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ACTIVE SLOT-RING ANTENNAS AS A RECEIVERS

S. Chatterjee[1, *] and B. N. Biswas[2]

[1]Kanailal Vidyamandir (Fr. Sec.), Chandernagore, Hooghly, West Bengal, PIN-712136, India

[2]Sir J. C. Bose School of Engineering, Mankundu, Hooghly, West Bengal, India

Abstract—A Gunn mounted active microstrip slot-ring antenna (ASRA) has been investigated for the reception of FM microwave signal. Current well/valley phenomenon has been successfully utilized to demodulate the modulation information. The monolithic behaviour of an active slot-ring antenna as a lock-in amplifier, FM (Frequency Modulation) to AM (Amplitude Modulation) converter and square law detector has been demonstrated in this paper. Theoretical analysis coupled with experimental results has been presented. The proposed receiving scheme is unique in the sense that it does not require IF electronics for the purpose of demodulation. It also works well in a multi-channel environment due to the excellent noise-squelching property of an Injection Locked Gunn Oscillator.

1. INTRODUCTION

The urgency as well as necessity of 'Global Connectivity' to anyone in anywhere at anytime for satisfying the needs of the 'Information Age' has created an urge for development of very large bandwidth systems, both at transmitting and receiving ends. Antennas, as an integral part of the system, being the port through which communication is made, follow this growth pattern and their electrical and structural characteristics are improved to fit each particular application. At higher band of frequencies microstrip antennas present some well known advantages such as low profile, small size, and low cost [1–5]. Another important feature is the possibility of integrating wide variety of active elements like diodes, transistors, MMIC circuits

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* Corresponding author: Somnath Chatterjee (somnathchat@yahoo.com).

or passive lumped miniature elements such as resistors, capacitors, or inductors [6–15]. This papers looks into the possibility of monolithic behaviour of an active slot-ring antenna that is manifesting transmission, reception, and demodulation at the same time [16–22]. Specially, these papers demonstrate that (1) an active microstrip slot-ring antenna can act as a tracking demodulator while it is receives with excellent noise squelching capability, and (2) it can act as an aid to the development of a software defined discriminator which can adapt to different radio environment.

2. WHAT AND WHY?

An active slot-ring antenna (ASRA) is a slot ring antenna to which an active element (Gunn diode) is integrated [1, 2]. It serves the purpose of generation and radiation. This paper concentrates on the behaviour of ASRA when a modulated electromagnetic wave is allowed to shine on it. Thus here ASRA's operation is audited from to angles (1) the response of oscillator to a forcing signal and (2) the modification of the devices characteristics in such a situation.

Since an ASRA is an oscillator, it exhibits the well-known phenomenon of injection synchronisation in which case the instantaneous frequency of the ASRA follows that of the forcing signal provided the difference of frequency between them lies within a specified range called the locking range [21, 22]. Over the locking band ASRA exhibits (i) the phenomenon of FM-AM conversion, (ii) discrimination against interfering tones or unwanted disturbances and (iii) square law current voltage characteristics. Thus the property (i) and (iii) together serves the basic requirement of an FM discriminator and the properties add to the noise filtering ability of ASRA discriminator — all in a single device eliminating the necessity of a separate amplifier and discriminator.

3. THEORETICAL APPROACH

An Active microstrip slot-ring antenna integrated with a Gunn diode can be used as an injection locked Gunn oscillator (ILGO). Injection locking technique is efficient to demodulate the signal [3, 21]. The Slot-Ring antenna is modeled as a resonant circuit with $Y(s)$ as the admittance function across which a Gunn diode is connected across the tank circuit as shown in Fig. 1. Therefore, the system equation can be written as

$$I_{inj} = Y(s)v + f(v). \tag{1}$$

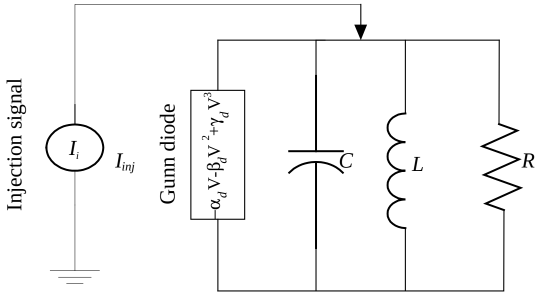

Figure 1. Equivalent circuit of an injection locked oscillator.

So equation of a negative resistance oscillator in presence of injected microwave FM signal can be written as [4, 5]

$$I_{inj} = \frac{1}{L}\int v(t)\,dt + C\frac{dv(t)}{dt} + G_1 v(t) - \alpha_d v(t) + \beta_d v(t)^2 + \gamma_d v(t)^3 \quad (2)$$

where L, C, G_1 = Inductance, capacitance and conductance of the parallel tuned circuit respectively.

$$\begin{aligned} \alpha_d, \gamma_d &= \text{constants of Gunn diode.} \\ I &= \text{Current strength of the carrier signal.} \\ I_{inj} &= \text{synchronizing input.} \end{aligned}$$

Assuming the synchronizing input and the output of ASRA respectively as

$$I_{inj} = I\cos(\omega_c t + \theta), \quad (3)$$

$$\nu(t) = V(t)\cos(\omega_o t + \theta_o(t)) \quad (4)$$

where $\theta = m\sin(\omega_m t)$ represents an FM signal at X-band shining on the active antenna.

System equations are written as

$$\frac{dV}{dt} = \frac{\omega_o V}{2Q}\left(\alpha_k - \frac{3}{4}\gamma_k V^2\right) + \frac{\omega_o}{2Q}E\cos\phi \quad (5)$$

and

$$\frac{d\phi}{dt} = \frac{\omega_o}{2}\left(\frac{\omega_c}{\omega_o} - \frac{\omega_o}{\omega_c}\right) - \frac{\omega_o}{2Q}\left(\frac{E}{V}\right)\sin\phi + \frac{d\theta}{dt}. \quad (6)$$

here E is the equivalent voltage corresponding to I_s and $\phi = \theta - \theta_o$ is the instantaneous phase difference between the two signals. Within the synchronization range the locked oscillator loses its identity and obey command from the forcing signal, and the oscillator is said to be injection locked (phase locked) to the synchronization signal.

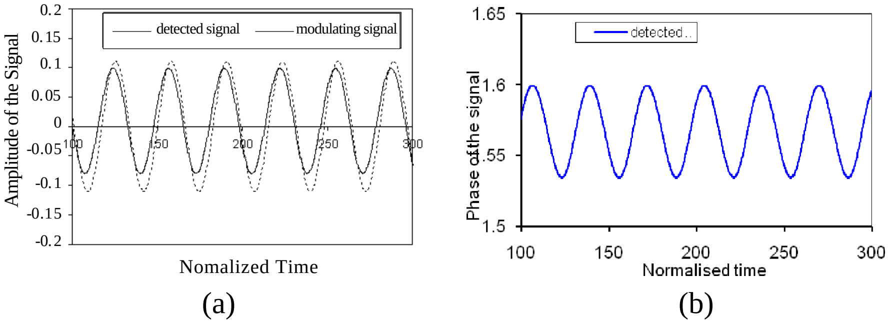

Figure 2. Numerical solutions of amplitude and phase.

Equations (5) and (6) are mutually coupled non-linear differential equations. These two equations address to the aspects like (1) locking band of the synchronized ASRA and (2) FM-AM conversion capability of ASRA. FM-AM conversion is a phenomenon in which the frequency modulation of a given carrier gets converted into amplitude modulation of the same carrier. FM-AM conversion occur in regenerated as well as passive circuit in which the magnitude of the device impedance varies linearly or nearly linearly with the frequency of the input signal. Numerical solutions of Equations (5) and (6) are obtained, and the results are plotted in Figs. 2(a) and 2(b).

Modulating signal is a sinusoidal one of frequency 1 MHz and modulation index 0.122. Total Q of the active antenna is taken as ~ 150 [6]. Fig. 2(a) shows amplitude modulation of the injection locked active slot-ring antenna along with the modulating signal. Perfect conversion has been achieved by choosing the peak frequency deviation ($m\omega_m = 0.122$ MHz) much less than locking range ($\omega_c - \omega_o = 5$ MHz.). Slight phase difference exists between the amplitude modulated signal given by the injection locked oscillator and the modulating signal. Fig. 2(b) shows the phase modulation of the active antenna when locked to the FM signal.

4. EXPERIMENTAL OBSERVATIONS

Microstrip slot antenna is fabricated by using a 0.787 mm thick Takonic TLY-5-0310-CH/CH substrate with $\varepsilon_r = 2.2$ and the active device used is commercially available low power MA/COM packaged Gunn diode (MA 49104) with typical dc to rf conversion efficiency of approximately 1.5%. The slot line ring resonator was designed [8–10] for 10 GHz has a mean radius 4.216 mm and a line width of 1 mm. The slot line ring resonator was designed for characteristic impedance of 158.057 Ω.

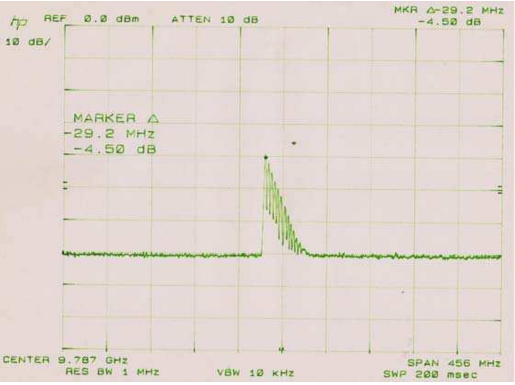

Figure 3. Locked spectra of the active slot-ring antenna.

The slot line notch antenna uses an exponential taper to match the impedance of the ring to free space. The gap at the feed point is 1 mm and the gap at the mouth of the antenna is 11.894 mm. The Gunn diode is mounted on a piece aluminum that serves as the heat sink required by the low dc-to-RF conversion efficiency of the diode. The dc bias to the Gunn diode is provided directly to the center ring by a thin wire. The Slot is biased using a broadband bias T (A 391001 from Anritsu). A bias voltage of 9.887 volt is applied to the diode so that it oscillates at 9.646 GHz. A standard gain (18 dB) X-band horn antenna (Vidyut Y Udyog X5041) served the purpose of transmitting antenna. The horn is connected to a microwave generator (sweep oscillator 8350B from HP) generates the injection carrier signal. A 333 kHz sinusoidal tone signal, obtained from a Philips 807/DRF RF oscillator is used to frequency modulates the microwave carrier. The generator has a frequency sensitivity of 6 MHz/Volt and peak to peak swing of the tone signal is 260 mVolt. This gives the FM index $\left(\frac{\Delta f}{f_m}\right)$ to be 0.122. The receiving antenna is placed at a line-of-sight distance of 1.0 meter away from the transmitting one. The modulated signal is transmitted through the horn antenna, which irradiates the active slot. Frequency of the transmitted microwave carrier is suitably tuned so that it gets locked to the slot oscillator. Injection locking of the active slot antenna is shown in Fig. 3. It shows an locking range $\cong$ 29.2 MHz.

ILGO (here, the active slot-ring antenna) demodulates the FM signal and the demodulated output is obtained at the ac port of the bias T. The bias T has been used for demonstration purpose. However an RF choke would have some low frequency roll off. In actual circuit it should be replaced by a low dc resistance in order to have a uniform

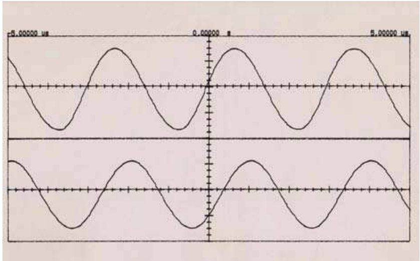

Figure 4. Oscillogram of the demodulated signal. Upper trace — Detecte FM signal of frequency 333 kHz. Lower trace — modulating signal of frequency 333 kHz.

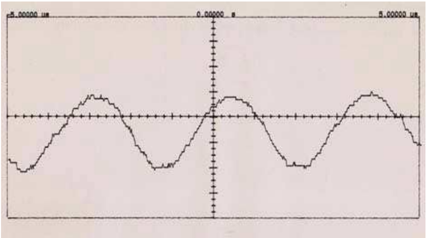

Figure 5. Demodulated output of the same FM signal received by a standard horn.

response over the demodulation band. Oscillogram of the demodulated signal is shown in Fig. 4. The detected signal is quite pure and almost in phase with the modulating signal. An online FFT analysis reveals that distortion is $\sim 1\%$. Amplitude of the demodulated signal depends upon the demodulation efficiency of the ILO, which may be adjusted by varying the diode bias. No additional circuitry is used to demodulate the information signal. Demodulated output of the same FM signal received by a standard horn is shown in Fig. 5.

5. DEMODULATION PERFORMANCE OF ACTIVE SLOT ANTENNA IN AN INTERFERING ENVIRONMENT

The reception capability of active antenna has been tested in multi-channel (two channel in our case) environment. An interference signal is chosen as noise generated from a (Marconi Inst 6158A) source. It has been placed 95 MHz away from the microwave carrier frequency. Spectrum of those microwave carriers are shown in Fig. 6. The interference carrier has been power combined with the microwave FM signal in a 10 dB coupler in order to transmit both the carriers simultaneously. The detected signal has been obtained at the ac port of the bias T.

The information signal becomes heavily corrupted by beat frequency noise as shown in Fig. 7(a). The beat frequency noise has been removed by using a passive low pass filter. Oscillogram of the filtered signal is shown in Fig. 7(b), almost free from noise. Noise filtering property of the active slot antenna has been successfully utilized here. The experimental setup is shown in Fig. 8.

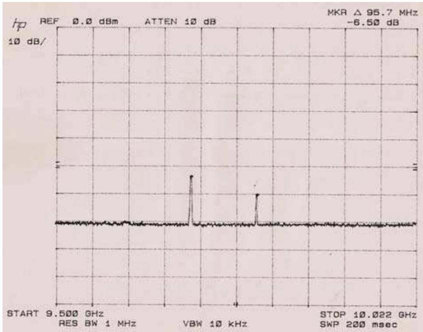

Figure 6. Spectrum of the microwave carrier in presence of Interference.

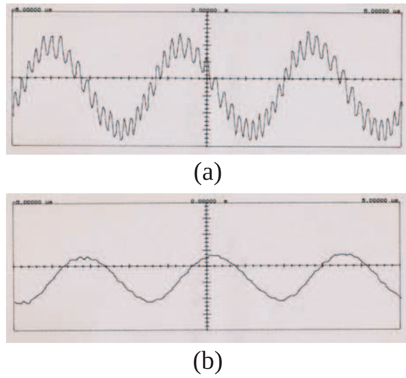

Figure 7. Oscillogram of the detected. (a) Before filtering. (b) After filtered.

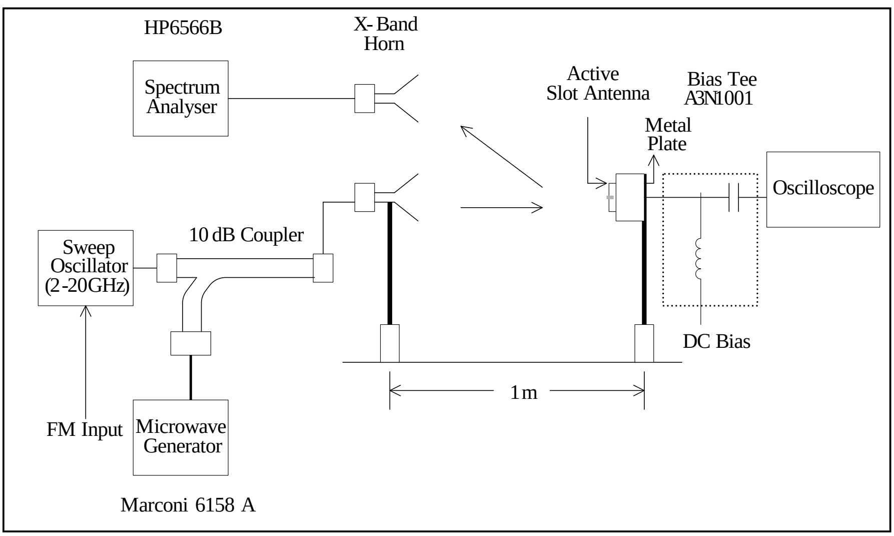

Figure 8. Experimental arrangement for observing demodulation of an FM by an active antenna in presence of interfering signal.

6. CONCLUSION

A Gunn mounted active microstrip slot-ring antenna (ASRA) has been investigated for the reception of FM microwave signal. Current well/valley phenomenon has been successfully utilized to demodulate the modulation information. The carrier is locked on to the active antenna oscillator by means of bias tuning the active antenna. Active slot-ring antenna shows an approximate capture range of the order of 29 MHz, that is very large compared to Active microstrip patch antenna [6]. With the present system configuration demodulation bandwidth in excess of 2.0 MHz is realizable which can successfully accommodate quite a large number of voice or data channels. The proposed receiving scheme is unique in the sense that it does not require IF electronics for the purpose of demodulation. It also works well in a multi-channel environment due to the excellent noise-squelching property of an Injection Locked Gunn Oscillator. Because of its simple circuit configuration and similarity in transmitter and receiver architecture, active slot-ring antenna is well suited for commercial and military application as a two-way microwave communication system.

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