A Novel Microwave Limiter-Discriminator: Design and Analysis

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Abstract—**A new microwave discriminator that incorporates an efficient amplitude limiter is described. The amplitude limiting action is obtained from a pair of low-noise Gunn oscillators synchronized with the input microwave signal. The proposed limiter-discriminator works on the principle of phase-splitting action of the waveguide line as in the case of a passive microwave discriminator. The figure of merit of the proposed discriminator is the highest among the passive and the active discriminators reported in literature. The implementation of the proposed limiter-discriminator can be easily extended to mm wave and sub-mm wave region of the electromagnetic spectrum.**

I. Introduction

A MICROWAVE discriminator is a device that produces an output voltage that is proportional to the instantaneous frequency deviation of the input microwave carrier from a nominal frequency. This frequency is called the cross-over frequency of the discriminator. It recovers directly the information/base-band signal embedded in the frequency of the microwave carrier. An alternative recourse of the microwave discriminator, which is usually adapted instead of this microwave device, is a microwave to RF down-converter followed by a RF demodulator. Microwave discriminators reported in literature can be divided into two categories, viz., passive nontracking discriminators [1], [2] and active tracking discriminators [3], [4].

In this letter, we propose a new microwave limiter-discriminator that produces a higher figure of merit compared with the existing passive discriminators [1], [2] and the injection-locked hybrid discriminator (ILHD) [3], [4]. The figure of merit of the microwave discriminator is defined as the product of the bandwidth and the frequency sensitivity of the discriminator per unit input power. The improvement in the figure of merit of the proposed discriminator owes its origin in the amplifying property of the Gunn oscillators. The bandwidth of the proposed discriminator is limited to the lockband of either Gunn oscillator.

II. Design and Principle of Operation

The proposed limiter-discriminator requires a magic-tee, two tunable crystal diode-detectors, two low-noise Gunn oscillators, two circulators, one waveguide line and a subtractor. The circuit diagram of the proposed limiter-discriminator is shown in Fig. 1. The subtractor is in the form of a differential amplifier of gain unity that can be realized using an operational amplifier. The use of the magic tee simplifies the hardware design of the proposed limiter-discriminator because it performs a double action, viz., equal power division at the hybrid junction and mixing operation of a pair of waves.

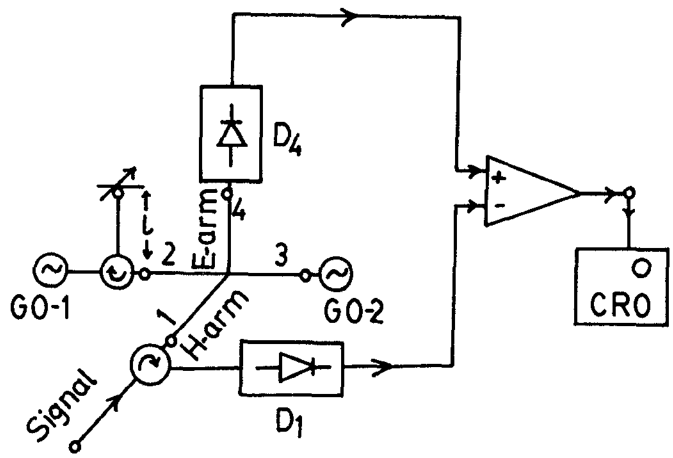

Fig. 1. Schematic circuit diagram of the proposed limiter-discriminator.

Referring to Fig. 1, the input signal entering the H arm of the magic tee splits into equi-amplitude, equi-phase waves at the hybrid junction which propagate down the colinear arms 2 and 3. The Gunn oscillators connected with the port 2 and 3 are injection-locked to the corresponding microwave signal injected into it. The output of the synchronized Gunn oscillator connected with the port 2 of the magic tee is directed into the shorted waveguide line by the circulator connected with this port, and is reflected back by the termination of the line. This reflected wave splits at the hybrid junction into two equi-amplitude, equi-phase waves that move along the H and E arms of the magic tee and in turn appear at the inputs of the crystal diode detectors D_1 and D_4. The output of the Gunn oscillator connected with the port 3 splits into a pair of equi-amplitude waves which travel down the H and E arms of the magic tee and appear at the inputs of the crystal diode detectors. These waves differ in phase by π radian. Assuming the crystal diode detectors to be identical and have a square-law characteristics, their outputs are subtracted and the output voltage is found to be proportional to the instantaneous frequency deviation of the input signal from the cross-over frequency of the discriminator. The frequency modulating signal is thus recovered by the proposed system and can be displayed in the CRO.

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The proposed limiter-discriminator works on the principle of the passive, non-tracking discriminator [1], [2] depending on the phase splitting action of a waveguide line for its operation. It may be mentioned that the principle of operation of the ILHD [3], [4] was based on continuous phase variation of the synchronized Gunn oscillator over its lockband. A co-channel interference or an additive random noise may accompany the useful FM signal that affect both the amplitude and frequency of the received signal. The injection-synchronized Gunn oscillator pair shake-off the undesired amplitude perturbation induced by interference or noise by virtue of its excellent amplitude limiting action [5]. Synchronization of the low-noise Gunn oscillators is a precondition of the proposed limiter-discriminator operation. So effectively the bandwidth of the proposed discriminator will be the common locking bandwidth of the Gunn oscillators. Thus, the super-wide bandwidth of the passive discriminator [1], [2], and [6] is limited at the expense of full amplitude limiting action of the proposed discriminator.

III. Analysis

Let the input microwave signal be represented by the voltage equation

$$v_i(t) = V_o \cos \omega t, \tag{1}$$

where $\omega = \omega_c + \Delta\omega$; $\Delta\omega$ is the instantaneous angular frequency deviation from ω_c and V_o is the voltage amplitude of the input signal.

The outputs of the Gunn oscillators marked 1 and 2 in Fig. 1 may be represented as

$$v_{o1}(t) = V_{s1} \sin(\omega_c t - \psi_1(t)), \tag{2}$$

and

$$v_{o2}(t) = V_{s2} \sin(\omega_c t - \psi_2(t)). \tag{3}$$

V_{s1} and V_{s2} are the voltage amplitudes of the outputs of the respective Gunn oscillators; $\psi_1(t)$ and $\psi_2(t)$ are the respective phase angles.

The length of the waveguide line, l [1], [2], and [7] is chosen as

$$l = [v_p(\omega_c)/\omega_c](2n+1)\pi/4, \tag{4}$$

where $v_p(\omega_c)$ is the phase velocity of the microwave signal of frequency ω_c inside the waveguide line and "n" is an integer including zero. The phase velocity of a wave of angular frequency ω inside an air-filled waveguide is given by

$$v_p(\omega) = c/\left(1 - \omega_{co}^2/\omega^2\right), \tag{5}$$

where c is the velocity of light in air and ω_{co} is the cut-off frequency of the waveguide.

Let us now assume that the tunable Gunn oscillators are identical in all respects. If the Gunn oscillators are identical, then their free-running frequency, output power, locking asymmetry [8], lockband for a given signal injection, etc., are equal. Then we can write $V_{s1} = V_{s2} = V_s$(say) and $\psi_1(t) = \psi_2(t) = \psi(t)$(say)

Assuming $\Delta\omega << (\omega_c - \omega_{co})$, the output voltage of the discriminator can be written as

$$V_{op} = \eta V_s^2 (-1)^{n+1} \sin\left[(2n+1)(\pi/2)\omega_c \Delta\omega/\left(\omega_c^2 - \omega_{co}^2\right)\right]. \tag{6}$$

η is the efficiency of the identical square-law diode detectors. The frequency sensitivity, which is given by the slope of the frequency response characteristics at the cross-over frequency of the proposed discriminator is given by

$$S_d = \left.\frac{dV_{op}}{d\omega}\right|_{\omega=\omega_c} = \eta V_s^2 (-1)^{n+1} ((2n+1)\pi/2)\left[\omega_c/\left(\omega_c^2 - \omega_{co}^2\right)\right]. \tag{7}$$

In the proposed discriminator, the maximum bandwidth that can be realized with full amplitude limiting action is equal to $2K_o$; where $2K_o$ is the lockband of the Gunn oscillators [8]. $K_o = \omega_2/(2Q_L G)$; $G = (P_o/P_s)^{1/2}$ is the locking gain [8]; P_o and P_s are the output power of the Gunn oscillator and the injected signal power, respectively. The cross-over frequency of the discriminator should be made equal to the center frequency of the lockband so that the discriminator bandwidth is symmetrically located around the cross-over frequency. If the locking asymmetry be negligible, then the free-running Gunn oscillator frequency is equal to the cross-over frequency of the discriminator. The sensitivity of this discriminator should be adjusted to yield an approximate bandwidth of $2K_o$. Under this condition,

$$2K_o \simeq [2\omega_c/(2n+1)]\left[\left(\omega_c^2 - \omega_{co}^2\right)/\omega_c\right]. \tag{8}$$

This equation can be solved for the integer "n", which will determine the length of the waveguide line for the optimum condition yielding maximum figure of merit. The figure of merit of the proposed limiter-discriminator can be calculated as

$$F = \left(1/V_o^2\right)|S \cdot 2K_o| = \eta G^2 \pi. \tag{9}$$

In the passive discriminator [1], [2], the frequency sensitivity, S varies directly while its bandwidth, BW varies inversely as the length of the waveguide line. So, there exists a trade-off between the sensitivity and the bandwidth of the passive discriminator, the figure of merit being independent of the length of the waveguide line. The figure of merit of the passive discriminator is given by

$$F_p = \left(1/V_o^2\right) S_p \times BW| = \pi\eta. \tag{10}$$

The figure of merit for the active injection-locked hybrid discriminator (ILHD) [3], [4] has been calculated as

$$F_I = 2\eta G. \tag{11}$$

Comparisons of the figure of merit of the passive discriminator, ILHD and the proposed limiter-discriminator are as follows:

$$F_D = G^2 F_p \tag{12}$$

and

$$F_D = G\pi/2F_I. \tag{13}$$

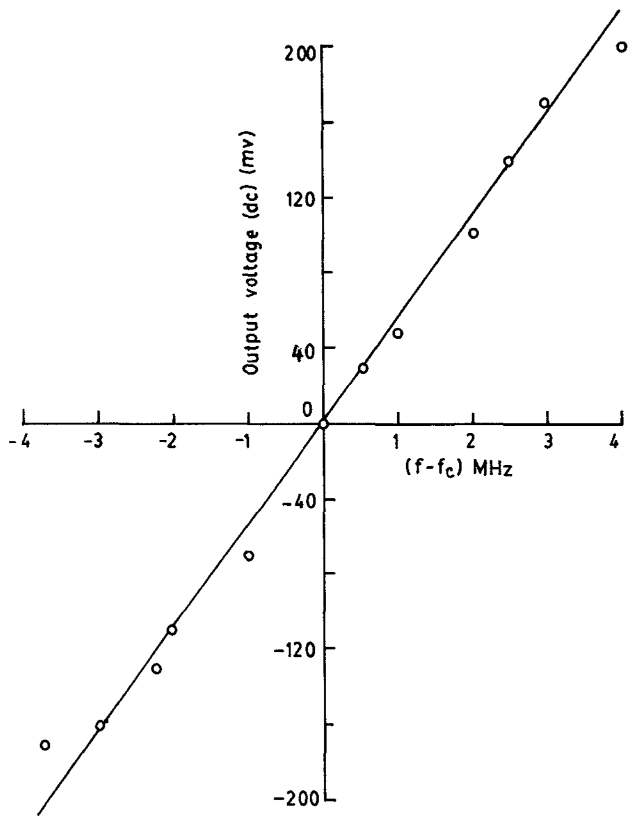

Fig. 2. Theoretical and experimental frequency response of the proposed discriminator.

Since the locking gain $G > 1$ [8],

$$F_D > F_I \quad \text{and} \quad F_D > F_p. \tag{14}$$

This improvement in the figure of merit of the proposed discriminator follows from the signal amplification characteristics of synchronized Gunn oscillator [8].

IV. Experiment

The experiment has been carried out at X-band using a Klystron signal source provided with a Klystron power supply with AM/FM capability. A typical theoretical plot with the experimental points superimposed on it are shown in Fig. 2 for waveguide line of length $l = 19.3$ cm which corresponds to $n = 2$.

V. Discussion and Conclusion

The theory and design of an active microwave limiter-discriminator has been presented. The proposed limiter-discriminator designed at the X-band can also be implemented in the mm wave and sub-mm wave region, because the same principle can be applied to frequencies beyond microwaves using waveguide components and solid-state oscillators corresponding to the particular frequency region of interest. The proposed limiter-discriminator having a higher figure of merit along with its interference and noise-squelching property derived from the amplitude limiting action achieved through the injection locking of the low-noise Gunn oscillators makes the device an important subsystem in the microwave and mm wave receiver design.

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