Synchronization and frequency division

Introduction:

— A pulse (or) digital system may involve several different basic generators like multivibrators, sweep generators, blocking oscillators etc as these are required for its subsystems and the system may require that all these generators be operated synchronously:— in step with one another

ie; each one of them arrives at some reference point in the cycle at exactly the same time.

— "Two (or) more generators are said to operate in synchronism if each one of them arrives at some reference point in its cycle at the same time". (ex: positive peak or negative peak)

— When two generators produce waveforms at different frequencies, it is essential for proper synchronization, that the frequency of one generator is an integral multiple of other generator.

Thus the frequency of the second generator may be twice, thrice or four times that of the first generator.

— Types of Synchronization:

1) Synchronization with one-to-one basis.

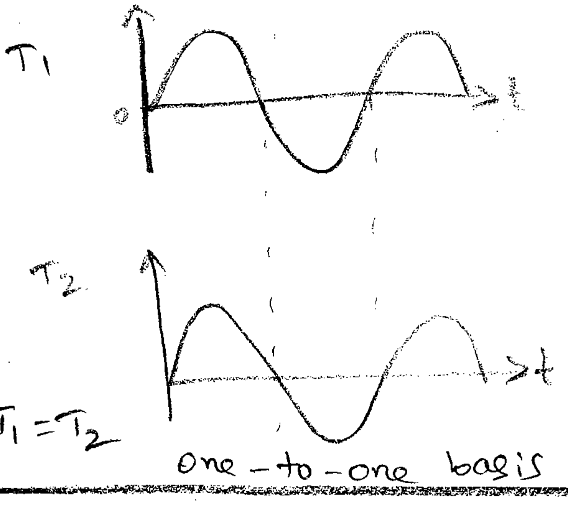
2) Synchronization with frequency division.

Synchronization with one-to-one basis:

"Synchronization is said to be on one-to-one basis if all the generators operate at exactly the same frequency and arrive at some reference point in the cycle exactly at the same time".

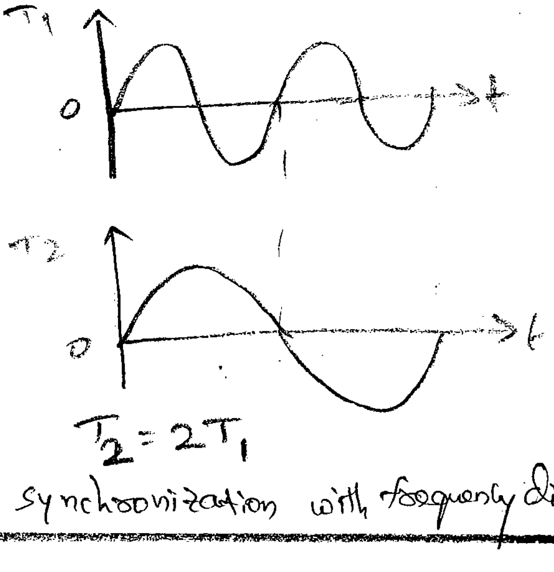
Synchronization with frequency division:

"Synchronization is said to be with frequency division if the generators operate at different frequencies which are integral multiples of each other but arrive at some reference point at the same time".



$T_1 = T_2$

one-to-one basis



$T_2 = 2T_1$

synchronization with frequency division

Principle of Synchronization : Pulse synchronization of Relaxation devices

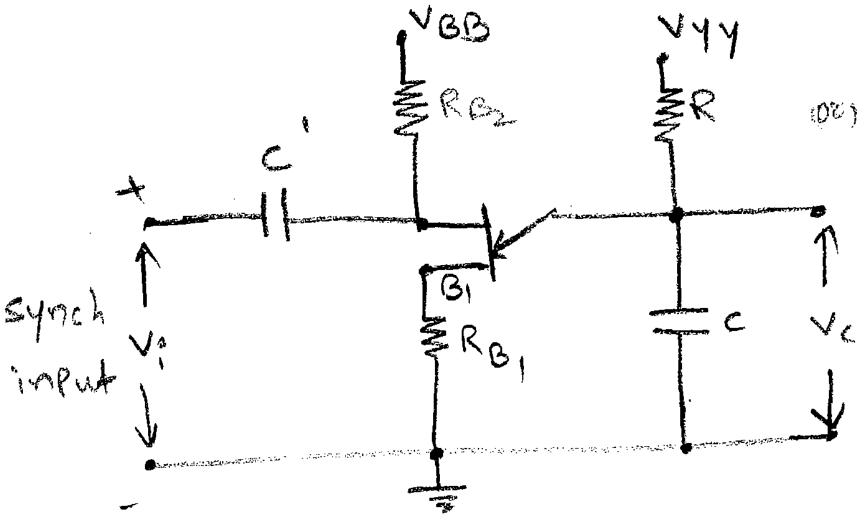
— Relaxation circuits

"These are circuits in which the timing interval is established through the gradual charging of a capacitor, the timing interval being terminated by the sudden discharge (relaxation) of a capacitor"

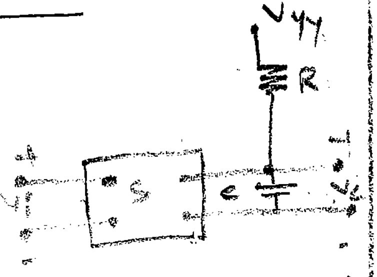
— multivibrators, sweep generator, blocking oscillator are the examples of relaxation circuits.

All these circuits have in common a timing interval and a relaxation (or recovery) interval and each exists in an astable or monostable form.

— Let a Unijunction transistor (UJT) relaxation oscillator be considered.



(OR)



V_i = Sync input

V_c = voltage across capacitor

It is a Current-Controlled, negative resistance device which can be used as a switch. It generates a voltage waveform.

The voltage rises exponentially as the capacitor charges with UJT OFF, until it becomes equal to the peak voltage Vp.

When the capacitor voltage equals Vp, UJT becomes ON and capacitor discharges.

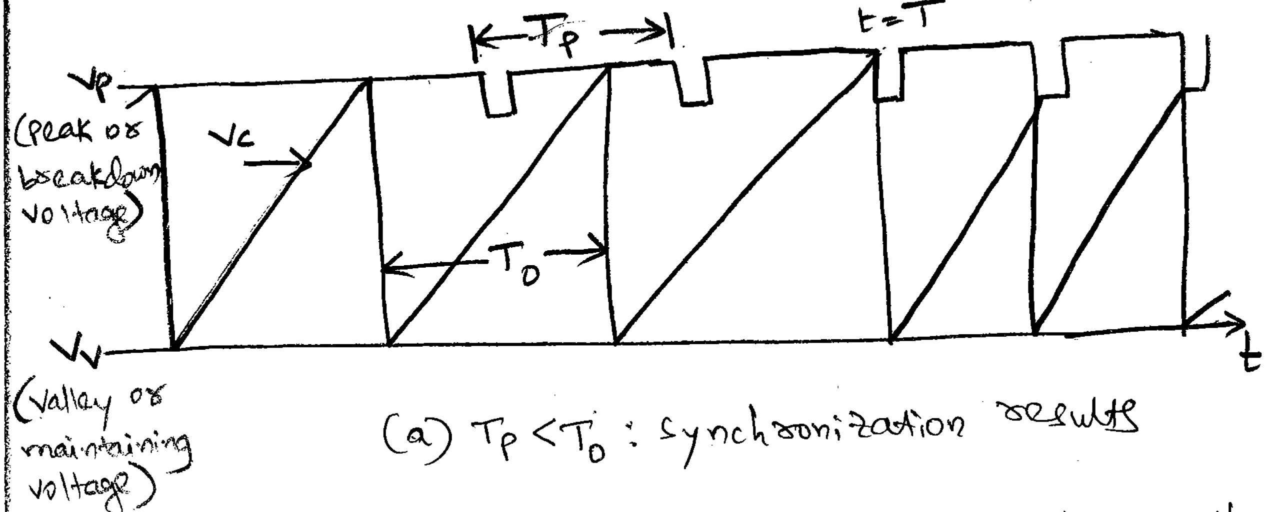
The voltage falls to value voltage V_v when again UJT becomes OFF and capacitor again charges. This process repeats.

— For all practical purposes the waveform of the capacitor voltage is considered as sawtooth. Let it be required to synchronise the sawtooth waveform to external synchronising pulses.

— synchronization can be done by applying an external synchronizing pulse at sync terminal in such a manner as to change the peak voltage Vp.

For UJT, a negative pulse is applied at B_2, which lowers Vp.

— fig (a) shows the situation which results when synchronizing pulses are applied.



(a) $T_p < T_0$: synchronization results

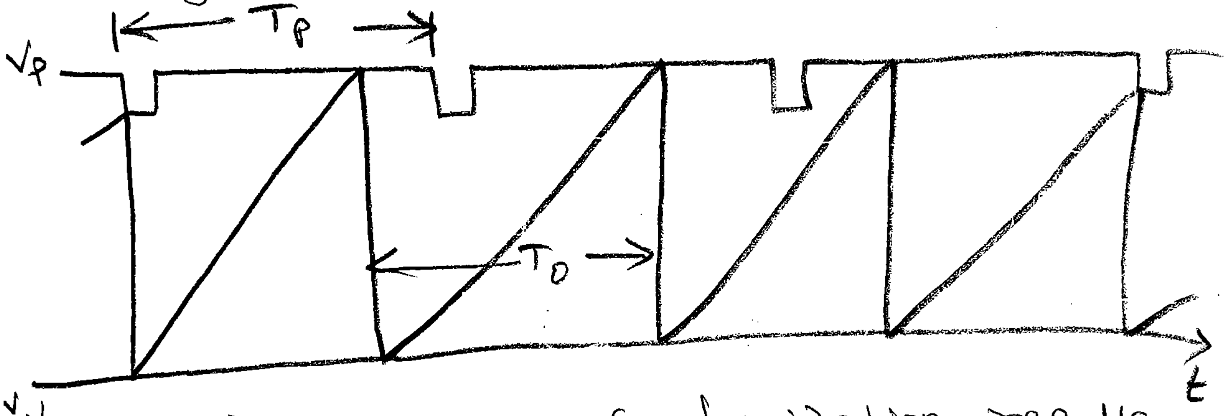
"The effect of synchronization pulse is to lower the peak (or) breakdown voltage V_p for the duration of the pulse".

— A pulse train of regularly spaced pulses is shown in fig(a) starting at an arbitrary time t=0. The first several pulses have no influence on the sweep generator because the amplitude of the sweep at the occurrence of the pulse plus the amplitude of the pulse is less than Vp. Hence, the sweep generator runs unsynchronized. Eventually, However, the exact moment at which UJT goes ON is determined by the instant of occurrence of a pulse (ie; at time T) and also each succeeding beginning of the

ON interval. From this point onwards, the sweep generator runs synchronously with the pulses.

— For synchronization to result, the time of occurrence of the pulse should be such that it can serve to terminate the cycle prematurely. i.e., T_p must be less than the natural period T_0 of the generator.

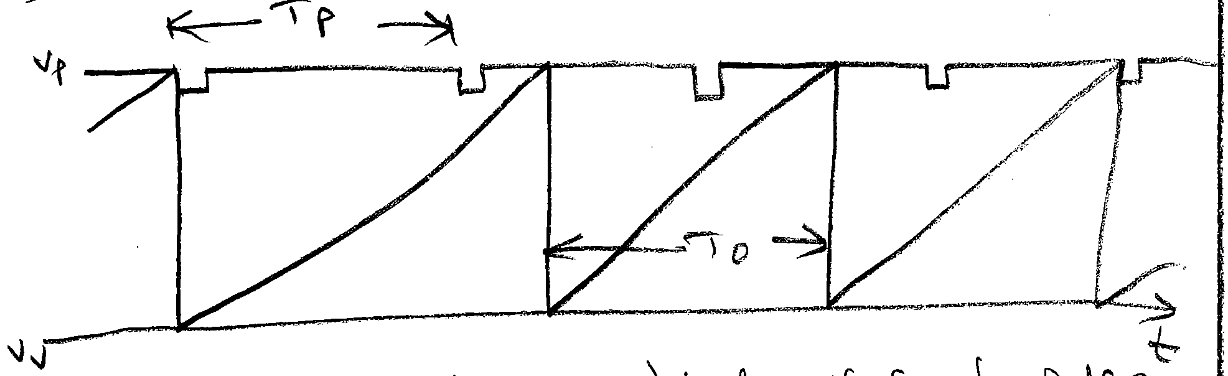
fig (b) shows the case in which $T_p > T_0$.



b) $T_p > T_0$: no synchronization results

— Here synchronization of each cycle does not occur. The pulses do serve to establish that four sweep cycles shall occur during the course of three pulse periods, but synchronization of this type is normally of no use.

— fig (c) shows a case in which $T_p < T_0$ as required, but synchronization does not result because the pulse amplitude is too small.



c) $T_p < T_0$: but amplitude of synch pulse is small, hence no synchronization results

— In fact, even if the requirement $T_p < T_0$ is met, synchronization cannot result unless the pulse amplitude is at least large enough to bridge the gap between the quiescent breakdown voltage and sweep voltage V_c.

frequency division in sweep circuit

— We have seen that synchronization (1:1 division) occurs i) when $T_p < T_0$ and ii) amplitude of pulse is sufficient to terminate ~~the~~ each cycle prematurely.

Even if $T_p < T_0$, if the pulse amplitude is too small, then each cycle may not get terminated.

— Let us consider the situation when T_0 is much larger than T_p ($T_0 > 2T_p$) and the pulse amplitude is adequately large.

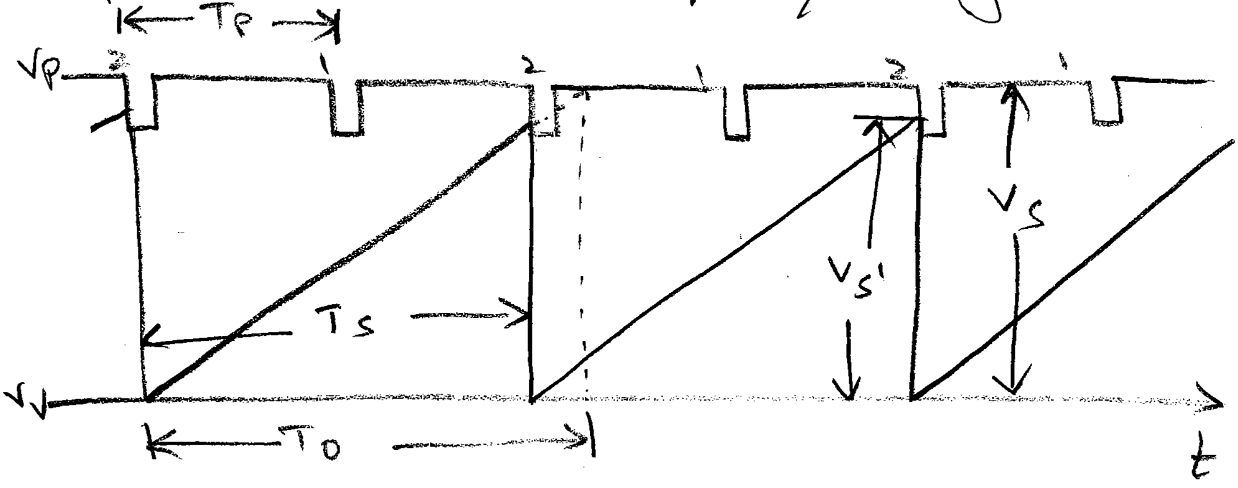


fig: frequency division by a factor of 2

— Odd numbered pulses (pulses marked as 1) are not effective in terminating the cycle prematurely whereas even-numbered pulses (pulses marked as 2) effectively terminate the cycle. Also sweep voltage is found to make one cycle for every two cycles of the synchronising pulses.

— After synchronization has been established, the period of the generator decreases slightly i.e. $T_S < T_0$

— The generator functions as a divider, with a division factor of 2, since for every two cycles of the synchronising pulses, there is one cycle of the generator voltage.

This mechanism of bringing about synchronisation is called as frequency division and the process of synchronisation is called as synchronisation with frequency division.

ex :

$T_0 > 2T_P$ with the result that $T_S = 2T_P$

$$\frac{T_S}{T_P} = 2$$

$T_0 > 3T_P \Rightarrow T_S = 3T_P$

$$\frac{T_S}{T_P} = 3$$

so, the generator will function as a divider and the division factor being 3.

— Amplitude V_s' of the sweep after synchronisation is less than the unsynchronized amplitude V_s.

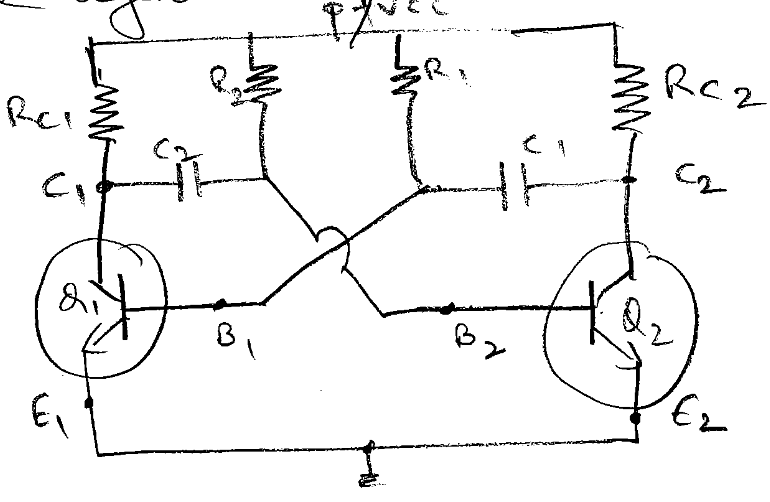
— In general, by making $T_0 > nT_p$ where n is an integer, a divider circuit with a division factor n can be built.

In such a circuit, for every n cycles of the synchronising pulses, the generator voltage will complete one cycle.

Astable Relaxation circuit

— An astable multivibrator has two Quasi-stable states and it keeps on switching between these two states on its own, without needing an external triggering signal.

— The transistors of the Astable multivibrator are regeneratively cross-coupled by capacitors.



— Astable multivibrator can be synchronized. (or) used as a divider by applying either positive (or) negative triggering pulses to either transistor (or) to both the transistors simultaneously.

— These pulses may be applied to collector, base or emitter.

— If the triggering pulses are positive, they may be applied to B_1 or C_2 and if they are negative pulses, they are applied to E_1.

— These triggers produce synchronization by establishing the exact instant at which Q_1 comes out of cut-off.

— However, if the triggering pulses are negative, they may be applied to B_2 or C_1 and if they are positive pulses, they are applied to E_2.

— when transistor Q_2 becomes ON and conducts, the negative pulses get amplified and inverted and they appear as positive pulses at B_1. Hence, again the pulses may establish the instant when Q_1 comes out of cut-off.

— fig (a) below shows the waveforms when positive pulses are applied to B_1.

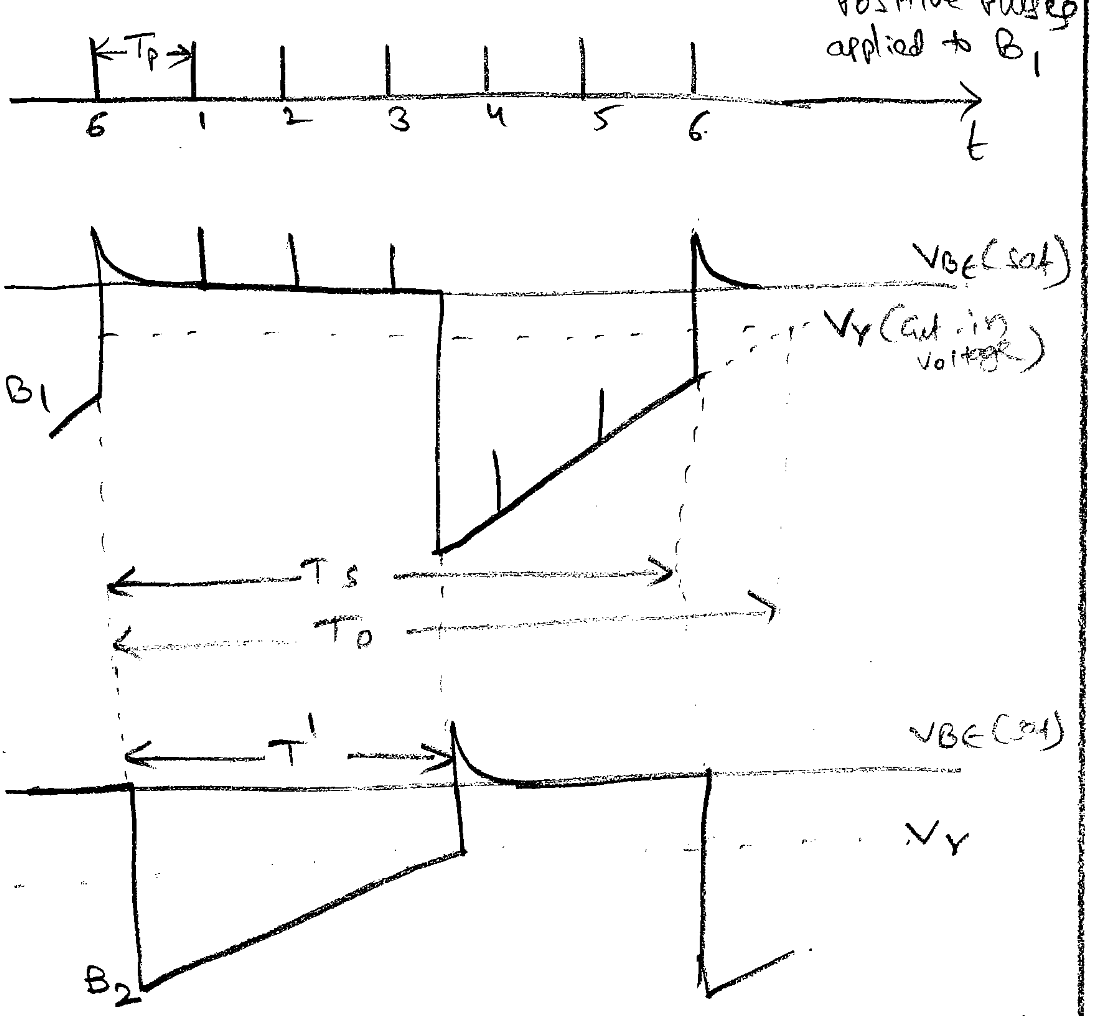


fig (a): Base waveforms for division by 6 through the application of positive pulses to base B_1.

— The division ratio is 6. The cycle will normally terminated at $t = T_0$, since at that instant the base voltage equals the cutin voltage V_γ.

— The cycle is prematurely terminated at the sixth pulse, since the amplitude of the sixth pulse is added to the base waveform B_1, at the time of the sixth pulse, raises the base voltage above V_r.

- ∴ Astable multivibrator functions as a divider, with a division factor of 6.

- It is of interest to note that the full period of the astable multivibrator has been synchronised but the individual portions have not been synchronized. Thus T' is same as what it would have been if there was no synchronisation.

- This is due to the fact that the waveform at base B_2 is not at all affected by the application of the triggering pulses.

- fig (b) shows the base waveforms for the case when negative pulses are applied to both bases simultaneously.

- Here the division ratio is 5. Both timing portions of the multivibrator waveform are synchronized and are necessarily of unequal duration since the division ratio is an odd number.

- The positive pulses superimposed on the exponential portions of the waveforms result from the combination of negative pulses applied directly and inverted and amplified pulses received from other transistor.

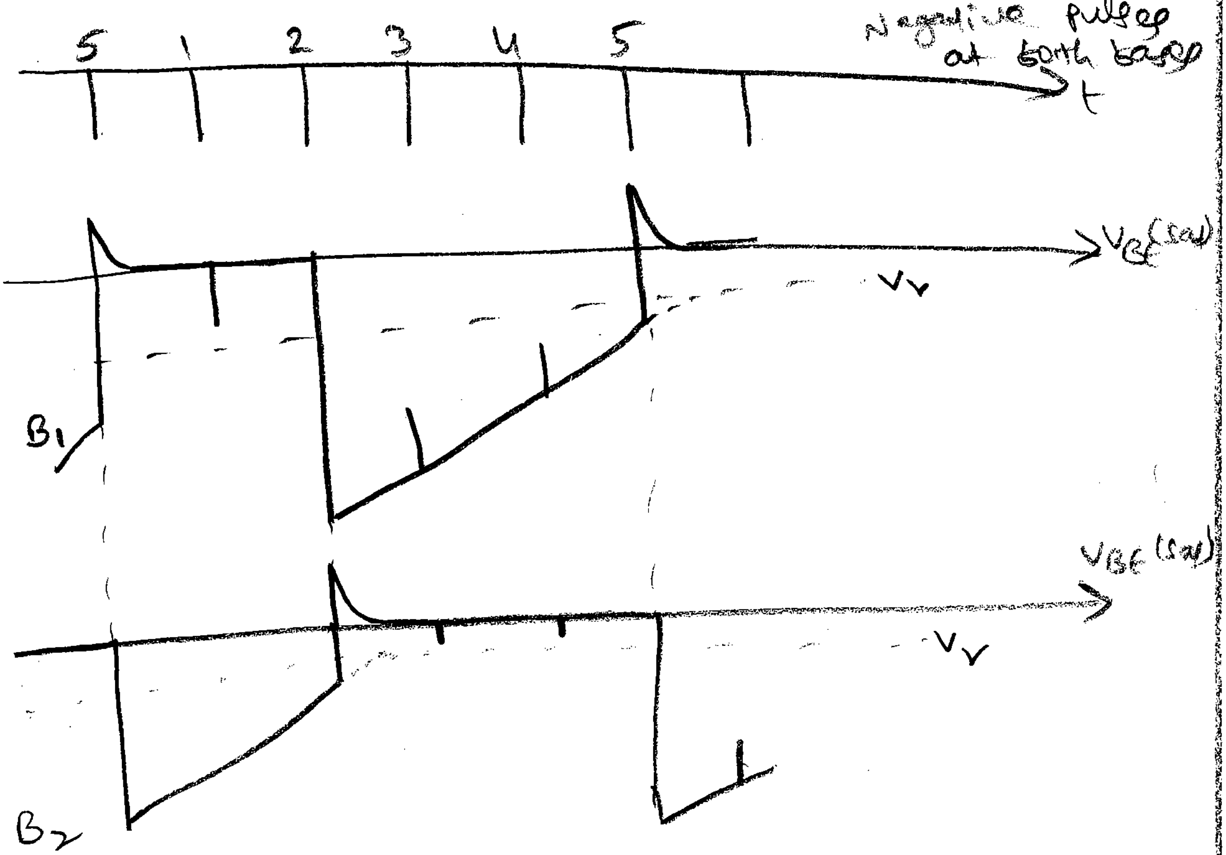


fig (b): base waveforms for division by 5 through the application of negative pulses to both bases.

Monostable Relaxation Circuit

— fig (a) shows the use of a monostable relaxation device, a monostable multivibrator for frequency division.

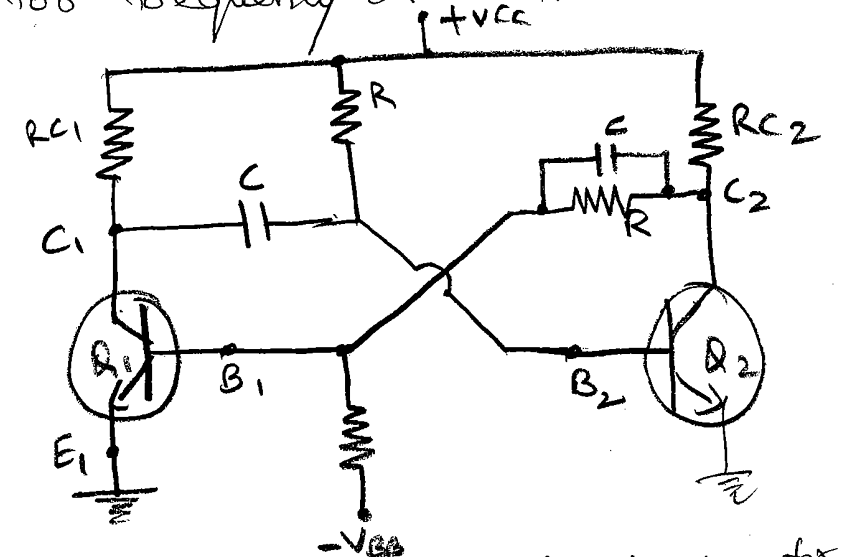


fig (a): Monostable multivibrator for frequency division

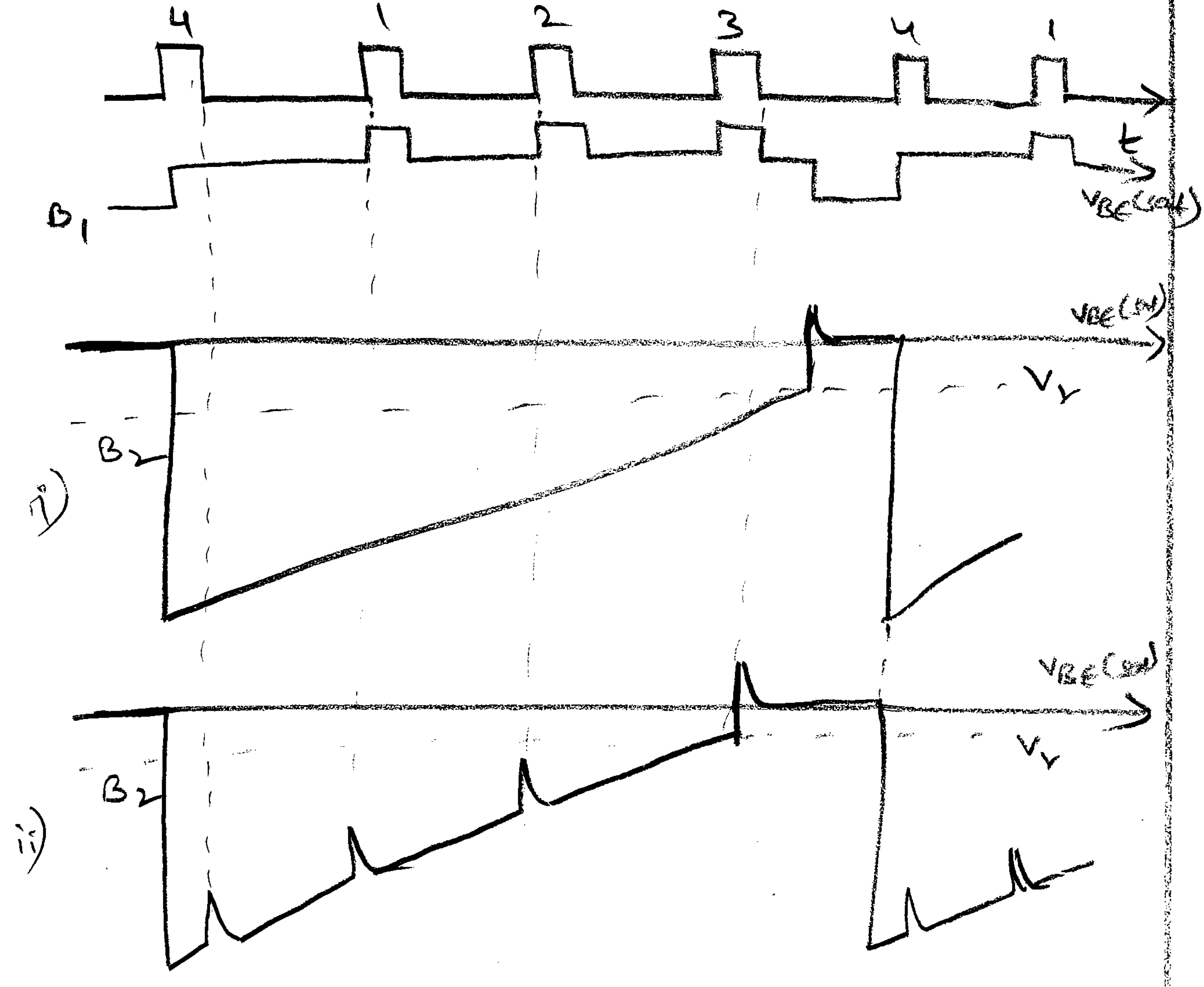
— The input pulses are applied to B_1 ~~or~~ C_1 depending on the polarity.

A coupling diode may be used to minimize the reaction of the multivibrator on the pulse source.

— fig (b) shows the voltage at B_1 and B_2.

— Each fourth pulse causes a transition of the multivibrator, the remaining pulses occurring at a time when they are ineffective.

— In this also, total period is synchronized but two separate portions are not synchronized.



i) waveform at B_2 with no pulse overshoot

ii) waveform at B_2 with pulse overshoot

— If positive pulses are applied directly at B_1 through a small capacitance from a low impedance source, the pulses are quasi differentiated during the conduction period of Q_1.

— The negative overshoot is amplified and inverted by Q_1 and appears as positive overshoot at B_2 and it may serve to terminate the cycle prematurely as shown in fig(ii).

- In this case, the two portions of the multivibrator wave form would be synchronized. Also, the counting ratio will change with increasing amplitude of pulse input.
- If the overshoot is large enough, the exponential will be terminated by the overshoot at pulse 2 (or) pulse 1 and in which case the counting ratio will become respectively 3 or 2.
- finally, with a large overshoot, the timing portion will terminate at the trailing edge of pulse 4 and the circuit will not operate as a multivibrator at all.

Phase Delay and Phase Jitter

- A relaxation oscillator can be synchronized (or) used as a divider.

Let us consider a divider with a division factor of 4. It is evident that for every four cycles of the synchronising pulses, the generator voltage completes one full cycle, and every pulse which is an integral multiple of

4 (pulses 4, 8, 12, 16, ...) prematurely terminates the cycle, and causes a change in the state of the oscillator.

— But, in practice between the instant of occurrance of the pulse which prematurely terminates the cycle (4th, 8th, ...) and the instant of the change of state of the oscillator, there is certain time delay, this delay is called as phase delay.

or

"The delay between the input pulse to a divider and the output pulse is called as phase delay."

— Phase delay results from finite rise time of the input trigger pulse and the finite response time of the relaxation time devices.

— The phase delay may vary with time due to variations in transistor characteristics and supply voltages.

— Additionally, some extraneous signal may be coupled unintentionally into the divider. Such a signal tends to change the exact instant at which a base waveform reaches cut-off.

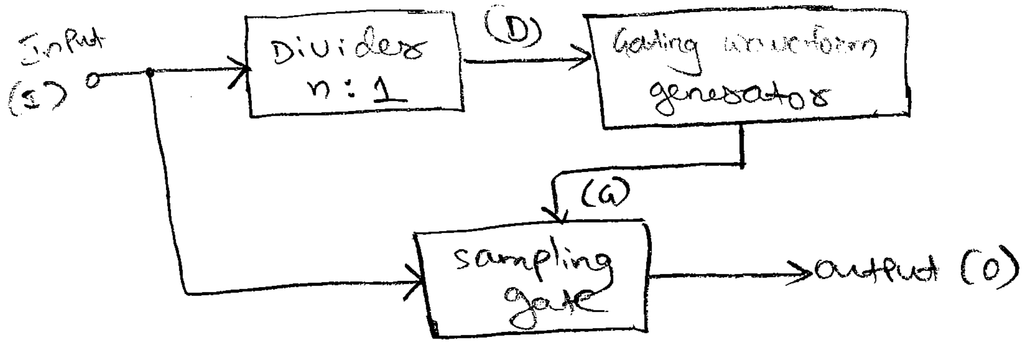
— All these factors which effect the phase delay gives rise to phase jitter.

— Phase jitter is undesirable and be overcome especially when its effect gets compounded.

Ex: In large-scale counters consisting of several stages, Phase jitter is compounded.

— In many applications, phase jitter is of no particular consequence but it plays a vital role and becomes an important difficulty in connection with nanosecond pulses.

— fig (a) shows a method for achieving division without phase jitter



fig(a) : Block Diagram

— The train of regularly spaced input pulses (I) is applied to the divider input.

— The output of the divider consists of the pulses (D). These pulses trigger a gating waveform generator, usually a monostable multivibrator

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which provides a gate of duration T_g adequate to encompass each pulse labeled '1'.

— This waveform is applied to a sampling gate which opens for a time T_g.

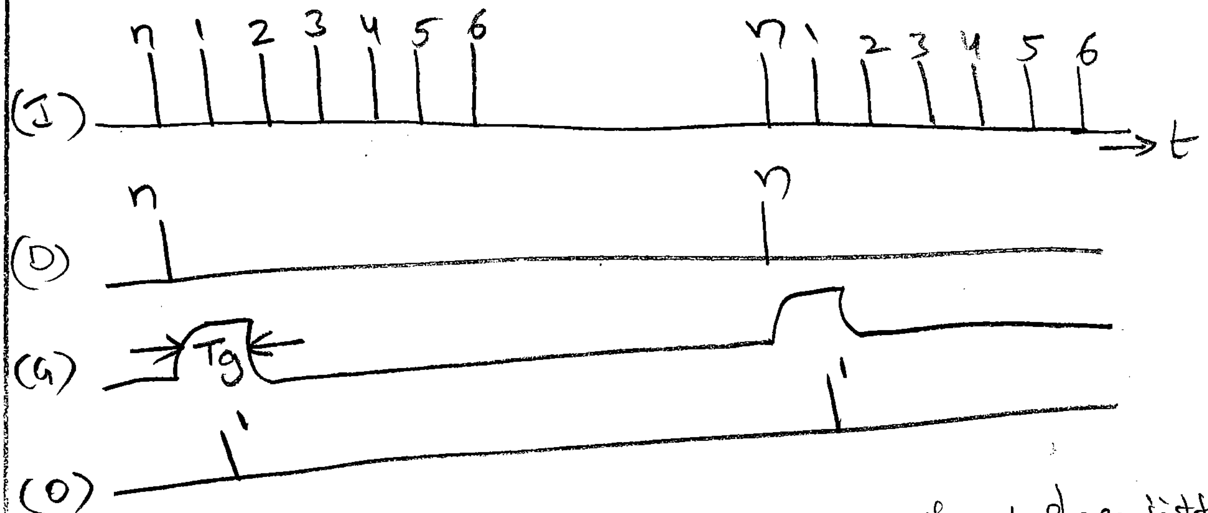

fig (b): waveforms for a divider without phase jitter

— The input pulse train is sampled and the output waveform (O) then consists of each pulse labeled '1'. Because of the phase delay between the waveforms (I) and (D) and the finite rise time of the gating waveform, we can ensure that pulse n does not pass through the gating circuit.

— The condition for proper transmission is

$$\boxed{T_P < T_g < 2T_P}$$

i.e; The gate width (T_g) is enough if it is longer than the interval between pulses and shorter than the interval between alternate pulses.

Synchronization of a sweep circuit with symmetrical signals

— In previous sections, we use the synchronising signal to be a train of pulses. A pulse waveform has leading edges which rise abruptly. Hence the variation of voltage is instantaneous but not gradual.

— Now we consider synchronising signals other than pulses. for such signals, the variation of voltage is gradual but never abrupt.

— The mechanism of synchronization for a gradually varying synchonizing signal is very nearly identical for all types of relaxation oscillators.

— Let us consider the sweep generator of fig(a) which uses current-controlled negative resistance switch. And further it is assumed that the breakdown voltage of the switch varies sinusoidally.

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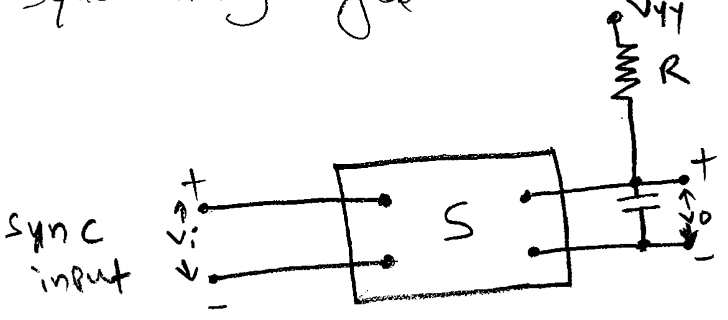
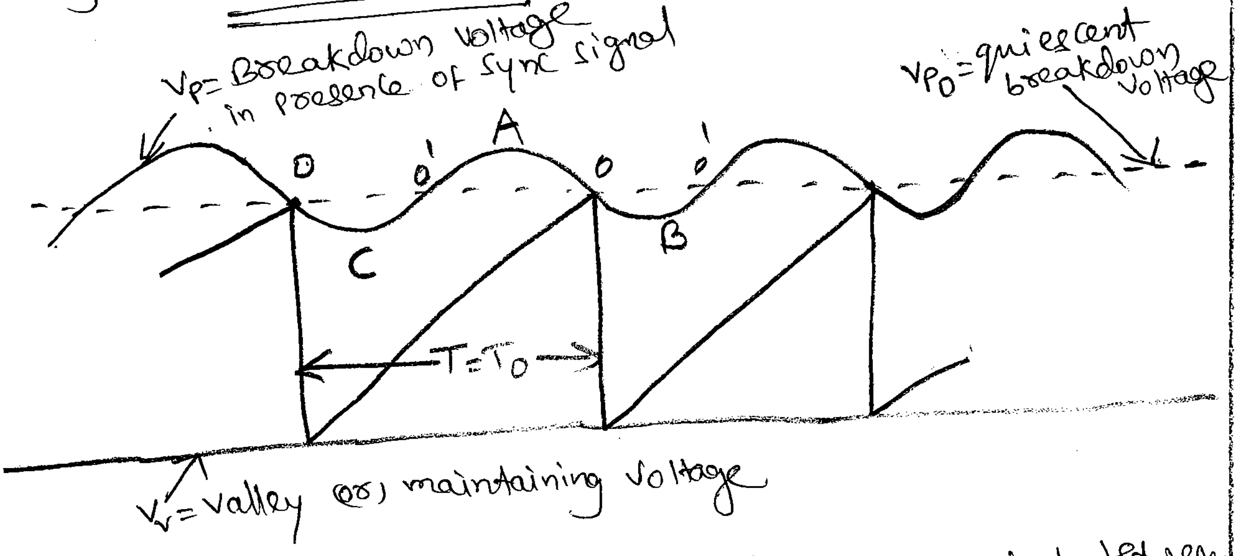
as a consequence of the application of the synchronising signal as shown in fig(b).



fig(a): Sweep generator



fig(b): The timing relationship that must exist between Vp and sweep voltage in a synchronized sweep when T=To

— The dashed voltage level Vpo is the breakdown voltage of the negative resistance device in the absence of a synchronizing signal.

— Solid curve Vp is the breakdown voltage in the presence of a synchronizing signal which is of symmetrical waveform.

T = period of synchronizing signal.

T_0 = Natural period of the generator.

— Consider the synchronization has been established with $T = T_0$. Such synchronization requires that the period of the sweep T_0 is not affected by the synchronising signal, otherwise synchronisation may not be possible.

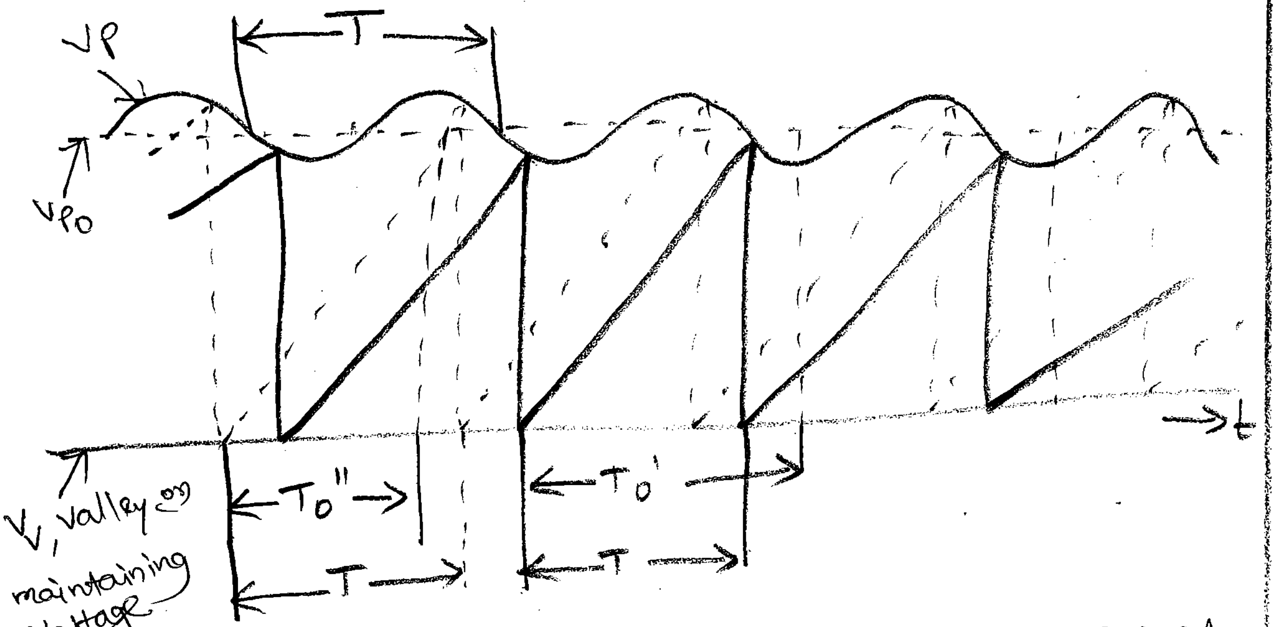
This implies that the sweep cycle must therefore continue to terminate at V_{P0} even after synchronization.

This result, in turn that at the time when V_P crosses V_{P0} at the points labelled 0.. It is possible that the sweep will terminate at the points marked 0'.

— In the case of pulse synchronization, we noted that synchronization could result only if the synchronizing signal period was equal to or less than the natural period.

— In the case of synchronization with symmetrical signals, however, synchronization is possible both when $T < T_0$ and when $T > T_0$.

— The timing relationship between the sweep voltage and the breakdown voltage for both the cases is shown in fig(c).



fig(c): Timing of the sweep voltage with respect to V_p for a case in which $T < T_0 = T_0''$

— The sweep voltage drawn as a solid line has a natural period $T_0' > T$.

— The sweep voltage meets V_p curve at a point below V_{P0} and is consequently prematurely terminated.

— The sweep voltage drawn as a dashed line has a natural period $T_0'' < T$. This sweep meets V_p curve at a point above V_{P0} and is consequently lengthened.

— In each case the synchronized period T_s equals the period T.

— The general situation may be described by reference to fig(d).

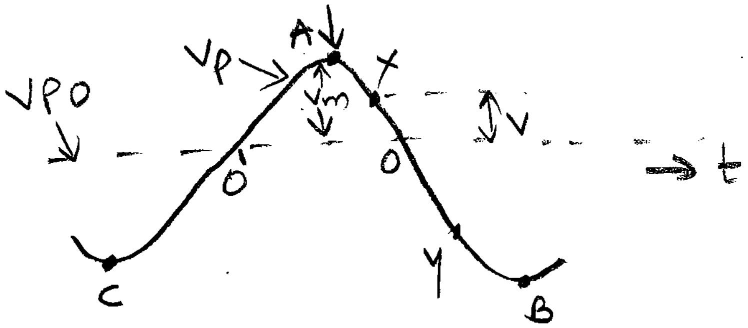


fig (d) : pertains to the case when $T \neq T_0$

i) when $T = T_0$, the sweep is terminated at point O, leaving the period unaltered.

ii) when $T > T_0$, the sweep terminates at a point such as X — between O and the positive maximum A.

iii) when $T < T_0$, the sweep terminates at a point such as Y — between O and negative maximum B.

— When the period T is such that the sweep terminates either at the point A or B, the limits of synchronization have been reached since at A, the sweep period has been lengthened to the maximum extent possible whereas at B the shortening is at maximum.

Sine wave frequency division with a sweep circuit

- In previous section, we discussed synchronization of a sweep generator using a symmetrical (sinusoidal) signal.
- The operation of a sweep circuit as a divider is an extension of the process of synchronization.
- fig (a) shows the operation of the sweep circuit for frequency division.

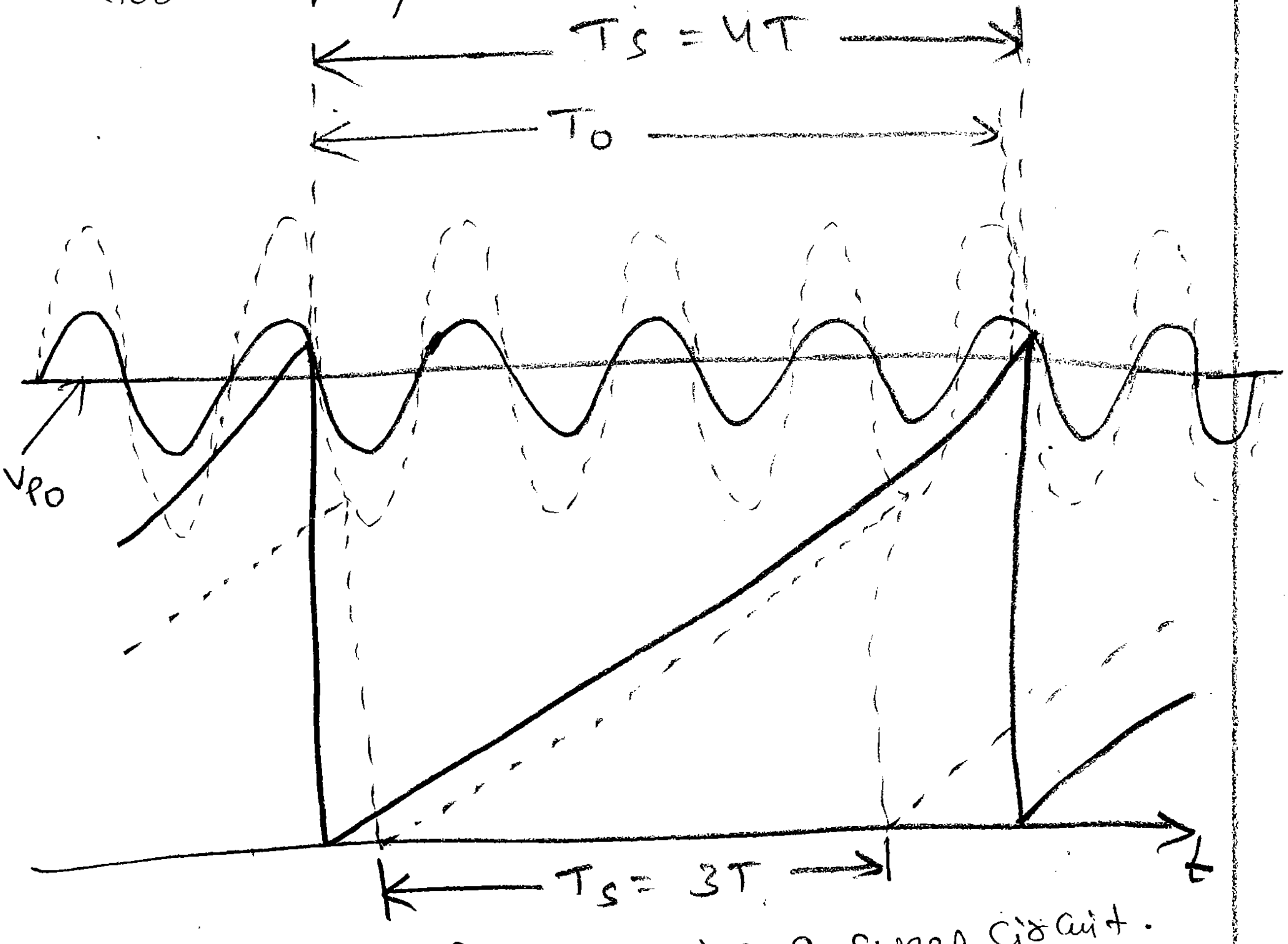


fig (a): Frequency division using a sweep circuit.
shows the change in frequency division ratio with sync signal amplitude

- The solid lines show the sweep and synchronizing waveforms for division by a factor of 4. This case is one in which the natural period T_0 is slightly smaller than 4T.
- The sync signal changes the sweep period from T_0 to T_s, where $T_s = 4T$.
- An increase in amplitude of the sync signal can change the division (Counting) ratio from 4 to 3 as shown by dashed sweep and synchronizing waveforms.
- A general observation that can be made with a sweep circuit as a counter is that if the sweep terminates on the descending portion of the V_p curve and if as a consequence the period T_0 is lengthened or shortened to T_s,

$$\text{where } T_s = nT$$

then the circuit will operate stably as an n:1 counter.

- Earlier it was assumed that the range of synchronization (or counting) extends from the point where the sweep intersects the V_p curve at a maximum to the point where the intersection is at a maximum of V_P curve.

— This normally holds only for small values of sync voltage, but may not hold when the sync amplitude is comparable to sweep amplitude.

— In fig (a) we can observe that the sweep will never be able to terminate at a maximum of V_P, because to do so, it is required that the sweep must first cross the previous negative excursion of V_P waveform.

Comparision between sine wave synchronization and pulse synchronization

1) Even though for small synchronization signals synchronization holds over a small range in the neighbourhood of integral relations between T and T_0 for both pulses and sine waves.

Pulse synchronization persists for variation of $\frac{T_0}{T}$ in only one direction, whereas sine-wave synchronization persists for variation of $\frac{T_0}{T}$ in either direction.

2) In both cases, the range of synchronization increases with the increasing synchronization signal amplitude.

3) With pulses, for large synchronization signal amplitudes, synchronization holds for all values of $\frac{T_0}{T_P} > 1$, whereas with sine waves, however, there is no guarantee that synchronization in a useful fashion occurs for all values of $\frac{T_0}{T} > 1$.

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