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THE FREE RUNNING MULTIVIBRATOR

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THE FREE RUNNING MULTIVIBRATOR

These notes were written as a guide for the design of a widely used transistor circuit - The Free Running Multivibrator. Limiting values for the resistors are obtained through simple static calculation of the bias conditions for a given temperature range.

The important advantages to be derived from this improved circuit are greater starting reliability and distinctly faster rise time.

This application note is being distributed in connection with the release and immediate availability of the Raytheon 2N 438, 2N 439, and 2N 440 Germanium fusion alloy NPN transistors designed for use in computers and switching applications where reliability is a primary consideration.

THE FREE RUNNING MULTIVIBRATOR

A. CONVENTIONAL CIRCUIT:

A conventional circuit for a saturating free running multivibrator is shown in Figure 1.

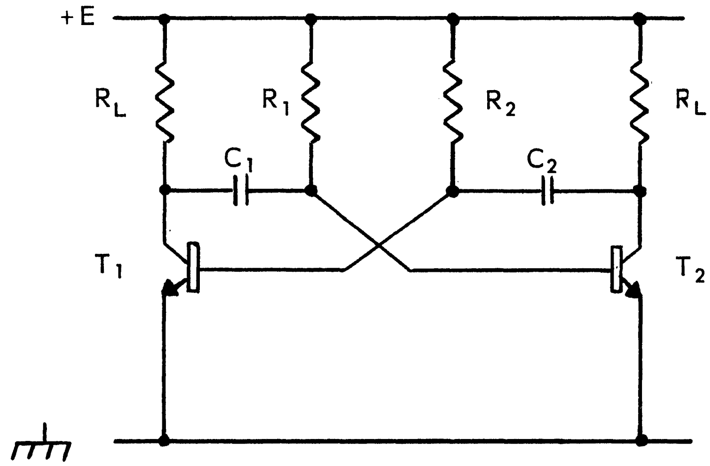

FIGURE 1

A disadvantage of this circuit is the long rise time, which can easily be explained as follows:

Suppose T_1 conducting, T_2 cutoff. The collector-emitter voltage of T_1 has then the saturation value V_s. As soon as the base of T_2 has a forward bias V_b, T_2 comes into conduction. At this moment the voltage across C_1 equals $(V_b - V_s) = 0.1V$ so that C_1 is practically completely discharged. As T_1 goes out of conduction, C_1 is recharged via R_L so that the collector voltage V_c of T_1 will rise exponentially toward +E. Neglecting the input resistance of T_2, V_c is given by:

$$V_c = E\left(1 - e^{-t/R_L C_1}\right) \qquad (1)$$

The rise time is then found to be:

$$tr = R_L\, C_1 \ln 10 = 2.3\, R_L\, C_1$$

An approximate formula for the period T is:

$$T = (R_1 C_1 + R_2 C_2) \ln 2$$

or if $R_1\ C_1 = R_2\ C_2$:

$$T = 2 \ln 2\, (R_1 C_1)$$

Combining:

$$\frac{tr}{T} = \frac{\ln 10}{2 \ln 2}\left(\frac{R_L}{R_1}\right) = 1.66\left(\frac{R_L}{R_1}\right) \qquad (2)$$

Saturation requires that $R_1 < hFE\ R_L$

so that:

$$\frac{tr}{T} > \frac{1.66}{hFE} \tag{3}$$

If the circuit is designed for a minimum hFE of 40 then tr/T = 4%. At 1 kcs this would mean a rise time of 40 μ sec.

Another disadvantage of this circuit is the possibility that T_1 and T_2 go both into saturation so that the circuit does not always start oscillating when switched on.

B. ALTERNATE CIRCUIT

A very satisfactory circuit is shown in Figure 2.

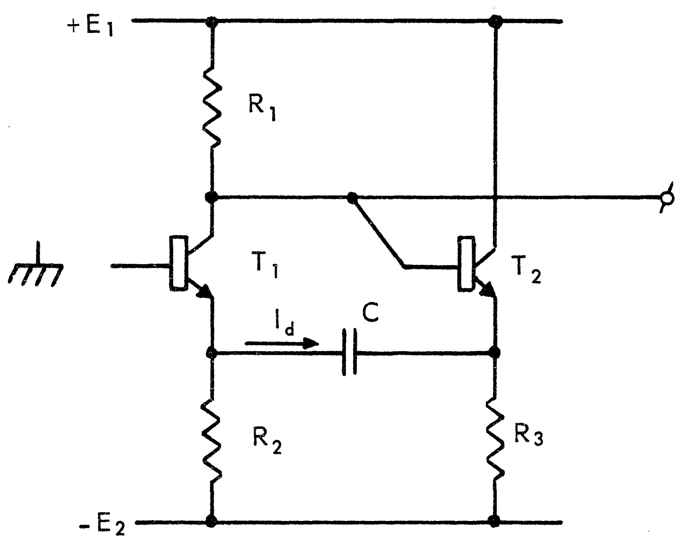

FIGURE 2

Initially both T_1 and T_2 are conducting, there is no charge on C. The proportioning of voltage and resistor values is such that there is no saturation under these conditions.

Since the loop gain is greater than unity, this situation is unstable. As a result, the emitter voltage of T_2 will rise, causing T_1 to cut off and base and emitter of T_2 will rise further until they are limited by the supply voltage.

C is now charged via R_2 and T_2.

Since V_b is fairly constant during the process, the drop of V_b is compensated by the initial charge on C equivalent to V_b, and V_b may be neglected here.

The resistor R_1 is equivalent to a resistor R_1/h_{FE2} in the emitter lead and can be neglected in most cases.

The charging voltage is $(E_1 + E_2)$ and the charging ends when the voltage across R_2 equals $(E_2 - V_b)$, when T_1 takes over.

Thus the charge time is: $t_1 = R_2 C \ln\left(\frac{E_1 + E_2}{E_2 - V_b}\right)$

Now T_1 is conducting and T_2 is cut off. C is discharged via R_3 and T_1.

The discharge time is the time required for the voltage across R_3 to drop from $(E_1 + E_2 - V_b)$ to $(E_2 - 2 V_b)$.

$$t_2 = R_3 C \ln\left(\frac{E_1 + E_2 - V_b}{E_2 - 2V_b}\right) \tag{5}$$

And the total period: $$T = R_2 C \ln\left(\frac{E_1 + E_2}{E_2 - V_b}\right) + R_3 C \ln\left(\frac{E_1 + E_2 - V_b}{E_2 - 2V_b}\right) \tag{6}$$

CALCULATION OF R_1:

R_1 can be calculated from the saturation conditions for T_1.

A maximum value can be found from the requirement that T_1 should not be saturated under static conditions.

The result is: $$R_1 < \left(\frac{E_1 + V_b}{E_2 - V_b}\right) R_2 \tag{7}$$

For a good wave-shape it is however required that T_1 be saturated under dynamic conditions.

Therefore: $I_{c1} R_1 = E_1$

or if we assume $\alpha = 1$

$$I_{e1} R_1 = E_1$$

Under dynamic conditions, I_{e1} is increased by the discharge current I_d.

I_d decreases exponentially from I_{d1} at the beginning to I_{d2} at the end of the discharge period, where

$$I_{d1} = \frac{E_1 + E_2 - V_b}{R_3}$$

$$I_{d2} = \frac{E_2 - 2V_b}{R_3}$$

Adding the static value of I_{e1}, $\frac{(E_2 - V_b)}{R_2}$, the following relationship is obtained.

$$\frac{E_2 - V_b}{R_2} + \frac{E_1 + E_2 - V_b}{R_3} > I_{e1} > \frac{E_2 - V_b}{R_2} + \frac{E_2 - 2 V_b}{R_3} \tag{8}$$

Taking the minimum value of I_{e1}, a minimum value for R_1 is found, so that

$$R_1 > \frac{E_1}{\dfrac{E_2 - V_b}{R_2} + \dfrac{E_2 - 2V_b}{R_3}}$$

A complication arises however, since the process described above will repeat only if the loop gain is greater than unity at the end of the cycle. This requires that T_1 is not saturated. For this reason it is advisable to choose R_1 equal to the minimum value of (9).

Example:

$E_1 = 4.5V$
$E_2 = 1.5V$
$V_b = 0.2V$

$\left.\begin{array}{l} T_1 \\ T_2 \end{array}\right\}$ Raytheon NPN units (such as 2N440)
$h_{FE} = 100$
Alpha Cutoff = 11 mcs

Of all three resistors one can be chosen, the two others can be found from conditions (9) and the equality of t_1 and t_2.

In this example we will choose $R_2 = 150$. R_3 can be found by equating (4) and (5).

$$R_2 \ln\left(\frac{E_1 + E_2}{E_2 - V_b}\right) = R_3 \ln\left(\frac{E_1 + E_2 - V_b}{E_2 - 2V_b}\right)$$

which gives $R_3 = 138\,\Omega$

Substituting the values of R_2 and R_3 in (9) yields:

$R_1 = 271\,\Omega$

Finally (6) gives $T = 459$ C seconds where C is stated in farads.

Figure 3 gives the measured period T vs capacitance.* As can be seen, the measured curve lies almost entirely $0.65\,\mu$ sec higher than the calculated curve. The discrepancy is due to finite switching times and storage effects, which have been neglected in the calculations.

Also it shows that the curve shifts up with temperature. From $-50^{\circ}C$ to $+70^{\circ}C$ it shifts from 0.5 to 0.85 μsec above the calculated curve. This is approximately 3 mμsec/$^{\circ}$C.

* Using the circuit of Figure 2 and the resistor values as calculated in this example.

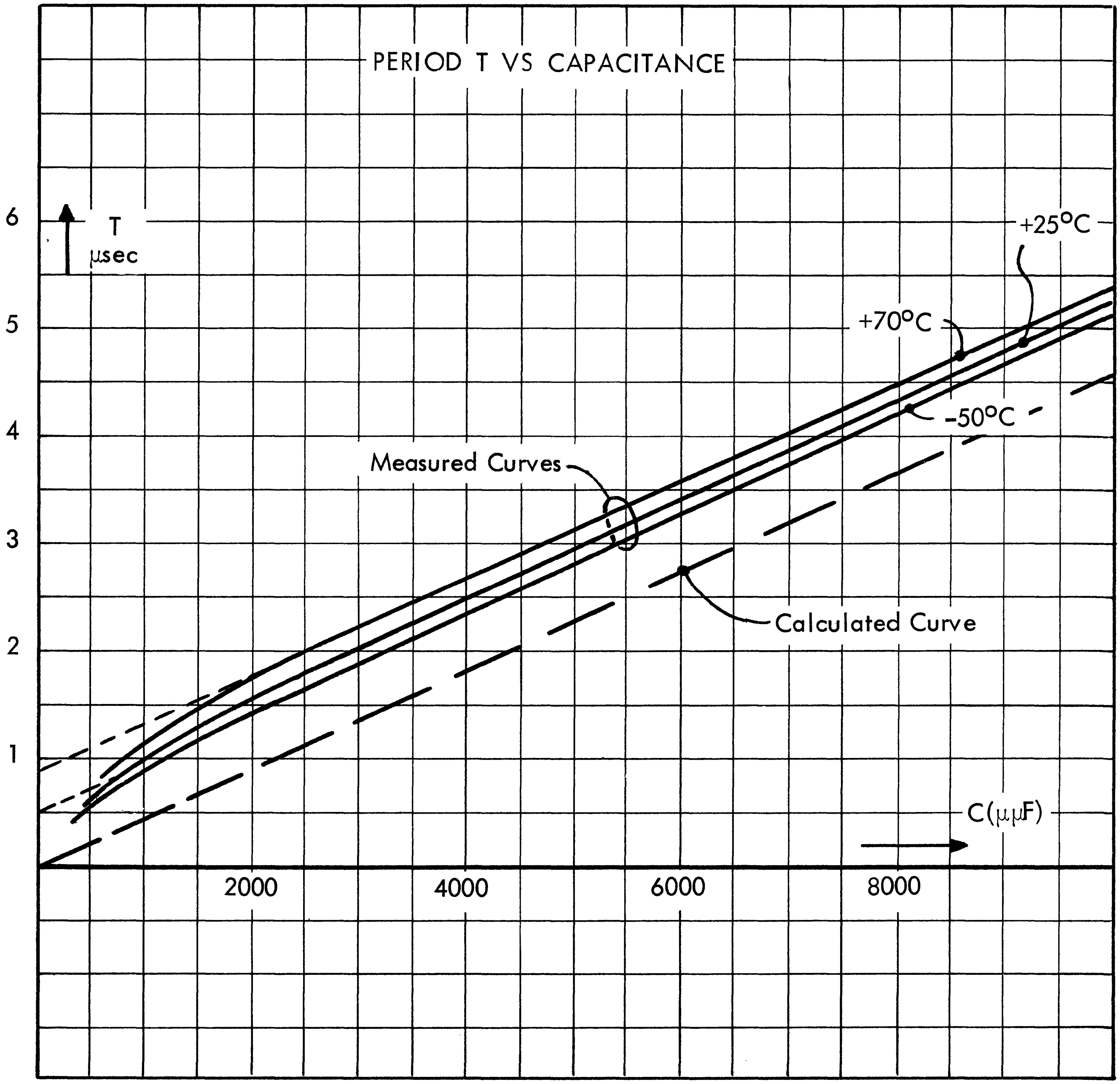
PERIOD T VS CAPACITANCE
6
5
4
3
2
1
T
μsec
+25°C
+70°C
-50°C
Measured Curves
Calculated Curve
C(μμF)
2000
4000
6000
8000

FIGURE 3