VE6HQ ADF_4351 Signal Generator

I rejoined the active amateur radio community after nearly a 50 years absence. In the late 1970's operating as VE6RI, I had conducted a series of exciting 432 mHz experiments using over the horizon tropospheric scatter propagation between Edmonton and Calgary.

Part of the process of building a modern VHF / UHF / SHF amateur radio shack was the acquisition or construction of RF test equipment to validate this new radio gear. It became apparent that a RF signal generator would be a valuable piece of test equipment.

I found many low cost (less than $100 CDN) RF signal generator boards that were based on the Analog Devices 4351 chipset available through online sources. ADF4351 features include:

- Output frequency range: 35 MHz to 4400 MHz
- Fractional-N synthesizer and integer-N synthesizer
- Power supply: 3.0 V to 3.6 V
- Logic compatibility: 1.8 V
- Programmable output power level
- 3-wire serial interface
- Analog and digital lock detect
- Cycle slip reduction

The ADF4351 allows implementation of fractional-N or integer-N phase-locked loop (PLL) frequency synthesizers when used with an external loop filter and external reference frequency. The ADF4351 has an integrated voltage-controlled oscillator (VCO) with a fundamental output frequency ranging from 2200 MHz to 4400 MHz. In addition, divide-by-1/-2/-4/-8/-16/-32/-64 circuits allow the user to generate RF output frequencies as low as 35 MHz.

A functional block diagram of the ADF4351 is shown as Figure 1.

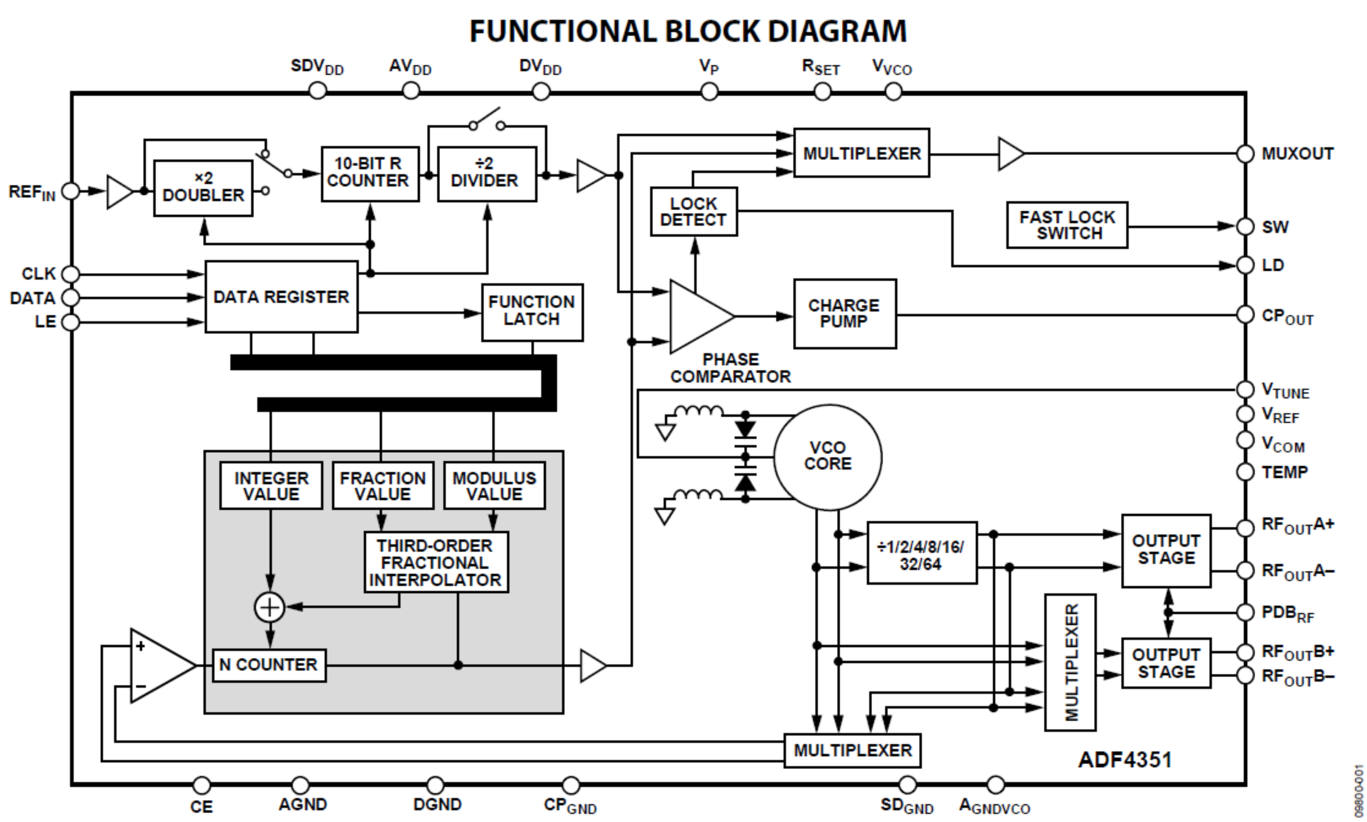


Figure 1 ADF4351 Functional Block Diagram

Construction was not complicated and required the ADF4351 board, a die cast aluminum case, SMA to BNC bulkhead connectors and a DC power bulkhead connector.

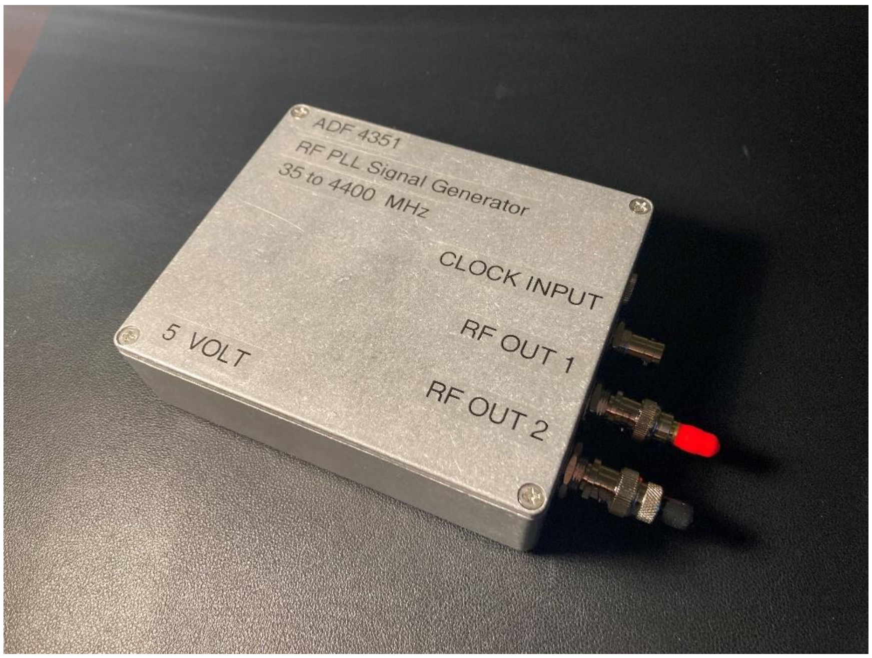


Figure 2 ADF4351 RF Signal Generator Exterior View

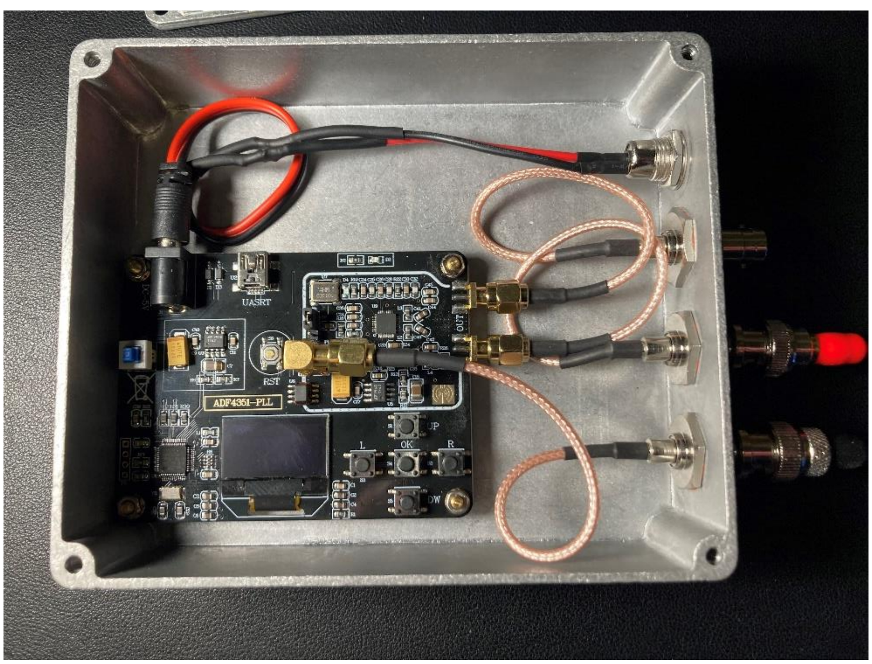


Figure 3 ADF4351 RF Signal Generator Interior View

The project was not complicated and all parts were easily acquired from the usual online sources. Noteworthy is the external 5-volt power source.

I have chosen to use a linear power and not the common switching power supplies that are prevalent today. I have found many switching-based power supplies extremely high RF noise generators and it is likely that this noise would be directly coupled into the ADF4351 RF PLL circuity. In addition, I would suggest elimination of RF noise source is an improved solution rather than attempting to suppress it though the addition of RF chokes and ferrite beads.

Visual inspection of Figure 3 shows a crystal oscillator located at the center – top of the AD4351 board. This crystal-controlled oscillator provides a frequency reference standard for operation of the phase locked loop (PLL) RF signal generator. In addition, an external frequency reference standard may be used trough selection of a jumper pin setting on the board and external signal applied to SMA connector located at the center location of the device.

My objective after completing construction of the RF signal generator was to evaluate device frequency accuracy and frequency stability.

A brief discussion of crystal-controlled oscillators and frequency stability is appropriate.

It is known that a crystal oscillator frequency stability is affected by:

Temperature	Mechanical stress
Aging effects	Drive level
Mechanical loading	Damage & shock

Temperature effects are in general the most significant short-term factor for frequency stability of a quartz crystal frequency-controlled oscillator. Introduction of TCXO and OCXO technology as summarized below has greatly improved frequency stability.

Quartz Crystals & Clock Oscillators (XO)

- *Typical aging rate: ±1 ppm/year to ±5 ppm/year*
- *Typical calibration tolerance: For an AT crystal, it would be ±10 ppm*
- *Typical Frequency Adjustment Range: ±10 ppm to ±20 ppm*

Temperature Controlled Crystal Oscillators (TCXO)

- *Typical Temperature Stability: ±0.20 ppm to ±2.0 ppm*
- *Typical aging rate: ±0.50 ppm/year to ±2 ppm/year*

Oven Controlled Crystal Oscillators (OCXO)

- *Typical Temperature Stability: ±1 x 10-7 to ±1 x 10-9*
- *Typical aging rate: ±2 x 10-7/year to ±2 x 10-8/year*

To measure RF signal generator frequency accuracy and stability a reference system / standard is required. In testing the ADF4351, I selected a GPS disciplined oscillator (GPSDO) controlled SDR radio. A GPSDO works by disciplining, or steering a high-quality quartz or rubidium oscillator by locking the output to a GPS signal via a tracking loop. The disciplining mechanism works in a similar way to a phase-locked loop (PLL), but in most GPSDOs the loop filter is replaced with a microcontroller that uses software to compensate for not only the phase and frequency changes of the local oscillator, but also for the "learned" effects of aging, temperature, and other environmental parameters. A GPSDO aims to utilize the best of both frequency sources, combining the short-term stability performance of the oscillator with the long-term stability of the GPS signals to give a reference source with excellent overall frequency stability characteristics

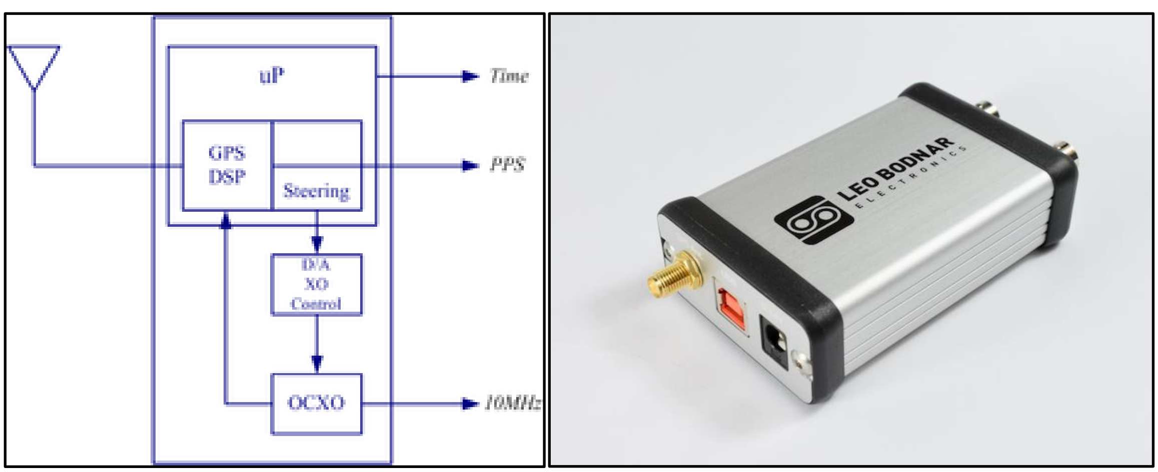
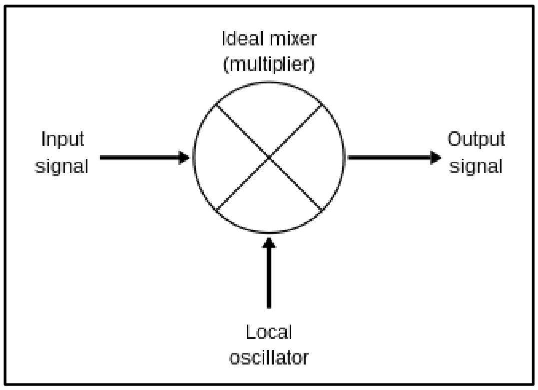


Figure 4 Leo Bodnar GPSDO used as a Frequency Standard

The heterodyne frequency measurement technique was used to determine frequency and stability of the ADF4351 RF signal generator. A heterodyne is a signal frequency that is created by combining or mixing two other frequencies using a signal processing technique called *heterodyning*, which was invented by Canadian inventor-engineer Reginald Fessenden.



The input signal from the device under test (DUT) is mixed with the local oscillator, in this case a GPSDO controlled source and the output signal frequency measured. Computer controlled output signal acquisition and processing using the Spectrum Lab software, developed by Wolf Buescher (DL4YHF).

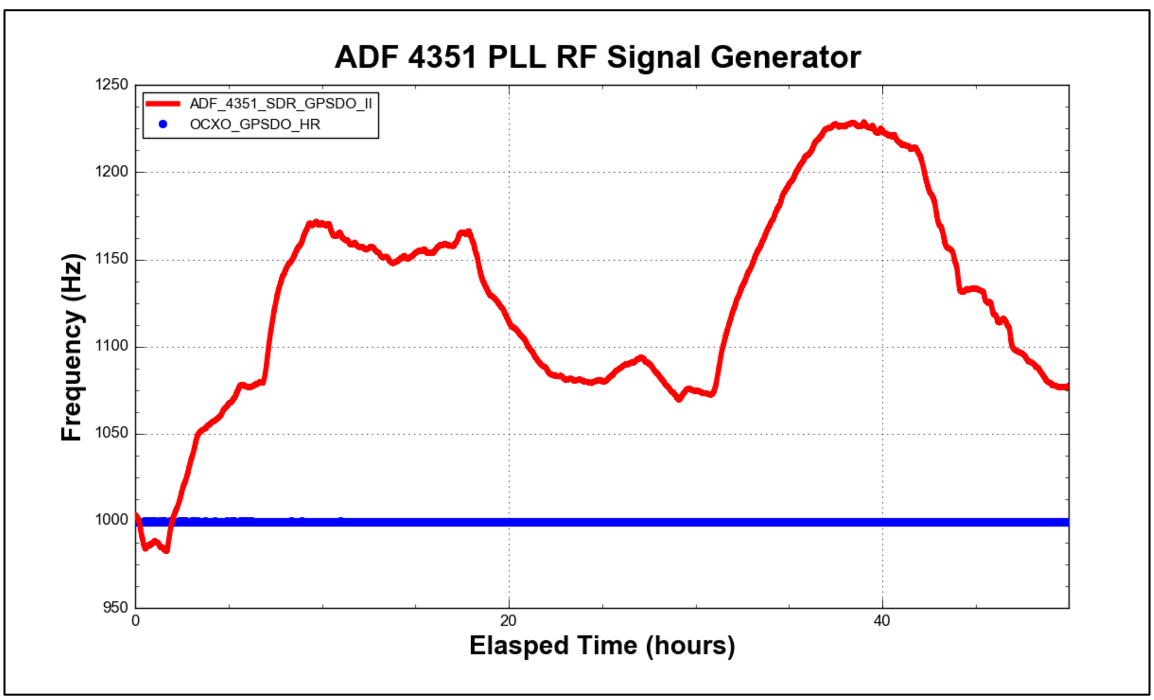


Figure 5 Frequency versus Time

Figure 5 illustrates data obtained through heterodyne frequency measurement technique. Fifty (50) hours of data with data sample period of 10 seconds (180,000 data values) was conducted. The Red coded data curve within Figure 5 is frequency variation / stability data obtained form the ADF4351 using its internal crystal-controlled reference source. A maximum frequency variation of 225 Hz was measured, with the ADF4351 set to an output frequency of 432.1 MHz. This indicates a frequency stability of ~ 0.5 ppm, which may be viewed as acceptable given the cost of the device.

However, my objective was to improve both accuracy and stability of the ADF4351 by using an external frequency reference source. I selected an available OCXO (~ $100 CDN) and repeated heterodyne frequency measurement experiment. The Blue coded data curve within Figure 5 is frequency variation for the OCXO. As shown within Figure 5, the external OCXO oscillator shows remarkably improved frequency stability compared to the internal "onboard" ADF4351 crystal oscillator.

I decided to conduct additional mathematical analysis of the frequency – time data that was collected from these two sets of experiments using the Allan variance function.

The Allan variance (AVAR), also known as two-sample variance, is a measure of frequency stability in clocks, oscillators and amplifiers. The Allan deviation (ADEV), also known as sigma-tau, is the square root of the Allan variance. The Allan variance is intended to estimate stability due to noise processes and not that of systematic errors or imperfections such as frequency drift or temperature effects. The Allan variance and Allan deviation describe frequency stability. An Allan plot of both data set is shown as Figure 6.

Figure 6 Allan Analysis ADF4351 and OCXO

Summary and Conclusions

- The ADF4351 based PLL RF signal generator is a low-cost wide frequency signal source for VHF / UHF / SHF signal source generation.

- Many different boards are available, including versions that may be software controlled with sweep frequency generation also practical.

- The addition of an external reference oscillator may be considered a valuable improvement of frequency accuracy and stability of this device.

- Extensive information and software are available on the internet to enhance and optimize this device for your specific requirements.

- It’s a fun and inexpensive project that you can construct with minimal tools and equipment.

About the Author

Don has pursued a lifelong interest in science and engineering beginning as a youth in western Canada. He received his first amateur radio license at the age of 15 while attending high school in Edmonton, Alberta, Canada.

Don continued this interest and graduated from the University of Alberta receiving a Bachelor Science in Electrical Engineering. During the last 41 years he has worked in the Energy Exploration industry in Canada, the United States, Europe, South America, the Middle East and the Far East.

His technical area of interest lead to publications of nuclear magnetic resonance applied to reservoir characterization. He was granted numerous US patents for developments of wireline pressure core technology. Don Westacott strongly considers training and technology transfer as an important part of his role within the E&P industry. Don accepted a role as guest lecturer at the Colorado School of Mines providing instruction to a new generation of petroleum engineering students. Don was honored to be the Distinguish Speaker at the Harvard University Energy Panel Arab Conference. During 2020, Don received the prestigious Hart Energy Innovators Award.

I was first amateur radio license was in 1967 as VE6ANW, a year later achieved the advanced certification as VE6RI. I initially pursued 20-meter DX working using the Drake R4B / T4XB / L4B equipment and a 3 element Yagi/Uda antenna at 70 feet. Soon after, I became interested in weak signal UHF propagation. Constructing of a "home brew" 70 cm radio system complete with 4CX250 linear amplifier based upon a novel resonant coaxial cavity design was completed. Three hundred (300) kilometer daily communications using over the horizon tropospheric scatter was achieved between his Edmonton QTH and VE6JX located in Calgary, Alberta.

After more than 50 years have passed, I have rejoined the amateur radio ranks and currently active on 20 meters and VHF / UHF bands. I was granted the KI5KGX call as an extra class USA amateur operator. Subsequently, we moved to Canada and I reinstated by Canadian amateur radio certificate and requested my current call VE6HQ.

Don and his wife Marilyn enjoy the success of their sons Matthew and Andrew.