FEATURE ARTICLE

by Stuart Ball (USA)

Build a Digital Dip Meter

A dip meter is a handy piece of test equipment typically used to check a device's resonant frequency or as a signal source to tune receivers. This article describes how to use a microcontroller to digitize a dip meter's display and explores how to maintain functionality when converting a design from analog to digital.

A dip meter, originally known as a grid-dip meter, is a piece of test equipment that goes back to the early days of amateur radio. It consists of a tunable RF oscillator with the tuning coil exposed outside the chassis. When the coil is brought near a resonant circuit (e.g., an inductor-capacitor tank circuit) and when the oscillator is tuned to the same frequency as the resonant circuit, the circuit will draw energy from the oscillator. This results in a dip of a meter that is in the oscillator's grid circuit (in an older vacuum-tube design). The coils plug into the dip meter so different coils may be used for different frequency bands.

The dip meter's coil is part of a tuning circuit consisting of the coil and a variable capacitor. The variable capacitor is connected to a dial on the front of the chassis that is marked with the oscillator's frequencies. When the meter "dips," indicating the dip meter oscillator is at the same frequency as the resonant circuit, you can read the frequency from the dial.

In a more modern dip meter, a transistor is used instead of a vacuum tube and the meter is typically in the gate circuit (if the transistor is a FET) or the base or collector (if the transistor is a bipolar type). Figure 1 shows a typical schematic for a transistor dip meter using an MPF102 FET. The meter is in the FET's gate circuit.

Although the schematic shows the meter's negative side connected to the gate circuit and the positive side grounded, it is not wired backward. Due to this circuit's self-biasing nature, the gate voltage is negative while the circuit is oscillating. The oscillator sine signal appears at the gate, but it is shifted below ground so the average (DC) level is negative. C5, the capacitor across potentiometer RV1, filters out the RF leaving the negative DC value applied across the meter.

A dip meter's typical purpose is to check the resonant frequency of an LC tank circuit, crystal, or antenna. Dip meters can be used as signal sources for tuning receivers. I have even used one as a local oscillator for an RF mixer circuit.

Dip meters are simple to build and use. Thousands have been bought, constructed from kits, or built from scratch by amateur radio operators over the years. Fewer amateurs build their own equipment now and many of the dip meter's uses have been taken over by other equipment (e.g., inexpensive frequency counters). In addition, many circuits that dip meters used to measure (e.g., LC tanks) are now implemented with ceramic filters or other methods.

Why discuss an obsolete tool for amateur radio in a magazine that isn't necessarily oriented to radio amateurs? The answer is

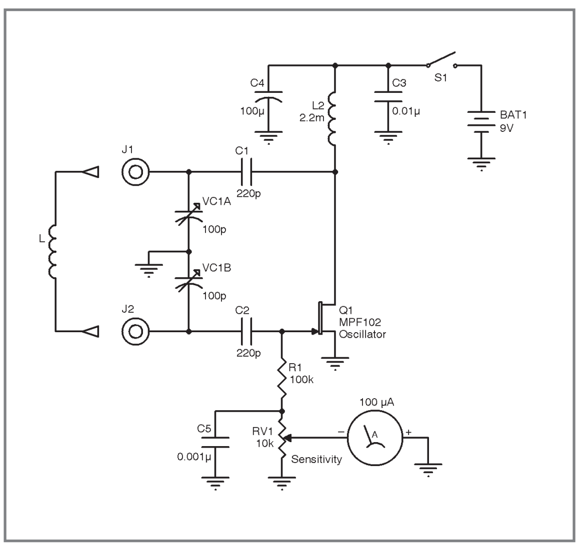

Figure 1—Here is a typical analog dip meter circuit's schematic. The 100-µA meter in the gate circuit dips when the oscillator is tuned to the same frequency as the circuit it is measuring.

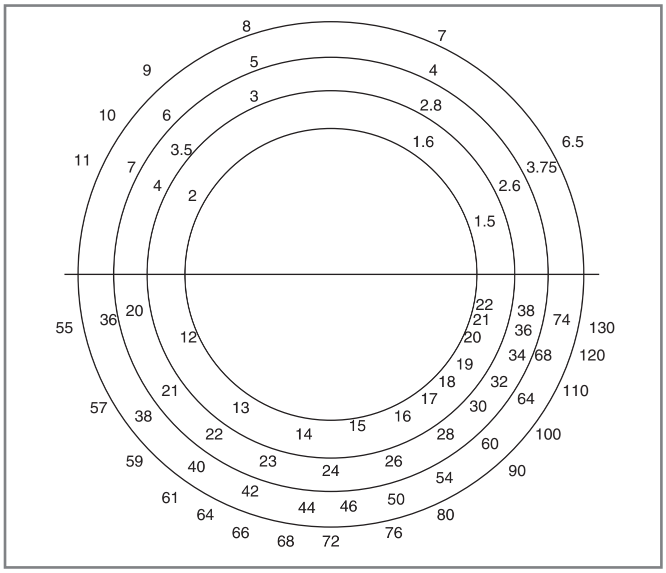

Figure 2—This is a dial from an old homemade analog dip meter. Note the compression of the frequency bands to the end of the dial with the higher frequencies.

straightforward: because this project uses a microcontroller to digitize a dip meter's frequency display, which solves several problems to using dip meters. Consequently, this article provides an instructive look at what is needed to convert a design from analog to digital while retaining the original functionality. It also demonstrates some issues and obstacles that can be solved by adapting an older analog design to digital.

THE OLD WAY OF DOING THINGS

Although the dip meter is a simple circuit with a simple concept, it does suffer from some drawbacks. I will discuss each of these in detail.

Frequency pulling: This is one of the most problematic issues in dip meter use. When the dip meter's coil is brought near a resonant circuit, the resonant circuit draws energy from the oscillator. It also pulls the oscillator frequency. In some cases, the resonant circuit can pull the oscillator by several megahertz. There are some ways around this. Usually, you try to couple the oscillator to the resonant circuit as loosely as possible by increasing the distance between the oscillator coil and the resonant circuit's coil. This reduces but does not eliminate the issue, and it reduces the dip meter's sensitivity so the dip is less pronounced and harder to see.

Even with minimal coupling, there is some frequency shift. And, since the frequency markings on the dip meter dial are fixed, you do not know how much the frequency has been shifted.

Bandspacing: A dip meter's dial is usually circular or semicircular. Figure 2 shows a typical dial from a homemade meter. There are only so many bands that can be shown on the dial. So, if there is room for eight bands on the dial, then only eight coils can be made and only eight frequency ranges can be used. The typical frequency range using a common variable capacitor is about 2:1, so for a dip meter that is going to operate from 1 to 100 MHz, you might have seven bands like this:

1–2 MHz, 2–4 MHz, 4–8 MHz, 8–16 MHz, 16–32 MHz, 32–64 MHz, 64–128 MHz

If you were building a dip meter like this, you would actually put in a little overlap. So, the second band might be 1.9 to 3.8 MHz so it overlaps the first band, the third band would be 3.6 to 7.2 MHz, and so on. But either way, if you wanted to have expanded tuning over the range of, say, 4 to 4.5 MHz, you would need another frequency band on the dial. You would quickly run out of dial space if you did this for more than one or two frequency bands.

Dial compression: Because of the way variable tuning capacitors work, the frequencies tend to be compressed at one end of the dial. Figure 2 shows that the first third of the frequency span takes up half the dial and the remaining two thirds are compressed into the last half of the dial. This makes the higher frequencies harder to read.

Dial resolution: It can be difficult to read the frequency precisely due to the inability to show more than a limited number of lines on the dial and the parallax of reading the frequency from a tuning dial connected to the variable capacitor's shaft.

Calibration: This is not a problem for a purchased meter, but if you were building a meter from scratch, you would have to calibrate the dial. This means you need a relatively

Photo 1—This digital dip meter prototype shows an external LC circuit and the various tuning coils. The block of wood is used so the test circuit will be the same height as the dip meter coil.

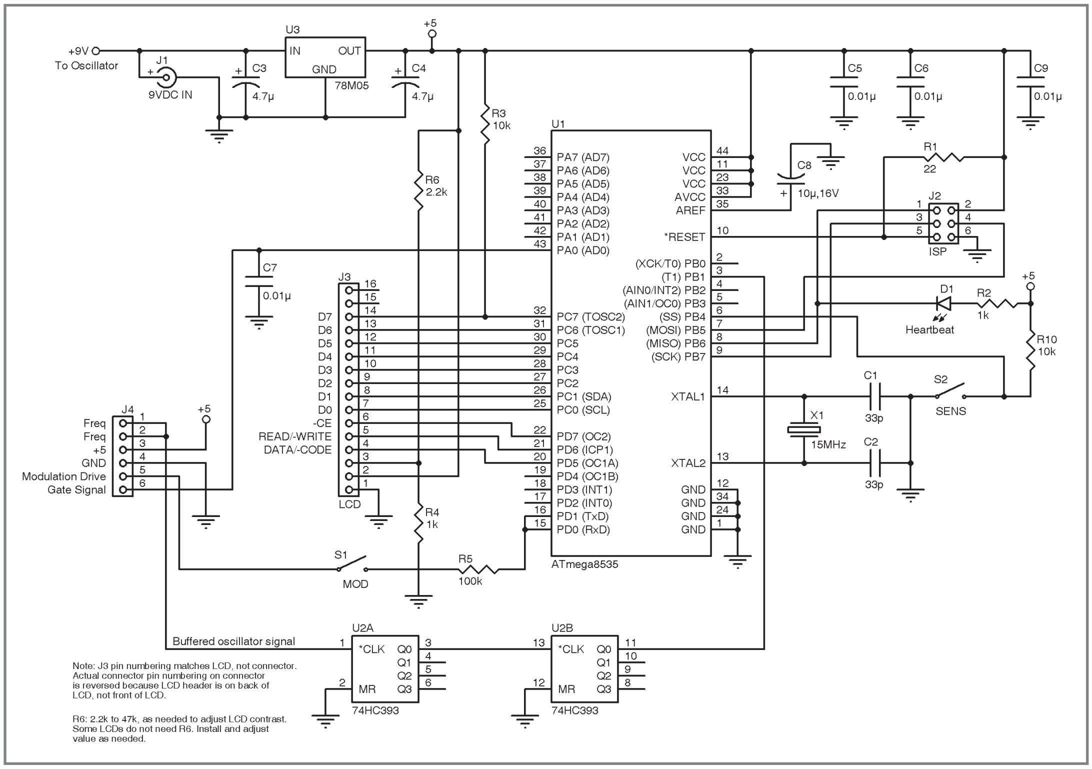

Figure 3—The circuit uses an Atmel ATmega8535 microcontroller in a PLCC-44 package.

accurate receiver, oscilloscope, or frequency counter to calibrate each band.

NEW SOLUTIONS

This project's circuit solves most of those problems by using an LCD to digitally display the frequency. I will now detail how each of the problems are resolved.

Frequency pulling: The resonant circuit will still pull the frequency, but since the LCD directly reads the actual frequency, you know exactly how much. When I tested the prototype, I was surprised at how much a crystal or resonant LC circuit would pull the oscillator frequency.

Bandspacing: Since there is no dial, there is no limitation on the number of coils. Consequently, you can have coils for much smaller bandwidths that will enable more precise frequency tuning. In the prototype circuit, I bridged the coil for 6.7 to 15.5 MHz with a 56-pF capacitor and the frequency span became 4.8 to 6.3 MHz. So, the new tuning range is 1.3:1 instead of 2.3:1.

Dial compression, dial resolution, and calibration: The digital meter has no dial, so there are no compression or resolution issues and no calibration is needed. It is true that the compression effect is still there. The last half of the tuning arc is still the last two thirds of the tuning range. But the frequency can be directly read, so this is more a problem of manual dexterity than accuracy.

CIRCUIT COMPLEXITY

These improvements do come at a cost, of course. Some of the drawbacks are detailed below.

Increased circuit complexity: Instead of a simple, single-transistor circuit, the circuit has four transistors, an additional regulator, a microcontroller, a crystal, and assorted other parts. In addition, the microcontroller firmware must be developed.

Increased design complexity: The original circuit can operate to about 200 MHz if carefully constructed. The only limiting factor is the transistor itself and the circuit layout. For the digital design, the maximum frequency can be limited by the oscillator transistor, the microcontroller's divider, and the buffer amplifier. In the prototype, the divider IC limits the maximum operating frequency to about 100 MHz.

CONSTRUCTION

Photo 1 shows the digital dip meter. The schematic is shown in Figure 3 and Figure 4. The circuit is built on three prototype boards so everything fits in the case. You could build it on one board, but you might find it difficult to get the circuit to fit neatly into the case since the LCD and the tuning capacitor are at different heights.

All components are standard 0.25-W resistors, 10% or 20% capacitors at 25 or 50 V. The transistors were TO-92. The Texas Instruments (TI) UA78L05 fixed-voltage IC voltage regulator was a TO-92. The TI UA7805 was a surface-mount power package used for voltage regulators and transistors, but a TO-220 would also work. Electrolytic capacitors can be radial or axial types. Of course, you could make a PCB and use all surface-mount components to shrink the circuit size.

The digital dip meter features an Atmel ATmega8535 microcontroller, which is readily available, inexpensive, and has an on-chip ADC for the meter function. It also has a counter with an external count input, which is essential for frequency counting. Aside from the requirement for an external count input, almost any microcontroller can be used (although some would obviously need an external ADC). The prototype's microcontroller was in a plastic leaded chip carrier (PLCC) package so it could be easily socketed.

The display is an 8 × 2 LCD. The top

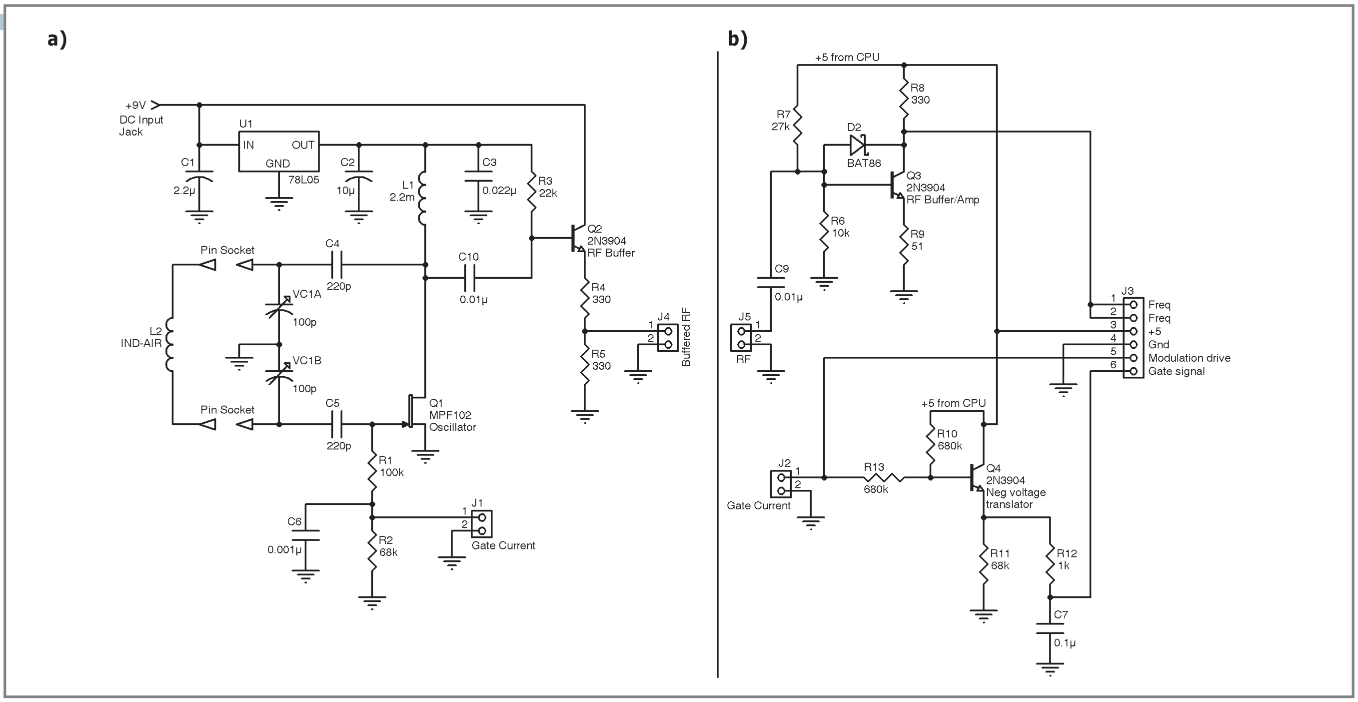

Figure 4—These are the schematics for the digital dip meter's oscillator board **(a)** and buffer board **(b)**.

line displays the frequency (four digits) and the bottom line shows the analog gate current (really the voltage) amplitude. The analog meter function uses custom characters programmed into the LCD memory to simulate an analog display. Using this technique, an eight-character LCD can display up to 40 analog values. I described this technique in my article "Analog Bar Graph Display" (*Circuit Cellar* 183, 2005).

On the oscillator board, transistor Q1 is the oscillator, which is the same as in the analog design. Q2 buffers the RF signal so the digital front end doesn't load the oscillator signal.

On the buffer board, Q1 is a negative voltage translator. The voltage at the oscillator transistor's gate is negative so it has to be translated to a positive voltage for the microcontroller ADC. Q2 buffers and normalizes the RF signal. Note that diode D2 on the buffer board is a Schottky diode. This is important to keep Q3 from saturating. Without D2, or if D2 is a normal silicon diode, Q3 will saturate and the operating frequency will be severely limited.

The buffered RF signal from the buffer board connects to U2 on the processor board. U2 is an NXP Semiconductors 74HC393 CMOS device that is wired to divide the incoming frequency by 32. This enables operation to about 100 MHz. The divider is needed because the microcontroller can only accept a frequency input up to about 3.75 MHz.

The microcontroller accepts the divided frequency output into one of its counter inputs and counts the frequency by periodically capturing and sampling the count. I chose the 15-MHz crystal to make the math easy when converting counts to megahertz.

The buffered, level-shifted voltage at the oscillator gate drives the analog input on ADC0. The gate voltage's negative value must be translated and scaled to match the microcontroller ADC's analog input range. The scaling circuit is fairly simple because the display is viewed by the user, so precise scaling is not needed. Some analog circuit conversions require more complicated level shifting and scaling circuits to bring an analog signal into an acceptable range.

Switch S2 is read by the microcontroller and used to adjust the analog meter's sensitivity so dips can be more easily seen when the gate voltage's value is low. Because the oscillator gate goes less negative when it is in resonance with an external circuit, the "dip" is actually a "peak" in this circuit (i.e., the meter voltage jumps up, not down, when resonance with an external circuit is reached).

The software senses S2's value (high or low) and either divides the ADC output by 2 or by 4 before displaying the analog value on the LCD. The ADC is configured to use the microcontroller's internal 2.5-V reference.

Switch S1 provides an audio modulation output to the oscillator via the gate circuit when closed. The modulation signal is generated on the asynchronous serial output pin by the microcontroller. The microcontroller continuously sends a fixed-serial byte to the asynchronous serial transmitter to generate a fixed tone. This enables the dip meter to be used as a modulated signal source for checking receivers.

Coils are connected to the circuit using a pair of sockets from a pin-and-socket connector, soldered to the oscillator board, and passed through two holes drilled in the case. Banana jacks or pin jacks can also be used.

The prototype's coils are simply off-the-shelf inductors mounted on perfboards for strength. Ordinarily, they would be covered with heatshrink tubing. I left them uncovered so the construction would be obvious. You could also hand-wind coils using wood dowels or plastic forms as cores.

The tuning capacitor is not critical. It needs to be a two-section variable capacitor with a shaft on which a knob can be attached. This type of capacitor is not as common as it once was, but you can still find them on the Internet. I used an air-variable capacitor. You could also use the type of poly capacitors that come from a transistor radio. The schematic shows the capacitor with two identical 100-pF sections. You could also use capacitors with two 270-pF sections or other values. The two sections do not need to be identical values; 135- and 100-pF sections would work. You could go down to something such as 50-pF per section, but you would need more coils to cover the same frequency range. The circuit runs from an external "wall wart," 9-VDC, 300-mA power supply.

TESTING THE CIRCUIT

The circuit is fairly easy to test. You simply plug in a coil, apply power, and verify that the oscillator frequency is displayed and the analog value is showing on the display's bottom line. As you tune across the frequency band, the analog voltage will vary.

You can test the dip functionality by connecting an inductor and capacitor in parallel and checking for a dip. Photo 1 shows an old choke from my junkbox in parallel with a ceramic capacitor. When you tune through their resonant frequency, there will be a small jump in the analog reading.

You can also check the circuit by connecting a crystal's leads with a two-turn link of wire then placing the wire link near the dip meter coil. However, crystals have very sharp tuning, so you must tune very slowly to see the peak. Once you tune the circuit to resonance, you can see how much the resonant circuit pulls the oscillator frequency by moving the dip meter away from the resonant circuit and watching the frequency change.

GOING FURTHER

You can improve the circuit. You can replace U2 with a front-end counter. This would enable the circuit to operate at the oscillator's full range.

You could replace switch S1 with a potentiometer connected to analog input ADC1 so the sensitivity is continuously variable, as on the analog dip meter. The potentiometer would just provide a varying voltage to the microcontroller that would be used to determine the analog signal's scaling factor. Or, you could use a potentiometer to vary the analog voltage to the microcontroller ADC input and no software scaling would be needed. You could replace R5 on the oscillator board with a 300- or 500-Ω potentiometer.

A 16-character LCD would enable better resolution of the analog "meter" value by enabling 80 discrete analog voltages to be displayed instead of 40. But that would come at the expense of a larger case.

This project demonstrated some interesting design considerations. It also showed the advantages of converting an analog circuit like this to digital monitoring and control. ■

Stuart Ball is a registered professional engineer with a BSEE and an MBA. He has more than 30 years of experience in electronics design. He is currently a principal engineer at Seagate Technologies.

RESOURCE

S. Ball, "Analog Bar Graph Display," *Circuit Cellar* 183, 2005.

SOURCES

ATmega8535 Microcontroller
Atmel Corp. | www.atmel.com

74HC393 CMOS Device
NXP Semiconductors | www.nxp.com

UA78L05 and TI UA7805 Fixed-voltage IC voltage regulators
Texas Instruments, Inc. | www.ti.com