THE ROLE OF SAW OSCILLATORS IN MILITARY RADAR SYSTEMS

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Abstract

Surface Acoustic Wave (SAW) oscillators are beginning to find growing applications for military radar systems. This paper deals with the capability of SAW oscillators and the impact on system performance relative to meeting missile and radar requirements.

Introduction

As missile and ground radar systems become more sophisticated, the demands upon subsystems that generate waveforms become increasingly stringent. The generation of waveforms must include broadband capabilities, frequency agility, reduced spurious levels and must exhibit low noise performance. The technology to meet these requirements must also satisfy the conditions of reduced size and minimal complexity.

Conventional approaches to producing microwave oscillators using low frequency oscillators and high multiplication ratios including phase locked loops have become prohibitively complex. The use of SAW oscillators in the UHF and L-band regions of the frequency spectrum requiring low multiplication ratios has made SAW devices very attractive for many microwave oscillator applications.

For many years, SAW devices have been used for specialized applications such as the generation of chirp waveforms and non-dispersive delays. In recent years SAW oscillators have become increasingly popular, and translation of SAW devices from a laboratory to a field environment is expected to increase dramatically.

Since microwave oscillators are a necessary component for any radar, the expected use of SAW lines to fill the varied number of radar oscillator applications is expected to increase greatly. High fundamental frequency operation, low noise peformance, and the ability to operate under rugged environmental conditions have made SAW oscillators most attractive for meeting the stringent requirements of military systems. Over the past few years, SAW oscillators have been developed by Raytheon Company in the frequency range of 300-600 MHz. Developments that are covered in this paper include delay line and resonator SAW devices for application as master oscillators in coherent radar systems. The operation and differences between each are explained.

Current component capabilities, hardware evelopments, and performance under environmental conditions are discussed and data is presented. The impact of noise parameters on system performance is also presented.

Coherent Radar System Master Oscillator Requirements

Noise

The effects of AM and FM noise on performance are well understood for coherent radar systems. In general, it can be said that FM noise is more predominant than AM noise, since AM noise can be reduced by limiting. FM noise characteristics determine the quality of a microwave oscillator for transmitter and local oscillator applications. Subclutter visibility, velocity resolution, range, and range rate determinations are the principal factors in radar systems that are governed by the magnitude of FM noise.

Microwave oscillator noise requirements for CW radar systems are more stringent compared to pulse radar systems. In a doppler radar the received signal competes with direct leakage and close-in clutter. The FM noise spreads this noise power throughout the doppler band. The larger the transmit power, the greater the noise power to carrier power ratio required.

For low prf pulse radars, the direct leakage and very close-in clutter problems are avoided and the requirements relate to competition of clutter and target at the same range. As pulse repetition rates increase and duty cycles begin to approach CW conditions, low noise again becomes a requirement. Evidence of this can be seen from the typical FM noise requirement curves for CW and MTI pulse radar systems in Figure 1.

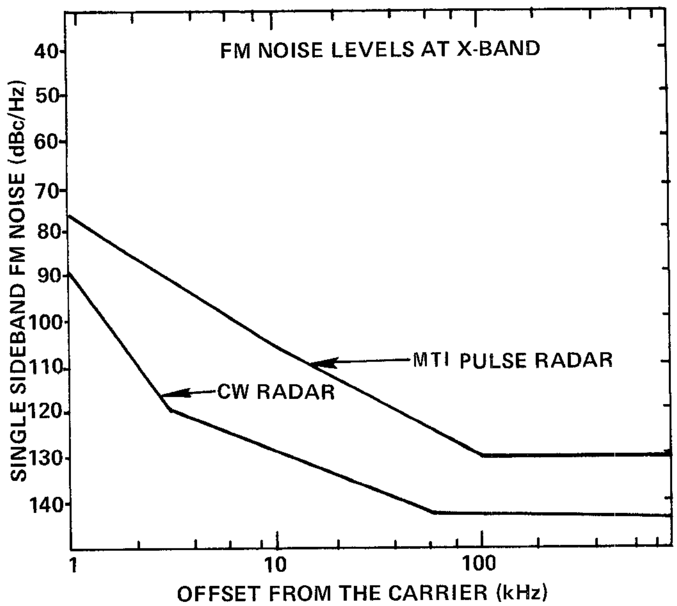

Figure 1 - Typical Oscillator FM Noise Requirements for MTI Pulse and CW Radar Systems

Frequency Agility

Requirements for today's modern radars must include frequency agility over broad bandwidths and low noise, factors that are not always compatible with one another. Up to now, requirements for frequency agile CW X-band systems could only be satisfied by using dual cavity high "Q" klystron oscillators operating over relatively narrow bandwidths. Multifrequency operation for frequency separations of greater than 10 MHz could only be accomplished by adding additional klystrons. Switching between klystrons at RF frequencies adds significant size and equipment complexity. Alternatives to this are the crystal and the SAW oscillators; however, as will be pointed out, crystal oscillators lack in performance. SAW oscillators are particularly suited to meet these requirements since switching between multiple SAW devices in a common oscillator feedback loop is relatively straightforward and is accomplished in a small volume.

A major advantage of the SAW derived oscillator is that the high fundamental operating frequency (compared to crystal oscillators) minimizes the need for high multiplication factors and therefore minimizes the effects of multiplied noise.

Typical noise characteristics for the crystal oscillator, SAW delay line, and SAW resonator oscillators, multiplied to X-band, are shown in Figure 2. The data indicates that crystal oscillators are only effective for regions of noise close-in to the carrier. This is due to the superior "Q" factor of the crystal, which enhances close-in noise performance. On the other hand, it becomes evident, when comparing Figures 1 and 2, that reduced multiplier requirements provide a clear advantage for SAW derived oscillators in meeting noise requirements for large carrier offsets, in both CW and pulse radar systems.

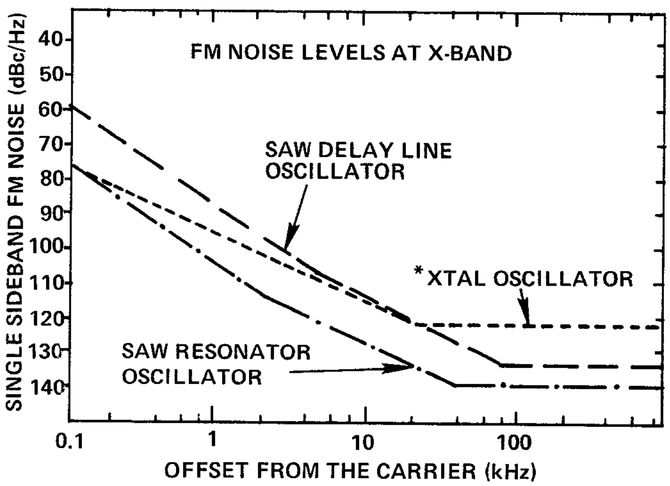

Figure 2 - Typical Noise Characteristics at X-Band

Delay Line vs Resonator

SAW oscillators may be implemented using either a delay line or a resonator as the feedback element of an oscillator loop.

The delay line structure consists of two transducers, which form a narrowband device. The phase slope or group delay ($\tau = d\phi/d\omega$) is determined by the center-to-center separation of the transducers. The SAW resonator structure consists of two wideband transducers placed between two periodic gratings. The gratings act as narrowband reflectors and create a cavity for the surface wave. The phase slope of a resonator is determined by propagation loss, leakage through the gratings, and the degree of coupling.

At low frequencies, the resonator offers higher Q (larger phase slope) and lower insertion loss than a delay line; however, the resonator is more difficult to fabricate. The delay line offers a wider bandwidth for the same phase slope and therefore has a greater tuning range. This feature can be useful for trimming the frequency or for frequency modulation. The delay line is also less affected by fabrication errors.

Table 1 compares some of the important device parameters.

*Taken from California Microwave published data.

TABLE 1. Comparison of Key Parameters of SAW Delay Lines and Resonators

Item	Delay Line	Resonator
"Q" Factor	2,000	10,000 - 20,000
Insertion Loss	20-23 dB	10 dB
Aging	<5 PPM/Year	Same
FM Noise (X-Band)	-80 dBc/Hz @ 1 kHz	-100 dBc/Hz @ 1 kHz
Frequency Tunability	$\pm.1\%$ of f_o	$\pm.01\%$ of f_o
Frequency of Operation	100 MHz - 2.5 GHz	100 MHz - 1.0 GHz

Hardware Development

Multifrequency X-Band Source

An internal development effort at Raytheon Company has produced a 6-frequency X-Band source capable of being electronically switched to any one of six frequencies in less than 50 μsec in a volume of 20 cubic inches. The X-Band source (see Figure 3) consists of a UHF section in which any one of six SAW delay lines are selected in a common feedback circuit to produce the desired frequency. A X24 multiplier coverts the UHF frequency up to X-Band. A photograph of the entire assembly is shown in Figure 4.

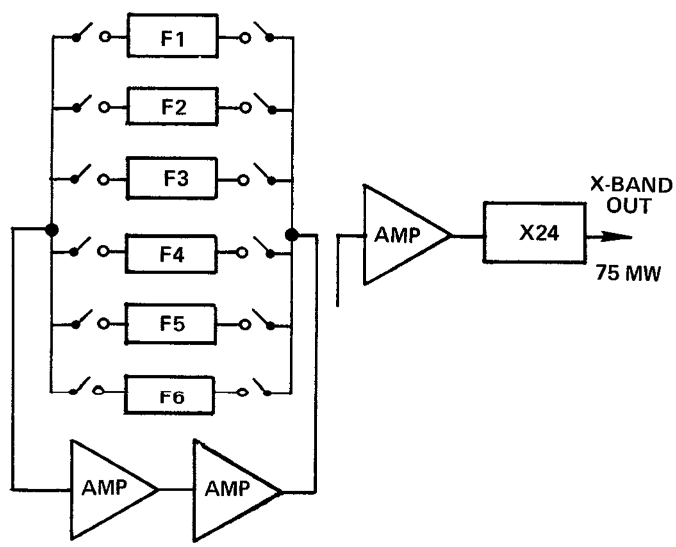

Figure 3 - X-Band Source Block Diagram

Vibration

Electrical immunity from mechanical vibration is one of the more important requirements of a microwave oscillator for military applications. The X-band source was vibration isolated at two levels, the UHF assembly level which housed the SAW lines and the UHF circuitry, and at each of four corners of the housing assembly. Vibration tests for this configuration were conducted with SAW delay lines and SAW resonator devices. The SAW substrates in the flat pack package were mounted on a four-point support, using L-shaped steel clips and polyimide adhesive. The FM noise data of the entire X-band source, using both SAW delay line and resonator oscillators, is shown in Figure 5. The vibration input level was 4 Grms in the frequency range of 10 Hz to 3 kHz.

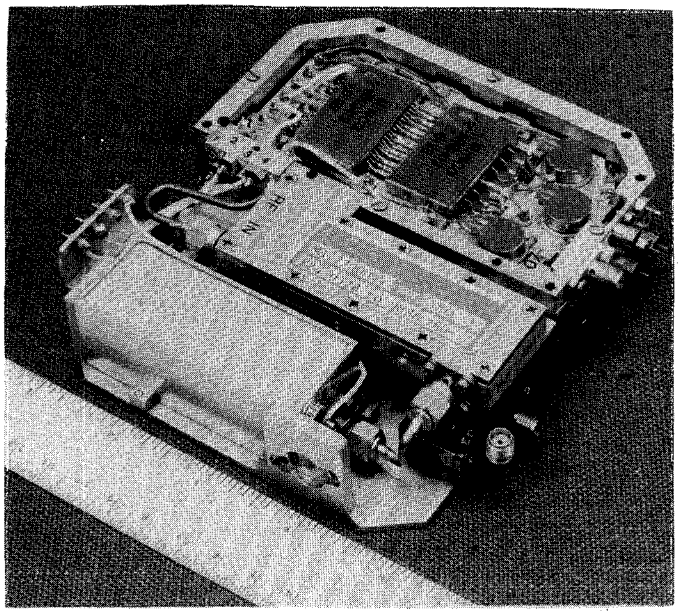

Figure 4 - Multi-Frequency X-Band Source

It is interesting to note that the same degradation levels were measured for the SAW delay line and resonator oscillator at 1 kHz from the carrier, even though quiescent levels were significantly better for the resonator. At 4 kHz from the carrier, all evidence of the vibration induced noise was gone for the delay line oscillator. For the resonator, all evidence of noise was gone at 12 kHz from the carrier.

Frequency Stability (over temperature)

Another requirement of a microwave oscillator for military applications is fast warm-up. Measurements were made on the X-band source for soak temperatures ranging from -46^{o}C to +60^{o}C.

A proportional control heater circuit was used to stabilize the SAW oscillator at the zero temperature coefficient point of the SAW line. Foil heaters were used on the SAW line and amplifier packages to avoid frequency drift due to changes in temperature.

To remove any effects of thermal lag, a thermistor (one side of the bridge) was placed directly on the SAW line quartz material. The control circuit was form factored and housed within the 20 cubic inch volume of the X-band source.

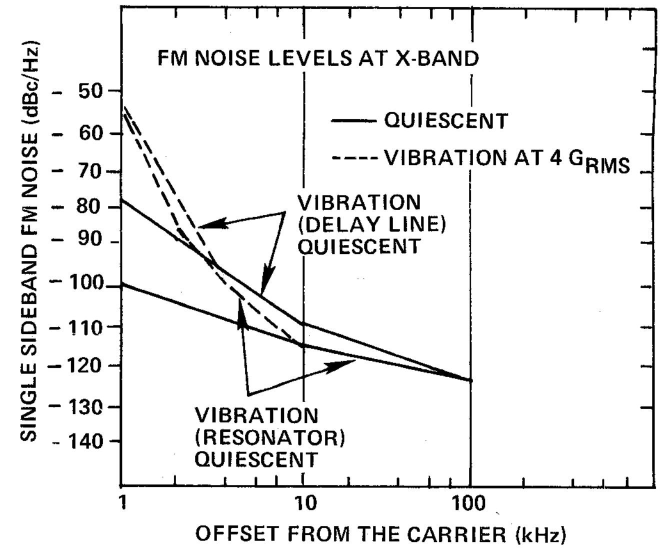

Figure 5 - Noise Levels at X-Band for SAW Resonator and SAW Delay Line

Data was taken from T=3 min to T=15 min over the range of soak temperatures. The data indicated that drift was within ± 1 ppm. Different frequencies were noted over the soak temperatures, due to the different gradients across the circuit board. It should be pointed out that the overall frequency drift over the range of soak temperatures was within ± 7 ppm.

Conclusions

This paper has given consideration to some of the more important requirements of microwave oscillators. Low noise performance, operation under vibration, and stability over a broad temperature range have been demonstrated by using SAW oscillators to meet the requirements of CW and pulse radar systems. The high fundamental frequencies of SAW oscillators have shown that low multiplication requirements have also achieved minimal hardware complexity.

Encouraging progress being made in the area of long term aging and frequency settability have made SAW oscillators excellent candidates for meeting military radar requirements.

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