ELECTRONIC DEVICES AND CIRCUITS IV

module MCM6/EV

Volume 1/2

THEORY AND EXPERIMENTS

TEACHER / STUDENT manual

ElettronicaVeneta

"Final English version provided by cambridge Open Learning"

CONTENTS

APPENDIX A: DATA SHEETS

SAFETY RULES

Keep this handbook at hand for any further help.

After the packaging has been removed, set all accessories in order so that they are not lost and check the equipment integrity. In particular, check that it shows no visible damage.

Before connecting the equipment to the +/- 12V power supply, be sure that the rating corresponds to the one of the power mains.

This equipment must be employed only for the use it has been conceived, i.e. as educational equipment, and must be used under the direct supervision of expert personnel.

Any other use is not proper and therefore dangerous. The manufacturer cannot be held responsible for eventual damages due to inappropriate, wrong or unreasonable use.

LESSON B33: RC and WIEN BRIDGE OSCILLATORS

OBJECTIVES

- To understand and use an RC oscillator circuit
- To understand and use a Wien bridge transistor oscillator

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod. PS1-PSU/EV, module holder structure mod. MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (this module can operate autonomously, faults are inserted through dip-swicthes available in in the module. When external control units are used, these four dip-swicthes will be set to OFF, that is downwards)
- experiment module mod.MCM6/EV
- oscilloscope

B33.1 BASIC THEORY

An oscillator is a circuit which can generate an alternating (ac) signal from a dc power supply source.
Generally an oscillator has four main requirements:

- a dc power supply
- an amplification circuit
- a network which determines the frequency of oscillation
- positive (also called "regenerative") feedback.

An oscillator can be thought of as an amplifier which supplies its own input signal. To produce oscillations the signal fed back must have the correct phase.
The frequency of oscillation is determined by:

- a passive R-C network (for low frequencies)
- a passive L-C network or a quartz crystal (for high frequencies)

Phase shift or RC oscillator

Figure B33.1 shows the typical circuit of a phase shift oscillator.

It basically consists of a common emitter amplifier, whose output is taken from the collector to the input or base by an RC network which shifts the signal by 180°. The input signal will then allow self-oscillation of the circuit.

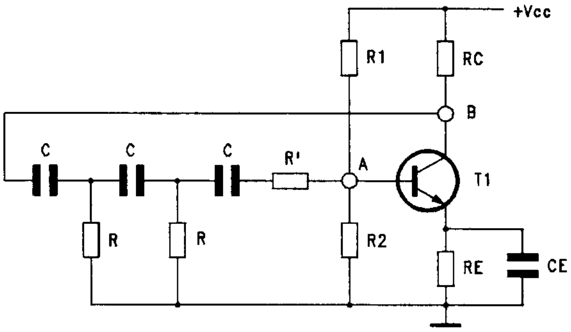


fig. B33.1

The oscillation depends on the ratio R/Rc and on hfe. In addition the following condition must be met:

hfe ≥ 44.5

The frequency of oscillation is:

$$f_o = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{[6 + 4 \cdot (R_c / R)]}} \qquad \text{(Hz)}$$

Another configuration of phase shift oscillator is shown in figure B33.2, where the lay-out of the capacitors and the resistors is now reversed. In this case the frequency of oscillation for this circuit is :

$$f_o = \sqrt{6 / (2\pi \cdot R \cdot C)} \qquad \text{(Hz)}$$

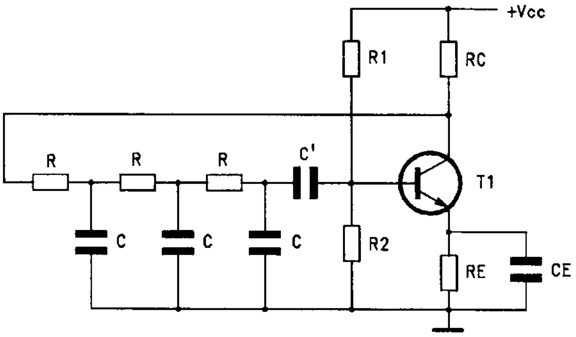


fig. B33.2

The RC oscillator is used to generate frequencies ranging from a few Hz to many hundreds of kHz. It is not so efficient for frequencies in the order of MHz, for which LC oscillators are used. To obtain variation of the oscillation frequency over a large range, the three capacitors (or the three resistors) must be varied simultaneously. In this way, the impedance of the shift network is kept constant and so consequently, is the amplitude of the oscillations. The amplifiers used for these oscillators usually operate in class A, in order to minimize signal distortion.

Wien Bridge oscillator

Wien bridge oscillators also use the principle of positive feedback. The circuit of figure B33.3 represents the basic circuit diagram of this type of oscillator. In this circuit, non inverting amplifiers are used.

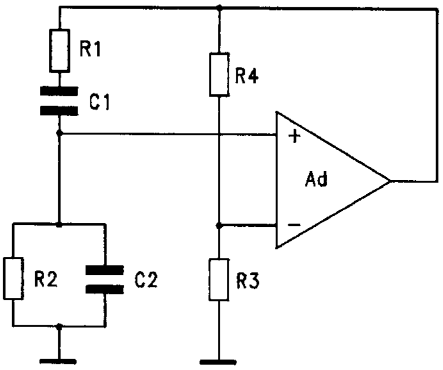


Fig. B33.3

The circuit consists of two potential dividers:

- the first is a series RC and a parallel RC network. This provides the positive feedback
- the second consists of R4 and R3 and is purely resistive. This provides negative feedback.

Generally we have R1=R2=R and C1=C2=C. In this case the circuit can oscillate if the following condition is satisfied:

$$\frac{R_3}{R_3+R_4}=\frac{1}{3}-\frac{1}{A_d}$$

From this it can be seen that the gain Ad of the amplifier cannot be less than 3. Otherwise the resistances would be negative, which is physically impossible. If as is usual, the gain of the amplifier is very high, the oscillation condition simply becomes:

$R_3/(R_3 + R_4) \approx 1/3$

And the frequency of oscillation is then simply: $f_0 = 1/(2\pi \cdot R \cdot C)$.

B33.2 EXERCISES

➲ ***MCM6***	**Disconnect all jumpers**
➲ ***SIS1***	**Turn all switches *OFF***
➲ ***SIS2***	**Insert lesson code: B33**

RC oscillator

- Insert jumpers J1, J2, J5 to produce the circuit shown in fig.B33.4.

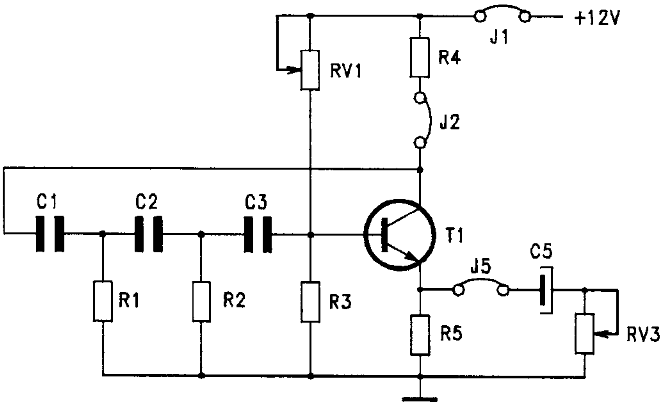


fig. B33.4

- Adjust RV3 to its half way position.
- Adjust RV1 to obtain approximately 6Vdc voltage at the collector of T1.
- Slowly adjust the resistance value of trimmer RV3 until a perfect sine wave is displayed on the oscilloscope from the collector of T1.
- Check that RV3 enables the signal distortion to be adjusted, and also that it can stop oscillations by changing the circuit amplification.

The trimmer RV3 is decoupled from the emitter resistance by means of the capacitor C5, which blocks dc. In this way, by adjusting RV3, the dynamic gain of the circuit can be adjusted, and consequently the conditions necessary for oscillation can be satisfied.

- Vary RV1 and observe that this allows the amplitude of the oscillations to be adjusted.
- Measure the frequency ***fo*** of the signal.

Q1 *What is the approximate frequency of oscillation?*

SET

A	*B*	
1	6	1 Hz
2	3	1 kHz
3	5	1 MHz
4	2	100 Hz
5	1	50 kHz
6	4	500 Hz

- Display the signals at the base and collector of T1.

Q2 *What is the phase shift, approximately, between these two signals?*

SET

A	*B*	
1	5	0°
2	6	90°
3	1	10°
4	3	180°
5	2	120°
6	4	150°

- Examine the sine wave across the resistors R1, R2, R3 and note the progressive shift in phase of the signal.

➲ *SIS1*	**Turn switch S10 *ON***
➲ *SIS2*	**Press *INS***

- if necessary, adjust RV3 to make the circuit oscillate again

Q3 *Examine the wave forms. How has the circuit changed?*

SET

A	*B*	
1	5	the transistor has been short-circuited between its base and collector
2	1	a resistor has been inserted in parallel to R3
3	2	the power supply voltage has been changed
4	3	the feedback line has been disconnected
5	4	the amplification of the circuit has been changed

➲ *SIS1*	**Turn switch S10 *OFF***

- Remove jumpers J2, J5, insert J3, J4 to produce the circuit of figure B33.5.

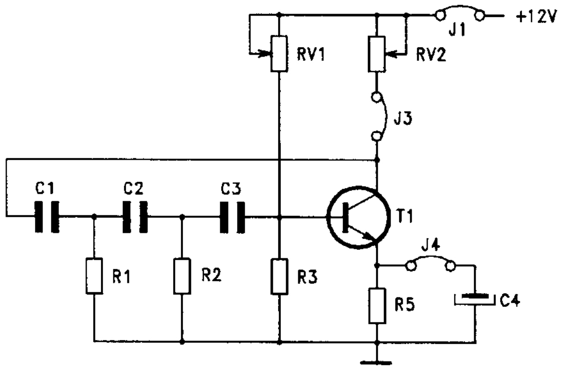


fig. B33.5

- Connect the oscilloscope to T1 collector.
- Vary RV1 and RV2 to make the circuit oscillate.
- Note the effect of RV2, the collector resistance, on the oscillator operation.

Wien bridge oscillator

- Remove all jumpers, insert J6, J9 to produce the circuit of fig.B33.6.

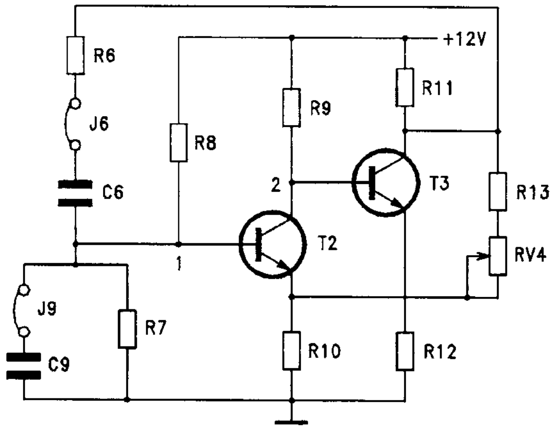


fig. B33.6

- display the signal present on the collector of T2
- adjust RV4 to obtain a sine wave, and measure its frequency
- compare the theoretical frequency with the measured frequency (R=R6=R7=10 KΩ, C=C6=C9=0.1 μF)
- change capacitors C6 and C9 for the 10 nF capacitors C8 and C11, by disconnecting jumpers J6 and J9 and connecting J8 and J11
- adjust RV4 to obtain oscillation, and measure the new frequency of oscillation
- change capacitors C8 and C11 for the 1 μF capacitors C7 and C10, by disconnecting jumpers J8 and J11 and connecting J7 and J10
- adjust RV4 and measure the new frequency of oscillation

Q4 *How is the measured frequency affected by capacitance?*

SET

A	*B*	
1	3	it is independent of the capacitance value
2	1	it decreases with capacitance value
3	2	it increases with capacitance value

- remove jumper J9

➲ ***SIS1***	**Turn switch S9 *ON***
➲ ***SIS2***	**Press *INS***

Q5 *From the measurement of the new frequency of oscillation, and in relation to the previous measurements, what is the capacitance value in the parallel circuit?*

SET

A	*B*	
1	4	1 µF
2	6	2 nF
3	1	10 µF
4	5	10 nF
5	3	100 nF
6	2	47 nF

➲ ***SIS1***	**Turn switch S9 *OFF***

- Insert J9, connect the oscilloscope channel 1 at the T2 base and channel 2 to T2 collector and than to T3 collector in turn.
- Observe the phase and amplitudes of the signals.
- From these observations, the need to use at least 2 stages to produce oscillations with BJTs can be seen.

As the stability of a Wien bridge oscillator depends on the amplification level of the circuit, it is necessary for the first common emitter stage to have a high gain. However this amplifier inverts the signal: so a second common emitter stage must be used, to obtain a further shift of 180°. It also gives some extra amplification.

B33.3 SUMMARY QUESTIONS

Q6 *To produce an oscillator with an inverting amplifier, the phase shift provided between the output and input must be:*

SET

A	*B*	
1	3	0 degrees
2	1	90 degrees
3	5	180 degrees
4	2	270 degrees
5	4	120 degrees

Q7 *To obtain a 180° shift in a RC oscillator, the minimum number of stages needed is:*

SET

A	*B*	
1	3	1
2	1	2
3	5	3
4	2	4
5	4	5

Q8 *Calculate the frequency of the RC oscillator in fig.B33.1, with R=33 Kohm, C=22 nF, Rc= 10 Kohm* :

SET

A	*B*	
1	3	fo = 513 Hz
2	2	fo = 81 Hz
3	5	fo = 89.5 Hz
4	1	fo = 51 Hz
5	6	fo = 2 kHz
6	4	fo = 8 kHz

Q9 *Calculate the frequency of the Wien bridge oscillator, with R = 33 Kohm, C=22 nF:*

SET

A	*B*	
1	6	fo = 513 Hz
2	1	fo = 1377 Hz
3	4	fo = 219 Hz
4	5	fo = 1200 Hz
5	3	fo = 100 kHz
6	2	fo = 22 MHz

LESSON B34: COLPITTS OSCILLATOR

OBJECTIVES

To understand and use a Colpitts oscillator, made with a BJT circuit:

- the dependence of the frequency on the inductance and capacitance values
- measurement of the frequency for different capacitance values
- effect of power supply voltage on the frequency of oscillation

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- oscilloscope and frequency meter

B34.1 BASIC THEORY

The Colpitts oscillator is a sine wave oscillator which uses an LC feedback circuit. Figure B34.1 shows the general principles. The circuit comprises an amplifier and a π -feedback network, consisting of one inductor and two capacitors.

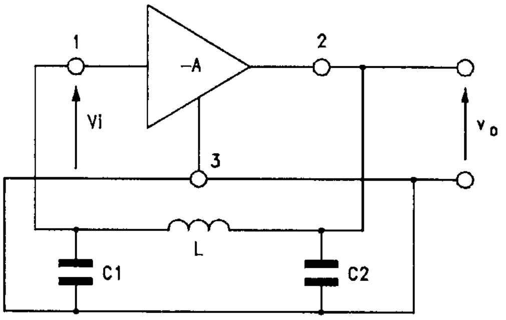


fig. B34.1

Provided that the amplifier has a high input resistance, the circuit of figure B34.1 can be represented by the equivalent circuit of figure B34.2, where A is the amplification of the system.

If the resistor Rs of the inductance L is neglected, the conditions for oscillation of the circuit are:

$$A \cdot C_1/C_2 = 1$$

$$w_0 \, . \, L - C_1 . 1/\omega_0 - C_2 . 1/\omega_0 = 0$$

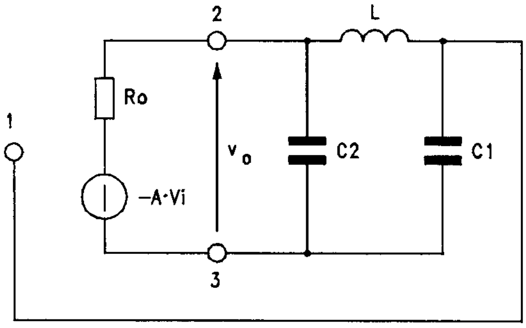


fig.B34.2

From this, the frequency of oscillation ***fo*** is:

$$f_o = \frac{1}{2\pi} \cdot \sqrt{\frac{C_1 + C_2}{L \cdot C_1 \cdot C_2}} \qquad \text{(Hz)}$$

If C1 = C2 = C, the frequency of oscillation is inversely proportional to the square root of the product LC :

$$f_o = \frac{1}{\pi\sqrt{(2 \cdot L \cdot C)}} \qquad \text{(Hz)}$$

Practical considerations

The Colpitts oscillator, as all LC oscillators, is used at high frequencies (from tens of kHz to hundreds of MHz). If the active device of the amplifier is a BJT (figure B34.3) the previous equations are not strictly true. The transistor does not, in fact, have a high input resistance and besides, can present parasitic capacitances across its terminals. These must be considered in the calculation of C1 and C2 in the circuit.

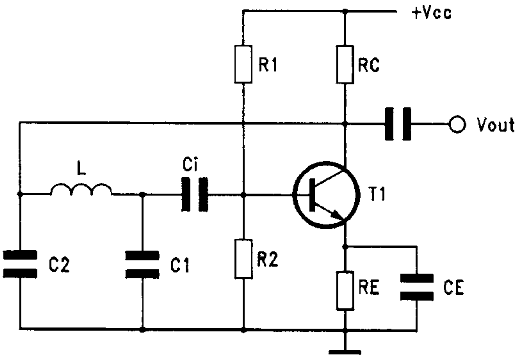


Fig. B34.3

B34.2 EXERCISES

➲ *MCM6*	**Disconnect all jumpers** **Set in OFF all S switches**
➲ *SIS1*	**Turn all switches *OFF***
➲ *SIS2*	**Insert lesson code: B34**

Frequency dependence on L and C

- Set +Vcc adjustable power supply to 12 V .
- Insert jumpers J13, J14, J16, J20, J21, J22, J24, J28 to produce the circuit of figure B34.4.

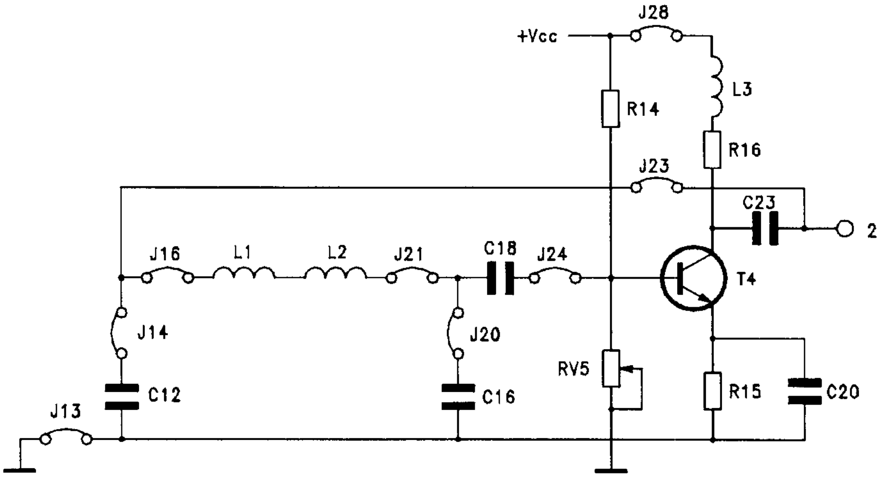


Fig. B34.4

- Display the AC output signal present at terminal 2.
- adjust RV5 to obtain a sine wave
- measure the signal frequency
- rotate the core of the coil (L1+L2) and note the variation of signal frequency
- change the last circuit, removing jumper J14 and connecting J15, so that the capacitor C12 is changed with C13.
- if necessary, adjust RV5 to obtain oscillation
- measure the new frequency of oscillation

Q1 *From measurements on the circuit, what is the result ?*

SET
A B
1 4 the frequency of oscillation of the circuit increases as capacitance of the feedback circuit increases
2 1 there is a large increase in amplitude of the output voltage as the capacitance increases
3 5 the frequency remains unchanged as capacitance is varied
4 2 the frequency of oscillation decreases as the capacitance increases
5 3 there is a large decrease in amplitude of the output voltage as the capacitance increases

Frequency of oscillation as a function of the power supply voltage

- Return the circuit to the starting conditions of figure B34.4, removing jumper J15 and connecting J14, and adjust RV5 to obtain oscillation
- vary the power supply voltage Vcc of the 20%, and measure the corresponding frequency of oscillation with the frequency meter
- check if, and how the frequency of oscillation varies as the power supply voltage varies

Q2 *From the above measurements, these changes to the power supply voltage, change the frequency by:*

SET
A B
1 2 less than the 0.01%
2 4 between the 0.01% and the 0.5%
3 1 between the 0.5% and the 5%
4 3 more than the 5%

- Set +Vcc adjustable power supply to 12 V .

➲ *SIS1*	**Turn switch S1 *ON***
➲ *SIS2*	**Press *INS***

Q3 *A very important modification has been made to the circuit: what is it?*

SET
A B
1 5 the power supply voltage has been cut off
2 1 the feedback between output and input of transistor T4 has been disconnected
3 2 there is a short-circuit between the collector and emitter of the transistor
4 3 the bias point of the circuit has been varied
5 4 the dynamic gain of the transistor has been reduced

➲ ***SIS1***	**Turn switch S1 *OFF***

➲ ***SIS1***	**Turn S11 *ON***
➲ ***SIS2***	**Press *INS***

Q4 *Why doesn't the circuit oscillate?*

SET
A B
1 5 the power supply has been disconnected
2 1 the feedback between the output and input of transistor T4 has been disconnected
3 3 the base of transistor T4 has been short-circuited to ground
4 2 there is a short-circuit between the collector and emitter of the transistor
5 4 the bias point of T4 has been changed

➲ ***SIS1***	**Turn switch S11 *OFF***

B34.3 SUMMARY QUESTIONS

Q5 *The feedback circuit of a Colpitts oscillator consists of:*

SET

A	B	
1	2	an inductance and two capacitances
2	1	a capacitance and two inductances
3	5	a resistance and two inductances
4	3	two resistances and an inductance
5	4	two capacitances and a resistance

Q6 *In a Colpitts oscillator, the following equation applies:*

SET

A	B	
1	3	$\omega o = 1/R \cdot C$
2	4	$fo = 1/\pi \cdot \sqrt{(2 \cdot L \cdot C)}$
3	1	$A = L/C1 + C2$
4	5	$A = (C1 + C2)/C1$
5	2	$A = C2/(C1 + C2)$

Q7 *Calculate the operating frequency of the Colpitts oscillator, when $L = 300\ \mu H$ and $C1 = C2 = C = 33\ pF$:*

SET

A	B	
1	6	fo = 2.6 MHz
2	1	fo = 2.26 MHz
3	5	fo = 21 kHz
4	2	fo = 32 MHz
5	4	fo = 500 Hz
6	3	fo = 226 MHz

LESSON B35: HARTLEY AND MEISSNER OSCILLATORS

OBJECTIVES

- Analysis of the frequency of oscillation as a function of the inductance and capacitance
- frequency behavior with variations of the power supply voltage

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- oscilloscope and frequency meter

B35.1 BASIC THEORY

Hartley Oscillator

The Hartley oscillator is a sine wave oscillator with an LC feedback circuit. Figure B35.1 shows the general principles.

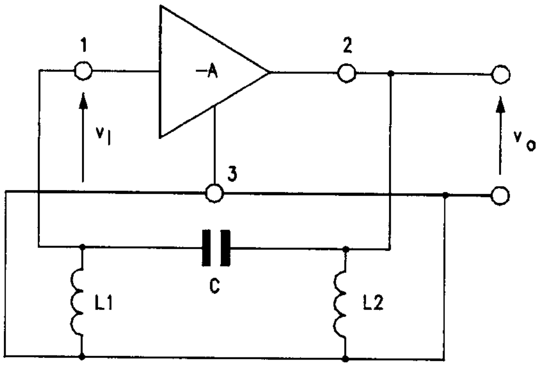


Fig. B35.1

The circuit comprises an amplifier and a π-feedback network, consisting of two inductances and a capacitance. Provided the amplifier has a high input resistance, the circuit of figure B35.1 can be represented by the equivalent circuit of figure B35.2, where A is the amplification of the system.

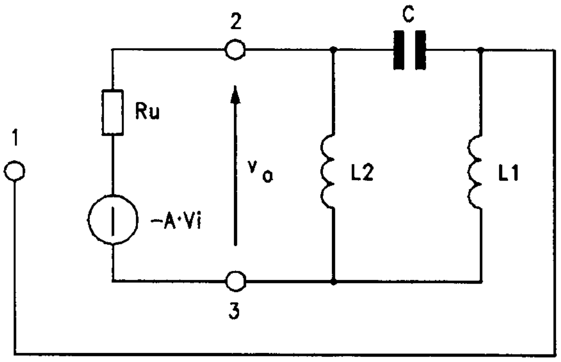


Fig. B35.2

If the two inductances have a mutual inductance M, and if their internal resistances are neglected, the conditions for oscillation are expressed by the following relationships:

$A = (L_2+M)/(L_1+M)$ $\omega_o \cdot (L_1 + L_2 + 2\cdot M) - 1/\omega_o \cdot C = 0$

From the second relation you can determine the frequency of oscillation fo:

$f_O = 1/2\pi\cdot\sqrt{(L\cdot C)}$ [Hz] where $L = L_1 + L_2 + 2\cdot M$

As in the Colpitts oscillator, the frequency of oscillation is inversely proportional to the square root of the product L·C.

If the active component of the amplifier is a BJT, a suitable circuit is the one of figure B35.3, in which the feedback is taken from the collector.

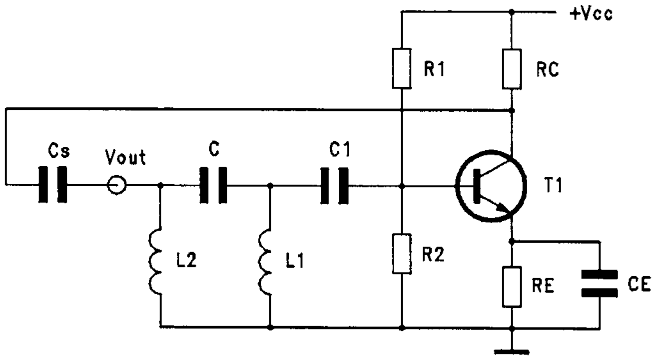
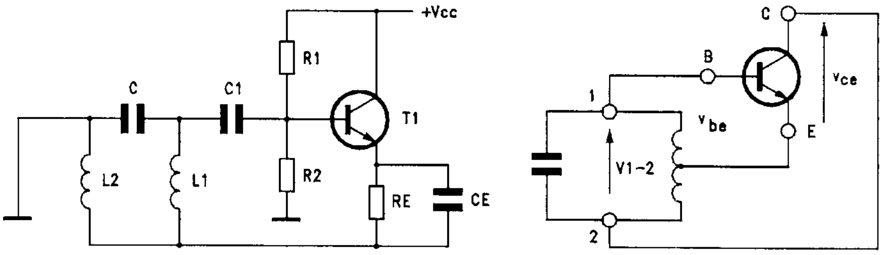


Fig. B35.3

Another possible configuration is the one of figure B35.4a, in which the feedback signal is taken from the emitter. The dynamic equivalent of the circuit is represented in figure B35.4b.



a) b)

Fig. B35.4

At switch-on, a starting perturbation creates a free oscillation in the resonant circuit, and causes a voltage $v_{12}=v_{bc}$ between points 1 and 2. Thanks to the mid-point connection in the inductor (or inductive divider), v_{cb} is divided into two voltages v_{be} and v_{ce}, which are phase shifted and so satisfy the condition for self-oscillation.

Meissner Oscillator

The Meissner oscillator uses a transformer as a feedback system, as shown in figure B35.5.

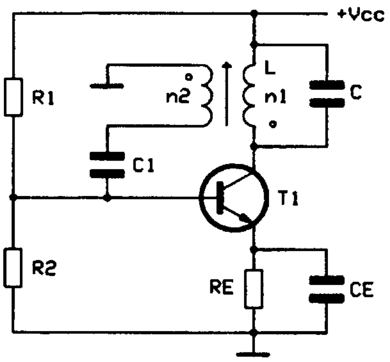


Fig. B35.5

A tuned resonant circuit, consisting of a winding of the transformer and a capacitance C is connected to the collector. Neglecting the losses of the transformer, there must be a frequency (called the resonant frequency) at which the impedance of the resonant circuit is purely resistive. In these conditions the signal between collector and ground is shifted by 180° with respect to the base input signal.

If the winding of the transformer connected to the base is opposed to the one of the collector, the transformer introduces a further shift of 180°, and takes the output signal back in phase with the input one (positive reaction).
At the resonant frequency, the phase condition required for oscillation is met. The frequency is:

$$fo = 1/(2\pi\cdot\sqrt{(L\cdot C)})\ [\text{Hz}]$$

B35.2 EXERCISES

➲ *MCM6*	**Disconnect all jumpers** **Set in OFF all S switches**
➲ *SIS1*	**Turn all switches *OFF***
➲ *SIS2*	**Insert lesson code: B35**

Due to the capacitance introduced by the measurement probes, it's better to use the 10:1 compensated probes.

Hartley Oscillator with Collector Feedback

Frequency dependence on L and C

- Set +Vcc adjustable power supply to 12 V .
- Insert jumpers J13, J16, J17, J19, J21, J23, J24, J28 to produce the circuit of fig.B35.6.

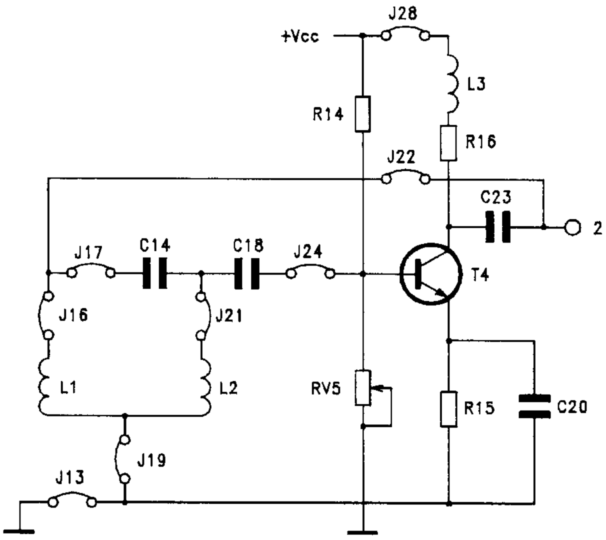


Fig. B35.6

- display the signal present at the output (terminal 2) on the oscilloscope. Adjust RV5 and the core of L1,L2 to obtain the best sine wave possible, and measure its frequency
- simultaneously display the signal present at terminal 2 and the base of the transistor T4

Q1 *What is the approximate phase shift between these two signals?*

SET

A	B	
1	5	0°
2	3	30°
3	1	270°
4	2	180°
5	4	90°

The two signals must be phase shifted to satisfy the condition necessary for the oscillation, when an inverting amplifier is used as in this case.

- rotate the core of the coil L1-L2 and observe the effect on the frequency of the generated signal
- remove jumper J17 and connect J18 so that the capacitor C14 is replaced with C15
- measure the new frequency of oscillation

As in the case of the Colpitts oscillator, a reduction of capacitance or inductance value in the feedback network causes the frequency of oscillation to increase, and vice versa.

Frequency of oscillation as function of the power supply voltage

- Using this new circuit, measure the frequencies of oscillation of the circuit when the Vcc power supply voltage is varied of the 20%
- note that this oscillator too, is only slightly sensitive to the power supply voltage variations.

Hartley Oscillator with Emitter Feedback

- Set Vcc adjustable power supply to 12 V .
- Remove jumpers J13, J22, insert J12, to produce the circuit of figure B35.7.

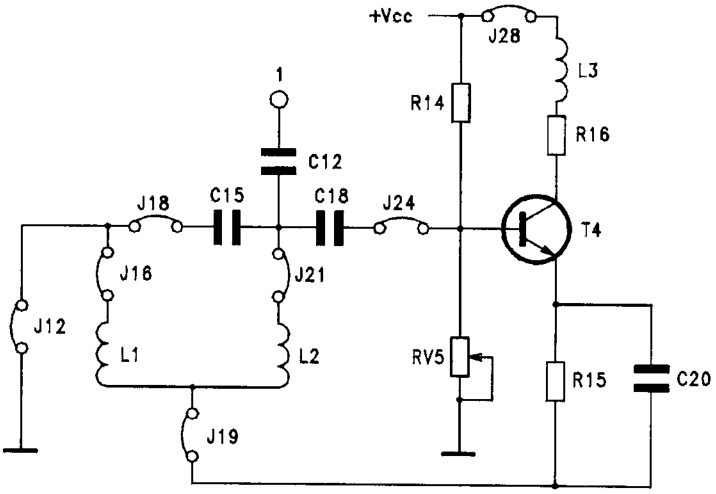


fig. B35.7

- Display the signal present at terminal 1 on the oscilloscope, adjusting RV5 to obtain the best sine wave.
- measure the frequency of the output signal
- display the signals present on the base and emitter of the transistor T4 on the oscilloscope.

Q2 *What is the approximate phase shift between the two displayed signals?*

SET

A	B	
1	1	0°
2	3	60°
3	5	90°
4	2	180°
5	4	270°

➲ ***SIS1***	**Turn switch S3 *ON***
➲ ***SIS2***	**Press *INS***

Q3 *Note that frequency have been changes: from this, what is the change of capacitance in the feedback circuit?*

SET

A	B	
1	3	the capacitance is increased. Another capacitance has been connected in parallel with C15
2	1	the capacitance is diminished. Another capacitance has been connected in series with C15
3	4	no modification has been carried out.
4	2	the capacitance is increased. Another capacitance has been put in series with C15

➲ ***SIS1***	**Turn switch S3 *OFF***

- rotate the core of the coil L1-L2, or remove J18 and insert J17, so that the capacitor C15 is replaced with C14. Note the change in frequency
- measure the oscillation frequency of the 20% variation of the power supply voltage.

Meissner Oscillator

- Set Vcc adjustable power supply to 12 V .
- Remove all jumpers, insert J13, J25, J27, J29 to produce the circuit of figure B35.8.

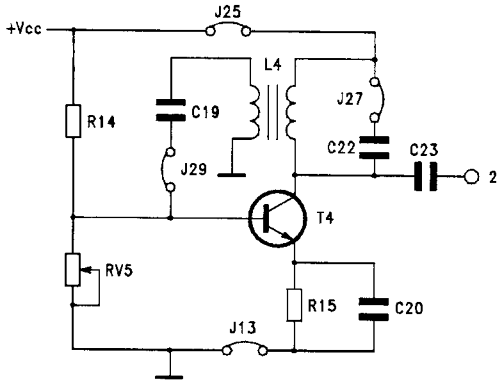


fig. B35.8

- display the output signal present at terminal 2 with the oscilloscope
- adjust RV5 to obtain a sine signal
- measure the output frequency
- display the signals present at terminal 2 and on the base of transistor T4, and examine the phase relation

As an inverting amplifier is used, in this case too, circuit oscillation is possible if the two signals are phase shifted.

- Rotate the core of L4, and note the frequency change in the output signal
- if necessary, adjust RV5 to obtain the sine waveform without distortions
- remove jumper J27 and insert J26, so that capacitor C22 is replaced with capacitor C21, and note the change in frequency

Q4 *From the frequency measurements carried out, and knowing the value of capacitances C21 and C22, it is possible to determine the value of the inductance. What is the approximate value of inductance ?*

SET

A	B	
1	3	100 H
2	1	0.1 μH
3	5	1 H
4	4	1 mH
5	6	10 mH
6	2	10 μH

- measure the change in frequency for a 20% variation of the Vcc power supply voltage.

B35.3 SUMMARY QUESTIONS

Q5 *The π-feedback circuit of a Hartley oscillator consists of:*

SET		
A	B	
1	5	and inductance and two capacitances
2	1	a capacitance and two inductances
3	2	a resistance and two inductances
4	3	two resistors and a capacitance
5	4	two capacitances and a resistance

Q6 *Neglecting the mutual inductance, the oscillation condition in a Hartley oscillator is:*

SET		
A	B	
1	3	$A = L_2/L_1$
2	1	$A = C_1/C_2$
3	4	$A = C/(L_1 + L_2)$
4	5	$A = (L_1 + L_2)/2$
5	2	$A = 2/(L_1 + L_2)$

Q7 *Neglecting the mutual inductance, calculate the operating frequency of a Hartley oscillator with $C = 300\,pF$ and $L1 = L2 = 33.3\,\mu H$:*

SET		
A	B	
1	5	fo = 0.58 MHz
2	3	fo = 567 MHz
3	2	fo = 1.12 MHz
4	1	fo = 919 kHz
5	4	fo = 1 kHz

Q8 *Neglecting the mutual inductance, calculate the angular frequency of a Meissner oscillator circuit which has a capacitance $C = 10\,pF$, $L1 = L2 = 400\mu H$:*

SET		
A	B	
1	2	$\omega o = 2.52 \cdot 10^6$ rd/s
2	3	$\omega o = 11.18 \cdot 10^6$ rd/s
3	5	$\omega o = 1.45 \cdot 10^6$ rd/s
4	1	$\omega o = 4.07 \cdot 10^6$ rd/s
5	4	$\omega o = 5 \cdot 10^6$ rd/s

LESSON B36: QUARTZ OSCILLATORS

OBJECTIVES

- Using a quartz oscillator with a BJT amplifier
- measurement of the frequency of oscillation
- frequency of oscillation as a function of the supply voltage

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- oscilloscope and frequency meter.

B36.1 BASIC THEORY

Frequency Stability of Oscillators

The frequency of oscillation of an oscillator can deviate from its normal fixed value for the following reasons:

- components aging
- change of the ambient conditions (temperature, humidity, etc.)
- unstable power supply voltage, which causes the bias point of the active device to shift, with consequent variation of the device parameters.

Crystal Oscillators

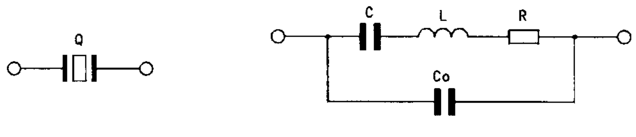
These are oscillators characterized by a high frequency stability, obtained by inserting a piezoelectric quartz crystal into the feedback network. The behavior of a quartz crystal is similar to an LC resonant circuit with a very high Q factor.

Some natural or synthetic materials, such as quartz, have piezoelectric properties. If they undergo a mechanical deformation, they generate a potential difference between their faces. The reverse situation also applies: the application of a constant voltage across the crystal will mechanically deform it. Removing this voltage, the deformation disappears, passing through a series of intermediate states, in a damped oscillation. The frequency of this oscillation depends on the geometric and mechanical characteristics of the crystal.

The excitation of the crystal with an AC voltage whose frequency equals the natural one will greatly increase the amplitude of vibration. The resonance is highly selective, occurring over a very narrow frequency range. At resonance, the mechanical and electrical energy exchange occurs with very low losses in the crystal. As a result it constitutes an electromechanical resonator of very high quality.

Quartz Crystal Equivalent Circuit

Figures B36.1a/b represent the symbol for a quartz crystal, and its equivalent electrical circuit.



a) b)

fig. B36.1

The capacitance Co is the electrostatic capacitance of the two metallic faces of the crystal, and of the parasitic capacitances due to the terminals and the container.

The series R, L, C represent the equivalent electrical circuit of the crystal itself.

Ignoring resistor R (usually a low value), the crystal consists of reactive components. The reactance behavior is illustrated in figure B36.2. From the graph, note that the impedance is zero for two values of angular frequency, called ωs and ωp, which are respectively:

$\omega_S^2 = 1 / (L \cdot C)$ $\omega_p^2 = (1/L) \cdot [(1/C) + (1/C_o)]$

$f_s = \omega_s / 2\pi$ is called "series resonant frequency", $f_p = \omega_p/2\pi$ "parallel resonant frequency". As the value of C is much lower than Co, they have almost equal values.

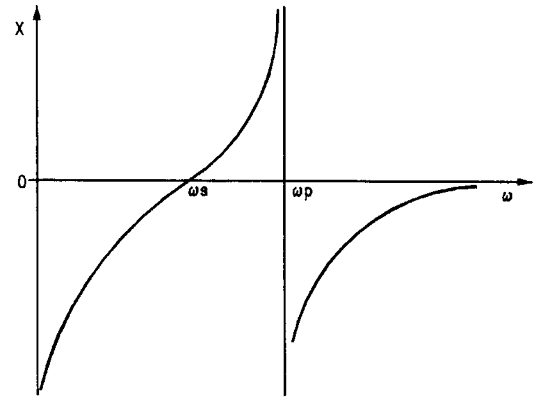


fig. B36.2

From the curve it can be seen that:

- when the operating frequency ranges between ω_s and ω_p the quartz has an inductive behavior
- outside this range, the crystal behaves as a capacitance.

Quartz Oscillator with BJT

The circuit shown in figure B36.3 is known as a Pierce oscillator.

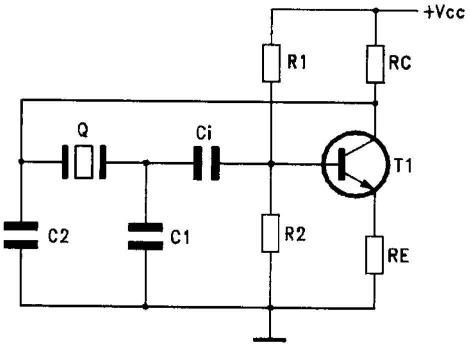


fig. B36.3

The Pierce oscillator is similar to the Colpitts one, where the inductance has been replaced with the quartz. To make the system oscillate, the quartz operation must be inductive, and so the frequency of oscillation must lie between fs and fp. The equivalent diagram of the Pierce oscillator is represented in figure B36.4.

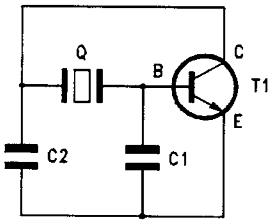


Fig. B36.4

This circuit can be modified to obtain a slight adjustment of the operating frequency of the oscillator. To do this, a variable control capacitance CC is connected in series with the quartz (figure B36.5).

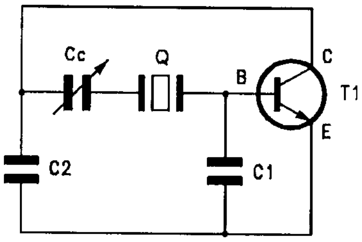


Fig. B36.5

B36.2 EXERCISES

➲ *MCM6*	**Disconnect all jumpers** **Set in OFF all S switches**
➲ *SIS1*	**Turn all switches *OFF***
➲ *SIS2*	**Insert lesson code: B36**

- Set +Vcc adjustable power supply to 12 V .
- Insert jumper Jcc, to produce the circuit of figure B36.6.

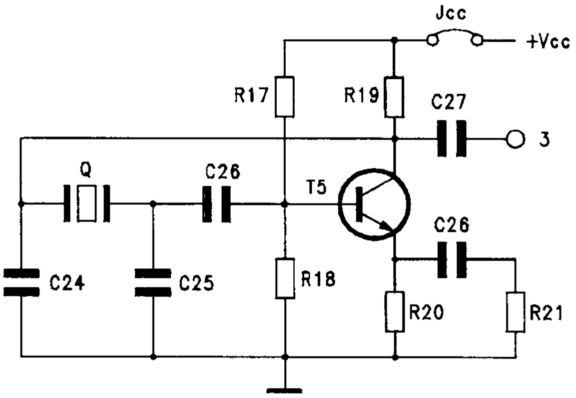


Fig. B36.6

- on the oscilloscope, display the output signal present at terminal 3. Use a 10:1 probe to limit its capacitive effect
- measure the output signal frequency
- compare the measured frequency value to the nominal one which is generally printed on the quartz crystal case

Q1 *What is the output signal frequency?*

SET

A	B	
1	3	100 kHz
2	1	10 kHz
3	5	1 kHz
4	6	20 kHz
5	4	1 MHz
6	2	10 MHz

- On the oscilloscope, display the signals present at the output of terminal 3, and also on the base of the transistor T5

Q2 *What is the approximate phase shift between the two signals?*

SET

A	B	
1	3	0°
2	1	90°
3	6	120°
4	2	180°
5	4	360°
6	5	270°

The amplifier stage used is inverting; so to obtain the oscillation condition, the signal present at the input must have been phase shifted with respect to the output signal.

Variation of the Power Supply Voltage

- In this Pierce oscillator measure the frequency when the power supply voltage is varied of the 20%.

  A special characteristic of the quartz oscillator is the high stability of the frequency of oscillation. The measured frequencies should practically coincide.

- Adjust the +Vcc variable power supply to 12V.

➲ ***SIS1***	**Turn switch S4 *ON***
➲ ***SIS2***	**Press *INS***

Q3 *From the analysis of the wave-forms and the voltages, what modification has been added to the circuit?*

SET

A	B	
1	4	the power supply voltage is halved
2	5	the connection between R17 and the transistor's base is removed
3	2	the resistor R18 is short-circuited
4	3	the base and emitter of T5 are short-circuited
5	1	the resistor R19 is short-circuited

➲ ***SIS1***	**Turn switch S4 *OFF***

B36.3 SUMMARY QUESTIONS

Q4 *What main advantage does a quartz oscillator generally provide?*

SET

A	B	
1	4	a small output resistance of the oscillator
2	1	a frequency depending on temperature
3	3	a high frequency stability
4	5	a variable frequency of oscillation on a wide range of values
5	2	the generation of a signal with many harmonics.

Q5 *The operating condition of a crystal in a Pierce circuit requires that the crystal's behaviour is mainly:*

SET

A	B	
1	3	capacitive
2	1	inductive
3	5	resistive
4	2	resistive - inductive
5	4	capacitive resistive

Q6 *What is the frequency of oscillation "f" of a Pierce oscillator which uses a quartz characterized by* $fs = 2$ *MHz and* $fp = 2.01$ *MHz ?*

SET

A	B	
1	3	$f < fs$
2	1	$f > fp$
3	2	$fs < f < fp$
4	5	$f > (fp + fs)/2$
5	4	$f < fp/4$

Q7 *What determines the frequency of oscillation of a Pierce circuit?*

SET

A	B	
1	1	the quartz crystal
2	4	the power supply voltage
3	5	the gain of the amplifier used
4	3	the output load of the device
5	2	the bias point of the transistor used

LESSON B37: ASTABLE MULTIVIBRATOR

OBJECTIVES

- Using a BJT astable multivibrator:
    - analysis of the wave-forms present in the circuit
    - measurement of the frequency and the amplitude of oscillation
    - relationship between frequency and time constant RC
    - pulse generator (calculation of the "duty cycle")

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- oscilloscope

B37.1 BASIC THEORY

The astable multivibrator is a digital oscillator, as the square wave output can take only two values. Figure B37.1 represents the basic circuit of a BJT astable.

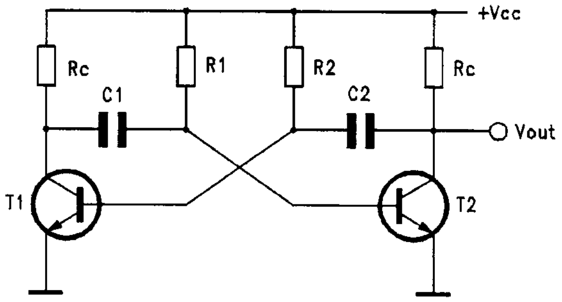


fig. B37.1

Operation

Suppose at first that T1 is off and T2 saturated. In this condition capacitor C1 has its right hand side connected to the voltage V_{BEsat}. The left side will rise to Vcc by a charging current through C1 and Rc. The capacitor C2 meanwhile, has its left side at the potential -Vcc, and the right one at V_{CEsat}. Starting from these conditions C2 begins to charge up through resistor R2, starting from the voltage -Vcc and rising towards Vcc: in this way the base voltage of the transistor T1 goes to a positive potential. This charging process is characterized by a time constant:

$$\tau_2 = C_2 \cdot R_2$$

Once the threshold voltage of T1 is reached, it switches on, going into saturation (figure B37.2). As the voltages across capacitor C1 cannot change instantaneously, the voltage on the right side, connected to the base of T2, drops to -Vcc, forcing T2 to cut off.

The switching process can continue as the roles between the transistors T1 and T2 are now reversed.

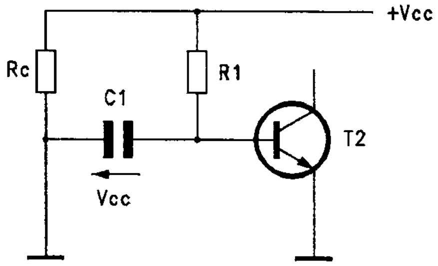


fig. B37.2

The frequency of oscillation of the circuit is:

$$f = 1 / ((\tau_1 + \tau_2) \cdot \ln 2) \qquad [Hz]$$

where $\tau_1 = C_1 . R_1$

$\tau_2 = C_2 . R_2$

$\ln 2 \approx 0.69$

If $C_1 = C_2 = C$ and $R_1 = R_2 = R$ so:

$$f = 1/(2 \cdot R \cdot C \cdot \ln 2) = 1/(1.38 \cdot R \cdot C) \qquad [Hz]$$

B37.2 EXERCISES

➲ *MCM6*	**Disconnect all jumpers**
➲ *SIS1*	**Turn all switches *OFF***
➲ *SIS2*	**Insert lesson code: B37**

- Insert jumpers J31, J33, J41, J44, J48, J53 to produce the circuit of fig.B37.3.

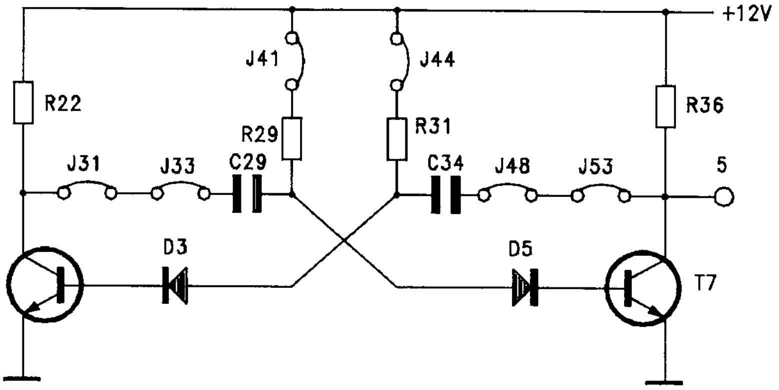


fig. B37.3

- Using the oscilloscope display the signals present at terminal 5, and at the collector of transistor T6. If the circuit does not oscillate, remove and then insert jumper J41.

Q1 *How do the displayed signals behave?*

SET

A	B	
1	4	the signal on the collector of T7 is almost a square wave, the other is triangular
2	1	the signal on the collector of T6 is almost a square wave, the other is a sine wave
3	5	both signals have a sine wave behavior
4	2	both signals are similar to a square wave, but are in phase opposition
5	3	the signals have a saw-tooth behavior

The symmetry of the circuit makes the voltages of the collectors of the two transistors equal but opposite in phase, as when the transistor T6 conducts, transistor T7 is cut off, and vice versa.

➲ *SIS1*	**Turn switch S6 *ON***
➲ *SIS2*	**Press *INS***

Q2 *By analyzing the signals, what modification has been introduced into the circuit?*

SET		
A	B	
1	4	the capacitance C29 is increased
2	5	C29 and R22 are increased
3	1	C34 is decreased
4	2	C34 is increased
5	3	R31 is decreased

➲ *SIS1*	**Turn switch S6 *OFF***

- display the voltages present at terminal 5, and at the common point between the resistor R31 and the capacitor C34
- insert jumpers J32 and J52 and note the variations of the signals

Q3 *What improvement can you notice on the output signal?*

SET		
A	B	
1	2	no significant change can be noticed
2	1	the signal has steeper rising edges
3	5	the signal has less steep rising edges
4	3	the signal has larger amplitude
5	4	the signal has a variable frequency

At the common point between R31 and C34, the signal has an exponential behavior as it is the voltage of capacitor C34 which charges to Vcc through R31. When the jumpers J32 and J52 are inserted, some resistors are placed in parallel to R22 and R36. This reduces the charging time of capacitors C34 and C29. In the meantime the transistors are cut off.

- Keep jumpers J32 and J52 inserted

➲ *SIS1*	**Turn switch S8 *ON***
➲ *SIS2*	**Press *INS***

Q4 *The rising edge has now changed. Why is this?*

SET
A B
1 3 the power supply voltage is changed
2 1 the resistor R36 is increased
3 5 the resistor R36 is disconnected
4 2 the diode D5 is short-circuited
5 4 the value of the resistor R29 is changed

➲ *SIS1*	**Turn switch S8 *OFF***

- The rise time of the output signal can be improved by creating the circuit shown in figure B37.4, removing jumpers J31 and J53.

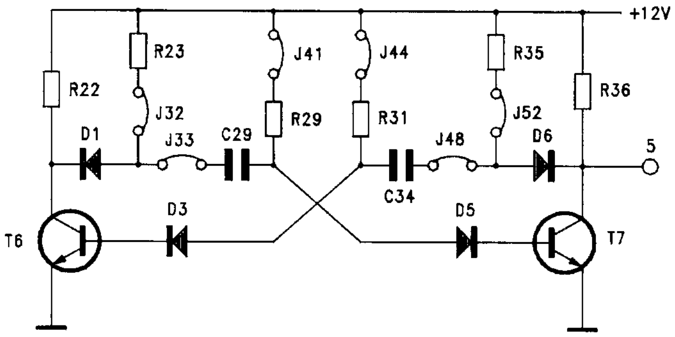


fig. B37.4

- display the signals present at terminal 5, and at the common point of R31 and C34, on the oscilloscope
- analyze the behavior of the rising edges of the displayed voltages. Compare them with those obtained in the last circuit
  When the transistor T7 is cut off, the charging of the capacitor C34, due to the presence of the diode D6, does not occur anymore through the collector resistance R36, but instead through resistor R35, letting the collector rise quickly to the voltage Vcc.
  Finally, note that when the transistor is conducting, the diode conducts too, and the collector resistance is equal to the parallel equivalent of R35 and R36
- remove jumper J41 and insert J40 so that the resistor R29 is replaced with the R28

Q5 *What change is observed on the output signal?*

SET
A B
1 6 the signal now has a saw-tooth behavior
2 5 the signal is now sinusoidal
3 1 the signal is now all negative
4 2 the signal has a triangular wave behavior
5 4 the signal is a square wave with an average value of zero
6 3 the duration of the positive pulses is reduced

- measure the duration T_{ON} of the positive pulses and the complete period $T=T_{ON} + T_{OFF}$ of the rectangular wave
- the duty-cycle of a pulse signal is defined as the percentage ratio of the duration T_{ON} of the pulse and its period T:
- Duty-cycle = $(T_{ON}/T)\cdot 100$
- calculate the duty-cycle of the generated pulse signal.

➲ *SIS1*	**Turn switch S5** ***ON***
➲ *SIS2*	**Press** ***INS***

Q6 *Why has the duty-cycle changed?*

SET
A B
1 2 the power supply voltage is changed
2 1 R28 is reduced
3 5 R28 is increased
4 3 a capacitance has been placed in parallel with R28
5 4 the emitter and collector of T6 are short-circuited

➲ *SIS1*	**Turn switch S5** ***OFF***

B37.3 SUMMARY QUESTIONS

Q7 *What type of circuit is an astable multivibrator ?*

SET

A	B	
1	3	a bistable with two stable states
2	5	a frequency divider
3	1	an oscillator
4	2	a frequency multiplier
5	4	a sine wave generator

Q8 *The output of an astable multivibrator has:*

SET

A	B	
1	3	a constant amplitude
2	4	a constant pulse duration
3	2	both a constant amplitude and a constant pulse duration
4	1	neither a constant amplitude nor a constant pulse duration

Q9 *Determine the frequency of oscillation of the astable of figure B37.1 with* $C1 = 10\ nF$, $C2 = 0.1\ \mu F$, $R1 = 100\ K\Omega$ *and* $R2 = 10\ K\Omega$

SET

A	B	
1	3	f = 361 Hz
2	6	f = 1000 Hz
3	1	f = 724 Hz
4	2	f = 100 Hz
5	4	f = 127 Hz
6	5	f = 1421 Hz

LESSON B38: MONOSTABLE MULTIVIBRATOR

OBJECTIVES

- to understand and use a BJT monostable multivibrator
- analysis of its operation with square wave input
- duration of the output pulses as a function of the frequency of the control signal
- relationship between time constant RC and duration of the output pulse

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- function generator
- oscilloscope
- multimeter

B38.1 BASIC THEORY

The monostable multivibrator produces a pulse of fixed duration, when triggered by an input pulse of very short duration. When used in this way the monostable multivibrator is also called a "pulse generator". The figure B38.1 shows the basic circuit of a transistor monostable.

The duration T of the output pulses depends on R and C and is given by:

$T = R \cdot C \cdot \ln 2 \qquad [s]$

where $\ln 2 \approx 0.69$

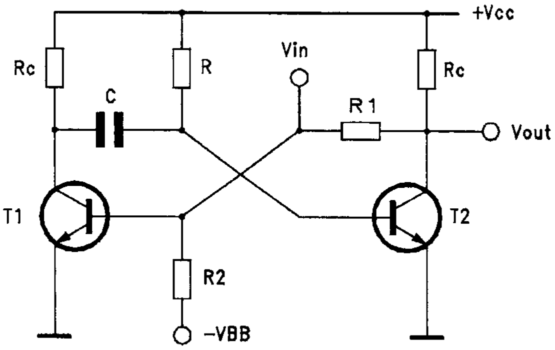


fig. B38.1

Operation

In the normal or quiescent state, T2 is kept saturated by the base current flowing through R. The collector of T2, which is connected by R1 to the base of transistor T1 is at the potential V_{CEsat} This ensures that T1 is held in the OFF state. The capacitor C is charged to the voltage Vcc.
If a sufficiently large signal is sent to the multivibrator input it will turn on T1, reversing the previous condition. T2 is now cut off, while T1 saturates. This situation is not stable however, as the right hand side of C, now at potential -Vcc, charges through R rising towards Vcc. When its voltage reaches and then exceeds V_{BE2} of the T2, then T2 will start to conduct and so return the circuit to its original stable configuration.

Control Circuit

The circuit of fig. B38.1 switches on a positive voltage edge. It is often more useful to start the multivibrator on a falling edge of the input signal, as shown in fig.B38.2. The circuit of figure B38.3 will do this.

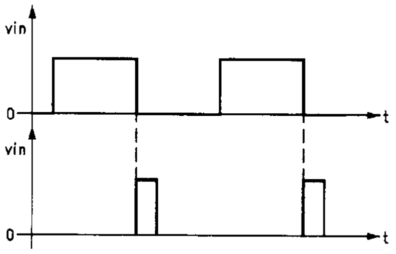


fig. B38.2

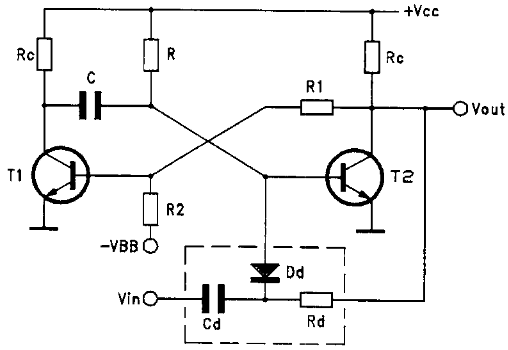


fig. B38.3

The starting circuit has some extra components Cd, Dd and Rd which form a differentiator circuit.

Suppose that in the normal or quiescent state T2 is conducting, and that a rectangular wave signal is applied to Cd. On the falling edge of the input signal, i.e. when the input value goes towards zero, this signal is differentiated and Cd transfers this variation to the cathode of diode Dd. The cathode, which initially is at an almost zero volts due to Rd connected to the collector of T2, now goes to negative values. The diode starts is now forward biased, and so it is conducting. The base of T2 goes to a lower voltage, so switching it off. If the input signal variation is positive (rising edge) there is a positive voltage on the cathode of Dd, which stays reverse biased, keeping T2 on.

B38.2 EXERCISES

➲ *MCM6*	**Disconnect all jumpers**
➲ *SIS1*	**Turn all switches *OFF***
➲ *SIS2*	**Insert lesson code: B38**

Monostable Multivibrator in the Quiescent State

- Insert jumpers J31, J34, J36, J40, J42, J43, J49, J50, J53 to produce the circuit of figure B38.4.

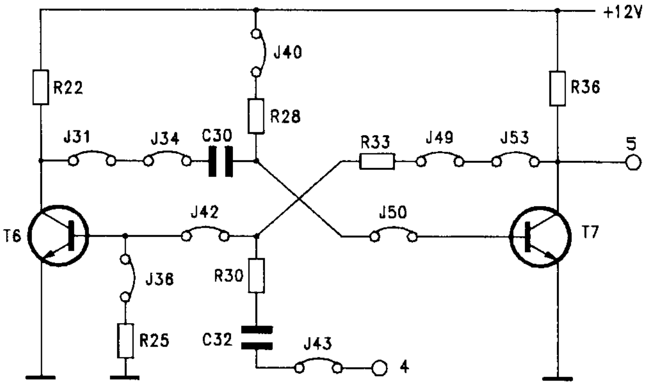


fig. B38.4

- measure the dc voltages present at the base and collector of transistor T6, and repeat for the base and collector of the transistor T7

Q1 *What is the condition of the two transistors T6 and T7?*

SET

A	B	
1	5	both transistors are off
2	4	both transistors are saturated
3	3	transistor T6 is off, T7 is saturated
4	1	transistor T6 is saturated, T7 is off
5	2	transistor T6 is off, T7 is in an intermediate state

Using the multivibrator to give a square wave output

- Connect at terminals 4 and Ground the function generator with square wave signal, 1 KHz and zero voltage amplitude initially.
- Connect the oscilloscope channel 1 at terminal 4 (input signal supplied by the generator) and channel 2 at terminal 5 (output signal of the multivibrator).
- Slowly increase the input signal amplitude until the display shows a rectangular wave at the output.
- change channel 1 of the oscilloscope so that the signal on the base of T6 is displayed. You should obtain voltages similar to those shown in figure B38.5.
-

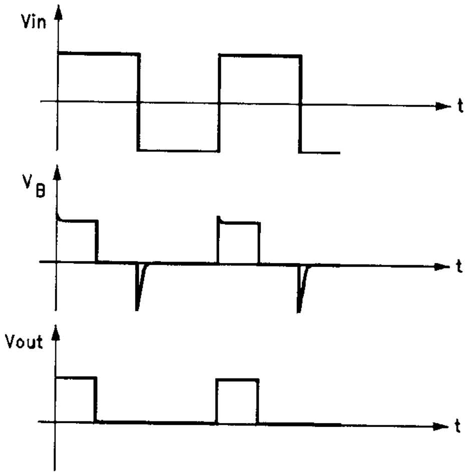


Fig. B38.5

Capacitor C32 allows pulses to be sent to the base of T6 on the rising and falling edges of the square wave from the generator. Resistor R30 limits their amplitude. The positive pulses make T6 switch on and start the pulse seen at the output. The negative pulses negatively bias the base of T6, which keep it off.

Frequency of the Synchronization Pulses

- From last circuit, measure the output pulse duration.
- vary the input signal frequency in the range 500 Hz - 2 kHz. note whether the duration of the output pulse changes
- increase the input signal frequency to about 3 KHz, and note the behavior of the output signal

Q2 *How do the output pulses change as the input frequency is varied?*

SET
A B
1 2 the amplitude and duration of the output pulses remain the same
2 1 the pulses vary in amplitude, but not in frequency
3 5 the output frequency drops as the input frequency rises
4 3 the output signal has very sharp pulses when the input passes through zero
5 4 the output signal starts to look like a sine wave

- increase the input signal frequency again and note that for an operating frequency above approximately 3 KHz, the output pulses are no longer synchronized to the input ones
- measure the maximum frequency of the control pulses before this loss of synchronization occurs

Output Pulse Duration

- Now, set the input square wave signal with 10 KHz, and measure the output pulse duration
- Insert jumper J33, so to increase the capacitance connected; measure the output pulse duration
- Remove jumper J40 and insert J41, so that the inserted resistor increases; evaluate again the output pulse duration

Q3 *How is the duration of the output pulse affected?*

SET
A B
1 5 when the resistance increases the pulse duration decreases
2 4 when the capacitance increases the duration decreases
3 2 the duration is not changed by increasing either the capacitance or resistance
4 1 the duration is increased by increasing either the capacitance or the resistor
5 3 either of these changes reduces the output signal to zero

- replace R29 with R28 by removing J41 and connecting J40

➲ ***SIS1***	**Turn switch S5 *ON***
➲ ***SIS2***	**Press *INS***

Q4 *How has this modified the circuit?*

SET
A B
1 2 the power supply voltage has changed
2 5 the base current of T6 has changed
3 4 the capacitance has been increased
4 1 R28 is increased
5 3 R28 is decreased

➲ ***SIS1***	**Turn switch S5 *OFF***

Synchronization on the Falling Edge of the Input Signal

- From last circuit insert jumper J46 to produce the circuit of figure B38.6.

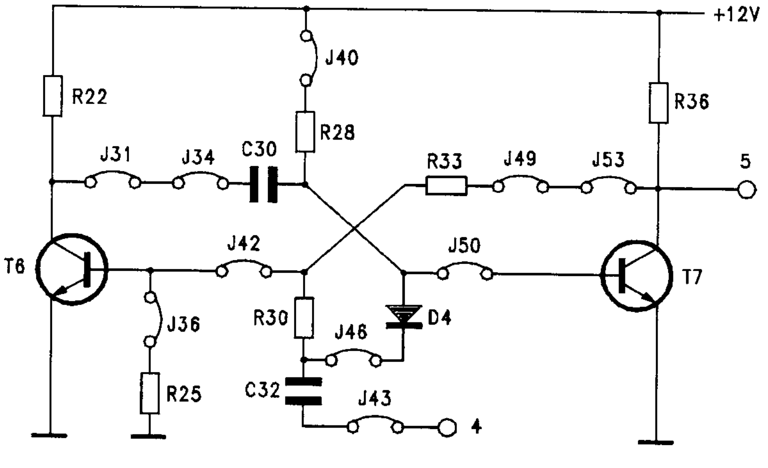


fig. B38.6

- Adjust the input square wave signal with 1KHz and about 5 Vpp.
- Display the input and the output signal on the oscilloscope. Check to see if the output is synchronized to the rising edge or the falling edge of the input signal

B38.3 SUMMARY QUESTIONS

Q5 *An astable multivibrator can generate:*

SET		
A	B	
1	2	a sine wave
2	1	a pulse
3	5	a triangular pulse
4	3	a square wave
5	4	a saw-tooth wave

Q6 *The output pulse duration of a monostable is:*

SET		
A	B	
1	2	dependent on the input signal frequency
2	5	fixed, and depends only on the time constant RC
3	4	independent of the time constant RC of the monostable
4	1	dependent on the power supply voltage
5	3	dependent on the gain of the active device

Q7 *In its quiescent state, the output voltage of a monostable is:*

SET		
A	B	
1	2	zero
2	5	a maximum
3	1	variable
4	3	similar to a sine wave
5	4	exponential in shape

Q8 *Determine the value of the capacitance C required to obtain a pulse of 2 milliseconds from a monostable using a resistor R of 270 KΩ:*

SET		
A	B	
1	5	$C = 100$ nF
2	3	$C = 5.4$ μF
3	4	$C = 54$ nF
4	2	$C = 100$ μF
5	1	$C = 10$ nF

LESSON B39: BISTABLE MULTIVIBRATOR

OBJECTIVES

- To understand and use a BJT bistable multivibrator
- Quiescent state operation
- Dynamic operation with square wave input

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- function generator
- oscilloscope
- multimeter

B39.1 BASIC THEORY

The bistable multivibrator is so called because it has two stable operating states. The circuit can pass from one state to the other if correctly triggered at the input. This means that a bistable multivibrator can be used as a memory circuit: it can switch under the control of a small pulse sent to one of its inputs, and then keep in that state until a new pulse is sent Figure B39.1 represents the basic diagram of a transistor bistable.

The bistable multivibrator is also called a "flip-flop".

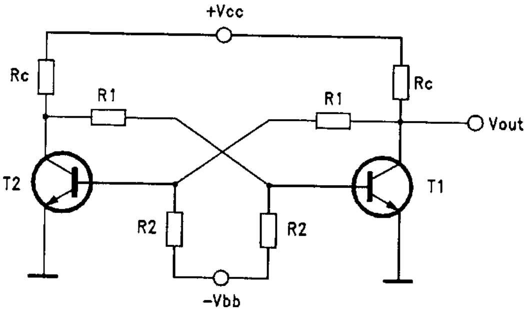


Fig. B39.1

Operation

The circuit of figure B39.1 is designed so that when T1 conducts T2 is switched off, and vice versa. When T2 conducts, its collector is almost at zero potential, which keeps the transistor T1 off, as the collector of T2 is connected to the base of T1 through R1.

If at the base of T1 you apply a signal sufficient to make T1 conducting, the situation is reversed: the transistor T2 is cut off, as its base is connected to the collector of T1. T1 will now remain conducting, as the collector of T2 is at the voltage Vcc. If the control signal disappears, it does not change the new, stable state of the flip-flop.

Control Circuit and Propagation Times

The circuit of figure B39.2 is an example of a symmetrical control circuit. A control is called symmetrical when the switching occurs at every pulse, irrespective of the state of the bistable.

With diodes D1 and D2, a negative pulse acts only on the transistor which is conducting, causing it to cut off and the bistable to switch.

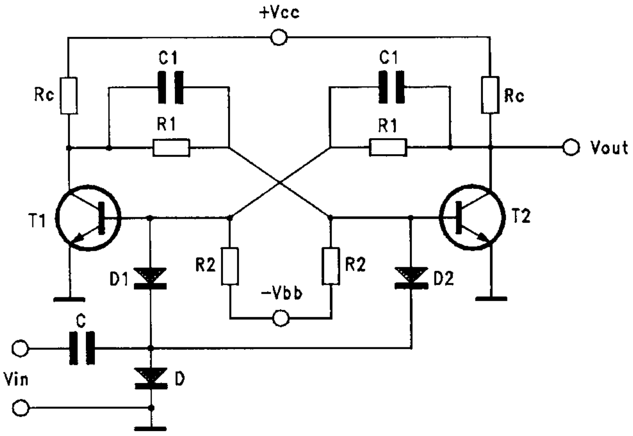


Fig. B39.2

The propagation time is the time lapse between the application of the input pulse and the output switching. This time can be reduced by inserting two small capacitors C1, in parallel with the bias resistors R1.

Suppose that T2 is "ON" and a pulse is applied to the input, to change the state of the device. The transistor T2 is cut off and its collector voltage rises rapidly towards Vcc. This voltage is transmitted to the base of T1 by means of the capacitance C1, which short-circuits the resistor R1, driving more current into the base of T1.

These switching capacitors are called "speed-up" capacitors. The value of the speed-up capacitors used depends on the input capacitance of the transistor and the resistors R1 and R2.

B39.2 EXERCISES

➲ ***MCM6***	**Disconnect all jumpers**
➲ ***SIS1***	**Turn all switches *OFF***
➲ ***SIS2***	**Insert lesson code: B39**

Circuit conditions in a stable state

- Insert jumpers J31, J32, J35, J37, J42, J45, J49, J50, J52, J53 to produce the circuit of figure B39.3.

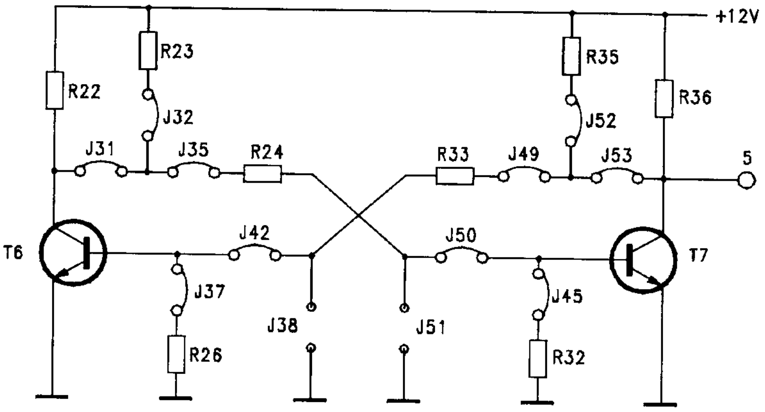


fig. B39.3

- measure the voltages on the bases and the collectors of the transistors T6 and T7, and determine which transistor is on and which is off
- connect the oscilloscope to display the output voltage at terminal 5
- using jumper J38 or J51, short circuit the base of the conducting (ON) transistor temporarily to ground, and describe the changes in output voltages

The act of connecting the base of the conducting transistor to ground turns it off and makes the bistable switch. Removing the short circuit has no further effect.

- Using jumpers J38 or J51, short circuit to ground alternately the base of the conducting transistor and check the two-stage operation of the bistable multivibrator.

Frequency Divider

- From last circuit insert jumpers J30, J39, J47, J54 to produce the circuit of figure B39.4.

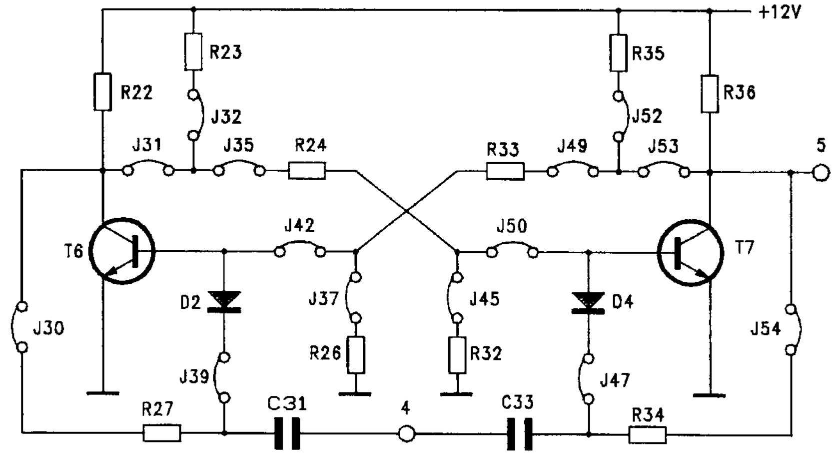


Fig. B39.4

- Connect at terminals 4 and ground the function generator with a square wave, 1 KHz and 6 Vpp.
- display the input and output signals on the oscilloscope, and describe their behavior
- measure the frequency and amplitude of the output signal

Q1 *What are the values measured?*

SET

A	B	
1	5	the voltage and frequency are zero
2	1	the voltage is about 10 V and the frequency is double the input frequency
3	2	the voltage is half the input one and the frequency is equal to the input frequency
4	3	the voltage is double the input one and the frequency is equal to the input frequency
5	4	the maximum voltage is about 10V and the frequency is half the input frequency

The bistable switches on the negative voltage edges only; this means that the flip-flop can be used as frequency divider.

Maximum Switching Frequency

- Increase the input frequency, until the bistable circuit does not operate properly anymore. This can be observed from the waveform of the output signal, when its frequency is not related to the input one anymore
- measure the maximum frequency at which the circuit still operates properly
- insert jumpers J33 and J48, so that the two capacitors C29 and C34 are put in parallel with resistors R24 and R33
- measure the new maximum frequency at which the circuit operates properly

Q2 *From these measurements which one of the following applies?*

SET

A	B	
1	3	the additional capacitances reduce the presence of spurious pulses in the output signal
2	5	the capacitances reduce the heat dissipated by the transistors
3	2	the capacitances reduce the switching times of the transistors, and increase the useful frequency range of the circuit
4	1	the capacitances filter out intermittent pulses introduced by the power supply
5	4	the capacitances do not produce any sigificant advantage

B39.3 SUMMARY QUESTIONS

Q3 *A bistable multivibrator can switch when triggered by:*

SET

A	B	
1	5	pulses
2	3	fast voltage changes
3	4	square wave signals
4	2	large variations of power supply voltage
5	1	all of the above

Q4 *In a stable state, the output of a bistable*:

SET

A	B	
1	3	is always low
2	1	is always high
3	2	can be high or low
4	5	has a sine wave behavior
5	4	has a pulsing behavior

Q5 *In a flip-flop configuration the bistable can be used as a:*

SET

A	B	
1	4	pulse generator
2	5	sine signal generator
3	2	frequency divider
4	1	frequency multiplier
5	3	voltage doubler

Q6 *The switching frequency of a flip-flop can be increased by using:*

SET

A	B	
1	5	a frequency divider input signal
2	1	"speed-up" capacitors
3	3	a coupling inductance
4	2	a reduction of the power supply voltage
5	4	a resistor between collector and emitter of the transistors

LESSON B40: SCHMITT TRIGGER

OBJECTIVES

- to understand and use a BJT Schmitt trigger:
  - measurement of the two stable output voltages
  - calculation of the lower and upper switching thresholds
  - circuit response to triangular waves
  - switching speed (use of the speed-up capacitor)

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV, module holder structure mod.MU/EV), Individual control unit mod. SIS1/SIS2/SIS3
- experiment module mod.MCM6/EV
- function generator
- oscilloscope
- multimeter

B40.1 BASIC THEORY

The Schmitt trigger is a comparator circuit with hysteresis. Figure B40.1 shows how V_{OUT} changes with V_{IN} for a Schmitt trigger.

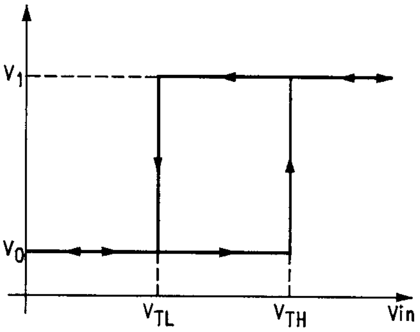


fig. B40.1

The output has only two values, V_0 and V_1. When the output level is low ($V_{OUT} = V_0$), the input voltage must get to the higher threshold level V_{TH} before the circuit will switch. The output voltage then jumps to its high value (V_1). Because the circuit has hysteresis, the input voltage must drop to the lower threshold voltage value V_{TL} in order to make the output switch back to its lower level.

A typical circuit of a Schmitt trigger is shown in figure B40.2.

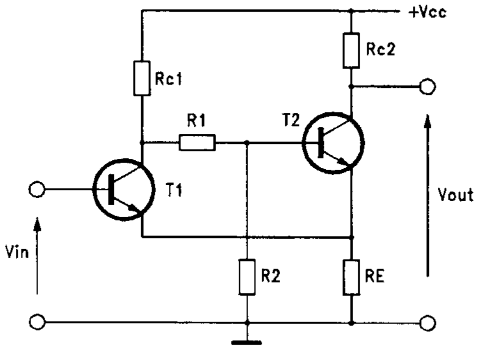


fig. B40.2

Description of Operation

Suppose that transistor T1 is off initially; the base of T2 is biased via R_{C1}, R1 and R2 which takes the transistor T2 to saturation. The output voltage Vout is then ($V_{CEsat} + R_E{\cdot}I_{C2sat}$), which represents the lower output level of the Schmitt trigger.

The transistor T1 will stay cut off, even when the voltage V_{IN} reaches the emitter voltage of V_{BE}. A higher value is needed, which is the upper threshold value given by $V_{TH}=V_{BE}+R_E{\cdot}I_{C2sat}$. When T1 does finally switch on, its collector voltage suddenly drops cutting the transistor T2 off, and at the same time this reduces the current through R_E. Because of the lower voltage across R_E, the voltage V_{BE} of T1 increases, and makes it conduct even more. The new output voltage V_1 is then stable at its high level and is equal to Vcc.

Transistor 2 stays off until Vin falls to less than V_{TL}, the lower threshold voltage. As V_{IN} falls, the collector of T1 and bias voltage of T2 increase. At the same time the voltage across R_E falls. Finally, when T2 starts conducting the voltage across R_E will increase and quickly turn off T1. The system is then back to its starting conditions, i.e. with T1 off and T2 saturated, and with low output voltage V_0.

Schmitt trigger Parameters

The Schmitt trigger characteristics are, to a good approximation :

$V_1 = V_{CC}$

If T_2 is saturated ($V_{CEsat} << V_{CC}$)

$V_0 = V_{CC} - (R_{C2} \cdot V_{CC})/(R_{C2} + R_E)$

If $(R_{C1} + R_1) \cdot R_2/(R_{C1} + R_1 + R_2) << (R_E \cdot h_{FE})$:

$$V_{TH} = R_2 \cdot V_{CC}/(R_{C1} + R_1 + R_2)$$

If $V_{BEO2} << R_2 \cdot V_{CC} / (R_{C1} + R_1 + R_2)$ and neglecting V_{BEO1}:

$$V_{TL} = \frac{R_2 \cdot R_E \cdot V_{CC}}{(R_2 \cdot R_{C1}) + (R_E \cdot (R_{C1} + R_1 + R_2))}$$

B40.2 EXERCISES

➲ ***MCM6***	**Disconnect all jumpers**
➲ ***SIS1***	**Turn all switches *OFF***
➲ ***SIS2***	**Insert lesson code: B40**

Output voltages

- Insert jumper J57 to produce the circuit of figure B40.3.

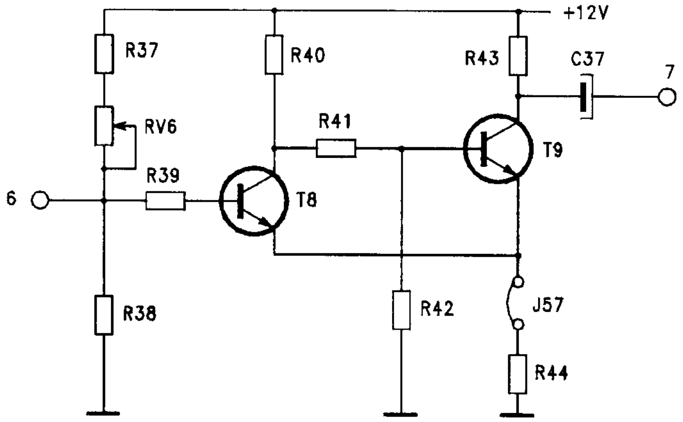


fig.B40.3

- connect the oscilloscope between terminals 6 and ground and adjust this voltage to a minimum using trimmer RV6
- connect the oscilloscope to the collector of T9, and measure the output voltage
- vary the input voltage at terminal 6 with RV6, and observe the behavior of the output voltage

Q1 *What is the result?*

SET

A B	
1 4	as the input voltage increases the output voltage increases linearly
2 5	as the input voltage increases the output voltage goes to zero
3 1	the output voltage can have only two fixed values
4 2	the output voltage has a sine behavior
5 3	the output voltage has a triangular behavior

- measure the two output voltage values, V_0 and V_1 and check that these values correspond to the values calculated from the formulae given in the theoretical section

  A low value should be found for V_0, and a value close to Vcc for V_1.

- Remove J57 and insert J58, so that R45 replaces R44. Measure V_0 and check that it is proportional to the resistance of emitter resistor, R_E

Q2 *What is the new value of V_0, approximately?*

SET

A B	
1 6	1 V
2 3	1.5 V
3 4	.5 V
4 1	9.5 V
5 2	5 V
6 5	12 V

Threshold Voltages V_{TH} and V_{TL}

- Adjust RV6 and measure the two input voltages at which the circuit triggers, by connecting the oscilloscope to the input terminal 6 and to the collector of T9
- Use your results to complete the following table:

	$R_E = 560\ \Omega$	$R_E = 100\Omega$	$R_E = 0\Omega$
V_{TL}			
V_{TH}			
ΔV_T			

- Remove jumper J58 and insert J57 to connect R44 resistor in circuit.
- repeat the last measurement and enter the data into the second column of the table
- Remove J57 and insert J59 to connect the emitters to ground.
- repeat the last measurement and enter results into the last column
- complete the table by calculating the hysteresis of the circuit: $\Delta V_T = V_{TH} - V_{TL}$, and note how the hysteresis varies as function of the values of the resistor R_E. The hysteresis increases as RE increases, so when RE = 0Ω the threshold voltages are almost the same.

Circuit Response to Triangular and Sine Waves

- Remove jumper J59, insert J55, J58 to produce the circuit of fig.B40.4.

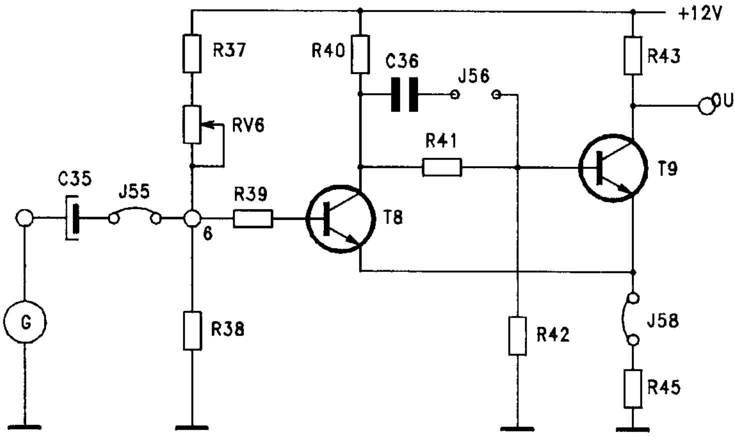


Fig. B40.4

- Connect the function generator at the circuit input terminals with triangular wave, 1 KHz and 5 Vpp.
- Connect the oscilloscope channel 1 at terminal 6 (input signal) and channel 2 at terminal 7 (trigger output signal).
- vary RV6 and describe the output voltage behavior as function of input voltage present on the base of T8. (This consists of a dc component plus the generator signal)
- check that the trigger switches when the voltages V_{TL} and V_{TH} take the same values as previously measured

➲ *SIS1*	**Turn switch S12 *ON***
➲ *SIS2*	**Press *INS***

Q3 *What modification has now changed the circuit operation?*

SET

A	B	
1	5	the resistor R37 is short-circuited
2	1	the transistor T8 is off
3	4	the power supply voltage is absent
4	3	the emitter resistance of the transistors is zero
5	2	the bias of the base of T9 is altered

➲ *SIS1*	**Turn switch S12 *OFF***

Switching Speed

- Keep the last circuit configuration.
- Using trimmer RV6 , adjust the dc bias voltage at terminal 6 to 4 V
- Set a triangular input signal and 4Vpp amplitude.
- Increase the input signal frequency until you reach a maximum value above which the circuit does not switch
- measure this maximum value fmax
- Insert jumper J56 so that the 470pF capacitor C36 is connected in parallel to R41.

Q4 *What is the effect of connecting C36?*

SET

A	B	
1	4	a noticeable increase of the output signal amplitude
2	6	the current collector of T9 decreases
3	5	the circuit input resistance increases
4	3	the maximum operating frequency increases
5	2	the transistor dissipation T9 decreases
6	1	to provide positive feedback and improve stability of the circuit

B40.3 SUMMARY QUESTIONS

Q5 *A Schmitt trigger can be classified as:*

SET

A	B	
1	2	a bistable
2	1	a frequency divider
3	5	an oscillator
4	3	a voltage stabilizer
5	4	a frequency multiplier

Q6 *The Schmitt trigger exhibits:*

SET

A	B	
1	5	a maximum frequency independent of the "speed-up" capacitor
2	3	a maximum output level as function of the emitter resistance
3	1	a hysteresis between the switching levels
4	2	a very low output resistance
5	4	a low voltage gain

Q7 *In a Schmitt trigger with 2 transistors, the hysteresis is proportional to:*

SET

A	B	
1	2	the emitter resistance common to the two transistors
2	1	the collector resistance RC2 of the second stage
3	5	the gain of the second transistor
4	3	the input signal frequency
5	4	the input signal amplitude

Q8 *The Schmitt trigger is used:*

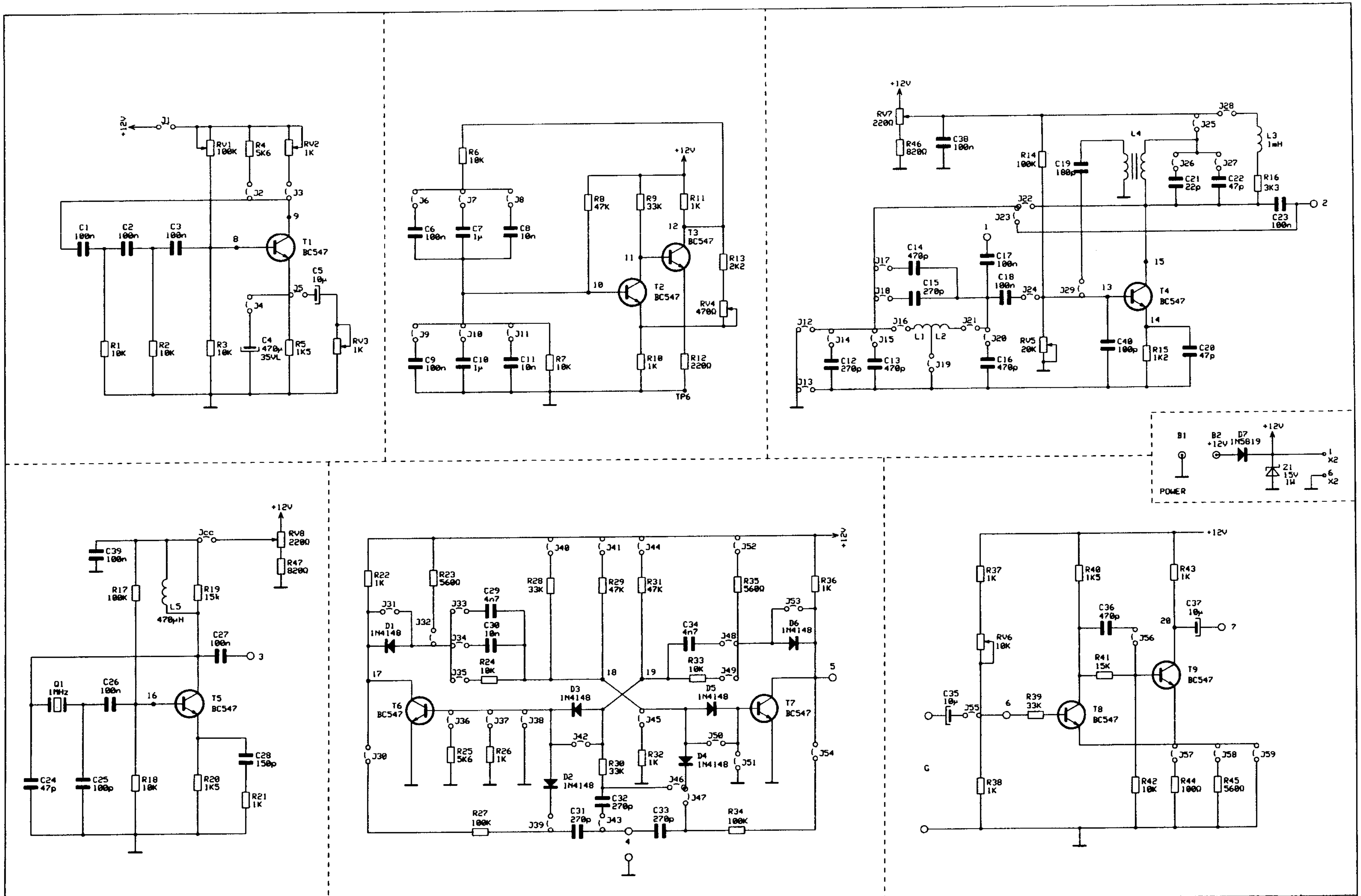
SET

A	B	
1	5	to amplify an analog signal
2	3	to reduce the noise in a signal
3	2	as a comparator with hysteresis
4	1	to match the impedance in a circuit
5	4	as low frequency oscillator

Q9 *The amplitude of the output signal of the Schmitt trigger used depends on:*

SET

A	B	
1	5	the resistance of common emitter resistor R_E
2	3	the voltage V_{CE} of T2
3	4	the collector resistance R_{C2} of T2
4	1	all of the above three parameters
5	2	none of these three parameters.



ELETTRONICA VENETA MOTTA DI LIVENZA - TV ITALY	DESCRIPTION : ELECTRONIC CIRCUITS AND DEVICES IV	REPLACES: MC0611	DWG Nº: MC062D01.FSH	DRAWN :
	EQUIPMENT : MODULE MCM6/EV	REPLACED BY: --	P.C.B.: MC0621	CHECKED :
	T.C. FILE : -- SCALE : --	REVISION: 0	SHEET : 1 OF 1	DATE : 03-10-05

APPENDIX “A” : DATA SHEETS

diode	1N4148
transistor NPN	BC337
transistor NPN	BC182

TYPES 1N4148, 1N4149, 1N4446, 1N4447, 1N4448, 1N4449
PLANAR SILICON SWITCHING DIODES

TYPES 1N4148, 1N4149, 1N4446, 1N4447, 1N4448, 1N4449
BULLETIN NO. SL-S 892269, OCTOBER 1966
REVISED AUGUST 1969

- **Small-Size, Whiskerless, Double-Plug Construction**
- **Extremely Stable and Reliable High-Speed Diodes**

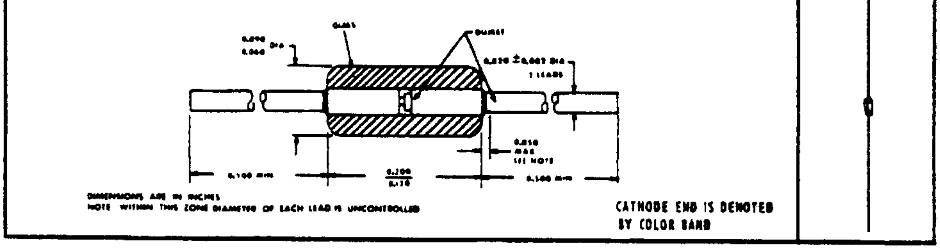
Electrical Equivalents

1N4148 • 1N914
1N4149 • 1N916
1N4446 • 1N914A
1N4447 • 1N916A
1N4448 • 1N914B
1N4449 • 1N916B

mechanical data

The glass-passivated silicon wafer is encased in a hermetically sealed glass package.

*ALL JEDEC DO-35 DIMENSIONS AND NOTES ARE APPLICABLE



DIMENSIONS ARE IN INCHES
NOTE: WITHIN THIS ZONE DIAMETER OF EACH LEAD IS UNCONTROLLED

CATHODE END IS DENOTED BY COLOR BAND

*absolute maximum ratings at 25°C free-air temperature (unless otherwise noted)

$V_{RM(wkg)}$	Working Peak Reverse Voltage	75 V
P	Continuous Power Dissipation at (or below) 25°C Free-Air Temperature (See Note 1)	500 mW
T_{stg}	Storage Temperature Range	−65°C to 200°C
T_L	Lead Temperature 1/16 Inch from Case for 10 Seconds	300°C

*electrical characteristics at 25°C free-air temperature (unless otherwise noted)

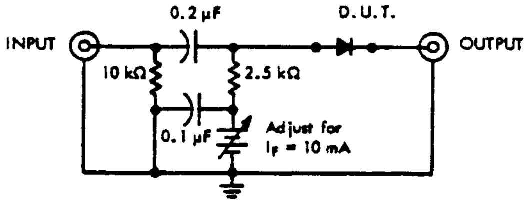
PARAMETER	TEST CONDITIONS	1N4148		1N4149		1N4446		1N4447		1N4448		1N4449		UNIT
		MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
$V_{(BR)}$ Reverse Breakdown Voltage	$I_R = 5\ \mu A$	75		75		75		75		75		75		V
	$I_R = 100\ \mu A$	100		100		100		100		100		100		V
I_R Static Reverse Current	$V_R = 20$ V		25		25		25		25		25		25	nA
	$V_R = 20\ V, T_A = 100°C$										3		3	µA
	$V_R = 20\ V, T_A = 150°C$		50		50		50		50		50		50	µA
V_F Static Forward Voltage	$I_F = 5$ mA									0.62	0.72	0.63	0.73	V
	$I_F = 10$ mA		1		1									V
	$I_F = 20$ mA						1		1					V
	$I_F = 30$ mA												1	V
	$I_F = 100$ mA										1			V
C_T Total Capacitance	$V_R = 0,\ f = 1$ MHz		4		2		4		2		4		2	pF

NOTE 1: Derate linearly to 200°C at the rate of 2.85 mW/°C.
†Trademark of Texas Instruments
*Indicates JEDEC registered data

*switching characteristics at 25°C free-air temperature

PARAMETER		TEST CONDITIONS	1N4148		1N4149		1N4446		1N4447		1N4448		1N4449		UNIT
			MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
t_{rr}	Reverse Recovery Time	$I_F = 10$ mA, $V_R = 6$ V, $i_{rr} = 1$ mA, $R_L = 100\ \Omega$, See Figure 1		4		4		4		4		4		4	ns
$V_{FM(rec)}$	Forward Recovery Voltage	$I_F = 50$ mA, $R_L = 50\ \Omega$, See Figure 2										2.5		2.5	V

*PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT

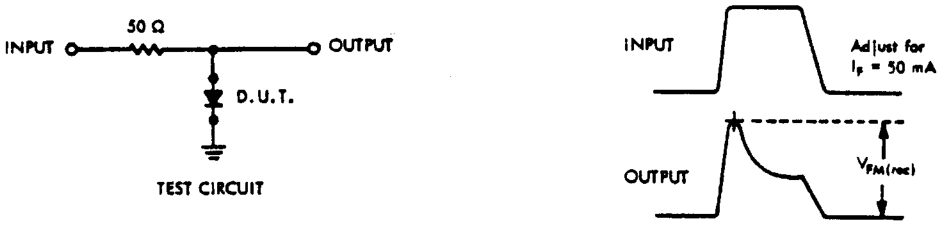
INPUT VOLTAGE WAVEFORM

OUTPUT CURRENT WAVEFORM

FIGURE 1 — REVERSE RECOVERY TIME

NOTES: a. The input pulse is supplied by a generator with the following characteristics: $Z_{out} = 50\ \Omega$, $t_r \leq 0.5$ ns, $t_p = 100$ ns.

b. The output waveform is monitored on an oscilloscope with the following characteristics: $t_r \leq 0.6$ ns, $Z_{in} = 50\ \Omega$.



TEST CIRCUIT

VOLTAGE WAVEFORMS

FIGURE 2 — FORWARD RECOVERY VOLTAGE

NOTES: c. The input pulse is supplied by a generator with the following characteristics: $Z_{out} = 50\ \Omega$, $t_r \leq 30$ ns, $t_p = 100$ ns, PRR = 5 to 100 kHz.

d. The output waveform is monitored on an oscilloscope with the following characteristics: $t_r \leq 15$ ns, $R_{in} \geq 1$ MΩ, $C_{in} \leq 5$ pF.

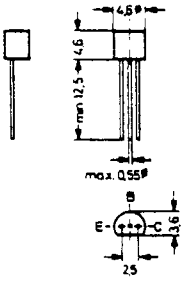
*Indicates JEDEC registered data

BC337, BC338

NPN Silicon Epitaxial Planar Transistors
for switching and amplifier applications. Especially suitable for AF-driver stages and low power output stages.

These types are also available subdivided into three groups -16, -25 and -40, according to their DC current gain. As complementary types the PNP transistors BC327 and BC328 are recommended.

On special request these transistors are also manufactured in the pinconfiguration TO-18.



Plastic package 10D3
according to DIN 41870 (≈ TO-92)
The case is impervious to light

Weight approximately 0.18 g
Dimensions in mm

Absolute Maximum Ratings

		Symbol	Value	Unit
Collector Emitter Voltage	**BC337**	V_{CES}	50	V
	BC338	V_{CES}	30	V
Collector Emitter Voltage	**BC337**	V_{CEO}	45	V
	BC338	V_{CEO}	25	V
Emitter Base Voltage		V_{EBO}	5	V
Collector Current		I_C	800	mA
Peak Collector Current		I_{CM}	1	A
Base Current		I_B	100	mA
Power Dissipation at T_{amb} = 25 °C		P_{tot}	625¹⁾	mW
Junction Temperature		T_j	150	°C
Storage Temperature Range		T_S	−55 to +150	°C

¹⁾ Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case

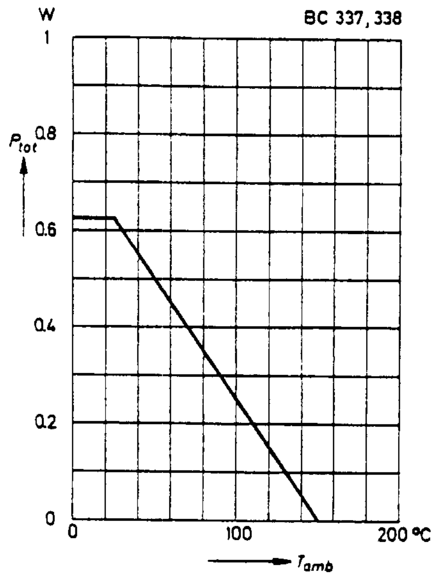
Characteristics at T_{amb} = 25 °C

	Symbol	Min.	Typ.	Max.	Unit
DC Current Gain					
at V_{CE} = 1 V, I_C = 100 mA **BC337, BC338**	h_{FE}	100	–	630	–
Current Gain Group 16	h_{FE}	100	160	250	–
25	h_{FE}	160	250	400	–
40	h_{FE}	250	400	630	–
at V_{CE} = 1 V, I_C = 300 mA **BC337, BC338**	h_{FE}	60	–	–	–
Current Gain Group 16	h_{FE}	60	130	–	–
25	h_{FE}	100	200	–	–
40	h_{FE}	170	320	–	–
Collector Cutoff Current					
at V_{CE} = 25 V **BC338**	I_{CES}	–	2	100	nA
at V_{CE} = 45 V **BC337**	I_{CES}	–	2	100	nA
at V_{CE} = 25 V, T_{amb} = 125 °C **BC338**	I_{CES}	–	–	10	µA
at V_{CE} = 45 V, T_{amb} = 125 °C **BC337**	I_{CES}	–	–	10	µA
Collector Emitter Breakdown Voltage					
at I_C = 10 mA **BC338**	$V_{(BR)CEO}$	20	–	–	V
BC337	$V_{(BR)CEO}$	45	–	–	V
Collector Emitter Breakdown Voltage					
at I_C = 0.1 mA **BC338**	$V_{(BR)CES}$	30	–	–	V
BC337	$V_{(BR)CES}$	50	–	–	V
Emitter Base Breakdown Voltage at I_E = 0.1 mA	$V_{(BR)EBO}$	5	–	–	V
Collector Saturation Voltage at I_C = 500 mA, I_B = 50 mA	V_{CEsat}	–	–	0.7	V
Base Emitter Voltage at V_{CE} = 1 V, I_C = 300 mA	V_{BE}	–	–	1.2	V
Gain Bandwidth Product at V_{CE} = 5 V, I_C = 10 mA, f = 50 MHz	f_T	–	100	–	MHz
Collector Base Capacitance at V_{CB} = 10 V, f = 1 MHz	C_{CBO}	–	12	–	pF
Thermal Resistance Junction to Ambient	R_{thA}	–	–	200[1]	K/W

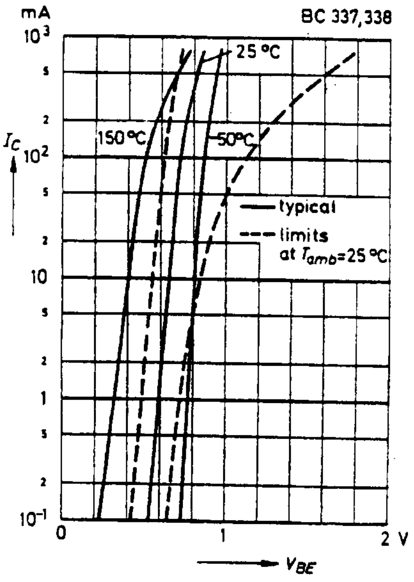
[1] Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case

Admissible power dissipation versus ambient temperature

Valid provided that leads are kept at ambient temperature at a distance of 2 mm from case

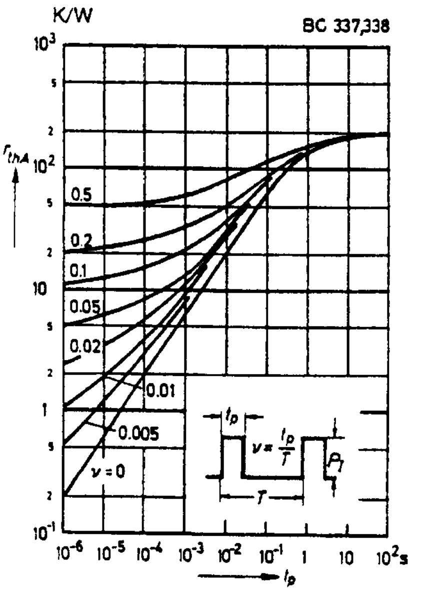


Collector current versus base emitter voltage

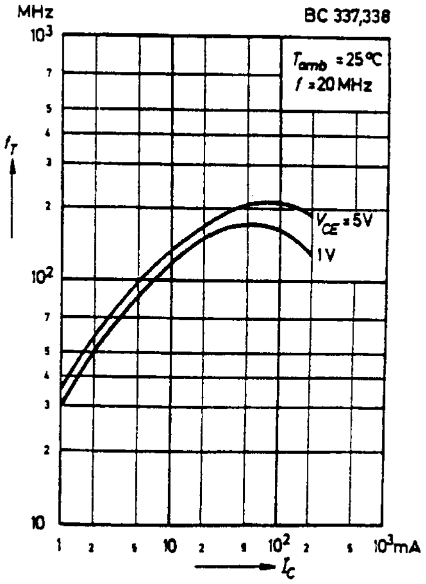


Pulse thermal resistance versus pulse duration

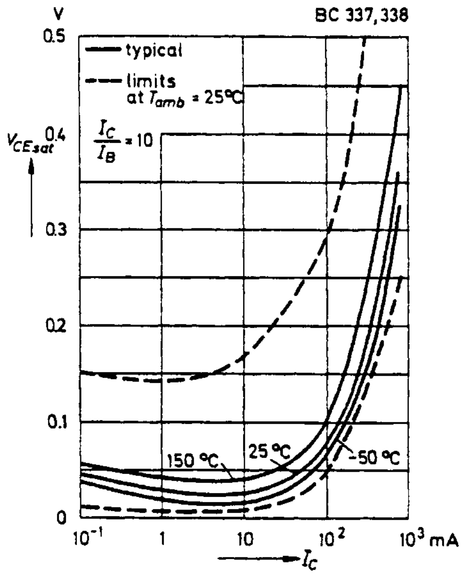
Valid provided that leads are kept at ambient temperature a a distance of 2 mm from case



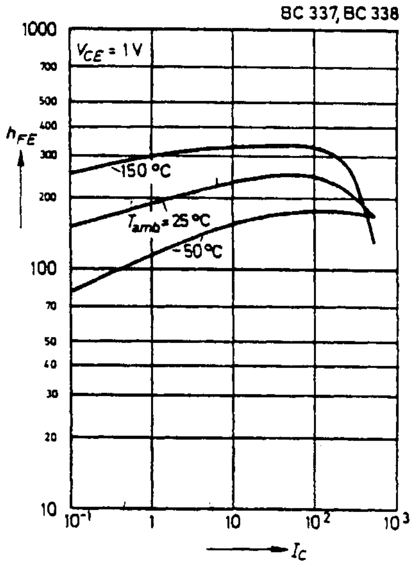
Gain bandwidth product versus collector current



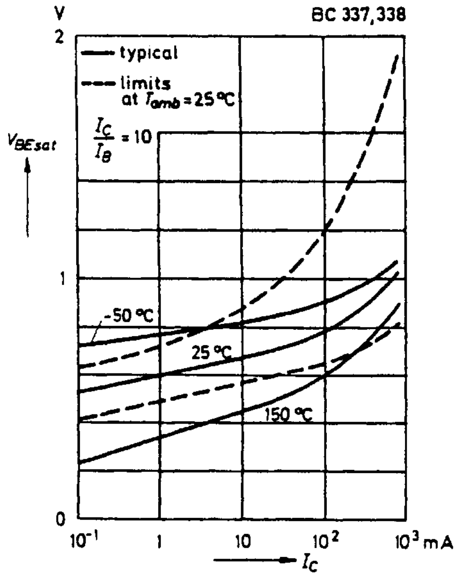
Collector saturation voltage versus collector current



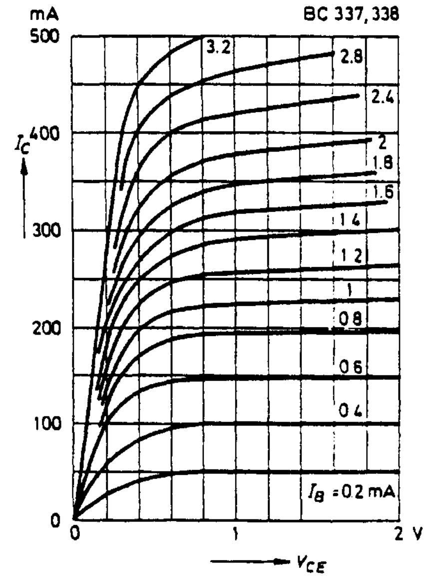
DC current gain versus collector current



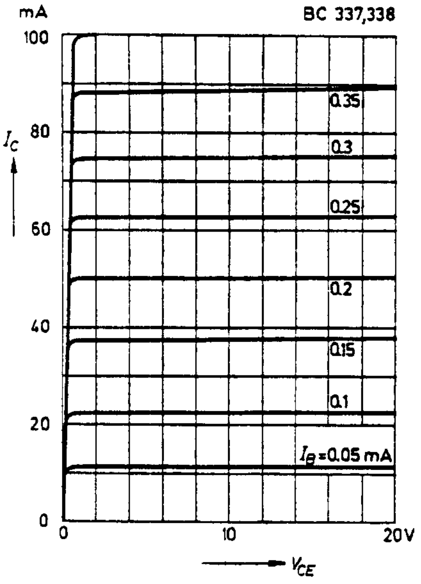
Base saturation voltage versus collector current



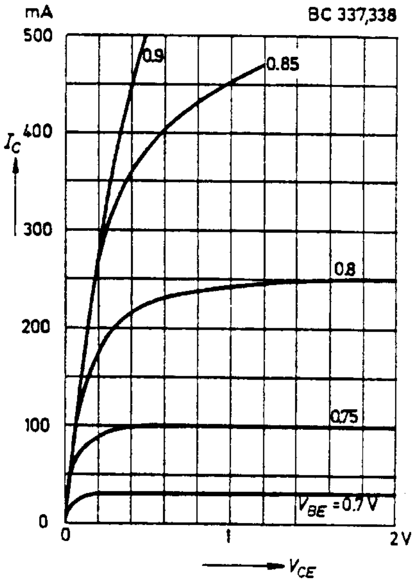
Common emitter collector characteristics



Common emitter collector characteristics



Common emitter collector characteristics



BC182, BC183, BC184
NPN-EPITAXIAL-PLANAR-SILICON-TRANSISTOR

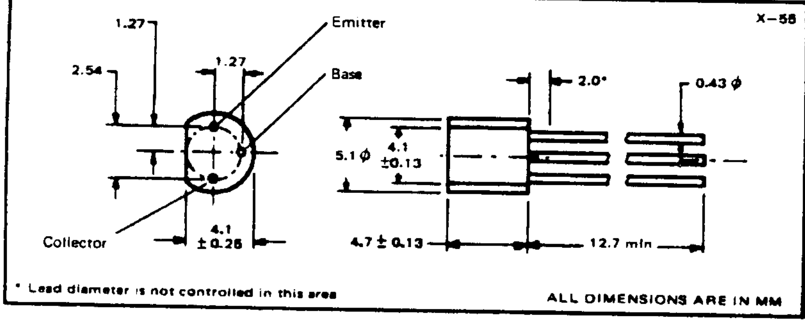
VLB n°116 – July 1973

- Pre-Amplifiers and Driver Stages
- DC-Amplifiers
- Low-Noise Pre-Amplifiers
- Complementary to BC212 Family
- h_{21e} = 125-900 at I_C = 2 mA, in 3 groups
- Noise Figure max 4 dB (BC184)

description

These components are tested according to the appropriate test method of MIL-STD-750. By special agreement, they can also be tested additionally to MIL-or DIN specifications.

mechanical data



* Lead diameter is not controlled in this area

ALL DIMENSIONS ARE IN MM

absolute maximum ratings at 25°C free air temperature (unless otherwise noted)

	BC182	BC183	BC184	UNIT
Collector-Base Voltage	60	45	45	V
Collector-Emitter Voltage (See Note 1)	50	30	30	V
Emitter-Base Voltage	6	6	6	V
Continuous Collector Current	200	200	200	mA
Continuous Device Dissipation at 25°C (See Note 2)	300	300	300	mW
Storage Temperature Range	–55 to 150	–55 to 150	–55 to 150	°C
Lead Temperature 1.6 mm from Case for 10 Seconds	260	260	260	°C

NOTES: 1. This value applies when the base-emitter diode is open-circuited.

2. Derate linearly to 150°C free air temperature at the rate of 2.4 mW/°C.

BC182, BC183, BC184
NPN-EPITAXIAL-PLANAR-SILICON-TRANSISTOR

electrical characteristics at 25° C free air temperature – BC182

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$V_{(BR)CBO}$	Collector Base Breakdown Voltage	$I_C = 10\ \mu A$, $I_E = 0$	60			V
$V_{(BR)CEO}$	Collector Emitter Breakdown Voltage	$I_C = 2$ mA, $I_B = 0$	50			V
$V_{(BR)EBO}$	Emitter Base Breakdown Voltage	$I_E = 10\ \mu A$, $I_C = 0$	6			V
I_{CBO}	Collector Cutoff Current	$V_{CB} = 50$ V, $I_E = 0$			15	nA
I_{EBO}	Emitter Cutoff Current	$V_{EB} = 4$ V, $I_C = 0$			15	nA
h_{FE}	Static Forward Current Transfer Ratio	$V_{CE} = 5$ V, $I_C = 10\ \mu A$	40			
		$V_{CE} = 5$ V, $I_C = 2$ mA	100		480	
		$V_{CE} = 5$ V, $I_C = 100$ mA See Note 3	80			
$V_{CE(sat)}$	Collector Emitter Saturation Voltage	$I_C = 10$ mA, $I_B = 0.5$ mA			0.25	V
		$I_C = 100$ mA, $I_B = 5$ mA See Note 3			0.6	
$V_{BE(sat)}$	Base Emitter Saturation Voltage	$I_C = 100$ mA, $I_B = 5$ mA See Note 3			1.2	V
h_{21e}	Small-Signal Common-Emitter Forward Current Transfer Ratio	$V_{CE} = 5$ V, $I_C = 2$ mA, $f = 1$ kHz ,	125		500	
		Group A	125		260	
		Group B	240		500	
V_{BE}	Base Emitter Voltage	$V_{CE} = 5$ V, $I_C = 10\ \mu A$		0.52		V
		$V_{CE} = 5$ V, $I_C = 100\ \mu A$		0.56		
		$V_{CE} = 5$ V, $I_C = 2$ mA	0.55		0.7	
		$V_{CE} = 5$ V, $I_C = 10$ mA		0.68		
C_{ob}	Common Base Output Capacitance	$V_{CB} = 10$ V, $I_E = 0$, $f = 1$ MHz		3.0	5	pF
C_{ib}	Common Base Input Capacitance	$V_{EB} = 0.5$ V, $I_C = 0$, $f = 1$ MHz		9.5		pF
f_T	Transition Frequency	$I_C = 10$ mA, $V_{CE} = 5$ V, $f = 100$ MHz		280		MHz
NF	Noise Figure	$V_{CE} = 5$ V, $I_C = 200\ \mu A$, $R_G = 2\ k\Omega$, $f = 1$ kHz, $\Delta f = 1$ Hz			10	dB

NOTE : 3. These parameters must be measured using pulse techniques $t_p = 300\ \mu S$, duty cycle $\leqslant 2\%$.

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