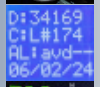
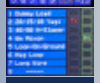
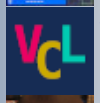
Tech Talk
Parlons Techno


10 GHz Transverter System and Dish

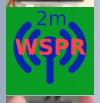

GPS-Derived Frequency Standard (Modernized)


Modern HyGain Rotator Controller

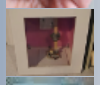

Smarter Remote Antenna Switch Control Box


VHF and Microwave Contest Logger Software


Stable Ultimate3S 2m WSPR Beacon


VE2ZAZ/B 144 MHz WSPR Beacon


Si5351 Synthesizer Board


Electronically-Disciplined Mechanical Pendulum


QEX's GPS-Derived Frequency Standard


Smart Thermostat with Raspberry Pi


QST's "At Last!" TR Sequencer


QEX's Rechargeable Battery Cycler


My Custom GPS Clock


WorkedGrids Ham Grid Square Mapping Software


WorkedFields Ham Field Square Mapping Software


Bluetooth headset with PTT for amateur radio


A CW Sidetone Bypass for the NESCAF Audio Filter


Test Instrument Contro Tidbits


HP 3586 A/B/C SLM: Stability & Accuracy Improvement Mod

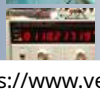

AM-6155 Amplifier Conversion to 432 MHz


TS-2000X 1.2GHz Tx Distortion Problem and Fix


Combined 2m Low-Pass and 70cm Notch Filter


Combined 70cm High-Pass and 2m Notch Filter

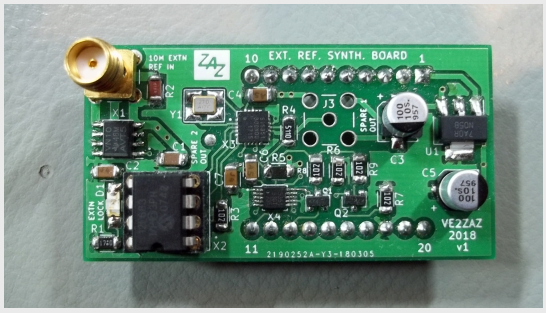

My Arrow-Style Satellite Antenna


12GHz Prescaler for HP 5328A Counter

A Stable 2m WSPR Transmit Beacon

By: Bertrand Zauhar, VE2ZAZ

Last updated: 21/11/2019



On this page, I describe my implementation of a frequency-stable 1-Watt 144 MHz (2m band) WSPR Transmitter (Beacon) based on **QRP Labs' Ultimate3S QRSS/WSPR kit**. Using the Ultimate3S for 2m WSPR is not possible unless a new approach is taken to guarantee the frequency stability required in WSPR transmission. What follows is a detailed description of what I did to make it operational, including the design data, and the final solution so that one can replicate the setup.

BACKGROUND

I was handed an assembled and functional Ultimate3S, with the objective of making it a 144 MHz WSPR beacon. A local amateur radio operator had previously tried to achieve this, but passed away before he could implement a solution. The Ultimate3S is a multi-mode self-contained HF QRP transmitter. It does a good job of transmitting WSPR data for propagation analysis. And the transmit frequency range includes the VHF 2m band, as long as proper output low pass filtering is implemented, obviously.

Here are some important characteristics of a WSPR signal:

- Modulation is continuous phase 4-FSK, with 1.4648 Hz tone separation.
- Occupied bandwidth is about 6 Hz.
- Duration of transmission is 110.6 seconds.

These impose very stringent stability requirements! The main challenge with using Ultimate3S is that its 27.000 MHz frequency reference is not stable enough to meet these requirements when running on 144 MHz. One must understand that the its 27 MHz frequency reference is "multiplied" by the Si5351 clock chip so that its output can reach 144 MHz. A reference instability that is acceptable on HF WSPR may become excessive on a VHF 2m WSPR signal. QRP Labs distribute an optional 27 MHz **OCXO frequency reference**, which I have evaluated. Unfortunately, its stability is still not sufficient to meet WSPR stability requirements on 144 MHz, as it made the frequency drift by more than one Hertz during a transmission cycle, mainly due to internal temperature variations.

Consequently, I had to design my own 27.000 MHz frequency reference to be plug-in compatible with the existing OCXO design. That frequency, despite being rounded, is not a "standard" frequency on the market, and it is next to impossible to find an stabilized oscillator at that frequency. But 10.0000 MHz is a common standard frequency, and stable ovenized oscillators are readily available.

The Silicon Laboratories Si5351 chip is a wonderful little beast for amateur radio. It is used everywhere in VFO and transmitter designs. Why not use an SI5351 as a frequency translator? 10.0000 MHz in, 27.0000 MHz out. Easy! But it has to be the C version of the chip, which has an external frequency reference input that can accept the 10 MHz reference. Some have used the A version (easier to solder leaded package) and brute-force 10 MHz into its 27 MHz crystal input. I do not like that solution, as it does not meet the chip's specs. The only real drawback of the SI5351C is that it is a lead-less, 4x4mm size QFN-20 package. Difficult to solder, but not impossible with a hot air rework station.

To understand the proposed solution, the reader should become knowledgeable of Si5351 chip features, possibilities and limitations. This web page assumes so, and does not expand on those.

DESCRIPTION

The best way to understand what the frequency reference translator board offers is by first consulting the Circuit Schematic of the board below (click on image to enlarge):

My 3.2m EME dish Project

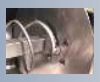
Amsat's Satellite L-Band Tx Converter with UHF Input

Atténuateur UHF 40W et Charge Fictive
UHF 40W Attenuator and Dummy Load

Basic RF Voltmeter for 1MHz - 1GHz

Parabolique 2.4GHz
2.4GHz Offset Dish

Hélicoïdale 435MHz
435MHz Helix



Hélicoïdale 2.4GHz
2.4GHz Helix

Source RF 2.4GHz
2.4GHz RF Source

Émetteur SuperQRP
SuperQRP Xmitter

RF Sensing Alarm

Resistor Finder for Windows

Tables Électroniques
Electronics Tables

Les Trucs de ZAZ

Mes Présentations Techniques
My Technical Presentations

Au sujet de VE2ZAZ
More about VE2ZAZ

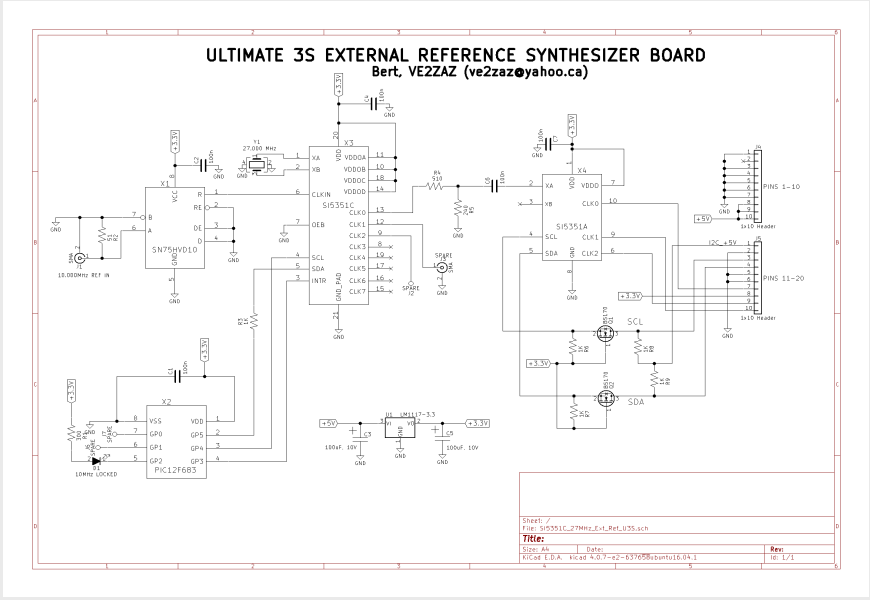
Je Me Présente...
I Present Myself...

My EME setup and Activity log

Ma Carte QSL
My QSL Card

Mon QSO Avec MIR
My QSO with MIR

Pour Me Joindre...
To Reach Me...



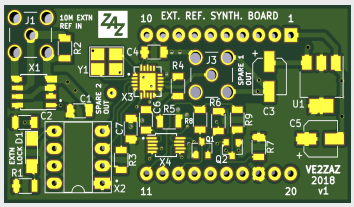
The circuit is rather straightforward. The main features of this printed circuit board are:

- Uses a 20-pin Si5351C chip (QFN-20 lead-less package), with the benefit of external reference (for example, 10MHz) support through an input SMA connector.
- Provides an external reference input scaling/shaping circuit based on the SN75HVD10 RS-485 bus transceiver, ensuring proper reference amplitude to the Si5351C, regardless of the shape or amplitude of the input signal.
- Has a 27 MHz crystal for situations where there is no 10 MHz external reference available (this crystal does not meet WSPR stability requirements on 144 MHz).
- Uses an 8-pin Microchip PIC12F683 micro-controller to configure and monitor the Si5351C chip via I^2C protocol emulation.
- Has an LED that shows external reference presence.
- Runs off the Ultimate3S +5V Supply.
- Has built-in +3.3V regulation to supply the entire circuit.
- Designed to be a plug-in replacement, and functionally equivalent to the Si5351A Synthesizer module kit or the optional 27 MHz OCXO frequency reference kit.
    - Includes an Si5351A chip, with its I^2C level translation transistors. This chip is the main clock source for the Ultimate3S, and its ATmega328 firmware controls it.
    - Has the exact same pin-out.
    - Has the same physical outline.

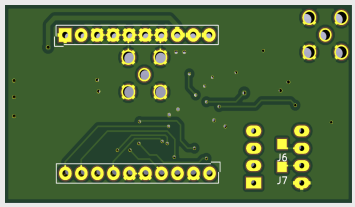
A side-by-side view of the QRP-Labs 27 MHz OCXO frequency reference (left),
and the VE2ZAZ Frequency Translator board (right). Both top and bottom sides are shown.

PCB

The Frequency Translator Printed Circuit Board is a double-sided design with plated-through holes, solder resist and silkscreen (marking). I provide the gerber and drill files for anyone who would like to replicate it. Such PCB can be ordered for around 20$ per lot of 10 PCBs. Simply provide the gerber files and the drill file to the manufacturer. I ordered from JLCPCB, but other manufacturers should produce the same quality. In your order, select 0.062" (1,6 mm) thickness FR-4 glass-epoxy material, the standard stuff.



PCB design drawing, top side


PCB design drawing, bottom side

Gerber Zip File

COMPONENTS

The following is a list of all required components to put together this project. Some procurement recommendations are provided in the right hand side column. Other than the details provided, part selection is not critical.

Quantity	Designator	Description	Package	Procurement Recommendation
5	C1,C2,C4,C6,C7	Capacitor 100 nF, 25V, Ceramic X7R type	SMD 1206	eBay
2	C3,C5	Capacitor, Aluminium Electrolytic, 100 uF, 10V, 20% tolerance	SMD 5.3x5.3mm	Digikey PCE3867CT-ND
1	D1	LED, green, surface-mounted	SMD 1206	Digikey 160-1456-1-ND
2	J1,J3(optional)	SMA Female, Straight	Through hole jack,	eBay
2	J4,J5	1x10 Header, Pitch 0.100", straight	Pitch 0.100"	eBay, long strip, cut to size
2	Q1,Q2	N-Channel MOSFET, (2N7002 or BS170 typical)	SOT-23	Digikey BS170-ND
1	R1	Resistor, 300 Ohms	SMD 1206	eBay
1	R2	Resistor, 51 Ohms	SMD 1206	eBay
5	R3,R6,R7,R8,R9	Resistor, 1K Ohms	SMD 1206	eBay
1	R4	Resistor, 510 Ohms	SMD 1206	eBay
1	R5	Resistor, 240 Ohms	SMD 1206	eBay
1	U1	Voltage Regulator, LM1117-3.3	SOT-223-3	Digikey LM1117IMPX-3.3/NOPBCT-ND
1	X1	SN75HVD10	SOIC-8	Digikey 296-39217-1-ND
1	X2	Micro-Controller, PIC12F683	DIP-8	Digikey PIC12F683-I/P-ND
1	X3	Clock Synthesizer, SI5351C	QFN-20 4x4mm Pitch 0.5mm	Digikey 336-5160-1-ND
1	X4	Clock Synthesizer, SI5351A	MSOP-10 3x3mm Pitch 0.5mm	Digikey 336-3908-1-ND
1	Y1	Crystal, 27.000 MHz, ±10ppm tolerance, ±10ppm stability, 10pF load capacitance, 60 Ohm ESR	SMD 3.2x2.5mm	Digikey 887-1328-1-ND
1	-	DIP-8 Socket	Through Hole DIP-8	eBay

ASSEMBLY

One major challenge in assembling this board is the Si5351C soldering, which requires a hot-air rework station, some magnifying apparatus (camera or microscope), some soldering flux and a lot of skill. This is one VERY SMALL package! If you have never soldered this kind of device (QFN leadless), I recommend that you document yourself on the Internet prior to performing the work, or find someone who is willing to help with that task. This is an expensive chip, and you do not want to spoil it!

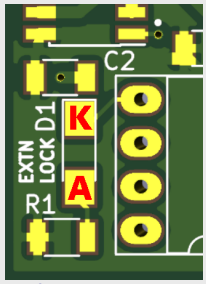
The Si5351A is also challenging, but to a lesser degree since it is a leaded package. The remaining of the board is not particularly difficult to assemble by hand if you can handle common surface-mounted components. A magnifying lamp, a fine tip soldering iron and a pair of tweezers are required.

The lowest profile components should be installed first, starting with the Si-5351C chip, followed by theremaining surface-mounted components. Note that The electrolytic capacitors, the headers, the micro-

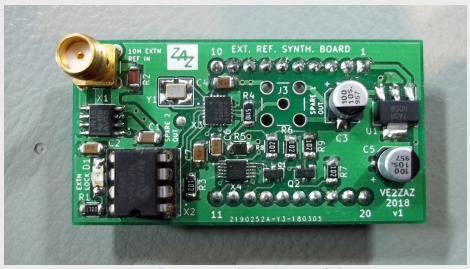
controller dip socket and the SMA connectors should be installed last.

The J4 and J5 headers must be installed on the PCB's bottom side, and soldered on the top side.

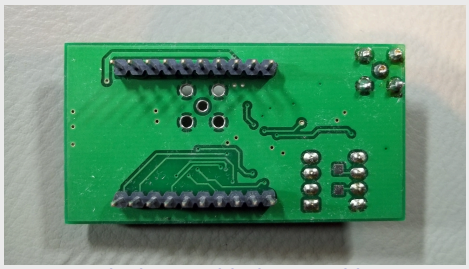
Care should be put in properly orienting the LED during soldering. Read the LED documentation to figure out which electrode is the anode. See the image to the right on proper LED orientation on the PCB.



The proper LED orientation



Final Assembly, top side


Final Assembly, bottom side

PIC FIRMWARE

The PIC12F683 firmware (the program) was written in Microchip XC8 C v1.45 language and compiled in MPLAB X v5.30, both being downloadable free of charge.

The code sets up the Si5351C for a 10 MHz input, translating into a 27 MHz output. Since there is no I^2C peripheral on that PIC, the protocol is emulated in software, albeit at a much slower speed than the typical I^2C bus. This does not cause any issue as this is a synchronous bus driven by the SCL clock signal.

Project Source Code and .HEX file

The calculated multiplier and PLL parameters are explained as comments in the "main.c" source file header. The source file also includes an optional configuration (currently commented out) for the spare output at 28.8000 MHz, a frequency commonly used to clock an RTL-SDR USB radio receiver. This could be useful to run an accompanying WSPR receiver.

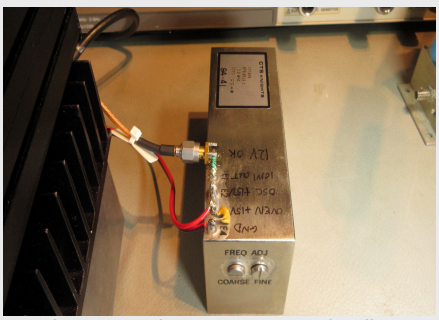
The .HEX file required for programming a PIC12F683 is located in the "dist/default/production" directory.

INTEGRATION

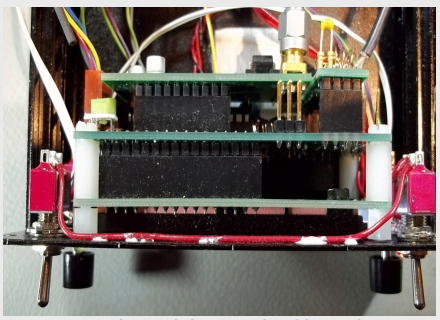
The final setup has three stacked boards inside the Ultimate 3S, namely the display board, the control board and the VE2ZAZ reference translator board. On the side is the plug-in low-pass-filter module. The VE2ZAZ reference translator board is plugged in lieu of the Si5351A Synthesizer module kit or the optional 27 MHz OCXO frequency reference kit. Other than the external reference coaxial cable, no other wiring is needed. The board is held in place by the header connectors friction.

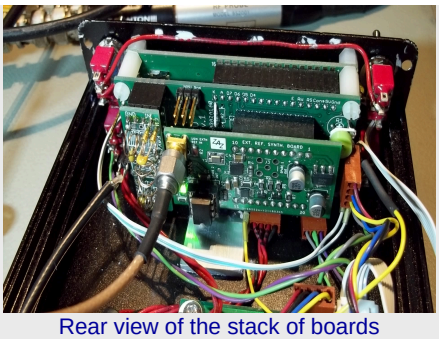
To boost the signal output from 100mW to 1W, I chose to use a pre-built Chinese-made 3.2W dual-stage broadband amplifier board. They are available everywhere on web sites such as eBay. These will run at a comfortable linear output of 1W. Notice that I have replaced the input attenuator on the amplifier board to get a 34 dB attenuation. The exact attenuation to get one Watt of RF output may vary from unit to unit, but do not send in the Ultimate3S output straight into the amplifier without proper attenuation!

Also important, I have added a 2m 7-pole low-pass filter on the amplifier output to filter out undesired harmonics. In the box, I have also included a T/R relay board for future applications where receiving WSPR would be required.

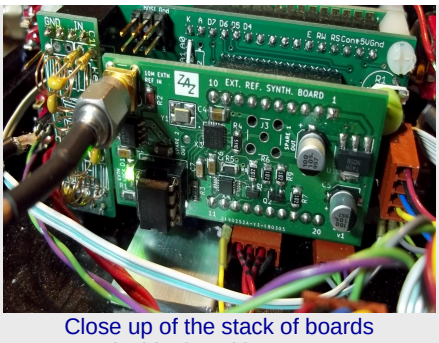


The external 10 MHz OCXO feeding the reference input


Top view of the stack of boards inside the Ultimate3S

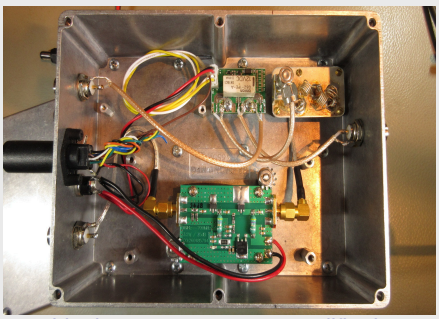


Rear view of the stack of boards
inside the Ultimate3S



Close up of the stack of boards
inside the Ultimate3S

The complete package: Ultimate3S,
Linear Amplifier box and 10 MHz OCXO.
Not seen is the 12V power supply.



Inside the 2-meter 1-Watt Amplifier box.
The amplifier, low pass filter and
T/R relay boards are visible.

CLOSING COMMENTS

Remember that the output clock shape generated by the Si5351 chip is a square wave. One must include proper lowpass or bandpass filtering if the output is to be used in radio applications, especially if it is to be used as a low power transmitter connected directly to an antenna! This is the case here!

I have been running the 2m WSPR beacon continuously for more than a year without any issue whatsoever. And the amplifier is still running fine. Receptions reports are not pouring in, but hey, this is 2 meters!