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Not Simply Another Keyer!

That's right! It's better.

Radio operators can send high-speed CW with a speed key similar to the Vibroplex "Bug," but it's even easier when they use a keyer with self-completing dots and dashes.

In a strict sense, a keyer is just the switch that is closed to turn on the transmitter, but usually it includes more: It generates dots and dashes. The keyer described generates a self-completing dot-space or dash-space sequence with the momentary closure of a key. Self-completing means that a momentary closure of the dot key generates a full dot-space sequence. A

Fig. 1. (a) The keyer is built with monostable multivibrators. (b) The monostable multivibrator uses CMOS ICs.

momentary closure of the dash key generates a full dash-space sequence. That is, when a dot or dash is initiated it cannot be interrupted. The keyer requires an SPDT key: one contact to make dots and the other to make dashes.

The keyer uses two inexpensive CMOS gates: a CD4001, a quad dual-input NOR gate, and a CD4011, a quad dual-input NAND gate, and a MOSFET switch. A run-of-the-mill N-channel power MOSFET can key anything from a low-power QRP transmitter to a California kilowatt. I used a TO-220 style MOSFET to key a 15 kW commercial transmitter.

This keyer has speeds adjustable from about 25 words per minute (WPM) down to about 10 WPM. Of course, you can select any other speed range that suits your fancy by changing R2, R3, and R6, or C1, C2, and C3 in **Fig. 2**. The speed control gets pretty touchy at the slow end of the control range — that's why the range is limited to about 2:1. An audio taper or log taper pot will ease the problem of making small changes to the speed control voltage for obtaining slower speeds.

I suggest that for slow-speed operations the characters be sent at 10 or 15 words-per-minute, but with letters

spaced to suit the receiver's speed. When a friend of mine went to take the test, she couldn't handle 5-word-per-minute characters, so the VEC upped the speed to ten and she had no problems. At 15 WPM or so you begin to hear the sound pattern that represents a letter, not the dots and dashes that form the letter. At 5 WPM the characters are so slow that you don't hear a pattern. Or at least I don't.

This keyer can be built for less than $10 and an evening's construction time. A printed circuit board is not necessary; point-to-point wiring or wire-wrap wire on perfboard is just as good. While I used wire-wrap sockets, it's certainly not required.

The keyer can run on a 9-volt transistor battery or four AAA 1.5-volt cells. A power MOSFET like the IRF630 can switch a final amplifier with 5 A of peak plate current and a cutoff voltage of 200 volts. The MOSFET needs a gate drive of less than 6 V, and the current is negligible. Battery drain is less than 0.1 mA.

The functional block diagram is shown in **Fig. 1(a)**. The timing blocks are three monostable multivibrators: One mono sets the time for the dot, one for the dash, and the third one for
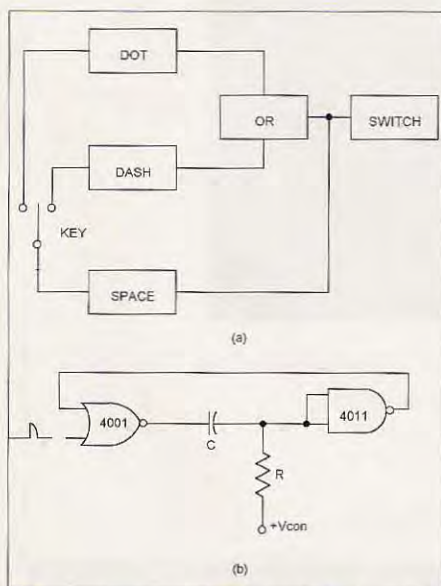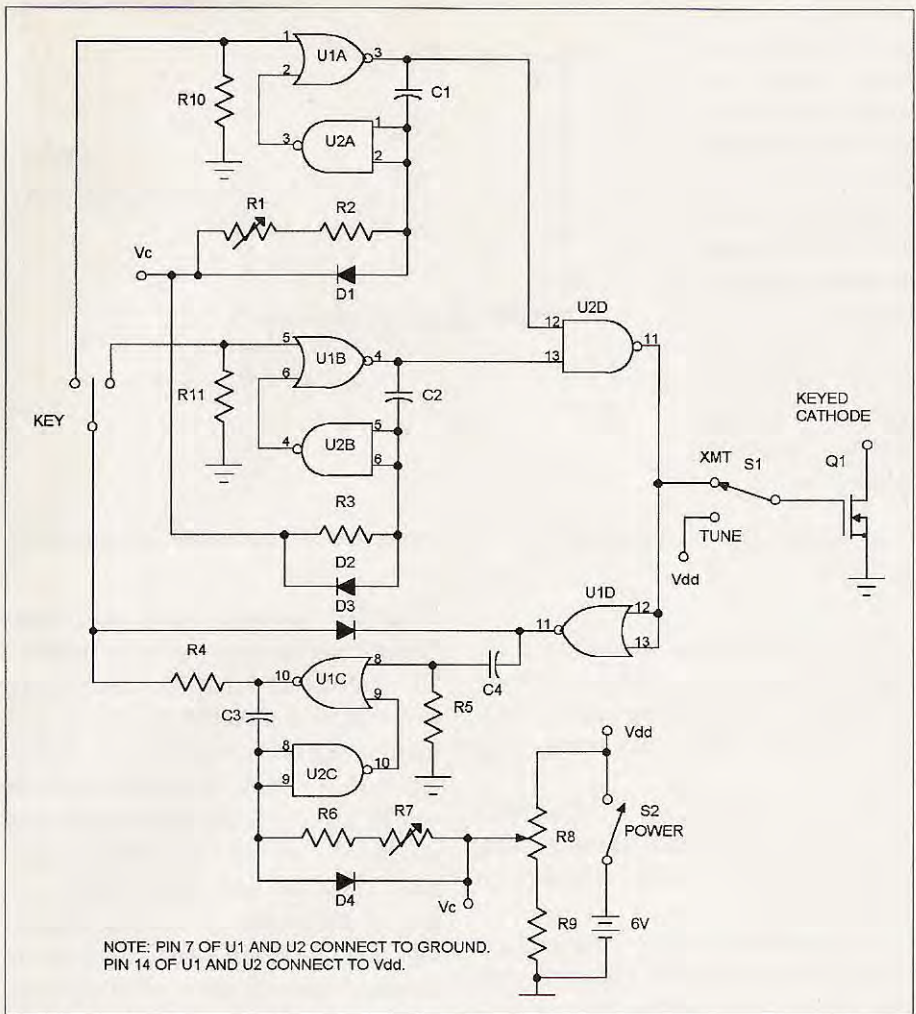
Fig. 2. *The keyer uses 2 CMOS ICs and a MOSFET.*

the space. The basic monostable multi-vibrator is shown in **Fig. 1(b)**. Timing is set by the RC product and the control voltage, Vc. The inverters used in the monos should all be in the same package so that the timing of the three will track as the control voltage is varied. The spec sheets for the CMOS shows worst case threshold voltage varying as much as ±10%. However, when the gates are on the same chip, the thresholds track much better than 1%.

An N-channel power MOSFET is used as the keying switch. A common garden variety power MOSFET like the IRF630 will do the job. For other MOSFETs, choose one with VDS greater than the tube's cut-off voltage and ID capable of carrying the tube's peak cathode current. For solid state transmitters, the voltage to be switched probably will be less than 24 volts and the current probably a few mils. This can be done with a small TO-92 MOSFET like Motorola's 2N7000.

The monostable multivibrator is built around the CD4001, a CMOS quad dual-input NOR gate, and an inverter. The inverter is actually a CD4011, a quad dual-input NAND gate, with both inputs tied together. The truth tables for the ICs is given in **Table 1**.

In the stable state, the inverter's input is V_c. When V_c is greater than the IC's threshold voltage, $0.55V_{DD}$, the inverter's output is zero. The inverter's low output is fed back to the NOR's

CD4001			CD4011		
A	B	C	A	B	C
0	0	1	0	0	1
0	1	0	0	1	1
1	0	0	1	0	1
1	1	0	1	1	0

Table 1. Truth tables.

input. In the stable state both inputs to the NOR are low. In the timing state, the inverter's output is high and the NOR's output is low. The "high" fed back to the NOR's input keeps the NOR's output low after the trigger is removed. Subsequent triggers during the timing period then have no effect.

The multivibrator is triggered by a momentary high from the key. The arm of the key is high after the space following either a dot or a space and low during the space period and while the transmitter is "key down."

Taking the trigger input of the NOR gate above the threshold makes the output go low. This change in the NOR's output from V_{DD} to ground is coupled through the capacitor C to the inverter's input. The inverter's output then goes high to V_{DD}, and is fed back to the input of the NOR gate which holds the NOR output low. This condition prevails until the capacitor charges to V_{TH} through R at which time the inverter switches to it's stable state.

The diodes from the inverter's input to V_c clamp the maximum input voltage to V_c and permits the inverter's input

voltage to return to V_c before the next trigger arrives. The diodes can be any small silicon diode — either the 1N4148 or 1N916 are good inexpensive choices.

The time required for the capacitor to charge to the threshold voltage is:

$$t = RC \times \ln(1 - V_{TH}/V_c)$$

where t is the time in seconds, ln is the natural logarithm, V_{TH} is device threshold, and V_c is the speed control voltage. V_c must always be greater than V_{TH}.

If you're comfortable working with logarithms you can skip the next paragraph, but if a little refresher is needed, read on.

A logarithm is the exponent to which the base must be raised to yield the number. For example, the common logarithm is base 10 and is written as log, but sometimes as $\log_{10}$. The $\log 1000 = 3$. That is, the base 10 must be raised to the 3rd power to produce 1000, $10^3 = 1000$. The base of the natural logarithm, denoted as epsilon e and written as ln, is 2.71828. To convert from the base 10 to base e, multiply the common logarithm by 2.3026, $\ln N = 2.3026 \times \log_{10} N$. Most calculators have entries for both common logarithms and natural logarithms. Just in case yours doesn't, remember that you can convert from common to natural logarithms by multiplying the common log by 2.3026.

The period of the shortest time, the dot or space, occurs when the control voltage is V_{DD}. The shortest time determines the maximum keying speed.

The period of a space or dot can be calculated from the standard word "PARIS" which is made up of 43 spaces. 25 words-per-minute equates to 1075 spaces per minute or 17.9 spaces per second. The time of a 25 words-per-minute (WPM) space or dot is about
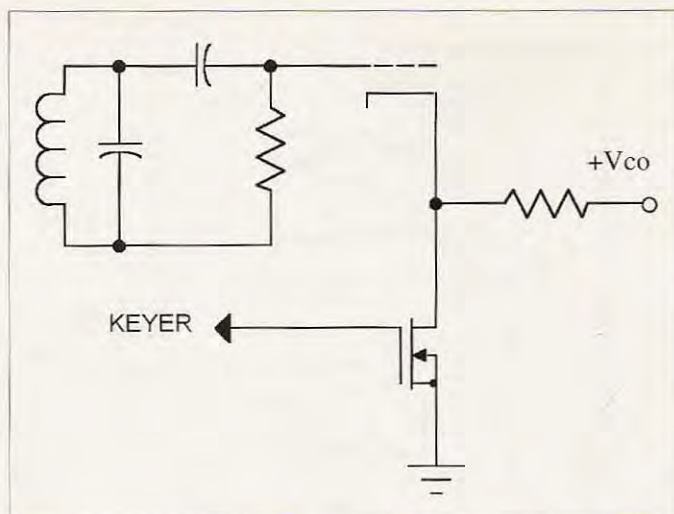
56 x 10^{-3} seconds. Since the multi-vibrator's minimum period is 0.69RC, RC is about 80 x 10^{-3} seconds (0.1 µF and 800k) for 25 WPM. If your normal highest operating speed is 15 WPM, the time of a space is 93 x 10^{-3} seconds and RC can be changed accordingly to about 133 x 10^{-3} (0.1 µF and 1.3 mego-hms). The dot and space monos can use 0.1 µF multilayer ceramic capaci-tors. For the dash mono, a 0.3 µF is needed. Three 0.1 µF in parallel are an economical choice, but a 0.33 µF ce-ramic and an R of 720k works, too. The RC product is the important concern.

A positive-going input to the NOR gate from the key triggers the "key-down" mono, dot or dash, and starts the timing sequence. The negative out-puts of the dot and dash NORs are combined in U2D, a NAND gate used as a negative input OR gate to produce a positive pulse to drive the N-channel MOSFET. From **Table 1** it is seen that U2D's output will be high if either in-put is low. The output is low when both inputs are high — that is, when the monos are in their stable states.

The output of U2D is inverted in U1D whose output goes high when the key is "up" after either a dot or dash. The positive transition of the output of U1D is differentiated with C4 and R5 to trigger the space mono. The output of the inverter U1D also clamps the arm of the key to ground during key-down so that neither the dot nor the dash can be triggered until after the full sequence is completed.

Fig. 3. A MOSFET can key the cathode of a vacuum tube amplifier.

Part No.	Value	Mfr. Part No.
C1, C2, C3a–c	0.1 µF ±10%	Kemet C320C104K5R5CA
C4	1,000 pF ±10%	Kemet C315C102K5R5CA
D1–4	1N4148 or 1N914	
Q1	IRF630	or similar, see text
R1, R7	500k ±20%	Piher PT15D-504
R2, R3, R6	680k ±5%	RC07GF684J or equal
R4	20k ±5%	RC07GF203J or equal
R5	100k ±5%	RC07GF104J or equal
R8	50k ±20%	Mouser 31CN405 or equal
R9	47k ±5%	RC07GF47J or equal
R10, R11	1 meg ±5%	RC07GF105J or equal
S1	SPDT	Mouser 633-M201201 or equal
S2	SPST	Mouser 633-M201101 or equal
U1	CD4001	Harris CD4001BE or equal
U2	CD4011	Harris CD4011BE or equal

Table 2. Parts list.

Fig. 2 shows the schematic of the complete keyer. The component values are given in **Table 2**. The parts used are commonly available from any electronics distributor. Radio Shack Unlimited is one source and Mouser Electronics is another. **Fig. 4** shows the wiring of 14-pin headers that hold the passive components. Wire-wrap headers and sockets for the ICs make it convenient for wire-wrapping. Of course, sockets aren't really necessary, just convenient.

The period of a dash is the reference time. The dash period is ideally equal to the period of three dots or spaces. The trimmers R1 and R7 are adjusted to account for component tolerances and to make the three-to-one timing, or to change the weight of keying.

Adjusting the trimmers is a piece of cake: Connect an average-reading voltmeter from U2-11 to ground: Put the key in the dash position and adjust the space trimmer R7 so that the meter indicates exactly 25% of V_{DD}. The dash is "key-down," V_{DD}, for three periods of time and "key-up," zero volts, for one period of time for a duty cycle of 25%.

Adjusting the dot trimmer is equally simple. Put the key in the dot position, and since the dot is ideally equal to a space, adjust the dot trimmer R1 to make the meter reading half of V_{DD}. That's it. The dot trimmer and space trimmer are set-and-forget.

It's a good idea to make the adjustments with the speed control set for the highest speed so that the meter doesn't try to follow the keying. While the adjustments described are for the ideal 1:1 dot-to-space ratio and 3:1 dash-to-space ratio, the keying weight can be changed by juggling the trimmers to suit your preference.

In passing, note that all digital DC multimeters do not necessarily indicate average. In that case, you'll need a low-pass RC filter between U2-10 and the meter. An R of 1 meg or more in series with the meter and a C of 0.1 µF or more across the meter will smooth out the fluctuations and keep the meter reading steady. While the indicated voltage depends on the voltmeter's input resistance, the absolute indication is of no concern. The relative value of

"key-up" to "key-down" is what's important. The "Tune" switch keeps the key down to get the "key-down" voltage reading.

Adjusting the keying weights off the air with a code practice oscillator is considerate of others on the band. A code practice relaxation oscillator that can be gated with the keyer is shown in **Fig. 5**. The simple code practice oscillator shown is built around two sections of a CD4011 that are keyed with the output of the keyer U2-11. The oscillator is gated "on" when the input from U2-11 is "high" or "key-down." The frequency of oscillation is approximately 1/(1.4RC). For 700 Hz C is 0.01 µF and R is 100k. The unused sections of the IC should be tied to ground or V_{DD}.

The edges of the oscillator waveform are very fast and can get into almost any AM radio, so that a separate audio amplifier won't be needed, use the radio to monitor your fist. If you want to use separate headphones, a

simple 2N3904 bipolar transistor operated as an emitter follower as shown in **Fig. 5** can easily drive them.

Fig. 3 shows how the MOSFET can key a typical vacuum tube final amplifier. When keying a tube's cathode, the MOSFET will be switching a voltage in the range of a hundred volts. For safety's sake, the switch should be located near the tube to keep the high voltage away from the operator.

Since the temperature near the tube is probably high, some nominal heat sinking of the MOSFET switch may be needed. The dissipation in the MOSFET is $I_{cath}^2 R_{DSon}$. For most kilowatt transmitters, the final's peak cathode current is under 3 A and the MOSFET's drain/source voltage is under 2 volts, so the dissipation is a few watts.

Even though the duty cycle of CW is low the transistor's thermal time constant is short, so that the transistor's junction temperature follows the peak dissipation. In any event, the MOSFET
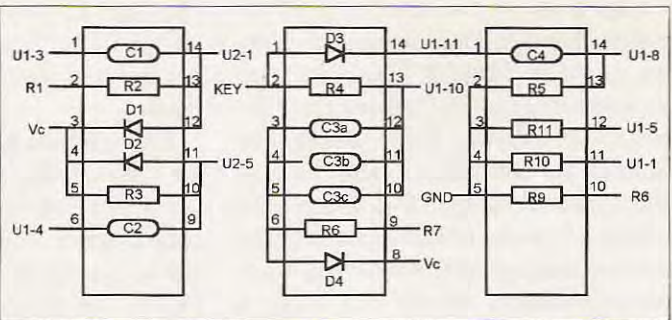
Fig. 4. *The passive components can be mounted on three 14-pin headers for wire-wrapping.*
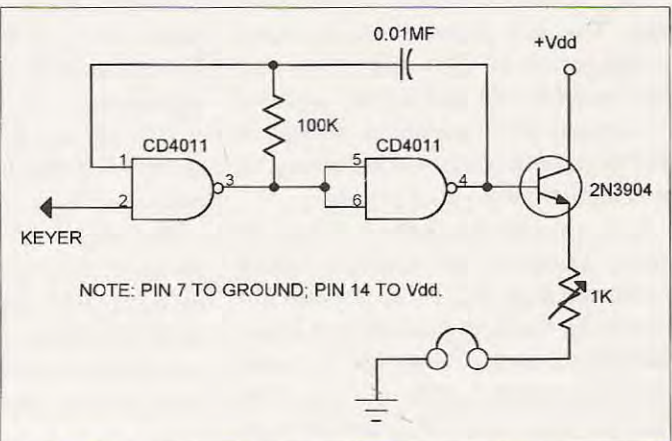
Fig. 5. *A code practice oscillator can be built with a CMOS CD4011.*

case should be kept below finger-tolerable hot. Blisters aren't desired. A small heat sink should keep things in bounds. The temperature of the collector can safely be sensed (touched) when the key is down, but when the key is up, the transistor tab (drain) voltage is high. I feel more comfortable touching the transistor immediately after the transmitter HV is turned off and the HV shorted to ground with a gimp stick or shorting bar on the HV before reaching in to touch the transistor's tab. Grounding the HV is a smart move when touching the transistor's tab. The temperature of the tab won't change that much while the HV is being shorted.

Keying a solid state amplifier doesn't require switching high voltages and the MOSFET switch can be located within the keyer. The power dissipation is a few milliwatts, so a small MOSFET like Motorola's MPF7000 is fine.

Adding a "Tune" switch S1 to keep the final on continuously while tuning can be accomplished with an SPDT switch that connects the gate of the MOSFET to V_{DD}.

When the keyer is enclosed in a minibox, the front has a "Speed" control potentiometer R8, an "On-Off" power switch S2, a "Tune" switch S1, and a jack or contacts for an external key.

This keyer can complement the CW fan's station without upsetting the budget or seriously detracting from operating time. The parts are available from Radio Shack Unlimited (RSU) at 1 (800) 843-7422, or Mouser Electronics, 958 Main St., Mansfield TX 76063, phone 1 (800) 346-6873. If you don't have their catalog, they'll be glad to send you one. 73