Direct Digital Synthesis for Those Classic Rigs

Bring that old favorite back from the display shelf with a stable and accurate frequency source.

Joe Lunsford, N4YG

How many older transceivers and transmitters are collecting dust just because the old VFO drifts badly and is so unstable that transmitting would be an embarrassment? Some of these old boat anchors were never particularly stable, but were acceptable 30 or 40 years ago. But now, with new digital modes such as PSK31, stability requirements are higher and so are expectations.

Many amateurs are continually repairing their PTOs and VFOs while others are overwhelmed with the thoughts of attempting repair. Direct digital synthesis (DDS) provides a solution that is within reach of the average amateur and provides just what is needed for a majority of transceivers that were popular from 1960 through the 1980s.

A Solution is Within Reach

This particular system was originally designed for the Heathkit HW-101 but has found wider applicability to other transceivers. It is even easier to install in some other transceivers, such as the Ten-Tec Corsair series and Drake TR-7. The design is also applicable to the construction of a VFO that can make those old boat anchor AM-CW transmitters of the 1950s sound as good as the highly stable rigs of today See Figure 1.

Why DDS?

There are many advantages to the DDS system, including that it provides stability equivalent to that of a fixed crystal oscillator. In addition, it offers exceptional flexibility and adaptability under software control. A digital frequency display is optional, but if selected allows calibration, as well as tuning, to an accuracy of a few hertz.

This design includes an optional liquid crystal display (LCD) for frequency and other status information. In addition, it offers receiver incremental tuning (RIT) and capability for dual VFOs to support split receiver and transmitter operation — big plusses to support the usual DX operating environment. The VFO also includes calibration routines with on-display prompts. The HW-101 version also provides a band sensor.

This article shows how to construct a stand-alone VFO. Separate descriptions of how the DDS system can be integrated into the Ten-Tec Corsair II, the Drake TR-7 and the Heathkit HW-101 are available and firmware versions for these applications on the QST-in-Depth website.[1] A big plus is that the integration of the new DDS system can be accomplished without permanent modification — important if these transceivers achieve collector status.

The HW-101 Saga

My HW-101 served me well during the 1970s and ’80s. Then it served my brother for 10 more years, after which it found its way back to me. It still worked, but it sounded awful. The one time I put it on the air I was embarrassed. Being a person who despises things that do not perform well, the choices were to either fix up the old thing or throw it away, the latter being a serious consideration. [I had one as well, until my usual weekly CW sked contact refused to tolerate my drifting — mine went to a flea market! — *Ed.*] Fortunately, the former was chosen and I was committed to fixing the old VFO. Repairing the VFO turned out to be practically impossible because the parts were not to be found. That set me on a new path — direct digital synthesis. The resulting modified HW-101 is now a pleasure to operate. I use it more than I do my modern transceiver. It sounds as good as any modern rig.

[1]Notes appear on page 00.

Figure 1 — The stand-alone DDS VFO, suitable for frequency control of ’50s transmitters such as Johnson Ranger, Adventurer, Navigator or Viking; Heathkit AT-1, DX-20, 35, 40, 60 or 100.

System Design

The DDS system was designed to be integrated into transceivers, initially into the HW-101. The firmware in the controlling processor supports all the functions required for integration into the HW-101 — features such as a band sensor and an LCD for displaying frequency and status information. These features are not required for installations in rigs from the 1970s and 1980s with digital frequency displays. Much of the firmware was applicable to these transceivers while some was simply disabled. Installation in this class of transceiver was much simpler, however.

Paul Reams, AD3G, was the first to incorporate the same design into his RV-7 (remote VFO for the Drake TR-7) and later directly into his TR-7. He was successful and quite pleased with the result. Cap Allen, WØCCA, was the first to replace a Ten-Tec PTO with the DDS system. Cap accomplished the installation in his Corsair II without a hitch. I am sincerely thankful for the help provided by Paul and Cap and also by Joe Basham, N5CQK.

It has been gratifying to observe the excitement as these and others first turned on their transceiver after installing the DDS. The things that seem to be most evident are the exceptionally smooth and effortless feel (and sound) of the main tuning knob, the rock solid stability and the convenience of dual VFOs.

The DDS Module Design

Direct digital synthesis is, as the name implies, a digital technique except for the final step in which the digital sine wave is converted to analog segments. A stable oscillator or clock is required whose frequency is at least three times that of the highest desired output frequency. The DDS that was designed for the author's HW-101 uses a 50 MHz crystal oscillator for its timing reference.

Every cycle of the timing reference causes three things to occur: 1) a phase increment is added to a modulo 2 π phase accumulator or adder, 2) the sine of the value in the phase accumulator is looked up in a table, and 3) the digital sine value is converted to an analog voltage. This analog voltage is the output of the DDS system.

All this occurs every 20 ns or 50 million times a second. The stability of the resulting signal is the same as that of the 50 MHz crystal oscillator. The above is a very brief explanation of DDS. *The ARRL Radio Amateur's Handbook* should be consulted for a more complete explanation.[2]

The exceptional flexibility of the DDS system is a significant advantage over the old analog VFO. Under software control, the operating frequency can be changed by several megahertz in less than a microsecond and the operating frequency can be controlled to within a small fraction of a Hertz. The output frequency can be readily displayed digitally. There are no moving parts except for an incremental encoder typically used for tuning the DDS system in an Amateur Radio application. There is only one disadvantage of the DDS system: its spurious output. While there are numerous spurs in the output from any DDS system, these are at least 60 dB below the main spectral line.

A DDS system would be very difficult to construct from common components, particularly for an amateur. Fortunately, Analog Devices has designed a family of devices particularly for DDS. The one chosen for this design is the AD9835 that features a fully DDS capable cosine table lookup and a 10 bit D/A converter. It can operate up to a maximum clock speed of 50 MHz. It comes in a 16-pin TSSOP (thin-shrink small outline) package that includes built-in serial communication with the processor. The peak output is 0.3 $V_{P\text{-}P}$.

Since I decided to design and build a DDS system for the HW-101 and since I selected the AD9835 DDS chip, I had to address two questions before proceeding. What were the reasonable expectations for what might be achieved in the design and what hardware and firmware would be required? Notice that the requirements were specific to the HW-101, but are sufficient for any transceiver. These are the general design goals that were established:

- Minimal modification to the transceiver.
- Alphanumeric display of DDS frequency and status.
- Integrated receiver incremental tuning (RIT), dual VFOs and receiver/transmitter frequency split capability.
- Variable tuning rate with frequency readout to 1 Hz and integrated digital calibration to less than 100 Hz.

The circuit diagram, Figure 2, results in a system that meets these requirements. The circuit diagram only includes components mounted on the PC board. A separate circuit diagram for the interconnections between the PC board and off-board components is shown in the Qst-in-Depth version.

Cables connect to points within the transceiver to inform the DDS processor of status information, such as transmit or receive mode. In Ten-Tec and Drake rigs, there are only one or two of these status lines to be connected. In the HW-101 there are several, BAND, RECEIVE or TRANSMIT mode and USB, LSB or CW mode.

There are only three means for the operator to interact with the DDS system, the MAIN TUNING knob that is connected to the incremental encoder, the DDS CONTROL button and the RIT potentiometer. The former is simply mounted where the old VFO or PTO shaft was removed. A pushbutton switch and potentiometer should be used if possible for the DDS CONTROL button and the RIT control so that the external appearance of the transceiver is preserved.

With this button the operator selects VFO A or VFO B, selects split operation and gains entry into the calibration routines (HW-101 only). While monitoring all these and other inputs, the 16F877A calculates the frequency desired and provides necessary data (phase increment) to the AD9835 DDS

Figure 2 — Schematic diagram and parts list of the main board of the DDS system. Mouser parts are available from www.mouser.com.

C1, C2 — 20 pF, 50 V, ±5% disc capacitor (Mouser 140-50N5-200J).
C3-C12, C15, C16, C19, C20, C28 — 0.01 μF, 50 V, –20%, +80% disc capacitor (Mouser 140-50V5-103Z).
C13, C17 — 10 μF, 20% tantalum capacitor (Mouser 80-T354E106M20AT).
C14, C18, C22-C24, C26, C27 — 0.22 μF, 20% axial lead capacitor (Mouser 581-SA-105E224MAR).
C21 — 470 μF radial lead capacitor (Mouser 140-HTRL25V470-RC).
C25 — 47 μF radial lead capacitor (Mouser 140-HTRL25V47-RC).
D1-D5 — 400 PIV rectifier diode (Mouser 512-1N4004).
J1 — Connector housing, 9 pin (Mouser 538-50-57-9009).
J2 — Connector housing, 7 pin (Mouser 538-50-57-9007).
J3 — Connector housing, 5 pin (Mouser 538-50-57-9005).
J4, J6, J7 — Connector housing, 4 pin (Mouser 538-50-57-9004).
J5 — IDC ribbon connector (Mouser 653-XG4M-1630-T).
JP1-JP4, JP6, JP7 — Single row header pins (Mouser 517-6211TG).
JP5 — Dual row header pins (Mouser 517-2340-6221TG).
OS1-OS3 — Photo interrupter (Mouser 512-QVE00118).
R1 — 39 kΩ, ¼ W carbon film resistor (Mouser 291-39K-RC).
R2, R11 — 1 kΩ, ¼ W carbon film resistor (Mouser 291-1K-RC).
R3, R4 — 47 kΩ, ¼ W carbon film resistor (Mouser 291-47K-RC).
R5 — 100 Ω, ¼ W carbon film resistor (Mouser 291-100-RC).
R6 — 3.9 kΩ, ¼ W carbon film resistor (Mouser 291-330-RC).
R8 — 5 kΩ, ¼ W trimmer potentiometer (Mouser 652-3306F-1-502).
R9 — 10 kΩ, ¼ W carbon film resistor (Mouser 291-10K-RC).
R12 — 470 Ω, ¼ W carbon film resistor (Mouser 291-470-RC).
R13 — 33 kΩ, ¼ W carbon film resistor (Mouser 291-33K-RC).
R14 — 5 kΩ, linear taper panel mount potentiometer (Mouser 31CN401-F).
R15, R16 — 6.8 Ω, ¼ W carbon film resistor (Mouser 291-6.8-RC).
R17 — 20 kΩ, ¼ W trimmer potentiometer (Mouser 652-3306F-1-203).
S1 — Pushbutton switch (Mouser 101-0361-EV).
U1 — Microcontroller, 40 pin (Mouser 579-PIC16F877A-I/P).
U2 — 50 MHz crystal clock (Mouser 815-ACH-50-EK).
U3 — DDS surface mount chip, 16 lead (Analog Devices AD9835BRU).
U4 — Voltage regulator, +12 V, 100 mA (Mouser 512-KA78L12AZTA).
U5 — Voltage regulator, +5 V, 3 A (Mouser 512-LM7805ACT).
U6 — Voltage regulator, –12 V, 100 mA (Mouser 512-KA79L12AZTA).
U7 — Video amplifier chip (Linear Technology LTC1253).
U8 — Liquid crystal display, 16 character × 2 line.
U9 — Incremental encoder, 128 pulses per revolution (Ten Tec Oak Grigsby 90Q064-02-00).
X1 — Parallel cut crystal, 20 MHz (Mouser 815-AB-20-B2).
PC board from author at n4yg@comcast.net.
Perfboard (Veroboard from Ocean State Electronics, www.oselectronics.com).

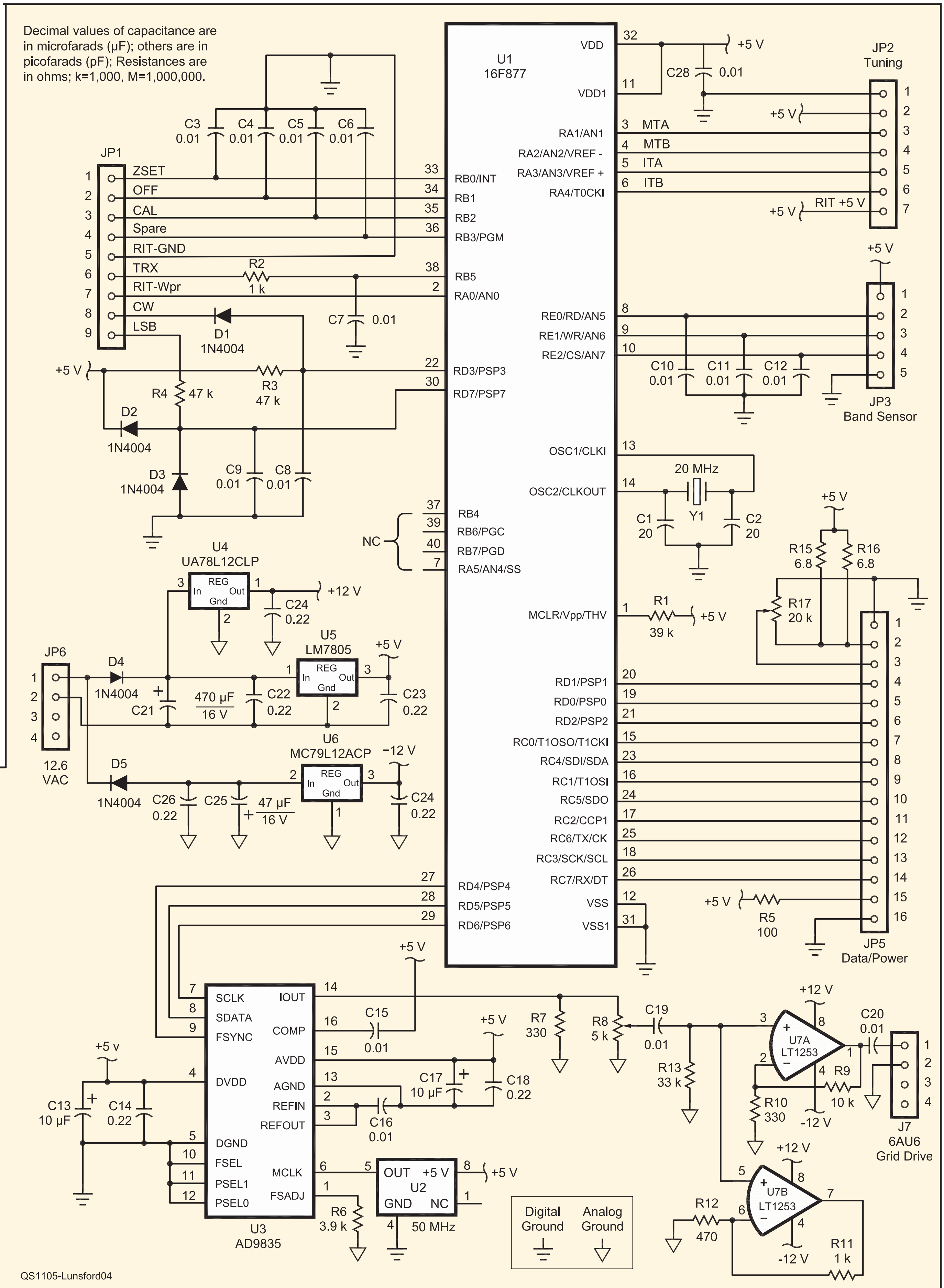
Decimal values of capacitance are in microfarads (µF); others are in picofarads (pF); Resistances are in ohms; k=1,000, M=1,000,000.
U1
16F877
VDD
VDD1
RA1/AN1
RA2/AN2/VREF -
RA3/AN3/VREF +
RA4/T0CKI
RB0/INT
RB1
RB2
RB3/PGM
RB5
RA0/AN0
RE0/RD/AN5
RE1/WR/AN6
RE2/CS/AN7
RD3/PSP3
RD7/PSP7
OSC1/CLKI
OSC2/CLKOUT
RB4
RB6/PGC
RB7/PGD
RA5/AN4/SS
NC
MCLR/Vpp/THV
RD1/PSP1
RD0/PSP0
RD2/PSP2
RC0/T1OSO/T1CKI
RC4/SDI/SDA
RC1/T1OSI
RC5/SDO
RC2/CCP1
RC6/TX/CK
RC3/SCK/SCL
RC7/RX/DT
RD4/PSP4
RD5/PSP5
RD6/PSP6
VSS
VSS1
JP1
ZSET
OFF
CAL
Spare
RIT-GND
TRX
RIT-Wpr
CW
LSB
C3 0.01
C4 0.01
C5 0.01
C6 0.01
R2 1 k
C7 0.01
D1 1N4004
R4 47 k
R3 47 k
D2 1N4004
D3 1N4004
C9 0.01
C8 0.01
+5 V
C28 0.01
JP2 Tuning
MTA
MTB
ITA
ITB
RIT +5 V
JP3 Band Sensor
C10 0.01
C11 0.01
C12 0.01
20 MHz
Y1
C1 20
C2 20
R15 6.8
R16 6.8
R17 20 k
R1 39 k
R5 100
JP5 Data/Power
U4
UA78L12CLP
REG In Out Gnd
+12 V
C24 0.22
U5
LM7805
JP6
D4 1N4004
C21
470 µF 16 V
C22 0.22
C23 0.22
12.6 VAC
D5 1N4004
U6
MC79L12ACP
−12 V
C26 0.22
C25
47 µF 16 V
C24 0.22
U3
AD9835
SCLK
SDATA
FSYNC
IOUT
COMP
AVDD
DVDD
AGND
REFIN
REFOUT
DGND
FSEL
PSEL1
PSEL0
MCLK
FSADJ
C15 0.01
C17 10 µF
C18 0.22
C16 0.01
C13 10 µF
C14 0.22
+5 v
R6 3.9 k
U2
OUT +5 V GND NC
50 MHz
R7 330
R8 5 k
C19 0.01
R13 33 k
U7A LT1253
R9 10 k
R10 330
+12 V
-12 V
C20 0.01
J7 6AU6 Grid Drive
U7B LT1253
R12 470
R11 1 k
Digital Ground
Analog Ground
QS1105-Lunsford04

Table 1

DDS CONTROL Actions and Results

Button Action	*DDS System Action*	*Result*
Click	Complement RX and TX VFOs	Swap RX and TX VFOs, A and B saved to memory
Double click	Complement TX VFO	Split or Unsplit, A and B saved to memory
Long click	Equate A and B to the RX VFO	A = B or B = A, A and B saved to memory
Very long click	Save A and B, Enter Calibration Mode (HW-101)	A and B saved to memory

chip, which changes the output frequency as desired. Unlike many DDS systems on the market that provide a low voltage output, the output of this VFO can be adjusted from 0 to 20 $V_{P\text{-}P}$. At the same time the 16F877A provides data to the LCD to display the desired frequency and other information. The 16F877A, clocked at 20 MHz, has ample speed to complete all these tasks within a fraction of a millisecond.

Implementation Approach

Power is taken from an 8 to 12 V dc or 12.6 V ac source within the transceiver. In Ten-Tec rigs, the 8 V source that powered the old PTO is the best source.

Extensive code is incorporated into the firmware of the 16F877A. Required tasks include the need to control and communicate data to the AD9835 and the LCD. It also must interpret the MAIN TUNING and RIT control inputs and set the frequency display accordingly. It must also accept and apply calibration for all band segments and modes (USB, LSB and CW).

The Main Board

You could decide to construct the main board as I did the first prototype using perforated prototype board and a surface mount adapter. The surface mount chip presents a difficulty, however. A printed circuit board makes the task much easier. The assembled PC board is shown in Figure 3.

Liquid Crystal Display(Optional)

Support for an LCD display is included in all firmware versions. If the transceiver already has an operational digital display, then it is recommended that it continue to be used with modification. Since the HW-101 has only an analog dial in its original configuration, a digital display is suggested.

Although several LCD modules will work, the one in the parts list is preferred. The line width of the 16 character display lines should be approximately 55 mm and the width of the module should be about 80 mm. The display module is mounted with two L shaped pieces of aluminum about 1¼ inches long and ⅜ inches wide, bent into an L shape with one flange ⅞ inches wide. The short flanges are attached to the display module with 2-56 hardware and the ⅞ inch flanges attach underneath the flange at the top of the front panel of the HW-101 with 4-40 hardware. Counter sink the heads of the 4-40 screws.

Getting To Know the DDS System

Controls

Operation may vary somewhat depending on the type of transceiver. These differences are generally only related to the display, which may be the original display. The original display will very likely be used in the TR-7 and the Corsair II, for example. The use of the DDS is very simple because there are only three controls, the MAIN TUNING knob, the DDS CONTROL button and the RIT control.

The MAIN TUNING control is simple, yet designed to make it easy to make small or large changes in operating frequency. This is accomplished with a variable tuning rate, measured in kHz per knob revolution. If rotated slowly, the tuning rate is slow for fine tuning. As the rotation rate is increased, the tuning rate increases, making it easy to move from one end of the band to the other.

The DDS CONTROL button, SPOT button in the Corsair II and ZERO SET in the HW-101, controls the two VFOs, A and B.

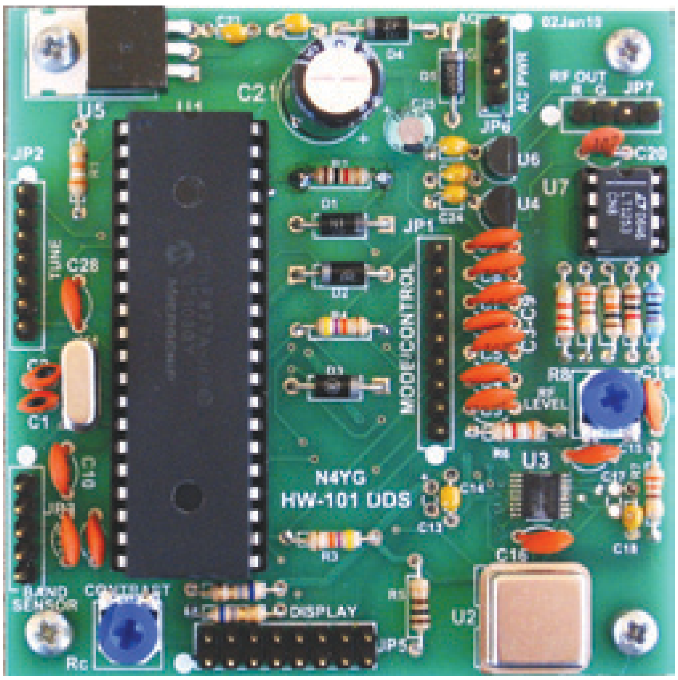

Figure 3 — PC implementation of DDS main board.

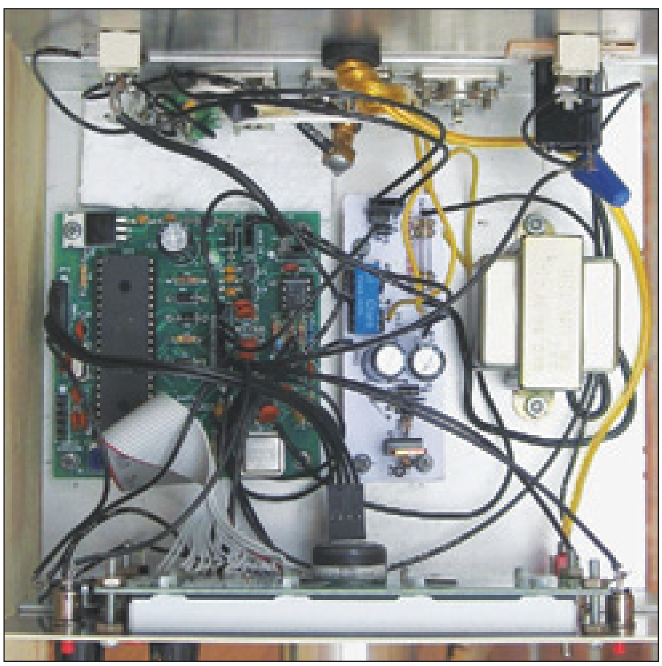

Figure 4 — Bottom view of assembled stand-alone version.

Hamspeak

Crystal oscillator — Circuit that generates a signal at a precise fixed frequency. The crystal is one of quartz, sliced and ground until it responds to electrical stimulation by mechanically vibrating at the desired frequency (the **piezoelectric** effect**).**

CW — Continuous wave. Term for the on-off keyed signaling associated with radiotelegraph transmission.

DIP (Dual in-line) package — Integrated circuit package characterized by two parallel rows of connecting pins.

DDS — Direct digital synthesis. A method of generating an ac signal in which a computer directly outputs the waveform by generating a series of voltage steps that add up to the desired time function.

LCD — Liquid crystal display. Structure that allows the transmission of light when energized. Multiple LCD segments are combined together to form display screens that are only visible upon application of light.

Potentiometer — Variable resistor with three terminals, two of which are attached to a fixed resistance element and the third can be mechanically moved along the element, presenting a different resistance to each of the fixed terminals.

PSK31 — Popular keyboard-to-keyboard amateur digital transmission system developed in 1999 by Peter Martinez, G3PLX.* This system is based on phase shift keying at a required bandwidth of 31 Hz, hence its name. This was the first popular "sound card mode," in which a PC sound card was used to encode and decode the data.

PTO — Permeability tuned oscillator. Variable frequency oscillator in which the frequency is changed by moving a tuning slug, often with a multi-turn screw thread, in and out of an inductor to change the inductance of the frequency determining circuit.

Transceiver — Radio transmitter and receiver combined in one unit. In many cases some circuitry is shared between the two functions.

VFO — Variable frequency oscillator. Oscillator with frequency established by resonant inductor-capacitor circuit. One or the other elements is adjustable to vary the frequency over a range, typically as wide as an amateur band.

*P. Martinez, G3PLX, "PSK31: A New Radio-Teletype Mode (reprint from *RadCom*)," *QEX*, Jul 1999, pp 3-9.

In the HW-101 it also gives access to and control of the calibration routine. The A and B values are saved to memory each time any action is taken with the DDS CONTROL button. The A and B values are retrieved each time the system is powered up so that it returns to the same frequencies. One of the VFOs must be designated for receive (RX) and one must be designated for transmit (TX). If the same VFO is designated for both transmit and receive, this is referred to as *unsplit*. If different VFOs are designated for RX and TX, then this is *split* operation.

The DDS CONTROL button has four functions that are invoked by what will be referred to as *clicks*, analogous to a click with a mouse. A click means a short tap of the button. A *double click* is two clicks in rapid succession. A *long click* means a button push and held for ½ second but less than 2 seconds. A very long click is a button pushed and held for 2 seconds or more. The functions invoked by these DDS CONTROL actions are enumerated in Table 1.

The RIT control is a potentiometer. In the center of rotation, there is a small dead band at which point the RIT value is 0. Rotating clockwise applies positive RIT up to 1.5 kHz. Counterclockwise applies negative RIT up to –1.5 kHz.

Frequency Readout Display

In transceivers with an original digital display, little difference will be noted, depending on how the DDS system is integrated with existing status displays. The DDS board has the functionality to control up to five discrete indicator LEDs. These indicate VFO A active, VFO B active and split operation. In the installation in the Corsair II by WØCCA, the original LEDs with original functions RF ATTN, OFFSET and PROCESSOR were used to indicate these new functions.

Installations in Drake gear may include five LED indicators, which, in addition to the three mentioned above, indicate LOCK and RIT status. Another existing pushbutton toggles the LOCK condition. The RIT LED is illuminated whenever there is a non-zero RIT value.

Stand-alone VFOs

An outstanding VFO for use with early crystal controlled vacuum tube transmitters can be easily constructed using the same DDS board. The author has constructed a VFO for use as a crystal replacement for the Knight T-50 transmitter. Figure 4 is a bottom view of the DDS VFO constructed with the same DDS board used for the HW-101. The only difference is the firmware load for the 16F877A.

The VFO shown in the photos has an integrated transmit/receive (TR) switch. The firmware supports the TR switch, however the TR switch may be omitted if desired. The RF output from the DDS board is a maximum of about 20 V_{P-P} into a 75 Ω load. It provides output in the 160, 80 and 40 meter bands. The display shows the output frequency on the first line and the output frequency of the transmitter on the second line (many radios of the time operated on multiples of the crystal frequency). The operator selects the multiplier, 1, 2, 3 or 4 times that of the VFO, to match the band of the transmitter. The firmware load for the stand-alone VFO and further details may be downloaded from the QST-in-Depth website.

Final Words

This has been a long term project, but one that I am glad I undertook. My HW-101 was useless, but now it is my favorite rig. It is a pleasure to operate. I never get anything but glowing reports on the air.

Notes

[1]The QST-in-Depth website at **www.arrl.org/qst-in-depth** includes firmware and installation instructions for the Corsair II, TR-7 and HW-101 versions and for the stand-alone VFO.

[2]*The ARRL Handbook for Radio Communications,* 2011 Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL order no. 0953 (Hardcover 0960). Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.

ARRL Member Joe Lunsford, N4YG, was first licensed as WN4RUF in 1969 and has held an Amateur Extra class license for 32 years. He has a Master's degree in electrical engineering. Joe is currently retired from his job of over 36 years. He is an avid CW operator who in previous years chased DX regularly, but now enjoys a nice CW QSO. He has designed a dozen or more electronic keyers. The most notable of these is the smart keyer series. He is also the designer of the smart filter. These products were produced and sold in the '80s and '90s, and several hundred remain in service. This venture was discontinued in the late '90s. Since retiring, Joe continues to work part-time, but manages to spend more time operating. Most of his additional time is spent designing electronic products for ham radio and other applications, playing golf and enjoying his seven grandchildren. You can reach Joe at 1304 Toney Dr, Huntsville, AL 35802 or at **n4yg@comcast.net**.