High Power Inverter using Gate Turn-off Thyristors

Using the new RCA G 5000 M gate turn-off thyristors an efficient, high-power DC/AC inverter can easily be built.

As most readers will probably know, conventional thyristors are extremely useful devices, but they do have their limitations. A thyristor requires only a small positive gate pulse at a current of perhaps a few milliamps to turn it on, but may control a current of hundreds of amps. The power gain of thyristors is typically tens of thousands.

Unfortunately, once a conventional thyristor is turned on the gate electrode has no further effect and the only way to turn off the device is to interrupt the current by some external means or to reverse the voltage applied to the thyristor. This makes thyristors fine for AC circuits, but not so good for DC applications. The gate turn-off thyristor, as its name implies, may be turned on by a positive gate pulse, but may also be turned off by a negative gate pulse. This means that it is ideal for DC applications such as power inverters to convert power from a DC source such as a battery to AC power.

Figure 1 shows the output section of such an inverter. The four thyristors are arranged in a bridge configuration and the diagonally opposite pairs are triggered alternately by an external pulse generator. i.e. GT01 and GT04 are turned on together while GT02 and GT03 are turned off. GT02 and GT03 are then turned on while GT01 and GT04 are turned off, reversing the direction of current through the primary of the transformer. The turns ratio of the transformer can be chosen to step up the DC supply voltage to any desired AC voltage, remembering that since the output stage has a bridge configuration the peak-to-peak primary voltage across the transformer is twice the DC supply voltage, neglecting the slight losses in the thyristors.

The thyristors can switch currents of up to 8.5A, and since each thyristor is on for only half the time the RMS current in the transformer primary may be up to 17A. This means that with a 12V supply such as a car battery the maximum theoretical inverter output is about 200 W (neglecting losses in the transformers). Using a higher supply voltage such as several 12V batteries in series even higher output powers may be attained, since the thyristors themselves will stand peak voltages of 600 V.

Since at the instant of triggering it is possible for all four thyristors momentarily to be turned on a choke L1 is included in series with the battery to limit the current and avoid damage to the thyristors. A suitable value for this choke is:

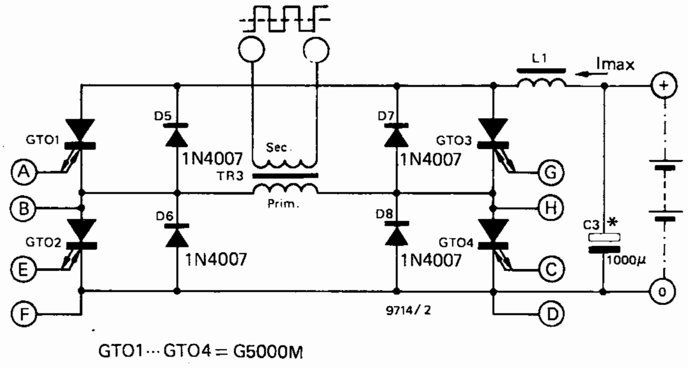
$$L = \frac{1.75\ V_{supply} \times 10^{-5}}{I_{max}} \text{ Henries.}$$

Where I_{max} is the current drawn from the supply under full loading of the inverter output.

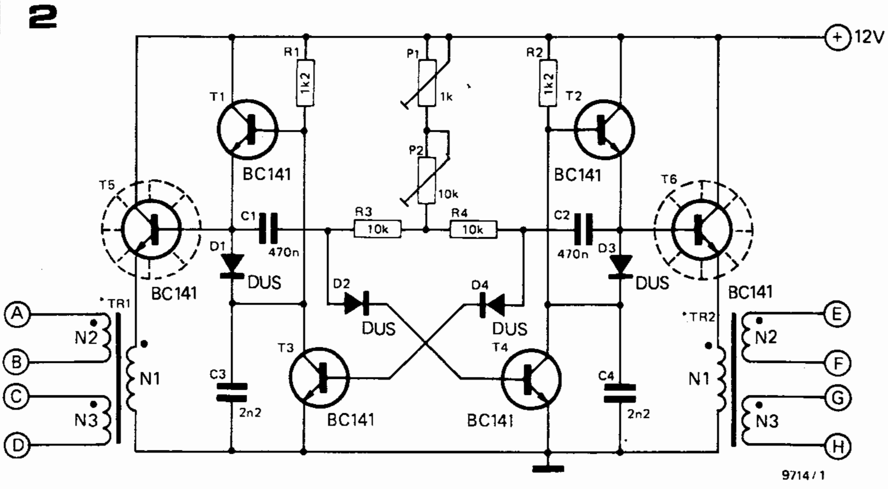
At the instant of switchover from one pair of thyristors to the other the stored energy in the transformer can cause a large reverse e.m.f. to be generated, which could damage the thyristors. For this reason diodes D5 to D8 are provided to protect the thyristors. These clamp the voltage at points B and H to no more than V_{supply} + 0.7 and no less than −0.7 V.

Capacitor C3 provides filtering of the supply voltage and its value depends on the maximum supply current. The value given should be adequate for most applications.

1



2



*see text

Figure 1. Output section of an inverter using four gate turn-off thyristors.

Figure 2. Trigger pulse generator for the inverter.

Trigger Generator

Figure 2 shows the circuit of the trigger generator. It comprises an astable multivibrator T3/T4, coupled to two output stages T1/T5 and T2/T6, which each drive a pulse transformer. The pulse transformers each have two secondary windings to provide trigger pulses for the four thyristors. Note that each pulse transformer supplies one diagonal pair of thyristors. It is important to ensure that the phasing of the pulse transformers is correct, otherwise more than two thyristors could be turned on simultaneously. P1 and P2 adjust the frequency of oscillation.

The prototype pulse transformers were wound on Siemens pot cores type B65651-K0250-A022, but any 18 mm or larger pot core with an inductance factor of about 250 nH/turn should be suitable. The winding details are as follows, using a three section former:

Primary (wound on centre section):
80 turns 0.1 mm enamelled copper wire.

Secondaries (wound on end sections):
each 40 turns 0.1 mm enamelled copper wire.

All three windings on each transformer should be wound in the same sense to maintain correct phasing.

Choice of Output Transformer

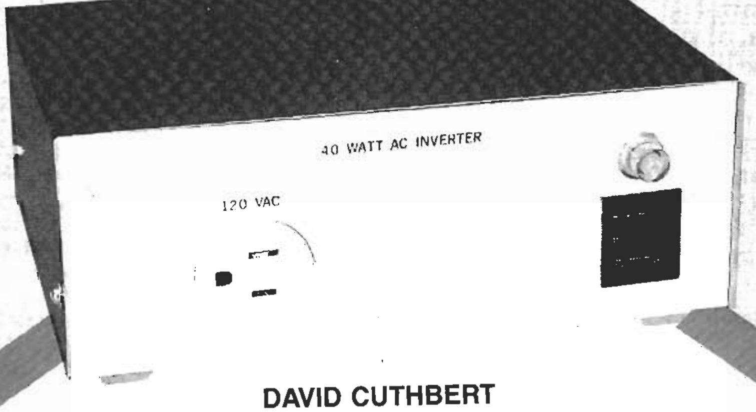
The beauty of this type of inverter circuit is that the output transformer requires no special feedback windings, so an ordinary mains transformer connected 'back to front' is adequate for most applications. The choice of transformer depends on the required output current and voltage of the inverter.

Applications

The possible uses of inverters are too numerous to list. They can be used to power small mains appliances such as shavers and hairdryers while camping, to power small electric drills or to drive emergency fluorescent lighting. There are, however, one or two points worth bearing in mind. Firstly, since the output waveform of the inverter is a squarewave the RMS output voltage is equal to the peak voltage and is 1.414 times the RMS voltage of a sinewave of the same peak voltage. This means that for driving mains appliances the peak output voltage of the inverter should be equal to the nominal RMS mains voltage. Secondly, mains appliances having a motor should be driven from the correct frequency (i.e. 50 or 60 Hz), but fluorescent lights will operate more efficiently if the inverter is run at a higher frequency of several hundred hertz. Finally, when using an inverter for camping, never run it from the main car battery, unless you enjoy pushing the car. A 100 W inverter, for example, draws over 8A and would quickly discharge the battery. Rig up an auxiliary battery that can be trickle-charged from the car generator. ◆

LINE POWER FROM 12 VOLTS

Build a 40-watt DC-to-AC inverter, and power AC appliances from your automobile cigarette lighter.



DAVID CUTHBERT

WOULD YOU BELIEVE THAT THIS ARTICLE was written on an electric typewriter while the author was sitting next to a stream on a camping trip? The typewriter was powered from our 40-watt inverter that can be plugged into an automobile's cigarette lighter socket. The unit has enough power for many items that normally don't go on camping trips, such as a TV, a stereo, an electric razor, or a desk lamp. However, it also has some uses that may not be as obvious; it can be used to power items such as an oscilloscope or soldering iron when doing electronics work in the field. On road trips, the inverter can be used to power a camcorder battery charger.

The inverter draws a maximum of 5 amps, which is completely safe for an automobile cigarette lighter socket, and the no-load current is only half an amp. The output voltage is regulated and remains fairly constant from no-load to full-load. Figure 1 shows the output-voltage waveform superimposed over a sine wave. The rectangular output waveform has the same RMS and peak voltage as the sine wave, so the device being powered will never know the difference. The rectangle-wave operation greatly increases efficiency. The waveform would look similar if displayed on an oscilloscope.

Operation

The inverter, the schematic of which is shown in Fig. 2, is actually a push-pull audio amplifier. The "input," or reference signal, is a 5-volt square wave. The output is 340-volt peak-to-peak AC signal. The feedback signal is rectified in order to match the DC reference signal. On one half of the AC waveform, the upper three FET's are gated on, and on the other half the lower three FET's are on.

Normally, 120-volt AC outlets have one side at ground and one side that's "hot." The hot side alternates from −170 to +170 volts. The inverter output is a little different. On one half of the AC cycle, one side is near ground and the other is at +170 volts. During the other half of the cycle the situation is reversed.

Op-amp IC1-a and its associated components form a 300-Hz clock oscillator, and counter IC2 divides the clock signal by four to obtain a 75-Hz inverter frequency. The 75 Hz, rather than 60 Hz, is used to avoid transformer saturation. Some electric clocks will run fast with that frequency, but most electronic gear will work just fine. Decade counter IC2 controls the timing of the reference signal and the gating-on of the error-amp signal to the proper set of FET's.

Figure 3 shows the timing relationships in the inverter. When IC2 pin 3 goes high, the output of buffer IC1-c is high. That reverse biases D1 and allows the error amp signal to reach Q1, Q2, and Q3. At the same time, IC2 pin 4 is low, which causes the output of buffer IC1-d to be low. That grounds the gates of Q4, Q5, and Q6 thereby turning them off. Pins 2 and 7 of IC2 are also low, so Q7 is off. A 5-volt reference from regulator IC3 is now present at the error-amp's (IC1-b) non-inverting input. The reference-signal rise time is slowed by R12 and C2 in order to avoid output overshoot, and the gain and frequency response of the error amp is set by R15, R25, and C3.

Next, pin 2 of IC2 goes high, which turns Q7 on and the reference signal is pulled to ground. Pins 3 and 4 of IC2 are now low

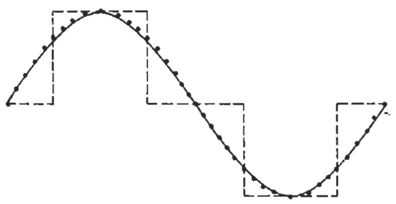


FIG. 1—BECAUSE THE OUTPUT-VOLTAGE waveform, which is shown here superimposed over a sine wave, has the same RMS and peak voltage as the sine wave, the device being powered will never know the difference.

and the FET gates are grounded, turning them off. Pin 4 of IC2 now goes high and the other three FET's are gated on. The reference signal now rises to 5 volts, and the other half of the AC output waveform is generated. The next clock pulse causes IC2 pin 7 to go high; all FET's are now off and the reference is set to zero. The following clock pulse resets IC2 and another cycle begins.

A filter that protects the CMOS circuitry against alternator spikes and reversed input polarity is formed by R7, C8, and D7. Components R9 and C4 filter output spikes, and R18–R21 are pre-load resistors to stabilize the inverter when no load is connected. Although the FET's have no current-equalizing source resistors, they still share current fairly equally. (When a FET "hogs" current it heats up more and its on resistance increases, causing it to draw less current.)

Construction

The inverter circuit was built on a perforated construction board. Transistors Q1, Q2, and Q3 share a 1.5- by 4-inch heatsink, and Q4, Q5, and Q6 share another; the heat sinks are made of aluminum sheet. Figure 4 shows an internal view of the inverter. In the prototype, the FET's were not insulated from the heatsinks because the heatsinks are isolated from ground and all other circuitry. If you use any other heatsinking configuration,

continued on page 68

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1–R7—100 ohms
R8—1000 ohms
R9—1000 ohms, ½-watt
R10, R11—4700 ohms
R12–R16—10,000 ohms
R17—10,000-ohm potentiometer
R18–R21—22,000 ohms, ½-watt
R22–R26—100,000 ohms
R27, R28—470,000 ohms
R29—1 megohm

Capacitors
C1—0.001 µF, ceramic disc
C2—0.01 µF, ceramic disc
C3—0.0047 µF, ceramic disc
C4—0.05 µF, 200 volts, ceramic disc or metal film
C5–C7—0.1 µF, ceramic disc
C8, C9—470 µF, 35 volts, electrolytic

Semiconductors
IC1—LM324 quad op-amp
IC2—4017 CMOS decade counter
IC3—LM7805 or LM340-5 +5-volt regulator
D1–D7—1N4003 diode
Q1–Q6—IRF511 60-volt 3.5-amp MOSFET
Q7—2N2222 or 2N3904 NPN transistor

Other components
T1—120/12.6 volt center-tapped 3-amp power transformer
J1—banana jack, red
J2—banana jack, black
J3—AC power receptacle
F1—5-amp slow-blow fuse
S1—SPST 6-amp switch
NE1—neon indicator light with series resistor

Miscellaneous: fuse holder, perforated construction board, enclosure, aluminum for heatsinks, standoffs for mounting circuit board, wire, solder, etc.

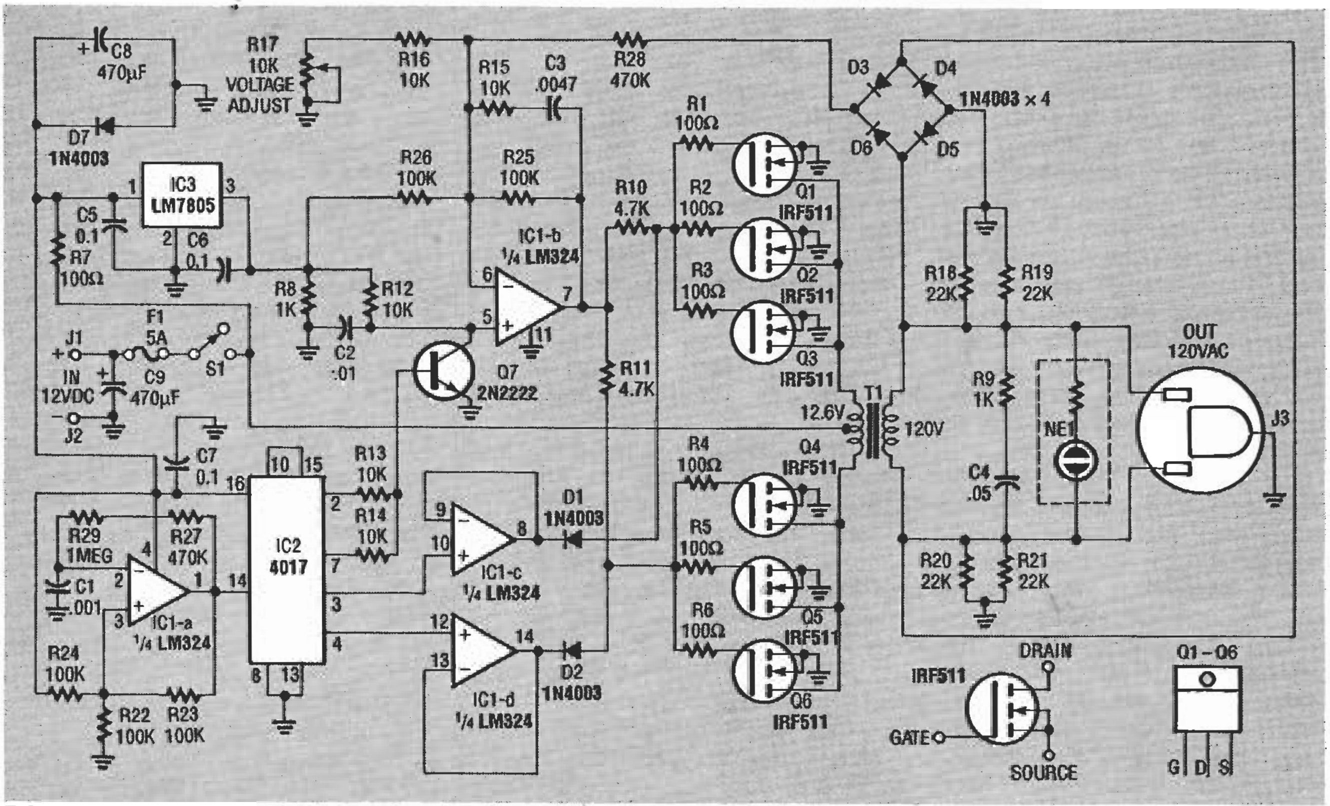


FIG. 2—THE INVERTER is actually a push-pull audio amplifier where, on one half of the AC waveform, the upper three FET's are gated on, and on the other half the lower three FET's are on.

POWER INVERTER

continued from page 44

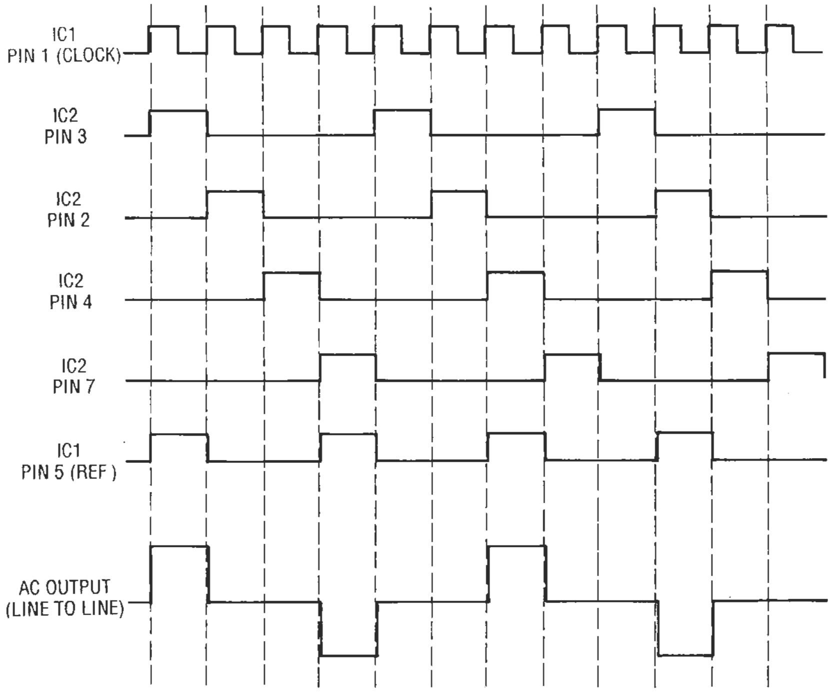


FIG. 3—THE TIMING RELATIONSHIPS in the inverter. When IC2 pin 3 goes high, the output of buffer IC1-c (pin 8) is high. That reverse biases D1 and allows the error amp signal to reach Q1, Q2, and Q3. At the same time, IC2 pin 4 is low, which causes the output of buffer IC1-d to be low. That grounds the gates of Q4, Q5, and Q6 thereby turning them off.

the FET's should be insulated.

Parts placement isn't critical except for the 100-ohm gate resistors. They prevent VHF oscillations and should be placed within half an inch of the FET's. Just make sure that everything is securely mounted inside the cabinet to prevent shorting. Also, the prototype's metal cabinet has had several half-inch holes drilled in the bottom and rear for ventilation.

Power up

To safely test the inverter, it should really be operated with a 1-amp current-limited power supply. If you don't have one, simply connect it to approximately 12-volts DC, and keep a look out for smoke or sudden failures.

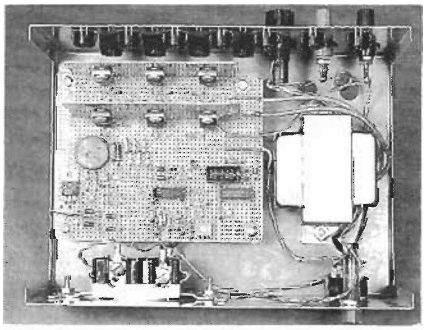


FIG. 4—IN THE PROTOTYPE, the FET's are not insulated from the heatsinks because the heatsinks are isolated from ground and all other circuitry.

Connect an oscilloscope ground to chassis ground and the probe to the junction of D3 and D6; you will see an alternating DC signal. The frequency should be between 70 and 90 Hz. If it isn't you can adjust it by changing the value of R27. Adjust trimmer R17 for 180-volts peak. If you use a DVM or a VOM, connect it across the inverter's AC outlet, and adjust R17 for 120-volts AC.

Now it's time for a full-power test. You will need a 12.6 volt, 10-amp power supply or a car battery. A 120-volt, 40-watt light bulb makes a good load for testing. With a 12.6-volt input, the inverter will deliver 150 volts peak, which will read about 105 volts on a DVM. With a 14.2-volt input, which is what an automobile alternator supplies, the output will be 115-volts AC.

We're sure you'll find many uses for your inverter at home or on the road. R-E