A MM-WAVE MINIATURIZED PHASE-LOCK SOURCE FOR LOW NOISE RECEIVER APPLICATIONS

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ABSTRACT

A mm-wave miniaturized phase-locked source has been developed using a modular concept. The mm-wave hardware is integrated into a single module, and the total phase-locked electronics is reduced to a 2 x 2 inch, 3-layer PC board using SMD (surface-mounted devices). The total phase-locked system with stable internal reference occupies less than 12 cubic inches. The system delivers 50 milliwatts at 84.1 GHz with crystal stability.

INTRODUCTION

The need for small, crystal referenced millimeter-wave sources is becoming increasingly important for integrated coherent radar, communications, and receiver system applications. This paper describes a new, miniaturized millimeter-wave phase lock source which incorporates an 80 mW W-band varactor tuned GaAs Gunn oscillator recently developed here at Hughes Aircraft Company.

The goal was to integrate the complete system into a compact volume of less than 15 cubic inches. Two different integration schemes are used, one to reduce the size of the mm-wave hardware, the other to miniaturize the phase-locked electronics. With our new, miniaturized, varactor tuned Gunn oscillator and planar harmonic mixer, the complete mm-wave hardware, which includes ouput coupler ad isolator, is integrated into a single compact module. The complete phase-lock electronics, which includes the phase detector, loop filter, and varactor drive electronics are miniaturized using surface-mounted devices (SMD) on a three layer PC board. Further size reduction was accomplished by incorporating a low frequency PLO provided by RFD., Inc., in its "ultra-min" package.

The preliminary and final system specifications areas shown in Table 1. The complete mm-wave phase-lock source is shown in Figure 1.

MM-WAVE PHASE-LOCKED SOURCE

The simplified diagram of the two loop phase-locked system is shown in Figure 2. A crystal reference oscillator is used to drive a microwave phase-locked oscillator generating 10.5 GHz output, which serves as a local oscillator for the harmonic mixer. A small portion of the Gunn output (-30 dB) is coupled to the harmonic mixer through a directional coupler and mixes with the 8th harmonic of the local oscillator. The resulting harmonic mixer IF output at 100 MHz is compared with the original crystal reference signal using a phase detector. The phase detector generates an output voltage proportional to phase difference and is applied to the input of the loop filter electronics, whose output drives the varactor terminal of a 84 GHz varactor tuned Gunn oscillator, thereby completing the loop.

Table 1. Preliminary and Final System Specifications

	Preliminary	Final
Frequency	84.1	84.1 GHz
Output	10	50 mW
Loop bandwidth	3	3 MHz
Tuning bandwidth	200	400 MHz
Spurious response	TBD	-30 dB
Warm-up time	TBD	30 S
Phase noise	TBD	-64 dBC/Hz @ 1 kHz -72 dBC/Hz @ 10 kHz -94 dBC/Hz @ 100 kHz -106 dBC/Hz @ 1 MHz
Reference input	100 MHz & 2 GHz (with external divider)	
Stability	depends on reference crystal	
Size	15	12 cu. in.

The system also provides outputs for trouble-shooting, such as a varactor voltage, 100 MHz reference monitor, 100 MHz IF monitor, and a lock alarm indicator.

PHASE-LOCKED ELECTRONICS

Figure 3 shows the details of the varactor tuned Gunn phase-locked electronics. The major elements are:

- Phase detector and IF amplifier (loop filter)
- Varactor drive electronics
- Gunn bias regulator
- Lock detector and mode switch
- Sweep generator
- Center frequency bias generator

The electronics operate in two modes: acquisition and lock. In the acquisition mode, all mode switches are

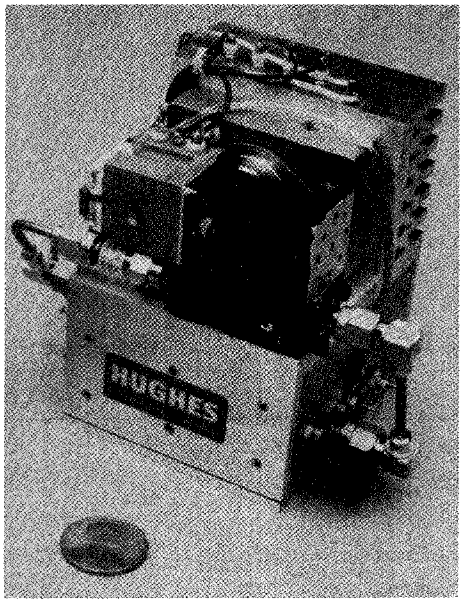


Fig. 1 An 84.1 GHz miniaturized phase-lock oscillator

closed, and the varactor tuned Gunn is swept about the VCO center frequency. When the cosine output from the phase detector has an amplitude greater than the lock threshold, the electronics are switched to the lock mode by opening all the mode switches. In the locked mode, both the sweep circuit and the center frequency bias circuit are disconnected from the error amplifier, since the sine output of phase detector supplies the DC correction signal. When in the acquisition mode, the switches are closed, and the loop amplifier is transformed into a gain of one amplifier.

MM-WAVE SOURCE MODULE

The mm-wave source module contains all the required mm-wave components for a typical locked system. It consists of a varactor tuned Gunn oscillator, a planar harmonic mixer, a directional coupler, and a 3-port terminated circulator as shown in Figure 4. The overall dimensions of the source module are .75 x 1.25 x 1.2 inches.

A varactor tuned Gunn is desirable for this application because of its low FM noise properties, and because the varactor drive electronics are simple. Our miniature varactor tuned Gunn oscillator consists of a thin metal disk, approximately half a free space wavelength in diameter, placed on top of the package Gunn diode forming a radial line resonator; the varactor diode is stacked on top of radial hat and the varactor voltage is provided through an RF choke. Each diode receives independent bias. The overall size of the miniature oscillator is .75 x .75 x .75 inches, including the heater. The VCO output power is 80 mW, with a tuning range from 83.2 to 84.6 GHz.

Using beamlead Schottky diodes on a suspended stripline, a miniature harmonic mixer was designed to meet the overall size of .75 x .5 x 1.2 inches including a TO-5, 30 dB gain amplifier. The harmonic mixer employed a balanced configuration for optimum conversion loss. Two diodes in anti-parallel are mounted on a suspended substrate stripline circuit. The sampled VCO output is fed to the diode pair by a printed circuit waveguide probe transition. The 10.5 GHz LO signal is injected through a DC block, which consists of a quarter-wave section of coupled line at the LO frequency. The IF is extracted via a band reject filter to minimize LO loading. A mm-wave spurline filter is used to prevent the LO/IF circuit loading of the RF port. Conversion loss is about 24 dB with a 10 mW LO drive using the 8th harmonic of the LO at 84 GHz.

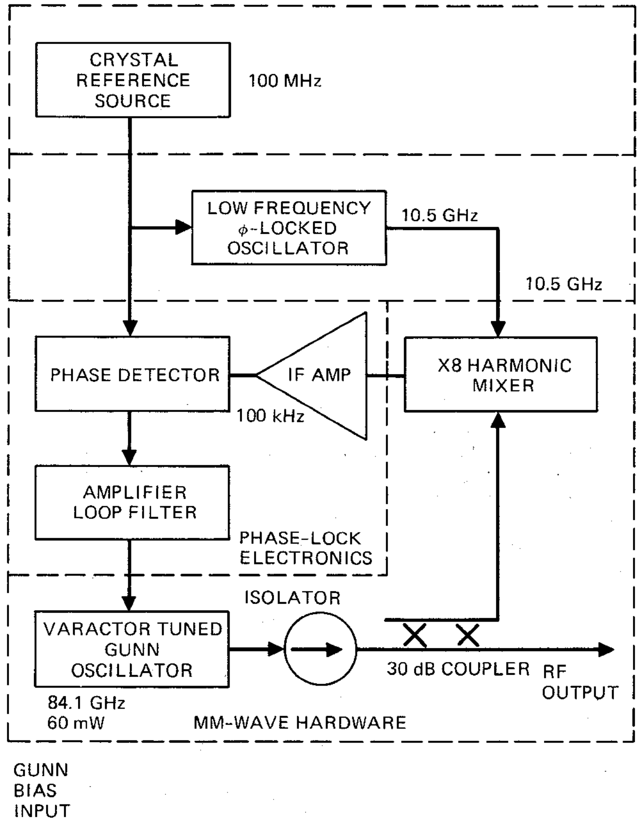


Fig. 2 Simplified diagram of an 84.1 GHz mm-wave phase-lock system

An isolator is used to provide a good match and prevent load pulling of the Gunn VCO. This is accomplished by implementing a 3-port terminated circulator integrated with the cross-guide coupler, which samples the RF to the harmonic mixer. The coupler is designed for 30 dB coupling. The combined insertion loss of the integrated isolator/coupler is 1.5 dB with 3 GHz bandwidth and greater than 20 dB of isolation.

PERFORMANCE

The frequency stability and phase noise characteristics of the mm-wave PLO depends directly on the crystal reference and 10.5 GHz microwave reference oscillators. The mmW output frequency has the same stability as the reference, and the phase noise is increased by at least 20 * log (84/10.5), which is equal to 18 dB. Using a spectrum analyzer and harmonic mixer, we measured the phase noise of the RFD microwave source and the mm-wave PLO.

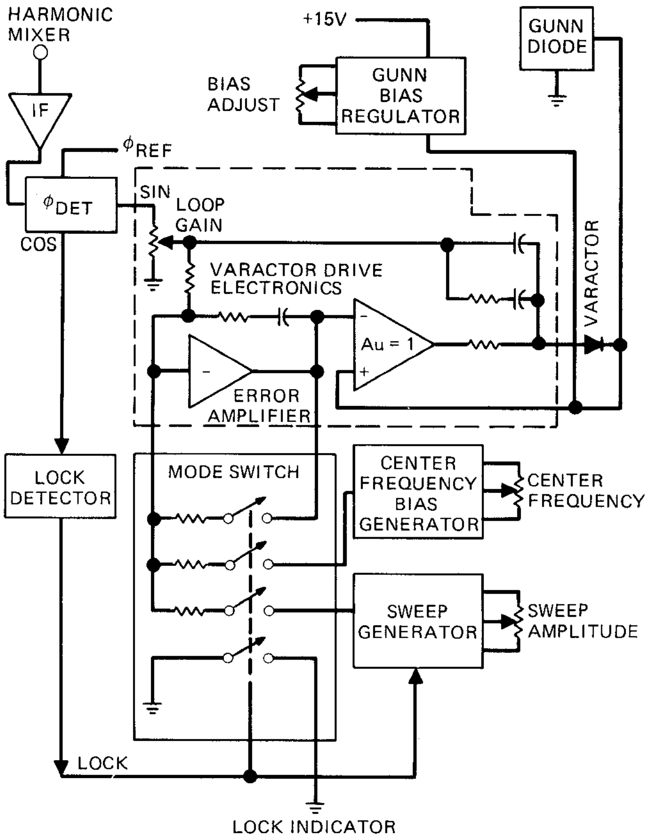


Fig. 3 Detail of Phase-lock electronics

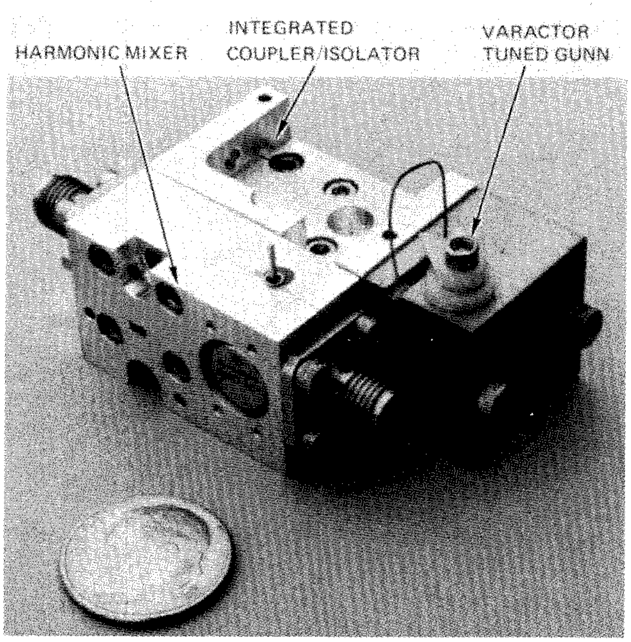


Fig. 4 MM-wave source module

The test set-up for this measurement is shown in Figure 5. The 84 GHz PLO output is downconverted using a harmonic mixer with the HP 8672 synthesizer as the LO and measured on the HP 8566B spectrum analyzer. Figures 6a and 6b show the locked and unlocked spectrum of the 84.1 GHz output. The output spectra at .001, .1, 1, and 10 MHz are shown in Figure 7a. The loop bandwidth is about 3 MHz as shown in Figure 7b.

Figure 8 shows the measured phase noise of the PLO output and the 10.5 GHz LO, and the predicted difference

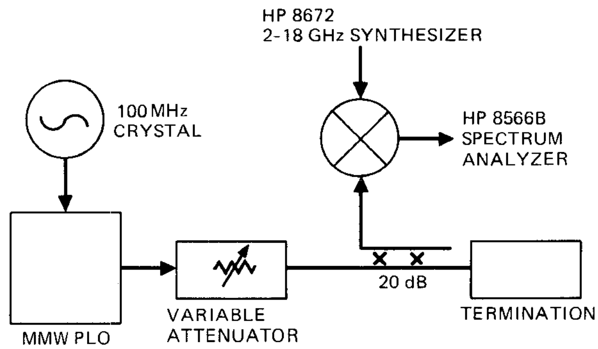
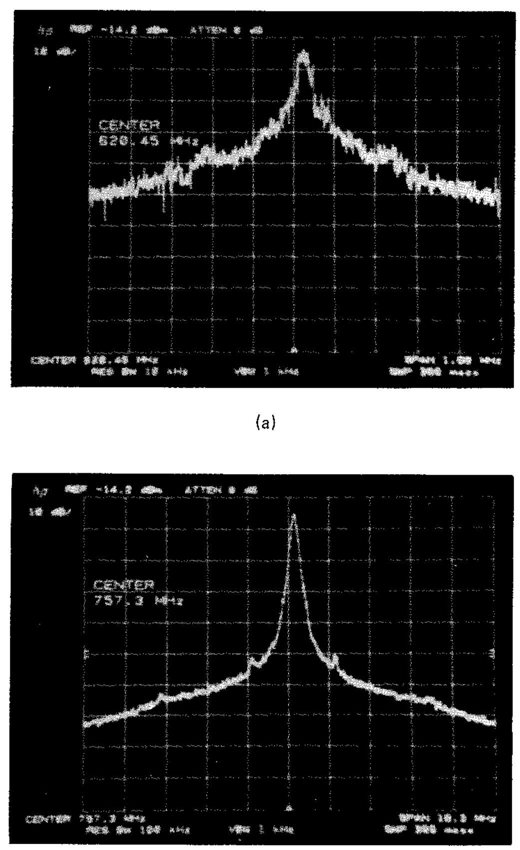


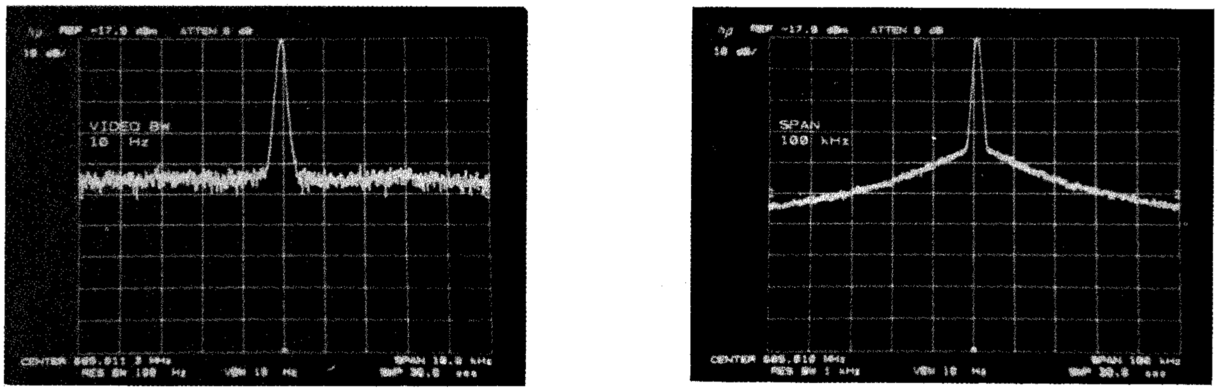
Fig. 5 Phase noise measurement test set-up



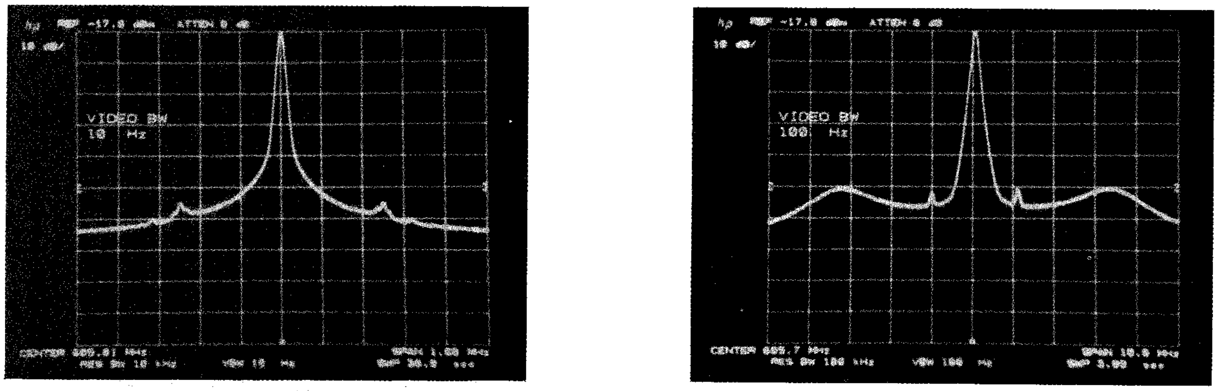
(a)

(b)

Fig. 6 Locked and unlocked spectrum of the 84.1 GHz output



(a)



(b)

Fig. 7 Output spectra of the 84.1 GHz source at different spectrum analyzer span settings

is close to 18 dB. Upon studying the data, it became evident that the phase noise of the LO, the synthesizer, and the spectrum analyzer were so close to each other that it was difficult to accurately determine the true noise. For this reason, the measured data should be considered an upper bound of the actual phase noise of the PLO.

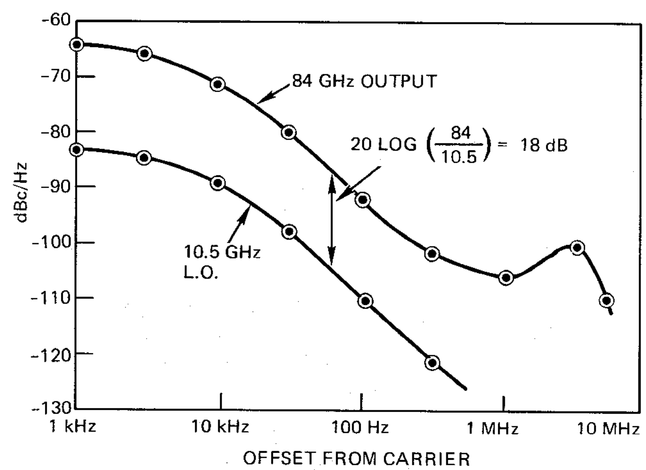


Fig. 8 Measured phase noise of the 84.1 GHz mm-wave source

CONCLUSIONS

A new, miniaturized mm-wave PLO has been described. The PLO incorporates a new varactor tuned 80 mW Gunn oscillator as the fundamental source at W-band. Miniaturization was accomplished by modular integration of millimeter-wave components using waveguide and printed circuit technology. Further size reduction was achieved by the use of a multi-layer PC board, with surface mounted components to fabricate the phase detector and loop filter electronics. The overall size of the mini-PLO is remarkable 12 cubic inches.

The PLO tracks the phase noise of the internal reference oscillator in accordance with theory, thereby substantiating its design.

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