ELECTRONIC SWITCHING WITH TRANSMISSION GATES

CMOS device provides "bounceless" switching at speeds to 10 MHz.

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LOW-LEVEL analog or digital signals must often be switched between various circuits at high speed. In such cases, a simple electromechanical switch, such as a relay or reed switch, must generally be avoided because of the inherent contact bounce and long switching time.

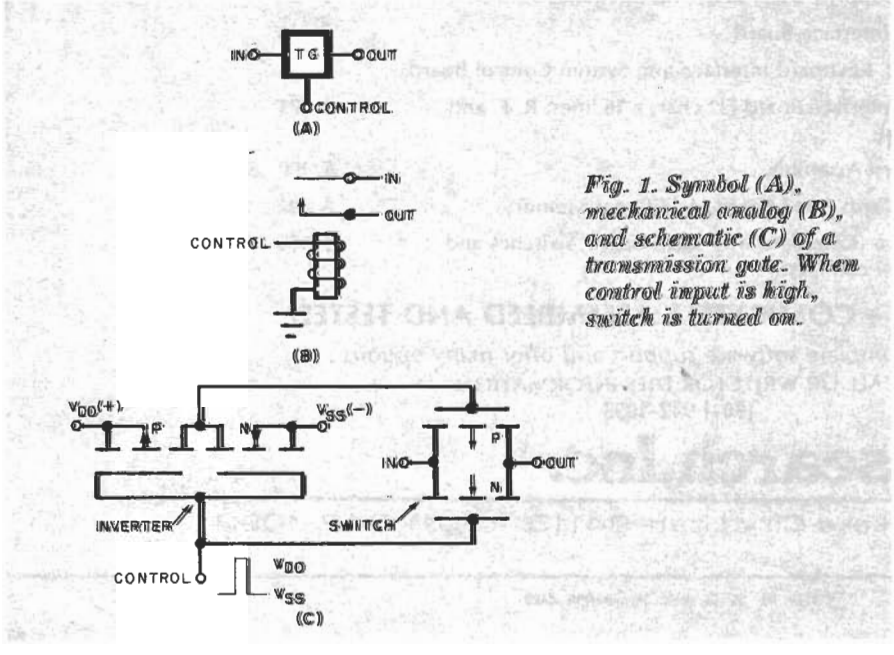

Fig. 1. Symbol (A), mechanical analog (B), and schematic (C) of a transmission gate. When control input is high, switch is turned on.

The practical answer to electronic switching requirements can be found in the type 4016 "bilateral switch" or transmission gate (TG). This is a unique form of logic found only in the CMOS family of devices. A high-speed, solid-state electronic spst switch, it can transfer ac or dc voltages or currents in either direction. It can switch at speeds up to 10 MHz, which is compatible with most modern digital systems. Although the TG's "on" resistance (300 ohms) is not the ideal short-circuit condition, its "off" resistance is extremely high. With a characteristic input resistance of 10^{12} ohms, it will not load down the switching source.

Theory. The symbol for a transmission gate is shown in Fig. 1A, while Fig. 1B illustrates the basic action of the device, similar to a relay contact which is closed when the CONTROL

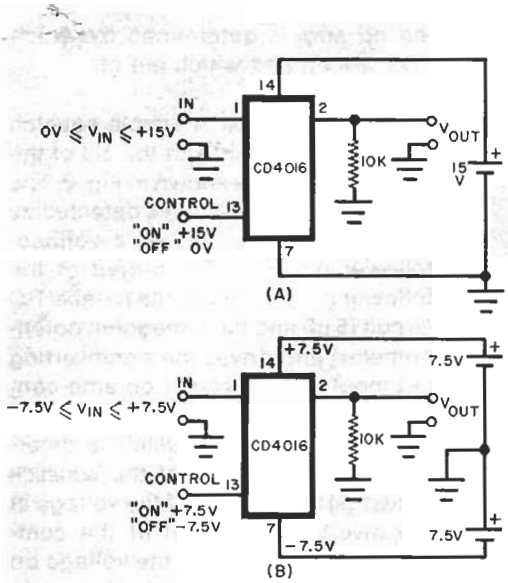

Fig. 2. The TG can switch positive dc signals (A) or bipolar signals (B), depending on power supply used.

input is high. The actual circuit for the TG, using enhancement FET's, is shown in Fig. 1C.

Note in Fig. 1C that, between the input and output terminals of the TG, there are an n-channel and a p-channel MOSFET. The gates of these MOSFET's are connected to the input and the output of an inverter. To turn on the TG, the CONTROL voltage should approximately equal V_{DD}. Conversely, to turn off the TG, the CONTROL voltage should be approximately V_{SS}.

The 4016 contains, in a 14-pin DIP assembly, four spst-type switches. Each switch has an "on" resistance of about 300 ohms over a 15-volt input-signal range, dependent on the values of V_{DD} and V_{SS}. The leakage current when the switch is off is about 10 pA, which is a result of its very high "off" resistance. The 4016 has an allowable control (clock) rate of 10 MHz, with a turn-on time of approximately 20 ns. As the recommended dc supply voltage is 3 to 15 volts, the input signal level must not exceed these values.

The 4016 can be used to switch positive dc or bipolar voltages as shown in Fig. 2. A peak potential of 15 volts (maximum) can be switched by the circuit shown in Fig. 2A. In this circuit, a single supply is required, with the V_{SS} terminal connected to ground. The Fig. 2B circuit illustrates how bipolar signals can be switched. Here, a split supply is used with the V_{DD} terminal at +7.5 volts and the V_{SS} terminal at −7.5 volts. In this case, the maximum input signal level can be 15 volts peak-to-peak. Note that in both circuits of Fig. 2, the control voltage is equal to V_{DD} for the "on" condition and to V_{SS} for the "off" condition. For most applications, the load resistance should be 10,000 ohms or greater. A maximum input signal frequency response of 40 MHz is attainable with V_{DD} at +5 volts and V_{SS} at −5 volts.

Switch Configurations. Because the 4016 contains four independent bilateral switches in one package, the individual switches can be arranged to function as a variety of switch types similar to the electromechanical switches for which they can be substituted. Two such arrangements are shown in Fig. 3. A pair of TG's can be wired to form a spdt switch as in Fig. 3A. Two such switches can be obtained from a single 4016. The control signals are out of phase as denoted by the line over one. This permits a conventional flip-flop to drive the switches.

The diagram in Fig. 3B illustrates how four TG's can be arranged to act as a dpdt switch. Again, the control inputs are driven out-of-phase in pairs, permitting the same flip-flop hookup.

Dual-Trace Converter. A dual-trace adapter for single-trace oscilloscopes is shown in Fig. 4. Besides the TG's, the circuit employs a 4001 quad-NOR IC as a multivibrator and phase inverter and a 536 operational amplifier IC.

This is a version of the principle of "time division multiplexing" in which each input of a two-channel system is coupled to the common output for a specific period of time, with the other channel shut off. The two channels alternate in supplying the output depending on the rate of the two-phase clock driving the multiplexer.

The op amp in this circuit is arranged as a summing amplifier. When one pair of TG's is on, it sums both the signal and the dc level determined by

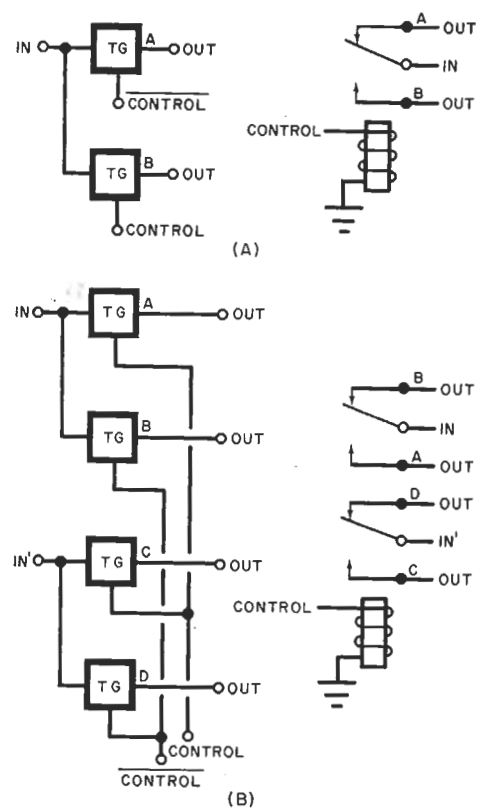

Fig. 3. Spst gates can be ganged for more complex switching circuits, such as spdt (A) or dpdt (B).

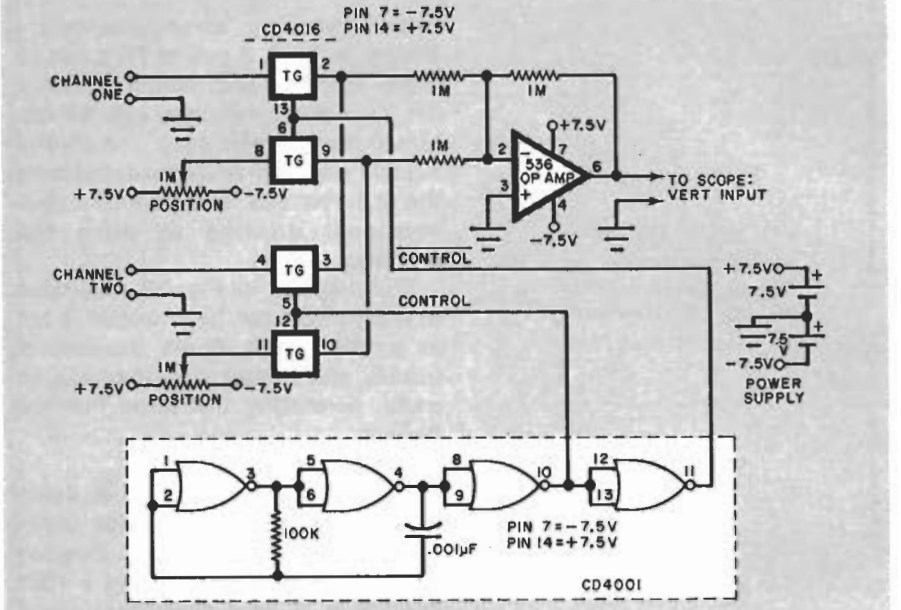

Fig. 4. TG's driven by a 2-phase clock time-multiplex vertical input.

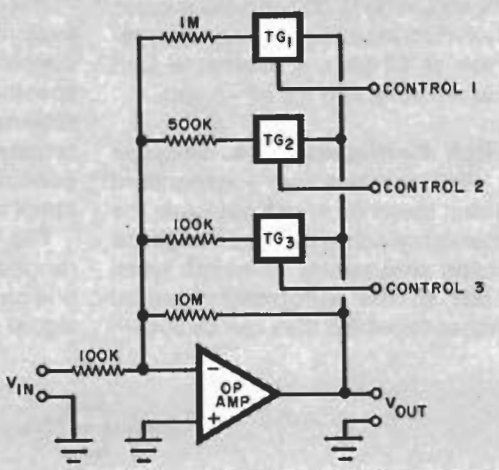

Fig. 5. In variable-gain amplifier, turning one of the TG's on sets the feedback resistance and, thus, gain of the op amp.

the POSITION control. This level determines where on the face of the scope's CRT that particular trace will be displayed. This basic approach is very similar to that used in commercial dual-trace scopes. You can vary the frequency of the clock oscillator so that it is not related to that of the input signal, thus avoiding a broken pattern.

Variable Gain Amplifier. Another application for the bilateral switch is shown in Fig. 5. The circuit is a basic op amp whose gain is determined by the ratio of the feedback to the input resistance. With none of the TG's on, the only feedback is through the 10-megohm resistor, to provide a gain of 100. (Note: This circuit is a phase inverter.)

If *TG1* is on and *TG2* and *TG3* are off, the total feedback resistance is 10 megohms paralleled by 1 megohm, producing a gain of 10. With *TG2* on and *TG1* and *TG3* off, the total feedback resistance of 500,000 ohms produces a gain of 5. Hence, the gain of the op amp is determined by which TG's are on and which are off.

Squelch Circuit. A simple squelch circuit can be built with the aid of the bilateral switch as shown in Fig. 6. The audio input signal is peak detected by *D1*, whose output drives a voltage-follower op amp. The output of the follower is averaged by the parallel RC circuit (5 μF and the 1-megohm potentiometer) and drives the noninverting (+) input of the second op amp connected as a comparator.

The level of the squelch is determined by the setting of the SQUELCH ADJUST potentiometer. If the voltage at the inverting (−) input of the comparator is greater than the voltage on the noninverting input, the comparator's output is almost at the maximum negative supply voltage. This signal keeps the TG off so that the audio input signal will not pass through to the audio amplifier.

If the averaged signal produces a voltage at the noninverting input of the comparator greater than that supplied to the inverting input, the output of the comparator swings to the maximum positive power supply level. This action turns on the TG and allows the received audio to pass to the amplifier. The off delay (up to several seconds) is determined by the time constant of the RC circuit.

Closing Comment. In this article, we have covered only a very small fraction of the possible applications for the versatile transmission gate. With a knowledge of what the TG can do, you can create many new applications for this unique solid-state switch. ◈

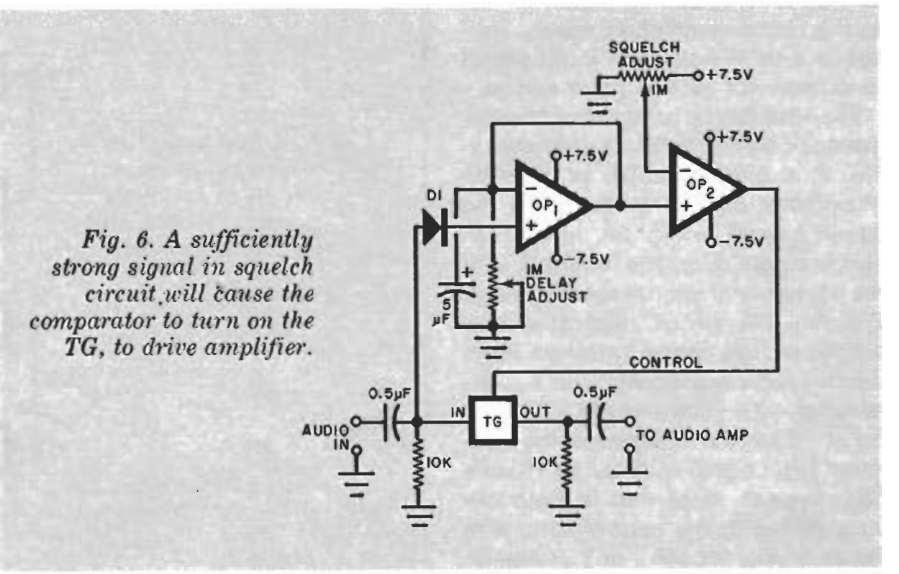

Fig. 6. A sufficiently strong signal in squelch circuit will cause the comparator to turn on the TG, to drive amplifier.