A Study on Active Microstrip Circular Patch Antenna

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Abstract

A two/three terminal active device integrated with a microstrip circular patch antenna is known as an Active Microstrip Circular Patch Antenna. In case of active antenna maximum possible radiated power can be realized when i) the generated power is maximized and ii) the radiator is matched to the intrinsic impedance of free space. To provide the best radiation performance a new relation based on nonlinear interaction between the device and circuit has been developed in this paper. Theoretical result verified with the experimental proofs.

Keywords: Active Microstrip Circular Patch Antenna, Gunn Diode, Radiation Pattern.

1. Introduction

The origin of active antenna start from 1966 when active dipole was invented (Ramsdale, P. A., 1971). Armstrong, et al (1980) developed an active BARITT integrated microstrip patch antenna in 1980. Morris proposed the Active microstrip patch integrated with a Gunn diode in 1984 (Morris, G., H J Thomas and D L Fudge). The use of an IMPATT diode in an active antenna was demonstrated by Dydyk in 1986. The FET integrated microstrip patch antenna was first proposed by Chang et al (1988). Active antenna elements with notch antennas were developed in 1990 by Chang et al . The Microstrip Ring Resonator was first proposed by P Traughton in 1969 for the measurements of the phase velocity and dispersive characteristics of a microstrip line. In the 1980s, applications using ring circuits as antenna and frequency-selective surfaces emerged. The concept of Microstrip slot antennas has evolved from slot antenna excited by a strip line. These types slot antennas have been extensively discussed in the literature (Waterman, A., et al, Fritz, W. A.,et al and Rao, J. S et al). Rectangular microstrip patch is the most commonly used microstrip antenna and is characterized by its length and width (Bhal, I J., and P Bhartia). Both theoretical and experimental studies of active microstrip patch antenna have been discussed in the recent articles (Biswas, B. N. et al 1999, 2000, Navarro, N A. Durga Prasad, T, Mandal, M. K , Chatterjee, S). Another configuration of common use is circular patch antenna and its geometry is characterized by its radius only. Some aspects on circular patch antenna have been discussed in this paper along with a comparison to rectangular active patch antennas.

2. System Equation and Modelling

A microstrip patch antenna is a radiating patch etched out on one side of a dielectric substrate, which has ground plane on the underside. The EM wave fringes off the top patch into the substrate, reflecting off the ground plane and radiates out into the air. This is illustrated in Fig. 1. Radiation occurs mostly due to the fringing field between the patch and ground. The radiation efficiency of the patch antenna depends largely on the permittivity of the dielectric. Ideally, a thick dielectric material with a low dielectric constant and low insertion loss is preferred for broadband purposes and increased efficiency. Whenever a two/three terminal active device is integrated with a microstrip circular patch antenna the assembly is known as an Active Microstrip Circular Patch Antenna. A circular active microstrip patch configuration is shown in Fig.1. Circular active microstrip patch antenna configuration with active device is placed on the patch is shown in Fig 2.

If G_r is the conductance at resonance for the feed location $r = a$, G_{in} may be written as

$$G_{in} = G_r \frac{Jn^2(ka)}{Jn^2(kr)} \tag{1}$$

The circular microstrip patch along with the Gunn diode can be treated as an oscillator. The steady state voltage output of such an oscillator can be written as

$$V_s^2 = \frac{4}{3} \frac{\alpha_d - G_{in}}{\gamma_d}$$

Power radiated

$$P_r = 2V_s^2 G_r = \frac{4}{3} \frac{\alpha_d - G_{in}}{\gamma_d} 2G_r \tag{2}$$

Maximum power is obtained by putting $\frac{dP_r}{dG_r} = 0$, giving

$$\alpha_d = 2G_r \frac{J_1^2(ka)}{J_1^2(kr)}$$

putting $\alpha_d = \frac{1}{R_d}$, dynamic conductance of the diode we can write

$$R_d = \frac{1}{2G_r} \left[\frac{1 - cos\left(\frac{\pi r}{a}\right)}{2} \right]^2 . \tag{3}$$

From the above equation

$$r = \frac{a}{\pi} cos^{-1}\left(1 - 2\sqrt{G_r R_d}\right) , \tag{4}$$

gives the location of the diode into the patch for highest possible radiated power. The value is slightly different from (Navarro, N A., and K Chang, 1996). Putting the value of α_d in expression (2) maximum power becomes

$$[P_r]_{max} = \frac{16}{3} \frac{G_r^2}{\gamma_d} \left[\frac{Jn^2(ka)}{Jn^2(kr)} \right] \tag{5}$$

This indicates that the maximum power radiation depends on radiation conductance, non-linearity, and location of the diode.

3. Experimental Results

In case of active antenna maximum possible radiated power can be realized when i) the generated power is maximized and ii) the radiator is matched to the intrinsic impedance of free space. The first one can happen when the device and antenna are perfectly matched in the dynamic condition, but not in the static condition as thought by earlier workers i.e. patch and the device are independently considered. To provide the best radiation performance the early workers (Navarro, N A., and K Chang, 1996, Durga Prasad, T., 2011 and Mandal, M. K, 2007) empirically offset diode from the centre. In this work a relation based on nonlinear interaction between the device and circuit has been developed. Two sets of circular patches have been designed and fabricated to operate at 8.5 GHz. In the first patch (C-1) the diode is placed within the patch according to expression (4) while, in the second patch (C-2) the diode is positioned at an arbitrary point. The same low power diode (MA/COM-49104, 25 mW) has been used in two cases. The design parameters are given below:

Frequency of resonance (f_r) = 8.5 GHz
Effective radius of the patch (a_{eff}) = 5.4187 mm
Physical radius of the patch (a) = 4.744 mm
Free space wavelength (λ_o) = 35.294 mm
Substrate chosen = Takonic TLY-5-0310-CH/CH
Relative permittivity of the substrate (ε_r) = 2.2
Effective dielectric constant (ε_{eff}) = 3.645
Guided wavelength (λ_g) = 18.486
Height of of the substrate (h) = 0.787 mm
Thicknes of the substrate (t) = 0.018 mm
Propagation constant (β_d) = 0.34

3.1 Bias Tuning

Free running power spectrum observed in a spectrum analyser (HP 8566B) to determine the locking gain and locking bandwidth of two circular patches of the active patch (C-1and C-2). Variation of oscillator power output and frequency with bias voltage of the patch (C-1) is shown in Fig.3.

3.2 Locking Range vs Locking gain and measurement of Q

An experimental set up to determine the above through injection locking is shown in Fig 5. Injection signal generated from a sweep oscillator (HP-8350B) has been transmitted by a standard gain pyramidal horn (Vidyut Y Udyog X5041).

Locking gain (dB) is defined as

$$G_e = 10\, log \frac{P_o}{P_i} \qquad (6)$$

P_i= injection lock signal power,

P_o= free running oscillator power.

Q-factor of a circuit can be determined with the help of locking bandwidth $(2\Delta f_{\max})$ and locking gain.

Two sided locking bandwidth

$$= \; 2\Delta\omega_{max} = \frac{\omega_o}{Q}\frac{E_i}{E}$$

$$\frac{\Delta f_{\max}}{f_o} = \frac{1}{Q}\sqrt{\frac{P_i}{P_o}} \qquad (7)$$

$$Q = \frac{f_o}{\Delta f_{\max}} \sqrt{\frac{P_i}{P_o}} \qquad (8)$$

Injection locking has been done with a sweep oscillator (HP-8530B) Using expression (6) and (8) locking gain and Q of the patches is measured. Injection locking bandwidth as a function of locking gain for the patch C-1 is shown in Fig.4. Locking gain (G_e) determines the power required to externally injection lock the antenna element. Patch C-1 exhibits a locking gain of 25 dB, lock range nearly 3.5 MHz at 8.40 GHz. Value of Q obtained is ~159, with a moderate locking range for C-1 whereas for C-2 lock range sharply decreases with an increase in Q.

3.3 Power output

According to Friis transmission formula

$$P_o = P_P G_P G_H \left(\frac{\lambda_o}{4\pi R} \right)^2 \qquad (9)$$

P_o = Power received by a standard horn (pyramidal antenna having gain G_H)

$G_H = \frac{2\pi ab}{\lambda_o^2}$, a, b being horn’s dimensions

P_P = power radiated by the patch antenna having gain G_P
R = linear distance between horn and patch antennas.

λ_o = free space wavelength

Power output from the two patches (shown in Table 1) is calculated according to equation (9). An X-band M/A COM 49106 medium power diode 50mW diode have been used to measure the same.
Radiation pattern of antenna C-1 is shown in Fig. 6. It is less directional compared to rectangular antenna pattern (Biswas, B. N et al, 1999).

5. Conclusion

A circular active microstrip patch antenna has been designed on the basis of cavity model. Device –antenna non-linear interaction has been considered. Location of the active device into the patch has been modified to equation (4) for highest possible radiated power. With a 25mW diode the maximum power obtained was 45.3 (EIRP~185.6). A circular patch having same dimension but diode placed at the point predicted by earlier workers has also been designed. But the output power of the active circular patch as suggested by the authors is higher than the conventional one. A large Q value (~159) for the circular active antenna has been realized with the said patch (C-1). A 4.744mm circular patch (C-1) exhibited a locking range of 3.5 MHz at 8.4 GHz. Bias tuning band-width of this patch was 1.43% even lower than that of a rectangular patch.

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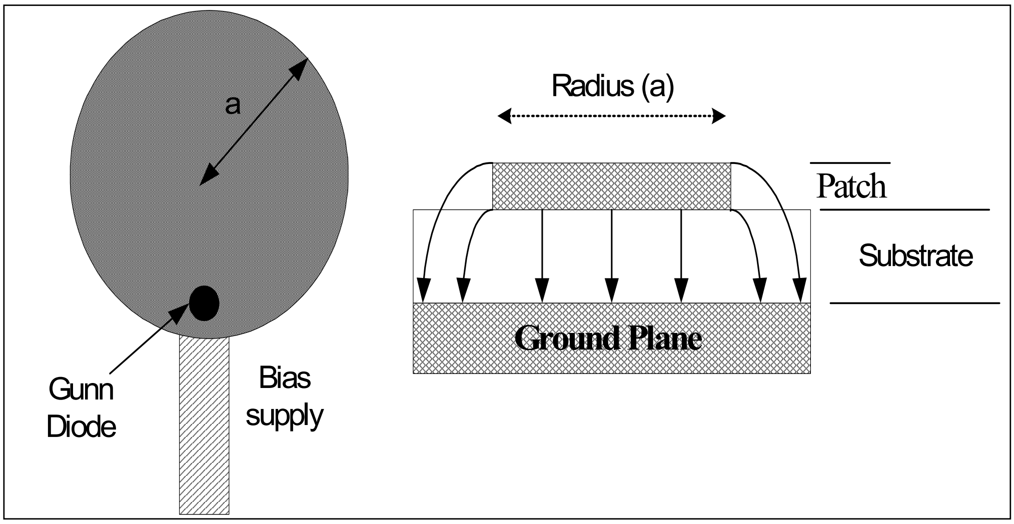

Fig. 1: Active Microstrip Circular Patch Antenna and its operation

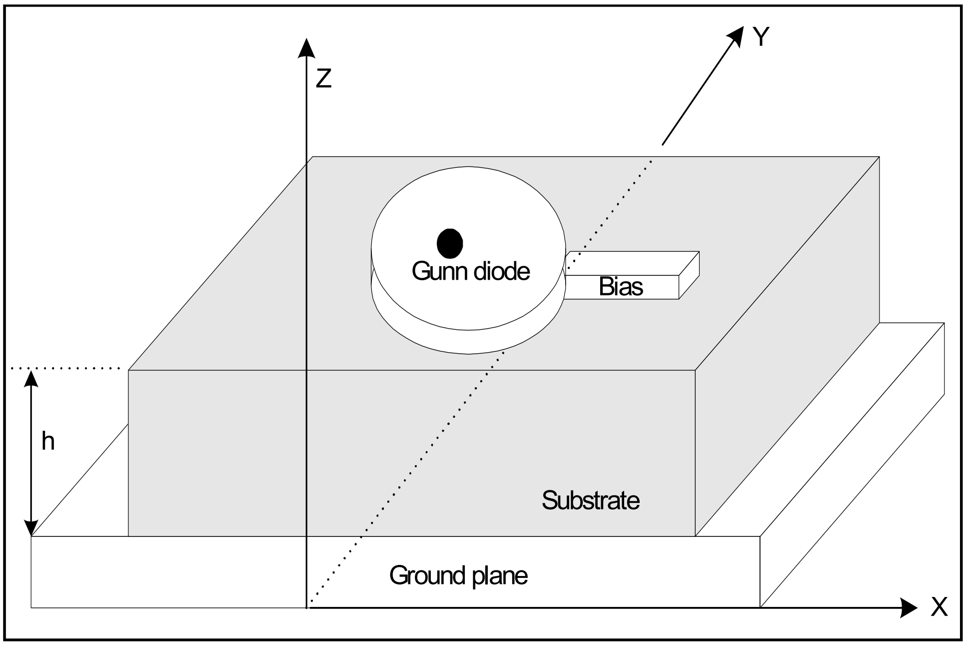

Fig.2 Circular active microstrip patch antenna configuration
Active device is placed on the patch

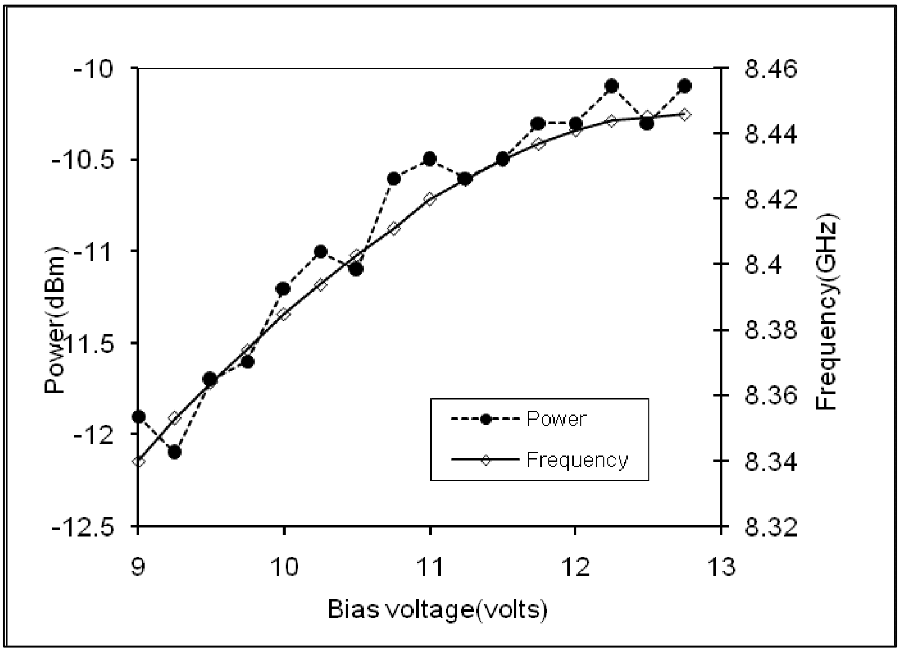

Fig.3 Variation of output power and frequency with diode bias voltage for the circular patch(C-1)

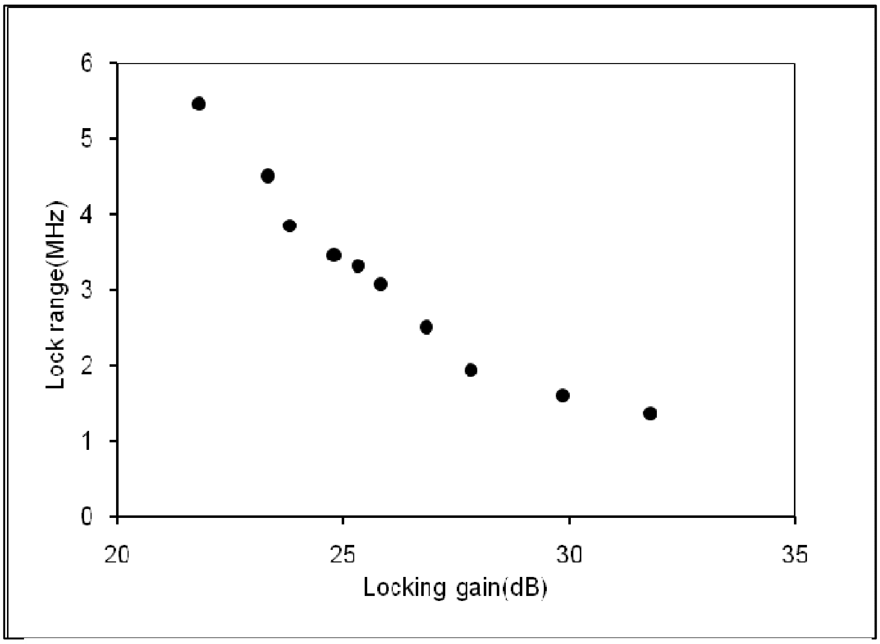

Fig.4 Injection locking bandwidth as a function of locking gain of the circular patch (C-1)

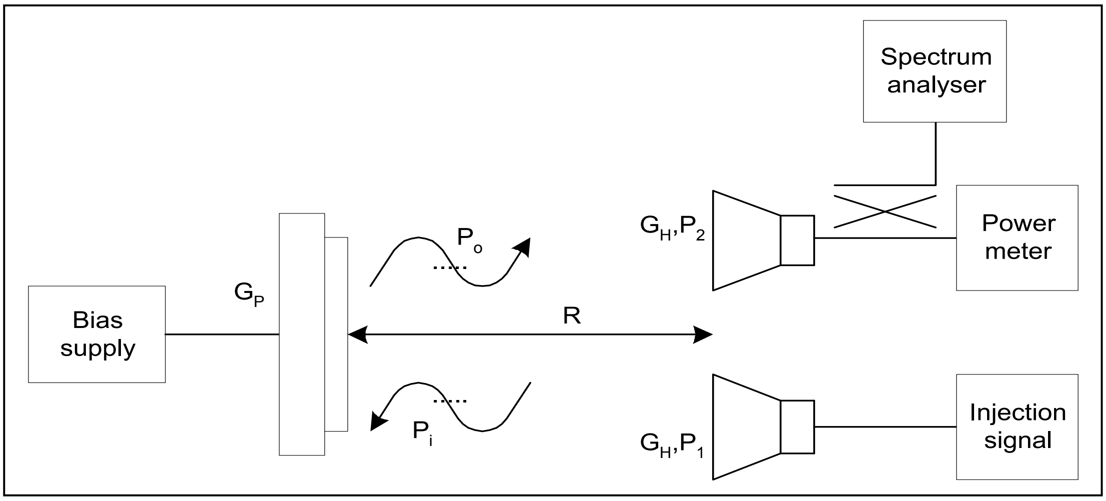

Fig 5 Injection locking arrangement

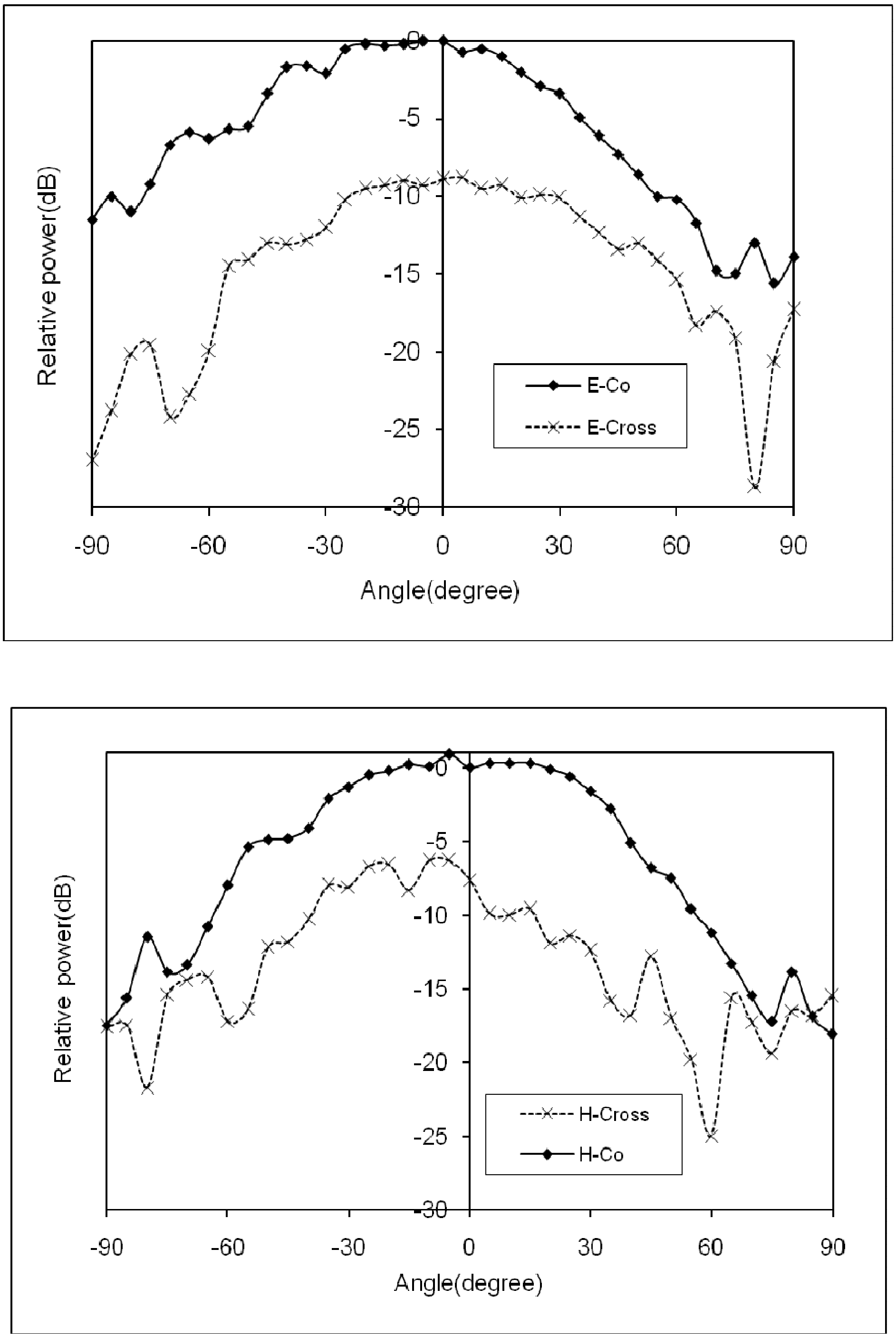

Fig. 6 Radiation pattern of a circular patch antenna
(Gunn diode placed on proper location)
(a) E-plane (b) H-plane

Table 1- Measured Antenna Powers at the operating frequencies

Antenna	f_o GHz	λ_o mm	R mm	G_P	G_H	P_o (mW)	EIRP $P_P G_P$ (mW)	Power P_P (mW)
C-1	8.40	35.71	840	4.04	63.095 18 dB	0.134 (E-Plane) 0.094 (H-Plane)	185.52 (E-Plane) 130.42 (H-Plane)	45.93 (E-Plane) 32.29 (H-Plane)
C-2	8.43	35.587	840	4.04	63.095 18 dB	0.0564 (E-Plane) 0.0625 (H-Plane)	78.64 (E-Plane) 87.151 (H-Plane)	19.47 (E-Plane) 21.57 (H-Plane)

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