HANDBOOK OF

Transistor Circuits

by Allan Lytel

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PREFACE

The use of semiconductor devices in industrial applications is growing at a rapid rate. Indeed, although much attention is being given to how the devices already in production can be used in various types of industrial applications, current emphasis is on the development of new solid-state devices with specialized characteristics for specific applications. Because of the tremendous effort made in manufacturing and developing semiconductor devices, it is very difficult to keep up with the state of the art as actually used in industry. It behooves us, therefore, to stop and take a close look at what has happened in the last few years.

This book is a compilation of transistor and rectifier circuits used for a wide variety of applications. Naturally it is impossible to include all of the many such circuits in a single volume; instead, a selection of typical designs has been included. In each of the 13 different circuit categories, schematic diagrams, parts lists, and text discussions of the operation are given for a number of representative circuits. In one reference source this book provides material that otherwise would be available only from the various manufacturers.

Acknowledgement must be given to the following manufacturers, who supplied much of the data from which this book was prepared: Shockley Transistor, Transitron Electronic Corp., Sylvania Electric Products, Inc., General Electric Co., Motorola Semiconductor Products, Inc., Minneapolis-Honeywell Regulator Co., Solid State Products, Inc., Ferroxcube Corporation of America, Westinghouse Electric Corp., Radio Corporation of America, Crystalonics, Inc., and Eastman Kodak Co.

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CONTENTS

SECTION 10

SECTION 11

SECTION 12

SECTION 13

SECTION 1

COUNTERS

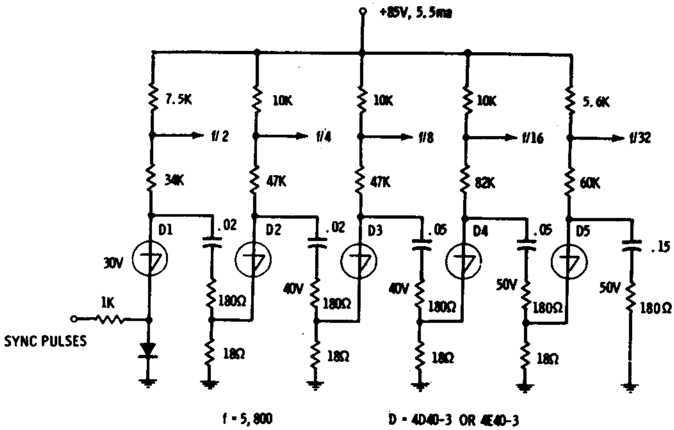
FREQUENCY DIVIDERS

The four-layer diode (a PNPN device) can be used to make simplified frequency-divider circuits, such as those used for electronic organs. A master oscillator is used to generate the basic, or original, frequency (f), which, for example, can correspond to middle C. Output from this master oscillator is then used to synchronize a sawtooth oscillator that uses a four-layer diode. This produces a large-amplitude sawtooth about 30 to 40 volts whose frequency is the same as that of the master oscillator. If it is desired to produce C below middle C, it is necessary to divide the frequency by two, but the output should remain a sawtooth. The technique for doing this is as follows.

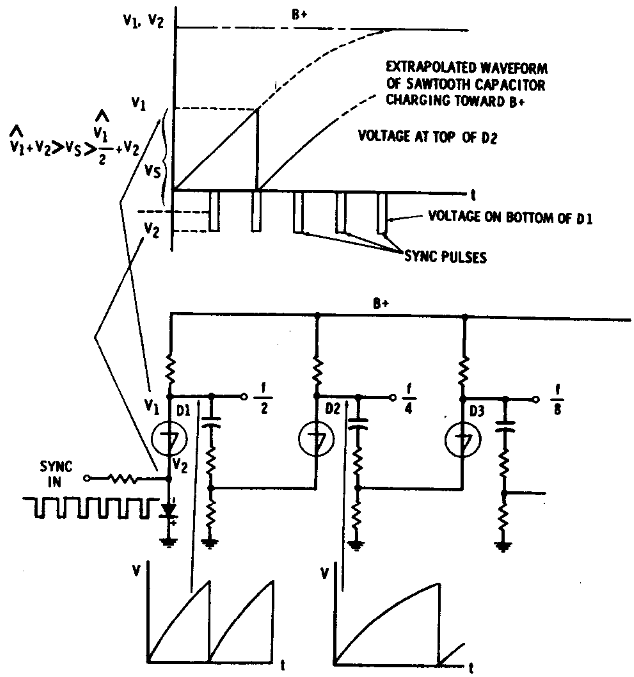
Diode D1 is a simple sawtooth oscillator which has a free-running frequency of just below ½ f, where f is the original oscillator frequency. However, sync pulses coming from the master oscillator are of the fundamental frequency (f). These pulses are adjusted in amplitude so that every other pulse triggers the four-layer diode (D1).

This circuit produces pulses across the series resistors in the path of the capacitor discharge. The 18-ohm resistor provides a pulse amplitude of the proper value. In turn, these pulses are fed to the next stage (D2) which produces an output of the original frequency divided by 4, since every second input pulse has sufficient amplitude to trigger the stage. Thus, in sequence the first stage produces an output whose frequency is the original divided by 2, the second is the original frequency divided by 4, the third is the original frequency divided by 8, etc.

A complete circuit that provides sawtooth-voltage outputs over



(A) Schematic diagram.



Courtesy Shockley Transistor, Unit Clevite Transistor.

(B) Waveforms.

Working organ circuit.

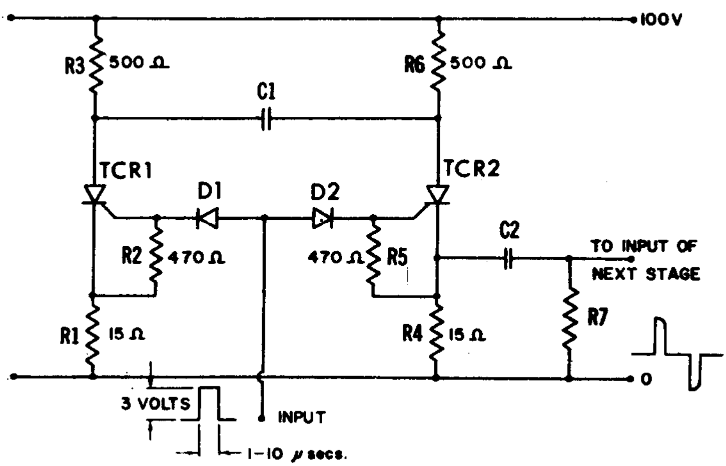
5 octaves is shown. Note that the component values are not similar for each stage, but they change as the frequency of the stage changes. Frequency control is obtained by varying the resistance and capacitance so that all of the diodes have the same switching voltage.

This frequency divider is free-running at incorrect frequencies if there is no sync pulse. It is necessary, therefore, to be sure that the original oscillator source signal is present and that each stage provides sync for the succeeding stages.

BINARY COUNTER 1

The binary counter uses a positive 3 volt, 1- to 10-μsec. input pulse to produce an output pulse that is either positive or negative, depending on which controlled rectifier is conducting when the input pulse is applied.

If controlled rectifier TCR1 is conducting, a 3-volt bias is developed across resistor R1 and applied to the cathode of diode D1 through resistor R2. When a positive 3-volt input pulse is applied to the junction of the anodes of diodes D1 and D2, the positive 3-volt bias on the cathode of D1 holds it at cutoff, and current flows through resistors R4 and R5 and diode D2. The current through R4 and R5 develops a positive voltage at the gate of controlled rectifier TCR2, thus gating TCR2 on. When TCR2 starts to conduct, the sudden presence of a positive voltage at the cathode of TCR2 produces a current through capacitor C2 and resistor R7. This current through R7 develops a positive pulse at the output. At the same time, when TCR2 starts to conduct, the sudden presence of a



Courtesy Transitron Electronic Corp.

Binary-counter circuit.

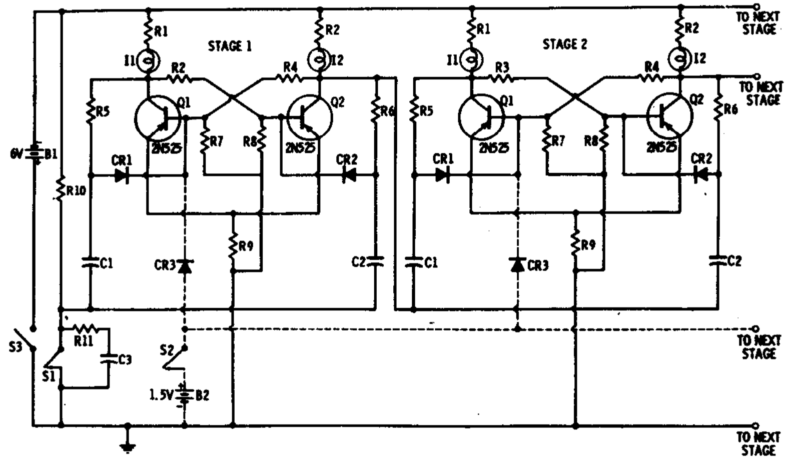
negative-going voltage at the anode of TCR2 is coupled through capacitor C1 to the anode of TCR1, cutting TCR1 off. Now diode D2 is back-biased and controlled rectifier TCR1 is in the Off state. When the next 3-volt pulse is received at the input, current through resistors R1 and R2 and diode D1 develops a positive voltage at the gate of controlled rectifier TCR1, gating TCR1 on. TCR1 is now On, and TCR2 is switched Off through coupling capacitor C1. When TCR2 is switched to the Off state, its cathode suddenly goes to ground potential. The sudden decrease in voltage produces a current through capacitor C2 and resistor R7. This current through R7 develops a negative pulse at the output. Therefore successive positive input pulses result in alternate positive and negative pulse outputs that can be used to drive a binary readout system. Several of these binary counters can be combined to form a binary counter system.

BINARY COUNTER 2

The binary counter can be used by science or mathematics teachers to demonstrate binary addition or by students as part of a science fair display of computer-type circuits. The circuit may be operated by a relay, as shown, or with a photocell in place of S1. It can be used to count objects moving on a conveyor belt or the number of persons who pass by the photocell. The schematic diagram shows two sages, but the counter can be extended to as many stages as desired. The counter counts from 0 to $(2^n - 1)$, where n is the number of stages. For example, with two stages it will count to 3, with three stages it will count to 7, with four stages it will count to 15, and so on. The counter consists of cascaded flip-flop circuits containing indicator lights so that the state of each stage of the counter can be observed.

Each time switch S1 is closed, the flip-flop of stage 1 changes state. For example, if Q1 of stage 1 is conducting, a positive pulse is coupled through capacitor C1 and diode CR1 to the base of Q1. This causes Q1 to be cut off, and consequently, Q2 is turned on and lamp I1 is lit. The positive pulse cannot pass through CR2 because it is reverse-biased through R6. The next time S1 is closed Q2 is turned off and Q1 is turned on. Each time Q2 of stage 1 is turned on, the second counter stage changes state. Similarly, each time Q2 of stage 2 is turned on, stage 3 changes state. Thus the first stage changes state each time S1 is closed; the second stage changes state every second time S1 is closed; the third stage changes state every fourth time S1 is closed; and so on.

If one adopts the convention that illumination of lamp I1 of a particular stage represents 1 and illumination of lamp I2 represents O, then a conversion table from decimal to binary counting can be



B1—6V. Battery, Burgess F4BP or equivalent.
B2—1.5V. Battery, Burgess #2R or equivalent.
C1, C2—.047 or .05 Mfd. Paper or Ceramic Capacitor.
C3—.1 Mfd. Paper Capacitor.
CR1, CR2, CR3—1N34A Diode.
I1, I2—Sylvania #48 or #49 2V., 60 ma. Pilot Lamp.
Q1, Q2—Sylvania 2N525 Transistors.
R1, R2—68Ω, ½w. Resistor.
R3, R4, R7, R8—1.2K ½w. Resistor.
R5, R6, R10—10K, ½w. Resistor.
R9—4.7Ω ½w. Resistor.
R11—27Ω ½w. Resistor.
S1—Switch, normally open momentary contact pushbutton type such as Graynill Type 2201 or equivalent.
S2—Same as S1.
S3—S.P.S.T. Toggle Switch.
NOTE: C1, C2, R1 through R9, CR1, CR2, CR3, I1, I2, Q1, Q2 must be duplicate for each stage used.

Courtesy Sylvania Electric Products, Inc.

Two-stage, binary-counter circuit.

Count	Stage 1	Stage 2	Stage 3
0	0	0	0
1	1	0	0
2	0	1	0
3	1	1	0
4	0	0	1
5	1	0	1
6	0	1	1
7	1	1	1
8	pattern	repeats	

TABLE I—Binary representation of count (least significant digit on right).

Count	Stage 1		Stage 2		Stage 3	
	Lamp I1	Lamp I2	Lamp I1	Lamp I2	Lamp I1	Lamp I2
0	off	on	off	on	off	on
1	on	off	off	on	off	on
2	off	on	on	off	off	on
3	on	off	on	off	off	on
4	off	on	off	on	on	off
5	on	off	off	on	on	off
6	off	on	on	off	on	off
7	on	off	on	off	on	off
8	pattern	repeats				

TABLE II—Count display for 3 stage counter.

N (number of counter stages)	$(2^N - 1)$
1	1
2	3
3	7
4	15
5	31
6	63
7	127
8	255
9	511
10	1023

TABLE III—Count capability as function of number of stages.

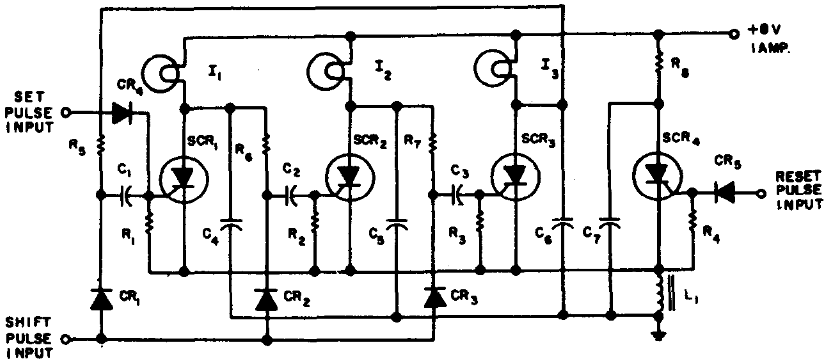
Courtesy Sylvania Electric Products, Inc.

made (Table I). In this table the count is given in its binary representation from right to left (least significant digit on right). Table II shows the count display for a three-stage counter, and Table III shows the highest count possible for various numbers of stages.

RING COUNTER

A ring counter may be considered as a circuit that sequentially applies voltage to two or more loads at a time. These may either be power loads or signal loads. In this circuit, controlled rectifiers SCR1, SCR2, and SCR3 form a three-stage ring counter. SCR4 is a reset pulse generator which is not required for all applications.

When power is first applied to the circuit, none of the SCR's are turned on. To set the circuit a positive pulse is applied to the set pulse input which applies a positive trigger to the gate of SCR1, switching SCR1 from the Off state to the On state and resulting



R_1, R_2, R_3 - 220Ω, 1/2w
R_5, R_6, R_7 - 4.7K, 1/2w
R_8 - 47Ω, 2w
C_1, C_2, C_3 - 0.1mfd, 50V paper
C_4, C_5, C_6, C_7 - 4mfd, 50V paper

$SCR_1, SCR_2, SCR_3, SCR_4$ - C9U or C12U
$CR_1, CR_2, CR_3, CR_4, CR_5$ - 1N1692
I_1, I_2, I_3, I_4 - 6.3V, 0.8A
L_1 - 200μh, 0.2Ω

PULSE SOURCE - 3-8 VOLT, 10-20μ sec, 15-20Ω

Courtesy General Electric Co.

Ring-counter circuit.

in current flow through lamp I1. Since SCR2 and SCR3 are in the Off state, their anode voltage is 8 volts, therefore reverse-biasing diodes CR1 and CR3. The cathode of CR2, which is connected to the anode of conducting SCR1, is at approximately 1 volt.

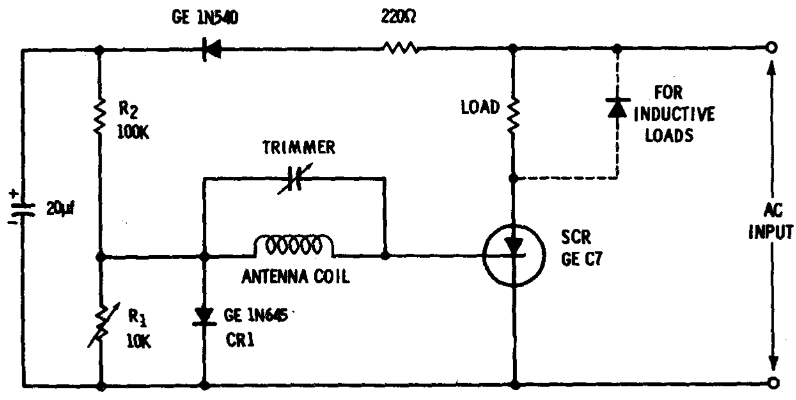
If a positive pulse with a peak amplitude of less than 8 volts and greater than 3 volts is applied to the shift pulse input, CR1 and CR3 block the pulse from the gates of SCR1 and SCR3, but the pulse is coupled through CR2 and C2 to the gate of SCR2. Thus, SCR2 is triggered on. Capacitor C5, which was previously charged through lamp I2, now discharges through SCR2 and inductor L1. The large voltage pulse developed across L1 reverse-biases SCR1, switching it off. Capacitor C4 holds the anode voltage of SCR1 down during the commutating interval. When successive shift pulses are applied, SCR3 is switched on and SCR2 is switched off, SCR1 is switched on and SCR2 is switched off, and so on in a similar manner. When a pulse is applied to the reset pulse input, SCR4 is switched on, and capacitor C7 discharges through SCR4 and L1, producing a large voltage pulse which reverse-biases whichever SCR is in the On state. SCR4 will continue to conduct until one of the other SCR's is switched on. Additional stages may be added to the circuit as desired. A ten-stage circuit using ten SCR's can be used to perform the function of a decade counter with direct lamp readout.

SECTION 2

POWER CONTROL

REMOTE-CONTROLLED SCR SWITCH

The silicon-controlled rectifier (SCR), which has many versions, is used as a static and sensitive latching switch; it can be substituted for relays, contact cores, or other devices. Alternating current can be used for the power supply where latching is undesirable. The circuit arrangement shown can be used for the remote-control actuation of various types of low-power loads such as relays, alarm systems, bells, or warning lights. A single semiconductor controlled rectifier is shown with an AC input that can be in the 100- to 200-volt range. The gate of the controlled rectifier is adjusted to a positive bias just below the triggering level by means of R1, R2, and the diode CR1. In this example the antenna coil and trimmer are tuned to a specific frequency used for remote control, such as a frequency in the 27-mc



Courtesy General Electric Co.

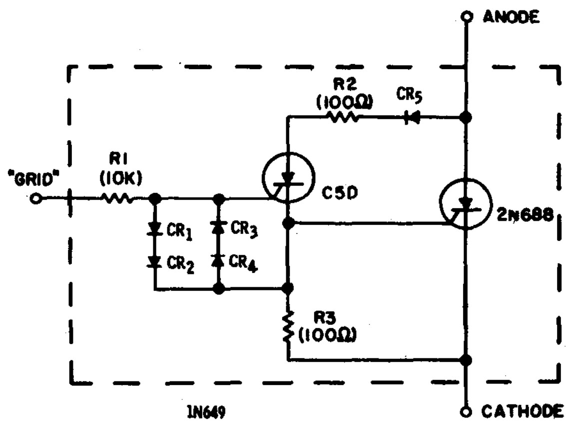
Remote-controlled SCR switch circuit.

Citizens band; R1 is adjusted so that the controlled rectifier triggers when it receives the proper transmitted signal. The bias arrangement allows for a low resistance path for the leakage current.

In this circuit there is reasonable temperature compensation, since CR1 and the controlled rectifier are maintained at about the same temperature. As a result a constant voltage differential exists between the steady-state bias voltage and the gate trigger voltage. If, however, the temperature of the controlled rectifier is raised to a sufficiently high value, the rectifier will spontaneously trigger. This temperature-triggering is put to practical use in other types of circuits.

A SOLID-STATE THYRATRON REPLACEMENT

A high-sensitivity controlled rectifier used as a controlled switch can be coupled with a rectifier in the circuit shown. This circuit acts like a thyratron in many ways, since it has a high signal-input impedance, low pickup and drop-out current, and can handle large amounts of power. In this circuit the grid, anode, and cathode connections for an equivalent thyratron tube are shown. With a



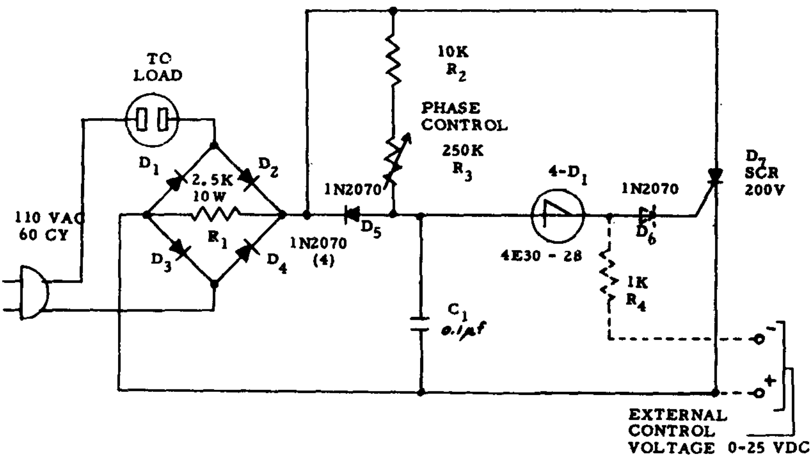
Courtesy General Electric Co.

Solid-state thyratron replacement circuit.

negative potential on the "grid" terminal, a stabilizing gate bias for the controlled switch is provided by CR1, CR2, and resistor R1. When the anode is positive and the grid is driven positive, the controlled switch starts conducting. This in turn triggers the larger controlled rectifier. Thus there is current flow from cathode to anode through the larger controlled rectifier. Diodes CR3 and CR4 are used to prevent excessive voltage from appearing across the gate-to-cathode terminals of the controlled switch, and CR5 is used to prevent transistor action of the controlled switch when positive grid voltage and negative anode potential occur at the same time.

AC CONTROL

The four-layer diode provides an efficient technique for the control of an SCR that is used in turn to control AC power. As shown, a full-wave bridge consisting of diodes D1 through D4 is in series with the load; an SCR (D7) is placed across the center terminals of the bridge so that when the SCR is fired, current will flow through the bridge, the SCR, and the load. The power delivered to the load is controlled by the phase angle at which the SCR fires.



Courtesy Shockley Transistor, Unit Clevite Transistor.

AC control circuit.

A simple RC network and a four-layer diode comprise the firing circuit. At the beginning of each cycle, C1 charges through R2 and R3. The charging rate is controlled by the setting of R3. When the voltage across C1 becomes equal to the switching voltage of the four-layer diode (4-D1), it fires, discharging C1 through the SCR gate and turning on the SCR. At the end of the half cycle, the voltage across the SCR drops to zero, turning off the SCR until it is fired again during the next half-cycle.

Suppose that R3 is at its maximum-resistance position; the time required to charge C1 to the switching voltage of D1 is greater than the period of one-half cycle; therefore, the SCR does not conduct. However, a discharge path must be provided to discharge C1 at the end of each half-cycle to prevent charge build-up on the subsequent half-cycle. This discharge path is through D5 and R1.