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ANALYSIS OF SHORTING PIN LOADED HALF DISK PATCH ANTENNA FOR WIDEBAND OPERATION

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Abstract—In the present paper the analysis of notch loaded shorted half disk patch is given. It is found that the bandwidth of the antenna depends inversely on the notch width whereas it is invariant with the notch length. Further, the antenna shows dual band behavior for a gap spacing below 7.5 mm in the gap coupled half disk shorted patch whereas it behaves as a wideband antenna for gap spacing more than 7.5 mm. Theoretical results are compared with simulated and experimental results.

1. INTRODUCTION

Microstrip antenna has its remarkable advantages over conventional antennas, such as small size, low weight, simplicity of manufacturing, compatibility to planar and non-planar surfaces, ease of being integrated with circuits, simplicity of creating antenna arrays, mechanically robust and suitable for multifrequency operation [1]. These attractive features made patch antennas more applicable in many noticeable communication systems. However their further use in specific systems is limited because of their relatively narrow bandwidth. Wide bandwidth of patch antenna can be achieved by several efficient approaches such as increasing the substrate thickness, incorporating

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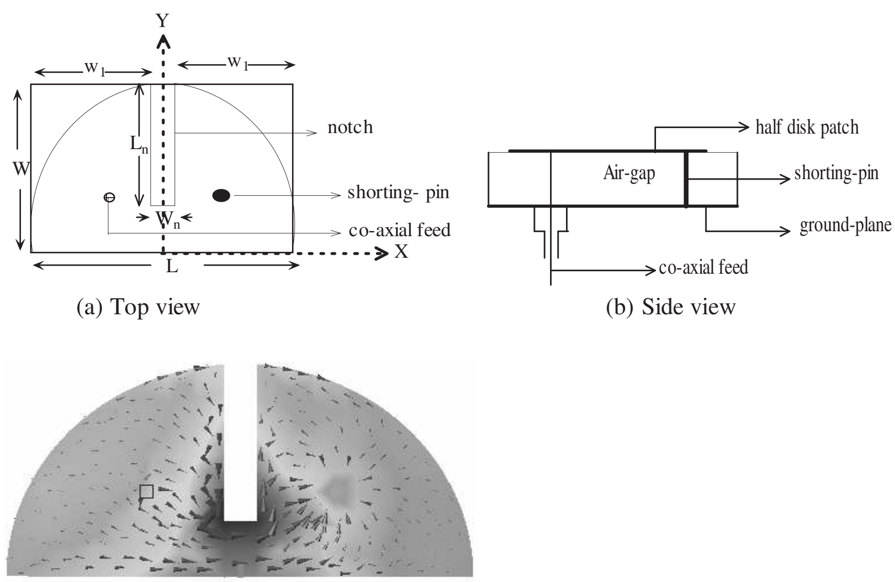
multiple resonances [2, 3] and using more than one layer of resonance patches [4–6].

At the same time microstrip antennas need to have small and compact configuration to accomplish the severe size constraints of some critical applications such as mobile cellular handsets, cordless phones and bluetooth devices. Miniaturization of the overall antenna dimensions can be achieved by using high permittivity substrate [7], short circuited post or shorting-pin [8] and modifying the basic patch shapes [9].

In this paper two patch antenna configurations have been proposed for wideband operation and theoretical results are compared with simulated [10] and experimental [11] results.

2. SHORTING PIN LOADED HALF DISK PATCH WITH A VERTICAL NOTCH

Side view, top view and the corresponding current distribution for the proposed antenna are shown in Fig. 1. A vertical notch with dimensions $L_n \times W_n$ is cut towards curved surface and perpendicular to the straight



(a) Top view (b) Side view

(c) Current distribution

Figure 1. Antenna geometry and its current distribution (f_r = 4.05 GHz) for notch loaded shorted half disk.

edge diameter of the half disk, further to miniaturize and compress the patch, a shorting pin is loaded in the half disk.

The analysis of a half disk patch is almost same as that of circular disk patch but the effective radius changes are due to 50% reduction in its size. A half circular disk is analyzed by supposing it equivalent to a rectangular patch with dimensions $L \times W$ [12], where $L = 2a$ and $W = \frac{\pi a}{4}$. The effective radius a_e of a half disk is calculated by equating the area of half disk to the expanded rectangular patch with dimensions $L_e \times W_e$, where L_e and W_e are calculated by [12].

The equivalent circuit of the half disk patch is shown in Fig. 2(a) in which the circuit parameters i.e., resistance (R_1), inductance (L_1) and capacitance (C_1) are calculated by [13]. The resonance frequency for the half disk patch is given as [14]

$$f_r = \frac{k_{mn}C}{2\pi a_e\sqrt{\varepsilon_e}} \tag{1}$$

where k_{mn} is the mth root of the Bessel function of order n and $k_{mn} = 1.8418$ for fundamental TM_{11} mode, ε_e is the effective dielectric constant [13], C is the velocity of light and $a_e = \sqrt{\frac{L_e W_e}{\pi}}$.

When shorting pin is loaded with patch, a parallel inductance L_s is added in the patch and consequently the equivalent circuit can be given as shown in Fig. 2(b). The value of L_s can be given as

$$L_s = \frac{\eta_0 \omega h}{2\pi c} \ln\left[\frac{4C}{E\omega d\sqrt{\varepsilon_r}}\right] \tag{2}$$

where C is the speed of light, d is the diameter of shorted pin, E is Euler constant and $\eta_0 = 120\pi$.

When a notch is introduced in the patch, the resonance behavior alters due to the flow of two current of different lengths (Fig. 1(c)). Therefore, this perturbation modifies the equivalent circuit of the

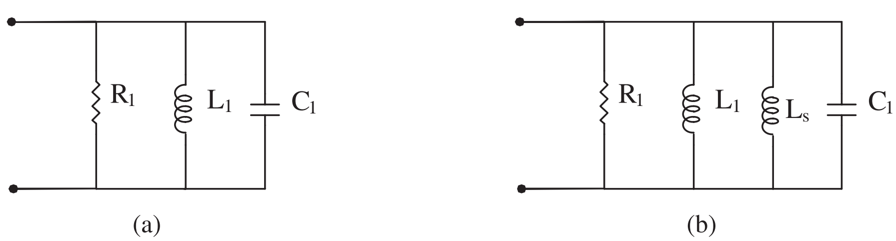


Figure 2. Equivalent circuit of (a) Half disk patch (b) Half disk patch with shorting pin.

initial patch with an additional series inductance (ΔL) and series capacitance (ΔC) [15, 16] as shown in Fig. 3 in which

$$\Delta L = \frac{h\mu_0\pi}{8}\left(\frac{L_n}{W}\right) \quad \text{where } \mu = 4\pi \times 10^{-7}\,\text{H/m}$$
$$\Delta C = \left(\frac{L_n}{W}\right) C_g$$

$C_g =$ gap capacitance which is calculated by [17].

The value of resistance R_2, after cutting the notch, is calculated by [18]. Thus the equivalent circuit of the proposed antenna can be given as shown in Fig. 4, in which L_m and C_m are the mutual inductance and capacitance between the two resonators (one is half disk and the other is half disk loaded with notch) and can be given as [19].

$$L_m = \frac{k_c^2\left(L_1 + L_2\right) + \left[k_c^4\left(L_1 + L_2\right)^2 + 4k_c^4\left(1 - k_c^2\right)L_1L_2\right]^{\frac{1}{2}}}{2\left(1 - k_c^2\right)} \tag{3}$$

in which $L_2 = \frac{L_1 \Delta L}{L_1 + \Delta L}$.

k_c is the coupling coefficient which is given as

$$k_c = \frac{1}{\sqrt{Q_1 Q_2}}$$

where Q_1 and Q_2 are quality factors for both the resonators which can be given as

$$Q_1 = R_1\sqrt{\left(\frac{C_1}{L_1}\right)} \text{ and } Q_2 = R_2\sqrt{\left(\frac{C_2}{L_2}\right)}$$

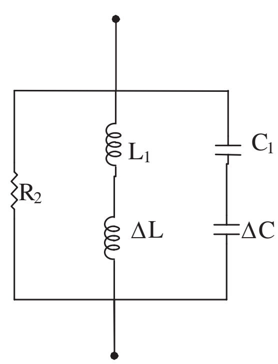


Figure 3. Equivalent circuit of half disk due to cutting the notch.

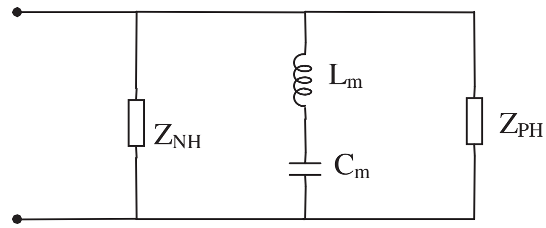


Figure 4. Equivalent circuit of notch loaded half disk patch.

and

$$C_m = \frac{-(C_2 + C_1) + \left[(C_1 + C_2)^2 + \left(1 - \frac{1}{k_c^2}\right) C_1 C_2\right]^{\frac{1}{2}}}{2} \tag{4}$$

where $C_2 = C_1 + \Delta C$.

Now from Fig. 4 one can calculate the total input impedance of the proposed antenna as

$$Z_T = Z_{NH} + \left(\frac{Z_{PH} \times Z_m}{Z_{PH} + Z_m}\right) \tag{5}$$

where

$$Z_{PH} = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + \frac{1}{j\omega L_s} + j\omega C_1}$$

$$Z_{NH} = \frac{1}{\frac{1}{R_2} + j\omega C_2 + \frac{1}{j\omega L_2}}$$

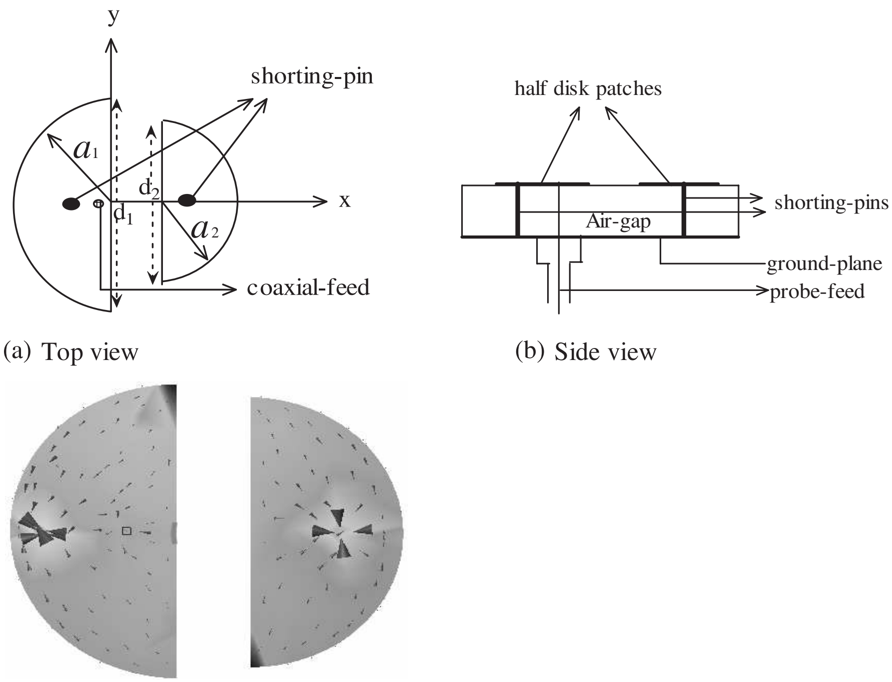
and

$$Z_m = j\omega L_m + \frac{1}{j\omega C_m}$$

3. ANALYSIS OF SHORTING PIN LOADED COPLANAR GAP COUPLED HALF DISK PATCH

Figure 5 shows two half disks; first one is the fed patch having radius a_1 while the other is gap coupled half disk with radius a_2 and both the patches are shorted with shorting pins.

A vertical gap between two microstrip lines is in asymmetrical form with conductors of unequal width on either side of the gap



(a) Top view (b) Side view

(c) Current distribution

Figure 5. Antenna geometry for the shorted gap coupled half disk patch antenna and its current distribution ($f_r = 2.15\,\mathrm{GHz}$).

(Fig. 6). The equivalent circuit for gap can be given as a π-circuit (Fig. 7), in which C_s is the gap capacitance which is given as

$$\begin{aligned} C_s \;=&\; 0.5 \times h \times Q_1 \times \exp\left(-1.86 \times \frac{s}{h}\right) \\ &\times \left[1 + 4.19 \times \left\{1 - \exp\left(0.785\sqrt{\frac{h}{d_1} \times \frac{d_2}{d_1}}\right)\right\}\right] \end{aligned} \tag{6}$$

where 's' is the gap between two patches and

$$Q_1 = 0.4598 \left\{0.03 + \left(\frac{d_1}{h}\right)^{k_0}\right\} (0.272 + \varepsilon_r \times 0.07)$$

in which $k_0 = \frac{1.23}{\left[1+0.12\left\{\left(\frac{d_2}{d_1}\right)-1\right\}^{0.9}\right]}$.

C_{p1} and C_{p2} are plate capacitances and the value of these parameters can be calculated by [20].

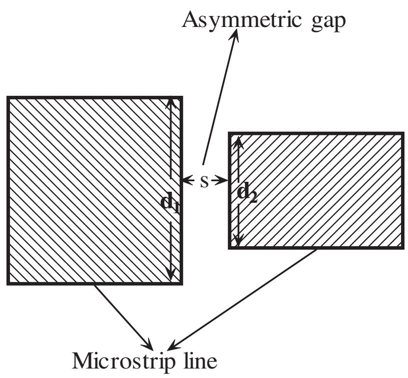


Figure 6. A transverse gap in microstrip line.

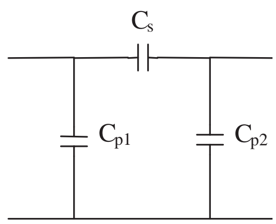


Figure 7. Equivalent circuit for microstrip gap.

Therefore the equivalent circuit for the gap coupled half disk patch loaded with shorting pin can be given as shown in Fig. 8. The total input impedance of the antenna can be calculated as

$$Z_T = \frac{Z_1 \left(Z_s + Z_2\right)}{Z_1 + \left(Z_s + Z_2\right)} \tag{7}$$

where

$$Z_1 = \frac{1}{\dfrac{1}{R_1} + j\omega C_{T1} + \dfrac{1}{j\omega L_{T1}}}$$

and

$$Z_2 = \frac{1}{\dfrac{1}{R_2} + j\omega C_{T2} + \dfrac{1}{j\omega L_{T2}}}$$

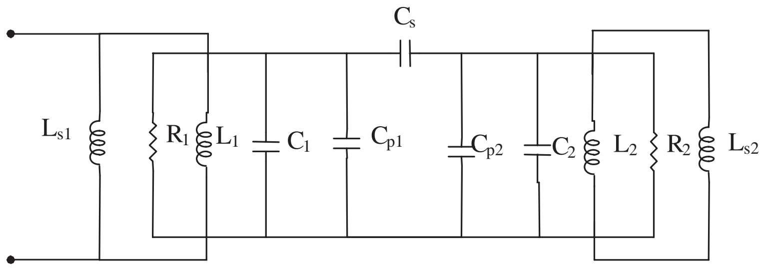


Figure 8. Equivalent circuit for the gap coupled shorted half disk patch antenna.

in which

$$L_{T1} = \frac{L_{s1}L_1}{L_{s1}+L_1}, \quad L_{T2} = \frac{L_{s2}L_2}{L_{s2}+L_2}$$
$$C_{T1} = C_1 + C_{p1}, \quad C_{T2} = C_2 + C_{p2}$$

where $L_{s1} = L_{s2}$ is the inductance due to shoring pin.

Now using Equation (7) one can calculate the total input impedance of the proposed antenna and various antenna parameters such as reflection coefficient, VSWR and return loss as

$$\text{Reflection Coefficient}\,(\Gamma) = \frac{Z_0 - Z_T}{Z_0 + Z_T} \tag{8}$$

where Z_0 = characteristic impedance of coaxial feed (50Ω)

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \;\text{ and }\; \text{return loss} = 20\log_{10}(\Gamma) \tag{9}$$

4. DESIGN SPECIFICATIONS

4.1. Design Specifications for Notch Loaded Shorted Half Disk

See Table 1.

4.2. Design Specifications for Gap Coupled Shorted Half Disk

See Table 2.

Table 1.

Substrate material used	air ($\varepsilon_{r_1} = 1$)
Thickness (h)	7.0 mm
Radius of half disk (a)	15 mm
Radius of shorting pin (r_s)	2.0 mm
Notch length (L_n)	11.0 mm
Notch width (W_n)	2.5 mm
Feed location (x_0, y_0)	(-6, 6 mm)

Table 2.

Substrate material used	air ($\varepsilon_{r_1} = 1$)
Thickness (h)	10 mm
Radius of fed half disk (a_1)	18.5 mm
Radius of gap coupled half disk (a_2)	17 mm
Gap between two half disk (s)	9.0 mm
Radius of both the shorting pins	0.625 mm
Feed location (x_0, y_0)	(-5.6 mm, 0)

5. DISCUSSION OF RESULTS

Variation of return loss with frequency for different notch length (L_n) is given in Fig. 9 for a constant value of $W_n = 2.5$ mm.

It is observed that the bandwidth of the antenna is almost invariant with the slot length (L_n) whereas bandwidth of the antenna depends inversely on the notch width (W_n) for a given value of notch length $L_n = 11.5$ mm (Fig. 10). Typically it is found to be maximum (46.98%) for $W_n = 1.0$ mm. Theoretical return loss along with simulated and experimental results are shown in Fig. 11. It is found that there is an almost close agreement between theoretical, simulated and experimental results as bandwidth of the antenna is concerned.

Figure 12 shows the variation of return loss with frequency for gap coupled shorted half disk for different values of gap separation 's'. It is observed that antenna shows dual frequency operation for gap length below 7.5 mm. However when gap separation increases above 7.5 mm antenna shows a wideband operation. It may be mentioned that bandwidth of the antenna decreases with increasing value of s. This is attributed to the fact that upper resonance is almost invariant

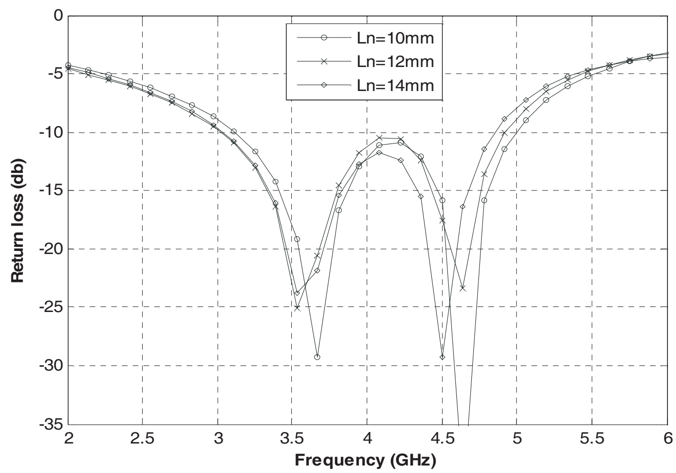


Figure 9. Variation of return loss with frequency for different notch length (L_n).

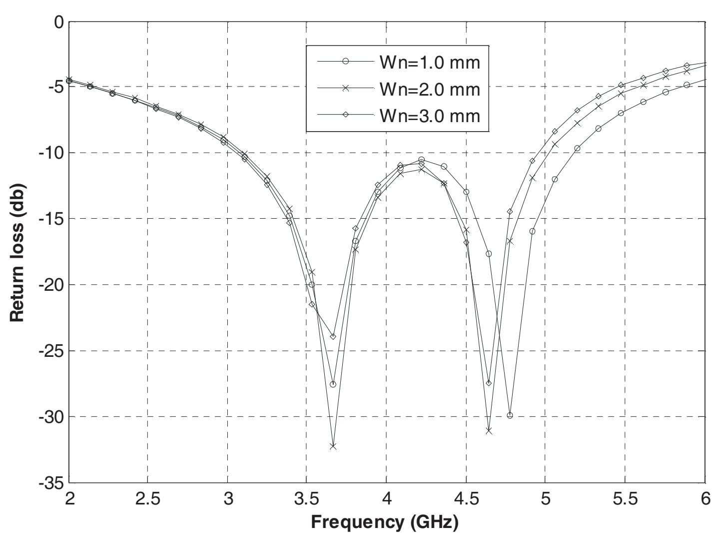


Figure 10. Variation of return loss with frequency for different notch width (W_n).

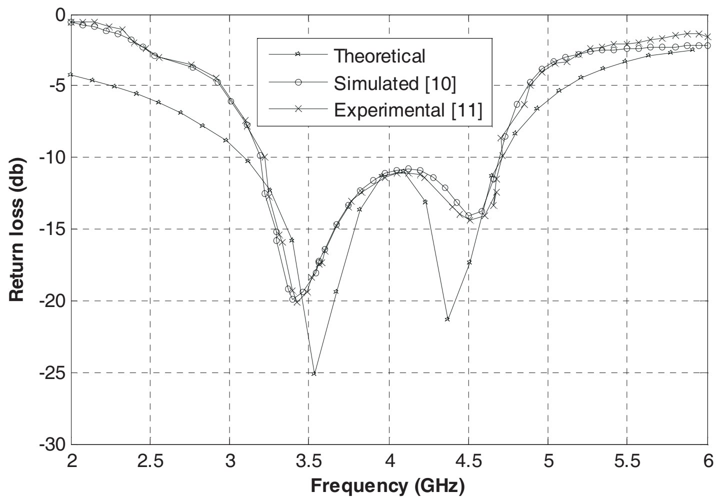


Figure 11. A comparative plot of return loss with simulated and experimental results.
[$L_n = 11\,\mathrm{mm}$, $W_n = 2\,\mathrm{mm}$, $h = 7\,\mathrm{mm}$, pin radius $= 2.0\,\mathrm{mm}$, half disk radius $= 15\,\mathrm{mm}$].

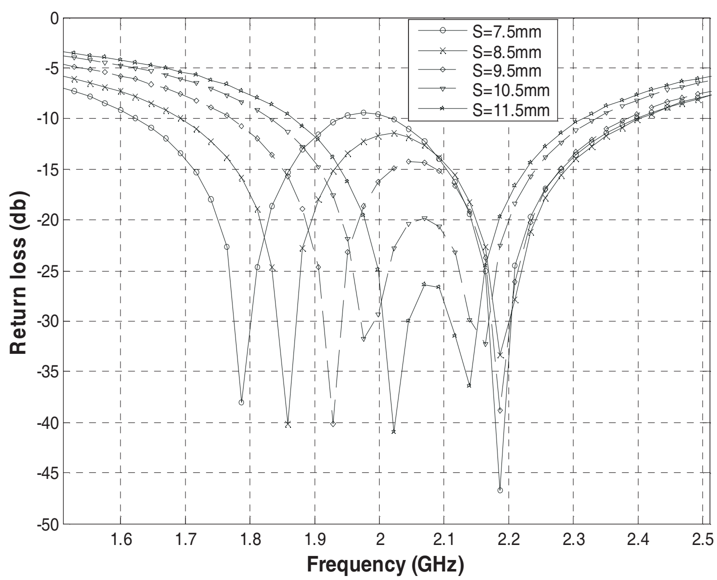


Figure 12. Variation of return loss with frequency for gap-coupled shorted half disk.

where as lower resonance increases with gap length.

Theoretical results are shown along with simulated and experimental results in Fig. 13. It is found that there is a small deviation in the theoretical bandwidth as compared to simulated and experimental data. Because of small variation in the bandwidth they may be treated to be in close agreement.

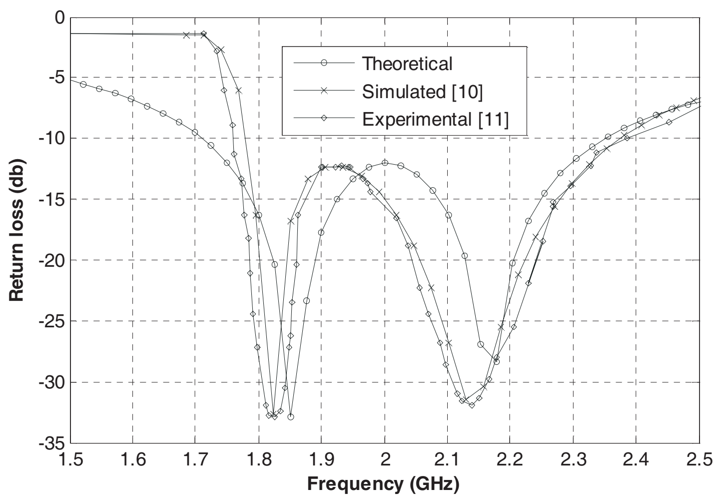


Figure 13. Theoretical graph with simulated and experimental results for gap-coupled shorted half disk ($a_1 = 18.5\,\text{mm}$, $a_2 = 17\,\text{mm}$, $h = 10\,\text{mm}$, gap 's' $= 8.0\,\text{mm}$, radius of shorting pin $= 0.625\,\text{mm}$).

6. CONCLUSIONS

From the above analysis it is inferred that the bandwidth of the antenna depends on the size of the notch, shorted pin and gap spacing in the gap coupled antenna.

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