Panel : Stabilization of Fundamental - Frequency Microwave Oscillators for Radio - Relay Systems

MICROWAVE BAW AND SAW OSCILLATORS

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Abstract: High frequency fundamental operation up to 2-3 GHz is possible with both surface acoustic wave (SAW) and bulk acoustic wave (BAW) oscillators. The present characteristics and the estimated future capabilities are described in view of radio-relay communication requirements.

Introduction

High frequency oscillators may be obtained by multiplication of conventional quartz oscillators output. This requires many electronic components, is power-dissipative and leads to a degradation of the oscillator characteristics, particularly in the frequency domain. Direct synthesis at high frequency is achieved using both SAW and BAW as shown on Fig. 1. The basic SAW oscillators use a delay line in a feedback loop with mode selection performed through the transducer geometry[1]. If ν_o is the center frequency and τ_g the group delay of the line, the Q - factor is equal to $Q = \pi \nu_o \tau_g$ [2]. The accurate frequency can be adjusted via an external phase-shifter. In the so-called resonator-oscillators the group delay is enhanced by two reflective arrays obtained by various technologies. So, the Q factor is now equal to $Q = \pi \nu_o \tau_g/(1-r)$ where r is the transmittance for a round trip. Similarly, BAW oscillators[3] use a bulk high-frequency delay-line. Unfortunately in this case, mode selection cannot be achieved "in situ". At last, the device is used as a 1 port impedance or as a 2 port delay line (fig. 1).

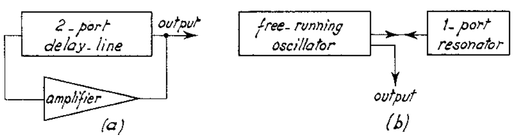


Fig. 1 : Fundamental frequency 1 or 2 port oscillators

Characterization of the oscillators

An oscillator is characterized in both time and frequency domains[4] (fig. 2). In the frequency domain the first important parameter is the *FM thermal noise floor* which only depends upon the loss and the power in the feedback loop. Due to the power level this basic floor is generally better in 2 port oscillators than in conventional low frequency quartz standards. A typical value is - 160 dBc. In addition, frequency multiplication by a factor n increases this value by a term = 20 log n. In radio-relay communications this noise is added in the mixer but is not generally very critical except for multimode BAW oscillators. The second important parameter is the *bandwidth of the carrier* which depends upon the Q factor but more strongly upon the so-called "flicker floor" σ_{yF} ($\Delta\nu \simeq 2\nu_o \sigma_{yF}$) in the time domain. Unfortunately, this parameter is rather impredictable and has to be made precise experimentally. In addition, its extrapolation toward higher frequencies is a priori hazardous.

Table 1 : Thermal noise floor at ν_o = 1 GHz (in dBc)	fundamental	1 GHz
High quality 5 MHz quartz	- 146	- 100
Typical 5 MHz quartz	- 120	- 84
SAW 100 MHz delay line	- 160	- 140
SAW 100 MHz resonator	- 170	- 150
SAW 1 GHz delay line[5]	- 150	- 150
SAW 1 GHz resonator (estimated)	- 140	- 140
BAW 1 GHz	multimode	multimode

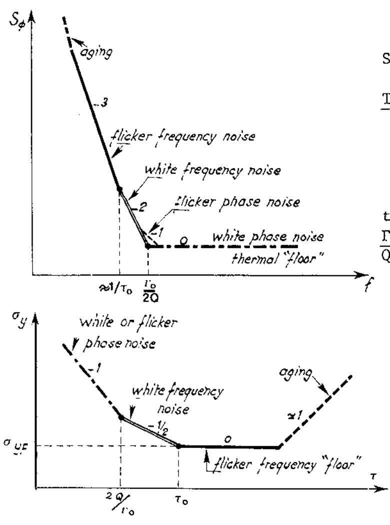
Furthermore, a stringent parameter is the *temperature behaviour (medium-term stability)*. The future requirement under study for radio-relay systems is an overall variation of less than 10^{-4} (470 < Fc < 2450 MHz). Taking into account the statistical addition of frequency errors on a radio link, the requirement is satisfied by a simple ST quartz-SAWO (27 ppm between - 10 to 50°C) or a $SiO_2/LiTaO_3$ - SAWO when aging is neglected. In addition, it is possible to use temperature compensation (TCXO) or oven control (OCXO). Moreover, "Surface skimming bulk waves" on quartz could have an AT - cut temperature variation. BAWO have a good behaviour with respect to temperature (20 ppm between - 40 to + 60°C) because the AT-quartz cavity is thermostated to prevent jumps from one mode to an other. Meanwhile, the overall efficiency remains fair[6].

Finally, the most severe and presently rather unknown parameter concerns the *aging rate*. This is the sum of several mechanisms (contamination, packaging, stresses ...) exhibiting both linear and logarithmic time dependance. The result found in our laboratory is typically a linear time dependance of - 10 ppm/year during 2 years. Other measurements[7] show - 30 to - 100 ppm per decade after 6 months, but recently, positive aging rate has been also reported[8].

Design of high frequency oscillators - Conclusion

Among the different technologies the very simple SAW delay line is probably the most convenient at high frequency where the propagation losses are predominant, leading to a fair thermal floor of - 150 dBc in the GHz range. For BAW oscillators the main restriction is likely the filtered noise in the frequency domain occuring in multimode oscillators.

High frequency acoustic oscillators seem very promising in radio-relay communications ; they already meet the short term requirements with a high reliability due to simplicity and ruggedness. The fair temperature behaviour using zero-temperature cuts does not require compensation except for stringent specifications. Long - term stability is currently under study but substantial improvement in packaging and pre-aging is expected. Finally, high frequency SAW and BAW oscillators up to 2 - 3 GHz should be available soon, the main limitation remaining the fabrication techniques.



Frequency domain

$$S_\phi(f) = \frac{\nu_0^2}{f^2}\left(\frac{h_{-2}}{f^2} + \frac{h_{-1}}{f} + h_0 + h_2 f^2\right)$$

Thermal "floor" (white phase noise) : $\nu_0^2 h_2 = 2\ kT/P_s$

ν_0 frequency of the oscillator

k Boltzmann constant

$P_s = P_0/FG^2$ P0 power

G amplifier linear gain

F amplifier noise factor

typical : $\nu_0^2 h_2 = 10^{-15}$ S (-150 dBc)

Filtered noise (white frequency noise): $h_0 = \nu_0^2 h_2/4Q^2$

Q quality factor (typical : $10^3 - 10^4$)

Time domain

$$\sigma_y^2 = 6.5\ h_{-2}\ \tau + 1.4\ h_{-1} + 0.5\ \frac{h_0}{\tau} + 0.08\ \frac{f_h}{\tau^2}\ h_2$$

Flicker "floor" (flicker frequency noise) $\frac{1}{2}$

typical : h_{-1} (experimental) $\simeq 10^{-20} = \sigma_{yF}$

depends upon : power supply, components, temperature instabilities

Aging

typical : $6.5\ h_{-2} \simeq 10^{-25}$ (experimental)

depends upon : materials, metallization, ...

Fig. 2 : Typical time and frequency domain characteristics of SAW oscillators.

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