FREQUENCY STABILIZATION TECHNIQUE FOR MILLIMETER-WAVE MICROSTRIP OSCILLATORS

D. Rubin & D. Saul
Naval Ocean Systems Center
San Diego, CA 92152

ABSTRACT

The crossover frequency of an integrated microstrip diplexer has been used in a feedback araangement to stabilize a microstrip millimeter-wave Gunn oscillator. Changes in the microstrip effective dielectric constant with temperature can be compensated for by the use of a temperature transducer in the feedback loop.

Introduction

Because of the low Q associated with microstrip resonators, MIC oscillators generally are much less stable than their waveguide counterparts. At microwave frequencies, passive ceramic resonators[1] have been used as well as active orthogonal microstrip resonators[2] for frequency stabiliaztion. Neither of these techniques has been shown to be effective at millimeter-wave frequencies.

The sharp fall-off at the band edges of coupled microstrip filters can be thought of as due to the combined effects of several resonant circuits in series. This band edge fall-off is far greater than obtainable from any single MIC resonator. Two bandpass MIC filters formed as a diplexer[3] can be arranged so that the crossover frequency is quite precise. Detectors placed at the output terminals of the diplexer can be used to determine whether the oscillator frequency is above or below the crossover frequency. With the aid of operational amplifiers connected in a feedback arrangement with the oscillator's varactor frequency control, the oscillator can be made to run precisely at the crossover frequency.

Due to the substrate's decreased dielectric constant with temperature, the crossover frequency, and hence the oscillator frequency, will increase with temperature. To correct for this, a temperature sensor,* in proximity with the diplexer, is used in the feedback loop. The frequency of oscillation can then be forced to be at one side or the other of the diplexer crossover frequency, the amount determined by the temperature.

I. Diplexer – Discriminator

Figure 1 shows the frequency response curve for a 36 GHz diplexer. The crossover, chosen several dB down from the highest output, is at a position where bandpass skirts are relatively sharp. Also shown (exaggerated), is the shift upward of the diplexer crossover frequency with temperature. Figure 2 gives the overall scheme of the feedback arrangement, including temperature compensation.

A1 amplifies the difference between the negative output voltages from the detectors The amplified difference voltage V_1 is compared to temperature control voltage V_c and applied, after further amplification, to the varactor tuning element in the oscillator. This output voltage is in the correct phase to bring the oscillator back to the crossover frequency. If V_c were set equal to zero and the oscillator instantaneously went high in frequency, V_1 would go high and V_2 would go low, decreasing the varactor back bias and decreasing the frequency. An instantaneous low frequency from the oscillator would result in an increase in V_2, resulting in more varactor back bias and an increase in frequency.

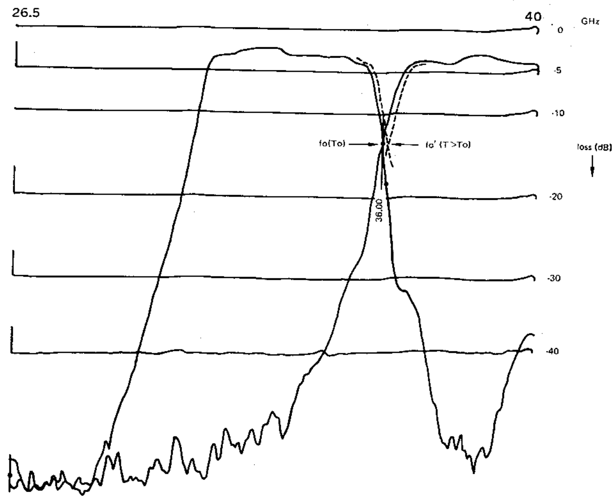

Figure 1. Typical non-contiguous diplexer used for oscillator stabilization. The dashed lines indicate (exaggerated) the crossover at elevated temperatures.

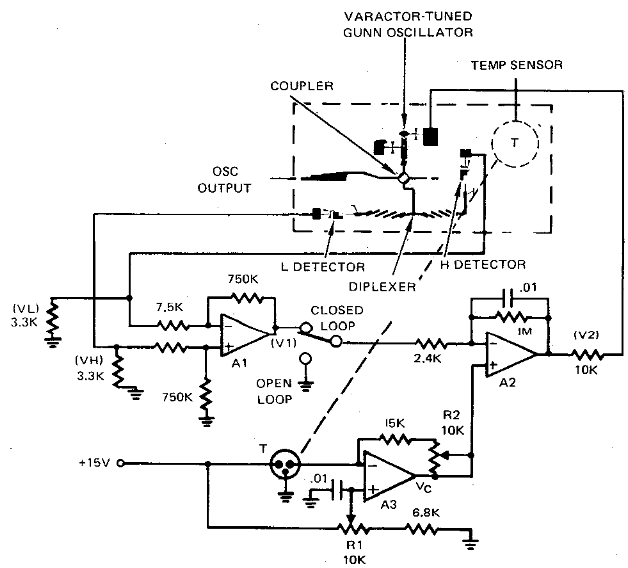

Figure 2. MIC oscillator and frequency stabilizing network. The temperature sensor T should be mounted on or adjacent to the MIC substrate.

* Analog Devices AD590

If V_c is set at some value not equal to zero, the frequency will change so that $V_1 \simeq V_c$, i.e., the oscillator will change frequency so that one detector produces more output voltage than the other. The required voltage function V_c (T) can be found by experimentally changing V_c with temperature so that the oscillator frequency remains constant.

This function will generally be found to be linear over the usual temperature ranges and can be generated in many ways. Figure 2a shows the utilization of a temperature sensor* (a very small integrated circuit) which produces a current proportional to the absolute temperature. Amplifier A3 has an offset (adjusted by R1) so that at room temperature (T_0) $V_c = 0$, and at other temperatures $V_c = k\ (T_0 - T)$. The value k is set by the gain control R2. Suppose the temperature is above T_0. Figure 1 shows that if the oscillator frequency is to stay at f_0, the low frequency detector must have more output voltage than the high frequency one. This would force V_1 to go negative. A negative voltage V_c from the thermal sensor amplifier A3, in effect, forces V_1 to go negative, hence moving the oscillation frequency away from the temperature dependent crossover frequency f_0', back to frequency f_0. Dielectric constant changes due to cooler temperatures are compensated by a positive voltage V_c, forcing V_1 positive. This is done through the varactor's increasing the frequency of the oscillator so that $V_H > V_L$. Experimentally, a 34.5 GHz MIC oscillator was stabilized to ±7 MHz over a ±25°C temperature change. More important, as shown in figure 3, FM noise due to oscillator instability was decreased dramatically.

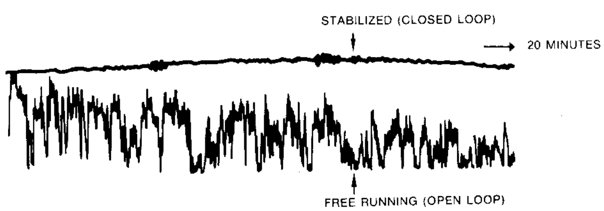

Figure 3. Relative FM noise of free running and stabilied oscillator.

II. Gunn Oscillator

Figure 4 shows the design of a 34.5 GHz oscillator (that frequency picked because it was the same as an available waveguide-type oscillator). Figure 5 is the corresponding model used for computer analysis[4]. The impedance calculated in figure 5 is that "seen" from the diode negative resistance. Oscillation will result in a frequency (or frequencies) where the total reactance of the circuit and diode capacitance is zero, given that the total circuit resistance does not exceed the small signal negative resistance of the diode at that point. With the growth of oscillations the negative resistance and capacitance of the diode will change. The computer analysis only gives a starting point for the subsequent oscillations.

Figure 6 shows the small signal results for the circuit values used. Indicated are the frequency crossovers for varactor capacitances between .1 and .5 pfd. The results shown between 25 and 50 GHz indicate only one likely mode of oscillation over that entire range.

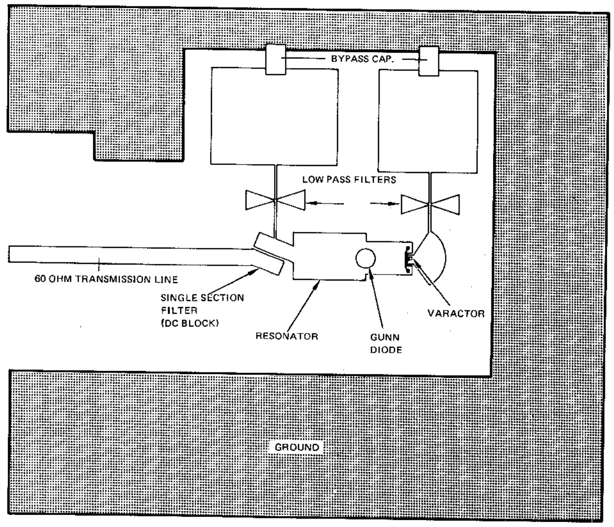

Figure 4. MIC Gunn Oscillator

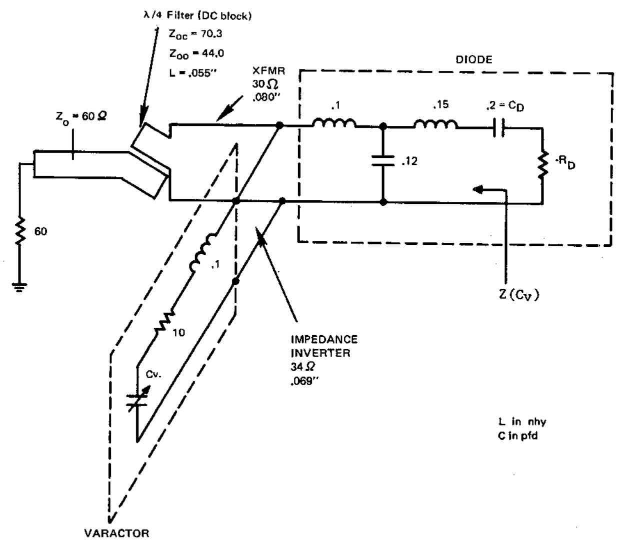

Figure 5. Varactor-tuned Gunn oscillator model.

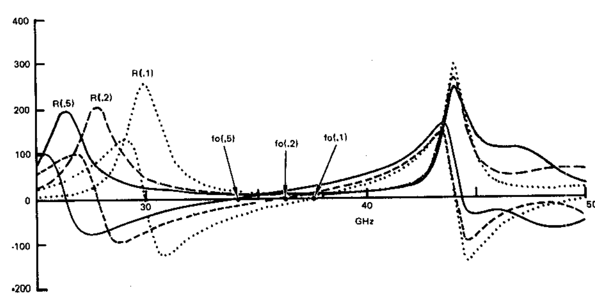

Figure 6. Impedance as "seen" by diode negative resistance - as a function of varactor capacitance (pfds.).

The actual circuit constructed from this model oscillated near the design frequency of 34.5 GHz and had a tuning range of over 1 GHz.

Conclusions

A new method of frequency stabilizing microstrip oscillators has been shown to greatly decrease FM noise. The frequency stabilizing element, a diplexer, can be fabricated on the same substrate as the MIC oscillator, or can be used externality in a temperature controlled environment. Without external temperature control, a method of correcting for frequency drift has been shown to yield better long term frequency stability than typical waveguide Gunn oscillators. Although applicable to any microwave frequency, the method would appear to be particularity suitable for lower millimeter wave (20-60 GHz) microstrip oscillators.

References

1. J. K. Plourde, et. al., "A Dielectric Resonator Oscillator with 5 PPM Long Term Frequency Stability at 4 GHz," 1977 IEEE Microwave Symposium Digest, pp. 273-276.

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4. D. Rubin, "Varactor-Tuned Millimeter-Wave MIC Oscillator," IEEE MTT-S Transactions, Nov. 1976, pp. 866-867.