

UNIT- V Part-A

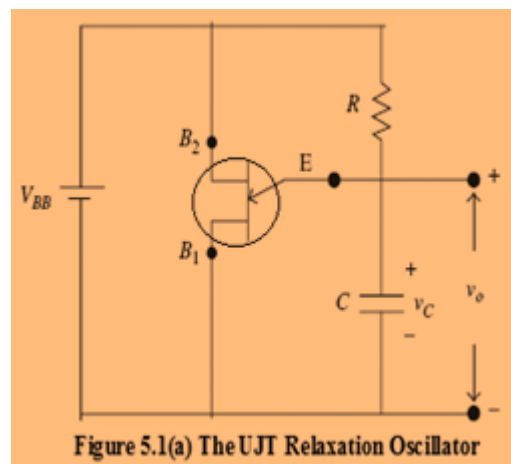
Synchronization and Frequency Division

Introduction: Many types of waveform generators (sinusoidal generators, square-wave generators, sweep generators, etc) are used in pulse and digital circuits. These different waveform generators may have the same frequency. In many applications, these generators are required to run in synchronism or in step with another—which means that they should arrive at some reference point in their cycle at the same time. Alternately, it is also possible that these waveform generators may operate at different frequencies. Also, it is possible that one generator completes one cycle, whereas the other may complete an integral number of cycles (2, 3, ..., n) in the same time period. Still, it becomes necessary that these generators should run in synchronism, that is, they should arrive at some reference point in their cycles at the same time instant. Then these generators are again said to be running in synchronism, though with frequency division. In this chapter, we will discuss the methods of frequency synchronization and division using pulses and symmetric signals (sinusoidal signals) as synchronizing (sync) signals.

First, we consider the synchronization of relaxation circuits like sweep generators and multivibrators with pulses as synchronizing signals. Synchronization is possible only when the pulse amplitude is reasonably large and the repetitive frequency of the sync signal is greater than or equal to the frequency of the relaxation circuit. Also the synchronization with the division can only be achieved under certain conditions. However, when it comes to symmetric signals as sync signals, synchronization is always possible, may be with division. The various conditions under which synchronization takes place are discussed in detail.

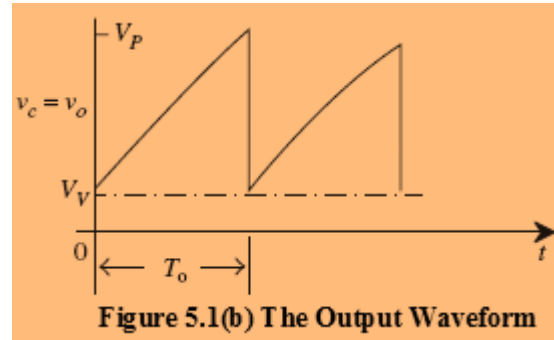
5.1 Pulse Synchronization of Relaxation Devices

We are going to consider synchronization of the output of a UJT sweep generator using a pulse train. Consider a circuit where a capacitor charges during a finite time interval and the sweep is terminated abruptly by the discharge (relaxation) of the condenser. Such a circuit is called a relaxation circuit. Some relaxation circuits that we have already considered include sweep generators, blocking oscillators and multivibrators. Let us consider a UJT relaxation oscillator shown in Figure 5.1(a).



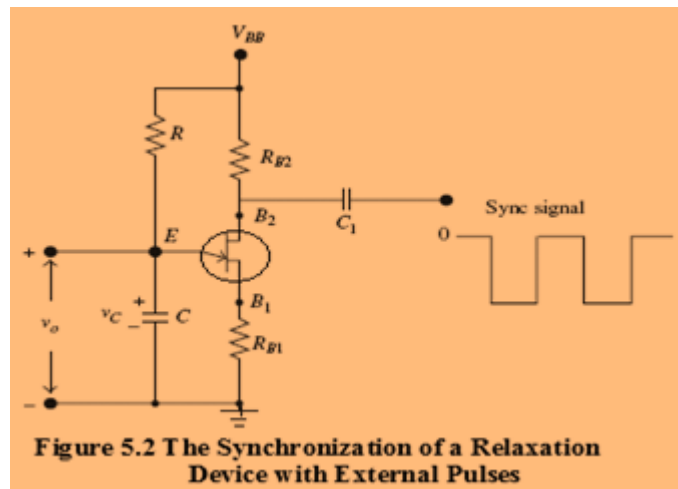
Here, the UJT is simply used as a switch. Initially, let the capacitor be uncharged. When the switch is open the capacitor tries to charge to V_{BB} . The moment the voltage across C reaches V_P (peak voltage or the breakdown voltage of the UJT), the switch closes, allowing the charge on the capacitor C to discharge almost instantaneously.

Again, when the voltage across C reaches V_V (valley voltage of the UJT), the switch opens, once again the capacitor charges. This process is repeated, resulting in a waveform as shown in Figure 5.1(b). It is now required to synchronize the output of this relaxation oscillator with an external signal, called the sync signal. This sync signal, which is essentially a negative pulse train, is

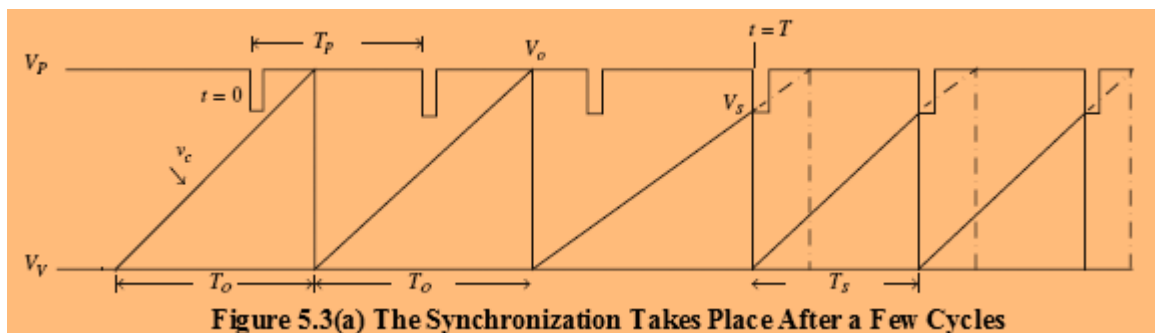


connected to the UJT circuit such that it changes its peak voltage V_P .

Thus, in a UJT circuit, the sync signal (negative pulses) is applied at B_2 to lower V_P , as shown in Figure 5.2. The resistances R_{B1} and R_{B2} are added in series with B_1 and B_2 respectively.

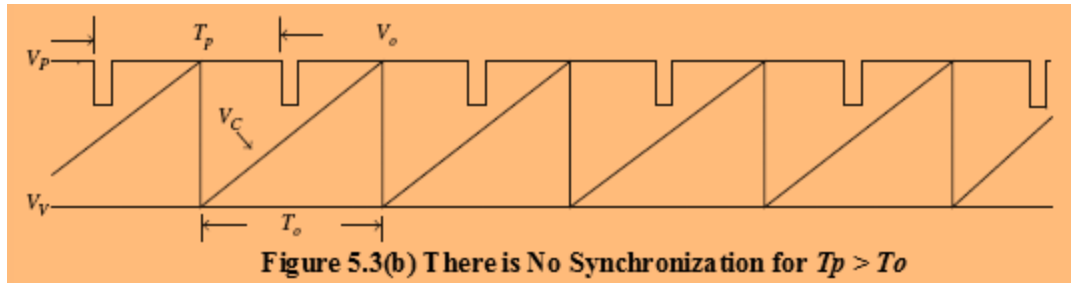


A repetitive pulse train, having a certain amplitude is shown in Figure 5.3(a), starting at $t = 0$. For the first few cycles the sweep generator runs at its natural frequency $f_o (= 1/T_o)$ with $V_P = V_o$ as its amplitude. The sweep signal and the pulse train run at different frequencies and no synchronization is established. At time $t = T$, the negative pulse reduces the peak of the natural sweep and the relaxation device switches ON, thereby terminating the sweep prematurely. This results in a new sweep time of T_s , which is the same as the spacing between the successive sync pulses, T_P and has the amplitude V_s which is smaller than V_o . From now onwards, the sweep generator output and the pulse train run in synchronism, as shown in Figure 5.3(a).

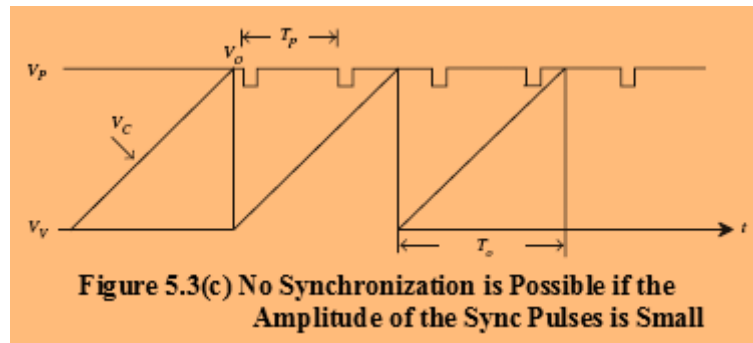


Thus, initially the two generators are not synchronized. However, the unsynchronized generators run in synchronism after a few cycles (from $t = T$ onwards). The synchronization

takes place only when the sync pulses occur at the time when they would terminate the sweep cycle prematurely. This means that for synchronization to be possible, the interval between the pulses, T_P must be less than the sweep duration T_O . Once synchronization takes place the sweep duration changes to T_S and the sweep amplitude to V_S . Now consider a case where $T_P > T_O$, as shown in Figure 5.3 (b).



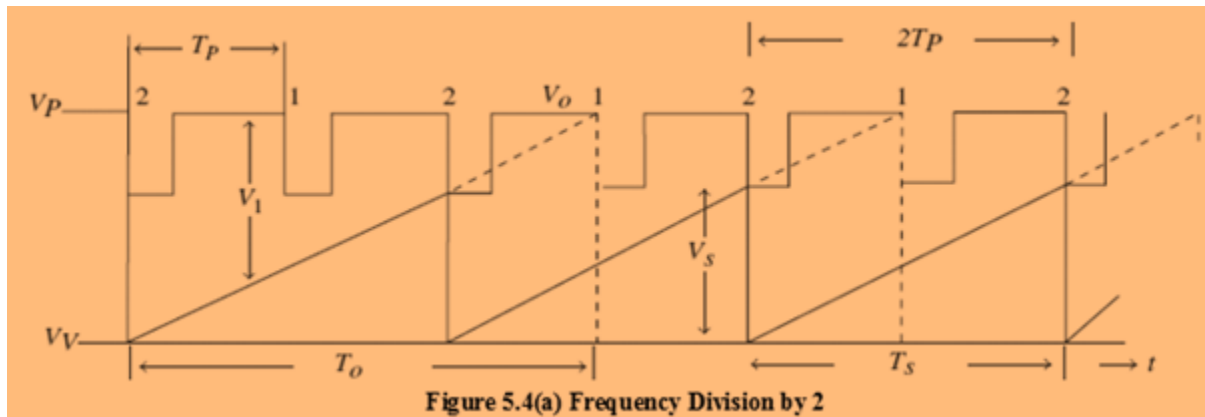
Here, $T_P > T_O$ and sync pulses occur at such instants of time that they will not be able to prematurely terminate the sweep cycle. Hence, no synchronization is possible between these two waveform generators. Obviously, synchronization cannot take place if T_P is greater than T_O . Let us consider another situation where $T_P < T_O$, but the amplitude of the sync pulses is small, as shown in Figure 5.3(c).



It is said that synchronization is possible when $T_P < T_O$. However, in the present case, as the amplitude of the sync pulses is small, they will not be able to prematurely terminate the sweep cycle. Hence, here again, no synchronization is possible. Thus, it may be inferred from this discussion that for synchronization to take place: (a) T_P must be less than or equal to T_O , and (b) the amplitude of the sync pulses should be large enough to bridge the gap between the quiescent breakdown voltage V_P and the sweep voltage v_C .

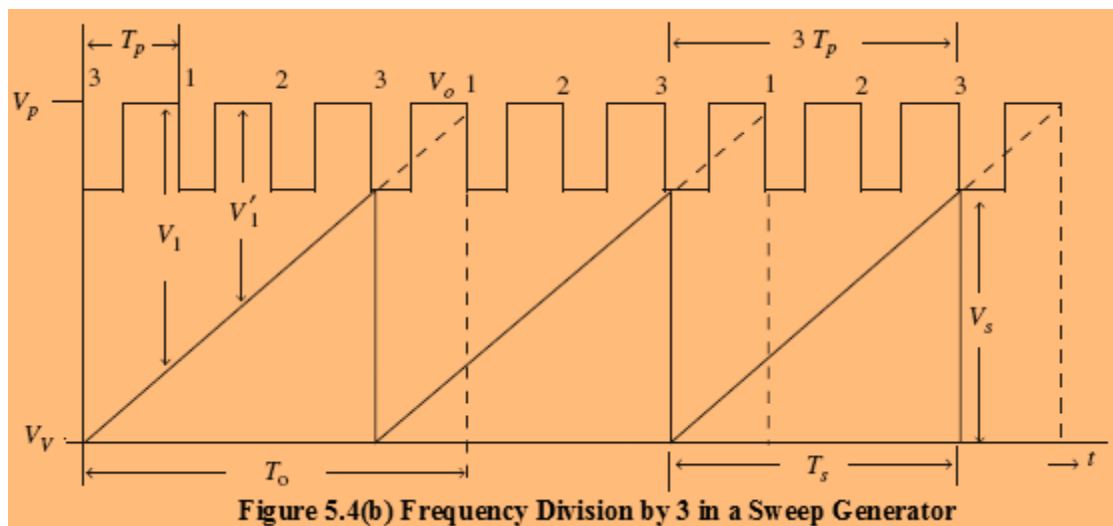
5.2 Frequency Division in a Sweep Circuit

Consider Figure 5.4(a) in which $T_P < T_O$. We see that the first two pulses (marked 2 and 1) do not have sufficient amplitude so as to lower V_P and terminate the sweep cycle. Hence, there is no synchronization. However, the third pulse marked 2 though has the same amplitude as pulses marked 1, but occurs at such a time instant so as to be able to prematurely terminate the sweep cycle. The next sweep is initiated at this instant. However, the next pulse once again marked 1 may still have the same amplitude as the rest of the pulses, but will not be able to terminate the sweep.



Once again the next pulse marked 2 occurs at such an instant that its amplitude may still be sufficient enough to prematurely terminate the sweep. Thus, we see that only pulses marked 2 will be able to terminate sweep cycle and not the pulses marked 1. For every two sync pulses there is one sweep cycle and these two generators are seen to be running in synchronization. The sweep generator is now called a divider—the division being by a factor 2. There is one sweep cycle for every two sync pulses, i.e., $T_S / T_P = 2$, because $T_S = 2T_P$, where T_S is the sweep duration after synchronization and T_P is the spacing between the sync pulses.

Consider Figure 5.4(b) where pulses marked 1 and 2 are not large enough to terminate the sweep cycle prematurely. Only when the amplitude of the pulse 1 is as large as V_I and that for pulse 2, it is they will be able to terminate the cycle prematurely to effect synchronization. However, pulses marked 3, though have the same amplitude, occur at such instants that they will be able to effect synchronization. Hence, for every three sync pulses the sweep generator completes one cycle. Therefore, the two generators are said to be synchronized with the frequency division being by a factor 3.



We can infer from the previous conditions that:

- (i) No synchronization is possible for pulses of smaller amplitude.

(ii) For a pulse amplitude large enough to prematurely terminate the sweep cycle, as T_P / T_S progressively decreases from 1 to 0, 1:1 synchronization holds, followed by 2:1 synchronization and then 3:1 synchronization and so on. T_S / T_P is called the counting ratio.

(iii) For a pulse amplitude that is very large, synchronization is always possible. As T_P / T_S decreases from 1 to 0, the division, however, changes from 1:1 to 2:1 to 3:1 and so on.

5.3 Synchronization of other Relaxation Circuits

Frequency synchronization and division is also possible using other relaxation circuits such as astable multivibrators and monostable multivibrators. We will consider the blocking oscillator circuits and conventional astable and monostable multivibrators.

5.3.1 Synchronization of Astable Blocking Oscillators

Synchronization of the output of an astable blocking oscillator with frequency division by a factor of 5 using positive sync pulses is illustrated in Figure 5.5(a). Q_2 acts as an inverter. The positive sync pulses that appear at the base of Q_2 , after amplification and polarity inversion by the CE configuration, appear as negative pulses at the collectors of Q_1 and Q_2 . Because of the polarity inversion by the pulse transformer, these negative pulses appear as positive pulses at the base of Q_1 as per the chosen dot convention on the windings. Consequently, the base current of Q_1 increases, its collector current further rises, the voltage at the collector falls still further, the voltage at the base increases further and so on.

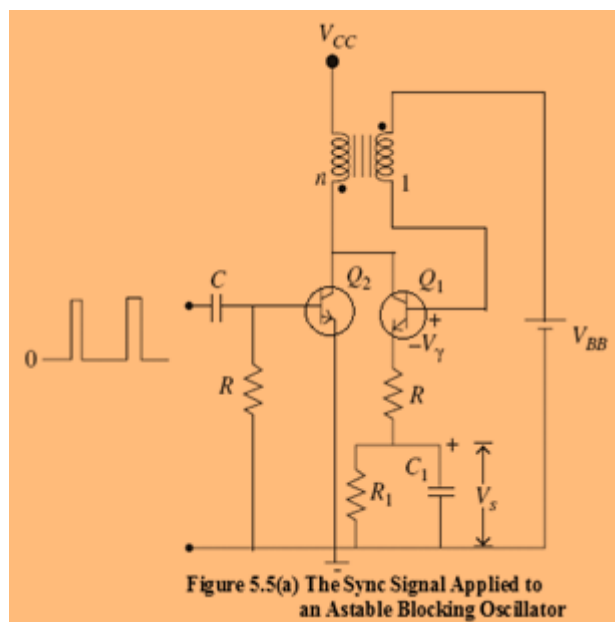
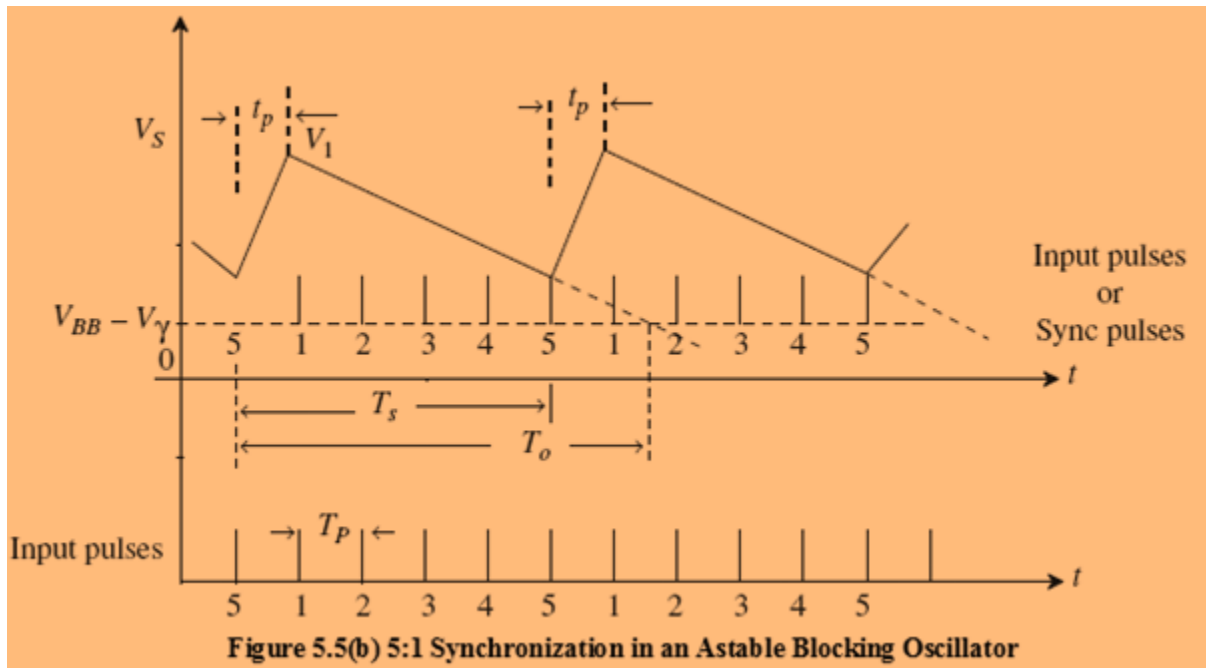


Figure 5.5(a) The Sync Signal Applied to an Astable Blocking Oscillator

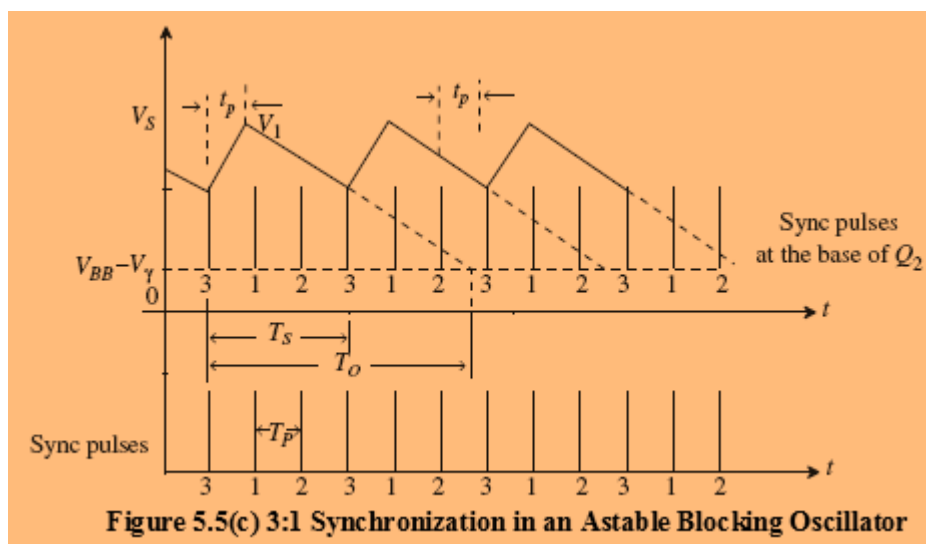
A regenerative action takes place, the transistor Q_1 is quickly driven into saturation, and a pulse of duration t_P is generated. During this period of pulse generation, the capacitor C_1 charges, the voltage across the capacitor at $t = t_P$ being V_1 , as shown in Figure 5.5(b). As this voltage reverse-biases the base – emitter diode of Q_1 , Q_1 now goes into the OFF state. As a result, the charge on C_1 discharges through R_1 and when the voltage across the capacitor terminals falls to $V_{BB} - V_\gamma$, then Q_1 is again ON and C_1 charges and this process is repeated. In the absence of sync pulses, a new sweep would have started at the voltage $(V_{BB} - V_\gamma)$, at which voltage Q_2 would have normally gone into the ON state. The output would have a time period T_O , as shown in Figure 5.5(b).

However, the sync pulses appear as positive pulses at the base Q_1 (after polarity inversion in Q_2 and further polarity inversion in the pulse transformer). Pulses numbered 1, 2, 3 and 4 do not have sufficient amplitude to terminate the sweep prematurely. However, pulse 5 occurs at such an instant and has sufficient amplitude that it prematurely terminates the cycle

as Q_2 goes into the ON state at the instant of occurrence of the 5th pulse, as regenerative action again takes place. C_1 again charges and so on.



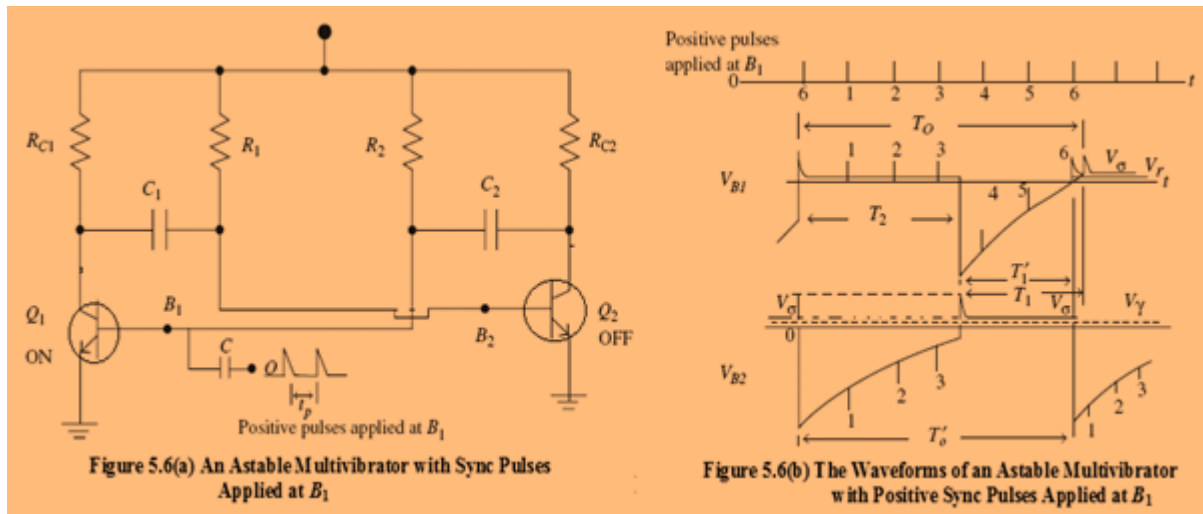
Thus, the cycle is prematurely terminated at T_S , and a new cycle starts. Synchronization with 5:1 division is accomplished. If, on the other hand, the amplitude of the sync pulses is increased, it could result in synchronization with 3:1 division, as shown in Figure 5.5(c). Thus, we can say that with the proper spacing between the sync pulses (proper choice of pulse repetition frequency) and proper choice of amplitude for these pulses, it is possible to achieve synchronization with desired frequency division.



5.4 Synchronization of Transistor Astable Multivibrators

Synchronization with frequency division in a transistor astable multivibrator can be accomplished by applying either positive or negative pulses to both the transistors or to any

of the transistors. Figures 5.6 (a) and (b) depict the circuit and the waveforms to achieve synchronization with a frequency division of 6:1. Here, positive pulses are applied at the base B_1 of Q_1 .



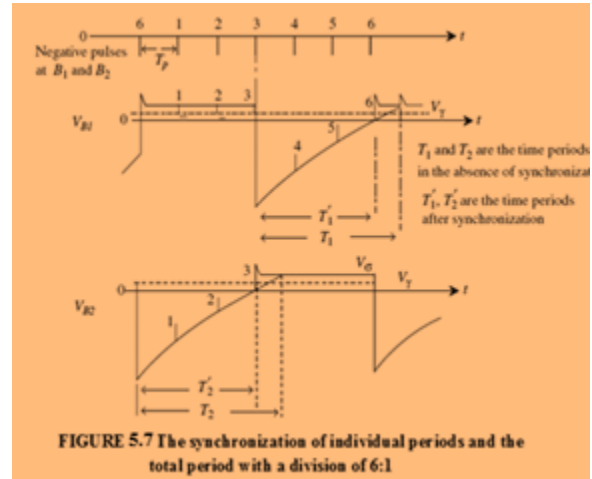
In the absence of sync pulses, the astable must have had a time period $T_O (= T_1 + T_2)$ when the cycle would have naturally terminated at V_{B1} or $V_{B2} = V_{\gamma}$. However, with sync pulses connected, the positive pulses applied at B_1 are amplified and inverted and appear as negative pulses at B_2 . During T_2 , the positive pulses at B_1 have no effect on the time period as Q_1 is already ON. Further the negative pulses 1, 2 and 3 appearing at B_2 will not be able to change T_2 . Hence, T_2 remains unchanged. However, during the time period T_1 , the pulses numbered 4 and 5 do not have sufficient amplitude to drive Q_1 into the ON state and terminate the time period T_1 prematurely. However, the 6th pulse has sufficient amplitude to prematurely terminate the time period T_1 as this pulse drives the base of Q_1 positive and hence, Q_1 goes ON. The new time period for which Q_1 is OFF is negative and the new sweep period is T'_O . In this arrangement, the multivibrator completes one cycle for every six sync pulses. Although the complete period is synchronized, the individual time periods are not synchronized. T_2 is the same as without synchronization.

5.5 Synchronization with Division of an Astable Multivibrator by Applying Negative Pulses at both the Bases (B_1 and B_2)

If an astable multivibrator is required to be synchronized during both the time periods T_1 , T_2 and also for T , then the negative pulses can be applied to both the bases B_1 and B_2 of transistors Q_1 and Q_2 . Let it be assumed that both the time periods are required to be synchronized with a division of 3:1 so that the total period is synchronized with a frequency division of 6:1, as shown in Figure 5.7.

The negative pulses applied at B_1 get amplified, inverted appear as positive pulses at the base B_2 . Similarly, the negative pulses applied at B_2 get amplified and inverted and appear as

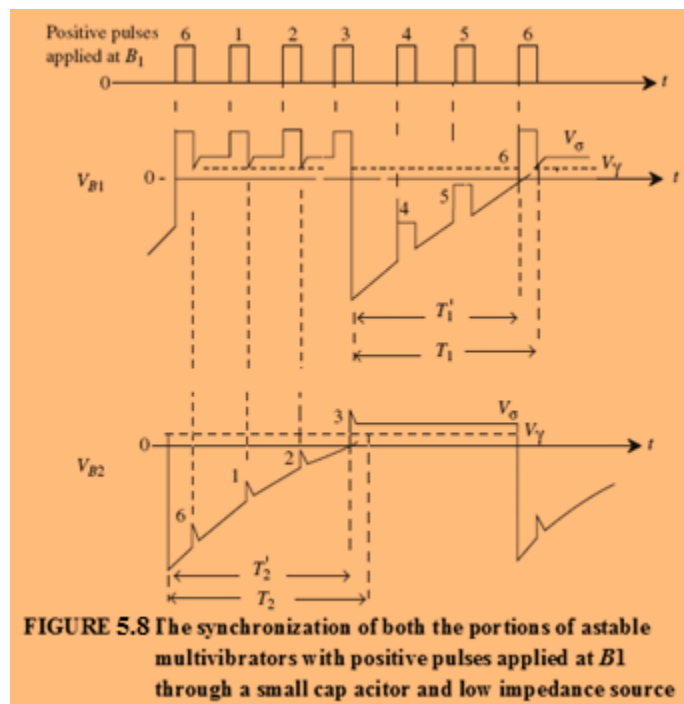
positive pulses at the base B_1 . Thus, the positive pulses superimposed on the exponential portion of the waveform at B_2 during T_2 are a combination of negative pulses applied directly and the inverted and amplified negative pulses from the other transistor which appear as positive pulses. The pulses marked 1 and 2 do not have sufficient amplitude. However, the pulse marked 3 has an amplitude that can terminate T_2 earlier, resulting in a new time period.



Similarly, during the period T_1 when Q_1 is OFF, pulses marked 4 and 5 will not have any influence on the time period T_1 . However, the pulse numbered 6 will terminate T_1 prematurely, resulting in a new time period. Each of these time periods are individually synchronized with a frequency division of 3:1 as the third and the sixth pulses prematurely terminate the time periods T_2 and T_1 . Hence, synchronization with a division of 6:1 occurs for the entire time period T of the astable multivibrator.

Positive Pulses Applied to B_1 through a Small Capacitor from a Low-impedance Source

Synchronization with the division of both the time periods of an astable multivibrator can be achieved by applying the positive pulses to only one base instead of at both the bases, say, B_1 . During the period when Q_1 is ON, as its input resistance is very small, the time constant of the pulse input is also very small. This RC circuit behaves as a differentiator and the pulse is quasi-differentiated. The negative spikes in this differentiated signal at B_1 of Q_1 appear as the positive spikes during the exponential variation at B_2 . Pulses 1 and 2 may not be able to drive Q_2 ON and terminate T_2 prematurely.

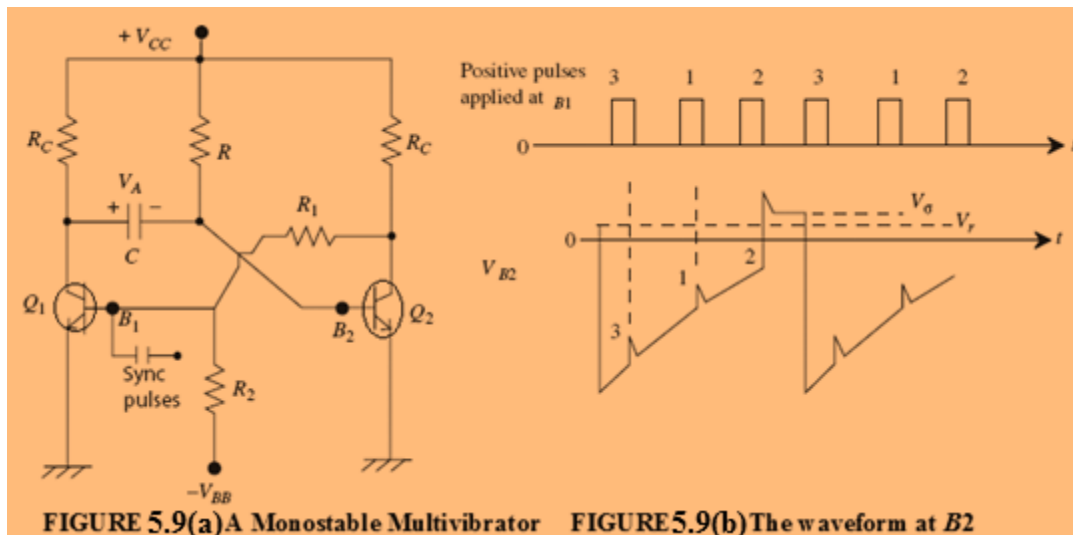


However, the positive spike appearing at the trailing edge of the pulse numbered 3 will prematurely terminate the OFF period T_2 of Q_2 . The new time period for which Q_2 is OFF is T_2' . During the exponential variation of the voltage at B_1 during T_1 , the positive pulses are superimposed and at the leading edge of the pulse numbered 6, the OFF period of Q_1 is prematurely terminated. The new time period for which Q_1 is OFF is T_1' . The original time period of the astable multivibrator was $T (= T_1 + T_2)$. Whereas, the new time period after synchronization is $T' (= T_1' + T_2')$. Thus, not only the entire cycle with time period T of the

astable is synchronized with a frequency division of 6:1 but the individual time periods and are also synchronized with a division of 3:1, as shown in Figure 5.8.

5.6 A Monostable Multivibrator as a Divider

A monostable multivibrator can be used for synchronization with frequency division [see Figure 5.9(a)] and the waveforms are shown in Figure 5.9(b). Here, the positive pulse train is applied at B_1 through a small capacitance from a low impedance source.

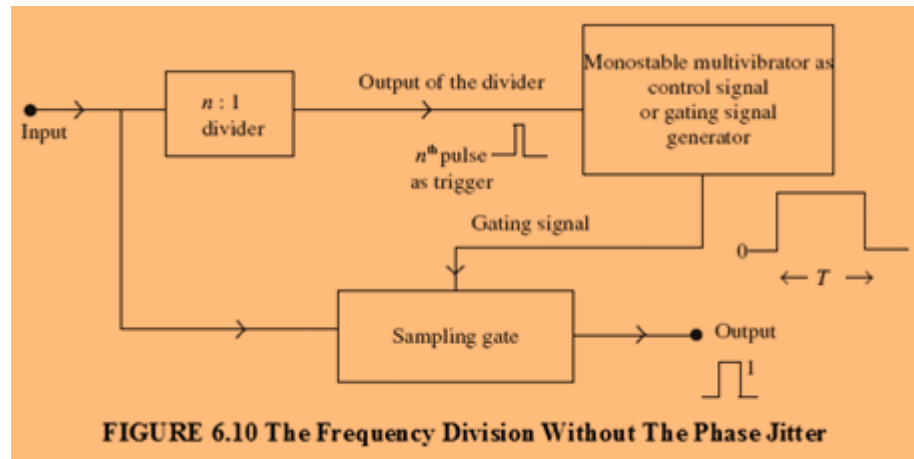


The positive pulse train applied at B_1 gets quasi-differentiated as discussed earlier in the Section 15.3.4. The negative spikes at the trailing edge of the pulses are amplified and inverted and appear as the positive spikes at B_2 . As a result, positive spikes due to the second pulse will prematurely terminate the time period resulting in synchronization with the frequency division of 2:1. On the other hand, if the amplitude of the pulses is large enough, pulse 1 may prematurely terminate the time period, thereby changing the counting ratio from 2 to 1.

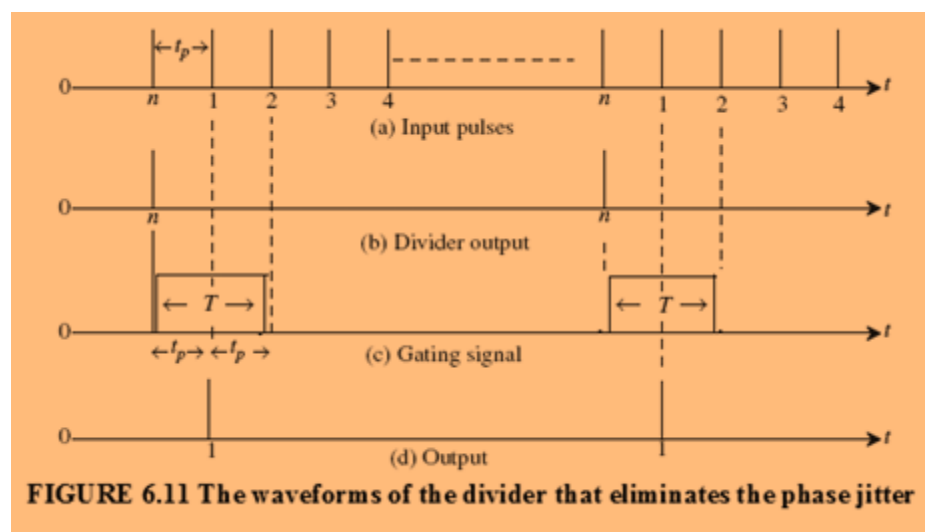
5.7 A Relaxation Divider that Eliminates Phase Jitter:

When a pulse train is applied to a divider, there could be a small time delay by the time it appears at the respective bases to cause a possible premature change in the state of the devices. This delay is called the phase delay. Also, as the pulse train is coupled to the divider circuit through an RC circuit, it could result in pulses having a finite rise time. Further the divider may have a certain response time which is liable to change with the frequency of the sync signals and the time constants associated with the circuit. As a result, this signal can influence the instant at which the base waveform would drive the device OFF. The phase delay could also be due to the variations in the device characteristics, supply voltages and the noise in the circuit.

The phase delay that varies due to the cumulative effect of all these factors is termed as phase jitter. The frequency division without the phase jitter can be implemented using the schematic arrangement shown in Figure. 5.10.



The waveforms are shown in Figure 5.11. The input to the divider is a train of pulses. The divider is an $n:1$ divider, i.e., for every n pulses, the n th pulse is obtained at the output of the divider. This n th pulse is applied as a trigger to the

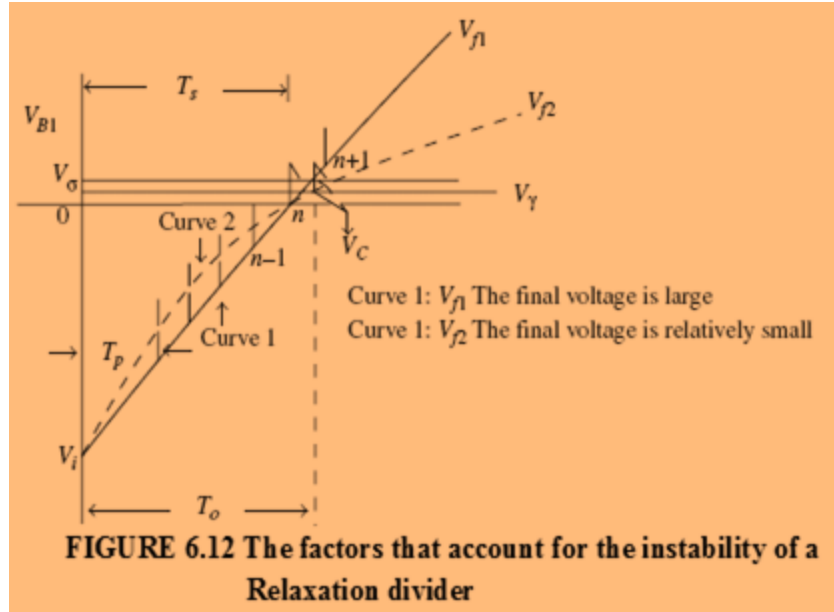


monostable multivibrator which generates a gated output, that is, a pulse of duration T . This pulse of duration T controls the sampling gate. A sampling gate is one which transmits the input to its output as long the enabling signal (the gating signal) is present. For the rest of the duration, there is no output for the sampling gate. As only the output of the divider (n th pulse) triggers the monostable multivibrator, a pulse of duration T occurs only at the end of the n th pulse. Though a sequence of pulses is present at the input of the sampling gate, only the pulse marked 1 is transmitted to the output, as during the occurrence of this pulse the sampling gate is enabled. The output consists of the pulses labeled 1 only. By adjusting the pulse width of the gating signal such that $T_P < T < 2 T_P$, we can ensure that the n th pulse does not pass to the output of the sampling gate. Thus, phase jitter can be eliminated.

5.7.1 Stability of the Relaxation Divider

In a frequency divider, due to phase jitter, if the n th pulse is required to prematurely terminate a sweep cycle, it is possible that either the $(n - 1)$ th pulse or even the $(n - 2)$ nd pulse may terminate a sweep cycle. This accounts for the instability of the natural timing period of the oscillator, which in turn may cause a loss of synchronization or an incorrect division ratio. The typical voltage variation at the base of an astable multivibrator is shown in Figure 5.12.

In order to calculate the time period of a monostable multivibrator, we use the relation $v_O(t) = v_f - (v_f - v_i)e^{-t/\tau}$ where, v_i is the initial voltage from which the charge on the capacitor discharges and v_f is the final voltage to which the capacitor would discharge, if allowed to discharge, as $t \rightarrow \infty$. Assuming that τ remains fairly constant, it is the changes in v_i and v_f and $v_C (= V_\gamma)$ that could be responsible for the



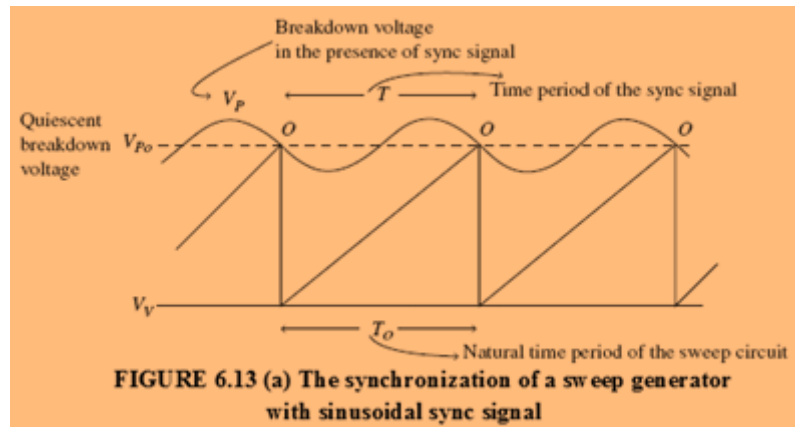
instability of the natural period. Let us consider the influence of these factors on the natural time period of the monostable multivibrator:

- (i) The parameters of the transistor are likely to change due to temperature variations. Also, if the existing transistor is replaced by another for some reason the transistor parameters may be affected. This could influence v_i and v_C , the voltage at which the period terminates. v_C can be the cut in the voltage of a transistor (V_γ) and v_f can change due to loading. Normally, a regulated power supply with sufficient current rating is used for v_f . Hence, the instability of the time period T_O due to the variation of v_f can be minimized or eliminated. The time period T_O can now mainly change due to the variations in v_i and v_C . However, the choice of v_f may influence the natural time period.
- ii) Let us consider the case when v_f is a large value, say, v_{f1} (curve 1). Then the variation between v_i and v_C can be approximately linear. Consequently, the change in T_O due to variation in v_C can be minimized to some extent. However, in curve 1, if v_i changes by a larger amount than v_C (with the same τ), then choosing a larger value of v_f may again give rise to instability of the time period.
- iii) On the contrary, if v_f is reduced to v_{f2} , the variation of the voltage between v_i and v_C is exponential in nature and hence, non-linear. Now if v_i varies, then a given percentage change in $(v_C - v_i)$ could cause a lesser percentage change in T_O (curve 2).

Hence, the variation in T_O i.e., instability of the time period, can be minimized by the proper choice of v_f , depending on whether the instability has occurred either due to the variation in v_C or v_i .

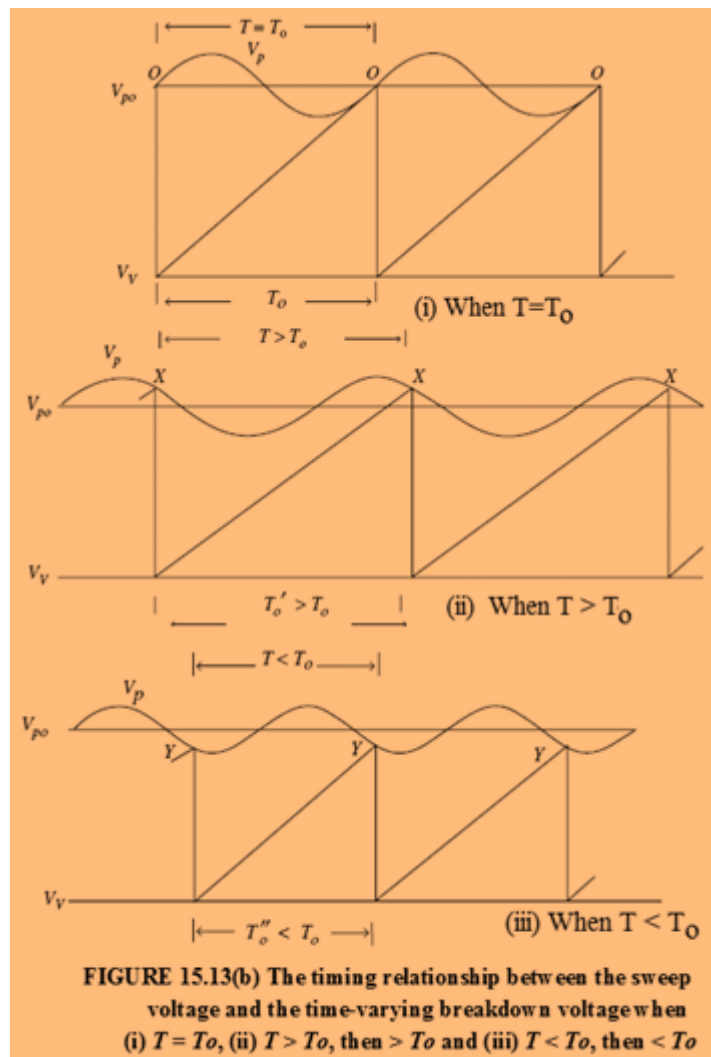
5.8 Synchronization of a Sweep Circuit with Symmetrical Signals

So far, we have considered the synchronization of relaxation circuits with external sync signals that are essentially pulses only. However, we can also synchronize a relaxation circuit such as a sweep generator with sync signals that could as well be gradually varying signals like sinusoidal signals. Let us



consider the output of a UJT sweep generator that is to be synchronized with a slowly varying sinusoidal signal, as shown in Figure 5.13(a).

Let it be assumed that the breakdown voltage of the UJT varies sinusoidally in the presence of the sync signal. Here, V_{PO} is the quiescent breakdown voltage of the UJT and V_P is the breakdown voltage in the presence of the sync signal. It is possible that synchronization can be effected with $T = T_o$. If this happens, then the period of the sweep is not altered by the sync signal and the sweep amplitude is also unaffected. The sweep cycle, as a result, terminates at V_{PO} , which means that the sweep terminates on its own at points labeled 'o' in Figure 5.13(a). Earlier, when synchronization was achieved using a pulse train as sync signals, it was observed that for synchronization to take place it was imperative that the spacing between pulses (T_p) should be less than or equal to the natural time period (T_o) of the relaxation circuit.



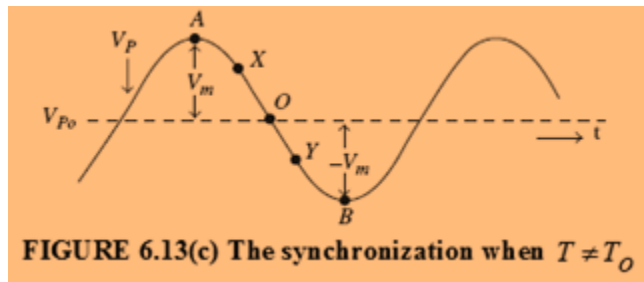
It was also observed that a pulse could prematurely and reliably terminate a sweep cycle (reduce the sweep duration) but will not be able to extend the sweep duration. However,

when it is a case of synchronization with symmetric signals, synchronization is always possible whether T (T_p in the case of a pulse train) is less than or equal to T_O or T is greater than T_O .

It is seen from Figure 5.13(b) that if the sweep voltage meets the V_P curve at a point above V_{PO} for $T > T_O$, say X , then the duration of the sweep is lengthened ($> T_O$). On the other hand, if the sweep voltage meets the V_P curve at a point below V_{PO} for $T < T_O$, the duration of the sweep is shortened ($< T_O$).

Let us summarize this with the help of Figure 5.13(c):

1. When $T = T_O$, the sweep is terminated at 'o' on the V_{PO} line, leaving the period and the amplitude of the sweep unaltered.



2. When $T > T_O$, if the sweep terminates at a point say, X that lies between 'o' and positive maximum, at A , then the sweep is lengthened and its duration is greater than T_O . This lengthening is maximum when the sweep terminates at A .

3. When $T < T_O$, if the sweep terminates at a point, say Y , that lies between 'o' and the negative maximum at B , then the sweep is shortened and its duration is smaller than T_O . This shortening is maximum when the sweep terminates at B . To calculate the range of synchronization let us consider an example.

Example Problem 5.1: A UJT sweep operates with a valley voltage of 4 V and peak voltage of 16 V. A sinusoidal synchronizing voltage of 3 V peak is applied as a sync signal. $\eta = 0.5$. If the natural frequency of the sweep is 1 kHz, over what range of sync signal frequency will the sweep remain in 1:1 synchronization with the sync signal.

Solution: The quiescent breakdown voltage, $V_{PO} = 16$ V.

Peak-to-peak amplitude of the synchronizing signal = 3 V

In the absence of the sync signal, the peak-to-peak swing of the sweep = $V_{PO} - V_V = 16 - 4 = 12$ V

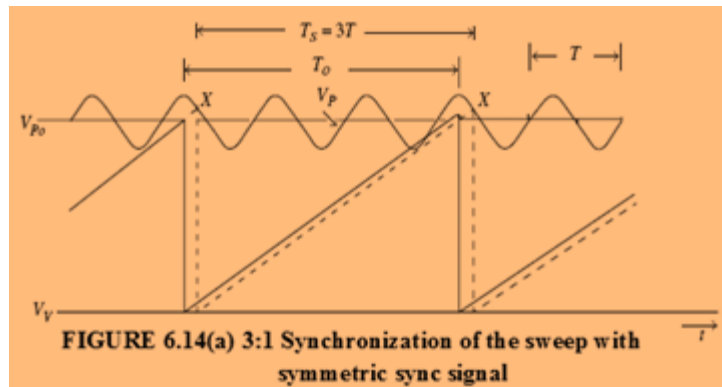
In the presence of the sync signal, the sweep amplitude must therefore lie in the range

$(12 - 1.5) = 10.5$ V and $(12 + 1.5) = 13.5$ V.

Time period of the sync signal, Amplitude of the natural sweep signal = $16 - 4 = 12$ V. And this sweep amplitude is generated in 1ms. Therefore, the time required to generate a sweep of, 10.5 V is and the corresponding frequency is, The time required to generate a sweep of 13.5 V is and the corresponding frequency is It is seen from the above calculations that the sweep generator remains synchronized as the frequency of the sync signal varies from 889 c/s to 1143 c/s.

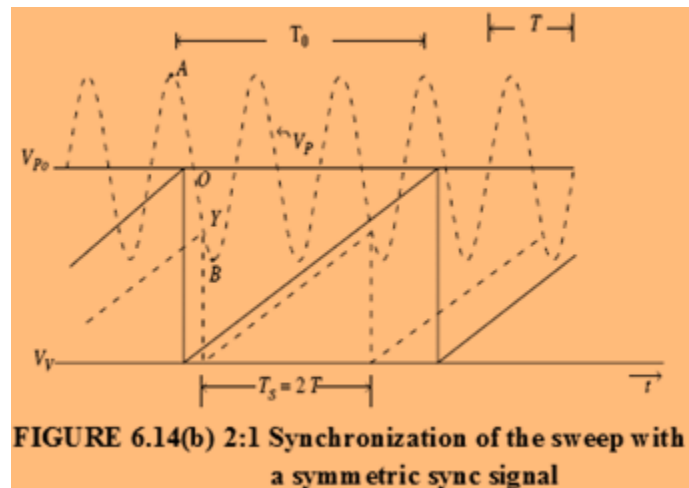
5.9 Frequency Division with Symmetric Sync Signals

Let us now consider the operation of a sweep circuit as a frequency divider using sinusoidal signal as sync signal, as shown in Figure 56.14(a). The solid lines represent the sweep with a time period T_0 and the sync signal with a time period T . The natural sweep terminates on V_{PO} line. In the presence of the sinusoidal sync

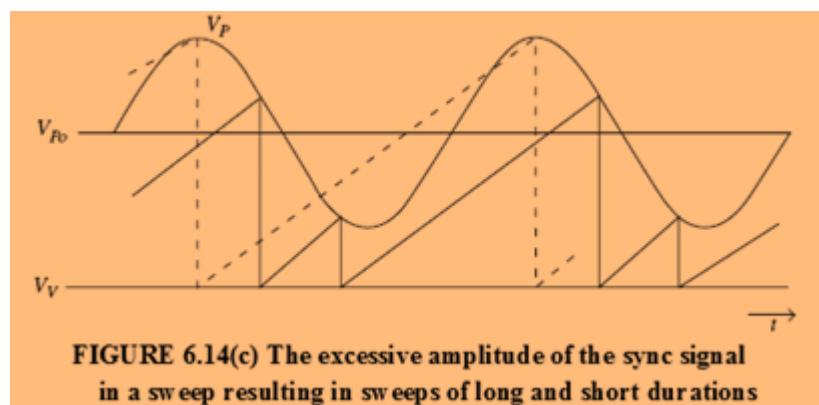


signal, if the sweep meets the sync signal above the V_{PO} line at X, the new time period of the sweep is T_S . Thus, the sweep period T_0 changes to T_S as a result of the sync signal. The sync signal completes three cycles during the period T_S , resulting in the division by a factor 3 as $T_S = 3T$ (counting ratio of 3).

If now the amplitude of the sync signal is increased (dashed line), keeping the time period the same as T , as shown in Figure 5.14(b), the sweep meets the sync signal at Y between O and B. The duration of the sweep is shortened (dashed line) resulting in a 2:1 synchronization (a counting ratio of 2). If the amplitude of the sync signals further increases, it could result in a counting ratio of 1. Hence, this circuit can operate as a counter.



Increasing the amplitude of the sync signal, in principle, can cause 1:1 synchronization. The sweep is terminated prematurely when it meets the sync signal below the V_{PO} line. Beyond this point once again the sweep voltage increases and this time it will terminate on the sync



signal above the V_{PO} line. Therefore, the actual sweep waveform consists of the alternate sweeps of short and long durations. The suggestion therefore is that if this sweep is used to cause deflection of the electron beam along the X-axis in a CRO, it is preferable to use a sync signal of smaller amplitude, as shown in Figure 5.14(c).