APPLICATION OF SAW OSCILLATORS TO LOW-NOISE COMMUNICATIONS SYSTEMS

E. J. Staples, J. S. Schoenwald, S. J. Dolochycki, J. Wise, and T. C. Lim
Science Center, Rockwell International
P. O. Box 1085
Thousand Oaks, California 91360

ABSTRACT

During the 1980's and beyond, there will be a need for low-cost, low-noise oscillator circuitry in high-frequency communications systems, such as JTIDS, GPS, Packet Radio, as well as in commercial satellite communications and navigation systems. In this paper, the use of SAW oscillators to achieve low phase noise in the 300-400 MHz frequency range without phase-locked loops or multiplier chains is described. In addition to low phase noise, SAW oscillators utilizing "chip-mounted" resonators reduce system size, weight, power, and cost.

Introduction

During the 1970's there has been a dramatic increase in satellite and microwave communication systems. Military systems such as JTIDS, GPS, and Packet Radio have become synonymous with the secure communications needs of the military. In addition, commercial satellite communications has matured into a viable enterprise. Technology forecasts for the 1980's and beyond indicate that low-cost, low-noise receivers are needed if these communications systems are to be utilized by all available users. At the heart of a low-noise communication system is a reference oscillator or time base. At present, this function is performed by a precision quartz oscillator. These oscillators operate typically at 5 or 10 MHz and determine the ultimate stability of the system reference. However, these communications systems operate in the UHF frequency range or higher and, hence, the reference signal must be translated. At present, two approaches illustrated in Fig. 1(a) and (b) are used. The first uses a frequency multiplier chain, with buffer amplifiers between successive stages of multiplication, to restore the signal amplitude after passing through the lossy multiplier stages. The

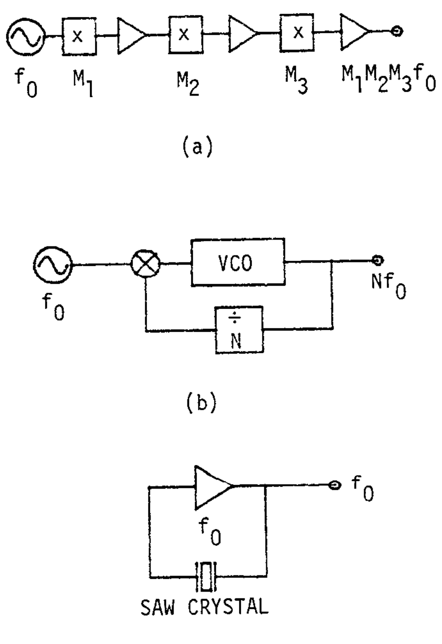

Fig. 1 UHF frequency standards using (a) multiplier chains, (b) phase-locked loops, and (c) SAW crystal oscillators directly.

second approach uses a frequency divider, phase comparator, and varactor phase shifter to lock a high-frequency oscillator to the 5 MHz quartz reference. In the former technique, the amplifiers required to restore signal level introduce noise and result in poor short-term frequency stability. In the latter case, the short-term stability of the high-frequency oscillator is poor because of insufficient loop Q, which, translated into the frequency domain, means high phase noise beyond the bandwidth of the phase-locked loop (PLL).

A third technique, discussed in this paper and illustrated in Fig. 1(c), is to construct a fundamental mode quartz reference oscillator in the UHF frequency range. Until recently,[1] fundamental mode quartz oscillator crystals were not available in this range. Using surface acoustic waves (SAW) and a high Q resonant structure,[2] quartz oscillator crystals in the 30-400 MHz range are now available. These crystals can be used in relatively simple oscillator circuits and offer improved performance over frequency-translated sources.

SAW Oscillator Crystals

Quartz SAW oscillator crystals are described by the same equivalent circuit as low-frequency bulk oscillator crystals. The device equivalent circuit contains a motional inductance and capacitance, L1, C1, a series resistance, R1, and a static capacitance. C_0, as shown in Fig. 2(a). For circuit design, device Q and series resonant resistance and frequency are normally specified. Typical values are Q = 20,000 and R1 < 100 ohms at 375 MHz. A typical Smith chart-impedance plot is shown in Fig. 2(b).

Short-term stability and phase noise are proportional to the inverse product of oscillator loop Q, frequency, and power. Increasing either the Q or the frequency results in less phase noise. Operating at equal power levels, the phase noise of a 375 MHz, Q = 20,000, oscillator will have the same relative stability as a 3.75 MHz oscillator with a loop Q of 2,000,000. Thus, it is not surprising that the stability of SAW resonator oscillators is equal to that of low-frequency bulk quartz oscillators.

SAW quartz crystals are truly chip-components and as such can be directly mounted in hybrid circuit configurations. This is fortuitous since circuit parasitics rule out the use of separately packaged oscillator crystals in the UHF frequency range. To illustrate this important point, shown in Fig. 3 is a photograph of several 375 MHz oscillator crystal chips mounted in TO-5 holders prior to sealing in a capacitance discharge vacuum welder. In this case, chip size is .082 × .202 × .025 inches. Chip-mounted oscillator crystals result in improved resistance to shock and vibration and have less thermal inertia.

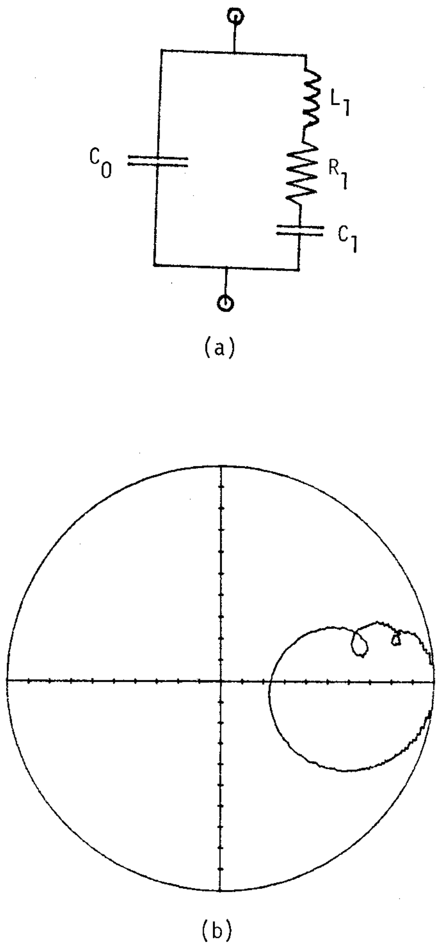

Fig. 2 SAW oscillator crystal: (a) equivalent circuit, and (b) Smith chart showing series impedance.

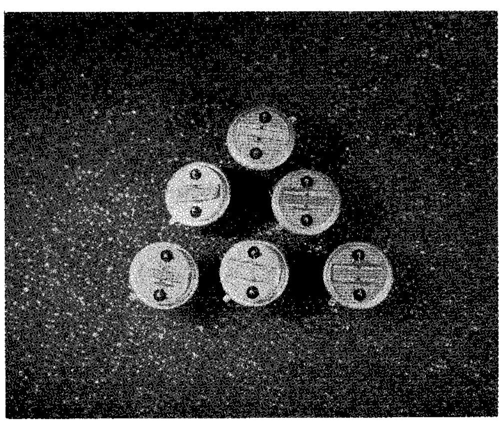

Fig. 3 Photograph of SAW crystal chips mounted in TO-5 enclosures.

SAW Oscillators--Experimental Results

The achievement of high Q and a good inductive reactance in SAW oscillator crystals enables many types of oscillator circuits to be considered. A study was made of the following types: Clapp, Colpitts, Pierce, and impedance inverting or negative resistance types. Of these, the Pierce, shown in Fig. 4, had the highest frequency stability with moderate power output. In addition, this circuit was the simplest in terms of design and hybrid fabrication.[3]

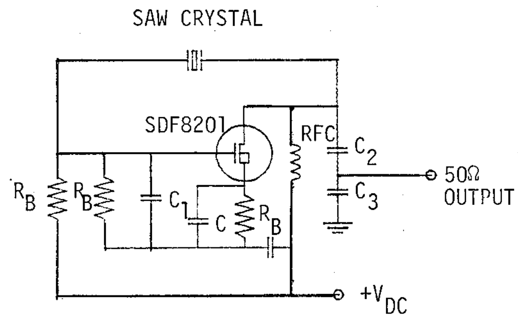

Fig. 4 Pierce oscillator circuit used with SAW Oscillator crystals.

Frequency stability for these oscillators was compared with various types of conventional system references, i.e., multiplier chains and PLL's based on a 5 MHz reference oscillator. Frequency stability was measured in the frequency and time domains using an HP 5390 stability analyzer. Both the SAW oscillator and PLL were analyzed against an HP 8660C frequency synthesizer. Typical results of this comparison for phase noise are shown in Fig. 5. The phase noise of

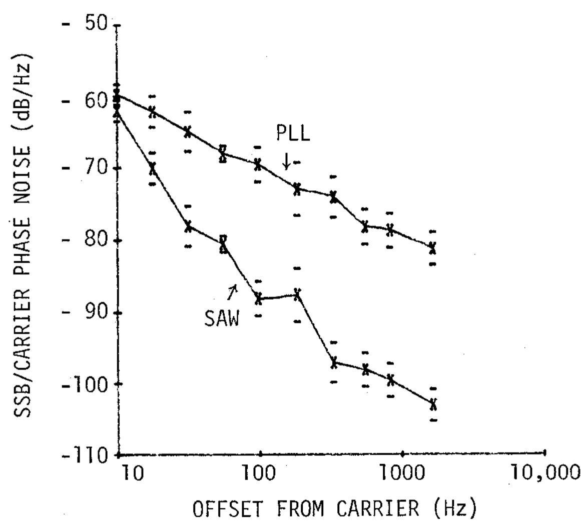

Fig. 5 Comparative phase noise of a 375 MHz PLL, locked to a 5 MHz crystal standard, vs fundamental mode SAW crystal oscillator at 375 MHz.

of the SAW oscillator in this case was better than the PLL beyond 10 Hz from the carrier because of the higher loop Q of the SAW oscillator. Below 10 Hz, the SAW oscillator showed somewhat higher noise due to temperature fluctuations since the SAW was not ovenized in this case. Oven temperature control or temperature compensation is required for long-term stability in these oscillators, just as it is in bulk crystal frequency standards. With oven control, the phase noise of the two types is approximately equal down to 1 Hz from the carrier.

Conclusion

Fundamental mode oscillator crystals with Q and impedance values commensurate with low-frequency crystals enable the fabrication of high-stability oscillators in the 300-400 MHz range. The phase noise of these oscillators is considerably lower than conventional system clocks and reference oscillators in this frequency range. In addition, SAW technology enables thin film hybrid fabrication techniques to be applied which results in overall size and weight reductions. These new oscillators will be useful wherever low-noise, low-cost frequency sources are required.

References

1. J. S. Schoenwald, R. C. Rosenfeld, and E. J. Staples, "Surface Wave Cavity and Resonator Characteristics--VHF to L-Band," 1974 IEEE Ultrasonics Symposium, pp. 253-256.

2. R. C. J. Li, R. C. Williamson, D. C. Flanders, and J. A. Alusow, "On the Performance and Limitations of the Surface WAve Resonator Using Grooved Reflectors," 1974 IEEE Ultrasonics Symposium, pp. 257-262.

3. M. E. Frerking, Crystal Oscillator Design and Temperature Compensation (Van Nostrand Reinhold Co., New York, 1978), Chapter 7.