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Design, Realization And Measurements of Microstrip Patch Antenna Using Three Direct Feeding Modes For 2.45ghz Applications

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ABSTRACT

A microstrip patch antenna is a metal patch placed on a substrate. Different feeding modes are used such as: coaxial probe feed, microstrip line feed, proximity-coupled feed, coplanar wave guide feed (CPW) and others. These feeding modes are divided in two kinds, direct or indirect.

The patch can take different shapes; the most known forms are rectangular, square, circular, hexagonal... The microstrip patch antenna is low-profile, conformable to planar and non-planar surfaces, simple and cheap to manufacture using modern printed-circuit technology.

In this paper, a microstrip patch antenna for 2.45GHz applications is designed based on the transmission line method. The design is optimized with the Method of the Moments (frequency domain method) because it's one of the accurate methods for wire and planar antennas. The three direct feeding modes are studied, manufactured and measured. Simulations were performed with CADFEKO and measurements were performed with Vector Network Analyzer (VNA) Anritsu MS2026C.

Keywords: *Antenna Design, Feeding Modes, Microstrip Patch Antenna.*

1. INTRODUCTION

With the development of wireless applications and their integration in restrict environment like smartphones, laptops and other embedded systems, the microstrip patch antennas are widely used because of their planer structure, low profile, light weight good efficiency, ease of manufacturing and integration with active devices.

There are many configurations that can be used to feed microstrip antennas. The most popular are the coaxial probe, microstrip line, proximity coupling, coplanar wave guide and others. Each feeding mode have some advantages and disadvantages and it was be used in depending on the requirements[1]–[7].

In this paper, first, a design methodology is presented. Next, the three direct feeding modes are simulated, manufactured and measured. After that, a comparison of the results is presented.

2. THE PATCH ANTENNA DESIGN METHODOLOGY

2.1 The Design of Miscrostrip Patch Antenna

The microstrip patch antennas can be analyzed in various methods, the most popular are:

- Transmission-line method (TLM)
- Cavity method (CM)
- Full-wave methods: Are based on solving Maxwell's equations in differential or integral forms. The most popular are the Method of the Moments (MoM), the Finite element method (FEM), Finite-Difference Time Domain (FDTD)[2], [8]–[10].

Although the transmission line model has the least accuracy, it is the easiest method to implement and gives good physical insight. According to Balanis[1], the transmission-line model represents the microstrip antenna by two slots with a width of W and separated by a transmission line of length L (Fig. 1).

For the microstrip line shown in Fig. 2 (a), the field lines are inside the substrate and some of them are extended to outer space (Fig. 2 (b)). For this, an effective dielectric constant (ε_{reff}) is introduced to account for fringing and the wave propagation in the line (Fig. 2 (c)).

ε_{reff} can be calculated from [1] by the formula (1)

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \times \left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (1)$$

Where, W/h >1
ε_{reff}: Effective dielectric constant
ε_r: Dielectric constant of the substrate
W: Width of the radiating patch
h: Height of the substrate

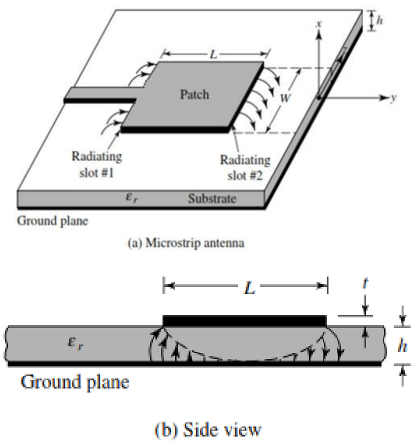


Fig .1. Microstrip antenna [1]

As shown in Fig. 3, fringing effects looks greater than the microstrip patch dimensions. For the principal E-plane (xy-plane), the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of ε_{reff} and W/h given from [1] by the formula (2).

$$\frac{\Delta L}{h} = 0.412 \times \frac{(\varepsilon_{reff} + 0.3) \times (\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258) \times (\frac{W}{h} + 0.8)} \quad (2)$$

The effective length of the patch is given by the equation (3).

$$L_{eff} = L + 2.\Delta L \quad (3)$$

It is also given by the equation (4).

$$L_{eff} = \frac{\lambda}{2\sqrt{\varepsilon_{reff}}} \quad (4)$$

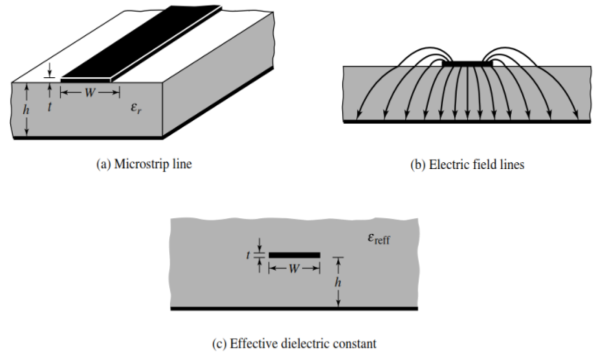


Fig .2. Microstrip line and its electric field lines, and effective dielectric constant geometry [1]

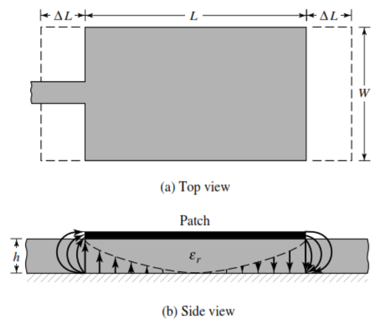


Fig .3. Physical and effective lengths of rectangular microstrip patch [1]

The width of the patch is given from [1] by the equation (5)

$$W = \frac{\lambda}{2}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad (5)$$

Where, λ is the wavelength given by the equation (6)

$$\lambda = \frac{c}{f} \quad (6)$$

To design a microstrip patch antenna operating in the frequency of 2.45GHz with the parameters: h = 1.6mm and ε_r = 4.4 we follow the previous steps.
The results are: W = 37.26mm, L = 28.83mm

2.2 Feeding Modes

There are many configurations that can be used to feed microstrip antennas. These feeding modes are divided in two kinds, direct or indirect. The three direct modes are: microstrip line, coaxial probe, coplanar wave guide. (Fig. 4)

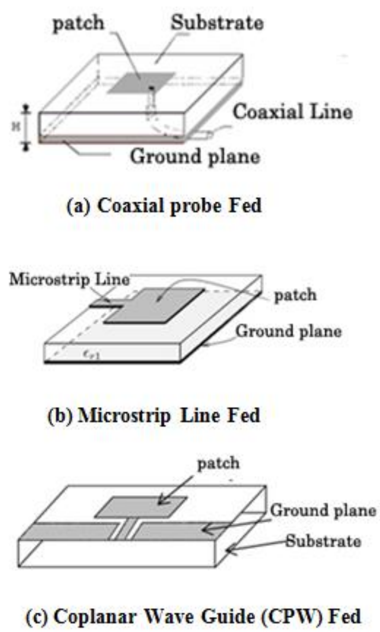


Fig. 4. The three direct feeding techniques [1], [5]

In the next section, simulation, realization and measurement of the rectangular patch antenna will be done when we feed it with the three direct feeding techniques.

3. SIMULATION, REALIZATION AND EASUREMENTS FOR DIFFERENT FEEDING MODES

To validate the previous design, the microstrip patch antenna was simulated with CADFEKO witch based on the Method of the Moments (MoM), one of the more accurate methods for wire and planar antennas[8]–[12]. Three direct feeding modes are studied: coaxial probe, microstrip line, and CPW.

3.1 Coaxial probe Feeding

Fig. 5 illustrates the geometry of the patch antenna fed by a coaxial prob. The antenna is printed on a substrate EPOXY FR4 with relative permittivity ε_r = 4.4 and a thickness of 1.6mm. The other parameters are: W_p = 37.26mm, L_p= 28.83mm, W_s = $2W_p$, L_s= $2L_p$. The feeding probe is placed at the point F, placed at the y_f position from the center of the patch (y_f = 4mm).

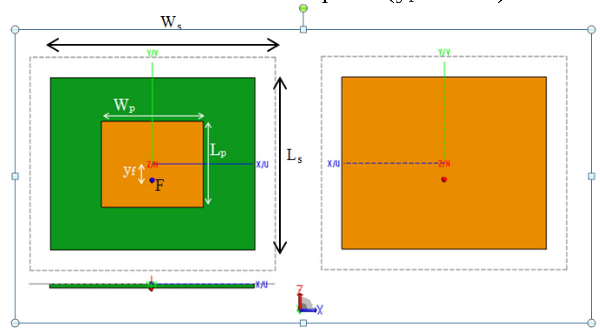


Fig. 5. Geometry of the patch antenna with coaxial probe fed

Fig. 6 shows the S_{11} parameters. The simulated resonance frequency is 2.33GHz, 130MHz lower than the resonance frequency given by TLM. The design is optimized to have 2.45GHz as the resonance frequency with MoM. The new dimensions of the patch are: W_p = 35.66mm and L_p = 27.56mm. fig. 7 shows the S_{11} for the optimized antennas. To have a good impedance matching, the feeding point must be placed at a specific position. For that a parametric study is done. Fig . 8 shows the behavior of S_{11} versus y_f. We observe that we have a good impedance matching for y_f = 6mm. The 3D gain pattern is shown in Fig . 9, the maximum gain is 4.6dB.

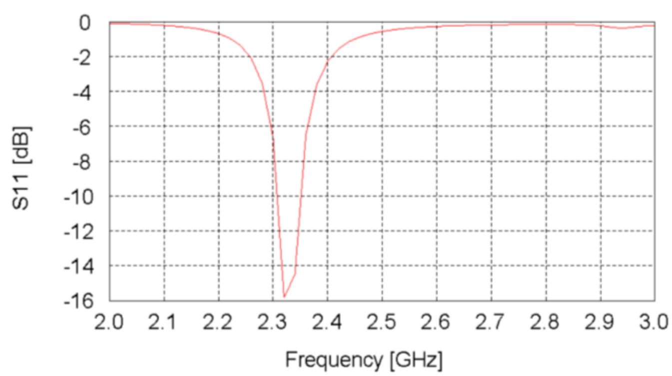


Fig. 6. S_{11} parameter for the patch antenna with coaxial probe fed

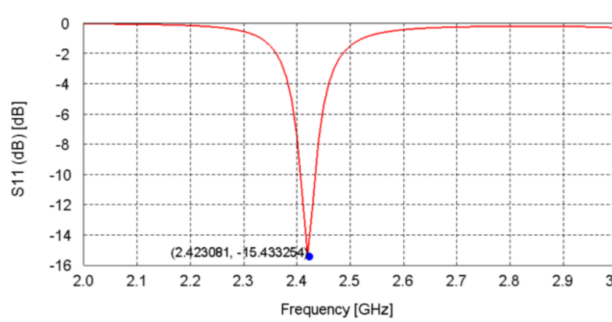


Fig. 7. S_{11} parameter for the optimized patch antenna with coaxial probe fed

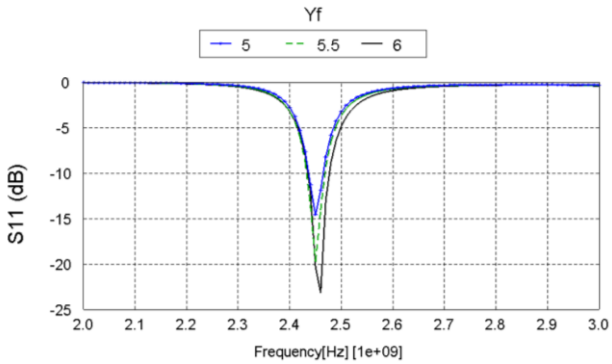


Fig. 8. Parametric study of S_{11} versus y_f

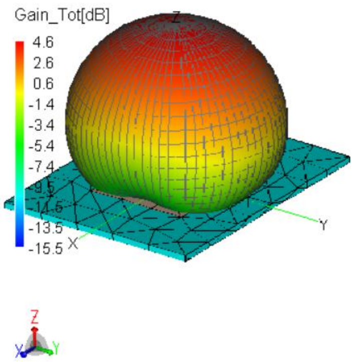
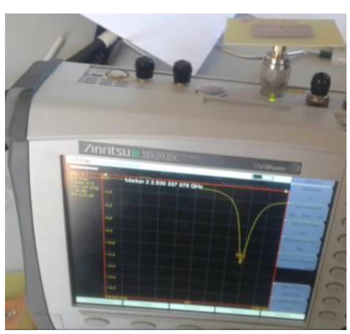


Fig. 9. 3D gain pattern for the resonance frequency (fr = 2.45GHz)

After realization and measurements (fig.10) of the rectangular patch antenna with probe feeding and with y_f=6mm, a good agreement is observed between simulation and measurement in term of S_{11} parameter (fig.11).

(a) Rear side

(b) Front side



(c) Measurement with VNA Anritsu MS2026C

Fig. 10. Fabricated patch antenna with probe feeding (a-b) and measurement with ANRITSU VNA (c)

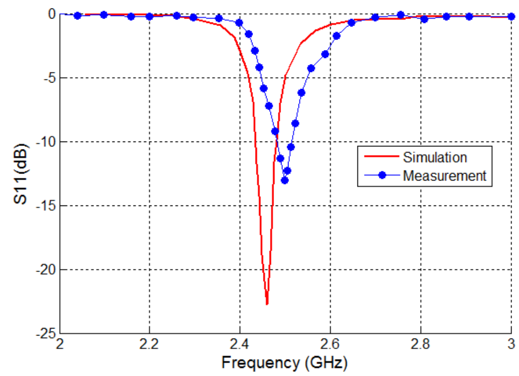


Fig. 11. Simulated and measured S_{11} parameter for the rectangular patch antenna with probe feeding

3.2 Microstrip Line Feed

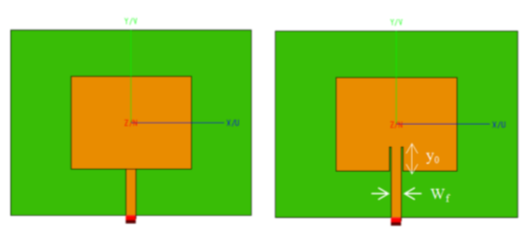
The same patch antenna is fed by a microstrip line smaller in width as compared to the patch and having a characteristic impedance of 50Ω. The width of this line is 2.95mm based on the equation (7).

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_r}\left(\frac{W_f}{h} + 1.393 + 0.667\ln\left(\frac{W_f}{h} + 1.44\right)\right)} \quad (7)$$

With Z_0 : the characteristic impedance of the microstrip line.

W_f : the width of the microstrip line.
h : the high of the substrate.

Two configurations are studied, the first one without the inset feed point (fig. 12(a)), the second one with the inset feed point (fig. 12 (b)). The S_{11} parameter and the 3D gain pattern for the two configurations are given by Fig.13. We observe that when we set up the inset feed point; we obtain a good impedance matching and a better efficiency. Also a parametric study is done to know the effect of the length of the inset point (y_0). Fig. 14 shows the variation of S_{11} versus y_0. A better impedance matching is obtained when y_0 = 7.5mm.



(a) **(b)**

Fig. 12. Geometry of the patch antenna with Microstrip Line Feed

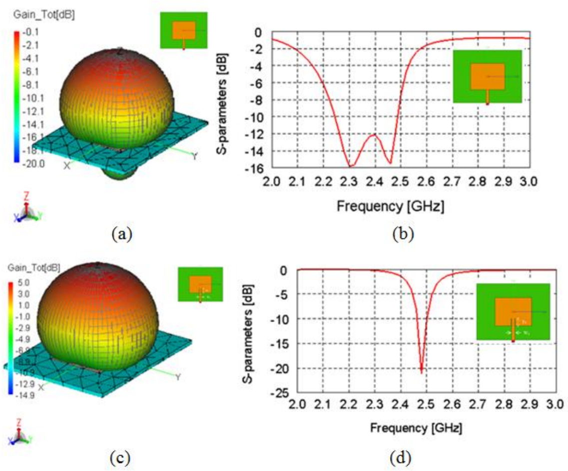


Fig. 13. 3D gain pattern and S_{11} parameter for the two configurations

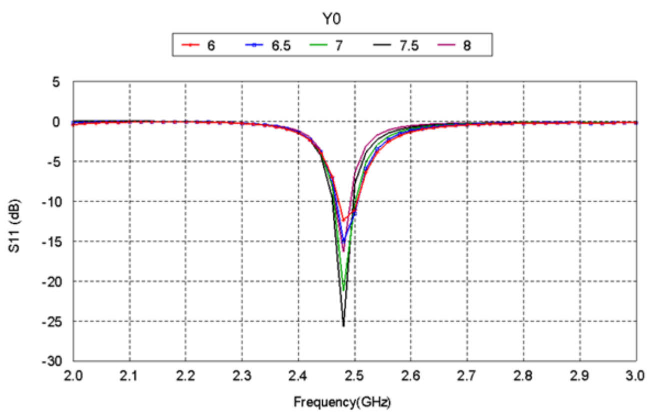


Fig. 14. Parametric study of S_{11} versus y_0

After realization and measurements (fig.15) of the rectangular patch antenna with microstrip line feeding and with y_0=7.5mm, a good agreement is observed between simulation and measurement in term of S_{11} parameter (fig.16).

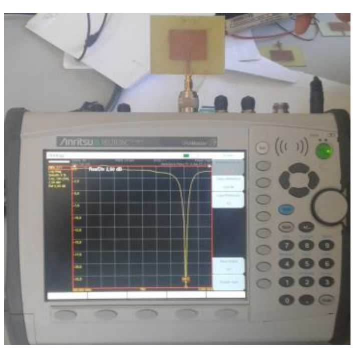


Fig. 15. Fabricated patch antenna with microstrip line feeding and measurement with ANRITSU VNA

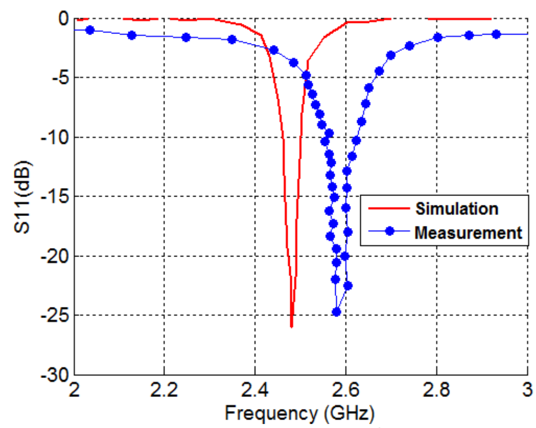


Fig. 16. Simulated and measured S_{11} parameter for the rectangular patch antenna with probe feeding

3.3 CPW-feeding mode

This kind of feeding technique is also called CoPlanar Wave guide feeding (CPW-feeding). The ground plane is placed on the same plane as the patch as shown in fig. 17. This antenna is easy to manufacture compared to the three first antennas using the Printed Circuit Board technique (PCB), in general it's used to obtain a large bandwidth, several studies used this technique to design antennas for Ultra Wide Band (UWB) and Broadband antennas.

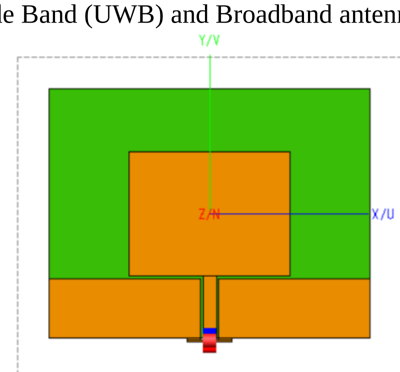


Fig. 17. Geometry of the patch antenna with CPW-feeding

The S_{11} parameter of the antenna is given by fig. 18. We observe that the resonance frequency is 2.6GHz with a large -10dB bandwidth (420MHz: 2.4-2.82GHz). The 3D gain pattern is given by fig. 18, we observe that the maximum gain is 1.3dB, also the antenna is omnidirectional.

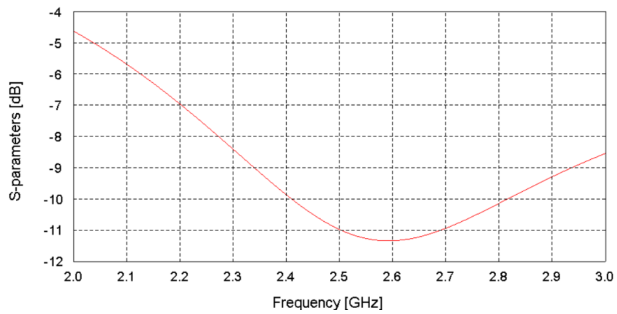


Fig. 18. S_{11} parameter for the patch antenna with CPW-feeding mode

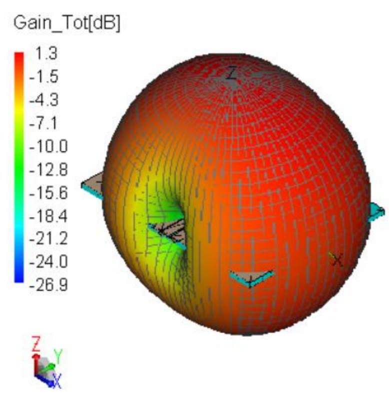


Fig. 19. 3D gain pattern for the patch antenna with CPW Feed

After realization and measurements (fig.20) of the rectangular patch antenna with CPW feeding, a good agreement is observed between simulation and measurement in term of S_{11} parameter (fig.21).

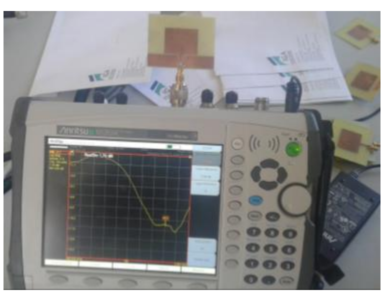
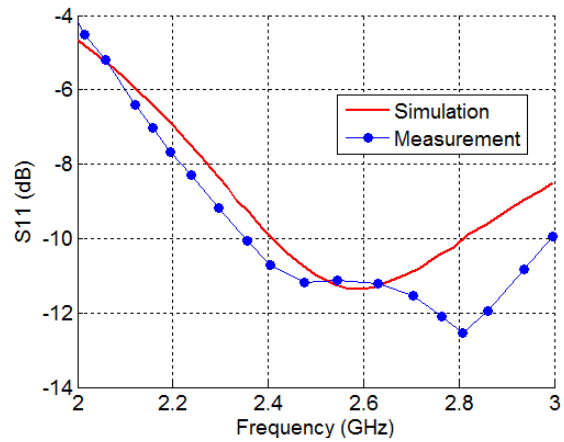


Fig. 20. Fabricated patch antenna with CPW feeding and measurement with ANRITSU VNA



4. COMPARISON OF DIFFERENT FEEDING MODES

Each studied configuration has some advantages and disadvantages. The patch antenna with CPW feeding technique is simple to manufacture, omnidirectional, broadband but having a poor gain. The antenna with coaxial probe feed and microstrip line feed have the same behavior. There gain is important, directional but having a low bandwidth. Table 1 summarizes simulated and measured resonance frequencies, S11 parameter and bandwidths.

Table 1: simulated and measured resonance frequencies, S_{11} parameter and bandwidths for the three feeding modes

	Resonance frequency (GHz)	***S_{11} (dB)***	***Bandwidth (From-To)***
	Probe feeding		
Simulated	2.44	-17.6	45MHz (2.41-2.46)
Measured	2.49	-13	30MHz (2.48-2.51)
	Microstrip Line feeding		
Simulated	2.48	-26.2	40MHz (2.46-2.5)
Measured	2.58	-24.7	60MHz (2.56-2.62)
	CPW feeding		
Simulated	2.6	-11.4	420MHz (2.4-2.82)
Measured	2.8	-12.54	700MHz (2.3-3)

5. CONCLUSIONS

The microstrip patch is an adequate solution to design low profile antennas with important performances. It's also a good solution for designing embedded systems where the weight, cost and the ease of installation are the important requirements. The different feeding modes allow having some advantages: The CPW feeding mode increases the bandwidth of the antenna and having omnidirectional gain pattern. The coaxial probe and microstrip line feeding modes allow having antennas with short bandwidth and important gains.

To design microstrip patch antenna, the adopted feeding mode will be depend on the requirements performances.

As perspective of this work, the indirect feeding modes like proximity coupled and aperture feeding should be studied.

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