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A voltage controlled oscillator for obtaining a frequency reference constantly locked to L1 GPS carrier for power quality assessment applications

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Abstract- The need to correlate as accurately as possible Time to the power quality events pushes towards the necessity to develop circuits able to yield a time reference that is referable to International Time Standards. Moreover, the necessity to deploy distributed power quality monitoring systems requires these time references to be easy to disseminate, making them available on specific monitoring sites. In this paper, the possibility to obtain a time reference continuously traceable to a Cs133 atomic standard is proposed, by locking the Cesium-derived L1 GPS satellites carrier by means of a specifically designed GPS receiver. Such time reference would simply require visibility of one GPS satellite in order to be operative. In particular, the overall architecture of such receiver will be first outlined and then attention will be focused on the design and realization of the VCO which is one of its fundamental building blocks. Measurements carried out on a prototype of the proposed VCO show that its performances are adequate for the aim.

I. Introduction

The constant growth of electrical energy use and its inherent problems forced the scientific community before and the legislators after to be involved in Power Quality (PQ) problems. Modern life depends on electrical energy, making both Electrical System Reliability and Power Quality important topics. Although there are innumerable contributions on the subject of Power Quality, the definition of power quality parameters has not been completed by the scientific community [1,2]. There are lots of deviations from ideal waveforms that allow to evaluate the quality of energy, such as disturbances, distortions, etc. [3]. The effects of these deviations are many and each one creates economic problems which can sometimes be very expensive.

The only way to quantify these problems is to perform measurements of the PQ parameters specified in the normative, by using instruments able to measure them possibly in real time. One of the most important problems in case of civil suit is to determine as accurately as possible the time of the fault. Therefore, it would be desirable that the synchronisms of the instrument, and particularly, of the sampling, were linked to a referable time standard.

Precise time can be obtained via several methods, one of the most accurate and reliable of which is to use time derived from the Global Positioning System (GPS) [4]. The GPS is based on 24 satellites located in six orbital planes at a height of 20200 km which orbit the Earth approximately every 12 h. At any time and any location on the earth, a GPS receiver should have a direct line of sight and be receiving signals from 4 to 11 satellites. Each GPS satellite sends the Coordinated Universal Time (UTC) in which the zero is fixed as midnight on the night of January 5/morning of January 6 of 1980, and the GPS time scale is maintained to be within one μs of UTC (module of one second). Navigation data is transmitted using a spread spectrum code division multiple access (CDMA) technique that makes GPS a spread-spectrum system. All 24 satellites transmit on the same frequencies and interference between signals of different satellites is avoided using pseudorandom signals with low cross-correlation for the CDMA modulation. Two services are provided by GPS: a precise positioning service (P-code) whose use is restricted to military applications, and standard positioning service (coarse acquisition, C/A-code), less precise than the P-code but available to everyone. All satellites use two frequencies: L1 is the primary frequency and carries both the C/A and P code with a QPSK modulation, and L2 is the secondary frequency and carries the P code only with BPSK modulation. The two frequencies are derived from a 10.23 MHz frequency reference generated by an atomic Cs133 time standard mounted on each satellite. The frequency of L1 is 1575.42 MHz (154 times the atomic clock) and that of L2 is 1227.6 MHz (120 times the atomic clock). Internationally recognized traceability of GPS to national UTC clocks is provided.

Embedded GPS timing devices offer a high performance, reduced cost, quick time to market for system designers. GPS delivers timing accuracy of better than 100 nanoseconds and frequency references with short term accuracy of about 1 part in 10^{12}. In addition to high performance, GPS offers worldwide, 24 hours availability essential for mission critical applications. The products that use GPS timing acquire time from the GPS satellite constellation and provide the host system with GPS timing via a 1-pulse-per-second (1 PPS) output, a programmable time comparison strobe output, and frequency via a 10 MHz reference signal. The 10 MHz output from a high stability crystal oscillator is steered to match the 1 PPS derived from GPS. In fact, the 1 PPS and time comparison strobe are cycle-locked to the 10 MHz, an important design consideration as shown in Figure 1.

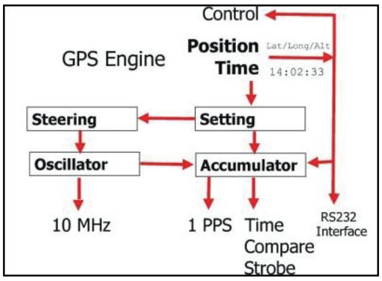


Figure 1. Architecture of a GPS embedded timing system

Although the accuracy of these devices is very high, the local clock is locked to the GPS time standard only one time every second. Therefore, continuous traceability to the Cs133 atomic standard is not ensured.
One possibility to obtain a time reference continuously traceable to a Cs133 atomic standard is to lock the Cesium-derived L1 GPS satellites carrier by means of a specifically designed GPS receiver. In this paper, the overall architecture of such receiver will be first outlined and then attention will be focused on the design and realization of the VCO which is one of its fundamental building blocks.

II. Proposed GPS receiver architecture

In order to track the L1 GPS signal, the C/A code information, used to spread the L1 carrier with a rate of 1.023 Mchip/s, must be removed. As a result, it requires two phase-locked loops to track the L1 GPS signal, as shown in the left part of Figure 2. One loop is to track the C/A code and the other one is to track the carrier frequency [4,5]. After removal of the C/A code (de-spreading) the L1 carrier is BPSK modulated by the 50 bit/s navigation data. Because of phase transitions caused on the carrier by BPSK modulation, a conventional PLL design is usually replaced by the well-known Costas loop [5,6]. As an example, the Costas loop used to track the L1 carrier is shown in the right part of Figure 2. The loop gets as inputs the L1 signal coming from the front-end and the C/A code coming from the C/A code tracking loop. The de-spreading blocks are used to remove the C/A code BPSK modulation, leaving only navigation data modulation. The low-pass filters (LPF), with a cut-off frequency of about 100 Hz, are used to limit the noise level. The loop filter is chosen so as to give the loop an equivalent noise bandwidth of approximately 20 Hz, small enough to ensure a good tracking of the carrier even in the presence of very low SNR on the incoming L1 signal.

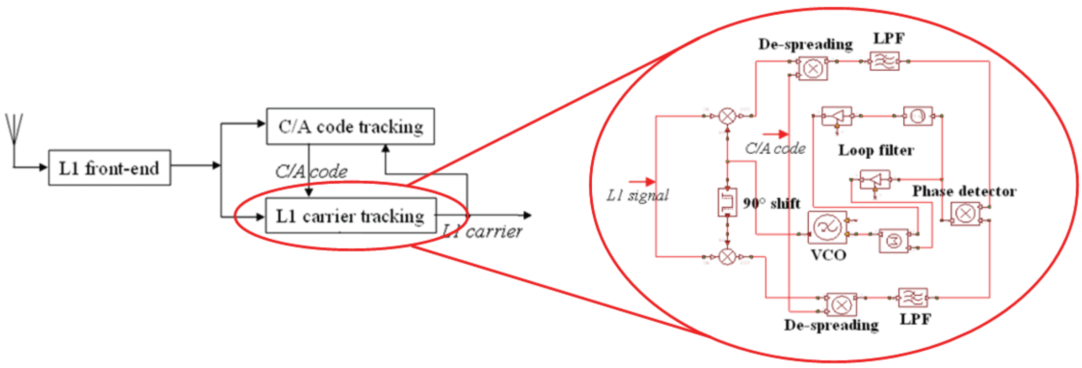


Figure 2. Proposed GPS receiver architecture

III. The voltage controlled oscillator (VCO)

The L1 carrier tracking loop requires the use of a VCO able to tune its frequency in a narrow range around the nominal central frequency of 1575.42 MHz with an output power of the order of 10 dBm, which is the level usually required by mixers. Therefore, rather than adopting commercially available VCOs which cover much larger bandwidth than required, a specifically tailored VCO has been designed and realized. The proposed VCO has been designed by using AWR Microwave Office™ CAD tool on the basis of the approach suggested in [7]. The ideal schematic of the oscillator is presented in Figure 3. The resonant element of the oscillator is a ceramic resonator and a varactor is used to tune the frequency.

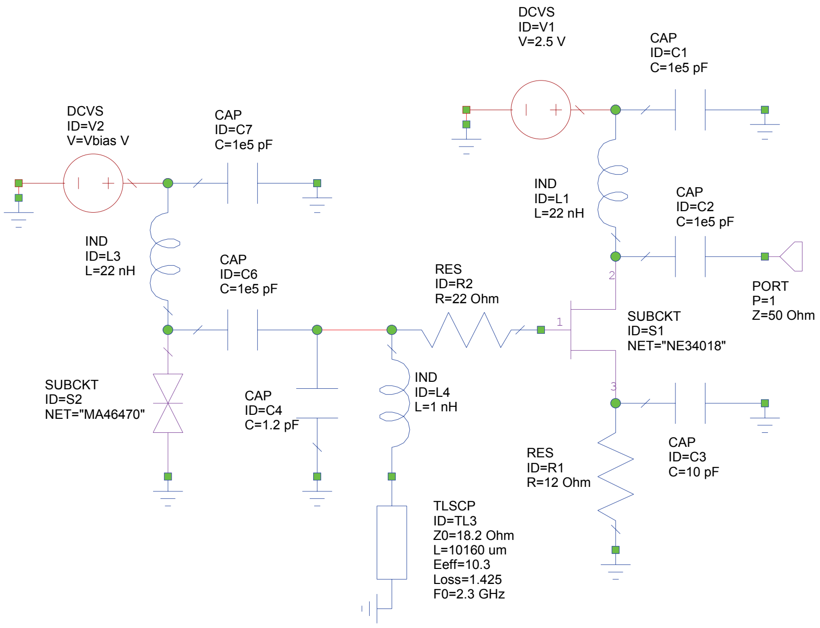
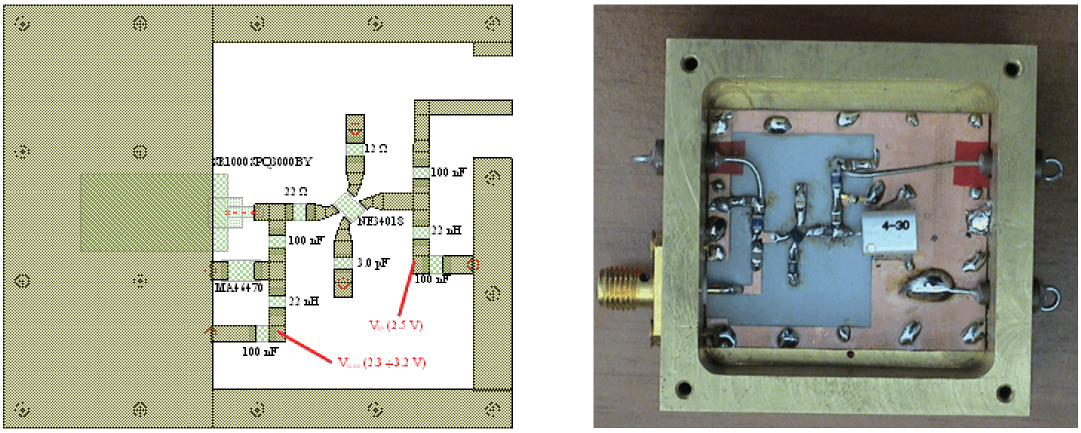


Figure 3. Proposed VCO schematic

First the NE34018 FET, with an output power of more than 10 dBm at P_{1dB}, has been chosen to guarantee the specified output power. The active device has been connected in common source configuration and self-biased in saturation region. Then, a feedback capacitance has been added in order to maximize, around 1.575 GHz, the reflection-coefficient module at the transistor gate. The resulting capacitive reactance on the transistor gate has been compensated by the coaxial resonator (SR1000SPQ3000BY quarter-wave coaxial resonator from Trans-Tech) operating in its inductive region. A varactor (MA46470 from Macom), together with a shunt capacitor, has been added in parallel to the resonator in order to tune the frequency in the desired range. Finally, a series resistance has been added on the transistor gate in order to limit the oscillation amplitude thus reducing harmonic distortion. During the design of the layout, the value of the feedback capacitance has been optimized in order to compensate for parasitic effects and, for the same reason, the shunt capacitor of the varactor has been eliminated. The final layout and a picture of the realized circuit are shown in Figure 4.
The realized prototype has been first characterized in terms of voltage tuning curve, measuring the tuning voltage with a Fluke 8840A digital multimeter (uncertainty: 0.006 % of reading + 3 digits) and the output frequency by means of a EIP 548B microwave counter (relative uncertainty: $1 \cdot 10^{-6}$). The obtained tuning curve is reported in Figure 5, showing a sensitivity of about 20 MHz/V. Then, a frequency domain characterization of the VCO has been carried out with the aid of an Anritsu MS8608 spectrum analyzer. As an example, the measured harmonic distortion is reported in Figure 6, showing that higher harmonics are at least 20 dB below the fundamental frequency.



(a) (b)

Figure 4. Layout (a) and physical prototype (b) of the proposed VCO

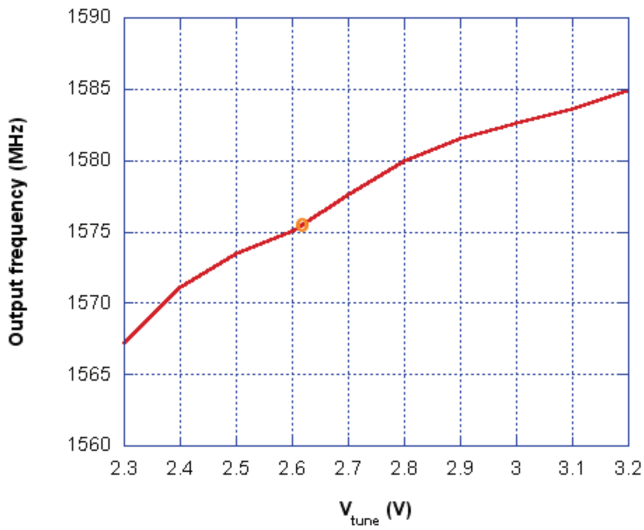


Figure 5. Measured tuning curve of the proposed VCO

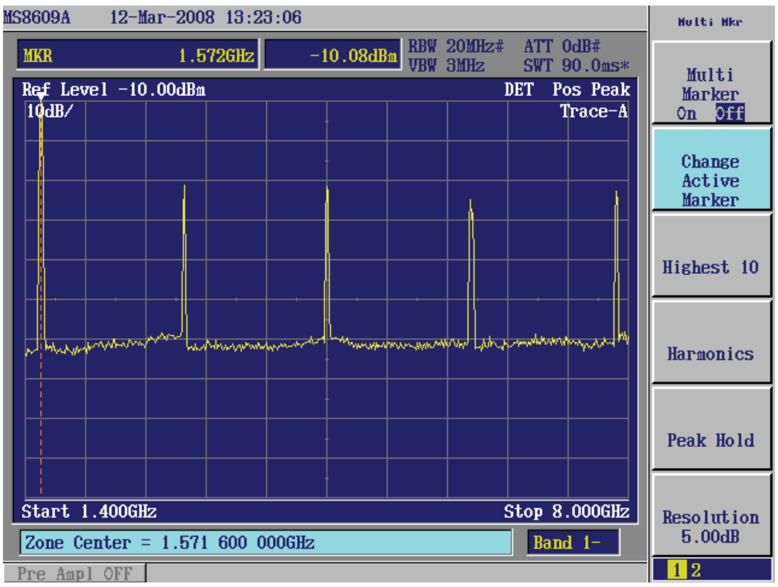


Figure 6. Measured harmonic distortion of the proposed VCO

IV. Conclusions

A VCO to be used inside a receiver for locking the L1 GPS carrier has been designed and implemented. The VCO is the first building block of the whole receiver, that will be adopted to obtain a frequency reference constantly locked to the Cesium-derived L1 GPS satellites carrier.

This frequency reference will be essential inside a monitoring system for real time distributed power quality measurements. Indeed, one of the most important problems in case of civil suit is to determine as accurately as possible the time of possible faults in the power system.

Measurements carried out on a prototype of the proposed VCO show that its performances are definitely adequate for the aim.

The next step in the realization of the GPS receiver will be the design and prototyping of the whole carrier tracking phased-lock loop.

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