COMPUTER CONTROLLED, PHASE-LOCKED 126-147 GHZ TRANSFERRED ELECTRON OSCILLATOR SYSTEM

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***Abstract*- A digitally controlled phased-locked 126-147GHz Transferred Electron Oscillator (TEO) system is described. This agile solid-state source is compact and easily integrated into existing RF systems. The system can be used as a bench top source for testing millimeter wave systems, or as a low noise broadband local oscillator for heterodyne receivers. The general specifications include a continuously tunable output frequency of 126-147 GHz, maximum output power of 30-50mW over the band, frequency accuracy and resolution of at least ±10 Hz when phase-locked, and a set and phase-lock time of about 60 seconds. The system can be operated in sweep mode, a fixed frequency output mode, or a programmable output-frequency mode.**

I. INTRODUCTION

The millimeter and submillimeter wave range has long been of vital interest to radio astronomers and atmospheric scientists, and is becoming increasingly important for commercial receiver, transceiver, and radar applications. Progress in the development of such systems will depend critically on the availability of reliable, low noise, and compact solid state sources. Solid state oscillators such as Transferred Electron Oscillators (TEO) have demonstrated excellent reliability, low noise, and medium power in 50-200GHz regime [1-5]. In this paper we will discuss the design, construction, and testing of a digitally controlled, phased-locked, 126-147 GHz TEO that can be used as a bench top source to develop high frequency radar and receiver systems.

II. OVERVIEW OF THE SYSTEM DESIGN

The block diagram of the system is shown in Figure 1. The interchangeable heart of this system is the Stable Depletion Layer (SDL) Transferred-Electron Device (TED) [3,5] and resonant cavity [1]. The TEO is a mechanically tuned Carlstrom style cavity [1] incorporating one mechanical back-short tuner for power and one back-short tuner for frequency. The back-shorts are positioned throughout a 40-mil range using digitally controlled micro-stepping motors. The performance of the oscillator has been manually characterized in terms of backshort positions and DC bias to optimize output power over the frequency range of 126-147GHz. This characterization provides the initial, crude source of reference for the digital controller to adjust the power and frequency back-short positions appropriately.

The digitally controlled phase-lock loop operation is straightforward and functions in two steps, coarse and fine frequency lock, respectively. During coarse tuning, the user enters the operating frequency using a convenient Labview [6] PC interface. Then both the frequency and power back-shorts are crudely set according to a look-up table. A fraction of the oscillator output signal is sampled through a -10db coupler. The sampled signal is sent to both the r.f. input of the harmonic mixer, and a fast power-detection diode. The detector diode and IF output from the mixer are used to feedback frequency and power values to the digital controller. The harmonic mixer local oscillator (LO) (8-18GHz) is provided by a phase-locked frequency-agile X-band YIG oscillator. The LO frequency is set by the PC according to the RF output frequency set point. The power back short is controlled and adjusted by the PC until peak power is measured by the fast power-detection diode. At this point, the RF output frequency is only approximately set to within about 70 MHz, and the peak power point has been achieved.

After this first frequency capture step, all back-short adjustments are set and the XL phase-lock unit is activated. Within the XL phase-lock unit, the sweep bias circuit injects a current into an integrator amplifier in a manner that sweeps the operating voltage (0.4 volts above and below the nominal operating voltage set by the bias circuit (9 volts). If the resultant IF frequency becomes equal to the 10 MHz reference frequency and the IF level is large enough, locking will occur. After the phase-lock is on, the output frequency of the TEO will be maintained at a value, which is given by the following equation (1):

$$FRF=9*FLO+FIF \text{ (GHz)} \qquad (1)$$

where FRF is the frequency of the TEO, FLO is the frequency of the YIG oscillator, and FIF is the system 10 MHz reference frequency. This reference signal is provided by an oven controlled crystal oscillator (OCXO) which is a built-in part of the XL source locking counter. The temperature stability of the OCXO is 1×10^{-8} for a temperature range of 0°C to 50°C. An external reference source can be used if needed. A source locking counter [7] is used to phase lock the YIG oscillator. The locking resolution is 1Hz and the accuracy is $\pm$1Hz. So the frequency accuracy of 126-147 GHz RF output is $\pm$9 Hz after phase-lock. After the frequency and power are set and locked, the system look-up table containing the back-short position versus frequency and power is updated. Hence the look-up table is dynamic and the system control of frequency and power is intelligent.

The Labview software of National Instruments, Inc., and the programming language G are used as control, display, and interface software. The system front panel and interface is shown in Figure 2. After the lock is on, an indicator on the front panel will light. The output frequency and power, as well as the positions of the frequency and the power backshorts are also displayed on the front to the user.

The system can also work in the sweep mode and program output mode. When working in the sweep mode, the stepper motors move to their prescribed positions according to the look up table at a given sweep speed. When working in program output mode, the system can maintain a frequency output for a given period time on any day of the year. So after you set times and dates, the system will intelligently set and change the RF output frequency over an extended period of time.

III. TESTING RESULTS

The RF output has been measured using a Tektronics 2784 spectrum analyzer with an accompanying 90-140 GHz WM782F waveguide mixer. The Tektronics system is capable of measuring signals in the 90-140 GHz band, but with limited resolution. The minimum resolution bandwidth of the Tektronics system is 300 kHz and therefore this instrument is not capable of resolving the phase-locked TEO output. None-the-less, direct measurement of the TEO output signal is possible as the system is set to different frequencies between 126-140 GHz. For this band, the TEO system was observed to set the output frequency correctly and with a resolution finer than the resolution of the Tektronics spectrum analyzer system.

In order to more carefully measure the resolution and accuracy of the TEO set point, the YIG LO input and 10 MHz IF output from the Pacific Millimeter Wave mixer were measured using an HP 8562A (9 kHz –50GHz) higher resolution spectrum analyzer. The resolution bandwidth of this spectrum analyzer is approximately 1 Hz. Figures 3a-c show the measured 14.998888889 GHz YIG LO signal to the 9th harmonic mixer, the 10.0 MHz IF signal output by the 9th harmonic mixer, and 135.0 GHz RF output spectrum after system phase lock. As shown, the resolution and accuracy of the LO and the IF are 1Hz which indicate that the RF output resolution and accuracy are better than 10 Hz.

As indicated, the resolution and accuracy of the XL microwave source locking counter is specified as 1Hz. When the RF frequency is set to 135 GHz the frequency counter indicates the LO frequency is appropriately set to 14.998888889 GHz. However, at this set point the HP8562A indicates the LO frequency is 14.998888724 GHz. We believe the XL frequency counter has greater accuracy than the HP8562A and the frequency is accurately set to within 1Hz (since the minimum resolution bandwidth of the Tektronics spectrum analyzer is 300 kHz, the bandwidth of the RF output can not be directly resolved and incorrectly appears to be about 300 kHz in Figure 3c).

IV. CONCLUSIONS AND ACKNOWLEDGMENTS

A digitally controlled, phase locked 126-147 GHz TEO source has been described. Approximately 30-50 mW of output power is available across the band and the system frequency resolution and accurately are better than 10 Hz. The system is relatively compact and includes a Labview interface for easy use and integration with other RF systems. This system can be used as bench top source for developing and testing millimeter and sub-millimeter wavelength components and systems as well as a low noise source for heterodyne receivers. The described system can be expanded to include multiple TEO outputs for situations where broader bandwidth or arrays of sources are required. For this case one controller unit is needed, but multiple TEO and phase locked YIGs are required.

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V REFERENCES

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[6] National Instruments, Austin Texas, (512) 794-0100, offers both instrumentation hardware and software. See http://www.natinst.com for more information. The system described in this paper makes use of Labview software, data acquisition boards, GPIB boards, and Nulogic motion control boards that are all offered by National Instruments.

[7] XL Microwave, Oakland California, (510) 428-9488, offers phase lock units and frequency counters for microwave systems. The system described here makes use of the XL TEO phase lock unit and the YIG source locking counter. More information regarding phase lock circuits for TEOs can be found in reference 3.

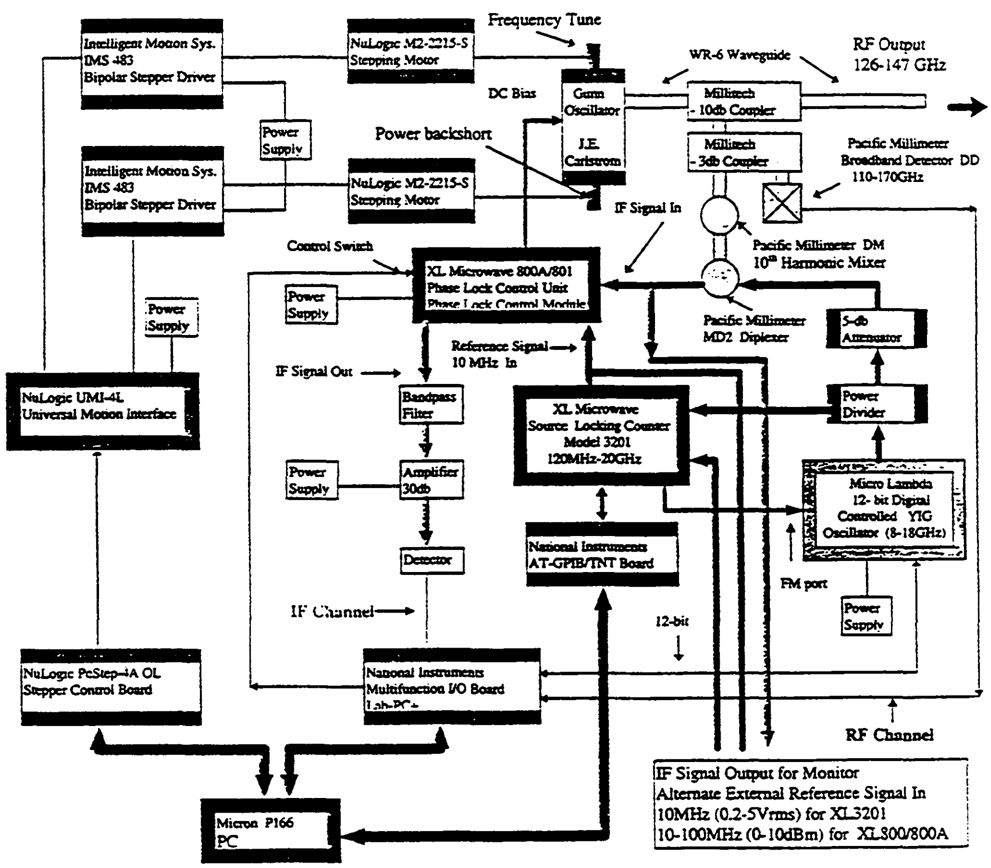

Figure 1 System schematic showing basic components used for the digitally controlled 126-147 GHz TEO.

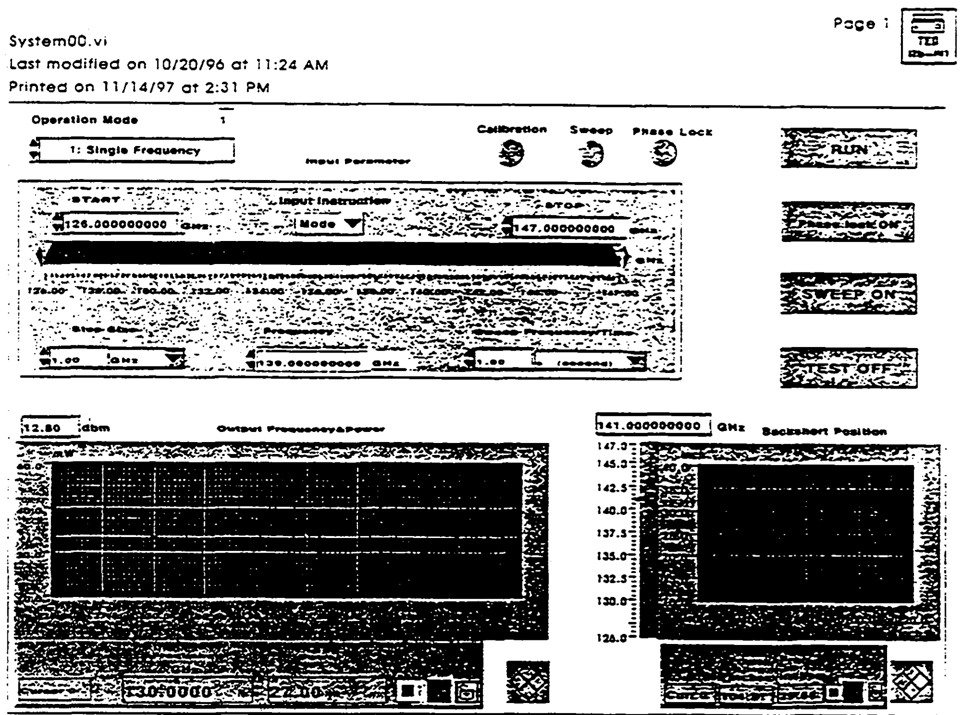

Figure 2 Diagram of the LabView front panel used by the user.

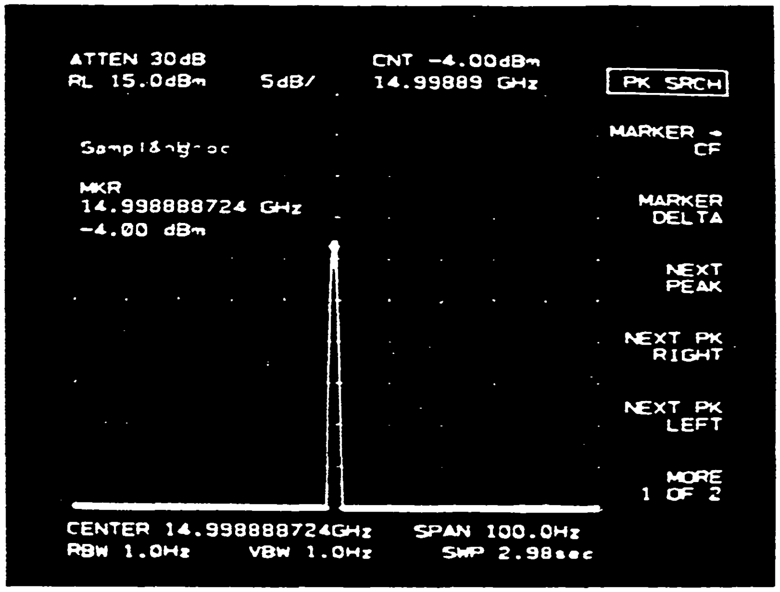

Figure 3a Output spectrum for the YIG LO that is driving the harmonic mixer used to down convert the 135 GHz RF output.

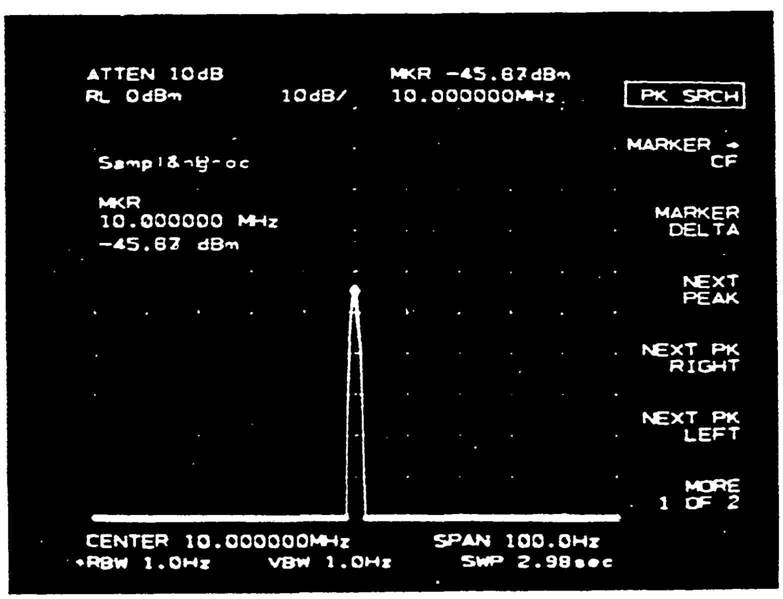

Figure 3b Output spectrum for the harmonic mixer IF down converted from the 135 GHz RF output.

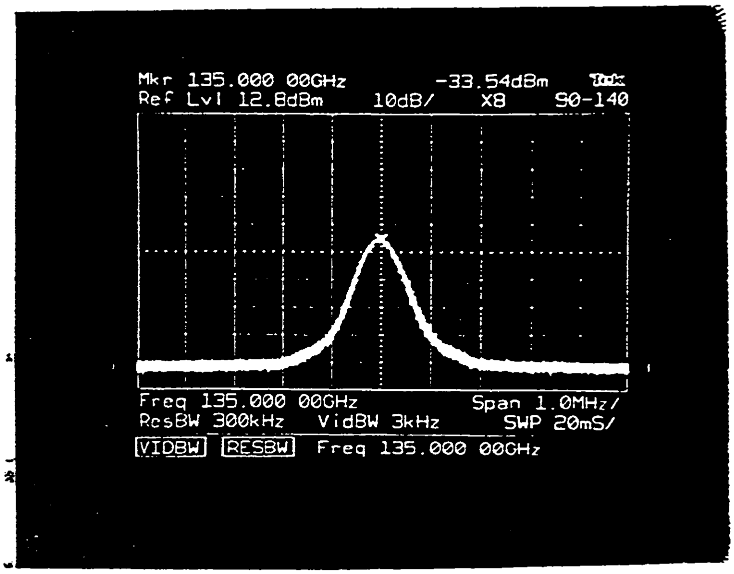

Figure 3c The output spectrum at 135 GHz is shown. The minimum resolution bandwidth of the spectrum analyzer is only 300 KHz and unable to accurately display the narrow band phase-locked TEO.