AN ACTIVE, TRACKING MICROWAVE NOTCH FILTER USING A PAIR OF GUNN OSCILLATORS

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ABSTRACT:

In this paper, we have designed a signal tracking microwave notch filter at X-band (8 GHz-12.4 GHz) which is tunable. The experimental notch frequency is 9.42 GHz and a 3-dB bandwidth of this filter is 105 MHz. The theoretical response agrees well with the experimental response of this notch filter. The frequency can be tuned by tuning the Gunn oscillators. The Gunn oscillators being injection –locked to the input signal make the notch filter tracking in character.

Keywords:

Notch Filter, Microwaves, X-band, Gunn oscillators, Lockband, Active device.

1. INTRODUCTION

Microwave notch filters [1-19] are essential components of a microwave communication system. It finds application in satellite communication in order to eliminate interference which can produce jamming in a microwave receiver. It also finds application in microwave distortion analyzer where the notch filter suppresses the fundamental component. Another important application of the notch filter in rf/microwave domain is to separate the luminance signal of a colour television from the composite luminance-chrominance TV signals.

The microwave notch filter can be designed electronically [1-11] as well as optically [12-15]. Optical realizations of tunable microwave notch filter have reported in literature [12-15]. In this paper, we report the electronic design of a microwave notch filter which is tunable, active and signal tracking in character simultaneously. Notch filters are special cases of band reject filters [20-24] where the attenuation at a particular frequency becomes maximum and have a narrow bandwidth.

Looking into literature, it is seen that the microwave bandstop filters have been designed with barium strontium titanate thin film varactor technology [1]. A tunable narrowband microwave notch filter has been reported [2] to be designed at X-band with transmission minimum at 30 dB and bandwidth of 20 MHz. Jackwoski et.al. have designed [3,4] microwave tunable notch filter using microstrip configuration. Microwave filter design has been discussed in detail in [5-8]. Active microwave filters have been reported to be designed [9] using negative resistance devices. Simulation work on the design of microwave notch filter can be found in [10]. In a recent work, the authors have designed a microwave notch filter [11] using a pair of unilaterally injection-locked Gunn oscillators. In the present design, the authors have designed a microwave active notch filter in which the injection signals to two Gunn oscillators are not in phase but they differ in phase which is signal frequency dependent. In the present filter, the locking signals injected into two Gunn oscillators differ in phase by $\frac{\pi}{2}$ radian. As a result, the mechanism of interference suppression is different in the present design from that reported in [11]. The experimental frequency response of the present notch filter is seen to fit with the theoretical response much better than that reported in [11].

2. SYSTEM DESCRIPTION

The circuit diagram of the microwave notch filter is shown in Fig.1.

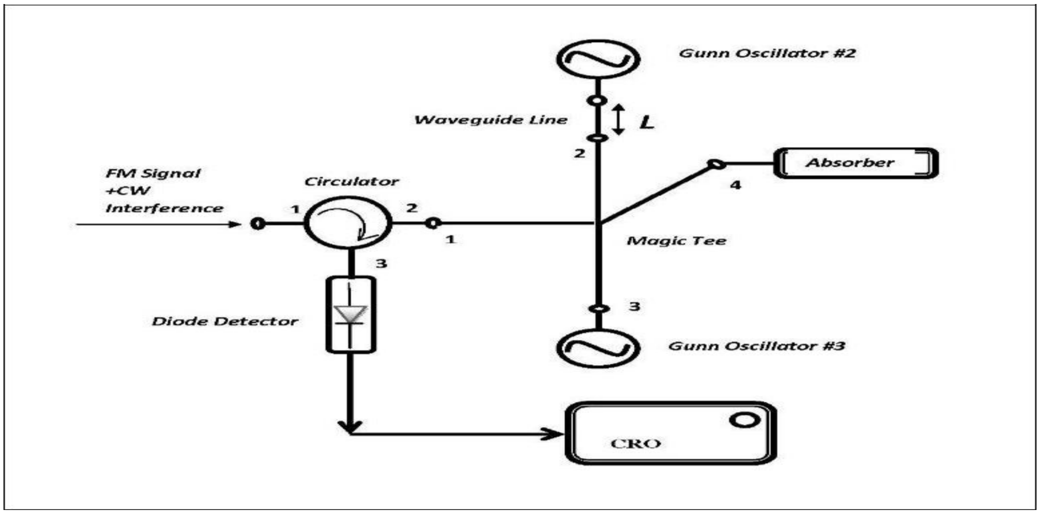

Fig. 1. Schematic diagram of the active, tracking microwave notch filter.

The notch filter is implemented using a magic tee, two identical Gunn oscillators, a waveguide section of length L, a circulator and a waveguide vane microwave absorber. The FM signal accompanied by CW interference enters port-1 (H-arm) of the magic tee and undergo half power division at the magic tee junction. One of these waves is injected into Gunn oscillator #3 connected at the end of collinear arm-3 of the magic tee and makes oscillator fall in synchronism with the interfering tone which is to be eliminated. The other wave travels down arm-2 of the magic tee and propagates through the waveguide section of length 'L' which finally gets injected into Gunn oscillator #2. The Gunn oscillator #2 gets injection locked to the interfering tone. The Gunn oscillators #2 and #3 are identical. The composite microwave signal finally emerges through port-1 of the magic tee. The input signal and the emerging output signal are separated by the circulator. The power of the emerging signal is measured by detecting it in a Schottky diode detector. The dc voltage output of the detector gives the measure of the microwave power input to the detector. This detector does not form any part of the notch filter. It is only used to measure the microwave power output.

3. ANALYSIS

The input signal is assumed to be FM. We perform a static analysis of the system. The input frequency is assumed to vary slowly. Let the microwave injection signal to Gunn Oscillator #2 be represented by the voltage equation

$$v_{inj}(t) = V_i \sin(\omega_{in} t - \theta_L) \qquad (1)$$

where V_i is the voltage amplitude, ω_{in} is the input signal frequency in radian and θ_L is the phase shift of the injection signal during its propagation through the waveguide of length "L". Here,

$$\theta_L = \frac{\omega_{in} L}{v_p(\omega_{in})} = \frac{L}{c}\sqrt{\omega_{in}^2 - \omega_{co}^2} \qquad (2)$$

where $v_p(\omega_{in})$ is the phase velocity of the signal of radian frequency ω_{in} and 'c' is the vacuum velocity of light. ω_{co} is the cut-off frequency of the waveguide line. For Gunn oscillator #3 connected with the port-3 of the magic tee, $L = 0$. $\therefore \theta_L = 0$.
The output of the locked oscillators are assumed to be of the form

$$v_{on}(t) = V_{on}\sin(\omega_{in} t - \varphi_n) \qquad (3)$$

for $n = 2,3$. V_{on} is the voltage amplitude of oscillator n (for $n = 2,3$) . φ_n is the output phase of the corresponding oscillator. For Gunn oscillator #2, the input-output phase error is $(\varphi_2 - \theta_L)$ while the same for Gunn Oscillator #3 is φ_3 . The phase equations for Gunn oscillator #2 and #3 are given by

$$\frac{d\varphi_2}{dt} = \frac{\omega_{02}}{2}\left(\frac{\omega_{in}}{\omega_{02}} - \frac{\omega_{02}}{\omega_{in}}\right) - \frac{\omega_{02}}{2Q_L}\sqrt{\frac{P_{inj}}{P_{02}}}\sin(\varphi_2 - \theta_L) \qquad (4)$$

and

$$\frac{d\varphi_3}{dt} = \frac{\omega_{03}}{2}\left(\frac{\omega_{in}}{\omega_{03}} - \frac{\omega_{03}}{\omega_{in}}\right) - \frac{\omega_{03}}{2Q_L}\sqrt{\frac{P_{inj}}{P_{03}}}\sin\varphi_3 \qquad (5)$$

respectively.

The free-running radian frequencies of Gunn oscillator #2 and Gunn oscillator #3 are ω_{02} and ω_{03} respectively. In experiment, ω_{02} and ω_{03} are made identical. Q_L is the external Q-factor of the Gunn oscillators. P_{inj} is the injection power to Gunn oscillators which is the same for two oscillators. P_{02} and P_{03} are free running output powers of Gunn oscillators #2 and #3 respectively.
The detector input voltage, using complex representation, is given by

$$v_{Din}(t) = \frac{1}{\sqrt{2}}\left(v_{02}e^{-j\theta_L} + v_{03}\right) \qquad (6)$$

Now,

$$|v_{Din}(t)|^2 = \frac{1}{2}\left(v_{02}^2 + v_{03}^2 + 2\,v_{02}\,v_{03}\cos(\varphi_2 - \varphi_3 - \theta_L)\right) \qquad (7)$$

In the steady state, $\frac{d\varphi_2}{dt} = 0$ and $\frac{d\varphi_3}{dt} = 0$

From equation (4), in the steady state, we get

$$\varphi_2 - \theta_L = \sin^{-1}\frac{\omega_{in} - \omega_{02}}{\omega_H} \qquad (8)$$

where ω_H is the half lockband of the Gunn oscillator #2.

From (5), in the steady state, we get

$$\varphi_3 = \sin^{-1}\frac{\omega_{in} - \omega_{03}}{\omega_H} \qquad (9)$$

We take $\omega_{02} = \omega_{03} = \omega_0$ (say). Equation (7) can now be recast as

$$|v_{Din}(t)|^2 = \frac{1}{2}\left[v_{02}^2 + v_{03}^2 + 2\,v_{02}\,v_{03}\cos\left(\sin^{-1}\frac{\omega_{in}-\omega_{02}}{\omega_H} - \sin^{-1}\frac{\omega_{in}-\omega_{03}}{\omega_H} - 2\theta_L\right)\right] \qquad (10)$$

The detector output voltage is given by

$$v_{Do} = \eta\,|v_{Din}(t)|^2 = \frac{\eta}{2}\left[v_{02}^2 + v_{03}^2 + 2\,v_{02}\,v_{03}\cos\left(\sin^{-1}\frac{\omega_{in}-\omega_0}{\omega_H} - \sin^{-1}\frac{\omega_{in}-\omega_0}{\omega_H} - 2\theta_L\right)\right] \qquad (11)$$

The output phase φ_2 and φ_3 of the injection locked Gunn oscillator #2 and Gunn oscillator #3 as functions of input signal frequency are plotted in fig. 2 and fig. 3 respectively.

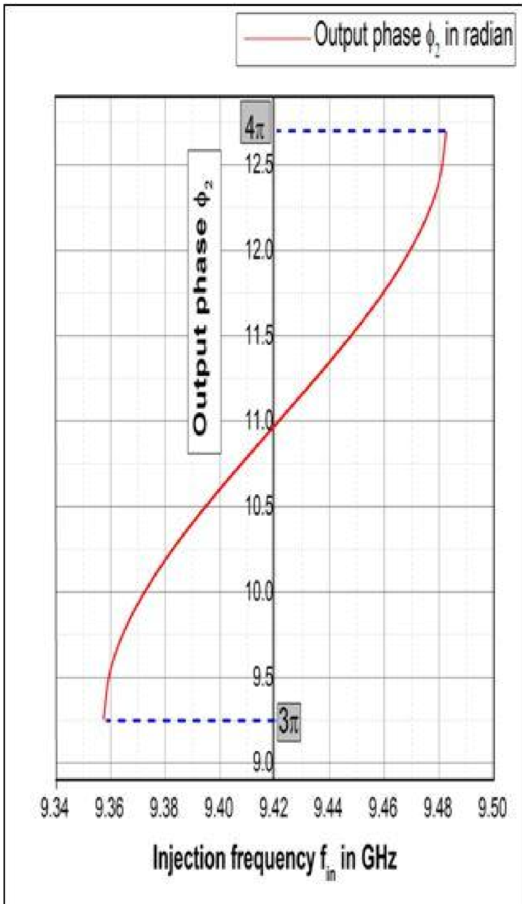

Fig. 2. Variation of output phase of Gunn oscillator #2 with injection frequency.

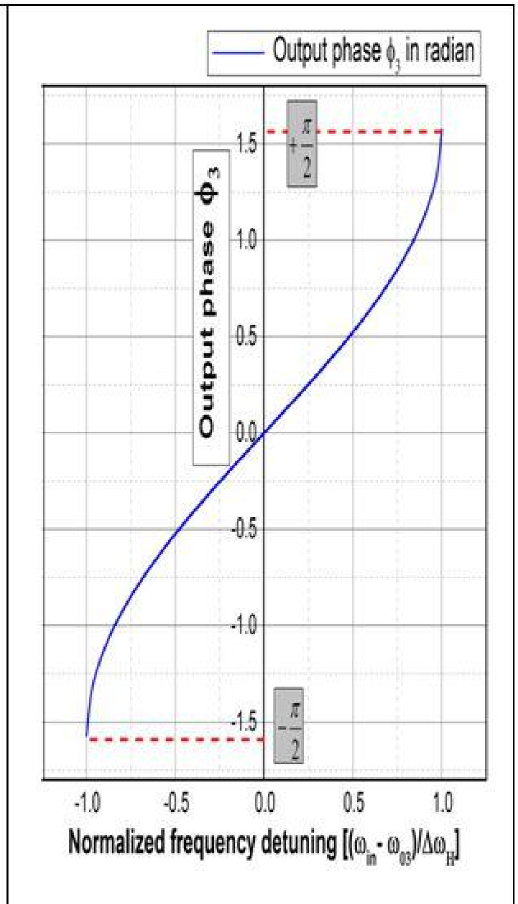

Fig. 3. Variation of output phase of Gunn oscillator #3 with normalized frequency detuning.

The input-output phase error, φ_3 , varies between $-\frac{\pi}{2}$ and $+\frac{\pi}{2}$ radian when the input signal frequency is swept from the lower end of the lockband to the upper end of the lockband. The output phase φ_2 of the Gunn oscillator #2 varies from 3π radian to 4π radian when the input signal frequency is swept from the lower end of the lockband to the upper end of the lockband. The waveguide line of length "L" inserted between the port-2 of the magic tee and Gunn oscillators #2 produces a phase shift of the injection signal by an amount $\theta_L = \frac{2\pi L}{c}\sqrt{f_{in}^2 - f_{co}^2}$.

At the notch frequency f_n = 9.42 GHz, θ_L is calculated to be $\frac{7\pi}{2}$ radian. Thus, at the notch frequency the locking signals for Gunn oscillators #2 and Gunn oscillators #3 differ in phase by $\frac{7\pi}{2}$ radian. The experimental response of the notch filter is shown in fig. 4.

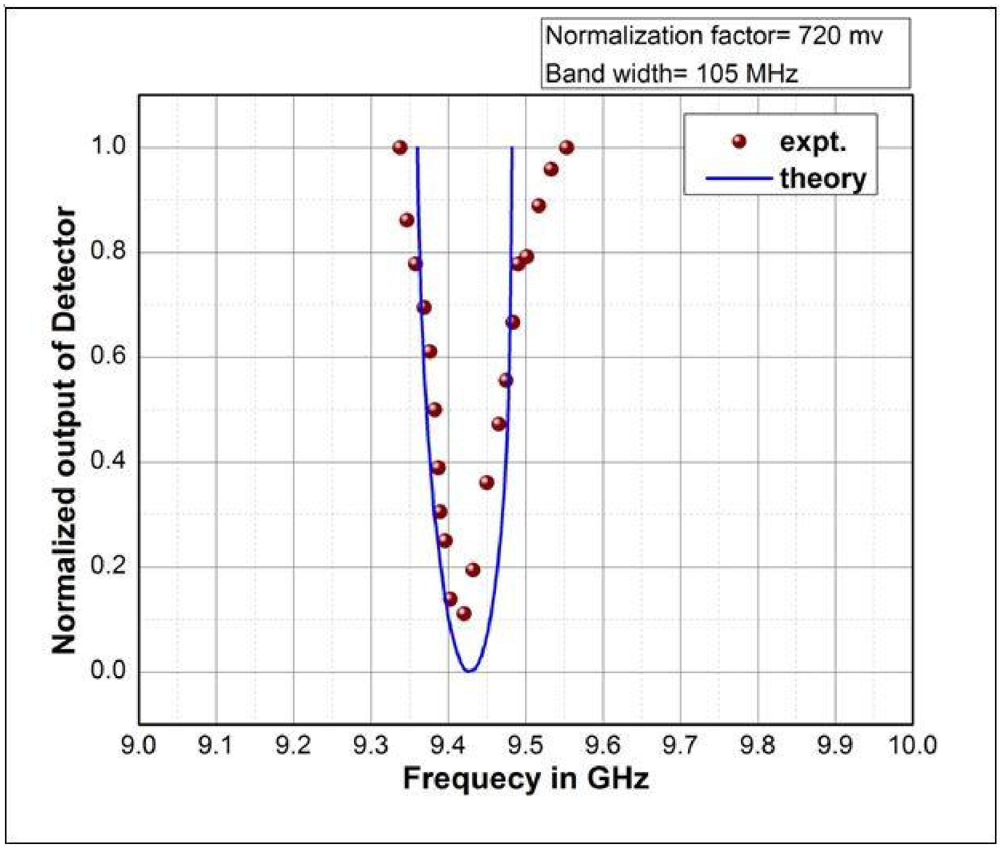

Fig. 4. Theoretical and experimental frequency response of the proposed notch filter

The 3-dB bandwidth of the notch filter measured experimentally is 105 MHz. The calculated response of the notch filter fits well with the experimental response. The Gunn oscillators are micrometer-tunable. So, the notch frequency can also be tuned by tuning the Gunn oscillators. The input signal tracking character of the designed microwave notch filter originates from the injection locking technique being employed in the design. The microwave diode detector is not any part of the notch filter. It is only used to measure the output microwave power by detecting the microwave signal appearing at its input.

4. CONCLUSION

We have designed a tracking microwave notch filter at X-band (8 GHz-12.4 GHz) by using a pair of Gunn oscillators. The notch frequency measured in the experiment to be 9.42 GHz and the 3-dB bandwidth measured experimentally is 105 MHz. The theoretical response of the notch filter fits well with the experimental response. Two Gunn oscillators are injection-locked to the input signal with the injection signal for Gunn oscillator #2 phase shifted by $\frac{\pi}{2}$ radian at notch frequency. If the interference frequency, to be eliminated, shifts with time the notch frequency also follows the interfering signal. This is the tracking behaviour of this notch filter. The tracking range is limited within the lockband of the Gunn oscillators. The injection locking technique also reduces amplitude noise of the desired signal due to its amplitude limiting action.

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