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An Unusual Multi-Band WSPR Transmitter

Use an Arbitrary Waveform Generator to make a multi-band WSPR transmitter.

Arbitrary Waveform Generators (AWG) are among the most important and flexible instruments available to the experimenter. These sophisticated devices employ Direct Digital Synthesizer (DDS) technology to provide stable, precise, low distortion signals. Due to their programmability and arbitrary waveform capability these generators are able to create a wide variety of complex waveforms specified by the user. With these units becoming more affordable, I wondered if an arbitrary waveform generator could be used to make a multi-band WSPR transmitter. Here's how I did it.

WSPR, the "weak signal propagation reporter" digital mode, has always held a special fascination for me. WSPR is able to communicate to the far corners of the world using very little power. A combination of special modulation techniques and software that can reliably decode signals near the noise threshold makes this possible. Joe Taylor, K1JT, and Bruce Walker, W1BW, described the details in their *QST* article[1] "WSPRing Around The World".

Normally, ordinary SSB radio transceivers are used to send and receive WSPR signals using a sound card connection to a PC that is running WSPR software. Actually, you don't always need a transceiver — usually a receiver or transmitter will do. Using just a receiver, teachers, students and short-wave listeners (SWLs) routinely report receptions. They find it instructive and exciting since they can then view real-time results on the *WSPRnet* world map. Receivers work well in this situation because they allow monitoring the entire WSPR band at one time without tuning for individual stations. But Amateur Radio operators usually find that using a transmitter is more fun, which happily provides more targets for the receivers. Sometimes single-band, low-power transmitters[2] are used for this purpose. This takes the strain off the big equipment.

Figure 1 — Photo of FY6600 dual channel function, arbitrary waveform generator used in this project.

AWG Technology

I wondered if AWG technology could be employed to make a stand-alone WSPR transmitter. Modern DDS generators can provide a wide variety of signals. Today's units are capable of sine, square, triangle and numerous other waveforms from 1 μHz to 60 MHz, with variable amplitude and adjustable dc offset. Many generators include features such as variable symmetry, frequency sweep, AM, FM, PM, ASK, FSK and PSK modulation, and gated burst mode, in addition to groups of predefined and user-defined waveforms. The output waveforms are low distortion and available through a nominal 50 Ω output impedance.

Prices of AWGs from the major names have been very high, in some cases more than a thousand dollars. Recently, however, I noticed the price of some lesser known arbitrary waveform generators was falling, making them less costly for general experimentation. While surfing the internet one day, I found a dual channel 60 MHz AWG that seemed to satisfy most of my requirements at the amazing price of US$85 including free shipping. Of particular interest was the 14-bit high speed D/A converter, the 250 MS/s sample rate, and the ability to store 64 arbitrary waveform data files, each one with storage depth of 8192 points and 14 bits. It also supported various standard waveforms

Figure 2 — Photo of WSPR map showing receptions of this unusual transmitter on the 17 meter band.

and modulation types, while functioning as two standard, independent full-function channels, where the phase between channels could be adjusted. Most importantly, the waveform in channel 1 could be modulated by the waveform in channel 2. After another look at the specifications, I placed an order for the FY6600 AWG shown in Figure 1.

Caveat Emptor!

What follows is a description of the trials and tribulations I experienced after discovering several major design deficiencies of the FY6600. I had to perform major circuit board surgery! Details related to making these hardware changes are described in the next section. The sections after that describe the work involved in getting this AWG to transmit a WSPR signal.

In spite of a bad start to this project, it ended happily. Figure 2 shows a *WSPRnet* world map showing the stations that reported receiving my 17- meter signal over a period of about an hour. The remarkable part is that the FY6600 was running just 100 mW into a wire dipole antenna raised just 7 feet above my office floor.

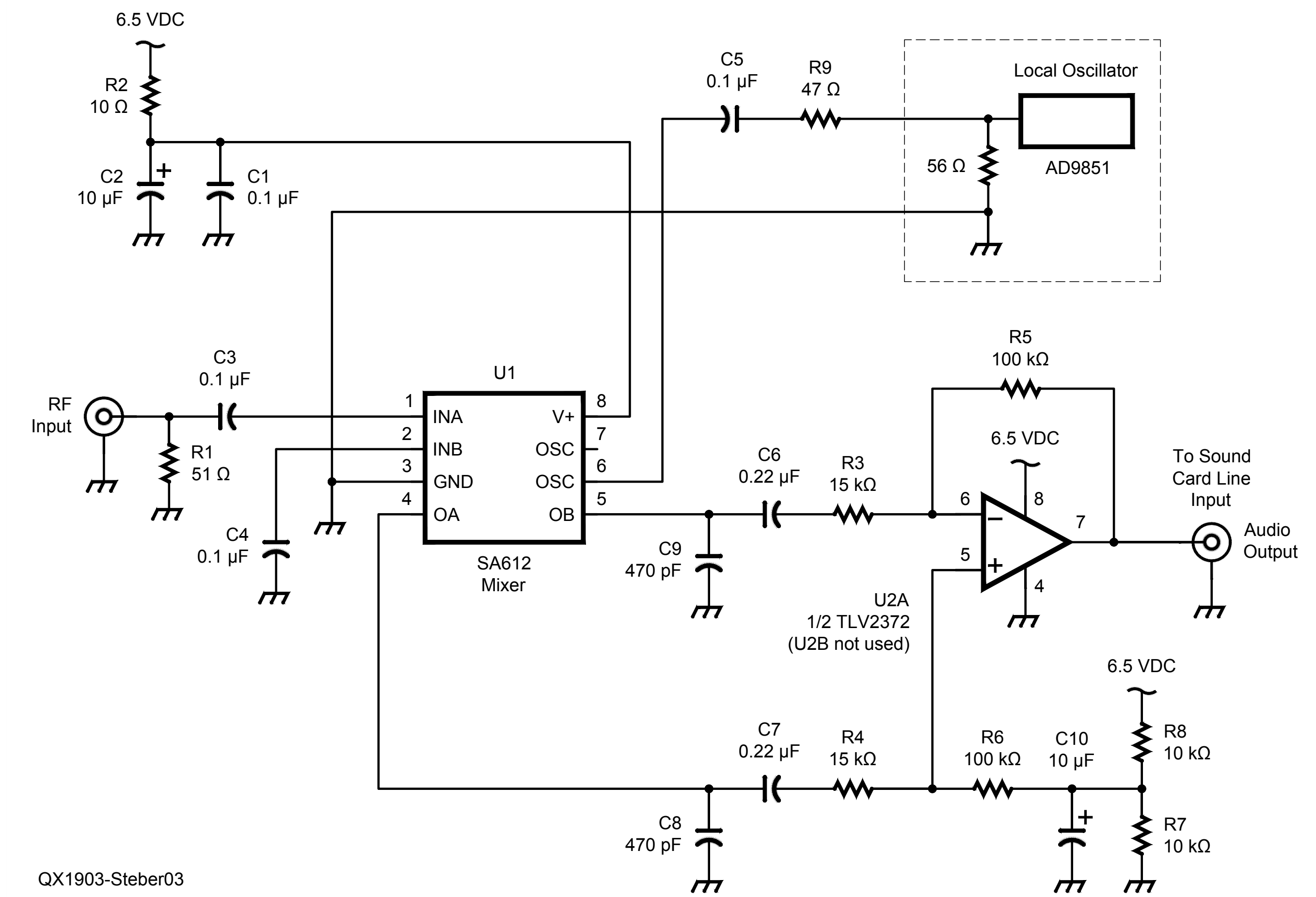

Figure 3 — RF down-converter mixer circuit. Audio output is processed with sound card FFT program. A large FFT is used to look for jitter.

The FY6600 AWG

The 60 MHz FY6600 arrived in good condition several weeks after I placed the order. The number of features it provides is overwhelming. It is a compact dual channel, function generator, arbitrary waveform generator, pulse generator, analog/digital modulator, VCO, sweeper and frequency counter. It has 96 groups of functions and preset waveforms and 64 groups of user-defined waveforms.

It had many features that I wanted to try immediately, such as the variable phase setting between channels, with amazing resolution of 0.01°. I thought this function might be handy for teaching phasor concepts to students. So, right out of the box, I examined this feature using some simple, predictable phase-shift circuits. I used a dual-channel oscilloscope as a phase detector between the two channels. This worked fine and the results agreed well with theory. However, this was not my main reason for obtaining this AWG.

Most of all I wanted to investigate the possibility of modulating the signal of one channel from the other channel. From the user manual, it looked like this would be easy to do. The plan was to generate an RF carrier on channel 1 and modulate it with a baseband WSPR signal from channel 2.

Since WSPR uses very narrow-band 4-FSK modulation, with frequency shift of 1.46 Hz per symbol, it is necessary that the carrier be very stable and not have any significant FM modulation of its own. To check for this possibility, I used a frequency down-converting mixer circuit (Figure 3). This circuit is basically the same as the one described in my *QST* spectrum analyzer article[3]. By choosing a slight offset of the LO frequency from the input signal frequency an audio signal is produced at the output. For this test, the frequency of a 10 MHz RF signal from the AWG is converted to audio and then processed by an FFT program, in this case,[4] *SpectrumView* by Grant Connell,WD6CNF. I used a waterfall plot to look for frequency jitter. Using a large FFT provides high resolution, down to better than1 Hz.

Many low cost DDS signal generators are noted for having more jitter than conventional signal generators. I was not prepared to find the large amount of jitter in the FY6600 signal. Figure 4 shows three sine wave signal generators, operating at about 10 MHz, in an FFT waterfall plot, displaying about 2 FFTs per second. The one in the middle is the FY6600, the one on the left is a Marconi 2022D, and the one on the right is a DDS-based AD9851. The signals on the left and right are shown for comparisons. The FY6600 shows average frequency jitter of 5 to 6 Hz with some peaks up to 10 Hz. There was also significant drift with temperature. My poor WSPR signal would get lost in that amount of noise and drift!

At this point my dreams began to fade for making a WSPR transmitter out of this AWG. I searched the internet for possible answers, and came across the **eevblog.com** forum where problems with the FY6600 were being thrashed out. One of the main problems concerned the stability of the reference 50 MHz oscillator chip used in the design, and the large amount of jitter it contributed to the output signal. Some forum members found that replacing this oscillator chip with a more stable TCXO chip improved stability dramatically. But this involves removing a surface-mount chip and replacing it with another. I was not sure I could do that.

There were other technical problems with this AWG. It seems the designers used a dual output op-amp chip for the signal outputs and that it did not perform well. It had poor frequency response with some distortion at higher frequencies and power levels. Examination of the FY6600 circuit board revealed that it had been originally designed

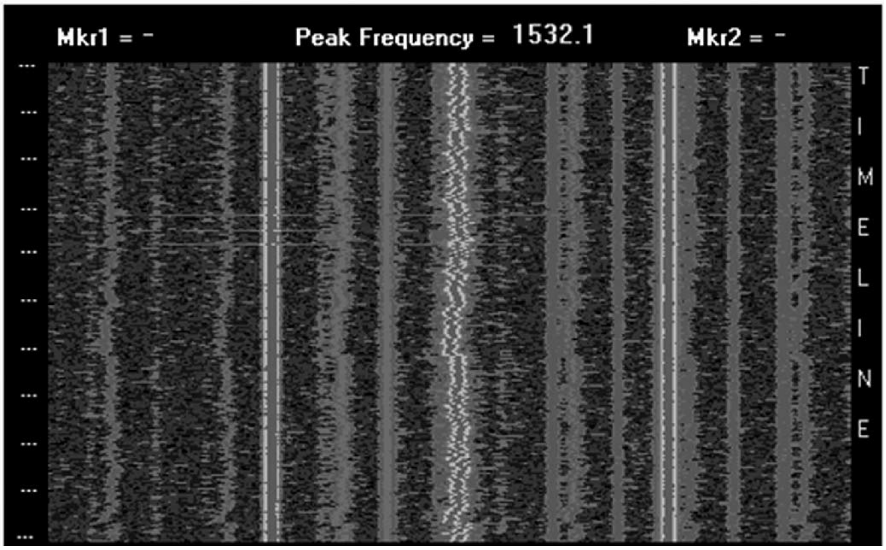

Figure 4 — FFT waterfall plots of three signal generators. The plot in the center is from the FY6600 and has 5 to 6 Hz jitter.

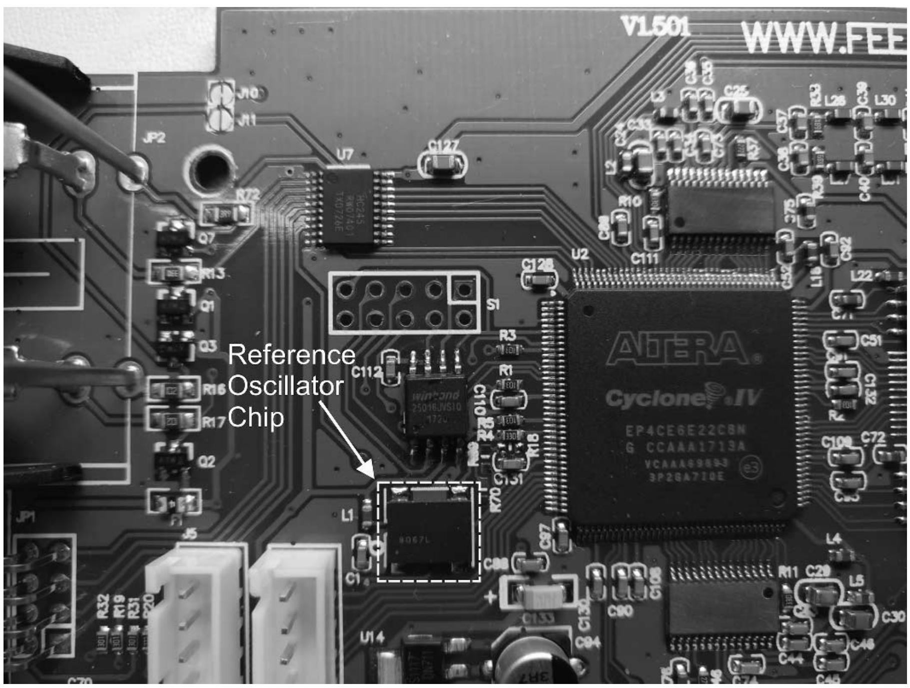

Figure 5 — Photo of main board of FY6600 showing location of the reference oscillator chip.

for separate amplifiers on each channel and the main board was laid out for these chips, but not implemented. Fixing this problem would involve removing another surface mount chip and adding two more chips.

The last problem of importance involved grounding the device to the electrical ac power input. It was inexplicably left floating. This could be remedied by replacing the two-wire ac connector on the back with a three wire grounded ac connector. At last, this was something that could be fixed easily within my capabilities.

After some time for consideration and encouragement from the group at **eevblog.com**, I decided to risk it and go ahead with these three modifications. They are discussed in more detail in the next section.

Modifying the FY6600 AWG

First on the list was to order the parts for the modifications. The three-wire ac connector was already on hand, left over from another project. So I just needed to order the three ICs. I chose to replace my 50 MHz oscillator chip with a Connor Winfield D75J-050.0M TCXO, which has frequency stability of 1 ppm and a nominal 0.5 ps jitter. The two IC op-amps I chose were Texas Instruments THS3095D. They are high-voltage, low distortion, high speed, current-feedback amplifiers available from Digi-Key for US$31.28.

Replacing the Oscillator IC

I replaced the original oscillator chip first. This was the most difficult of the tasks. This IC (Figure 5) is on the main board located close to the lower left corner of the main Cyclone IV processing chip. The forum suggested that a hot air gun be used to remove the IC. I carefully covered the area around the IC with Kapton tape to prevent heat damage to adjacent parts. Then I applied hot air to the IC with a slow circular motion, while at the same time prying the chip with a small tool. After about one minute, the oscillator chip went flying into the air, now free from the board. Fortunately there was no damage to the board pads.

Installing the new 5 mm by 7 mm surface-mount TXCO IC chip was not easy. First of all, the pads on the board were not the same size as the ones on the new IC chip. Another problem was that the new IC did not have any legs that could be used as solder attachments. My solution was to make my own wire legs for the IC. I did this using very flexible silver wire-wrap wire soldered on the tiny pads on the bottom of the IC. With the four legs now soldered to the oscillator IC, I carefully positioned it over the correct pads on the board and soldered pin 1 to the pad. I soldered the other three wire legs in a similar way while holding the legs with needle nose pliers. The final result did not look pretty, but it was solid and proved to work well.

Replacing the Op-amp

Replacing the dual output op-amp was a bit easier. It was located under the main heat sink. I again used a hot air gun to remove this chip. Figure 6 shows where the old op-amp was removed and two new THS3095D ICs were soldered in place. These ICs had legs so they could be soldered in with a fine-tip soldering iron. After installation, I placed the thermal heat pads on top of the new ICs and replace the heat sink.

The Three-wire AC Connector

Installing the new three-wire ac connector on the back was straight-forward but required a lot of filing to enlarge the opening. The back part of the cabinet is very thin so there was a danger of cracking the case. After installing the new connector, I soldered a wire from the ground pin on the connector to the ground plane on the internal power supply. This ensured that the BNC connectors on the front panel were grounded.

Testing the FY6600 AWG Modifications

After I put the FY6600 back together, it was time to see if the modifications worked. First, I tested the reference 50 MHz oscillator, albeit indirectly. A 10 MHz sine wave signal was output on both channels and observed with an oscilloscope. It appeared very clean and noise free.

I examined the 10 MHz signal for jitter using the circuit described above (Figure 3). I found that no jitter could be seen within the limit of my measuring setup — estimated to be 0.1 Hz. The TXCO was stable within about one minute of power on. I saw no perceptible drift in frequency after the short warm-up.

I calibrated the FY6600 in frequency using the procedure found on the forum, since the procedure was not in the manual. I uses a GPS disciplined HP5384A frequency counter for this procedure. After calibration, the AWG was spot on frequency (compared to the LCD displayed value) over most of the range, while deviating slightly, within 2 Hz, beyond 30 MHz. The replacement of the old reference oscillator chip with the new one was hugely successful in solving the major problems of jitter and temperature drift with this AWG.

The new THS3095D output amplifiers performed better than the original dual amplifier. The THS3095D is a high voltage, low distortion, high speed, current-feedback amplifier designed to operate up to ±15 V for applications requiring large, linear output signals. The specification sheet claims a total harmonic distortion as low as -69 dBc at 10 MHz. Observations with a spectrum analyzer confirmed very low levels of distortion. Harmonic distortion was about -69 dBc at 1 MHz, increasing to -38 dBc at 40 MHz, while producing 10 V p-p output into 50 Ω. With this modification, the AWG now provides a nice, clean low-power WSPR signal without the need for filtering.

Implementing the WSPR Transmitter.

With a well-functioning AWG now at

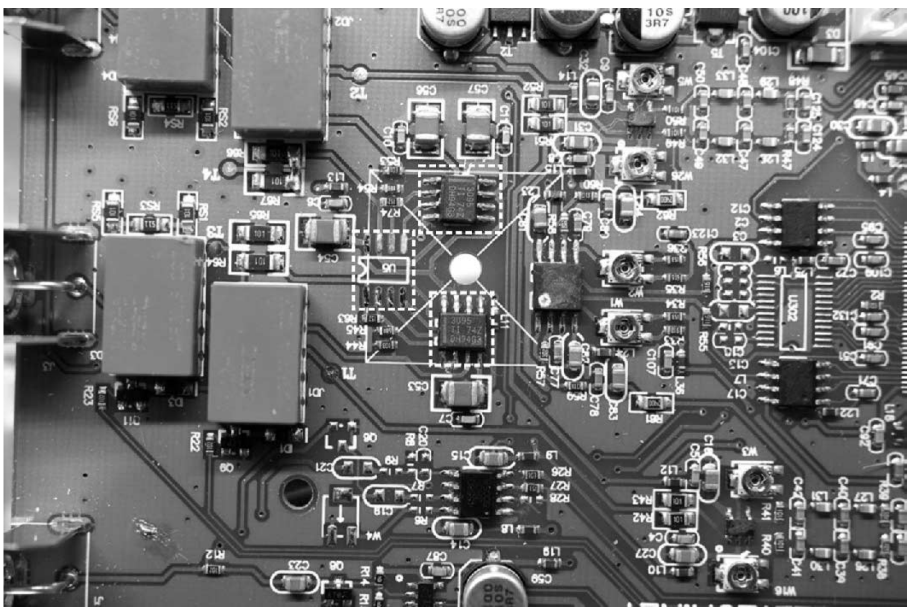

Figure 6 — Photo of main board of FY6600 showing location of the two new amplifier chips near the center of the board. The space to the left of these chips is where the original amplifier chip was located.

hand it was time to consider implementing a WSPR transmitter. The plan was to generate a sine wave RF carrier on channel 1 (CH1) and modulate it with a baseband WSPR signal from channel 2 (CH2). The output of CH1 could then be fed directly from the BNC connector on the front panel to an antenna for transmission. The WSPR band/frequency chosen corresponds to the carrier frequency set in CH1. Hence multi-band WSPR capability is obtained directly.

This particular AWG offers modulation of a carrier on CH1 from either the internal source (from CH2) or via the external VCO input port. It seemed that internal FM modulation of CH1 from CH2 would be the simplest to use. It is effortless to setup. All that is necessary is to click the modulation button and then select FM internal from CH2. The next step is to create a baseband WSPR signal for use in CH2. These details are shown below.

Details of the WSPR Coding

It is helpful to recall some characteristics of a WSPR signal. WSPR modulation is basically continuous phase 4-FSK, with tone separation of 1.4648 Hz. This narrow-band signal occupies a bandwidth of about 6 Hz. Since a transmission can last more than 110 s, frequency stability is a major factor to consider in a WSPR transmitter.

Standard messages are most often used in WSPR communication, and are quite short. They include just a call sign, a 4-digit Maidenhead locator, and the power used in dBm. An example would be "K1ABC FN20 37". There are provisions for compound call signs and/or a 6-digit locator, but these are not discussed further here.

Standard message components after lossless compression are: 28 bits for the call sign, 15 bits for the locator, and 7 bits for the power level, for a total of 50 bits. Forward error correction (FEC) uses another 112 bits. Thus there are a total of 162 bits in each WSPR transmission. The WSPR software on the PC takes the standard message components and creates the 162 binary channel symbols. These symbols are then used to produce the 4-FSK sound output on the PC. In our case we need to take a different route since we are not using a sound card.

We need to find the 162 channel symbols and form a baseband signal equivalent to the 4-FSK tones. Fortunately there are WSPR symbol generator utilities that can create the symbols. One of the easiest to use is[5] *WSPRMSG.exe* by E. C. Marcus, W3PM. It prompts for all inputs and produces a text message with the symbol data.

Table 1 shows the symbol data for my call, location and power, in this case 1 W.

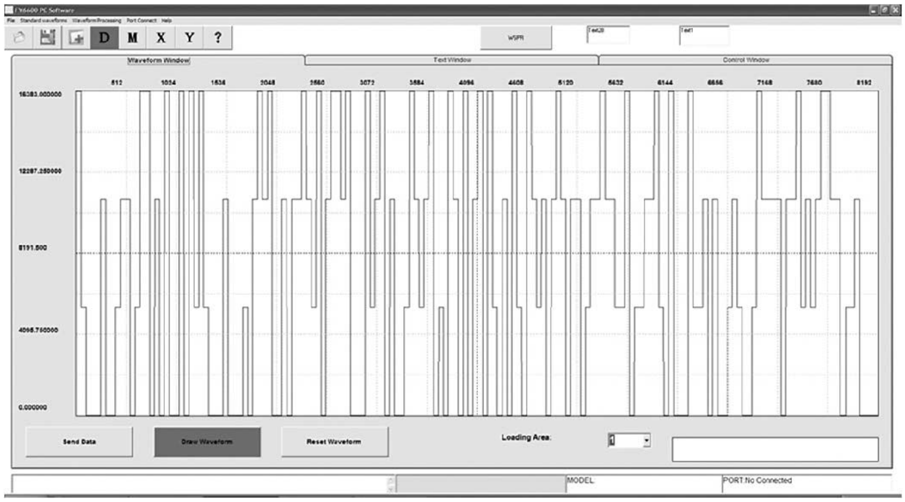

Figure 7 — Screen shot showing the baseband WSPR signal. This waveform is used to FM modulate the sine wave in channel 1.

Table 1.
Symbols for 'WB9LVI EN63 30' (generated from *WSPRMSG.exe*)

3,1,0,0,0,2,0,0,1,2,2,0,1,3,3,0,2,0,3,0,0,3,0,3,1,3,1,0,0,0,2,0,
0,0,1,0,2,3,2,3,0,0,2,0,2,2,3,2,1,3,0,2,3,3,2,3,0,0,0,3,1,2,3,0,
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0,2,3,2,0,2,2,0,1,2,2,3,2,2,1,1,3,0,1,1,2,2,3,1,0,3,0,0,0,3,1,1,
2,0,2,0,0,1,2,1,0,0,1,3,2,2,2,2,0,2,2,3,1,2,1,2,3,3,2,2,0,1,1,2,
0,0.

Table 2.
WSPR tone frequencies for the Symbols that FSK-modulate the carrier frequency.

Symbol	*tone freq., Hz*
0	0.0 Hz
1	1.4648 Hz
2	2.9296 Hz
3	4.3944 Hz

These 162 symbols comprise my WSPR transmission. Each symbol level changes by 1.4648 Hz. For example, the symbols 0, 1, 2, and 3 correspond to the tone frequencies in Table 2. Each symbol lasts for 683 ms. Hence, the transmission time equals 162 symbols times 0.683 s or 110.646 s. This symbol stream must now be translated and transferred to one of the 64 arbitrary waveform memories of the FY6600 AWG.

The FY6600 has a USB port and the supplied software allows loading of arbitrary waveforms as well as control over the unit. An arbitrary waveform consists of 8192 points with each point having an amplitude in the range of 0 to 16383. Mapping the 'symbol' amplitudes is easy. Let '0' = 0, '1' = 5461, '2' = 10922, and '3' = 16383.

If we use a length of 50 points for each symbol, this uses 8100 points with 92 left over. The left-over points will be at the end of the transmission and ignored. The 8100 points should take 110.646 s, or 73.2 points per second. But since we need to set the period for the entire waveform, including the extra 92 points, we set the period to 111.9 s. This corresponds to a frequency of 0.00893655 Hz set in CH2. But the FY6600 does not have quite that amount of precision and rounds it off to 0.008937 Hz, which yields a period of 111.8943 s, a small difference.

The WSPR waveform is most easily constructed using a spreadsheet. All 8192 points, as defined above, must be entered. Cutting and pasting helps a lot. It is a time-consuming effort, but fortunately has to be done just once. The CSV spreadsheet with the WSPR waveform is then read into one of the waveform memories of the FY6600 where it is saved. Figure 7 shows the resulting waveform as displayed using the FY6600 software. This is the actual FM modulation function that will be applied to channel 1.

WSPR Operation

Operating the AWG as a WSPR transmitter is easy. First select the desired WSPR frequency in CH1 and set it to a sine wave. Then select the baseband WSPR signal in CH2 from the stored arbitrary waveforms. Set its frequency to 0.008937 Hz. Then select MODE as FM (internal from CH2). Lastly, select the BIAS parameter to 4.5. This parameter tells the unit to use a maximum of 4.5 Hz for the FM modulation. The exact amount will be determined by the FY6600 as the CH2 waveform is played back. These settings can be saved in the AWG for later retrieval.

Now connect your dipole antenna (50 Ω nominal) to the CH 1 output BNC connector. Set the output level to the value desired, typically 2.2 V rms for 100 mW output. You can control the FY6600 from the front panel or by using the PC software via USB.

Start with both CH1 and CH2 off. You need to observe an accurate clock since WSPR transmits on even numbered minutes (0, 2, 4, etc.). The clock must be accurate within 1-2 s of UTC. When the next even minute approaches, just click on CH1 followed by CH2. Your WSPR transmission has just started. At the end of the two minute period, turn off both channels.

This procedure is fine for checking out the unit, and does work well. But it would be nicer if it was automated. Fortunately the FY6600 interface source code in Visual Basic (VB) is provided on the CD. It can easily be modified to automate the process. I created a WSPR button in VB and added it to my software. Now a single click does it. It transmits as two minutes on and two minutes off, continuously. A copy of this code is available on the **www.arrl.org/*QEX*files** web page.

You don't have to be connected to the internet to transmit with WSPR. But to see if you are being received you must check **WSPRnet.org**, enter your call sign and view the map like one shown in Figure 2.

Final Thoughts

This project started out badly when I discovered that the FY6600 had a number of design flaws. Instead of giving up, I employed some difficult surface-mount soldering to salvage the unit. Things worked out well but I cannot recommend this route if you are not well versed in working with these very small chips.

In spite of the difficulties that I encountered, it was very enjoyable to get this multi-band WSPR transmitter on the air. It has provided many hours of enjoyment, and it is very convenient to use. I have employed dipole antennas with a 1:1 current balun with this setup without problems. Dipole impedance varies a bit with height and the proximity to objects, but I did not notice any matching problems. The antennas were resonated in the center of the WSPR band to get the most out of this little transmitter.

Recently I added a 1 W linear amplifier to the output of the AWG. This adjunct has increased the number of receptions by WSPR receivers substantially. So far, I used this transmitter on the 30-, 20- and 17-meter WSPR bands. I must say that the 17 meter band can be full of surprises, as Figure 2 illustrates. One day it is dead and another day full of life.

I hope you enjoyed reading about this WSPR transmitter project. Hopefully it has generated some interest in WSPR. As the technology continues to evolve I expect to see many other innovations. With agreeable propagation, perhaps your WSPR signal will be copied in the far distant regions of the world!

George R. Steber, PhD, WB9LVI, has an Advanced Class license, is a life member of ARRL and IEEE, and is a Professional Engineer. George is Emeritus Professor of Electrical Engineering and Computer Science at the University Of Wisconsin-Milwaukee. He is now semi-retired, having served over 35 years. His last article for QEX was "A Tunable RF Preamplifier Using a Variable Capacitance Diode" in the November 2017 issue. George has worked for NASA and the USAF and still lectures on special topics at the University. He is currently involved in cosmic ray research and is developing methods to detect and study them on a global basis. When not dodging protons, pions and muons, he enjoys WSPR/JT9 Amateur Radio, racquetball, astronomy, and jazz. You may reach him at ***steber@execpc.com*** *with "WSPR" in subject line and email mode set to text.*

Notes

[1]J. Taylor, K1JT and B. Walker, W1BW, "WSPRing Around The World", *QST*, Nov., 2010, pp. 30-32.

[2]G. R. Steber, WB9LVI, "An Easy WSPR 30 Meter Transmitter", *QST*, Jan., 2015, pp. 47-50.

[3]G. R. Steber, WB9LVI, "Experimenter's RF Spectrum Analyzer", *QST*, Oct., 2008, pp. 36-40.

[4]*SpectrumView* by G. Connell,WD6CNF, **www.hotamateurprograms.com/Vista%20Installs/SpectrumView.exe**.

[5]*WSPRMSG.exe* by E. C. Marcus, W3PM,. **www.knology.net/~gmarcus/WSPR/WSPRMSG.exe**.