f is in direct contact with one of the radiating edges of the patch of length L and width W. The feed position at the edge provides the impedance control. Microstrip-line patches have several advantages over other feeding techniques. Since the feed layout and patches can be etched on one board, it eases fabrication. The level of the input impedance is easily controllable.

Microstrip line patches have bandwidth and gain characteristics which are relatively narrow. This technique also suffers from poor surface wave efficiency and relatively high spurious feed radiation [10], [13]. Material suitable for efficient radiation for the antenna also causes the feed network to radiate.

2.3 Proximity Coupled Feed

The whole antenna consists of a grounded substrate where a microstrip feed line is located. Above this material is another dielectric layer with a microstrip patch etched on its top surface. The power from the feed network is coupled to the patch electromagnetically, thus creating an alternative to the shortcomings of the contacting feeding techniques.

In contrast to the direct contact methods, which are predominantly inductive, the proximity-coupled patch's coupling mechanism is capacitative in nature. The difference in coupling significantly affects the obtainable impedance bandwidth, thus, bandwidth of a proximity-coupled patch is inherently greater than the direct contact feed patches [13].

3. Antenna and Feed Design

The main objective of this work is to design a rectangular-shaped microstrip patch antenna. The antenna is designed to resonate at the frequency of 2.4 GHz. Since a suitable and similar substrate must be chosen in order to provide a general platform for all feeds to be simulated, the chosen substrate is FR-4, which has a dielectric constant (ε_r) of 4.5, dielectric loss tangent ($tan\delta$) of 0.019 and substrate height (h) of 1.6mm.

To account for the fringing of the electric field above the microstrip (where air is the medium), an effective dielectric constant is defined; which allows the microstrip to be modeled as if it a homogeneous dielectric medium of ($\varepsilon_{r,eff}$). Thus the parameter values in Table 1 have been calculated as an initial value, using design frequency of 2.4GHz.

A significant upwards shift in resonant frequency has been reported in [3], as much as 8.3% for a proximity-coupled patch. Thus before designing the patch, a lower design frequency must be determined experimentally to compensate for the amount of upward shifts. A batch of prototype with different feeds has been fabricated and its amount of shift calculated so that it could be taken into consideration when designing for the actual prototypes. Its results are shown in Table 2.

Other than Microwave Office, antenna CAD program in [6] was also used in verification of calculated parameters. It provided an approximate value of the resonant parameters, but tweaking to the values provided by the software is necessary to achieve optimal simulation results at desired resonance.

4. Results and Discussion

4.1 Coaxial Probe Feed

For a coaxially-fed microstrip patch antenna to resonate at 2.4GHz, W must be designed at 37mm while its L is 30mm, as it is shown in Fig.1. The patch is fed using a 50Ω SMA connector with 1mm inner conductor's diameter; while outer conductor is soldered to the ground plane. To determine the circuit model equivalent to the coaxially-fed patch, the literature [4] is referred. It derived and proposed the model as it is shown in Fig.2.

The results for both simulations and measurements are shown in Table 3. The resonant frequency for MoM simulation and circuit model differs less than 1%, showing an excellent approximation of the designed circuit model against the antenna simulated in MoM environment. The bandwidth which differs about 16% is the highest among the three feed techniques, and shows a poor approximation of the proposed circuit model against MoM simulation.

The measurement results also show very little difference in bandwidth and resonant frequency, which is 2% and 5.6% respectively. The return loss is still within the acceptable range i.e less than -10dB; while the upward frequency shift is compensated (as was analyzed in Table 2) down to 1%, rather than 2.1%, from the target design frequency of 2.4 GHz.

Since this type of feed technique produces low bandwidth for an electrically-thin substrate [6], the produced amount of bandwidth is reasonable. The shift in resonant frequency is caused by the representation of the feed reactance as a combination of the inductive feed and the capacitive feed reactance between the patch and the ground as proposed in [11]. The feed reactance, X_{FEED}, in this work is taken as [4].

Table 1: Initial calculated values in designing a rectangular patch

Feed Method	Calculated (2.4 GHz)	W (mm)	L (mm)	ε_{reff}
Line Feed	Calculated (2.4 GHz)	37.663	29.097	4.174
	Calculated at new freq (2.29 GHz)	39.473	30.522	4.185
	Actual	39.000	29.000	NA
Coax Feed	Calculated (2.4 GHz)	37.663	29.097	4.174
	Calculated at new freq (2.36 GHz)	38.302	29.600	4.178
	Actual	37.000	30.000	NA
Proximity Coupled	Calculated (2.4 GHz)	37.663	29.097	4.174
	Calculated at new freq (2.33 GHz)	38.795	29.988	4.181

Table 2: Experimentally determined resonant frequency shift

Feed Technique	Simulated Res Freq (GHz)	Measured Res Freq (GHz)	Amount of shift (%)	New Design Freq (GHz)
Line Feed	2.45	2.56	4.583	2.29
Coaxial Probe Feed	2.41	2.48	2.075	2.36
Proximity Coupling	2.38	2.45	2.917	2.33

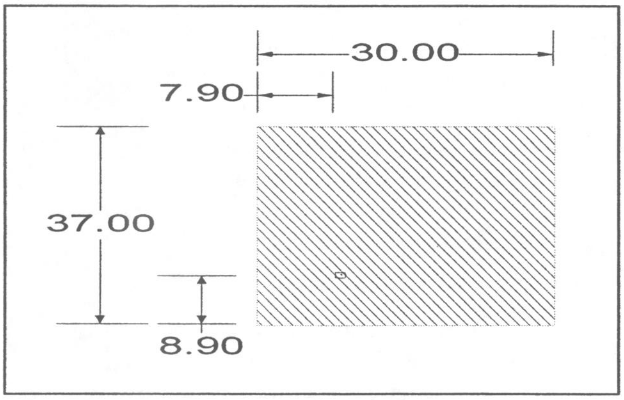


Figure 1: Coaxially-fed microstrip antenna dimensions

Measured radiation patterns are shown in Fig 3 for E plane and Fig. 4 for H plane, while numerical results are listed in Table 4. The fabricated antenna produced satisfactory isolation on both E and H plane (HPBW>20dB). It also shows a larger isolation and half-power beamwidth (HPBW) on the H Plane. H plane HPBW grows inversely proportionate with larger W [7] and the smaller the substrate thickness (h), the broader E plane HPBW will be [4]. Coaxially-fed patch has the smallest value of W and h.

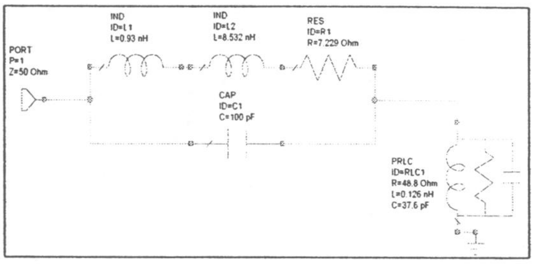


Figure 2: Equivalent circuit model for coaxially-fed microstrip antenna

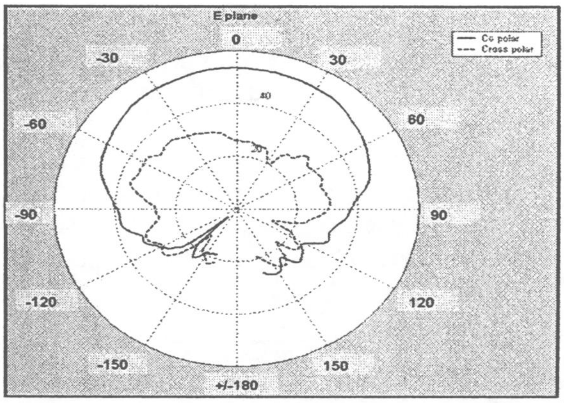


Figure 3: E plane measured radiation pattern for coaxially fed patch antenna

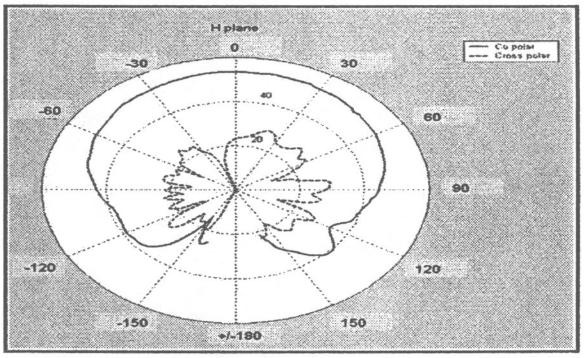


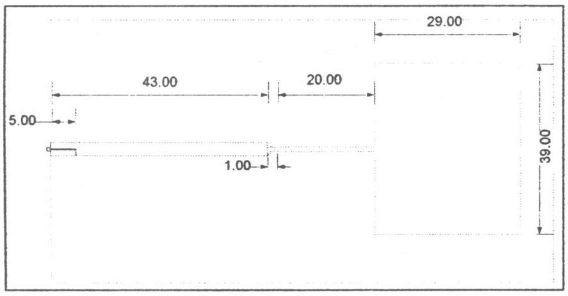
Figure 4: H plane measured radiation pattern for coaxially fed patch antenna

The measured return loss also exceeded expectation compared to MoM simulation, which produced a good value of -40.77dB. This is due to the variation of the materials' ε_r value along the length, width and height in practice, not to mention its varying value with operation frequency [4], [12]. This will cause unexpected and unpredictable results in terms of return loss. The measured resonant frequency tends to vary about 2% from the simulated result, while difference from 2.4GHz is reduced to less than 0.5% from nearly 5%.

4.2 Microstrip Line Feed

For a similar rectangular element, transmission-line-fed microstrip antenna could be designed with the initial values listed in Table I, but minor tweaking and optimization will produce a *W*=39mm and *L*=29mm. It is fed by a microstrip line and a matching quarter-wave line. The antenna's full dimension is shown as in Fig.5. In designing the equivalent circuit model, literature [2] is deemed most helpful. The antenna's equivalent circuit is shown in Fig. 6.

The results for both simulations and measurements are again shown in Table 3. The circuit presented for this feed technique produced closest approximation compared to its MoM equivalent in terms of bandwidth and return loss, which yielded deviations of less than 1% for both parameters. However, this feed technique produced the smallest bandwidth, as it is prone to spurious radiation [6].



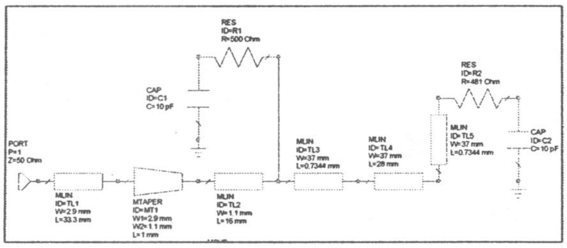


Figure 6: Equivalent circuit model for transmission line-fed microstrip antenna

The pattern measurement result for this feed technique is shown in Fig. 7, Fig. 8 and Table 4. Microstrip line feed technique also produced a relatively moderate E and H plane isolation level and HPBW values, in the acceptable range (<-20dB). Since it has the largest *W* value, the H plane HPBW produced is the smallest; while a similar h value produces an E plane HPBW similar to its coaxially-fed counterpart. Smallest value of E plane isolation further proves the extensiveness of the spurious radiation affecting this feed technique.

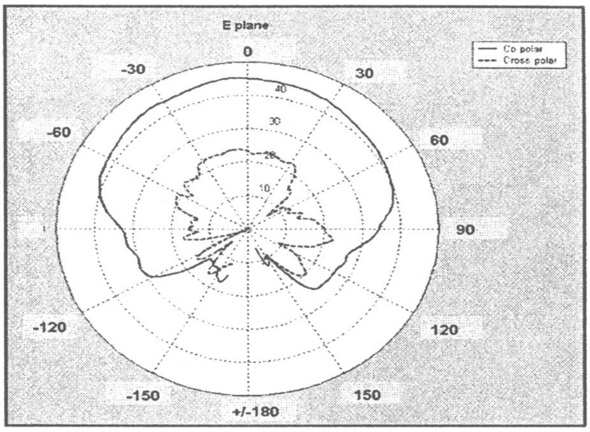


Figure 7: E plane measured radiation pattern for microstrip line fed patch antenna

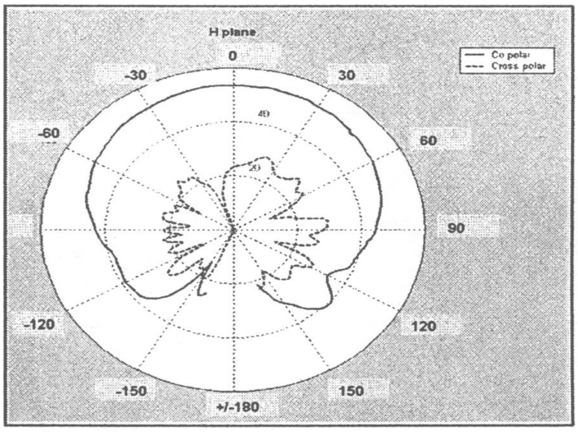


Figure 8: H plane measured radiation pattern for microstrip line fed patch antenna

4.3 Proximity-Coupled Feed

Contrary to different substrate usage for each of the layers as proposed in [3] for increased radiation efficiency, the antenna designed here uses the same substrates which is the FR-4 for both upper and lower layers.

Using the software provided in [6] and calculation method as proposed in [1], the layout dimensions are shown as in Table 1, Fig. 9 and 10 shows its equivalent circuit.

Both simulations for MoM and its equivalent circuit results produced good return loss at the desired resonance (Table 3). It also yielded close results in terms of bandwidth and return loss, with larger differences of 4% and 10% respectively. Difficulty in modeling the circuit is already mentioned in [3]; suggesting that the equivalent circuit presented will have difficulty in predicting the bandwidth size.

This is due to the property of the equivalent circuit that could not accurately model couplings to the environment and between elements. Since coupling is the main mechanism of the proximity coupled feed, a larger difference is already expected between the two models.

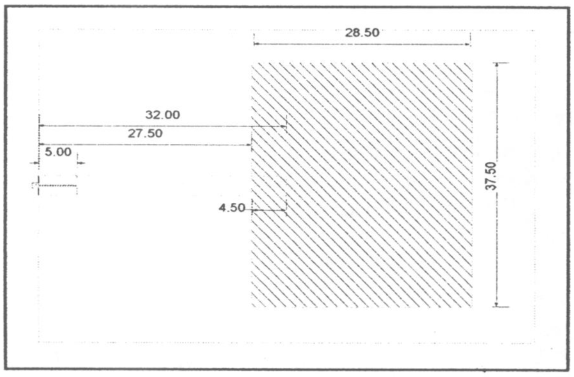


Figure 9: Equivalent circuit model for proximity-coupled microstrip antenna

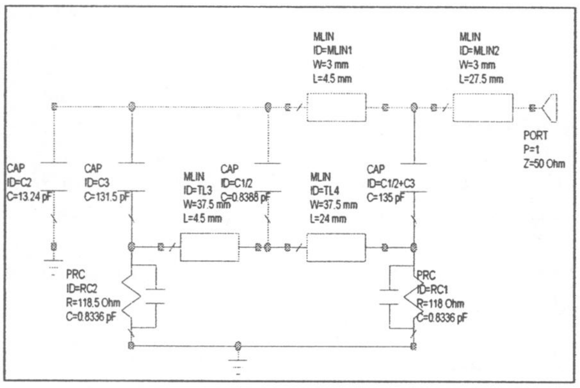


Figure 10: Equivalent circuit model for proximity-coupled microstrip antenna

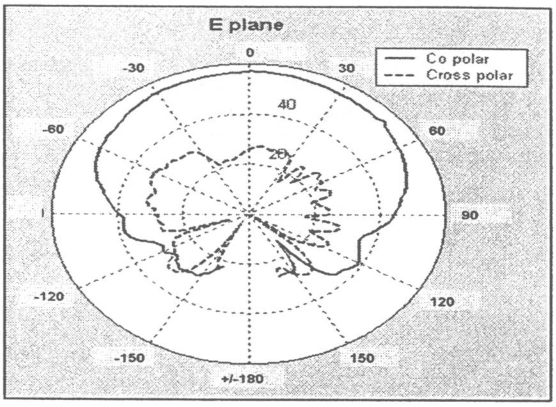


Figure 11: E plane measured radiation pattern for proximity coupled patch antenna

Comparison of simulated and measured results shows a decline in return loss, indication of matching difficulty, even if it produced a reasonable value (RL<-10dB). It produced a bandwidth and resonant frequency difference of about 5% and 6% respectively. An antenna's *h* is proportionate to the increase in bandwidth [4]. Since this feed network is twice as thick as compared to the two previous feed techniques, added with strong coupling, it is expected to produce the largest bandwidth. A good bandwidth of 4.1% is yielded, which makes the patch employing this feed technique to be operational in the wireless LAN 802.11b/g domain.

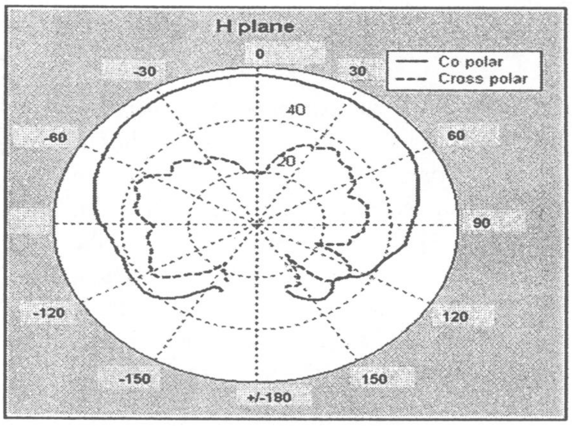


Figure 12: H plane measured radiation pattern for proximity coupled patch antenna

Table 3: Measured parameter values for different feed techniques

Feed Type	Rep Model	Return Loss (dB)	Resonant Freq (GHz)	Band width (%)
Coax Feed	Circuit	-32.660	2.31	2.600
	MoM	-31.760	2.29	2.180
	Meas	-23.350	2.43	2.210
Line Feed	Circuit	-23.619	2.38	2.520
	MoM	-22.480	2.36	2.540
	Meas	-40.770	2.41	2.070
Proximity Coupling	Circuit	-28.740	2.42	3.312
	MoM	-31.934	2.32	3.840
	Meas	-21.360	2.44	4.100

Table 4: Measured radiation patterns for different feed techniques

Feed Type	Coax Feed		Line Feed		Proximity Coupling	
	E-Plane	H-Plane	E-Plane	H-Plane	E-Plane	H-Plane
W	37.00		39.00		37.50	
h	1.6		1.6		3.2	
0° Isolation (dB)	27.53	30.22	21.86	32.24	31.02	37.68
HPBW (degrees)	98	102	94	76	94	96

Proximity coupled feed is able to produce a very low cross polarized field (as showed in Fig. 11 and 12) thus producing the highest isolation in both E and H planes. It also yielded the narrowest E plane HPBW since it has a large *W*, and relatively moderate H plane HPBW due to its thickness.

5. Conclusion

A method of comparative simulation between MoM analysis and its equivalent circuit models is proposed. Comparison and simulated results are also compared with fabricated hardware's measurement. All three designs of feeding technique achieved the best return losses at the desired frequency region, which is 2.4 GHz. For MoM simulations, some percentage of design frequency shifts is introduced. This is to accommodate for the resonant frequency shift when the hardware is fabricated. The equivalent circuit proposed also exhibits similar bandwidth and return loss as the antenna simulated in MoM mode. Although hardware measurements will indicate larger variations, its results are acceptable and will reflect the true property of the feed technique.

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