AN X-BAND FREQUENCY AGILE SOURCE WITH EXTREMELY LOW PHASE NOISE FOR DOPPLER RADAR

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INTRODUCTION

Doppler radar systems frequently impose severe demands on spectral purity in order to discriminate between targets and clutter. In the case of radars operating at X-Band, the region from a few hundred Hz out to a few KHz from carrier is normally the most critical as far as phase noise and spurious signal performance are concerned.

This paper presents a 25 channel fast switching X-Band frequency agile source design capable of achieving a repeatable phase noise performance of -125 dBc / Hz at 1 KHz from carrier. Given that the current state of the art for this type of unit is around -110 dBc / Hz at 1 KHz, the design described represents a significant advance in the technology.

BASIC APPROACH

To achieve fast switching speed in addition to high spectral purity, radar frequency agile sources are normally based on a combination of direct and indirect frequency synthesis, a useful summary of suitable techniques being given in references (1) and (2).

The present design differs from those previously described in two important respects. Firstly, the entire synthesis process is performed in the UHF band, the resulting frequency agile signal being up-converted to X-Band by mixing with an ultra-low noise microwave reference signal, as shown in Figure (1). Secondly, the phase noise of the microwave reference signal is not critically dependent on piezo-electric device technology.

ULTRA-LOW NOISE MICROWAVE REFERENCE SOURCE

Principle

The microwave reference source is based on the application of new technology to what is fundamentally an old idea, namely stabilisation of a voltage-tuned microwave source by a frequency discriminator employing a high Q cavity resonator.

In recent years there has been a revival of interest in this method of stabilisation, driven by a need to obtain better and more repeatable close to carrier noise performance than may be realised by multiplying from or phase locking to a piezo-electric reference. Walls (3), for example, describes a scheme employing both the reflected and transmitted signals from a two-port cavity in order to obtain increased discriminator sensitivity. Similarly, Dick et al (4) discuss discriminator stabilisation methods with reference to cooled sapphire ring resonators as an alternative to conventional cavities.

Block Diagram

A block diagram of the discriminator stabilised source employed in the present work is shown in Figure (3). This design has proved capable of significantly better performance than any previously published scheme. Three key factors have contributed to this success:

(a) The method of implementing the voltage-tuned microwave source.

(b) The avoidance of amplification or resistive loss in the baseband feedback path.

(c) The choice of a discriminator configuration providing high sensitivity and a low noise floor.

Voltage-Tuned Microwave Source

As shown in the block diagram, this item is implemented by up-converting the signal from a relatively low frequency VCO, using a fixed frequency crystal/multiplier or phase locked microwave source as local oscillator. By this means, it is possible to realise a microwave voltage-tuned source combining high tuning sensitivity and wide tuning port bandwidth with a phase noise performance approaching that of the source employed as local oscillator.

As a result, only a modest value of open-loop gain is required of the stabilisation loop, in order to reduce the voltage-tuned source noise to the desired level. This gain is provided entirely by the source tuning constant and discriminator sensitivity, without the need for a baseband amplifier.

The low open-loop gain and wide tuning port bandwidth also make it a simple matter to stabilise the loop, and to obtain a closed-loop bandwidth out to a limit imposed by the discriminator cavity.

Frequency Discriminator

The discriminator is a carrier suppression type of conventional design, employing a fixed frequency copper-plated invar TE012 mode cavity for high frequency stability. This cavity is rated at 10 watts C.W. power handling capacity, but at present is operated at a power level below 1 watt.

It may be shown that the discriminator sensitivity is:

$$\frac{2}{\pi}\sqrt{2.P_i.R_o}\ .\ \frac{Q_u}{f_o}\quad v/Hz \qquad (1)$$

Where P_i = input power to cavity
R_o = input resistance to PSD
Q_u = cavity unloaded Q factor
f_o = frequency of operation

In addition to its use in calculating the open-loop gain, this expression may also be employed to determine the noise floor of the system, below which the source noise cannot be reduced by feedback, no matter how low the initial open-loop noise, nor how high the loop gain. For the academic case of a noiseless PSD, for example, conversion of thermal noise at the PSD output to equivalent source noise at the discriminator input yields:

$$10Log_{10}\left\{\left(\frac{\pi^2.K.T.R}{2.P_i.R_o}\right).\left(\frac{f_o}{Q_u}\right)^2.\left(\frac{1}{2.f_m^2}\right)\right\} \qquad (2)$$

Where K = Boltzmanns Constant
T = absolute temperature
R = PSD output resistance
R_o = RF impedance level
f_m = offset from carrier in Hz
and P_i, f_o and Q_u are as defined above.

For T = 293 deg. K and R = R_o, the thermal floor becomes:

$$\left\{ - 200 - 10Log_{10}\left(P_i\right) + 20.Log_{10}\left(\frac{f_o}{Q_u}.\frac{1}{f_m}\right)\right\} \quad dBc/Hz \tag{3}$$

This represents a noise floor of -200 -10.Log_{10} (P_i) dBc/Hz, which is constant at offsets far from carrier, and starts to rise at 20 dB/decade at an offset frequency equal to the cavity half-bandwidth.

System Parameters

The reference source employed in an initial demonstrator model had the following parameters:

Voltage Tuned Source:

Tuning Constant: 2.5 Hz/µV (2.5 MHz/V)
Phase Noise: Curve (a) in fig. (2)
Tuning port bandwidth: 2.0 MHz
Tuning Range: +/- 5 MHz

Frequency Discriminator:

Cavity Uploaded Q: 30,000
Input Power Level: 1 watt
RF Losses: 2.5 dB
Sensitivity: 16 µV / Hz
Temp. coeff. of freq.: 0.5 ppm/deg. C

Open-loop gain: 32 dB, 3 dB down at 25 KHz, Gain 0 dB at 1.2 MHz
(compensated)

Output Signal:

Frequency: 8.7 GHz
Power Level: + 15 dBm

Performance

Figure (2) shows the measured phase noise performance of the reference source with the stabilisation loop both open and closed. At 1 KHz from carrier, the closed-loop noise is -127 dBc / Hz, which is around 3 dB better than would be obtained were it possible to ideally multiply the best obtainable bulk wave crystal source to a frequency of 8.7 GHz.

In the demonstrator system, a crystal/multiplier unit was used as the local oscillator in the voltage-tuned source, resulting in an open-loop noise floor of -125 dBc/Hz. Hence the closed-loop noise eventually rises to equal this figure at an offset from carrier of around 1 MHz, when the open-loop fain has fallen to zero. This effect may be avoided by employing a phase-locked DRO as the local oscillator in the voltage-tuned source.

Practical features of design

In addition to the basic functions described so far, the demonstrator model included an auxiliary loop for initial acquisition of frequency lock, and an automatic power shut-down facility to protect the PSD from excessive power in the event of loss of lock. The former function is omitted from figure (3) for clarity.

UHF/L-BAND FREQUENCY SYNTHESIZER

Basic Approach

A block diagram of the frequency synthesizer employed in the demonstrator model is shown in figure (4). To fulfil typical radar requirements, the system was designed to generate 25 channels over an agility bandwidth of 512 MHz to 1024 MHz, channel derivation being as indicated in the figure.

Implementing the synthesis in this band with the necessary performance has been made possible by the recent availability of low-cost UHF and L-band VCOs capable of tuning over octave bandwidths with excellent phase noise characteristics, as shown in the plot included in figure (4). Compared to synthesizing directly at X-band, this approach offers the following advantages:

(a) The VCO cost is reduced by a factor of typically 20:1, and it ceases to be a critical item, the required phase noise performance being achieved with ease rather than with difficulty.

(b) UHF/L-band VCOs have superior tuning linearity and frequency stability compared to X-band units, thus simplifying and increasing the reliability of the loop design. Frequency stability, for example, is typically 20 KHz per deg. C, for a VCO tuning over 500 MHz bandwidth. The lower current consumption of the lower frequency VCO is instrumental in achieving this stability.

(c) Because the signal from the loop is translated rather than multiplied up to the final microwave band, the demands on the loop are much less than when implemented directly at X-band. A smaller loop bandwidth may be employed, making it easier to reject spurious signals.

(d) Since gain at UHF and L-Band is cheap, reverse isolation and matching may be achieved by attenuator pads and amplifiers, without recourse to ferrite isolators.

(e) The microwave band may be changed, simply by changing the final output filter and the frequency of the reference signal from the discriminator stabilised source.

(f) The entire synthesis section of the system may be constructed on a standard FR4 glass-fibre printed circuit board, greatly simplifying packaging and reducing production cost.

Performance

On comparing the VCO and multiplied reference phase noise curves included in Figure (4), a minimum loop bandwidth of 300 KHz is necessary for the synthesized signal phase noise to track that of the reference. With the bandwidth set at this figure, spurious signal suppression of greater than 90 dB may be readily obtained.

In the demonstrator model, to obtain a reasonable compromise between spurious suppression and switching speed, a bandwidth of 1 MHz was chosen, resulting in a switching time of under 10 µs and a maximum spurious signal level of -80 dBc.

OVERALL SYSTEM PERFORMANCE

At the time of writing, the phase noise performance of the final X-Band synthesized output signal had not yet been measured. Since this signal is formed by a simple up-conversion process, however, its phase noise may be reliably inferred by combining the measured results for the discriminator stabilised reference and the 512-1024 MHz synthesizer:

Offset	Phase Noise (dBc/Hz)		
	8.7 GHz Ref.	UHF Synth.	Combined
300 Hz	-112	-125	-112
1 KHz	-127	-135	-126
3 KHz	-138	-140	-136
10 KHz	-147	-145	-143

CONCLUSION

A frequency agile source design with extremely low phase noise has been presented. Because the close to carrier noise is controlled by a simple fixed tuned cavity, the system offers a high degree of repeatability in performance.

The fact that the final output signal is not coherent with some lower frequency reference is not usually a problem in a typical Doppler radar system architecture, which would use the synthesized signal as the local oscillator to the transmitter drive up-convertor and first receiver mixer. In fact, the possibility exists of varactor tuning the discriminator cavity, which would allow clutter tracking to be applied at the best possible place, namely to the receiver first local oscillator signal.

It is also worth noting that the radar transmitter may be included within the reference signal discriminator loop, if the frequency agility is first removed by mixing with the UHF synthesizer signal.

REFERENCES

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3. Walls, F.L., and Felton, C.M., 1990, “High Spectral Purity X-Band Source”, 44th Annual Symposium on Frequency Control Proceedings U.S.A.
4. Dick, G.J., Saunders, J., and Tucker, T., “Ultra-Low Noise Microwave Phase Stabiliser using Sapphire Ring Resonator”, 1990 ibid.

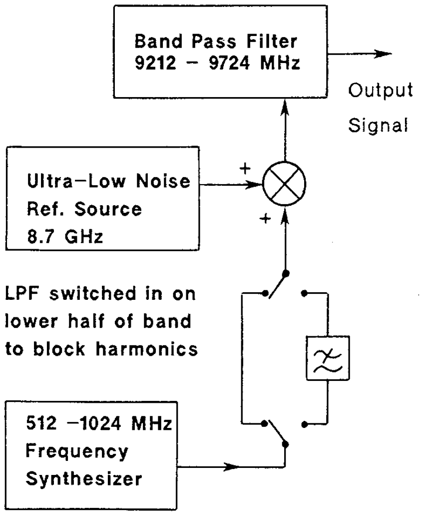


Figure 1 High level block diagram of Frequency Agile Source

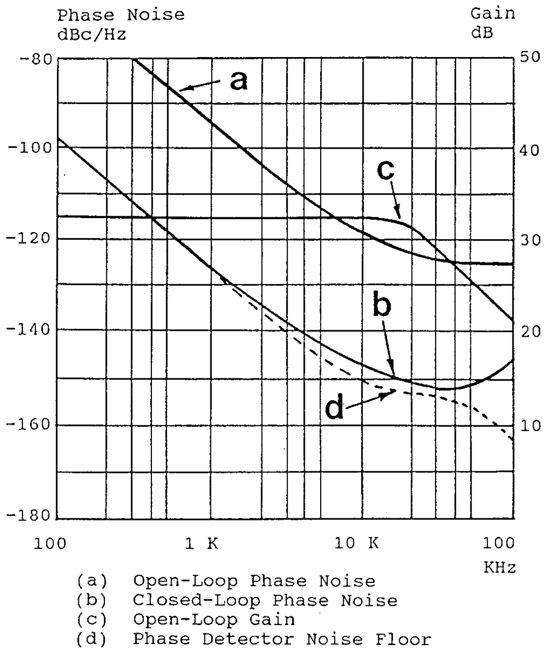


Figure 2 Measured phase noise, open-loop gain and PSD noise floor of Ultra-Low Noise Microwave Reference Source

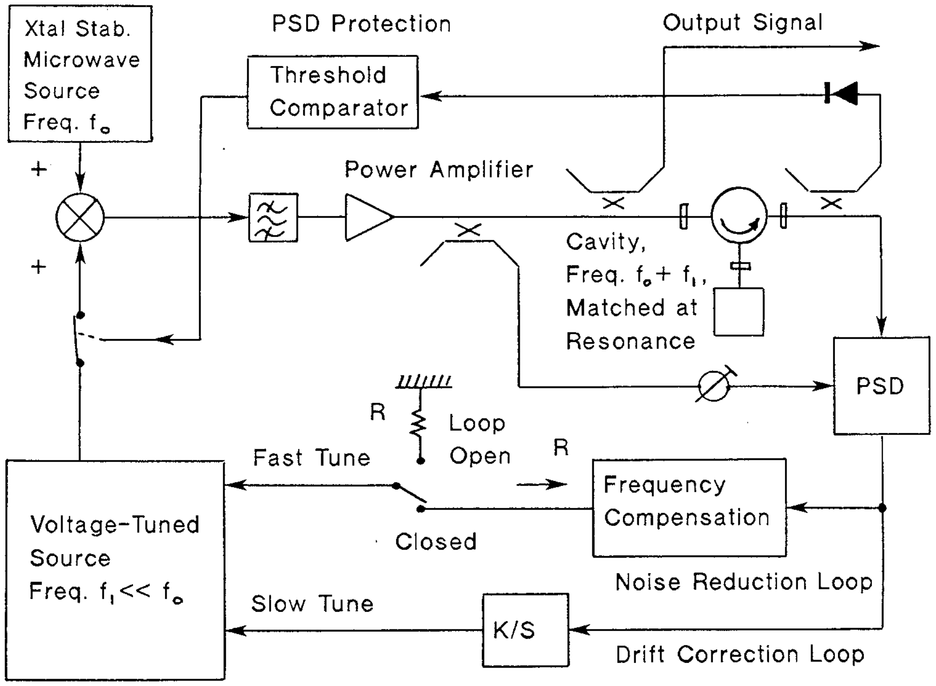
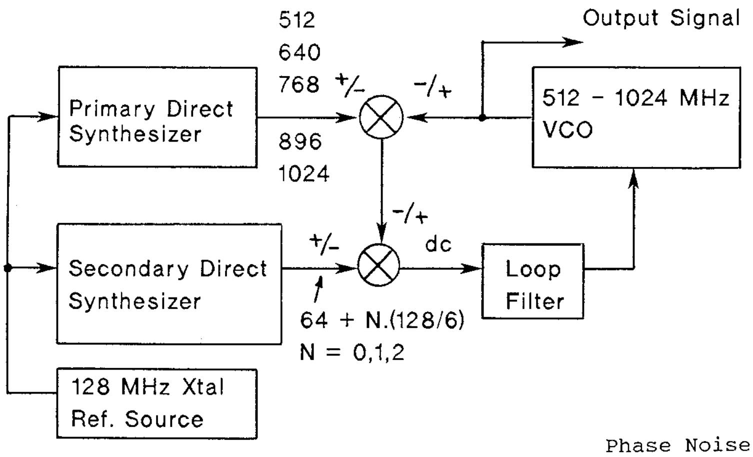
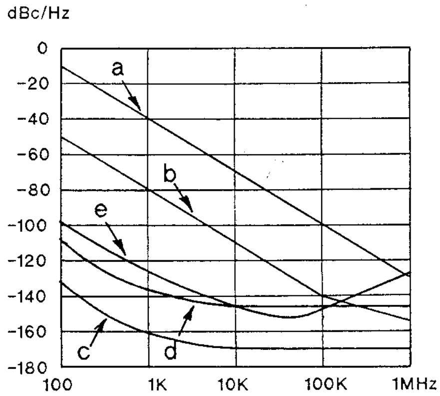


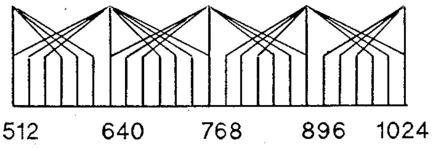
Figure 3 Block diagram of Ultra-Low Noise Microwave Reference Source





Phase Noise of:

(a) Typical X-band VCO with 500 MHz tuning range
(b) 512 - 1024 MHz VCO
(c) 128 MHz crystal reference oscillator
(d) Reference oscillator multiplied to 1024 MHz allowing 5 dB degradation relative to ideal
(e) Discriminator stabilised ultra-low noise microwave reference source



Synthesis Loop Channel Derivation

Figure 4 Block diagram of 512 - 1024 MHz Frequency Synthesizer, including channel derivation diagram and relevant phase noise plots