ANALYSIS OF RECTANGULAR MICROSTRIP ANTENNA SYMMETRICALLY LOADED WITH GUNN DIODES

Verma Alka*, Shrivastava Neelam*, Verma Doshant*

Address for Correspondence

a Moradabad Institute of technology, Department of Electrical Electronics and Instrumentation Engineering, Moradabad,
b Institute of engineering and Technology, Department of Electronics and Communication, Lucknow,
c Bharat Sanchar Nigam Limited, Moradabad,

E mail: alkasinghmail@rediffmail.com, doshant@yahoo.com, neelam.srivastava @ietlucknow.edu

ABSTRACT

Analysis on rectangular microstrip antenna with symmetrically loaded Gunn diodes using equivalent circuit concept reveals that the bandwidth is increased to 12.49% over the 2.9% of patch alone. It is observed that the rectangular microstrip antenna symmetrically loaded with Gunn diode offers wider tunability (9.254GHz-9.134GHz) for bias voltage from 8-15V for a given threshold voltage of 4.4V. It is also observed that the radiated power is enhanced by 0.13dB as compared to patch alone.

KEYWORDS

Rectangular microstrip antenna, symmetrically loaded Gunn integrated Rectangular microstrip antenna, Gunn diode.

1. INTRODUCTION

Rectangular microstrip antenna has found its application in various fields but its application in various practical cases is limited due to its limited bandwidth. Various techniques have been proposed by various researchers to enhance its bandwidth. The conventional methods to widen the bandwidth are addition of parasitic elements, laterally or vertically [1]. But, the stacked geometry increases the thickness of the antenna and the coplanar geometry increases its lateral size. Therefore, these geometries are less preferred for modern wireless communications. One of methods suggested is loading of one or more active devices with the patch could enhance the bandwidth and gain of the microstrip patch antenna and its tunability can be improved by adjusting the bias voltage of the active device only[2]-[4] The active solid-state device could be a diode such as Gunn, IMPATT, BRITT, etc, or a transistor such as MESFET, high electron mobility transistor (HEMT), heterojunction bipolar transistor (HBT). In present paper, an analysis has been done on rectangular microstrip antenna by symmetrically loading Gunn diode on it and observing that performance of the antenna is thus improved. The figure 1 shows two identical Gunn diodes being symmetrically loaded on rectangular microstrip antenna (RMSA). Analysis is based on circuit theory and details of the analysis are given in the following sections.

Figure 1: Top view of symmetrically loaded Gunn diodes on RMSA
### Table 2.1: Parameters Of RMSA

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate material</td>
<td>RT Duroid 5870</td>
</tr>
<tr>
<td>Relative permittivity of the substrate</td>
<td>2.23</td>
</tr>
<tr>
<td>Thickness of the dielectric substrate</td>
<td>0.159 cm</td>
</tr>
<tr>
<td>Design frequency</td>
<td>9GHz</td>
</tr>
<tr>
<td>Length</td>
<td>1.01 cm</td>
</tr>
<tr>
<td>Width</td>
<td>1.39 cm</td>
</tr>
<tr>
<td>Resistance</td>
<td>50.2Ω</td>
</tr>
<tr>
<td>Inductance</td>
<td>11.3 nH</td>
</tr>
<tr>
<td>Capacitance</td>
<td>2.756pF</td>
</tr>
</tbody>
</table>

### Table 2.2 PARAMETERS OF THE GUNN DIODE

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>M/A COM 49104, GaAs, n</td>
</tr>
<tr>
<td>Threshold voltage (V&lt;sub&gt;T&lt;/sub&gt;)</td>
<td>2.9 – 4.9 volt</td>
</tr>
<tr>
<td>Operating point I&lt;sub&gt;o&lt;/sub&gt;mA/V&lt;sub&gt;b&lt;/sub&gt;volt</td>
<td>200 mA/ 900 volt</td>
</tr>
<tr>
<td>Oscillation frequency (x-band)</td>
<td>8.2 – 12.4 GHz</td>
</tr>
<tr>
<td>DC resistance</td>
<td>8 Ω</td>
</tr>
<tr>
<td>Operating mode</td>
<td>LSA relaxation mode</td>
</tr>
<tr>
<td>Output power mW(&gt;25)</td>
<td>10-25 mW at 10 GHz</td>
</tr>
<tr>
<td>Conversion efficiency</td>
<td>2.5%</td>
</tr>
<tr>
<td>Device capacitance (C&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>0.1 pF</td>
</tr>
<tr>
<td>Packaging capacitance (C&lt;sub&gt;e&lt;/sub&gt;)</td>
<td>0.1 pF</td>
</tr>
<tr>
<td>Series inductance (L&lt;sub&gt;s&lt;/sub&gt;)</td>
<td>0.3 nH</td>
</tr>
<tr>
<td>R&lt;sub&gt;oLc&lt;/sub&gt; (K Ω/Watt)</td>
<td>25, threshold resistance between semiconductor layer and case</td>
</tr>
<tr>
<td>Package type</td>
<td>Pill with cap</td>
</tr>
<tr>
<td>Typical value of device negative resistance (-R&lt;sub&gt;d&lt;/sub&gt;)</td>
<td>-200 Ω</td>
</tr>
<tr>
<td>DC bias voltage</td>
<td>8.0 – 15.0 volt</td>
</tr>
</tbody>
</table>

### 2. THEORETICAL CONSIDERATIONS

#### 2.1 Analysis of Rectangular Microstrip Antenna

The equivalent of Rectangular Microstrip Antenna is represented as a parallel combination of resistor R, inductor L, and capacitor C as shown in figure 2(a). The values of R, L and C is given below which are based on model expansion cavity modal [5]. The impedance of RMSA is obtained from figure2(a)

\[ Z_{in} = \frac{R \omega^2 L^2 + jR \omega^3 L^2 C}{X} \]  

Where
International Journal of Advanced Engineering Technology

Separating the real and imaginary parts of the impedance of RMSA one gets

\[ \text{Re}(Z_{in}) = \frac{R_p \omega^2 L^2}{X_p} \]  \hspace{1cm} (3)

\[ \text{Im}(Z_{in}) = \frac{R_p \omega^2 L^2}{X_p} \]  \hspace{1cm} (4)

2.2 Rectangular microstrip antenna symmetrically loaded with Gunn diodes

The equivalent circuit of RMSA and Gunn diodes is shown in figure 2(a) and 2(b) respectively where \( R_p \) and \( X_p \) are coaxial probe feed resistance and reactance respectively [6]. \( R_d \) and \( C_d \) are negative differential resistance and capacity of fully depicted triangular domain for gunn diode [7]-[8] respectively. The values of \( R_p \), \( X_p \) and \( C_d \) are small as compared to other components and hence are neglected. The simplified equivalent circuit is shown in figure 2(d) and further simplified equivalent circuit is shown in figure 2(e). The impedance of symmetrically Gunn loaded RMSA is derived from figure 2 (e) as:

\[ Z = \frac{(R_d' - R) \omega^2 L^2 R_d' X_p + \omega^2 L C R^2 |R_d'|^2}{X_1} \]  \hspace{1cm} (5)

Separating the real and imaginary parts of the impedance of Gunn loaded RMSA one gets

\[ \text{Re}(Z) = \frac{(R_d' - R) \omega^2 L^2 R_d' X_p}{X_1} \]  \hspace{1cm} (6)

\[ \text{Im}(Z) = \frac{(1 - \omega^2 L C) R^2 |R_d'|^2 \omega^2 L}{X_1} \]  \hspace{1cm} (7)

Where

\[ X_1 = \left(1 - \omega^2 L C\right) R^2 |R_d'|^2 + \omega^2 L^2 |R_d' - R|^2 \]  \hspace{1cm} (8)

and

\[ R_d' = \frac{R_d}{2} \]  \hspace{1cm} (9)

Hence the input impedance of the circuit is \( Z_{in} = Z \). The reflection coefficient (\( \rho \)) can be calculated as

\[ \rho = \frac{|Z_{in} - Z_0|}{|Z_{in} + Z_0|} \]  \hspace{1cm} (10)

Where \( Z_{in} \) is input impedance of RMSA symmetrically loaded with Gunn diodes, \( Z_0 \) is impedance of the coaxial feed(50 \( \Omega \)).

Hence VSWR is calculated as

\[ \text{VSWR} = \frac{1 + \rho}{1 - \rho} \]  \hspace{1cm} (11)

The Return loss of antenna is given by

\[ \text{RL} = -10 \log \left(\frac{1}{\rho^2}\right) \]  \hspace{1cm} (12)

Figure 2(a): Equivalent circuit of resonant cavity (RMSA)
2.3 Operating frequency

The Gunn diode operates in limited charge accumulation (LSA) relaxation oscillator mode [9]. It may be mentioned that when the bias voltage is less than the threshold voltage, the diode is ohmic with relatively small parallel capacitance and the current is exponentially limited $L/R_0$ by time constant.

Thus, the time period $T_1$ can be written as

$$T_1 = \frac{L}{R_0 \left(\frac{V_b}{V_t}\right)}$$

(13)

Where, $R_0$- low field resistance when $V_b$-dc bias voltage; $V_t$- threshold voltage; $L$- inductance of the microstrip patch.
The RMSA resonator has its resonance frequency which is controlled by the \( L \) and \( C \) parameters of the patch and hence the time period for the patch can be written as

\[
T_2 = 2\pi \sqrt{LC}
\]  
(14)

Thus, the total time period \( T \) for the Gunn integrated RMSA can be given by

\[
T = T_1 + T_2
\]

\[
T = \frac{L}{R_0 \left( \frac{V_b}{V_t} \right)} + 2\pi \sqrt{LC}
\]  
(15)

Therefore, the operating frequency of the active integrated RMSA is given by

\[
f = \frac{1}{L V_T \left( \frac{V_b}{V_t} \right) + 2\pi \sqrt{LC}}
\]  
(16)

2.4 Radiation pattern

The radiation pattern for RMSA and symmetrically Gunn loaded RMSA can be calculated using the formula \[10\]

\[
E_\theta = -jVk_0 \frac{W e^{-j k_0 r}}{\pi r} (\cos(k r \cos \theta))
\]

\[
x \left[ \sin \left( \frac{k_0 \cdot W}{2} \right) \sin \theta \sin \phi \right]
\]

\[
x \left[ \cos \left( \frac{k_0 \cdot l}{2} \right) \sin \theta \sin \phi \right] \cdot \cos \phi
\]

\[
0 \leq \theta \leq \frac{\pi}{2}
\]  
(17)

\[
E_\phi = -jVk_0 \frac{W e^{-j k_0 r}}{\pi r} (\cos(k r \cos \theta))
\]

\[
x \left[ \sin \left( \frac{k_0 \cdot W}{2} \right) \sin \theta \sin \phi \right]
\]

\[
x \left[ \cos \left( \frac{k_0 \cdot l}{2} \right) \sin \theta \sin \phi \right] \cdot \cos \phi
\]

\[
0 \leq \theta \leq \frac{\pi}{2}
\]  
(18)

Where \( V \) is the radiating edge voltage, \( r \) is the distance of an arbitrary point; \( k \) is the \( k_0 \sqrt{r} \), \( k_0 \) is \( 2\pi/\lambda \); \( W \) is the width of the patch; and \( l \) is the length of the patch.

2.5 Quality factor

The quality factor of resonant RMSA is given by

\[
Q = \frac{R}{\omega_0 L}
\]  
(19)

while the quality factor of Symmetrically Gunn loaded RMSA is found as

\[
\frac{1}{Q_L} = \frac{1}{Q_e} + \frac{1}{Q'}
\]  
(20)

Where \( Q_e \) = external quality factor and is given as

\[
Q_e = \frac{|R_d|}{\omega_0 L}
\]  
(21)

\[
Q' = \frac{R'}{\omega_0 L}
\]  
(22)

where

\[
R' = \frac{R}{R + |R_d|}
\]  
(23)
Figure 3: Variation of Real $[Z_{in}]$ with bias voltage.

Figure 4: Variation of Imaginary $[Z_{in}]$ with bias voltage.
Figure 5: Variation of mod $|Z_{in}|$ with bias voltage.

Figure 6: Frequency versus bias voltage.
Figure 7: Frequency versus threshold voltage

Figure 8: Variation of Real Zin versus frequency
Figure 9: Variation of Imag Zin versus frequency

Figure 10: Variation of mod Zin versus frequency
Figure 11: Variation of VSWR with frequency

Figure 12: Variation of Return loss with frequency
Figure 13: Radiation pattern in E plane

Figure 14: Radiation pattern in H plane
4. CALCULATIONS
The input impedance of Symmetrically loaded Gunn integrated RMSA was calculated using equation 5-9 as a function of bias voltage and the graphs resulting from these calculation are shown in figure 3-5. Using equation 16 the operating frequency is calculated as a function of bias voltage for a particular value of $V_t = 2.9$ V and the resulted data are shown in figure 6. Also using equation 16 the operating frequency is calculated as a function of threshold voltage for $V_t = 8$, 10 and 12 V and is shown in figure 7. Input impedance, VSWR and return loss of symmetrically loaded Gunn diode on RMSA are calculated and shown in figure 8-12 in comparison with RMSA alone. Lastly using equation 17-18 the radiation pattern in E and H plane is calculated and shown in figure 13-14.

5. RESULTS AND DISCUSSIONS
In figure 3 variation of real part of with bias voltage for different threshold value is shown. It is seen that real part of impedance increases with bias voltage for a given value of threshold voltage ($V_t = 2.9$). It also increases with decreasing value of threshold voltage in which the increase is comparatively more in the lower bias as compared to higher biasing voltage.

Variation of imaginary part with bias voltage is shown in Figure 4. It is seen that the imaginary part of the input impedance increases with increasing bias voltage for a given value of threshold voltage ($V_t = 2.9$). It also increases with decreasing value of threshold voltage in which the increase is comparatively more in the lower bias as compared to higher biasing voltage.

It is observed that mod $Z_{in}$ increases with bias voltage for a given value of threshold voltage. From figure 5 it is observed that mod $Z_{in}$ increases with increasing bias voltage for a given value of threshold voltage, however, it depends inversely on the threshold voltage for a given bias voltage. It is observed that the increase in mod $Z_{in}$ is large ($43.58\Omega$-$47.93\Omega$) at lower bias (8V) as compared to higher bias (15V) was the increase is from $49.28\Omega$-$50.91\Omega$. This indicates that the symmetrically Gunn loaded RMSA impedance, is enhanced to a level where the matching is better at lower $V_t$ as compared to higher value of $V_t$. The impedance bandwidth is enhanced to 12.49% from 2.9% of RMSA.

For all the values of $V_t$ we observe in figure 6 that the operating frequency decreases with bias voltage, however the antenna operates at higher frequency range at higher value of $V_t$ and at lower frequency range at lower value of $V_t$. It is observed that at constant $V_t=2.9$, the operational frequency is 9.254GHz at 8V bias voltage and 9.134 GHz at 15V bias voltage.

Hence we find that frequency agility is achieved by loading of Symmetrically Gunn diode in which the operating frequency of the rectangular microstrip antenna is electronically controlled by the bias voltage of Gunn diodes.

From Figure 7 we observe that the frequency of operation increases with the threshold voltage. The band of operation is higher at higher $V_t$ (9.164-9.248GHz) and lower at lower $V_t$ (9.11-9.166 GHz) for the given range of bias voltage.

From figure 8 and 9 it may be noted that both real and imaginary parts of impedance for symmetrically Gunn loaded RMSA increases considerably due to the loading of the RMSA with symmetrical Gunn diodes which makes the absolute impedance of the symmetrically Gunn loaded RMSA near to characteristic impedance of feed line 50 ohm. as shown in figure 10. The impedance bandwidth is enhanced to 12.49% from 2.9% of RMSA. From figure 10 it is clear that on loading Symmetrically Gunn diode on RMSA it results in lower mismatch with the feed and hence lower VSWR as compared to RMSA which is shown in figure 11. From the return loss data as shown in figure 12 the above analyses of
lower mismatch resulting in better impedance matching is also observed, which indicates that return loss of Symmetrically Gunn loaded RMSA is lower in comparison to RMSA. It is observed from Figure 13 and 14 that the symmetrically Gunn loaded RMSA radiates enhanced power as compared to RMSA. The radiated power also depends on the bias voltage for a particular threshold voltage (2.9 V). The radiation is maximum (0.13db) at the lowest value of the bias voltage (8V) in E Plane. The radiated power decreases with the increasing bias voltage, which also affects the radiation pattern. In H plane the radiation is maximum (0.16db) at the lowest value of 8V bias voltage as seen in figure 14. This is attributed to the fact that the loading of the RMSA with Gunn diodes increases the operating frequency resulting into enhanced radiation.

7. ACKNOWLEDGEMENT

I would like to pay my sincere gratitude towards my guide Dr. Binod Kumar Kanaujia, Head, Electronics & Communication Department, Ambedkar Institute of Technology, New Delhi for his kind support and guidance throughout my work; who has enlightened my path with his technical expertise and elderly blessings and steered me towards success.

I would also like to appreciate the cooperation of Ms Anuradha, IIT Roorkee, Shri Ananjana Basu, Professor, IIT Delhi and Shri Manoj Parihar, IIT Delhi.

Last but not the least, I would also like to thank my family for giving full support in completing this project.

6. REFERENCES


