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A Cost-Effective WSPR Beacon Transmitter

As open-source, cost-effective, rugged, variable-power 5W WSPR beacon transmitter design for 160 meters (1.8 MHz) through 6 meters (50 MHz).

Introduction

WSPR (Weak Signal Propagation Reporter) is a digital communication protocol used by amateur radio operators. Part of the *WSJT-X* suite of protocols (**wsjt.sourceforge.io/wsjtx.html**), it allows the long-distance reception of low-power signals transmitted by beacon stations, enabling users to monitor and analyze radio frequency propagation. WSPR is not a two-way contact (QSO) mode and can run unattended. (Be sure to follow regulations for automatic control and unattended transmissions. – *Ed.*) WSPR networks collect reception reports from stations worldwide, providing valuable insights into radio propagation along with conditions in the ionosphere and of the geomagnetic field.

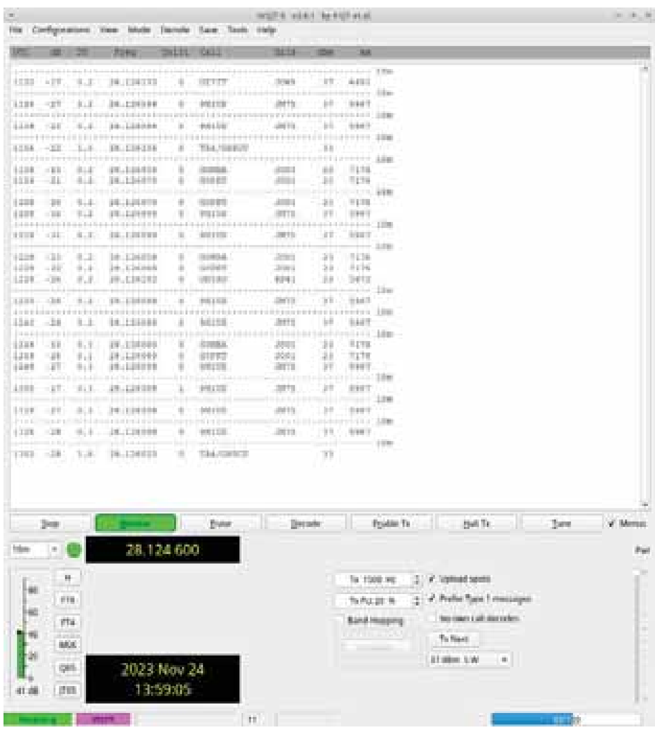

Figure 1 – *WSJT-X* software in its WSPR mode.

Overview and Block Diagram

Our goal is to make digital HF accessible to hobbyists through affordable, homebrew equipment. WSPR is a challenging digital mode due to its tight tone-shifting requirements and long transmit (TX) period with a 100% power amplifier (PA) duty cycle during transmissions. Our beacon transmitter design has these key features:

User-controlled power output up to 5W on 160 meters and HF bands (2W on 6 meters);

Modular, repairable design;

Cost-effective components;

Open-source hardware and software.

Figure 1 shows the *WSJT-X* software and its WSPR interface. This software displays the status of various WSPR transmissions and receptions, illustrating from where signals are being received. (WSPR can also be configured to automatically relay signal reception reports to WSPR reporting systems. – *Ed.*)

Figure 2 shows the block diagram of the complete WSPR beacon system. Our WSPR beacon system consists of four main components:

WSPR Signal Source;

Beacon Power Amplifier (PA);

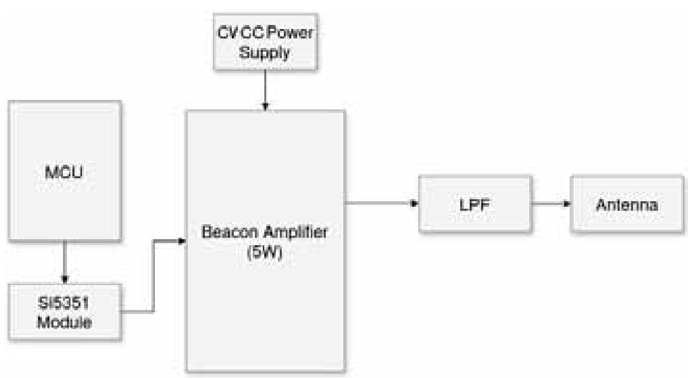

Figure 2 – Block diagram of the complete WSPR beacon system.

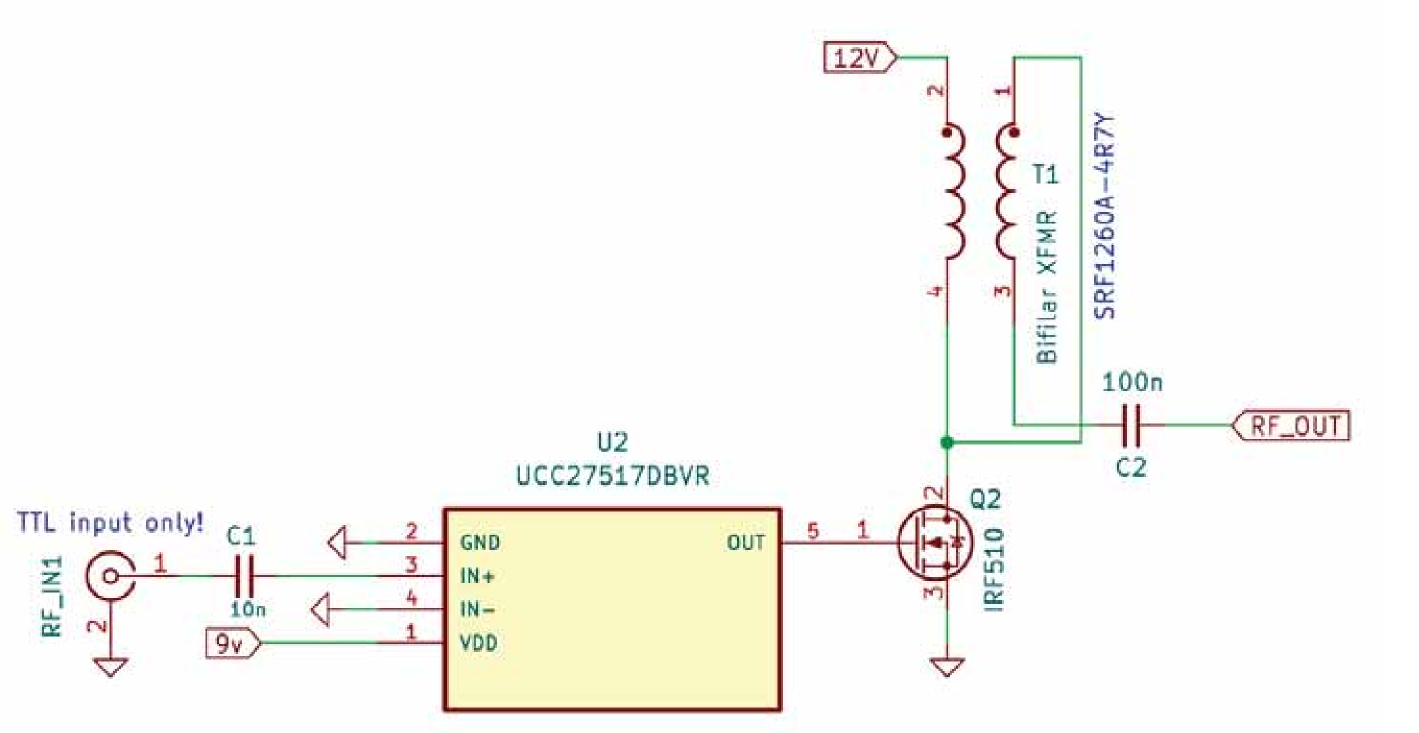

Figure 3 –Schematic of the beacon amplifier.

Power Supply;

Low Pass Filter (LPF).

The entire design is modular, very repairable, and can be easily adapted to meet different needs. Let's explore each component in detail.

WSPR Signal Source

The heart of our system is a Si5351 clock generator module controlled by a microcontroller (MCU). We've successfully tested various MCUs and single-board computers (SBCs) including Raspberry Pi Pico (W); Wemos D1 Mini (ESP8266) and ESP32-S3-Zero; and Raspberry Pi 3, 4 and Zero 2W.

For superior frequency stability, especially on the upper HF bands like 10 meters, we recommend using our custom Si5351 module with a 0.5ppm TCXO (Temperature Compensated Crystal Oscillator). Design files are available at: **github.com/kholia/Si5351-Module-Clone-TCXO**.

Beacon Amplifier

Figure 3 shows the schematics of the 5W beacon amplifier. The final amplifier MOSFET is operated in Class D by using a very fast gate driver (Texas Instruments UCC27511). The idea of using the UCC27511 gate driver originates from Henning Paul, DC4HP. By driving the MOSFET's gate on and off with the gate driver IC's very fast output rise and fall times, the MOSFET is operated as a switch and avoids operation in the linear region. This ensures higher PA efficiency and low power dissipation in the MOSFET.

Instead of manually winding the output bifilar coil, we borrow a trick from Jim Veatch, WA2EUJ and use a ready-made surface-mount (SMD) coupled inductor from Bourns. The amplifier generates around 5W on 160 meter through the HF bands with an efficiency of around 45 to 50%.

It generates close to 2W on the 6-meter band! TIP: If you are operating on lower frequency bands (below 17 meters), we can recommend using the IRFP140N MOSFET in a TO-247 package. It can generate up to 20W with 30V drain voltage and LC matching on the output. While 20W is overkill for WSPR, this power level can be useful for other FSK (frequency shift keying) digital modes (e.g. FT8). Design files are located at: **github.com/kholia/HF-PA-v10**. We have tested this beacon transmitter in various adverse conditions, such as : shorted load, open load, and high SWR (1:10) without any problems.

Power Supply Design

We strongly believe that one of the simplest ways to ensure the longevity of the beacon system is by operating the MOSFET within its Safe Operating Area (SOA). This is achieved by utilizing

Figure 4 – 4A DC-DC Step-down adjustable Constant Voltage - Constant Current (CVCC) module.

```
void tx(uint8_t *tones) {
  for (int i = 0; i < symbolCount; i++){
    si5351.set_freq(frequency + (tones[i] * toneSpacing), SI5351_CLK0);
    delay(toneDelay);
  }
  si5351.set_clock_pwr(SI5351_CLK0, 0);
  si5351.output_enable(SI5351_CLK0, 0);
}
```

a cost-effective CC CV power supply or DC-DC module to externally assert strong control of the MOSFET's operating conditions.

The power supply must be capable of supplying 1A @ 13.8 VDC. We can recommend the following switchmode power supply (SMPS) models: Mornsun LM25-23B12 SMPS (12V 2.1A) or Mornsun LM25-23B15 SMPS (15V 1.7A). Equivalent Mean Well or Omron SMPS models are fine, too.

This power supply is then connected to a DC-DC converter module which has Constant Voltage and Constant Current (CV CC) capabilities. We tested the DC-DC CV CC module shown in **Figure 4**. Set the output voltage to 12V by adjusting the CV potentiometer. Then, varying the CC potentiometer controls the output current and, ultimately, the RF power generated by the beacon amplifier.

Low-Pass Filter Design

The 5-pole (or better) low-pass filter (LPF) can be designed using online software such as **markimicrowave.com/technical-resources/tools/lc-filter-design-tool** (Note - the URL hyphen is required.). Alternatively, use *LTspice* for LPF design. Our 5-pole LPF design files are available at **github.com/kholia/HF-PA-v10**.

Software Implementation

WSPR utilizes 4-FSK modulation with 1.4648 Hz tone separation. Our implementation uses the RF Direct Digital Synthesis (RF DDS) technique, which involves controlling the Si5351 via I2C to generate the required frequencies directly, as in the code segment above.

The full source code for the WSPR beacon can be found at:
github.com/kholia/Multi-WSPR
github.com/kholia/Easy-Beacons-STEM
github.com/kholia/Easy-Digital-Beacons-v1

Practical Considerations:

Component Sourcing: Be cautious of counterfeit components, especially the IRF510 MOSFET. Source from trusted suppliers and verify authenticity (e.g., A genuine IRF510 should have gate-to-source capacitance (Cgs) of ~400pF or less on an LCR meter.)

HOA Restrictions:

To overcome antenna limitations we recommend:
Operate on higher frequency bands such as 15 and 10 meters;
Use of portable field setups;
Operate during 'off-peak' hours.

Employ loaded End-Fed Half-Wave (EFHW) antennas for lower frequency bands in limited spaces.
For more on portable antenna designs, see **github.com/kholia/HF-Balcony-Antenna-System**.

Conclusions

Our WSPR beacon design offers a cost-effective, reliable solution for amateur radio enthusiasts interested in propagation studies and digital HF operations. With its modular design and open-source approach, it's an excellent project for both learning and practical use. We've successfully operated this system continuously since early 2020, achieving intercontinental reception. Transmissions from this beacon system in MK68xm (West India) were received by K9AN in the USA and VK7JJ in Tasmania, among other locations. We encourage you to explore, build, and contribute to this open-source project. Happy beaconing!

Dhiru Kholia was first licensed as VU3CER in 2019. He received a BE degree in Electronics & Telecommunication from Pune University in 2006. He then pursued a career in software security engineering with various MNC firms. He became interested in electronics again after a long gap due to his growing passion for hardware security. Besides amateur tadio, he enjoys table tennis, chess, releasing miscellaneous projects on GitHub, and reverse-engineering software and hardware stuff.

Bradshaw Lupton, K1TE, was licensed as WA2IVF in 1968. He was an engineer at Honeywell and Polaroid for 33 years, and a physics and chemistry teacher in the Boston area for 11 years. Bradshaw advises the Sandwich Stem Academy and has developed WSPR/FT8 STEM classes for the Chatham Marconi RCA museum. His STEM students are learning the power of WSJTX digital with 3.3v and 1/100 watt making it, occasionally, from Buzzards Bay, Massachusetts to Melbourne, Australia.