Astable and Monostable Oscillators

COS/MOS gates provide cost and size reductions in multivibrator circuits because their high input impedance makes it possible to obtain large time constants without the use of large capacitors. This section describes several techniques which may be used to compensate for the normal threshold variation of MOS devices in the design of stable multivibrator circuits. Operating frequencies up to 1 MHz can be attained with the CD4000 series, and up to 2 MHz and more with the CD4000A series. The circuits shown can be formed by use of the individual inverters in various COS/MOS IC's, such as the CD4000A, CD4001A, CD4002A, or CD4007A.

Although only CD4000A–series devices are mentioned, this section applies equally to CD4000–series devices.

ASTABLE CIRCUITS

Fig. 100(a) shows an astable-multivibrator circuit that uses two COS/MOS NOR gates as inverters; NAND gates or ordinary inverters may be substituted for the NOR gates. Fig. 100(b) shows the waveforms for the circuit of Fig. 100(a). This simple circuit requires only one resistor and one capacitor and operates in the following manner. When waveform (a) at the output of inverter B is in a high or one state, capacitor C_{tc} becomes positively charged. As a result, the input to inverter A is high and its output is low or zero. Resistor R_{tc} is returned to the output of inverter A to provide a path to ground for discharge of C_{tc}. As long as the output of inverter A is low, the output of inverter B is high. As capacitor C_{tc} discharges, however, the voltage generated [waveform (b) in Fig. 100(b)] approaches and passes through the transfer-voltage point of inverter A. At the instant that this crossover occurs, the output of A becomes high; as a result, the output of B becomes low and capacitor C_{tc} is charged negatively (or low). Resistor R_{tc}, connected to the output of A, then provides a charge path for the supply voltage. Capacitor C_{tc} begins to charge to this voltage. Again, the voltage approaches and passes through the transfer-voltage point of inverter A. At that instant,

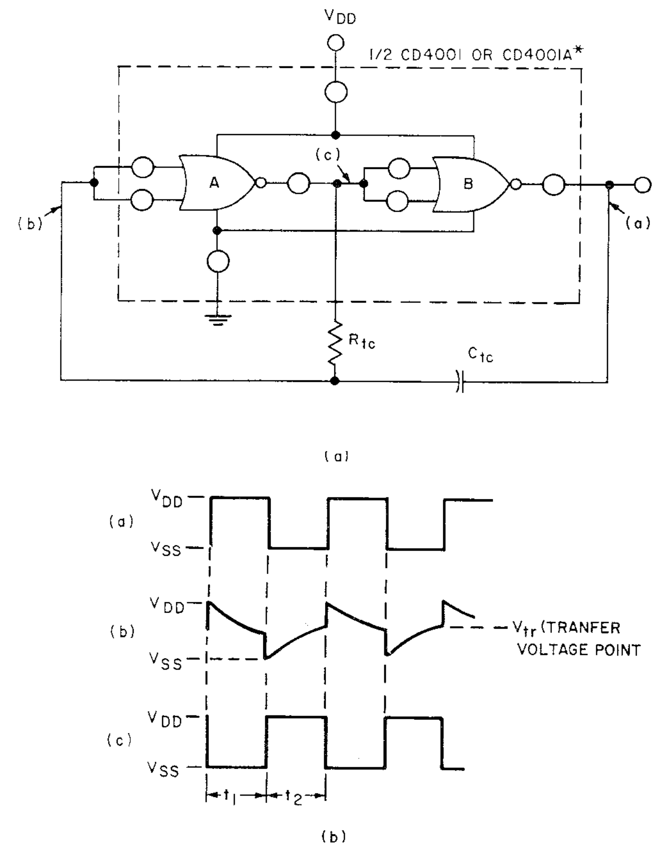


Fig. 100 - (a) Astable multivibrator circuit; (b) voltage waveforms.

the circuit again changes state (the output of A becomes low and that of B high) and the cycle repeats.

Because of the inclusion of input-diode protection circuits like the one shown in Fig. 101 in COS/MOS IC's, the generated drive waveform is clamped between V_{DD} and V_{SS}. Consequently, the time to complete one cycle is approximately 1.4 times the RC time constant because one time constant is used to control the switching of both states of the multivibrator circuit. Switching occurs when the charge or discharge reaches the transfer-voltage level, or when the time period reaches 70.7 per cent of its discharge. As shown in waveform (b) of Fig. 100(b) the transfer-voltage point V_{tr} is the same for t_1 and t_2. The time period T for one cycle can be computed as follows:

$$T = t_1 + t_2$$

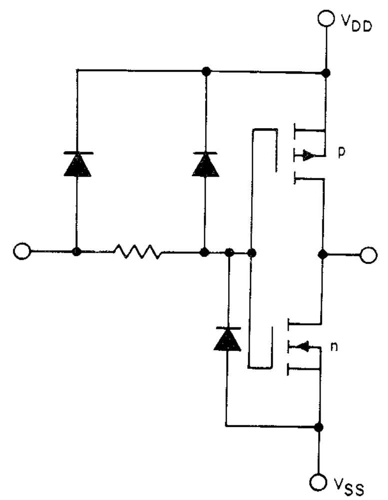


Fig. 101 - Diode protection circuit.

$$t_1 = -RC \ln \frac{(V_{DD} - V_{tr})}{V_{DD}}$$

$$t_2 = -RC \ln \frac{V_{tr}}{V_{DD}}$$

$$T = -RC \left[\ln \frac{(V_{DD} - V_{tr})}{V_{DD}} + \ln \frac{V_{tr}}{V_{DD}} \right] \quad (4)$$

If the time constant is assumed to be 1 x 10^{-6} second and the transfer voltage V_{tr} is allowed to vary from 33 to 67 per cent of V_{DD}, the period T varies from 1.4 microseconds at a value of V_{tr} equal to half of V_{DD} to 1.5 microseconds at either the 33- or 67-per-cent value of V_{DD}. Therefore, the maximum variation in the time period T is only 9 per cent with a ±33-per-cent variation in transfer voltage from unit to unit.

Oscillator operation can be made independent of supply-voltage variations by use of a resistor R_S in series with the input lead to inverter A, as shown in Fig. 102(a). The value of this resistor should be at least twice as large as that of resistor R_{tc} to allow the voltage waveform generated at the junction of R_S, R_{tc}, and C_{tc} to rise to V_{DD} + V_{tr}. The waveform is still clamped between V_{DD} and V_{SS} as shown by the waveforms in Fig. 102(b). The use of resistor R_S provides several advantages in the circuit. First, because the RC time constant controls the fre-

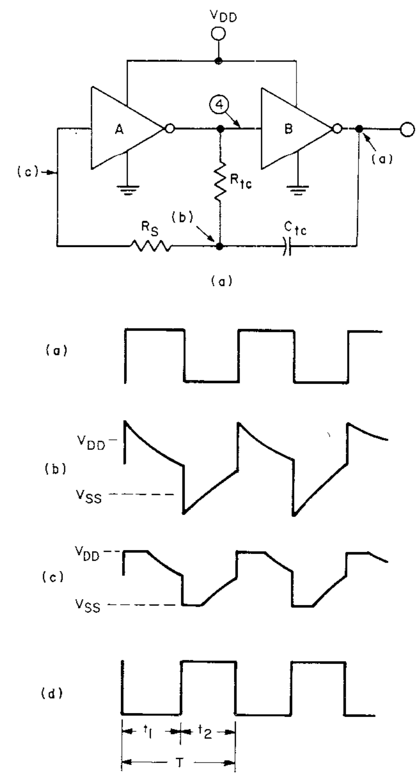


Fig. 102 - (a) COS/MOS inverter with resistor in series with one input to make circuit independent of supply-voltage variations; (b) voltage waveforms.

quency, the overall maximum variations in the time period are reduced to less than 5 per cent with variations in transfer voltage, as determined by the following equation:

$$T = -RC\left[\ln\frac{V_{tr}}{(V_{DD}+V_{tr})} + \ln\frac{(V_{DD}-V_{tr})}{2V_{DD}-V_{tr}}\right]$$

Resistor R_S also makes the frequency independent of supply-voltage variations. Table XIV shows data measured on typical units with and without the resistor.

Fig. 103 shows a typical transfer characteristic as a function of temperature. It can be seen that there is very little change in the characteristic from low to high temperature. Because the oscillator

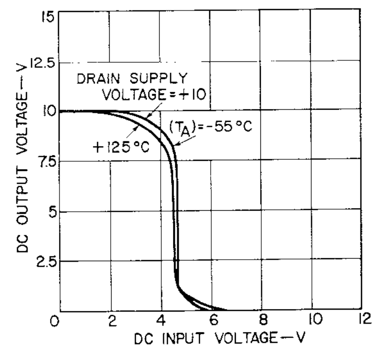


Fig. 103 - Typical COS/MOS transfer characteristic as a function of temperature.

Table XIV – Frequency variations of astable multivibrator with and without series resistor

Unit No.	V_{tr} @ V_{DD} = 10V (V)	Period Without Rs - (ms)			Period With Rs - (ms)		
		V_{DD} = 6V	V_{DD} = 10V	V_{DD} = 14V	V_{DD} = 6V	V_{CC} = 10V	V_{CC} = 14V
2	4.77	0.735	0.66	0.645	1.04	1.00	1.02
6	5.78	0.715	0.665	0.63	1.06	1.04	1.03
11	5.58	0.695	0.66	0.625	1.03	1.02	1.03
13	5.00	0.70	0.665	0.64	1.03	1.01	1.02
20	5.56	0.70	0.665	0.64	1.04	1.03	1.03

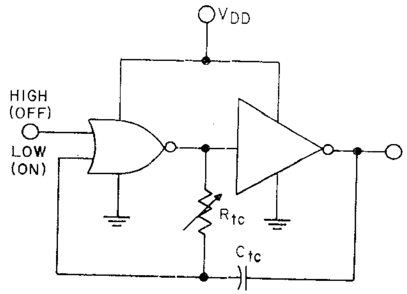
R_{tc} = 0.4 megohm, C_{tc} = 1000pF, R_s = 0.8 megohm

can also tolerate changes in the transfer characteristic without frequency instability, it requires no thermal compensation. The frequency at -55°C is the same as at +125°C. Table XV shows data measured on typical units at temperature extremes. The astable multivibrator shown in Fig. 100 can be gated ON and OFF by use of a NOR or NAND gate as the first inverter, as shown in Fig. 104.

Table XV – Frequency variations of astable multivibrator at temperature extremes

	Period (ms)					
	V_{DD} = 6V		V_{DD} = 10V		V_{DD} = 14V	
Unit No.	-55°C	+125°C	-55°C	+125°C	-55°C	+125°C
2	1.04	1.04	1.02	1.01	1.03	1.02
6	1.06	1.07	1.06	1.04	1.04	1.03
11	1.03	1.03	1.04	1.02	1.04	1.01
13	1.02	1.02	1.02	1.02	1.03	1.01
20	1.04	1.03	1.04	1.03	1.04	1.02

R_{tc} = 0.4 megohm, C_{tc} = 1000pF, R_s = 0.8 megohm



GATING OF OSCILLATOR

Fig. 104 - Astable multivibrator with NOR- or NAND-gate first inverter to permit gating of the multivibrator.

Compensation for 50-per-cent Duty Cycles

The variation in transfer voltage described above affects the output-pulse duty cycle, as shown in Fig. 105. A true square-wave pulse is obtained only when the transfer voltage occurs at the 50-per-cent point. However, the duty cycle can be controlled if part of the resistance in the RC time constant is shunted out with a diode, as shown in Fig. 106. Because adjustment of this diode shunt to obtain a specific pulse duty factor causes the frequency of the circuit to vary, a frequency-control resistor, R3, is added to compensate for this variation. It may also be necessary to reverse the diode to obtain the desired duty factor. The frequency of any of the circuits shown can be made variable by use of a potentiometer in place of resistor R_{tc}.

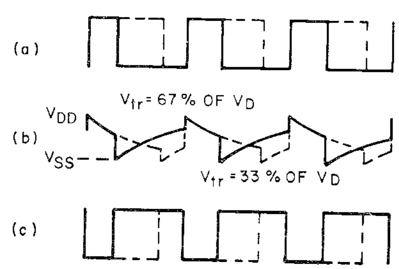


Fig. 105 - Effect of transfer voltage on multivibrator frequency.

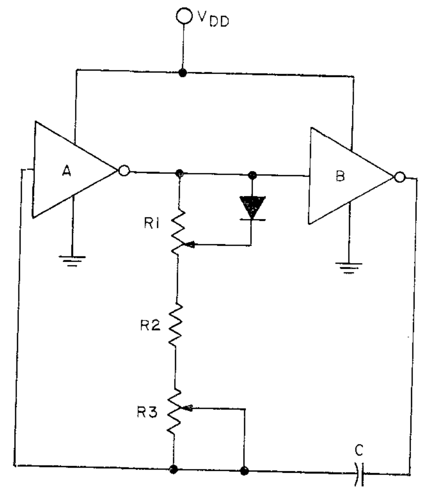


Fig. 106 - Astable multivibrator with duty-cycle control.

MONOSTABLE CIRCUITS

Basic Configuration

Fig. 107(a) shows a basic "one-shot" circuit that uses a single RC time constant. This circuit operates well provided it is adjusted to the COS/MOS unit used. If no adjustment is made, period T can vary by as much as -40 per cent to +60 per cent as the transfer voltage varies by ±33 per cent. These variations are illustrated in the waveforms of Fig. 107(b).

Compensated Circuit

Fig. 108 shows a compensated monostable multivibrator circuit that can be triggered with a negative-going

Astable and Monostable Oscillators

Feedback from (d) to the input of the NOR gate holds (b) low until the capacitor has charged and reaches the threshold- even if the input goes low. Therefore, this circuit provides an output pulse length which is independent of the length the input pulse. It is a true "one-shot", but it may require recovery time .

It is important to note that when (c) reaches the threshold it will jump to a voltage greater than the positive supply, where it will be clamped to about ½ V above the positive rail by the input diode of the gate. This is due to (b) going high and having the transition coupled through the capacitor. This effect is not shown on the waveform shown for (c).

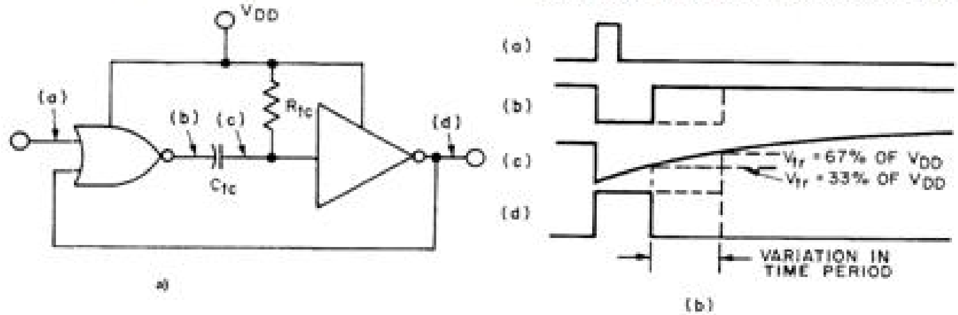


Fig. 107 - (a) Basic "one-shot" multivibrator circuit; (b) circuit waveforms.

pulse (V_{DD} to ground). In the quiescent state, the input to inverter A is high and the output low; therefore, the output of inverter B is high. When a negative-going pulse or spike is introduced into the circuit, as shown in the waveforms of Fig. 109, capacitor C1 becomes negatively charged to ground and the output of inverter A becomes high. Capacitor C2 then charges to V_{DD} through diode D1 and inverter A; the output of inverter B becomes low. As capacitor C1 discharges negatively, it charges through resistor R1 to V_{DD} [waveform (b)]. The output of inverter A remains high until the voltage waveform generated by the charge of C1 passes through the transfer voltage of inverter A; at that instant its output becomes low. Diode D1 temporarily prevents the discharge of capacitor C2 which was charged when inverter A was high [waveform (c)]. Capacitor C2 then begins to discharge to ground through resistor R2 [waveform (d)]. The output of inverter B remains low until the waveform generated by the discharge of C2 passes through the transfer-voltage point of inverter B; at that point the output returns to its high state [waveform (e)]: The advantage of using two inverters fabricated on the same chip is that they have similar transfer voltages.

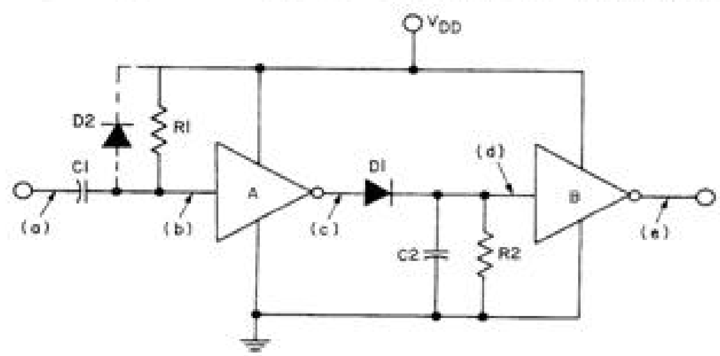


Fig. 108 - Compensated monostable-multivibrator circuit.

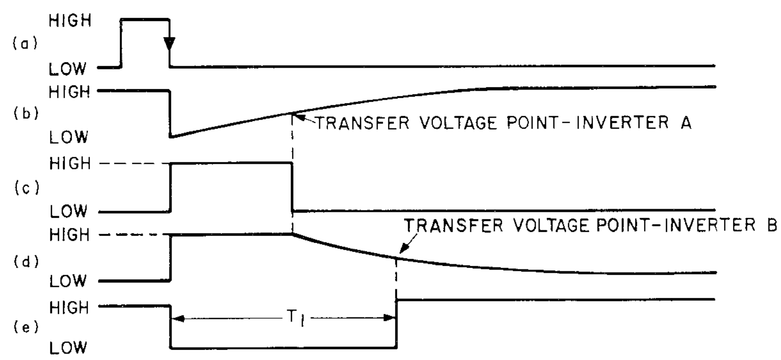


Fig. 109 - Voltage waveforms for the circuit of Fig. 108 with negative-going trigger pulse applied.

When two equal RC time constants are used (R1C1 equals R2C2), the effects of variations in transfer voltage from device to device are effectively cancelled out, as shown in Fig. 110. By use of Eq.(4), derived for the astable oscillator, it can be shown that the maximum variation in transfer voltage in the time period T is less than 9 per cent. The total time for one period T1 is approximately 1.4 times the R1C1 time constant.

Unlike the astable circuit, which shows no variation in frequency over the temperature range from -55°C to +125°C, the monostable multivibrator shows some change in time period T. The variation is less than 10 per cent. Table XVI shows data measured on five units over the temperature range. At 25°C, the variation in the time period from unit to unit is quite small, usually less than 5 per cent at a V_{DD} of 10 volts.

The output from inverter B in Fig. 108 can be held in the low or zero state as long as the R2C2 time constant is recharged by another triggering pulse before the discharge waveform it generates passes through

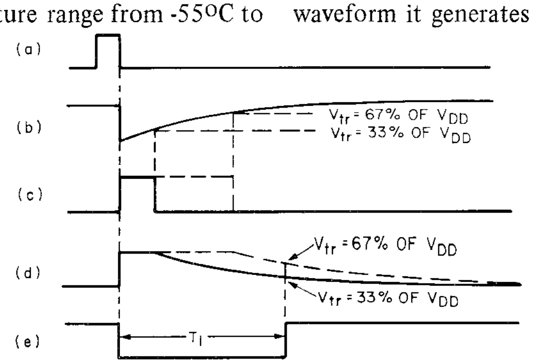


Fig. 110 - Cancelling effects of transfer-voltage variations of two COS/MOS inverters when two equal time constants are used.

Table XVI – Frequency variations of monostable multivibrators at three temperatures

Unit No.	Period @ V_{DD} = 10V (ms)		
	-55°C	+25°C	+125°C
2	1.06	1.08	1.00
6	1.015	1.03	0.99
11	1.00	1.02	0.98
13	1.01	1.03	0.97
20	1.02	1.02	0.99

$R_1 = R_2 = 1$ megohm, $C_1 = C_2 = 0.001\mu F$

the transfer voltage of inverter B. Diode D2 in Fig. 108 is internal to the COS/MOS circuit. As discussed for the astable oscillator, it is part of the input protection circuit shown in Fig. 101, and serves to clamp the input at V_{DD}.

Figs. 111 and 112 show two variations of the monostable circuit together with their associated waveforms. The circuit of Fig. 111 triggers on the negative-going excursions of the input pulse, in the same manner as the circuit of Fig. 108. The output pulse is positive-going and is taken from the first inverter. This circuit does not need an external diode. The circuit of Fig. 112 triggers on the positive-going excursion of the input pulse, and then locks back on itself until the RC time constants complete their discharge. The circuits of Figs. 111 and 112 cannot be retriggered until they return to their quiescent states.

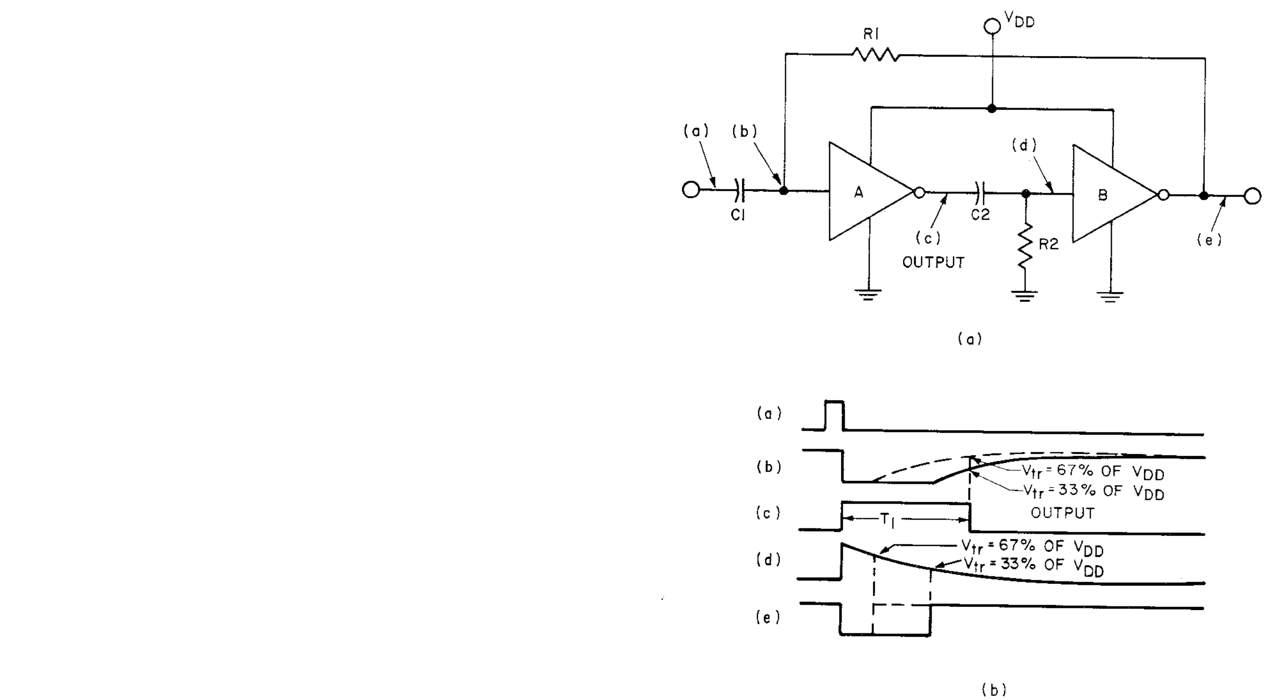


Fig. 111 - (a) Monostable multivibrator triggered by negative-going input pulse; (b) circuit waveforms.

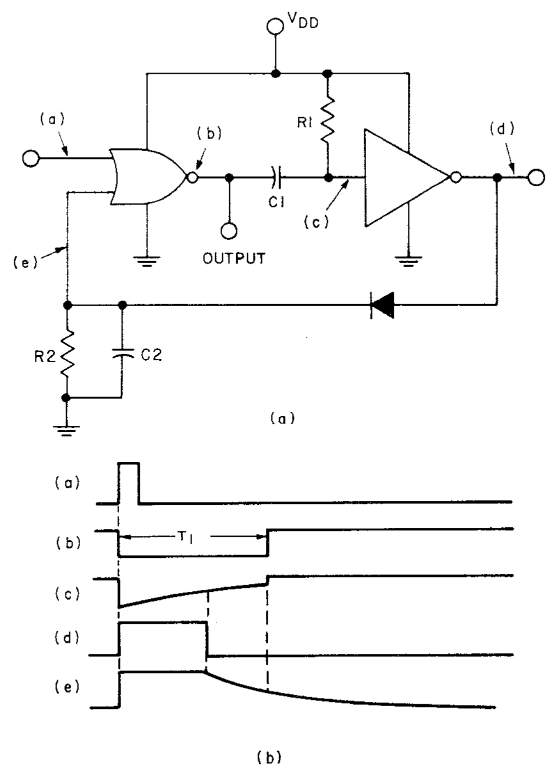


Fig. 112 - (a) Monostable multivibrator triggered by positive-going input pulse; (b) circuit waveforms.

Low-Power Circuit

The monostable circuits discussed thus far dissipate some power because one or both of the inverters are ON during the charging or discharging of the RC time constants. This power dissipation will be extremely low provided the "one-shot" pulse width is short compared to the over-all cycle time. Fig. 113 shows the current waveforms associated with the circuit of Fig. 108. This waveform is quite wide at the base, and some current flows for approximately twice the time period. Fig. 114(a) shows a circuit using the CD4007A which dissipates much less power than the other circuits shown, but does not have the same stability. This circuit operates as

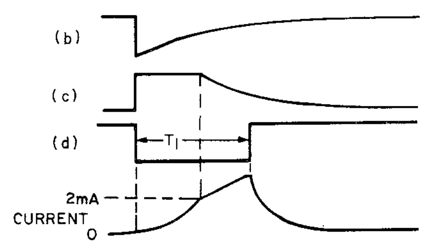


Fig. 113 - Current waveforms for the diode-compensated multivibrator of Fig. 108.

shown by the waveforms in Fig. 114(b). In the quiescent state, the p-channel transistor of the first inverter is biased OFF while the n-channel transistor (which derives its control from the output of the second inverter) is biased ON. Therefore, the output at C is low, and that at D is high. When a negative-going pulse is introduced into the circuit

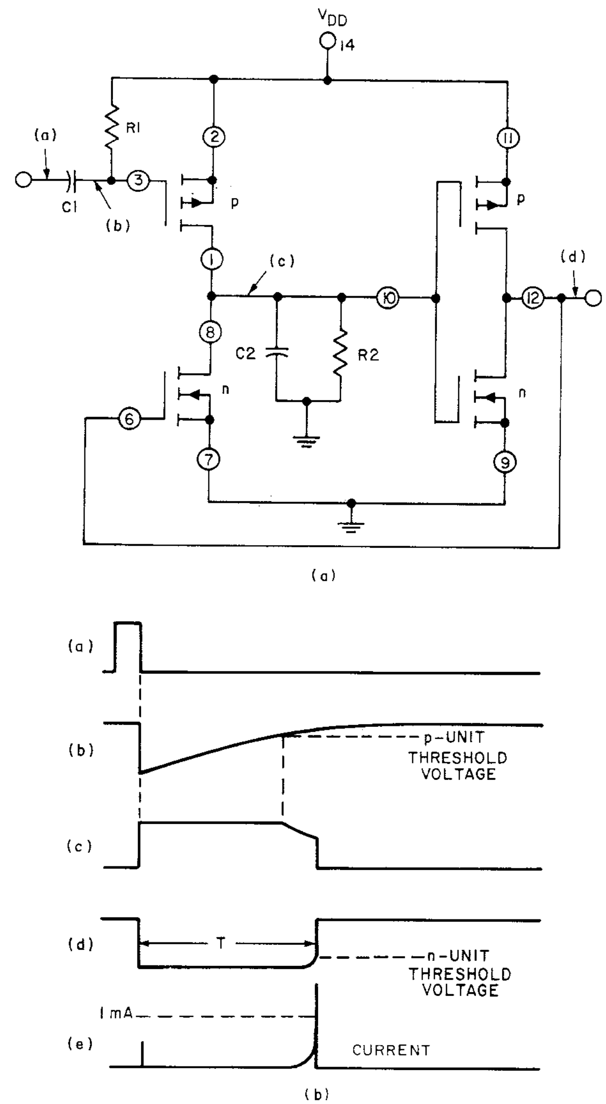


Fig. 114 - (a) Low-power monostable multivibrator; (b) circuit waveforms.

through capacitor C1, the R1C1 time constant becomes negatively charged, and the p-channel device is turned on. Capacitor C2 then charges to V_{DD}, the output at D becomes low, and the n-channel device of the first inverter is turned OFF. Capacitor C1 immediately begins to charge to V_{DD} through R1 [waveform (b)]. The p-channel transistor remains ON, keeping capacitor C2 charged to V_{DD}, until the waveform generated passes through its threshold-voltage level and turns it OFF. The n-channel transistor of the first inverter is still OFF because the output of the second inverter [waveform (d)] is still low. When the p-channel device of the first inverter turns off, capacitor C2 begins to discharge through resistor R2 [waveform (c)] to ground. As it discharges, it passes through the threshold voltage of the second p-channel transistor so that it begins to turn on. The voltage waveform at (d) then begins to rise, and the n-channel device of the first inverter turns on and provides a second discharge path for the capacitor C2. As a result, the output waveform changes state from low to high quite rapidly to complete the cycle.

The major advantage of the circuit of Fig. 114 is its low power dissipation. Because the circuit depends on the p-channel-transistor threshold, the time period T varies from unit to unit or with temperature variations. Some compensation can be provided if the R2C2 time constant is made approximately 3 times larger than the R1C1 time constant, as shown in Table XVII. For minimum current in the circuit of Fig. 114, capacitor C2 can be removed so that only stray capacitance is present at the input of the second inverter. A comparison of time-period variations under this condition is shown in Table XVIII. Again, the variations from unit to unit are caused by differences in p-channel transistor threshold.

Table XVII – Frequency variations of monostable multivibrator with temperature when R_2C_2 time constant is increased

Unit No.	Period with V_{DD} = 10V (μs)		
	-55°C	+25°C	+125°C
553	1090	1120	1160
554	1060	1090	1120
810	1030	1030	1020
900	1000	1020	990
939	1080	1100	1050

R_1 = 0.35 megohm, C_1 = 0.001μF
R_2 = 1 megohm, C_2 = 0.001μF
R_2C_2 is approximately $3R_1C_1$

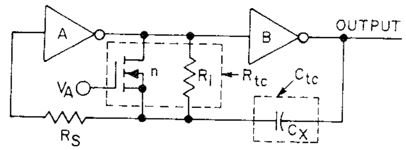
Table XVIII – Frequency variations of monostable multivibrator with temperature when C_2 consists of stray capacitance only

Unit No.	Period with V_{DD} = 10V (μs)		
	-55°C	+25°C	+125°C
553	870	940	1020
554	900	970	1050
810	900	1000	1080
900	810	880	960
939	780	850	920

R_1 = 0.62 megohm, C_1 = 0.001μF
R_2 = 1 megohm, C_2 = strays

APPLICATIONS

COS/MOS multivibrators can be used in a variety of applications including voltage-controlled oscillators, voltage-controlled pulse-width circuits, phase-locked voltage-controlled oscillators, frequency multipliers, and envelope detectors. Fig. 115(a) shows a voltage-controlled oscillator, a circuit similar to that of Fig. 102(a). (Inverters and n-channel device are available in a single COS/MOS package as the CD4007A.) C_{tc} is variable (by



TYPICAL VALUES

R_I = 10,000 OHMS C_X = 0.001 TO 0.004 μF

R_S = 100,000 OHMS $0 \le V_A \le V_{DD}$

(a)

PERIOD OF OUTPUT (MICROSECONDS) AS A FUNCTION OF V_A AND V_{DD}

V_A (VOLTS)	V_{DD} (VOLTS) 5	10	15
0	120	54	48
5	115	45	41
10	—	32	30
15	—	—	24

(b)

Fig. 115 - (a) Voltage-controlled oscillator using one CD4007A; (b) period of output as a function of V_A and V_{DD}.

adjustment of C_X) as is R_{tc} (by adjustment of V_A). The value of R_{tc} varies from approximately 1 to 10 kilohms. These limits are determined by the parallel combination of R1 (10 kilohms) and the n-channel resistance which varies from 1 kilohm (R_{ON}) to approximately 10^{11} ohms (R_{OFF}). When V_A and V_{SS} are equal, the n-channel device is OFF and

$$R_{tc} = \frac{R_{OFF}}{R_1} \approx R1 = 10 \text{ kilohms}$$

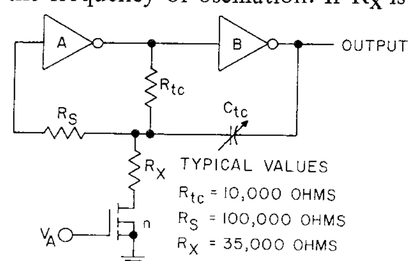
because R_{OFF} is much greater than R1. When V_A and V_{DD} are equal, the n-channel device is fully ON and

$$R_{tc} = \frac{R_{ON}}{R_1} \approx R_{ON} = 1 \text{ kilohm}$$

because R_{ON} is very much less than R1. The oscillator center frequency is varied by adjustment of C_X. Fig. 115(b) shows a comparison of the period of the output waveform as a function of V_{DD} and V_A.

Voltage-Controlled Pulse-Width Circuit

Fig. 116(a) shows a further modification of the circuit of Fig. 102(a) which causes the pulse width to be modulated, by varying V_A, only when R_X is sufficiently high. For example, if C is 0.0022 microfarad, then R_X is approximately 35 kilohms. Lower values of R_X affect the frequency of oscillation. If R_X is



TYPICAL VALUES

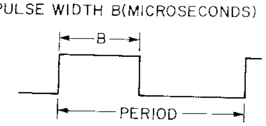
R_{tc} = 10,000 OHMS

R_S = 100,000 OHMS

R_X = 35,000 OHMS

C_{tc} = 0.0005 TO 0.0025 μF

PULSE WIDTH B(MICROSECONDS)



V_A (VOLTS)	V_{DD} (VOLTS) PERIOD (MICROSECONDS) 5 V 41.5 μS	10 V 35 μS	15 V 33 μS
0	23	19.3	17
5	20	17.7	16.2
10	—	16.2	15.5
15	—	—	14.3

C_{tc} = 0.0015 μF

Fig. 116 - Voltage-controlled pulse-width circuit.

less than 10 kilohms, there is a value of V_A which will cause the oscillator to cut off. Fig. 116(b) shows the output waveform and values of pulse width (B) for various values of V_A and V_{DD}.

Phase-Locked Voltage-Controlled Oscillator

The voltage-controlled oscillator (VCO) can be operated as a phase-locked oscillator by the application of a frequency-controlled voltage to the gate of the n-channel device. Fig. 117 shows the block diagram of an FM discriminator using the phase-locked VCO. The first block is the same circuit as that shown in Fig. 115. When the two inputs to the phase comparator are different, the comparator produces an output which is fed to the gate of the n-channel device (V_A). The change of V_A causes the output frequency of the VCO to change. This change is divided by 2^N and fed back to the phase comparator.

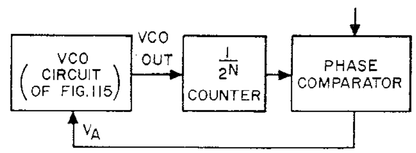


Fig. 117 - FM discriminator using the phase-locked voltage-controlled oscillator.

Frequency Multipliers

Fig. 118(a) shows a frequency doubler. A 2^N multiplier can be

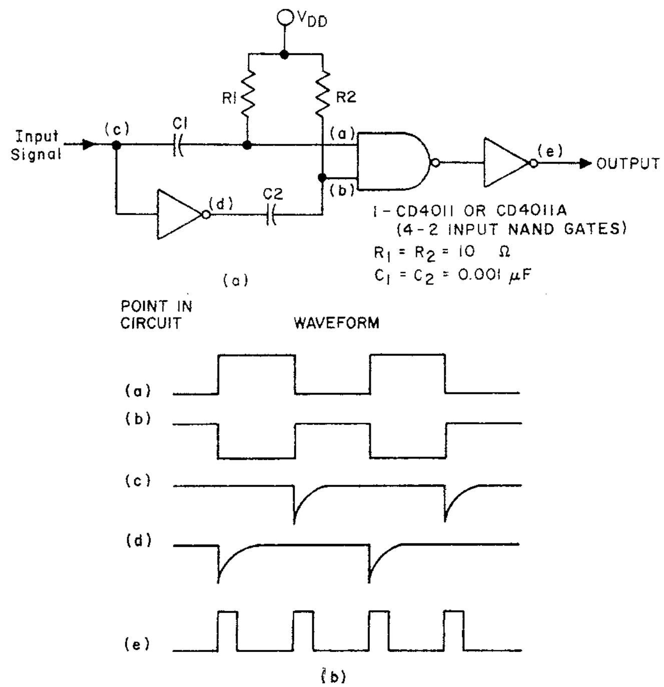


Fig. 118 - (a) Frequency-doubler circuit CD4011A; (b) circuit waveforms.

realized by cascading this circuit with N-1 other identical circuits. The leading edge of the input signal is differentiated by R1 and C1 and applied to input (a) of the NAND gate. This action produces a pulse at the output. The trailing edge of the input pulse, after being inverted, is differentiated and applied to input (b) of the NAND gate. This action produces the second output pulse from the NAND gate. The waveforms for 5 points in the circuit are shown in Fig. 118(b).

Modulation/Demodulation-Envelope Detection

Pulse modulation is accomplished by use of the circuit shown in Fig. 119(a), a variation of the circuit of Fig. 102(a). The oscillator is gated ON or OFF by the signal impressed at input (a) of the NAND gate. Waveforms for the pulse-modulation circuit are shown in Fig. 119(b).

Demodulation or envelope detection of pulse-modulated waves is performed by the circuit shown in Fig. 120(a). The carrier burst is inverted by inverter A. Its first negative transition at point (b) turns diode D ON and provides a charging path for C_{tc} through the n-channel resistance to ground. On the positive transition of the signal at point (b),

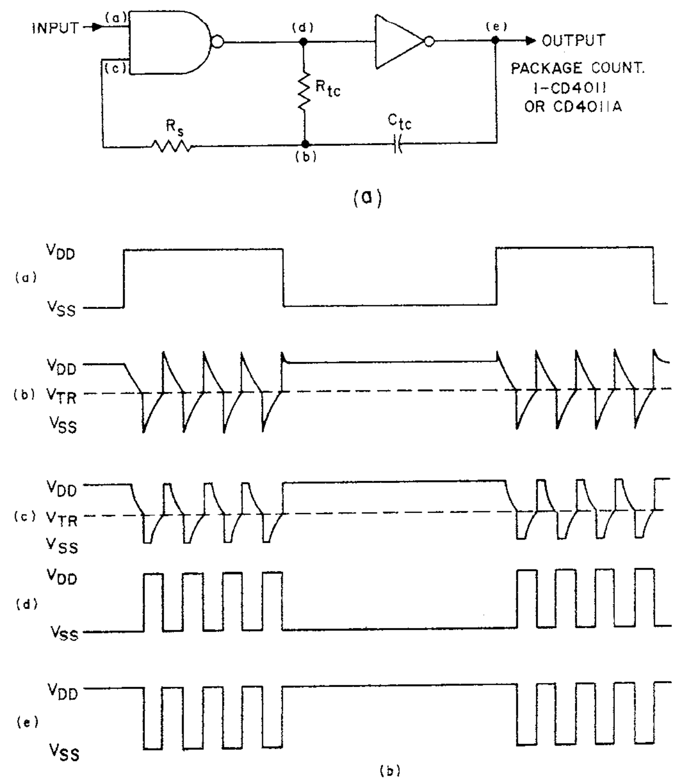


Fig. 119 - (a) Modulator circuit using one CD4011A; (b) circuit waveforms.

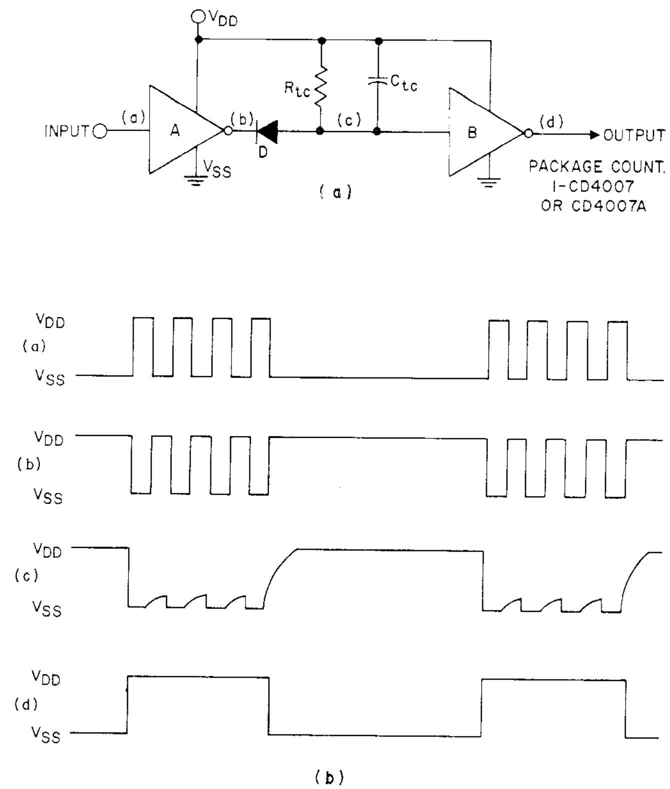


Fig. 120 - (a) Demodulator (envelope detector) circuit using one CD4007A; (b) circuit waveforms.

the diode is cut off and C_{tc} discharges through R_{tc}. The discharge time constant ($R_{tc}C_{tc}$) is much greater than the time of the burst duration. Point (c), therefore, never displays the conditions required for the switching of inverter B until the burst has passed. The waveforms for 4 points in the circuit are shown in Fig. 120(b).