SAW OSCILLATOR IN UHF TRANSIT SATELLITE LINKS

B. Y. Lao, N. J. Schneier, D. A. Rowe, R. E. Dietterle
Magnavox Advanced Systems and Products Company
Torrance, California 90503

J. S. Schoenwald, E. J. Staples, J. Wise
Rockwell International Corporation
Thousand Oaks, California 91360

ABSTRACT

A 375 MHz SAW resonator controlled oscillator is developed for application in the transit satellite marine navigation system. The SAW oscillator, in a two-cubic-inch hybrid package, contains a heater, voltage regulator and divider and is a direct replacement for a bulk wave oscillator and its multiplier chain. Short term stability of 2 x 10E -10 and aging of 3 x 10E -8/day were achieved at 75°C. Comparison tests showed that the navigation system accuracy with the SAW oscillator was equivalent to a bulk oscialltor.

INTRODUCTION

The application of a surface-acoustic-wave controlled oscillator in a commercial transit satellite marine navigator and the test results will be presented.

The MX1102 marine navigation system operates in the UHF band at 400 MHz. The Transit satellites circle the earth in 107-minute polar orbits at an altitute of 600 nautical miles. The orbits do not rotate with the earth so that every point on the earth's surface passes under each of the six orbits approximately twice a day. The signal transmitted by the satellite contains orbital information regarding the position of the satellite and the GMT. Updating by ground stations keeps the information accurate. The navigation receiver detects the signal and obtains the location of the satellite as a function of time. By analyzing the Doppler shift of the carrier signal and its shift rate, the receiver determines the exact time of the closest approach of the satellite and its distance to the satellite. The position of the receiver is then calculated from the above data through interpolation and triangulation methods. In addition to location fixes thus obtained, the navigator also provides dead reckoning between fixes based on inputs of the ship's speed and heading.

In the detection process, the RF signal from the satellite is first down-converted to 25MHz by the use of a mixer and a local reference signal at 375MHz. Since the Doppler shift rate is generally small (8KHz/5 min), the stability of the local oscillator directly determines the accuracy of the system fix accuracy. Therefore a high stability LO is required. The local oscillator signal is currently generated by multiplying a precision 5MHz quartz bulk-wave oscillator output to 375MHz. This approach suffers from the large volume occupied by the crystal oscillator and the associated multiplying chain and its relatively high cost. Fig. 1 is a block diagram of the RF section of the navigation receiver.

These problems can be solved by replacing the crystal oscillator and the multiplier chain by a more compact SAW oscillator with a fundamental frequency at 375MHz. This technique leads to potential cost savings due to the ability to batch process SAW resonators. The critical requirements for the local oscillator are stabilities of 1x10E-10 for 1 to 100 sec averaging time, 7x10E-10 for 1000 sec and

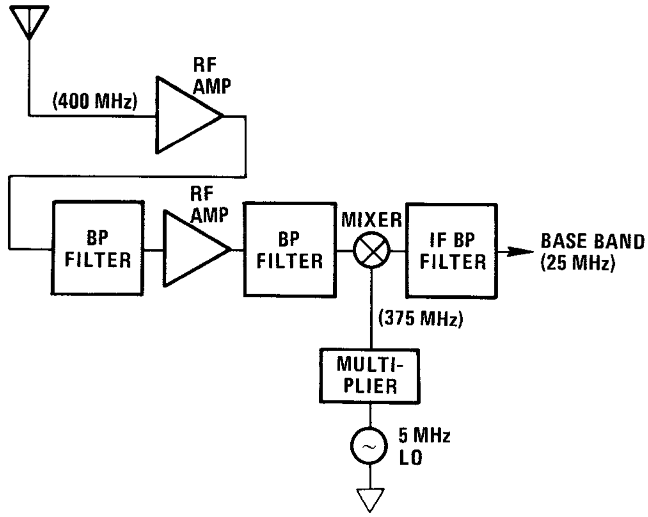

Figure 1. BLOCK DIAGRAM OF RF SECTION OF NAVIGATION RECEIVER

2x10E-9 per day aging. The oscillator frequency is required to be within 1 ppm of 375 MHz because of the limited pass band of the IF stages.

SAW RESONATOR

For this purpose, SAW resonators were fabricated on ST-quartz cut to provide a turning point of 75°C. They are single port devices using shallow groove reflective gratings and are evacuated and sealed in TO-5 cans.

The single port design was chosen over a two-port design because of its lower gain requirement which means less oscillator components and lower cost. The resonator was designed to operate at its series resonance mode with a series impedance of about 50 to 100 ohms.

During the fabrication process, over 200 metalized patterns (40Å of Cr and 1000Å of Al) are photolithographically formed on a 2"x2" quartz substrate (x propagating, 34° rotated for 75°C turnover). After spot-check probing of random devices a second masking with photoresist is used to protect the transducers during CF_4 plasma etching to form grooves in the reflector portion of the device. Following etching, the resist is removed and the wafer is spot probed again. The wafer is then diced into chips which are mounted on TO-5 headers using Abelbond 71-1 high temperature polyimide adhesive. A low power CF_4 plasma etch is used to place the mounted crystal on frequency just prior to sealing. Bake-outs before and after sealing are performed at 125° C for 24 hours. Fig. 2 shows the typical polar Smith chart response of the S_{11} scattering parameter of a sealed SAW resonator.

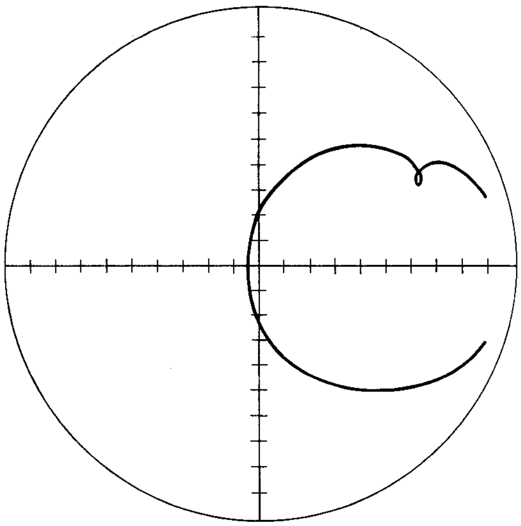

Figure 2. RESPONSE OF SAW RESONATOR PLOTTED ON SMITH CHART

OSCILLATOR

Initial attempts to replace the crystal oscillator with a SAW oscillator were hampered by turning point shifts, excessive voltage and load dependence. These problems were traced to circuit component variations which are relatively unimportant for crystal oscillators but become significant for SAW oscillators because of the lower Q. High resonator drive levels on the order of -5dBm into 50 ohms were also found to degrade the device over extended periods. Metal migration and subsequent crystalite formation are suspected to be the cause of this degradation.

These problems were solved by stablizing the oscillator with an AGC circuit which limits the power into the SAW resonator to -15dBm. Short term stabilities of 1-2x10E-10 and aging rates of 3x10E-8 per day at 75°C were achieved.

Fig. 3 shows a typical stability curve after one week aging. The long term drift, which is the limiting factor for stability at 1000 sec sampling time, generally improves by a factor of 4 after a one-month aging. A block diagram of the oscillator circuit is shown in Fig. 4.

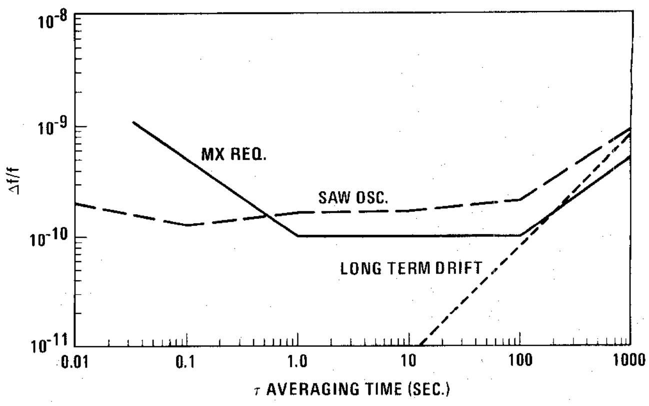

Figure 3. ALLEN VARIANCE OF SAW CIRCUIT AFTER ONE WEEK AGING

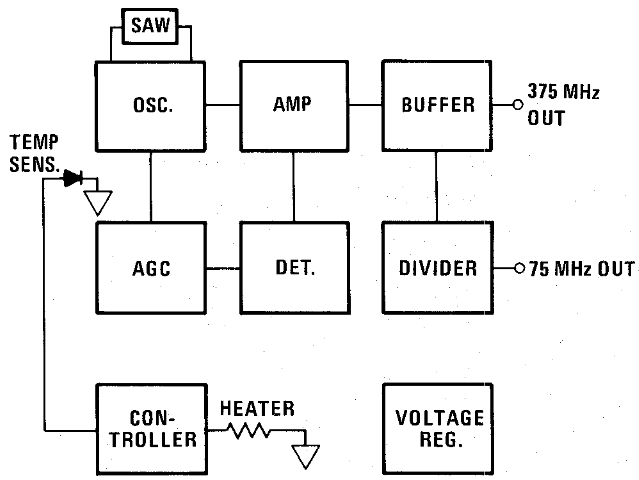

Figure 4. HYBRID OSCILLATOR BLOCK DIAGRAM

HYBRID PACKAGING

In order to take the full advantage of the reduction in size that a SAW resonator can offer, a hybrid oscillator package was built that contains the oscillator, buffer amplifiers, the temperature controller, the heater, the voltage regulator, provision for frequency adjustment, and a frequency divider all within a 1.8 x 1.8 x 0.65 inch (4.6 x 4.6 x 1.65 cm) package. The assembled package is shown in Fig. 5. The heater is thermally coupled to the oscillator circuit by attaching it on the back side of the circuit board. The design rules for the oscillator board were intentionally conservative with a minimum line width of .020 inches. Further size reduction is therefore possible. Chip resistors and PC boards were used rather than the standard film resistors and ceramic substrates for turn-around time considerations and low heat transfer requirements. The hybrid construction represents a volume reduction by a factor of 20 over the current production system. This is illustrated in Fig. 6.

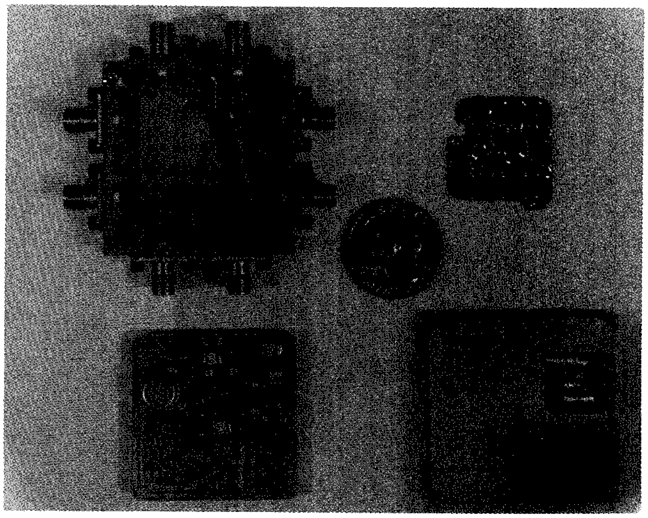

Figure 5. SAW HYBRID OSCILLATOR

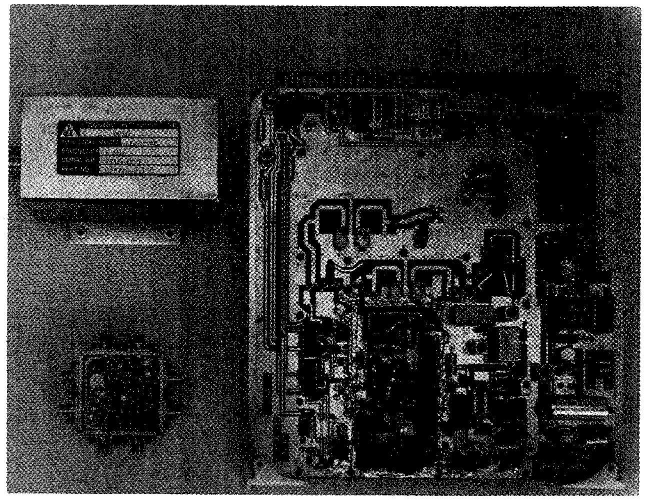

Figure 6. SIZE COMPARISON OF SAW OSCILLATOR AND BULK CRYSTAL OSCILLATOR WITH MULTIPLIER BOARD

The g-sensitivity of the hybrid oscillator was measured through phase noise measurement at 100 Hz. The corresponding fractional frequency change was found to be 5x10E-9 in two axes and 3x10E-9 in one axis. The g-sensitivity at this level is comparable to AT-cut quartz bulk-wave oscillators. The g-sensitivity may be reduced further by making the circuit assembly more mechanically rigid.

COMPARISON TEST IN SYSTEM PERFORMANCE

The bulk-wave crystal oscillator and its multiplier chain in the MX1102 navigator were then replaced by the SAW oscillator with its simpler divider circuitry. Satellite tracking and fixes were obtained before and after the replacement. The error of the fixes was calculated for both arrangements. The system accuracy for the location fixes with the SAW oscillator was as good as the bulk wave crystal oscillator. The standard deviation for both arrangements was on the order of .1 nautical miles at night for October 1980 when the sun spot activity was relatively high. Fig. 7 is a plot of the position of the fixes obtained with the crystal oscillator and the SAW oscillator in relation to the receiver antenna location. The average deviation of the fixes for both arrangements is shown in the lower left corner. The confidence level is indicated by the error bars. Thus, within experimental error, the SAW oscillator and the crystal oscillator provide comparable accuracy.

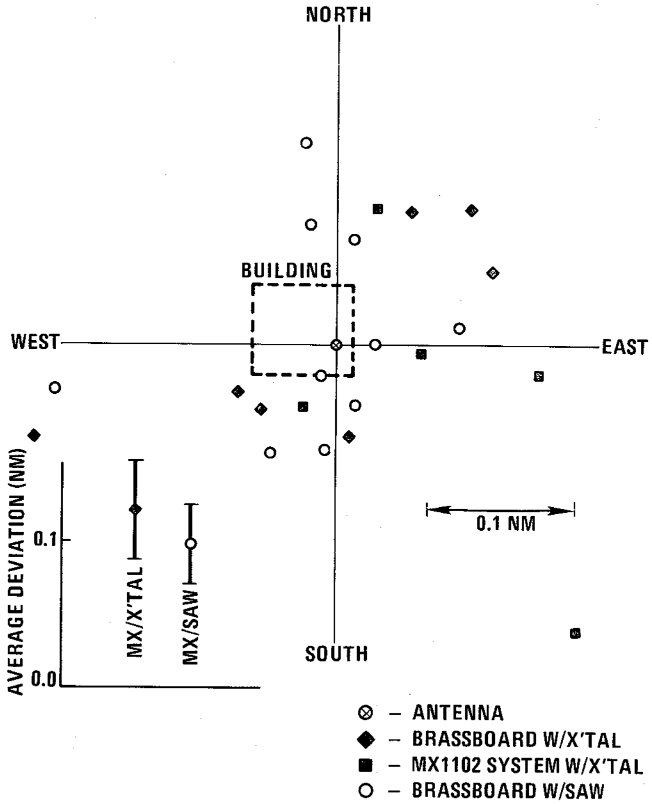

Figure 7. COMPARISON PLOT OF SYSTEM FIXES USING SAW AND CRYSTAL OSCILLATORS

FUTURE WORK

Future work includes reducing the long term aging rate to meet the ultimate goal of 2x10E-9 per day at 75 °C after 30 days preaging. It is believed that this can be achieved by greater surface cleanliness and better electrode stability.