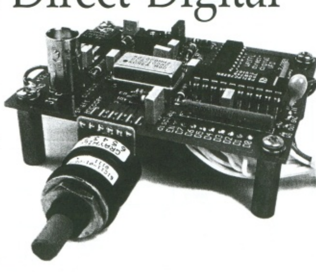
By James D. Hagerty, WA1FFL

A Compact, Direct-Digital VFO



Once available only in expensive commercial transceivers, the DDS VFO—with its accuracy, flexibility and precision—is now a home-brew reality. The VFO described here is compact, has a low parts count and is the perfect way to bring your homemade gear into the 21st century!

If you've been home-brewing radio projects for any length of time, you know that, until quite recently, the thought of using a DDS VFO for your next radio project was only a dream. But thanks to the march of technology, reduced pricing of single-quantity DDS ICs and their ever-increasing integration and performance, DDS technology is now within just about every builder's reach.

The DDS VFO described here is a complete, digitally tuned, variable-frequency oscillator (VFO) with six tuning step sizes—100 kHz, 10 kHz, 1 kHz, 100 Hz, 10 Hz and 1 Hz. The compact unit features a software-controlled spot/key line, a 50-Ω output driver using an RF op amp, a BNC output connector and a compact (2.5 × 3.0-inch) board size. The shaft encoder that tunes the VFO also has an integral pushbutton switch to select step sizes.

The VFO uses a tiny DDS (direct digital synthesis) integrated circuit that generates a digitally derived sine wave with a high-speed clock, cosine look-up table, 32-bit phase accumulator, frequency register and a digital-to-analog converter (DAC). (To brush up on the subject before you dig in, a well-written and interesting tutorial on direct-digital synthesis is available on CD-ROM from Analog Devices.[1])

Originally designed to replace the analog VFO in the W7ZOI/K5IRK high-performance receiver detailed in the 1990 *ARRL Handbook*,[2] the VFO tunes downward from 5.5 to 5.0 MHz to mix with a 3.5 to 4.0 MHz signal to produce a 9-MHz intermediate frequency (IF). The *Handbook* receiver is a real classic that is still viable today. It's an excellent foundation for building multi-band receivers. For added versatility, I've also programmed the single-band VFO for conventional tuning on 80, 40, 30 or 20 meters. The displayed frequency range could be extended by modifying the display software, which simulates a 0-500 "digital dial" (with three places after the decimal).

In the March 1996 issue of *QST*, Jay Craswell described a VFO controlled by a Harris DDS chip.[3] Like many other readers, I built one of Jay's kit VFOs. His design, one of the first published DDS VFO circuits, stimulated my interest in learning about this new technology.

[1]Notes appear on page 38.

In the same time period, several new DDS processors were introduced by Analog Devices. Some of the larger chips had staggering levels of integration. For example, the AD9854 (a big brother of the chip used here) features a 300-MHz clock rating and two built-in, 12-bit D/A converters, and multiple frequency- and phase-control registers.

More recently, other advances in integrated circuits have included microprocessors with integrated clock oscillators, LCDs with integrated, on-board data conversion circuitry and further strides in RF op-amp technology, simplifying DDS VFO design even further.

As I started the design process, a smaller device, the AD9835, appeared to be ideal for an amateur VFO. It has a 50-MHz clock speed rating, a built-in 10-bit DAC and two frequency registers. Unlike the Harris chip, it uses serial control signals. I decided to design a scratch-built VFO that used the new technology, banking on its potential for improved miniaturization, better close-in spurious energy suppression and simplified circuit architecture. [Editor's note: The ARRL Lab measured phase noise at a level about as low as the Lab can measure. Frequency

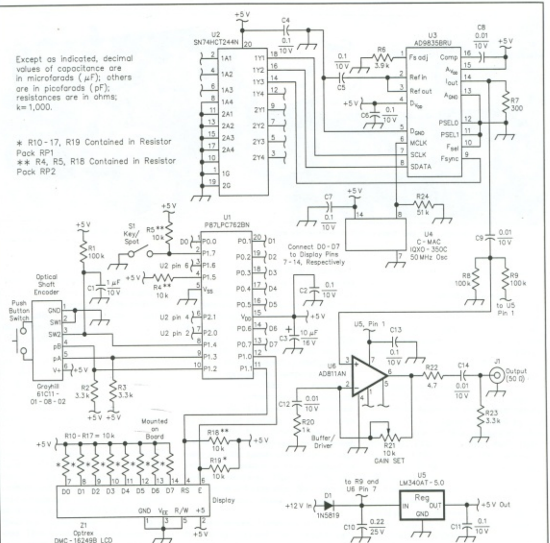
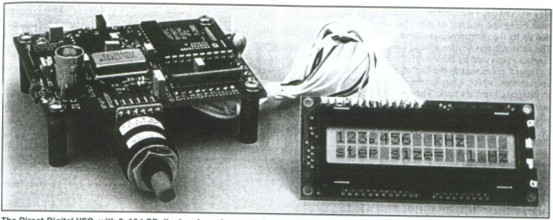


Figure 1—The Digital VFO schematic diagram and parts list.

C1—1 µF ceramic, 10 V or higher.
C3—10 µF tantalum, 16 V.
C2, C4, C5, C6, C7, C11, C13—0.1 µF, 10 V or higher, ceramic.
C8, C9, C12, C14—0.01 µF, 10 V or higher, ceramic.
C10—0.22 µF, 25 V or higher, ceramic.
D1—1N5819 Schottky diode (General Semiconductor), Digi-Key.
J1—PC-mount BNC connector, Amphenol 31-5329, Digi-Key.
R21—10 kΩ potentiometer, Bourns 3266W, Digi-Key 3266W103-ND.
RP1, RP2—10 kΩ resistor arrays (nine- and five-resistor versions, respectively) made by CTS, Digi-Key part numbers: RP1: 770-101-R10K-ND; RP2: 770-61-R10K-ND. These are used for R10-17, R19, R4, R5, and R18.
R1, R8, R9—100 kΩ, ½-W carbon film, 5% tolerance.
R2, R3, R23—3.3 kΩ, ¼-W carbon, 5%.
R6—3.9 kΩ, 5%, ¼-W carbon.
R7—300 Ω, ¼-W, 5%, carbon.
R20—1 kΩ, 5%, ¼-W, carbon.
R22—4.7 Ω, ¼-W, 5%, carbon.
R24—51 kΩ, ¼-W, 5%, carbon.
S1—SPST switch, C&K, Digi-Key (use surplus if available).
U1—Philips P87LPC762BN microprocessor. Available from New Tech Solutions, 781-229-8888.
U2—TI SN74HCT244N digital buffer.
U3—Analog Devices AD9835BRU direct-digital synthesizer (available in surface-mount package only). For distributors, call Analog Devices, 781-329-4700.
U4—50-MHz DIP oscillator, 10-TTL-load capability (C-MAC IQXO-350C, Advanced Component Group, Shrewsbury, MA, tel 508-845-2023; or ECS ECS-100AC).
U5—National LM340-AT-5.0 regulator.
U6—Analog Devices AD811AN operational amplifier.
Z1—LCD, 2×16 lines, Optrex DMC-16249B or DMC-16204 or Varitronix MDL-16265-LV, all available from Digi-Key. The Daewoo 16216L-5-VSO will also work and is available from All Electronics (catalog part no. LCD-53). Note: This display has an LED backlight: Pin 15 = +5 V; pin 16 = GND (place a 20-Ω, ½-W resistor in series with pin 15).
Optical Shaft Encoder—Grayhill 61C11-01-08-02.
20-pin IC socket for microprocessor—Digi-Key no. ED3120-ND.



The Direct-Digital VFO, with 2×16 LCD display. Any of several displays will work with this project. See the parts list in the caption for Figure 1.

accuracy was about 4 ppm, or 31 Hz at 7 MHz. Power output was measured at +13 dBm, more than enough to drive common mixers. Close-in spectral plots provided by the author showed spurious output well within FCC standards.]

The AD9835 data sheet specifies a maximum output frequency of 25 MHz with a 50-MHz master clock frequency. Because outputting a 25-MHz signal with the chip itself running at 50 MHz tends to produce a pretty ragged carrier, Analog Devices actually recommends programming the chip for a carrier frequency of 20 MHz or less.

In this VFO design the output frequency is also limited by the frequency response of U6. Interestingly, because the output frequency is controlled by 32-bit numbers that are loaded into the DDS phase accumulator, some output frequencies across a given 500-kHz band will appear noisier than others on an oscilloscope. This is normal and expected behavior with this type of numerically controlled oscillator.

The Microprocessor

As detailed in the schematic shown in Figure 1, the microprocessor is a critical component of any DDS system. It decodes the shaft encoder, sends updated information to the display, selects the tuning step size and calculates the new 32-bit constant for the frequency-control register inside the DDS (AD9835), thus "tuning" the output signal.

Because I had a reliable (although 10-year-old) 8051 assembler at my disposal, I chose to use an 8051-family subset. The Philips P87LPC762BN is a new chip design that is code-compatible with the time-proven 8051 instruction set. The "LPC" stands for "low pin count."

I was able to develop all of the software for the VFO's microprocessor using my trusty old 8051 assembler made by American Automation (no longer supported). If you don't happen to have access to a similar device, many 8051 assemblers are still available, including a deluxe model by Keil that's sold by Ceibo (**www.ceibo.com**). The Keil unit, recommended by Philips for its new microprocessors, supports virtually any 8051 variation. Other 8051 assemblers are available as shareware on the internet, but be careful of viruses when downloading unfamiliar products. Another Philips recommended 8051 development tool is available from Raisonance (**www.amrai.com**). All 8051-family derivatives are supported. The product I used to program the microprocessor was a Philips 8xC76x programmer, which cost about $100. It's PC-controlled, menu-driven, convenient and worked well.

In the process I discovered that many microprocessors are now available only as write-once programmable chips. The windowed, UV-erasable parts are becoming rather rare. This is the case for the Philips unit. Manufacturers say that it costs more to make the ceramic windowed case than it does to make the microprocessor itself. Still, I miss the flexibility of UV-erasable parts.

The Philips micro has only 20 pins and some unique, appealing features, including an internal 6-MHz clock oscillator and a built-in initial reset circuit, which makes it possible to configure the chip to execute code with no external components—a boon to miniaturization and EMI reduction.

The Circuit

The DDS control signals generated by the microprocessor (enable, clock and serial data) were all probed with a logic analyzer to confirm that they produced the correct timing and data waveforms.

The microprocessor (U1) reads the Grayhill shaft encoder and determines the direction of the coded "clicks." It translates these tuning inputs into a higher or lower tuning number for the direct-digital synthesizer, the AD9835, generating the proper serial control signals to download the new constant.

U2 is a buffer/line driver recommended by Analog Devices to provide the fast-rise-time signals needed by the AD9835. The '9835 is clocked by U4, a 50-MHz, TTL-compatible, dual-inline-package (DIP) oscillator. The two types that I used (C-MAC and ECS) were specified for 10 TTL loads.

The C-MAC oscillator (part no. IQXO-350C) has a stability tolerance of ±100 parts per million (ppm) and an accuracy spec of ±25 ppm. This particular part is also available in ±5 ppm and ±10 ppm tolerances (contact C-MAC, 919-474-3500, ext 3554.) The Analog Devices AD9835 evaluation board actually used one of the IQXO-350C units, which was terminated with a 51 kΩ resistor.

A software-controlled keying line is provided in the VFO package. The DDS can be initialized and even tuned in "sleep" mode until the operator is ready to turn on the AD9835's output stage. This is accomplished by polling one of the microprocessor port lines and providing the correct control signals to enable the DDS output.

The display is an affordable, parallel-loaded unit made by Optrex. Serial-loaded displays were investigated, and several were available with on-board conversion circuitry, but the price of these units approached $50. The parallel display worked quite well, the only compromise being the number of pins that are tied up by the microprocessor driving it. The software was written around timing diagrams provided by the manufacturer.

Optrex recommends the use of pull-up resistors, which I implemented with an integrated resistor pack. The displays mentioned in the parts list, including an older Varitronix unit, all worked well.

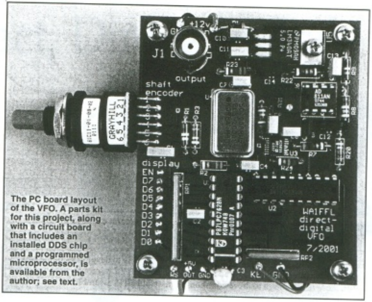
Finally, U6 buffers the DDS output and provides a small amount of gain in the lower HF region. This op amp, an Analog Devices AD811, can drive a 50-Ω load. In the output stage, R22 provides extra load stability and C14 gets rid of the dc offset. R23 provides a discharge path for C14 during testing, but is still large enough to avoid loading down a 50-Ω connection. A BNC output connector is provided for easy cabling to mixers, etc.

A number of frequency bands were programmed up to 14 MHz. At frequencies approaching 10 MHz, the output waveform begins to look a bit triangular. Analog's Bill Chestnut suggested I use some output filtering if the signal is amplified as-is with no conditioning. On the other hand, if the signal drives a diode-ring mixer (used in the W7ZOI/K5IRK design and many home-brew circuits), it will be clipped, anyway.

Once again, the application will determine whether filtering is required. Following the VFO with a high-Q tuned amplifier may be sufficient. The buffered VFO output stage will make it easier to drive a 50-Ω filter, if necessary. One approach is shown in the AD9850 data sheet (a cousin of the '9835), available at **www.analog.com**. The applications note shows an elliptical, low-pass output filter that can be scaled to provide the desired cutoff frequency.

Other filter circuits are available in the *ARRL Handbook*. A set of excellent band-pass filter designs is provided by Wes Hayward, W7ZOI, and John Lawson, K5IRK, in their "High-Performance Communications Receiver," which ran in the 1983-1990 editions of *The ARRL Handbook*.[2] The first section of this band-pass filter contains a five-pole low-pass filter that I used at the output of Jay Craswell's VFO circuit. Another amplifier stage might be necessary to offset the filter's insertion loss.

The VFO's double-sided printed circuit board was laid out using *Eagle* layout software. The completed board, along with a display and shaft encoder, is shown in the photographs. A parts kit for this project, along with a circuit board that includes an installed DDS chip and a programmed microprocessor is available. Please send me a note via e-mail or postal mail, and I will supply the details.



The PC board layout of the VFO. A parts kit for this project, along with a circuit board that includes an installed DDS chip and a programmed microprocessor, is available from the author; see text.

As with any VFO, I strongly recommend mounting the board inside a shielded enclosure. A rectangular window cut out of one side of the enclosure will allow the display to be mounted while preserving the shielding effect as much as possible.

Thanks

I'd like to acknowledge the help of Bill Chestnut and Chuck Kitchin of Analog Devices for their advice on the AD9835 and AD811, respectively, and Tom Riley for his significant advice on the PCB layout. His salary: a free VFO kit! Paul Mileski provided generous assistance in making spectrum measurements and plots.

I hope that this article has made DDS technology more accessible. It's not an exaggeration to say that this VFO has the tuning agility of an LC oscillator, the stability of a crystal and the precision of a 32-bit computer!

Notes

[1]Analog Devices, Norwood, MA 02062, "A Technical Tutorial on Digital Signal Synthesis" (CD-ROM).

[2]Wes Hayward, W7ZOI, and John Lawson, K5IRK, "A High-Performance Communications Receiver," *The ARRL Handbook for Radio Amateurs*, 1990, pp 30-8 through 30-15.

[3]James Craswell, "Weekend DigiBrain," *QST*, Mar 1996, pp 32-34.

[4]Data Sheet, Philips 87LPC762 Microprocessor, Philips Semiconductors, Sunnyvale, California (available at **www.philips.com**).

[5]Data Sheet, Analog Devices AD9835 Direct-Digital Synthesizer, Analog Devices, Norwood, MA 01062 (available at **www.analog.com**).

[6]Optrex LCD User Manual, Optrex America, Inc, Plymouth, Michigan (available at **www.optrex.com**).

James Hagerty, WA1FFL, was first licensed in 1965 as WN1FFL and became a 15-year-old Amateur Extra in 1968. He is an electrical engineering graduate of Cornell University and holds an MSEE degree from the University of Rhode Island. Jim has been a design engineer in Newport, Rhode Island for the past 26 years. He can be reached at 64 Nonquit Ln, Tiverton, RI 02878; **wa1ffl@arrl.net**.

STRAYS

QST Congratulates...

◊ John Cunningham, WB4JUN, of Columbus, Georgia. John made news recently when he donated $2 million to Columbus State University (CSU) for a new building that will be the first phase of a 60,000-square-foot conference center. The gift was the third largest in CSU's history and will establish the John Cunningham Sales and Leadership Institute. John, now retired, owned Radio Wholesale in Columbus that provided equipment to hams in the south-east and in many foreign countries.

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