SECTION 2

ASTABLE MULTIVIBRATORS

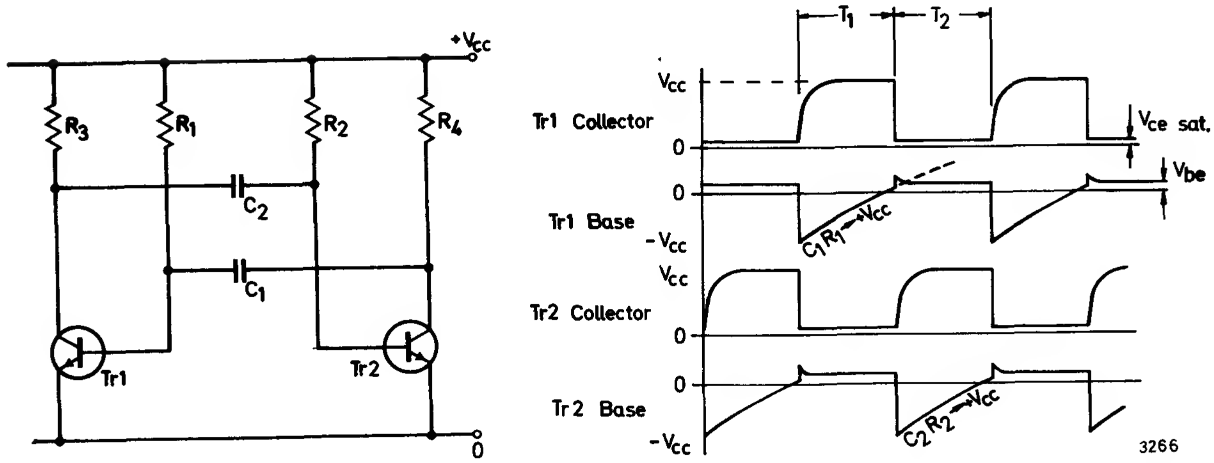
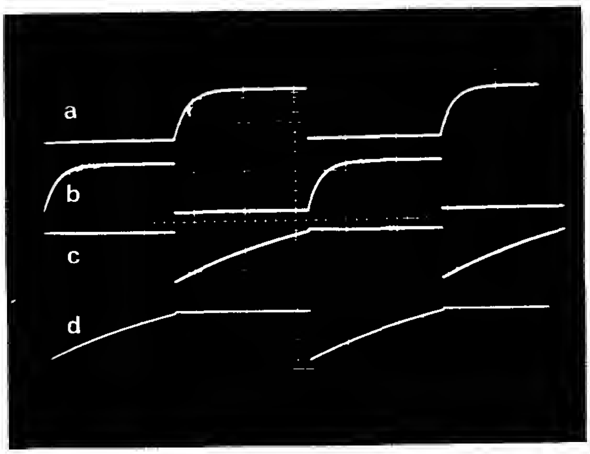


Figure 2.1. Basic Astable.

Typical component values: R1 = R2 = 15kΩ
R3 = R4 = 1kΩ
C1 = C2 = 0·047μF
Tr1 = Tr2 = ZTX300
+ V_{cc} = 5 volts



Oscilloscope trace
(a)—Tr1 collector
(b)—Tr2 collector
(c)—Tr1 base
(d)—Tr2 base

Frequency = 963Hz (measured).

The astable multivibrator (Figure 2.1) is basically an a.c. coupled two stage amplifier with phase inversion over each stage and with the output coupled back to the input. This positive feedback causes the circuit to oscillate continuously between two quasi-stable states. Suppose that Tr1 has just turned on and Tr2 is off. The voltage at the base of Tr2 rises exponentially towards the supply voltage as C2 charges through R2 until it reaches +0·7V, when Tr2 starts to conduct. The collector voltage of Tr2 starts to fall and this change is coupled through C1 to the base of Tr1. Tr1 now begins to turn off and its collector voltage rises, increasing the base current of Tr2 and further reducing its collector voltage. This regenerative action results in very rapid switching from the "off" state to the "on" state and vice-versa. The regenerative action ceases when Tr2 saturates. Tr1 is now completely cut off with its base reverse biased by (approximately) $-V_{cc}$. The potential of Tr1 base now rises exponentially with a time constant of (C1 × R1) as C1 charges towards the supply voltage ($+V_{cc}$). As the voltage at Tr1 base reaches +0·7V, Tr1 switches on, Tr2 is cut off and the cycle repeats.

If the transistor leakage currents are ignored and the collector saturation voltage and base-emitter "on" voltage are assumed to be zero, simple approximate formulae for the periods T1 and T2 may be derived as follows:

The instantaneous base voltage of T1, $V_{b1} = 2V_{cc}\left[1-e^{-\frac{t}{C_1R_1}}\right] - V_{cc}$

$$= V_{cc}\left[1-2e^{-\frac{t}{C_1R_1}}\right]$$

For $V_{b1} = O$ $\quad 2e^{-\frac{t}{C_1R_1}} = 1.$

$$t = T1 = C_1R_1 \log_n 2$$

$$\text{i.e.: } T1 = 0.693\ C_1R_1 \quad \ldots\ldots 2.1$$

similarly $\quad T2 = 0.693\ C_2R_2$

$T = 0.7CR$ is a useful approximation.

These formulae are sufficiently accurate for most practical purposes, but where a more precise estimate is required V_{cc}, V_{be} and $V_{ce(sat)}$ must be taken into account. T1 and T2 can be expressed more accurately as:

$$T1 = C_1R_1 \log_n \frac{2V_{cc} - V_{be} - V_{ce(sat)}}{V_{cc} - V_{be}} \quad \ldots\ldots 2.2$$

and similarly for T2.

For the circuit shown in Figure 2.1 the frequency calculated from equation 2.1 is 1·022kHz Assuming $V_{be} = 0{\cdot}7V$ and $V_{cc(sat)} = 0{\cdot}1V$ equation 2.2 gives – $T_1 = T_2 = C_1R_1 \log_n \frac{10-0{\cdot}7-0{\cdot}1}{5-0{\cdot}7}$

$$= C_1R_1 \log_n 2.14$$

$$= 0.047\ .\ 10^{-6}\ .\ 15.10^{3}\ .\ 0.761 \text{ secs.}$$

$$T1 = T2 = 0.536\text{mS}$$

Hence the total period is 1.072mS and the frequency is 934Hz. The frequency measured on the actual circuit was 963Hz with 1% components.

The maximum values of R1 and R2 are limited to h_{FE} . R3 and h_{FE} . R4 respectively, where h_{FE} is the minimum d.c. current gain of the transistors used. In practice it is advisable to use a value somewhat lower than this to ensure that the transistor is fully saturated.

The minimum values of R1 and R2 must be such as to allow the collector voltage to complete its full excursion during the pulse period. Referring to Figure 2.1, for Tr1 collector to recover to at least $0{\cdot}98V_{cc}$, T1 must be at least equal to $4C_2R_3$ since $(1-e^{-4}) = 0{\cdot}98$.

Hence $T1 = 0{\cdot}69\ C_1R_1 \geqslant 4\ .\ C2R3$.

if $C1 = C2$, $R1 \geqslant 5.8R3$

and $\quad R2 \geqslant 5.8R4 \quad \ldots\ldots 2.3$

If recovery to $0{\cdot}99\ V_{cc}$ is required these become:

$R1 \geqslant 6.7R3$

$R2 \geqslant 6.7R4 \quad \ldots\ldots 2.4$

The basic astable multivibrator as described so far has two disadvantages which can, where necessary, be overcome by modifications to the circuit.

(a) Edge Speed

The positive going edge of the collector waveform is slow because the timing capacitor has to re-charge through the collector load resistor. This can be avoided by providing a separate re-charge path for the timing capacitor as shown in Figure 2.2. When Tr2 turns off the diode is reversed biased and the collector voltage rises rapidly to V_{cc} whilst the voltage at point A rises exponentially with time constant C1 . R5 as C1 recharges. When Tr2 turns on the diode becomes forward biased and R4, R5 appear effectively in parallel. It is usually convenient for the values of R4 and R5 to be equal but this is not important so long as R5 is sufficiently small to completely recharge C1 in the period that Tr2 is turned off. The technique can of course be applied to both sides of the multivibrator when clean waves are required at both outputs.

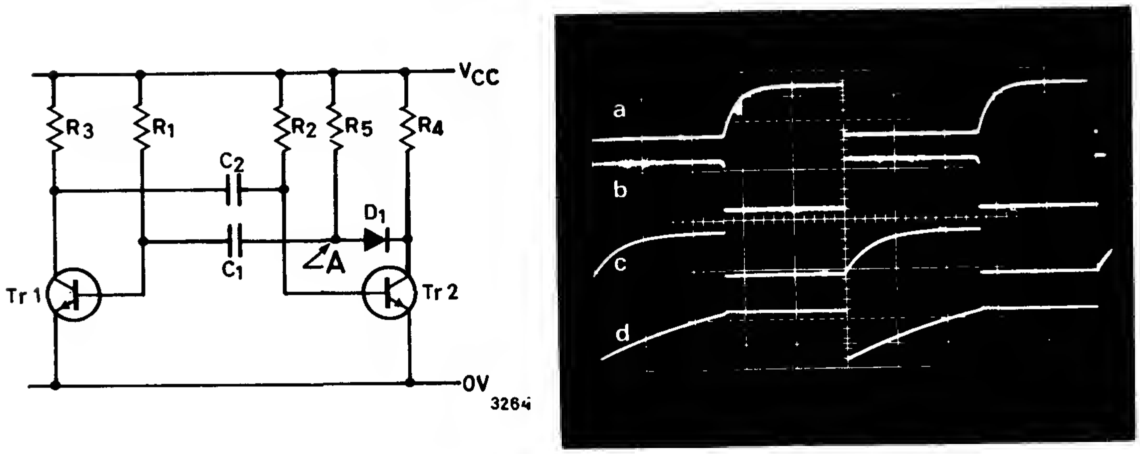


Figure 2.2. Astable modified for improved waveform.

Typical component values:

R1	=	R2	=	15kΩ
R3	=	1kΩ		
R4	=	R5	=	2k2
C1	=	C2	=	0·047μF
Tr1	=	Tr2	=	ZTX300
D1	=	ZS140		
$+V_{cc}$	=	5 volts		

Frequency = 1·066kHz (measured)

Trace (a) Tr1 collector
(b) Tr2 collector
(c) Point "A"
(d) Tr2 base

(b) Voltage Limitations

In the basic multivibrator (Figure 2.1) the transistor base is momentarily reverse biased to $-V_{cc}$. This limits the maximum value of V_{cc} to the base-emitter breakdown voltage of the transistor (usually 5V). This is too low for many applications but higher supply voltages can be used if the transistor is protected against base-emitter breakdown. Two circuits which do this are shown in Figures 2.3 and 2.4.

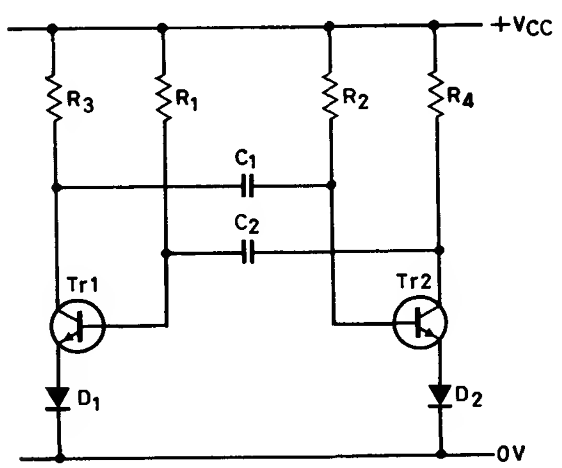


Figure 2.3

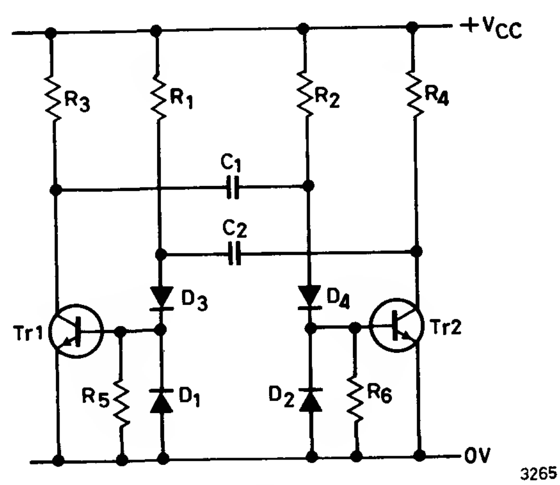


Figure 2.4

Typical component values:

R1 = R2 = 15kΩ
R3 = R4 = 1kΩ
C1 = C2 = 0·047μF
Tr1 = Tr2 = ZTX300
D1 = D2 = ZS140
Frequency = 1kHz
V_{cc} = 12V max.

Typical values are as Figure 2.3 except:

D3 = D4 = ZS120
R5 = R6 = 10kΩ
V_{cc} = 25V max.

In the circuit of Figure 2.3 diodes D1 and D2 become reverse biased when the base of the transistor is driven negative and prevents any current from flowing in the base-emitter junction. The diodes should preferably be high speed types such as ZS140 and the transistors chosen must have a collector-base breakdown voltage (V_{cbo}) of at least twice V_{cc}, since the collector is at $+V_{cc}$ when the base is reverse biased to $-V_{cc}$.

The maximum value of V_{cc} in the circuit of Figure 2.4 is limited to the collector-emitter breakdown voltage (V_{ceo}) of the transistor since diodes D3 and D4 completely isolate the transistor bases. In this circuit it is often advantageous for diodes D1 and D2 to be fast types (e.g. ZS140) and diodes D3 and D4 to be slow types (e.g. ZS120) as the stored charge in D3, D4 helps to turn the transistors off rapidly. At low speeds diodes D1 and D2 can be omitted if fast diodes are used for D3 D4.

Another technique which is particularly useful at high repetition rates is to "catch" the collector voltage at 5V by means of diodes D1 and D2 and zener diode D3, as shown in Figure 2.5. In this case the collector voltage swing, and hence the reverse bias applied to the base, is limited to 5V and the collector waveform is considerably improved. It should be noted however that the simplified formulae derived earlier no longer apply and the component values required must be calculated from first principles.

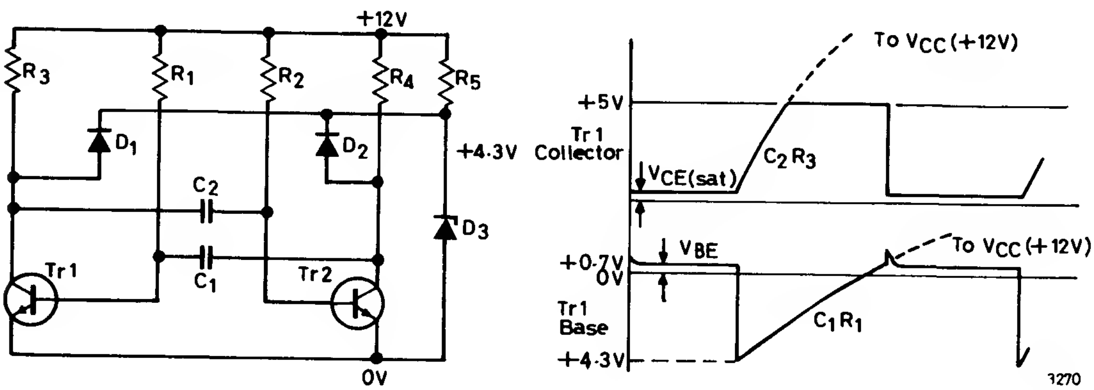
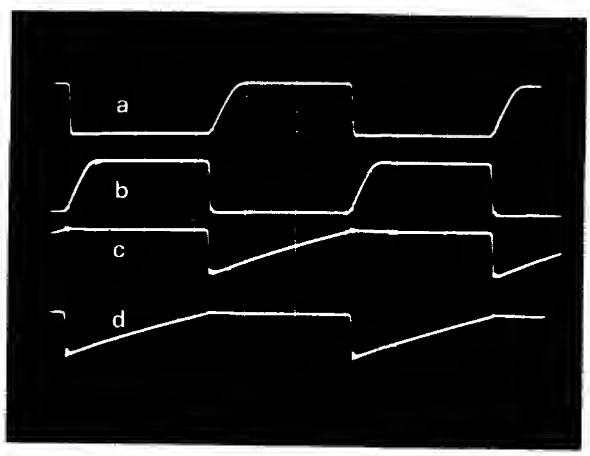


Figure 2.5. Astable with catching diodes.

Typical component values:

R1 = R2 = 10kΩ
R3 = R4 = 1kΩ
R5 = 4k7
C1 = C2 = 150pF
Tr1 = Tr2 = ZTX311
D1 = D2 = ZS140
D3 = KSO43A
Frequency ≈ 1MHz (903 kHz measured)
V_{cc} = +12V

Oscilloscope trace (a)—Tr1 collector
(b)—Tr2 collector
(c)—Tr1 base
(d)—Tr2 base



Horizontal scale = 200nS/cm., vertical scale = 5V/cm.

All these circuits can of course be used with p-n-p transistors if all diodes and the supply voltage are reversed. All the waveforms produced will also be inverted. Many of the techniques described here can also be applied to monostables.

The types of astable multivibrator described so far are the most generally used but there are other types which are useful in some circumstances.

The Current Mode Astable

In this circuit the transistors do not saturate. This greatly reduces the stored charge and enables the circuit to operate at much higher repetition rates than are possible with the simple saturating astable. The basic circuit is shown in Figure 2.6.

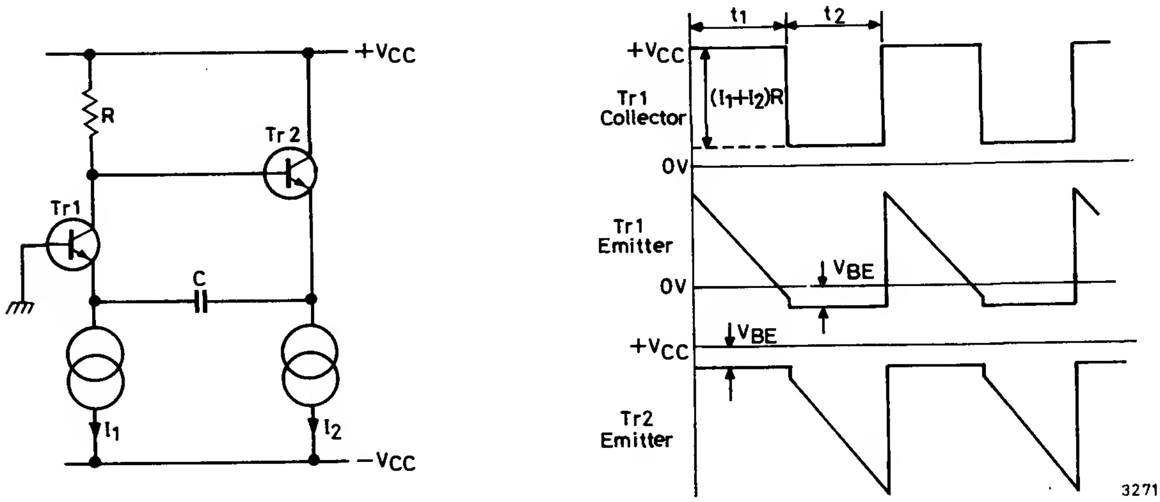


Figure 2.6. Basic Bowes Astable.

Assume that Tr1 has just been turned off and Tr2 is on. The potential at Tr1 emitter falls linearly as C charges with I_1 until the emitter reaches –0·7V when Tr1 starts to conduct. The collector voltage of Tr1 starts to fall and Tr2 is reversed biased. Both current sources I_1 and I_2 now flow into the emitter of Tr1 causing a voltage drop of $(I_1 + I_2) . R$ across the collector load resistor. This voltage drop must not be sufficient to saturate Tr1. The voltage at Tr2 emitter now falls linearly as C discharges with I_2 until it reaches 0·7V below the collector voltage of Tr1. Tr2 then starts to conduct, the current flowing into Tr1 emitter is reduced and the collector voltage of Tr1 rises until Tr1 is completely cut off and Tr2 is conducting I_1 and I_2. The cycle then repeats. Timing equations can be derived as follows, assuming that the transistor common base current gain is unity, and the leakage currents and V_{be} can be neglected.

$$\text{Voltage drop } V_1 = (I_1 + I_2) . R = \frac{I_1 t_1}{C} = \frac{I_2 t_2}{C}$$

(since CV = IT)

$$\text{therefore } t_1 = \frac{(I_1 + I_2)\,CR}{I_1} \text{ and } t_2 = \frac{(I_1 + I_2)\,CR}{I_2}$$

$$\text{hence the total period } t_1 + t_2 = \frac{(I_1 + I_2)^2\,CR}{I_1 I_2}$$

if $I_1 = I_2$ then $t_1 + t_2 = 4CR$ 2.5

or if $\frac{I_1}{I_2} = n$, for unequal currents, $t_1 + t_2 = \frac{(1 + n)^2\,CR}{n}$ 2.6

A practical circuit is shown in Figure 2.7 together with the waveforms obtained. Figure 2.8 shows the effect of replacing the current sources with resistors delivering the same average currents. As can be seen, there is some degradation of the waveform and the frequency is increased due to the exponential charging.

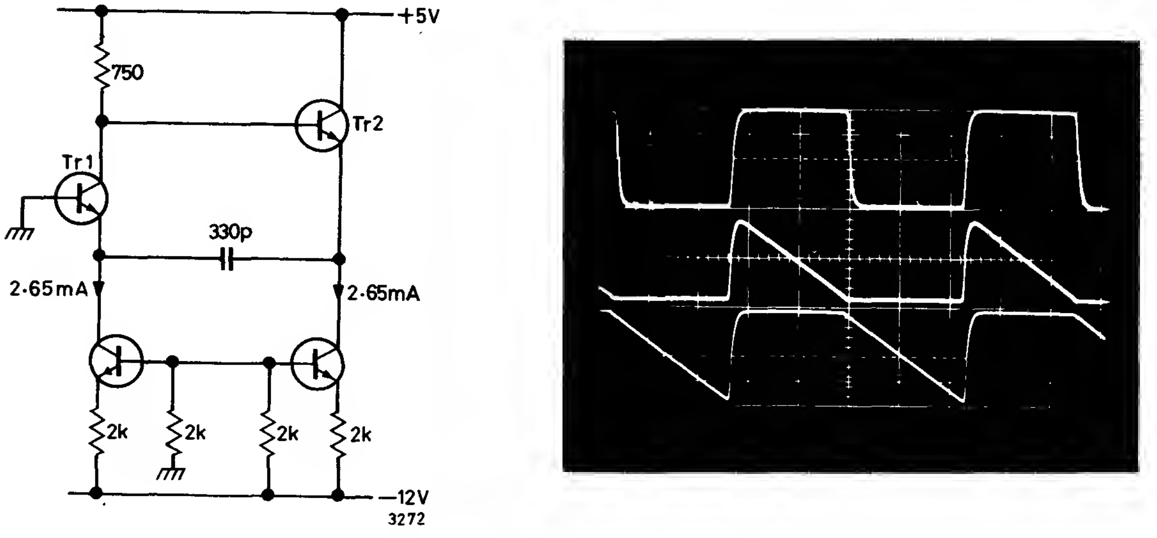


Figure 2.7

Practical circuit for 1MHz
All transistors—ZTX311
Measured frequency—1·09MHz

Upper trace, Tr1 collector
Centre trace, Tr1 emitter
Lower trace, Tr2 emitter
Vertical scale: 2V/cm
Horizontal scale: 200nS/cm

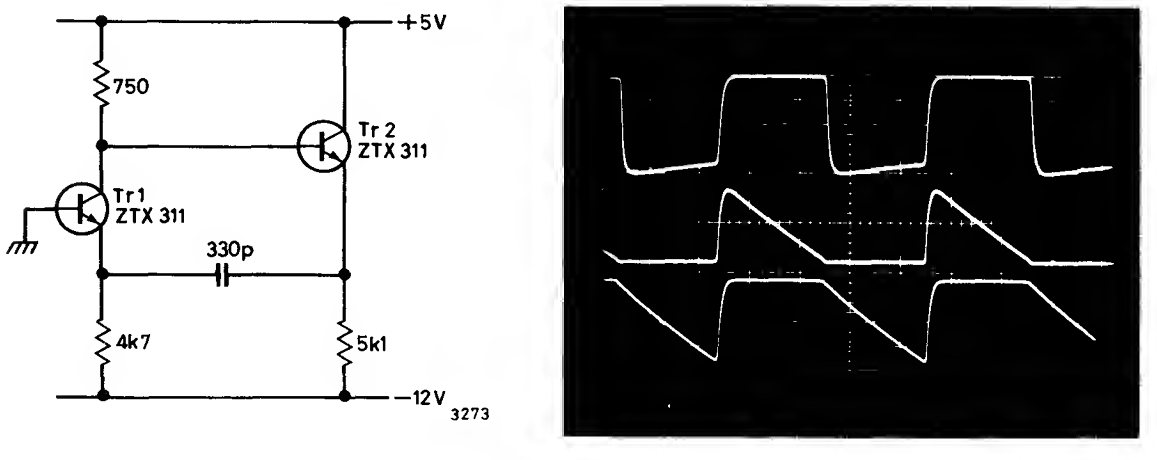


Figure 2.8. Bowes astable with resistor current sources. f = 1232kHz.

Serial Astable Circuits

Serial type astables, in which the two transistors are connected in series, have been described by various authorities. In most cases the design has been aimed at obtaining a better output waveform than that provided by the conventional astable.

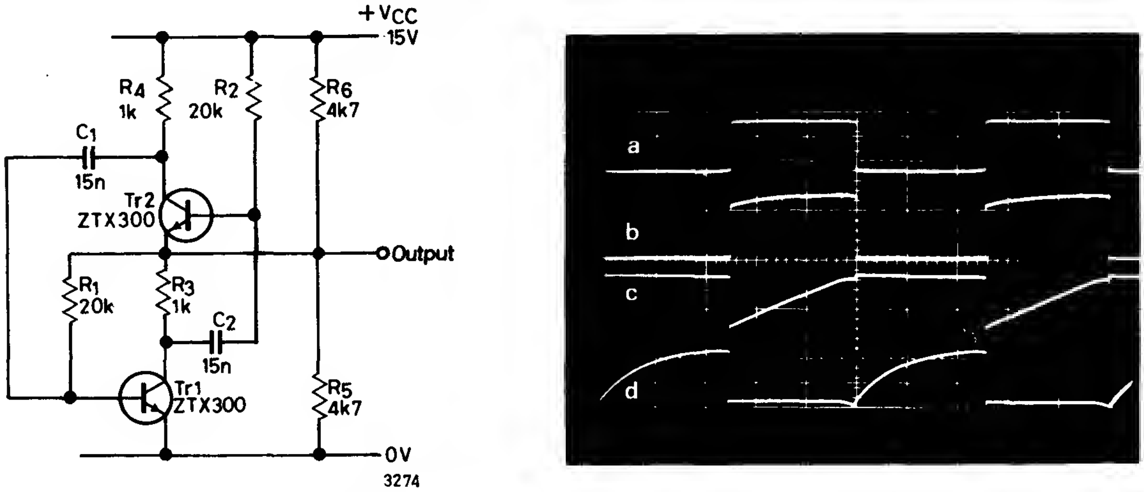


Figure 2.9. Modified Smith astable, with waveforms.

f_o = 10kHz

Trace (a)—Output
(b)—Tr1 collector (10V/cm)
(c)—Tr1 base
(d)—Tr2 collector (2V/cm)

Figure 2.9 shows a slightly modified version of the Smith astable (ref. 2). With ZTX300 series transistors the circuit will oscillate up to 100kHz, and to over 1MHz with ZTX310 series devices. The transition times are approximately 50nS on both edges. Output voltage swing with a 15V supply is approximately 10V pk-pk, the lower level being 2·5V and the upper level 12·5V. Frequency of oscillation with the component values shown $= \frac{3}{CR}$. R1 and R2 are the timing resistors.

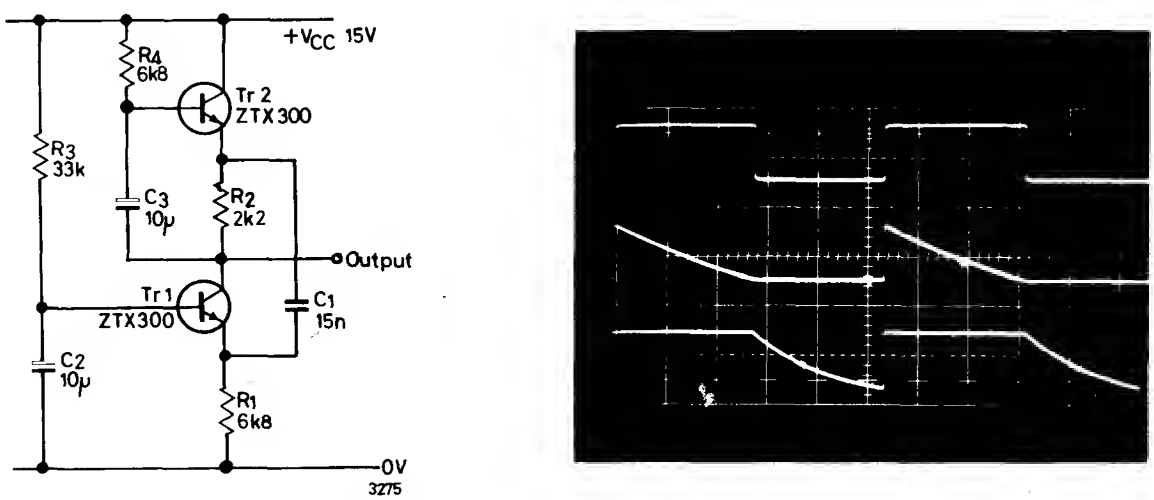


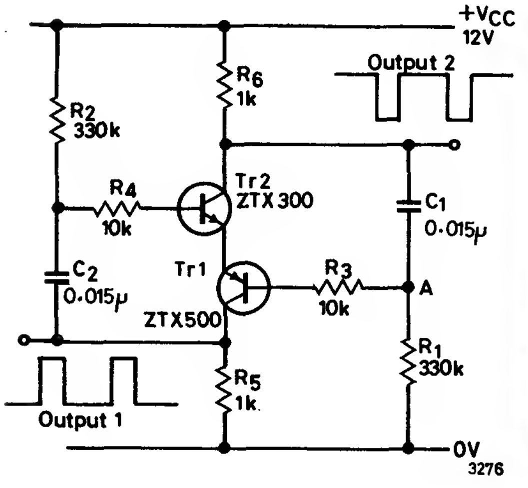
Figure 2.10. Ristic astable, with waveforms.

C2 and C3 are decoupling capacitors.

f_o = 9kHz.

Upper trace—output
Centre trace—Tr1 emitter
Lower trace—Tr2 emitter
Vertical scale = 5V/cm
Horizontal scale = 20μS/cm

Figure 2.10 shows a serial astable due to Ristic (ref. 3). The performance of this is similar to the Smith circuit except that the output voltage swing is reduced to about 5V with a 15V supply. Edge speeds are approximately 100nS and the frequency of oscillation is given by $f_o = \frac{1{\cdot}35 \times 10^{-4}}{C.}$ with the components values shown in Figure 2.10.



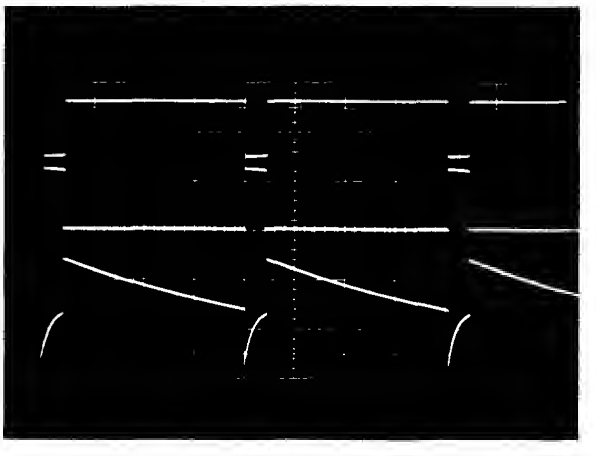


Figure 2.11. Ho astable, with waveforms.

Upper trace—Output 2
Centre trace—Output 1
Lower trace—Point A

Vertical scale—5V/cm
Horizontal scale—1mS/cm

Figure 2.11 shows a complementary serial astable due to Ho (ref. 4). Very large mark-space ratios are possible with this circuit which has two identical but complementary outputs. The pulse period is not well defined since it depends on the transistor h_{FE} but the period between the pulses is given by the normal astable formula; i.e. $T = 0{\cdot}7CR$. It is important that the base current provided by R1, R2 should *not* be sufficient to saturate the transistors or latch-up occurs.

References

(1) Dakin, C. J., and Cooke, C. E. G Circuits for Digital Equipment. Iliffe.

(2) Smith, J. H. Multivibrator Circuits, Electronic Engineering 35, 46. (1963).

(3) Ristic, V. M. A new type of Free Running Multivibrator, Electronic Engineering. 36, 232 (1964).

(4) Ho, C. F. Dual Polarity Astable Multivibrator, Electronic Engineerinng 41, 230 (1969).

Design Examples

Worst Case Design

The following factors should be remembered when performing a worst case design.

(a) The V_{be} of a silicon transistor falls by approximately 2mV for every 1°C increase in temperature.

(b) The h_{FE} of a silicon transistor rises by approximately 0·7% for every 1°C increase in temperature.

(c) Depending on the conditions of use the value of a resistor will change with time due to the effects of soldering, moisture and ageing, and may go outside its nominal tolerance. A moulded carbon resistor may change by 20% from its original value, a carbon film resistor by 5% and a metal oxide resistor by 1%. In the examples given it will be assumed that a 10% resistor will have an ultimate tolerance of 20%, etc.

Example 1

A 1kHz square wave astable to operate from a 5V ±10% supply. No d.c. load, but output impedance of 1kΩ. Ambient temperature −10°C to +50°C. (Circuit and waveforms shown in Figure 2.1).

(1) Choose transistor type ZTX300.

(2) Choose collector load resistor. 1kΩ nominal ±20%.

(3) Minimum supply voltage is the worst condition for turning the transistor fully on. With 4·5V d.c. supply, collector current = 4·5mA nominal.
= 5·6mA maximum with R3, R4 20% low.

(4) Minimum current gain of ZTX300 at 5·6mA = 45 at 25°C.
= 34 at −10°C.

Hence the minimum base current to saturate $= \frac{5·6}{34} =$ 0·165mA with base resistor 20% high.

(5) From ZTX300 curves, V_{be} at −10°C = 0·8V.

Hence the minimum value of base resistor R1, R2 $= \frac{4·5-0·8}{0·165} \times \frac{100}{120}$

i.e. Maximum value of R1, R2 = 18·7kΩ.

(6) The minimum value of R1, R2 to ensure recovery of the collector voltage to $0·99V_{cc}$ = 6·7kΩ (from equation 2.4). Any value of timing resistor R1, R2 between these two limits will be suitable. For a 1kHz square wave output both periods T1 and T2 must be 0·5mS.

$T = 0.7CR$, therefore $CR = \frac{0·5}{0·7} = 0·7$mS.

The above conditions are satisfied if R1 = R2 = 15kΩ.
C1 = C2 = 0·047μF.

Example 2

An astable to generate a 100μS pulse with a repetition time of 1mS. Other conditions as example 1.

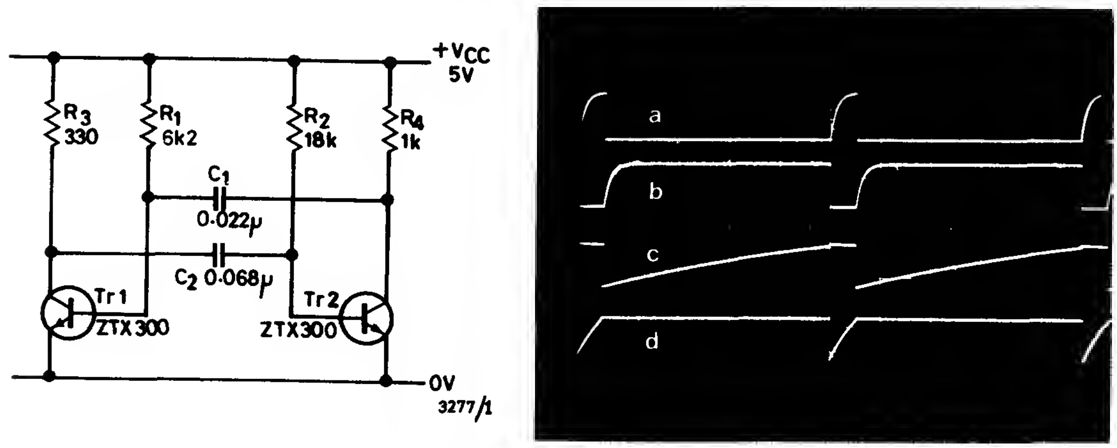


Figure 2.12

Trace (a)—Tr1 collector
(b)—Tr2 collector
(c)—Tr2 base
(d)—Tr1 base

Vertical scale: 5V/cm
Horizontal scale: 200μS/cm

(1) Choose transistor type ZTX300.

(2) Choose load resistor R4. 1kΩ $\pm$20%.

(3) (4) (5) Maximum value of R2 = 18·7kΩ (as example 1).

(6) Tr2 is held off for 900μS. Therefore time constant C2R2 $= \frac{900}{0{\cdot}7} = 1280\mu$S.

A reasonable approximation to this is obtained if R2 = 18kΩ. C2 = 0·068μF.

(7) R3 must be able to fully recharge C2 during the 100μS pulse. From equation 2.3; for recovery to 98% of the supply voltage.

$$R1C1 > 5{\cdot}8\ R3C2.$$

but R1C1 $= \frac{R2C2}{9}$ since a 100μS pulse is required from Tr1.

therefore R3 $< \frac{R2}{5{\cdot}8 \times 9} = \frac{18k}{52} = 350\Omega.$

The nearest preferred value below this is 330Ω.

(8) Worst case collector current of Tr1, with 4·5V supply $= \frac{4{\cdot}5}{330} \times \frac{100}{80} = 18{\cdot}7$mA.

minimum current gain of ZTX300 at 18·7mA = 54 at 25°C.
= 40 at –10°C.

therefore minimum base current to saturate $= \frac{18{\cdot}7}{40} = 0{\cdot}47$mA with R1 20% high.

(9) Maximum value of R1 $= \frac{4{\cdot}5 - 0{\cdot}8}{0{\cdot}47} \times \frac{100}{120} = 6{\cdot}6k\Omega$.

(10) Minimum value of R1, R2C2 > 5·8 R4C1

$$9\ R1C1 > 5{\cdot}8\ R4C1$$

therefore $R1 > \frac{5{\cdot}8R4}{9} = 650\Omega.$

However a value as low as this would be undesirable since it would impose an additional load on Tr2.

For a 100μS pulse C1R1 $= \frac{100}{0{\cdot}7} = 140\ \mu$S.

A reasonable approximation to this is obtained with R1 = 6k2, C1 = 0·022μF.

The finished circuit and output waveforms are shown in Figure 2.12.

Example 3

An astable to switch a 12V, 160Ω relay on for 3 secs. and off for 2 secs.

Supply voltage 12V ± 1V. Ambient temperature 0 to +50°C.

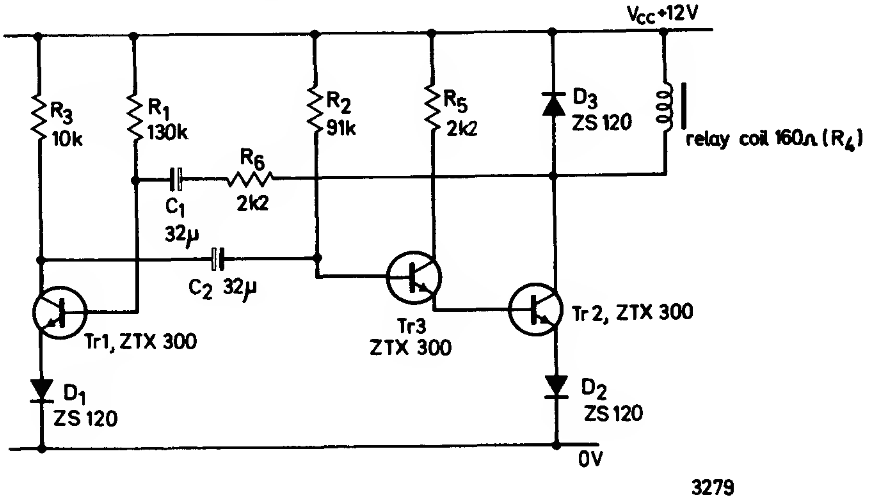


Figure 2.13. A low speed astable to switch a relay on for 3 seconds and off for 2 seconds.

Assume initially that a circuit similar to Figure 2.12 will be used with the relay coil replacing R4.

(1) With a 12V supply, protection diodes are required in the emitters of Tr1 and Tr2.

(2) Choose transistor type ZTX300, can switch required voltage and current.

(3) With 11V supply, assuming 20% tolerance on relay coil resistance:

$$\text{maximum collector current of Tr2} = \frac{11 - V_d - V_{ce(sat)}}{160} \times \frac{100}{80}$$

(V_d = diode voltage).

$$= \frac{10}{160} \times \frac{100}{80} = 78\text{mA}.$$

minimum current gain of ZTX300 at 78mA = 50 at 25°C.
= 41 at 0°C.

$$\text{minimum base current required to saturate} = \frac{78}{41} = 1{\cdot}9\text{mA with R2 20\% high.}$$

(4) $$\text{Maximum value of R2} = \frac{11 - V_d - V_{be}}{1{\cdot}9} \times \frac{100}{120}\ \text{k}\Omega.$$

$$= 4{\cdot}1\text{k}\Omega \text{ nominal.}$$

(5) $$\text{For the Tr2 to be turned off for 2 seconds CR} = \frac{2}{0{\cdot}7} = 2{\cdot}86 \text{ secs.}$$

If R2 = 3·9k then C2 = 730μF. This value is not impracticable but it is inconveniently high. A lower value can be used if Tr2 is replaced by a Darlington pair as shown in Figure 2.13.

(6) Referring to (3) above. Tr3 emitter current = 1·9mA.
Minimum current gain of ZTX300 at 1·9mA = 35 at 25°C.
= 29 at 0°C.

$$\text{Minimum base current required to saturate Tr3 with R2 20\% high} = \frac{1{\cdot}9}{29} = 65\mu\text{A}.$$

(7) $$\text{Maximum value of R2} = \frac{11 - V_d - V_{be2} - V_{be3}}{65\mu\text{A}} \times \frac{100}{120}$$

$$= \frac{8{\cdot}6}{65} \times \frac{100}{120}\ \text{M}\Omega = 110\text{k}\Omega.$$

If a value of 91kΩ is chosen for R2 then a close approximation to the required time constant is obtained if C2 = 32μF. R5 is chosen merely to limit the collector current of Tr3 to a safe value in excess of 1·9mA. 2k2 is suitable.

(continued overleaf)

(8) From equation 2.3 R1C1 > 5·8 R3C2.

but R1C1 $= \frac{3}{2}$ R2C2 since Tr1 is off for 3 secs.

hence R2C2 > 3·9 R3C2

i.e. R3 $< \frac{R2}{3{\cdot}9} = \frac{91k}{3{\cdot}9} = 23{\cdot}3k\Omega$.

This is the maximum value that may be used. In this design R3 = 10kΩ will be used.

(9) Maximum collector current of Tr1 $= \frac{11 - V_d - V_{ce(sat)}}{10k} \times \frac{100}{80}$

$= 1{\cdot}25mA$.

minimum current gain of ZTX300 at 1·25mA = 27 at 0°C.

minimum base current to saturate Tr1,

with R1 20% high. $= \frac{1{\cdot}25}{27} = 46{\cdot}3\mu A$.

(10) Maximum value of R1 $= \frac{11 - V_d - V_{be1}}{46{\cdot}3} \times \frac{100}{120}$ MΩ.

$= 170k\Omega$.

(11) If R1 is made 130kΩ a close approximation to the required time constant of $\frac{3}{0{\cdot}7}$ seconds is obtained with C1 = 32μF.

The finished circuit is shown in Figure 2.13. It was found necessary to include R6, to prevent spurious operation due to inductive ringing in the relay coil, but it has virtually no effect on the timing. Diode D3 protects Tr2 from the inductive spike produced when Tr2 turns off.

Example 4

A wide range astable for generating repetitive pulses.

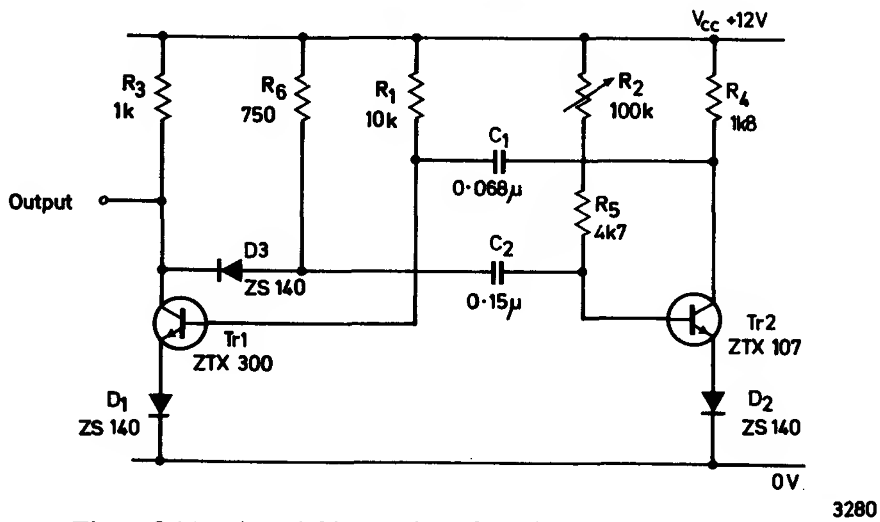


Figure 2.14. A variable speed astable with a 10 : 1 range.

No design procedure will be given for this circuit as it is basically the same as example 2, but the design is complicated by the need for the duration of one of the quasi-stable states to be variable over a wide range. A high gain transistor is essential for Tr2 and type ZTX107 was chosen.

With the component values shown T1 (= 0·7C1 . R1) is constant at 0·5mS but T2, defined by (R2 + R5), is variable over a range of 0·5 to 10·5mS. This gives a range of repetition time of 1mS to 11mS. Other time ranges can be accommodated by the choice of suitable capacitor values. A table is given below.

The output waveform at Tr1 collector is a rectangular pulse with rise and fall times of less than 50nS.

C1	C2	p.r.f.
680pF	1500pF	10μS to 110μS
6800pF	0·015μF	100μS to 1·1mS
0·068μF	0·15μF	1mS to 11mS
0·68μF	1·5μF	10ms to 110mS