X BAND BULK-WAVE DELAY LINE STABILIZED OSCILLATOR

Y. Amblard and A. Peyrat
THOMSON-CSF
AVS Division - RCM Department
178, Boulevard Gabriel Péri
92240 Malakoff - FRANCE

Abstract

A low noise X band oscillator, stabilized by a microwave delay line discriminator has been designed for Doppler Radar applications. It uses a Gunn varactor VCO and a bulk-wave . 5 µs delay line. The measured phase noise of this source is Single Sideband dBC of - 90 dB in a 1 kHz band at 100 kHz from the Carrier, in fairly good accordance with calculated figures.

Introduction

Modern airborne radars require high performances microwave sources gathering fast tuning and good short term stability for doppler signal process. Low FM noise solid state sources usually require multipliers and one or more crystal oscillators as reference. Some other low noise sources are cavity stabilized with high Q mechanically tunable devices. That king of oscillators does not satisfactory suit airborne equipements with hard temperature and vibrations conditions. The technic employed here is the phase discriminator using an acoustic bulk-wave delay line in an interferometer arrangement. The acoustic device operates as a high Q cavity but with a wide frequency range and a low vibration sensitivity.

Principle of operation

According to figure 1 the stabilized source consists of an X band VCO and a phase discriminator including power divider, delay line and phase detector. The phase lock loop is closed by a video amplifier and a switch.

- The VCO is a gunn varactor oscillator
- The power divider is a double directional coupler with three outputs
- The phase detector is a balanced mixer with low noise doppler diodes
- The video amplifier output controls the VCO varactor
- Eventually an analogic 0 - 2 π phase shifter allows an adjustment of the discriminator operating point.

The mode of operation of the loop is firstly dependent of VCO, discriminator and amplifier characteristics.

Output frequency F of the locked source is

$$F_{MHz} = F_F - S\ V_D\ G \qquad (1)$$

where F_F in MHz is the free frequency of the VCO with a null error voltage on the control input.

S in MHz/volt	control sensitivity of the VCO
V_D in volt	phase detector output voltage
G	video amplifier gain

The discriminator is characterized by the following expression

$$V_D = k \sin (2\pi\ \tau\ F - \varphi_o) \qquad (2)$$

with k in volt/radian : sensitivity of the phase detector

τ in µs : delay time of the acoustic device

φ_o in radian : insertion phase provided by the phase shifter

Figure 2 represents these two equations on a V_D versus F diagram. The equation (1) gives a straight line with moderate slope if the S.G product is high. For linear mixer operation, according to (2), the delay line discriminator presents a sine curve with a period

$F_o = \frac{1}{\tau}$ and a φ_o dependent origine.

Intercepts points of these two curves are approximately $\frac{1}{2\tau}$ spaced and the operating point is given by the positive section of this sine-curve nearest to the F_F point. From (1) and (2) and with V_D small, corresponding to the low slope of curve (1), the expression of the output frequency is :

$$F = \frac{F_F}{1 + k\ 2\pi\ \tau\ SG} + \frac{\varphi_o}{2\pi\ \tau} \qquad (3)$$

According to (3) fluctuations of F_F are compressed by the loop gain (k 2π τ SG), but F remains dependent of φ_o. A phase shift of 2π provides a frequency shift of $\frac{1}{\tau}$. The residual FM noise of the locked source, at ω off the carrier, is given by :

$$\Delta F\ (\omega) = \frac{\Delta\ F_F\ (\omega)}{1 + k.2\pi\ \tau\ SG} + \frac{N\ (\omega)}{k.2\pi\ \tau} \qquad (4)$$

with $\Delta\ F_F\ (\omega)$: FM deviation of the free VCO

$N\ (\omega)$: AM noise of the loop on the amplifier input.

The design and its characteristics

For airborne doppler radars the frequency range of interest is the 3 to 100 kHz band. The loop bandwith must be fitted to that range in function of other devices characteristics. With a VCO FM noise increasing at low frequencies, the first term of (4) is preponderant at these frequencies, and the second term is higher for high frequencies. The higher the discriminator sensitivity (k 2π τ) the lower the residual FM noise is. But the delay time (τ) and the k term have opposite variations since k is dependant of the delay line output level.

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In bulk wave lines, moderate insertion losses are attainable with medium bandwith. Typically in a X band acoustic device losses are :

- 18 dB in the acoustic material for 1 μs delay time, and
- 12 dB for each transducer with 10 % bandwith or 21 dB with 25 % bandwith.

A preliminary design of stabilized source was tested with a coaxial delay line having 20 dB insertion loss and 75 ns delay time to verify the expression (4). The values obtained were barely higher than calculated figures. Then the acoustic device stabilized source was realized with the following components :

- An X band Gunn varactor VCO electronically tunable on a 500 MHz range with 120 mW output power and a FM deviation of 100 to 200 Hz/$\sqrt{kHz}$ (figure 3a).
- A bulk wave delay line supplied by Teledyne MEC type 7938.

  Delay time : 0,5 μs   Insertion loss : 37 dB
  Center frequency : 10 GHz   Bandwith : 500 MHz
- A low noise balanced mixer and a wide band video amplifier having a 6 dB/octave decreasing gain at frequencies lower than 300 kHz and constant gain upper that.

With about 60 mW of microwave power on the acoustic line input, the phase detector sensitivity is k = 55 mV/radian and the discriminator sensitivity is $k.2\pi\ \tau$ = 172 mV/MHz.

Frequency tuning is set in 2 MHz steps with reference voltage applied to the VCO varactor in an open loop mode. Fine frequency adjustment is obtained by setting a 0 - 2π microwave phase shifter inserted in one discriminator arm.

The measured and calculated FM noise of the stabilized source is given on figure 3 curves (b) and (c). These two results are in good accordance for high frequencies but a 3 dB to 9 dB gap appears between measured and calculated values at low frequencies. The main causes being probably any intermodulation problem and inaccuracies of the noise bench. Other tests were performed during vibrations in 50 to 2000 Hz range. A 10 dB degradation could be observed at low frequencies for a 10 g vibration level. This effect is firstly imputed to an important increasing of the VCO FM noise at these frequencies.

Temperature stability measurements on the delay line and on the solid state source give a - 24 PPM/°C of linear drift coefficient. A good VCO stability is required to avoid undesirable $1/\tau$ steps of the output frequency.

Conclusion

A new model of microwave low noise oscillator has been designed and tested, using a bulk-wave delay line as reference. Good performances are obtained with this kind of stabilized source in comparison with crystal sources. Figure 4 represents the corresponding two phase noise curves of typical bulk-wave delay line and crystal stabilized sources. Crystal sources are the best close to the carrier but around 100 kHz off, this new solid state source presents better performances with a more simple design. Other advantage is multi-frequency capability with the source reference device. These sources seem well-suited for airborne equipments and missiles where Doppler frequencies of interest allow good performances in X or Ku band.

Acknowledgements

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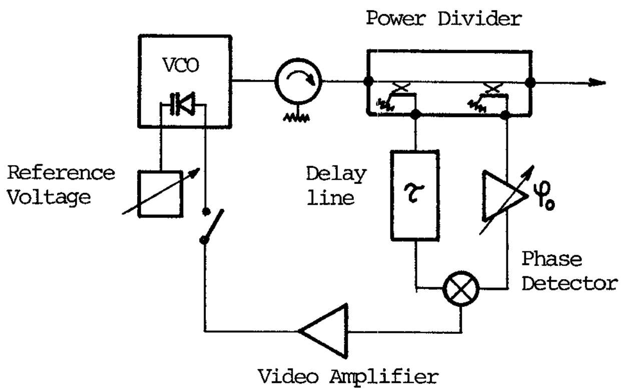

FIGURE 1 - STABILIZED SOLID STATE SOURCE

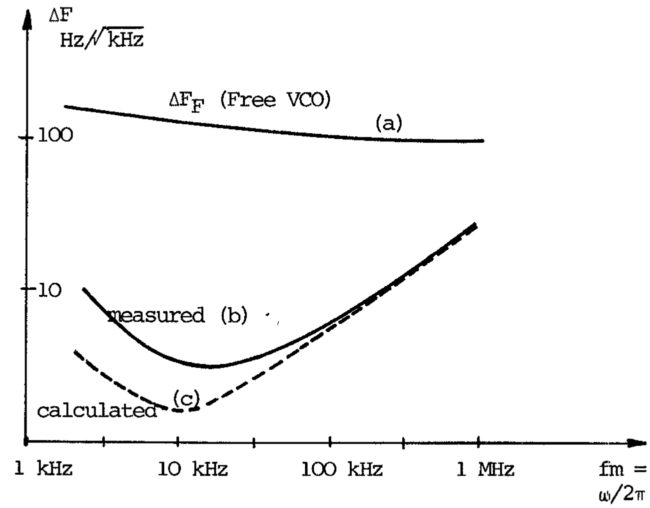

FIGURE 3 - FM NOISE OF VCO AND STABILIZED SOURCE

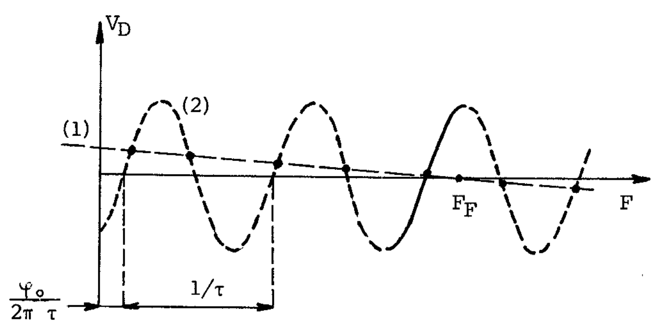

FIGURE 2 - DISCRIMINATOR MODE OF OPERATION

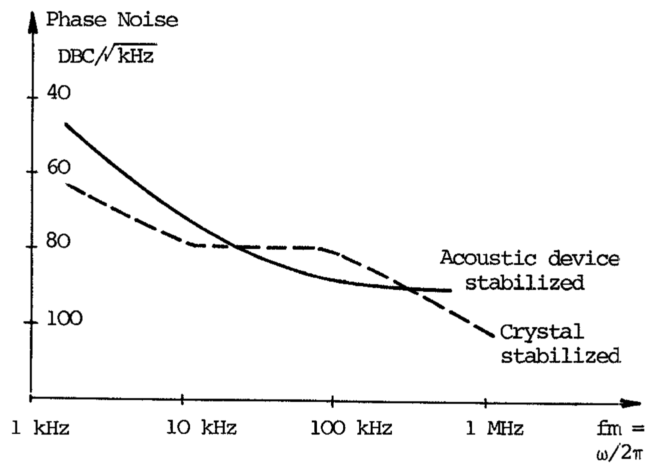

FIGURE 4 - PHASE NOISE OF CRYSTAL AND ACOUSTIC DEVICE STABILIZED SOURCES