A 2 GHZ SURFACE TRANSVERSE WAVE OSCILLATOR WITH LOW PHASE NOISE

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ABSTRACT

A hybrid oscillator at 1.9805 GHz was developed using acoustic surface transverse wave (STW) delay lines as the frequency controlling element. The STW delay lines were fabricated on 37.5° rotated Y–cut quartz substrates with a photolithographic technique. A very thin metallization of 25 nm was used to obtain low insertion loss. A split–isolated electrode design was employed for the transducers. The Q value and the untuned insertion loss of the STW filter were 3400 and 21 dB respectively. The phase noise and temperature stability of the oscillator were characterized. At a high power output of 6.5 dBm a single side band phase noise to carrier ratio of –100 dBc/Hz at 1 kHz was attained.

INTRODUCTION

In the gigahertz range oscillator phase noise specifications have been pushed to extremely low noise levels required for radar and navigation applications. Direct generation of frequencies which minimizes multiplication and avoids phase noise increase due to the multiplication process is achieved by surface acoustic wave (SAW) oscillators. A significant advantage of SAW controlled frequency sources over other oscillators is the very low FM noise level which can be achieved (1). Due to the limitations of the fabrication process the upper frequency limit of SAW delay lines forming the frequency selective element in the feedback loop is approximately 1.2 GHz if produced with optical lithography. By using surface transverse waves (STW) on quartz substrates having a 60% higher wave velocity than the common piezoelectric Rayleigh waves and by operating at a higher harmonic, the frequency range can be extended to above 3 GHz without using frequency multiplying circuits (2). A high performance 1.9805 GHz STW delay line oscillator is described, and its performance analyzed.

OSCILLATOR CIRCUIT

The construction of the STW oscillator is very similar to the SAW delay line oscillator. The block diagram is shown schematically in Figure 1. The components include the STW delay line, amplifiers, phase shifter, matching networks, and output coupler.

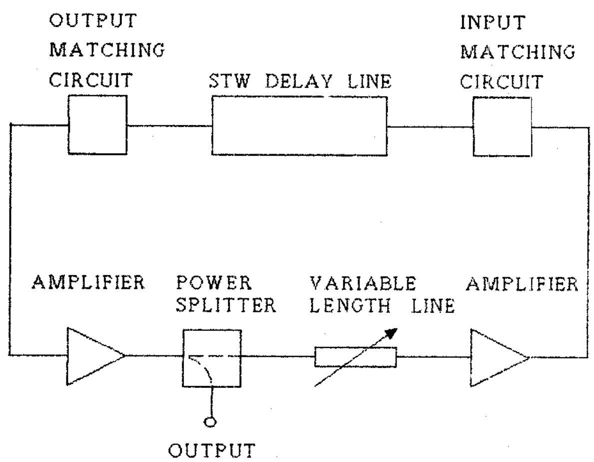

Figure 1 – STW Oscillator Block Diagram Schematic

The frequency of oscillation is determined by the frequency of the STW device in the feedback loop which in our case is 1.9805 GHz. The small signal gain of the amplifiers at the frequency of oscillation has to be greater than the loss associated with the delay line and any other loop components. In our hybrid design we use two identical commercially available silicon bipolar low noise MMIC amplifiers with a gain of 17.7 dB at 2 GHz. In order to achieve low phase noise the STW delay line must have low insertion loss and high Q (3). The design of the delay lines is described in more detail later. The phase around the loop has to be an integer number of 2π radians. As a phase shifter a variable length line is used which, like the remaining components, has been fabricated in softboard microstrip technology ($\epsilon = 10.5$). The dimensions of the substrate are 1 x 2 inches. The output coupler is a 3 dB Wilkinson power divider. No output buffer amplifier was used.

The computer–aided design and optimization of the complete circuit, including microstrip Wilkinson power splitter, matching networks and bias networks of the amplifiers, was done by using a standard microwave simulation and optimization program. The design has profitted by the fact that the output impedance of the amplifiers lies close to 50 Ω. Both the input impedance and the output impedance of the delay line have a real value of 20 Ω.

A photograph of the oscillator which has a power output of 6.5 dBm is included as Figure 2.

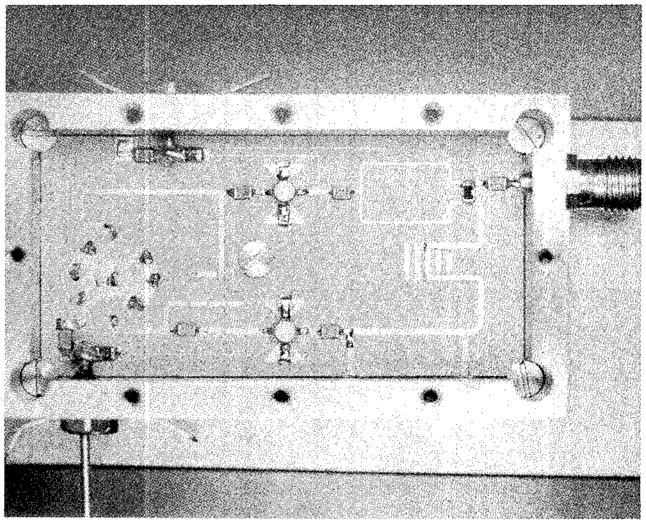

Figure 2 – 1.9805 GHz STW Oscillator

STW DELAY LINE DESIGN AND FABRICATION

The main advantages of the use of STW on quartz substrates instead of piezoelectric Rayleigh waves are the high propagation velocity on AT–cut quartz and the zero coupling of other modes (4,5). For low noise single mode oscillator applications the design parameters of the STW delay lines are mainly insertion loss and Q value (6).

The STW delay lines were designed with highly advanced analysis methods. A Greens's function method was applied to calculate the electrostatic charge distribution of the transducers (7). The excitation strength at harmonic frequencies was calculated very accurately in order to minimize the insertion loss. Each delay line consists of two identical split–isolated interdigital transducers. In the split–isolated transducer type every second electrode is floating, i.e. not connected to to the bus bars (8). Thus, the capacity and the radiation conductance are reduced by half. This allowes a reduction of acoustic diffraction effects by doubling the acoustic aperture without significant change of the impedance. A geometric period of 1.926 μm was used for the transducers. This transducer type shows a strong excitation of surface waves at the third harmonic. The delay lines were characterized by an untuned insertion loss of 21 dB, a 3 dB bandwidth as small as 1.2 MHz to ensure single mode operation and a group delay time of 550 ns. For measurements which were made with an HP8510B network analyzer the filters were mounted into standard TO–8 packages. The Q value is measured at approximately 3400 which is a very high Q value with respect to the frequency of almost 2 GHz. Figure 3 is a plot of the measured frequency response (upper trace) and the group delay time (lower trace) near the third harmonic.

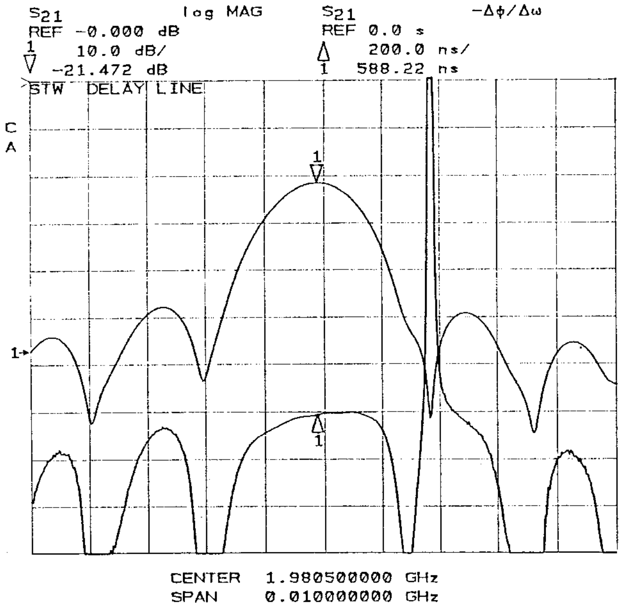

Figure 3 – Frequency Response and Group Delay Time of STW Delay Line

The STW delay lines are fabricated on 37.5° rotated Y–cut quartz substrates using a standard photolithographic process with 10:1 reduction projection printing and lift–off technique. The linewidth resolution is about 0.8 μm. A very thin metallization of 25 nm was used. With this process the transducer electrodes are fabricated with high precision and high reproducibility.

PHASE NOISE

The amplifiers of the STW delay line oscillator are operating in a saturated condition supressing the AM noise. The dominant noise is thus FM (9). The full line in Figure 4 is a plot of the measured single side band spectral density, $S_{\phi}(f_m)/2$, of the delay line. Here f_m is the frequency of the phase fluctuations, $\Delta\phi$. These phase fluctuations appear in the output signal if a noise free signal is passed through the delay line in series with the amplifiers. The frequency f_m is referred to as the modulation (Fourier) frequency. The relation

$$(\Delta\phi)^2 = S_{\phi}(f_m)$$

has been used, where $(\Delta\phi)^2$ is normalized to a 1 Hz bandwidth. Measurements were made with an HP3048A noise analyzer using the two STW device phase detector method described in Reference (10). This method of phase noise measurement requires two STW delay lines of very similar frequency, loss and Q value. By using this measurement technique it is possible to measure the phase perturbations in the delay line directly and without ambiguity. The delay line is the source of the close to carrier noise which is clearly seen to have a $1/f_m$ dependence (11). This $1/f_m$ dependence is commonly called flicker noise. The flicker frequency f_α is given by the expression

$$f_\alpha = \alpha P_c/(2\pi GFkT),$$

where α is an experimentally determined flicker noise parameter, P_c the carrier power level, G the amplifier gain, F the amplifier noise figure, k Boltzmann's constant, and T the temperature. The broken line in Figure 4 shows the calculated frequency dependence of the single side band spectral density, $S_\phi(f_m)/2$, of the open loop circuit.

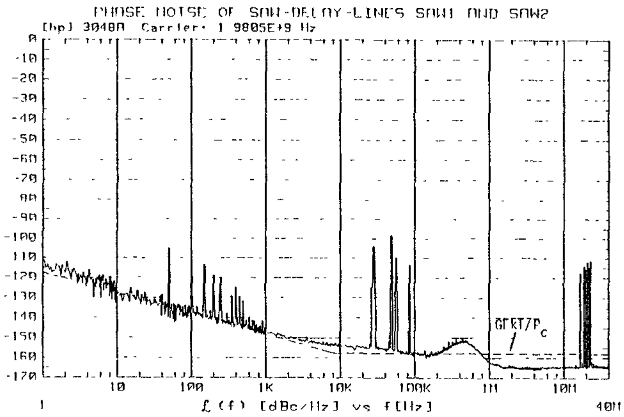

Figure 4 – Phase Noise Characteristics of STW Delay Line

Figure 5 shows the measured single side band phase noise spectrum of the (closed loop) oscillator. Again, measurements were made with the HP3048A noise analyzer using in this case a frequency discriminator method which is described in Reference (12). The sensitivity of the frequency discriminator is determined by the magnitude of the sinusoidal voltage fluctuations at the output which are proportional to $\sin(\pi f_m\tau)/(\pi f_m\tau)$. Here τ is the amount of delay provided by the STW delay line. To avoid having to compensate for the sin(x)/x response, measurements are accurate and sensitive only for modulation frequences f_m much less than $1/\tau$, where the first null of the transfer response occurs. In our case, measurements will become inaccurate for modulation frequencies above 300 kHz.

The $1/f_m$ phase noise in the delay line appears as a $1/f_m^3$ dependence in the phase noise spectral density of the oscillator below the flicker frequency f_α. This occurs because the open loop phase fluctuations cause frequency modulation of the closed loop circuit. Again, a thermal noise floor of $(GFkT)/P_c$ for modulation frequencies far away from the carrier is observed, but for frequencies below the oscillator–feedback bandwidth frequency f_τ, which is equal to $1/(2\pi\tau)$, the oscillator takes on an additional $1/f_m^2$ dependence. Here τ is the group delay time of the STW delay line. The relation between τ and Q is given by

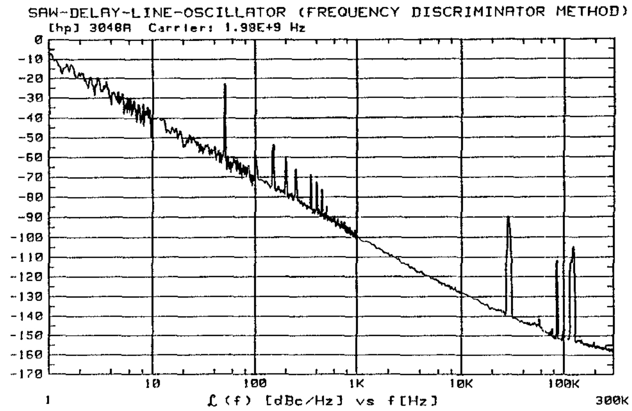

Figure 5 – Single Side Band Phase Noise of STW Oscillator

$$Q = \pi f\tau,$$

where f is the oscillator frequency.

The phase noise of a delay line oscillator, $S_\phi(f_m)/2$, which is the ratio of the single side band noise power in a 1 Hz bandwidth, P_{sb}, to the carrier power, P_c, is described by the equation

$$\left[\frac{P_{sb}}{P_c}\right]_{\frac{dBc}{Hz}} = 10\log\left[\frac{\alpha}{\omega^3\tau^2} + \left[\frac{GFkT}{P_c}\right]\left[\frac{1}{\omega^2\tau^2}+1\right]\right],$$

where $\omega = 2\pi f$.

Application of this noise theory to our oscillator yields a theoretical noise floor of –158 dBc/Hz. The oscillator–feedback bandwidth frequency f_τ equals 280 kHz. The flicker frequency f_α and the flicker noise parameter α are determined experimentally to be 8 kHz and $4.3\times10^{-11}\ s^{-1}$ respectively. The phase noise of the STW oscillator is –100 dBc/Hz at 1 kHz and –70 dBc/Hz at 100 Hz.

TEMPERATURE BEHAVIOUR

Our oscillator is designed for operating at 80 °C without a temperature compensating network. The temperature stability of the oscillator is controlled by the temperature behaviour of the STW delay line. The experimental temperature behaviour of the STW delay line is shown in Figure 6. The frequency vs. temperature curve is a parabola. The turn over temperature is approximately 80 °C which is mainly determined by the chosen cut of the quartz substrate.

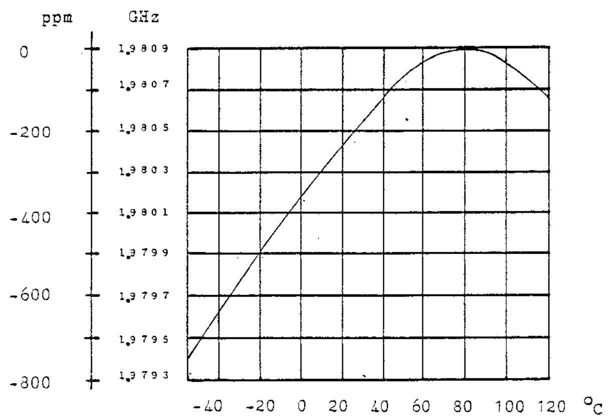

Figure 6 – Frequency vs. Temperature of STW Delay Line

CONCLUSION

This work demonstrates the feasibility of using high frequency STW delay lines operating at a higher harmonic as frequency controlling elements in the feedback loop of oscillators. By using highly advanced analysis methods and conventional photolithographic techniques STW filters with low insertion loss and high Q can be accurately designed at frequencies up to nearly 3 GHz. An experimental oscillator operating at 1.9805 GHz has been fabricated and analyzed. Excellent oscillator phase noise data are obtained at a high power output.

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