CIRCUIT TECHNIQUES FOR THE NOISE REDUCTION AND FREQUENCY STABILIZATION OF AVALANCHE DIODE OSCILLATORS

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The noise performance of avalanche oscillators is limited by the inherent noisiness of the avalanche process. It is shown that by suitable system design and the use of noise reduction techniques the device limitations can be overcome in many applications.

In Fig. 1 a typical plot of a measured AM noise power density spectrum normalized to the carrier power is presented. The AM spectrum is approximately flat in a frequency range from 1 KHz out to frequencies where the filtering effect of the RF resonance circuit becomes significant. Beyond the 3 db bandwidth points, the spectrum falls off at theoretically 6 db/octave for a simple RLC resonant circuit. It was found that in a frequency range extending from 100 KHz to several hundred MHz off the carrier frequency the shape of the spectrum is a sensitive function of the bias network impedance. In this range of the output spectrum, up-converted low frequency noise components predominate. The effect of these components can be minimized by providing a high impedance to the diode junction at the corresponding frequencies of the baseband spectrum. The FM noise spectrum is strongly dependent on the loaded Q of the oscillator resonant circuit and is practically constant in a frequency range from 1 KHz to several MHz. For a $Q_L \approx 100$, the FM deviation was measured to be typically 70 Hz RMS in a 100 Hz bandwidth.

The noise performance of a mixer is critically affected by the AM noise side bands of the L.O. signal. In a balanced mixer, a substantial reduction of the L.O. noise contribution can be achieved. Fig. 2 shows the degradation ΔF_N of the mixer noise figure as a function of the L.O. excess noise temperature ratio $t_{L.O.}$ with the mixer noise suppression S as parameter. $t_{L.O.}$ is the ratio of the noise side band power to the thermal noise power available at the L.O. port of the mixer and is obtained from the (N/S) ratio plot of Fig. 1.

$$t_{L.O.} = 10 \log_{10} \left[\frac{P_{L.O.}}{kT \Delta f} \left(\frac{N}{S} \right)^{\Delta f} \right] \qquad (1)$$

where:

$P_{L.O.}$: L.O. signal power

$(N/S)^{\Delta f}$: Noise to carrier ratio in a bandwidth Δf

$kT\Delta f$: Thermal noise power in a bandwidth Δf

The curves of Fig. 2 were obtained from the expression

$$\Delta F_N = 10 \log_{10} \left[1 + \frac{t_{L.O.} \; G_c/S}{F_{IF} + t_D - 1} \right] \qquad (2)$$

under the following assumptions:

Diode Noise Temperature:	t_D	= 1.1
IF Noise Figure :	F_{IF}	= 1.8 (2.5 db)
Conversion Gain :	G_c	= .25 (-6 db)

In deriving equation (2) it is assumed, that both noise side bands arrive unattenuated at the mixer diode and are equal in magnitude. Alternatively, for a given suppression factor and a maximum tolerable noise figure degradation, $t_{L.O.}$ can be obtained from Fig. 2. Using expression (1), the minimum required IF frequency is then easily determined from the (N/S) plot of Fig. 1. If an upper limit on the selection of the IF frequency is imposed, additional attenuation of the noise side bands can be obtained by the insertion of a narrow band-pass filter. The IF frequency is now determined only by the minimum bandwidth of the filter which conveniently can be realized to provide the necessary skirt attenuation. Fig. 3 shows a design example of an avalanche local oscillator at X-band. The unit is mechanically or electronically tunable within a 60 MHz range. An isolator between oscillator and filter prevents instabilities and reduces frequency pulling due to load changes. Using an IF frequency of 120 MHz, the noise figure degradation in a single ended mixer is less than .5 db compared to that of a klystron local oscillator as seen from Fig. 4. When used in a balanced mixer configuration, the noise figure degradation is negligible.

Noise reduction by means of negative feedback is also possible. With the progress made in microwave integrated circuitry some of these schemes have become more attractive. Fig. 5a and 5b show possible arrangements for AM and FM noise reduction, respectively. It is important to realize that either the frequency or amplitude has to be corrected without simultaneously affecting the other. Therefore, direct modulation of the diode current is not feasible. For amplitude corrections, a PIN modulator can be used. Isolation between modulator and oscillator is necessary because the oscillator frequency is sensitive to load changes. The frequency correction may be accomplished either by YIG tuning or varactor tuning. Varactor tuning has the advantage of being tunable at high rates and requiring low tuning power. The important parameter in these noise reduction techniques is the sensitivity of the signal detectors. In the AM case, the limiting sensitivity is determined by the overall noise figure of the detector system and is about 10 db above the thermal noise for diodes with low 1/F noise. Because of limitations in the gain - bandwidth product and noise figure of the amplifier, useful operation is restricted to a frequency range from approximately 1 KHz to a few MHz. The improvement in the case of FM is determined by the minimum frequency deviation that can be detected with the discriminator and is primarily a function of the resonator Q. An example of an integrated microwave (X-band) discriminator using a delay line as the phase sensitive element is shown in Fig. 6. Although the discriminator sensitivity is not sufficient for effective noise reduction, this simple circuit provides long term stabilization of the oscillator frequency against temperature and load variations within 1 part in 10^4. When the delay line was replaced by a small absorption type cavity resonator, the same circuit gave an improvement in FM noise of 25 to 30 db in the frequency range from 1 KHz to 100 KHz.

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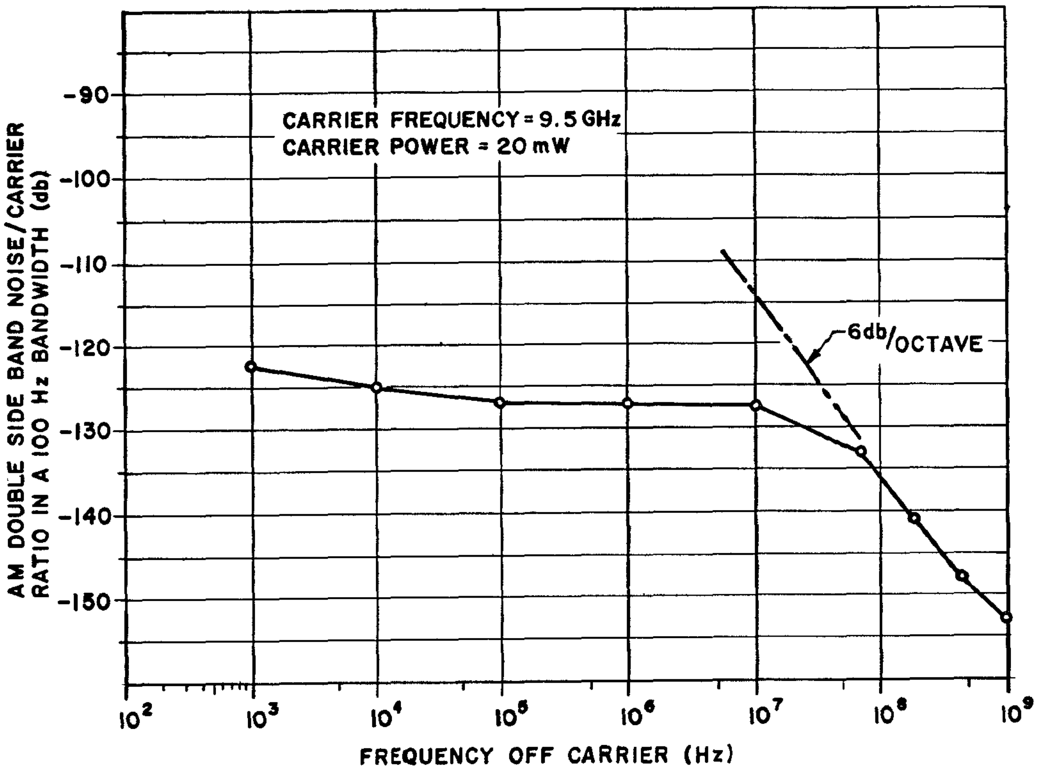


Fig. 1 Typical AM noise spectrum of X-band avalanche oscillator.

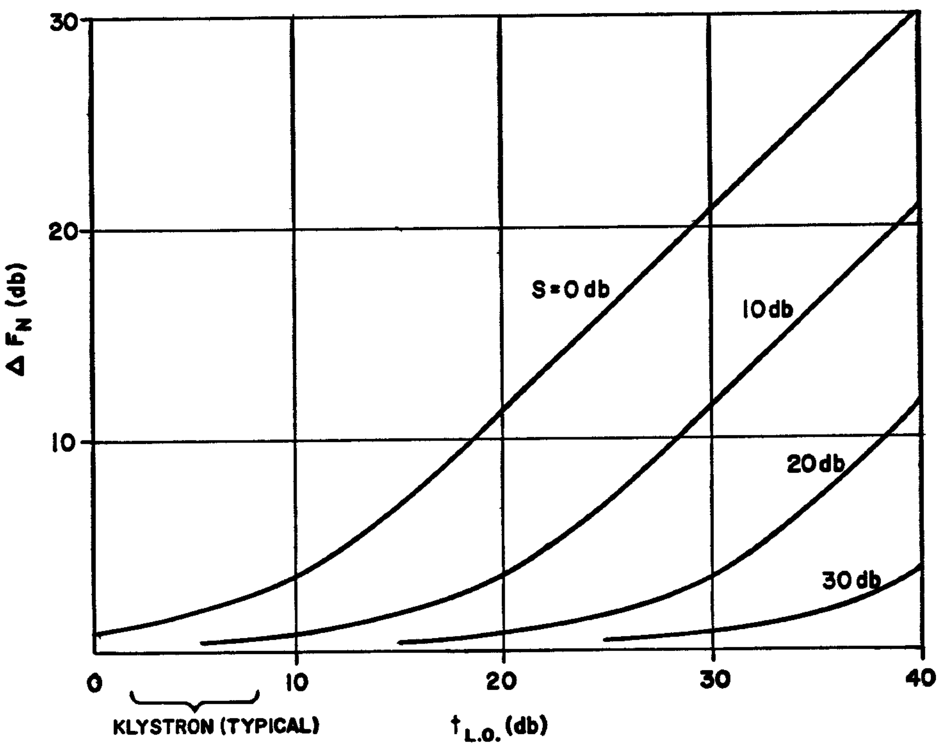


Fig. 2. Mixer noise figure degration due to local oscillator noise contribution.

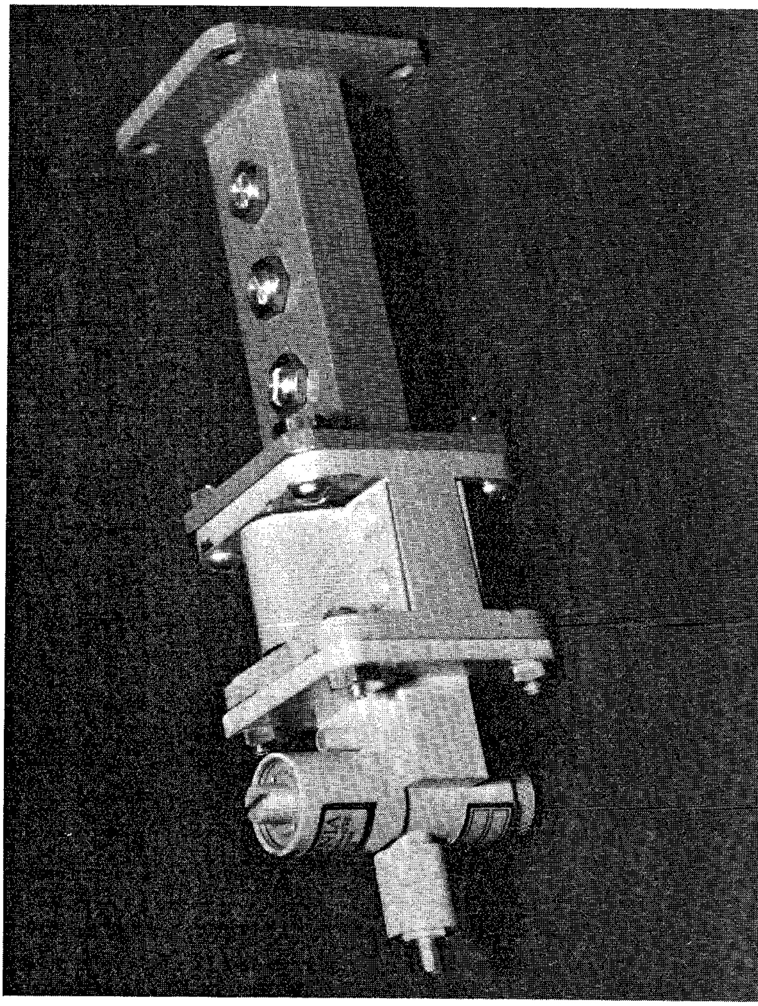


Fig. 3. X-band avalanche local oscillator including isolator and filter.

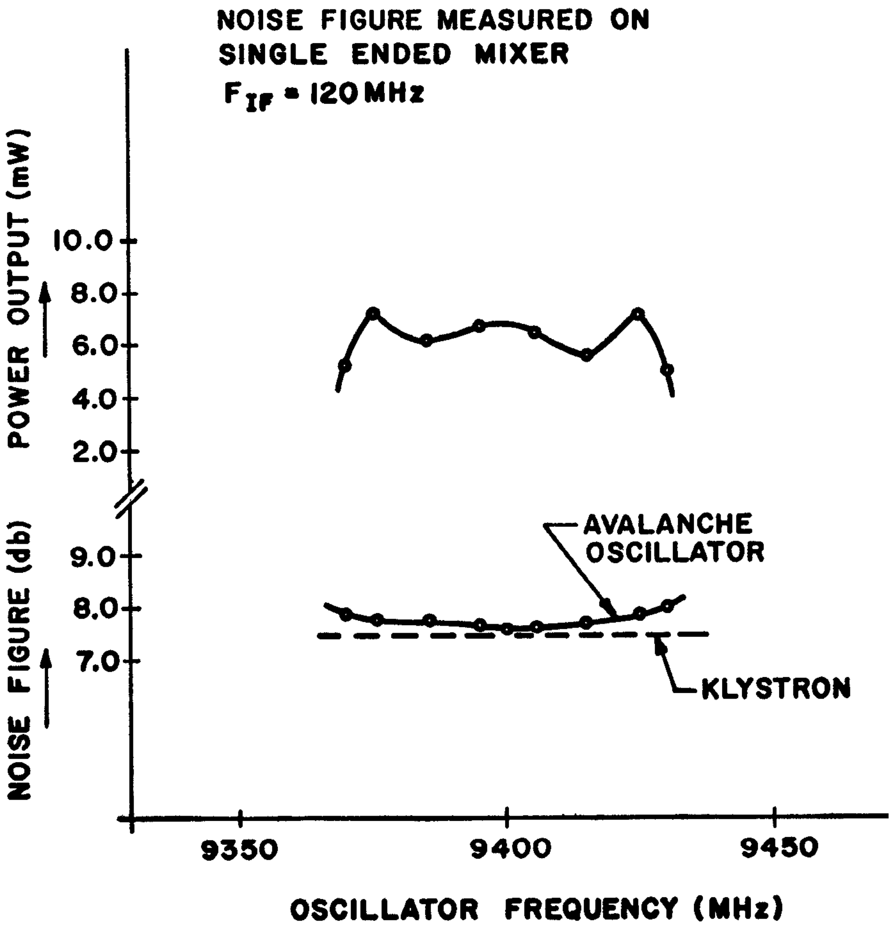
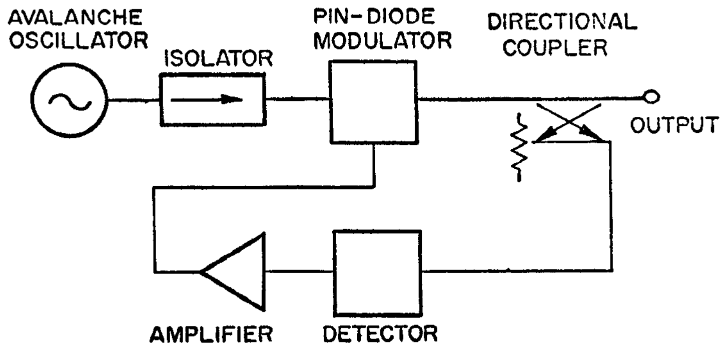


Fig. 4. Noise performance of avalanche local oscillator.



(a)

Fig. 5a. Block diagram of feedback loop for AM noise reduction.

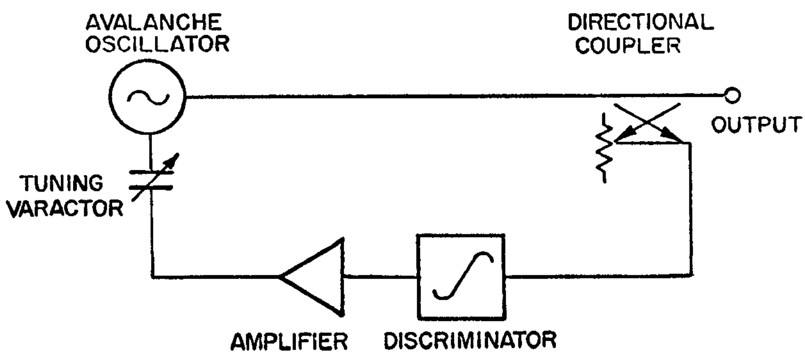


Fig. 5b. Block diagram of feedback loop for FM noise reduction.

(b)

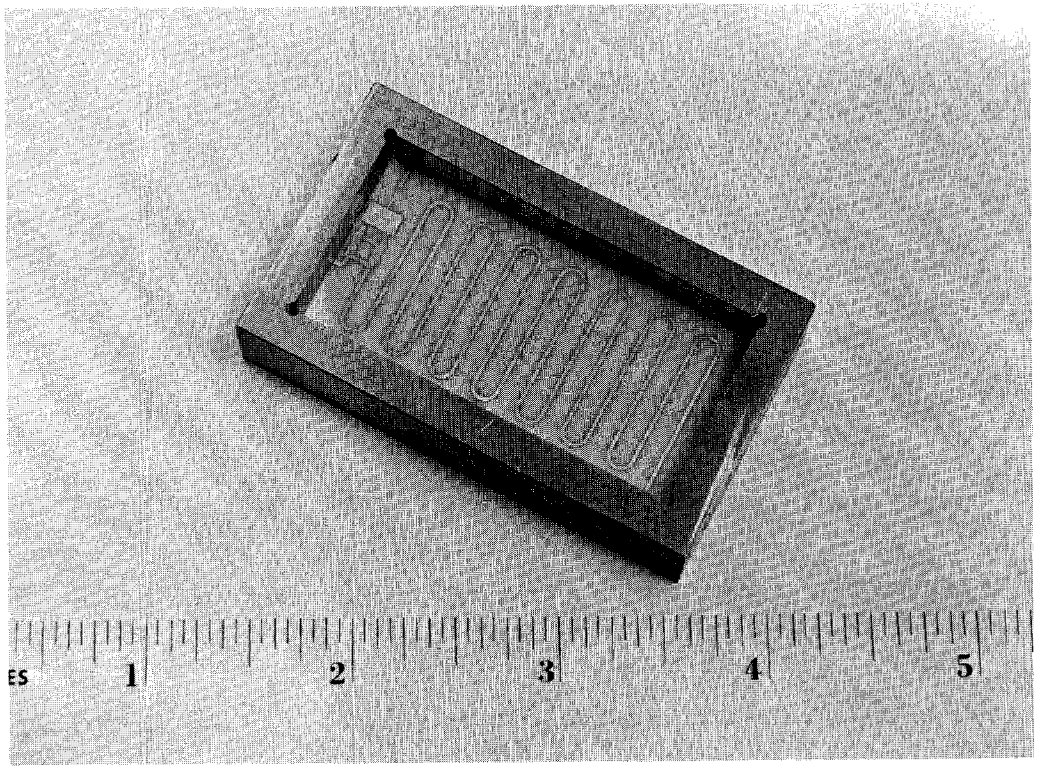


Fig. 6. Integrated microwave discriminiator using a microstrip line as a phase sensitive element.