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RECTANGULAR MICROSTRIP ANTENNA LOADED WITH TUNNEL DIODE

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Abstract-A resonant frequency agile microstrip *antenna with tunnel diode is proposed, in this the operating frequency is controlled by the bias voltage of the tunnel diode. The operating range of the described antenna is 55.92 MHz (6.67%), which is much better than the rectangular microstrip antenna.*

Key words*: rectangular microstrip antenna, tunnel diode, *bias voltage.

I. Introduction

Theoretically all the conducting element radiate electromagnetic wave but they are not efficient radiator that's why we use some specifics size and shape. Microstrip patch antenna have many attracted feature like easy to manufacture, small in size, light in weight, and low cost. Microstrip patch antenna is most versatile antenna in today's technology but their low gain and narrow bandwidth make these for limited use [1]. There are various technology for improving the gain and bandwidth (B.W.) of microstrip antenna [2]. One of them is use of active devices loaded microstrip. As in the case of multichannel application, small B.W. is required at a larger frequency range. In such applications instead of using a wide band antenna, a narrow band tunable antenna can be used [3, 4].

In the present paper work the study of different parameters of the symmetrically loaded, bias tunnel diode with rectangular microstrip antenna by using circuit model. The tuning frequency of the antenna is depends on the equivalent inductance '*L*' and equivalent capacitance '*C*'. The equivalent capacitance can be changed by changing the junction capacitance 'C_D' of the tunnel diode, which is varies according to bias voltage applied to tunnel diode, which affect the overall tuning frequency [7, 8, 10].

II.Theoretical consideration and antenna equivalent circuit

2.1 circuit model of rectangular microstrip antenna

A rectangular microstrip antenna can be seen as a parallel combination of capacitance C Inductance$L$ and resistance R, and the value of the above parameter is given by the modal expansion cavity model [2].

$$C = \frac{\varepsilon_0 \varepsilon_e\, wl}{2h} cos^2\left(\frac{\pi y_0}{l}\right)$$

$$L = \frac{1}{\omega^2 C}$$

$$R = \frac{Q_r}{\omega C}$$

And $Q_r$is given by

$$Q_r = \frac{c\sqrt{\varepsilon_e}}{4fh}$$

Where $\omega=2\pi f_r$, f_r is designed frequency, c is the speed of the light and $\varepsilon_e$is effective permittivity which is given by

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10h}{w}\right)^{-1/2}$$

Where $\varepsilon_r$and $h$is the relative permittivity and the thickness of the substrate material respectively, $l$and W are length and width of the rectangular microstrip patch respectively.

In tunnel diode equivalent circuit the inductance L_s resistance R_s are in series, and capacitance of the junction C_D and negative resistance ($-R_D$) are in parallel as shown below.

And the junction capacitance is given by

$$C_D = A\sqrt{\frac{q\varepsilon}{2(V_i - V_b)}\left[\frac{N_A N_D}{N_A + N_D}\right]}$$

Where, A is area of the junction, q is the electron charge, ε is the dielectric constant, (N_A, N_D) are concentration of the acceptor atom and concentration of the donor atom, V_i barrier potential and V_b is applied bias voltage.

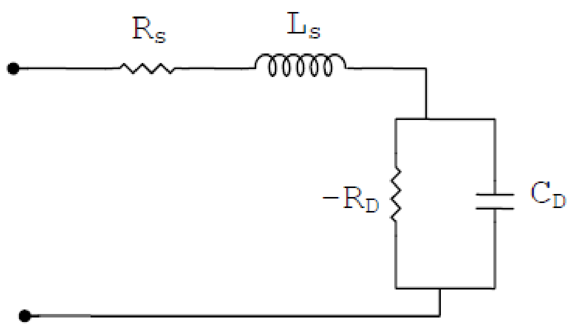


Figure 1: equivalent circuit of the tunnel diode.

A part of the IV characteristic of the tunnel diode shows the negative resistance that is as the voltage is increased beyond V_p the current is getting decrease, on further increasing voltage beyond V_v diode behave like ordinary diode. The region in between V_p and V_v is known as NDR (negative differential region) as shown in the below figure.

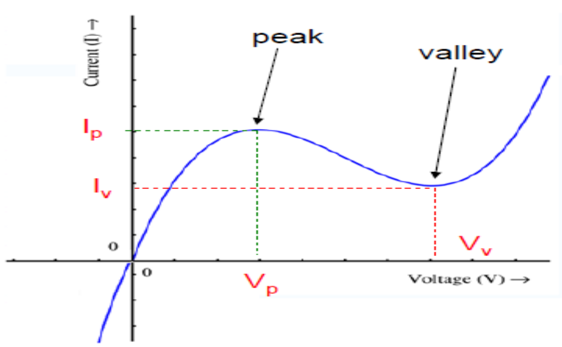


Figure 2: Tunnel diode characteristics

Due to NDR tunnel diode is used as an oscillator, whose operating frequency lies in range of the resistive cut off frequency f_r and self-operating frequency f_s and these value is given as

$$f_s = \frac{1}{2\pi C_D R_D}\sqrt{\left(\frac{C_D {R_D}^2}{L_S} - 1\right)}$$

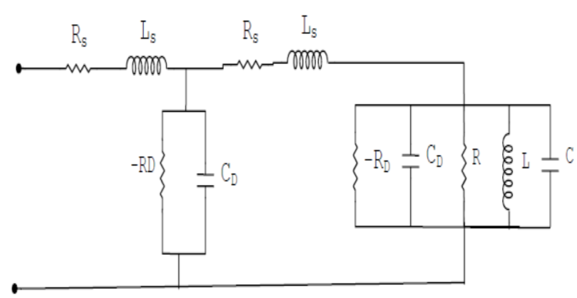
$$f_r = \frac{1}{2\pi C_D R_D}\sqrt{\left(\frac{R_D}{R_S} - 1\right)}$$

The frequency at which the negative resistance is goes to zero is known as the resistive cut off frequency f_r at this frequency the oscillation ceases. That why this frequency shows that the operating frequency of the antenna should be less than the resistive cut off frequency. And the self-resonance frequency is the frequency at which the imaginary part of the input impedance is zero that's why this frequency is known as self-resonance frequency [5, 8].

The location of the tunnel diode is such that the device impedance is matched with input impedance of the microstrip. And the diode location y_0 is given as.

$$y_0 = \frac{l}{\pi} cos^{-1}\sqrt{\frac{Z_d}{Z'_{in}}}$$

Where $Z'_{in}$are impedance of the rectangular patch, $Z_d$is impedance of antenna at the diode end, and l is the length of the microstrip.



The above figure is equivalent circuit of the patch with symmetrically loaded tunnel diode, here input impedance is given by

$$Z_{in} = Z_1 + (Z_2 \| Z_3)$$

Where

$$Z_1 = R_s + j\omega L_s$$

$$Z_2 = \frac{R_D}{(j\omega R_D C_D - 1)}$$

And

$$Z_3 = Z_1 + \frac{j\omega LRR_D}{j\omega L(R_D - R) - \omega^2 LRR_D(C + C_D) + RR_D}$$

Now the reflection coefficient Γ is calculated as,

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

Where Z_0 is characteristic impedance of the coaxial feed (normally 50Ω). And Z_{in} is input impedance of the antenna.

The return loss is given by,

$$R_L = -20log(\Gamma)$$

And the VSWR is calculated as,

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

And the radiation pattern of the antenna array can be calculated as,

$$E_{tp}(\theta) = AF * E_t(\theta)$$

$$E_{tp}(\phi) = AF * E_t(\phi)$$

Where *AF* is array factor.

2.3 operating frequency

Oscillation of the antenna with tunnel diode occurs when

$$Im[Y] = 0$$

Where Y is admittance of the microstrip with tunnel diode seen by the negative resistance (-R_D). And after evaluation the imaginary part of the admittance is,

$$\text{Im}[Y] = \frac{(a - \omega^2 b + \omega^3 c)(\omega^4 d - \omega^2 e) - (\omega^2 f - \omega^4 g - h)(l - \omega^2 k)}{(\omega^4 d - \omega^2 e)^2 + \omega^2 (l - \omega^2 k)}$$

Where

$$a = RL + LR_S + R(C_D R_S^2 - 2L_S)$$

$$b = RLC_D L_S + RL(C + C_D)(C_D R_S^2 + 2L_S^2) + 2LC_D L_S R_S + L_S^2 C_D R$$

$$c = RLC_D L_S(C + C_D)$$

$$d = RLC_D L_S^2$$

$$e = RL(C_D R_S^2 + 2L_S)$$

$$f = RLC_D R_S + 2RR_S(C + C_D) + L(C_D R_S^2 + 2L_S^2) + 2RR_S C_D L_S$$

$$g = 2RLC_D R_S L_S(C + C_D) + LC_D L_S$$

$$h = RR_S$$

$$l = 2RLR_S$$

$$k = 2RR_S LL_S C_D$$

2.4 radiation pattern of the antenna

The radiation pattern of rectangular microstrip with symmetrically loaded tunnel diode can be calculated as, [6, 9]

$$E_t(\theta) = -\frac{j\beta WVe^{-J\beta r}}{\pi r}\cos(khcos\theta) * \left[\frac{\sin\left(\frac{\beta W}{2}sin\phi \sin\theta\right)}{\frac{\beta W}{2}sin\phi \sin\theta}\right] cos\left(\frac{\beta l}{2}sin\theta sin\phi\right) * cos\theta cos\phi, \quad 0 \le \theta \le \frac{\pi}{2}$$

$$E_t(\phi) = \frac{j\beta WVe^{-j\beta r}}{\pi r}cos(khcos\theta) * \left[\frac{sin\left(\frac{\beta W}{2}sin\phi sin\theta\right)}{\frac{\beta W}{2}sin\phi sin\theta}\right] * cos\left(\frac{\beta l}{2}sin\theta sin\phi\right) cos\phi \qquad 0 \le \phi \le \frac{\pi}{2}$$

Where, *V* is voltage of radiating edge, *r* is distance from antenna, k=β√$\varepsilon_r$and β=2π/ʎ.

III. Antenna parameters

GaAs tunnel diode is used with junction area 4.906x 10^{-10}. And the size of the rectangular patch is (68.445mm x 8.8235mm). AndBakelite is used as a substrate material.

Thickness of substrate is =1.588mm

Relative permittivity is = 4.78

Length of patch is = 68.445mm

Width of patch is = 8.8235mm

Bias voltage is = 110V- 550V

Self-resonance frequency is = 0.7624GHz

Resistive cut-off frequency is = 1.49907GHz

IV. Results

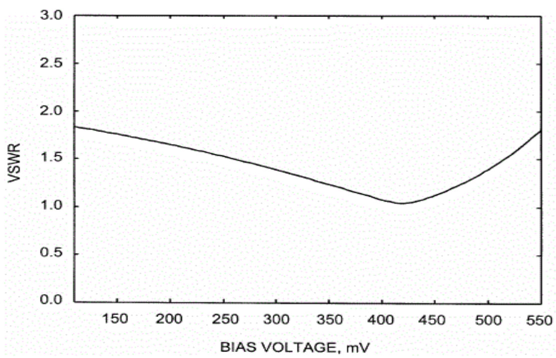


Figure 3: VSWR vs bias voltage

The figure 3: shows that how the VSWR is below about 2dB for the bias voltage (100mV to 550mV). And in the same way the return-loss of the antenna is vary as VSWR for different bias voltage.

And the variation of return loss with respect to the bias voltage is shown below.

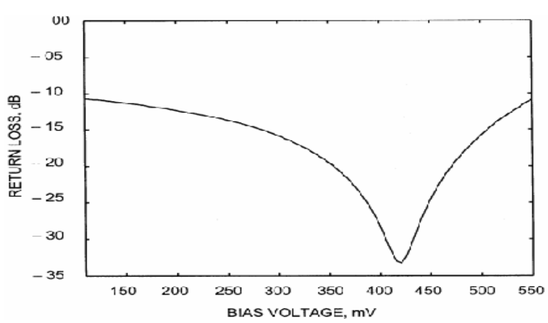


Figure 4: return-loss in dB vs bias voltage

v. Conclusion

In some application like frequency agile radio, and in radar system a narrow band antenna with tunable frequency is required instead of wide band antenna. Thus for tunable antenna we can use different active loaded devices like Tunnel Diode, Gun Diode. But on the other side it has also disadvantage, that the dependence of resonance frequency on the co-ordinate of Tunnel Diode, which increases lack of versatility.And one biggest advantage is that the variation of tuning frequency peak by varying the bias voltage, which change the impedance of the patch.

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