

## SURFACE ACOUSTIC WAVE OSCILLATORS

DIETER SEHMISCH and ERICH TRZEBA

Institute of Electrical Communication, Dresden University of Technology,  
Dresden 8027, Germany

**ABSTRACT.** There are principal advances in the field of application of surface acoustic wave (SAW) delay lines and resonators in stable microwave frequency sources in the frequency range from 100 MHz to 1 GHz and above. Advances, applications and fundamental design will be described. The center frequencies of the realized oscillators are near 70 MHz and 200 MHz. Requirements for the amplifier are presented. Results from frequency variation and modulation are demonstrated. Miniature SAW oscillators have been designed and fabricated based upon a combination of hybrid electronic circuitry and SAW delay line. The package for the oscillator is a PDL 24 with a volume of  $28 \times 34 \times 5 \text{ mm}^3$ . This results in a rugged system. Measurements of short and medium term stability of the oscillators will be described.

### INTRODUCTION

SAW devices directly allow to generate stable oscillations in a frequency range from 10 MHz to 1 GHz and above. Conventional crystal oscillators operate at fundamental frequencies up to 50 MHz, harmonic operation is realized up to 250 MHz. The utilization of thin-film membrane and composite structures deliver stable UHF and microwave frequency sources in the range from 50 MHz to 1 GHz and above. The conventional way to generate stable oscillations in this range is the application of multiplied standard crystal oscillators and associated filters. These multipliers and filters cause bad spectral purity and short-term stability, large size, weight, power and cost.

SAW oscillators offer a number of advantages to LC and conventional quartz crystal oscillators, such as planar construction, small size and mechanical stability. SAW oscillators can be in the form of a delay line or a resonator. SAW devices are fabricated by photolithography, and are compatible with microelectronic circuitry. At present there is a trend from SAW devices to more complex units. SAW devices are used as stable reference sources, voltage controlled and frequency modulated oscillators in the field of communication, radar, satellite, telemetry applications, sensors and consumer electronics.

Other types of elastic waves in solid states are used for high frequency ranges and for decreasing the demands for technology. The velocity of surface skimming

bulk waves (SSBW) in BT-quartz is about 1.6 times higher than the velocity of surface acoustic waves.

#### FREQUENCY SETTING, TRIMMING AND MODULATION

The SAW oscillator stability, frequency setting, trimming and modulation capability was tested. The phase slope of the delay line can be changed to meet user requirements for frequency variation or modulation by the choice of the acoustic pathlength  $l_d$ . A frequency trimming capability is necessary to adjust the desired frequency  $\omega_0$ . The phase of the amplifier and its dependence on temperature, supply voltage and load pulling must be taken into consideration. Frequencies within a given range must be reproducibly adjusted in some cases.

The Barkhausen conditions for oscillation are that the gain of the overall loop be unity and the loop phase length should be an integral multiple  $m$  of  $2\pi$  radians. The phase of the delay line results from

$$\varphi_{VZL} = \omega \cdot \tau \quad (1)$$

where  $\tau$  is the delay time. The frequency of oscillation is given by

$$\omega = \frac{2m\pi - \varphi_{e1}}{l_d} v_s \quad (2)$$

where  $v_s$  is the SAW velocity,  $l_d$  is the pathlength between transducer centres,  $\varphi_{e1}$  is the electrical phase shift associated with the amplifier and transducers. Referring to equation (2), it can be seen that the frequency can be changed by the variation of the electrical phase shift, the acoustic pathlength or the velocity.

Circuits have been constructed at Dresden University using varactors and PIN diodes in the network for changing the electrical phase shift (Fig. 1):

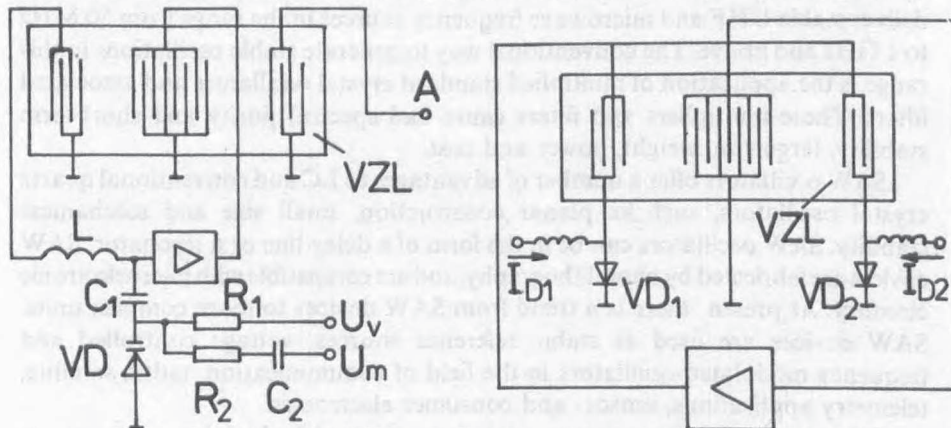


Fig. 1 SAW oscillators with varactor (a) and PIN diodes (b).

A frequency shift  $\Delta\omega/\omega_0 \approx 2500$  ppm was obtained at center frequencies of about 70 MHz and 197 MHz. This value is about ten times higher than that of the bulk wave oscillators. A frequency modulation which has a modulation

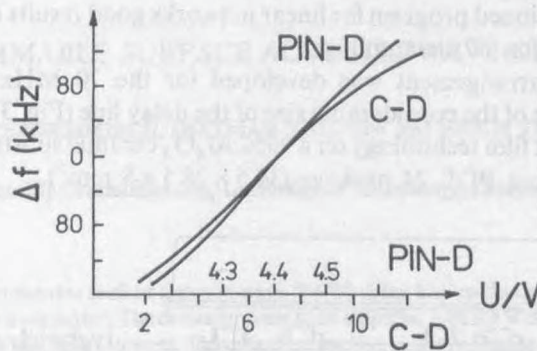


Fig. 2 Modulation characteristic.

depth of some hundred ppm delivers a low distortion of the modulated signal (Fig. 2). A special phase shifter associated with a multimode delay line produces a frequency shift of  $\Delta f/f_0 = 34\,000$  ppm. SAW oscillators having a higher quality factor results in a smaller frequency shift. This is well suited for fixed frequency oscillators.

#### HYBRID CIRCUIT SAW OSCILLATOR

A combination of hybrid electronic circuitry and ST-quartz delay line gives a rugged device which has a good reproducibility. Size, weight and power consumption are decreased. Miniature hybrid circuit SAW oscillators at 70 MHz and 197 MHz were developed at Dresden University. ST-quartz with zero first order coefficient of the temperature of delay time results in a frequency stability of  $\Delta f/f_0 \approx 3$  ppm in the range of  $\pm 4$  K at the turnover temperature of the frequency-temperature characteristic and in a good long term stability. A frequency deviation of about  $10^{-4}$  was obtained within a range from  $-20^\circ$  to  $+50^\circ\text{C}$ . The frequency of ST-quartz oscillators varies with temperature  $T$  according to the following equation

$$f = f_0(1 - 31 \cdot 10^{-9}(T - T_0)^2) \quad (3)$$

where  $f_0$  is the maximum frequency occurring at the turnover temperature  $T_0$ . Insertion loss was computed to be 40 dB for ST-quartz with transducers containing 100 and 10 pairs of fingers which have an aperture of about  $50\lambda$ . The optimum with an aperture  $w = 180\lambda$  in a 50 Ohm system has an insertion loss of about 16 dB, the measured value was about 20 dB. The pathlength was about

100 $\lambda$ . A second stage amplifier with a high band-width compensates the insertion loss of the delay line and the phase shifter of this feedback loop. A computer program for linear networks was coupled with a program for SAW devices. The oscillator loop requires a nonlinear computer aided design. However, by the use of the above mentioned program for linear networks good results can be achieved for the optimization of the amplifier.

A sandwich arrangement was developed for the 70 MHz hybrid circuit oscillator because of the considerable size of the delay line (Fig. 3). The amplifier is realized in thick film technology on a 96%  $\text{Al}_2\text{O}_3$  ceramic substrate. The device is encapsulated in a PDL 24 package ( $34.5 \times 28.5 \times 5 \text{ mm}^3$ ).

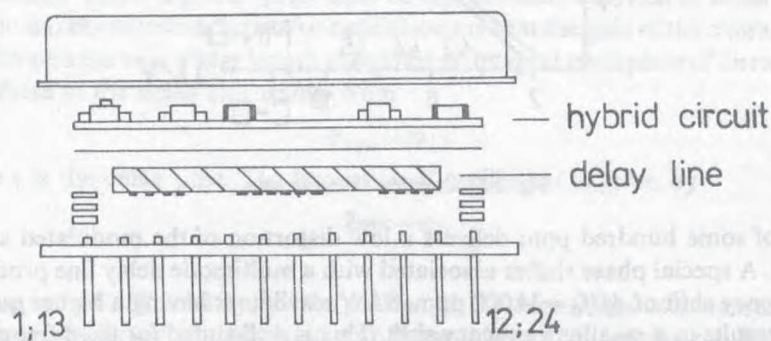


Fig. 3. SAW hybrid oscillator.

The proposed measure of frequency stability in the time domain is  $\sigma_y^2(\tau)$ , called the Allan variance, thus delivering the short term stability  $\sigma_y(\tau_x) = 2 \cdot 10^{-9}$  ( $\tau_x = 0.1, \dots, 1 \text{ s}$ ). A plane arrangement consisting of hybrid circuit and delay line with a center frequency of 197 MHz is also encapsulated in a package PDL 24. The delay line consists of two transducers containing 70 pairs of fingers. A special broadband amplifier was designed and realized as ceramic based thick film circuit and as surface mounted device [1, 2].

#### REFERENCES

- [1] Bergmann, A., Hybridoszillator, TU Dresden, 1984.
- [2] Thienel, T., AOW-Oszillator, TU Dresden, 1987.