Wireless World Circard

Series 2: Comparators & Schmitts

Though the introductory article was previously called "Switching circuits", this set of cards deals with comparators—exhibiting no hysteresis or backlash—Schmitt trigger circuits—having a finite hysteresis—and level detectors, which can belong to either class. Switching circuits of the astable kind are dealt with in Series 8 in this book; logic gates, digital counters, pulse modulators, and monostable circuits have been covered in later cards, available separately.

One of the two comparator circuits is interesting (card 4), not only in that it can be simply modified to act as a Schmitt trigger circuit, but because it shows how to use op-amp supply leads as signal outputs which may be used to drive push-pull circuits (see also series 7 cards 2 and 12). The other circuit (card 1) shows how to clamp the output of an op-amp at low current levels for op-amps with access to the output stage drive point.

Most of the other cards show variants of the Schmitt circuit, including three with low hysteresis (cards 2, 9 and 11).

Comparators & Schmitts

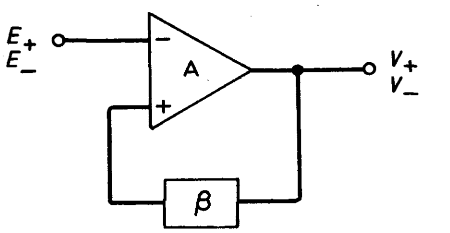
There is a need for circuits whose output changes by a large amount as the input passes through a particular level. There are four cases:

1. The change may be reversible without hysteresis, and those high-gain amplifiers called comparators belong to this class.
2. The change may be reversed at a different value of input, i.e. exhibit hysteresis, and Schmitt trigger circuits are examples. The output may fail to return to its original value when hysteresis is present, because the input is constrained within limits preventing such reversal, and such circuits are said to "latch".
3. The output, because of some intervening unidirectional device or circuit, may remain in its second state indefinitely regardless of any further excursions of the input unless returned to its original state by some alternative process, and bistable circuits such as the classic Eccles-Jordan belong to this category.
4. Finally, the circuit may respond to the second or succeeding excursions of the input through a given level in a given sense, and such circuits are used for dividing and counting in logic systems.

In types 3 and 4 above, the normal applications are such that precision of switching level is unimportant, as the systems in which they are used are digital, generally binary. Hence the input and output levels, need only be controlled within broad limits and can still be identified unambiguously. While precision in the switching levels may be combined with these other functions it is more usual to separate the functions as design constraints are so different.

Switching circuits to be considered here belong to types 1 and 2 above and can constitute an interface between analogue and digital systems – discrete changes in output are obtained at specified amplitudes of input.

Type 1 may be further sub-divided according to whether the input is differential or single-ended with respect to some prescribed level, often ground potential. The former is readily available in the form of integrated-circuit comparators with excellent performance. Early versions were designed for high-speed operation to be used in conjunction with particular logic families. Supply voltages are required to be within close limits of specific values not always compatible with those in common use for other purposes, e.g. $+12/-6$V as



$$E_+ = \beta V_+ \qquad E_- = \beta V_-$$
$$(E_+) - (E_-) = \beta\left[(V_+) - (V_-)\right]$$

against ± 15V for many analogue systems. For this reason newer versions have appeared capable of working from a wide range of supply voltages, and having lower input current requirements. Yet others are being produced with higher switching speeds.

Voltage gain of these comparators is high, with the full output swing being achieved for an input change of a few millivolts. Thus if one input terminal is taken to some constant reference voltage with the other input fed from the signal source, a sharp output transition occurs when the signal voltage exceeds that of the reference. Finite voltage gain together with offset (unbalance) effects limit the precision achievable at low cost to a few millivolts.

The indeterminate value of output for inputs close to the reference level, makes the use of low-gain amplifiers inappropriate as comparators, and discrete circuits with two or three transistors are less commonly found as type 1.

If positive feedback is applied to any amplifier then under the right conditions the output can be made to switch between two distinct states with little or no further change in output regardless of further variation of the input. This applies to low- and high-gain amplifiers alike, though with the former the magnitude of the feedback factor must be larger to ensure a complete switching action. The margin must be large enough to guarantee the switching action in the presence of parameter variations due to supply and environmental changes for a particular unit, and to cover component tolerances.

A further property resulting from the use of positive feedback is that the output transition in the positive and negative inputs occur at different values of input – the effect being called hysteresis of the circuit. This is illustrated in the figure where V_+ and V_- are the alternative output voltages of a comparator (or operational amplifier where high speeds are not critical) when fully switched. The input voltages E_+ and E_- are the voltages at which transitions occur. The output will switch from V_+ to V_- when the input exceeds βV_+ by a small amount of the order (V_+/A), where β is the fraction of the output voltage fed back and A is the voltage gain of the comparator in its active region.

Hence the hysteresis is obont $\beta\Delta V$, where ΔV is the change in the output, and provided A is large.

In various applications it may be necessary either to minimize the hysteresis or to increase it and define it. The former requirement indicates the need for a high value of A; the latter for an accurately defined product $\beta\Delta V$ and either large A or at least a defined value of A. Deciding on the precise value of A to be used in such calculations is difficult — the gain continually changes as the critical point is approached. Using i.c. comparators (or operational amplifiers at lower frequencies) the value of A is sufficiently high that the hysteresis can be defined by the resistive feedback network.

Discrete amplifiers, of which the Schmitt trigger is the classic version, are capable of a very wide range of characteristics with complementary versions increasing the choice of characteristics. A problem frequently encountered in such designs is that the switching levels, hysteresis etc, are often interdependent and have to be preselected using suitable algebraic equations. It may not be easy to achieve independent control of these parameters.

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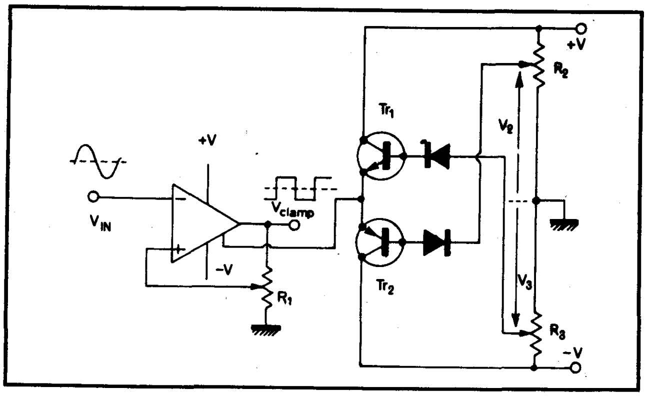
Op-amp comparator/Schmitt (bipolar clamping)



Useful frequency range: d.c. to approx. 160kHz. If a higher-speed operational amplifier is used, transistors may limit the frequency response unless high-speed versions are used.
Diodes may be omitted for low supply voltages and/or high reverse base-emitter breakdown transistors. Base-emitter junctions may receive supply voltage at extreme settings of R_2 and R_3.

Typical performance

Supplies: $\pm 5V$; IC: 748
Tr_1: BC125; Tr_2: BC126
Diodes: 1N914
R_1, R_2, R_3: 10kΩ
With V_{in} = 1V pk-pk at 10kHz, $V\pm_{out}$ adjustable ± 1.6 to $\pm 4.4V$.
Rise and fall times $\approx$ 700ns.

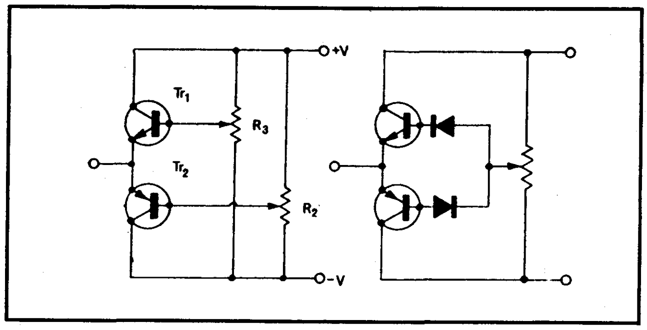
Supply currents $\pm 2.5mA$
Max $V_{in} = \pm V$.
For $0 < V_2 < 3V$
$V^+_{out} = V_2 + 3V_{be}$
$V^+_{clamp} = V^+_{out} - V_{be}$.
For $-3V < V_3 < 0$
$V^-_{out} = V_3 - 3V_{be}$
$V^-_{clamp} = V^-_{out} + V_{be}$.

Circuit description

Operational amplifiers used as comparators (or as level-sensing circuits when positive feedback is used for hysteresis) have output swings which vary with temperature and from unit to unit. Some amplifiers have access to the drive point of the output stage and this point may be clamped at selected positive and negative potentials by zener diodes or suitably biased transistors as shown. Clipping is at much lower current levels than if attempted directly at the output. Variable resistors R_2 and R_3 set the positive and negative clamping levels, R_1 determines hysteresis at the clamping levels. Diodes provide base-emitter breakdown protection.

Component changes

Useful range of supplies: ± 5 to $\pm 18V$.
Transistors: general-purpose silicon types.
Useful range of R_1: 1 to 100kΩ.
Useful range of R_2, R_3: 1kΩ (increases supply current drawn) to 100kΩ (produces error in V_2 and V_3 unless base current loading is reduced by use of higher-gain transistors).



Circuit modifications

- Diodes could be placed in series with the emitters of the transistors. This still provides base-emitter breakdown protection but the diodes then carry the larger emitter currents producing larger diode p.ds.
- R_2 and R_3 could be connected as shown on left allowing the base potentials of both Tr_1 and Tr_2 to be set positive or negative independently. It would then be possible for Tr_1 base to be positive and Tr_2 base to be negative, which would allow excessive conduction in Tr_1, Tr_2.
- Fig. on right shows a modification which allows the mean level of V_{out} to be set positive or negative by the potentiometer with its peak-to-peak value still determined by $\pm 3V_{be}$.

Further reading

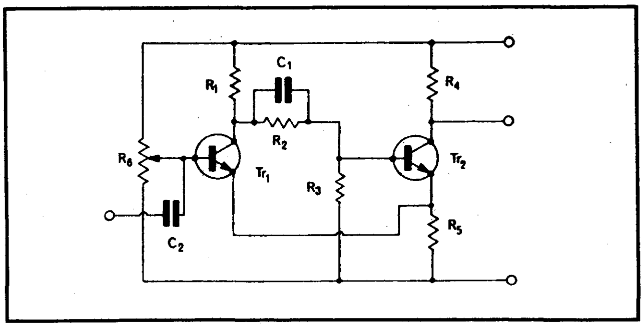
IC op.amp beats fets on input current, National Semiconductor application note AN-29, 1969, p.15.
Clayton, G. B., Operational Amplifiers, Butterworth 1971, pp.145-9.
Applications Manual for Operational Amplifiers Philbrick/Nexus Research, 1968, pp.59 & 101.

Cross references

Series 2, cards 4 & 6.

Wireless World Circard Series 2: Comparators & Schmitts 2

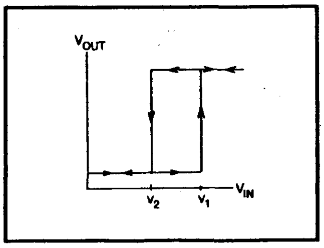
Basic Schmitt circuit



Typical performance

Transistors: BC125
Supply: +5V
R_1, R_4: 4.7kΩ
R_2, R_3: 2.2kΩ
R_5: 1kΩ ±5%
R_6: 4.7kΩ pot.
C_1: 100pF (speed-up)
C_2: 2.2μF
Signal level from 500-Ω source: 2V pk-pk.

Output swing: 1.5 to 5V up to 100kHz.



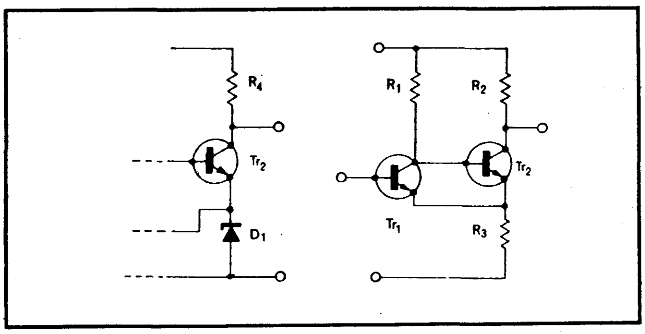
Circuit description

Emitter coupling between Tr_1 and Tr_2 introduces positive feedback causing a regenerative switching action into one of two states. When V_{in} is below threshold level V_1, Tr_1 is non-conducting and Tr_2 conducts, the base voltage being determined by R_1, R_2 and R_3. The emitter potential is then well-defined. As input voltage exceeds V_1, Tr_1 begins to conduct, reducing its collector potential, and hence that of the base and emitter of Tr_2. This drop in potential is fed back to the emitter of Tr_1, thus further increasing the conduction of Tr_1 until Tr_1 is on and Tr_2 is off. A similar regenerative action occurs when the input voltage is reduced below the threshold level V_2, returning the circuit to its original condition. A typical input-output voltage characteristic is shown above, where $V_1 - V_2$ is termed the hysteresis or backlash of the circuit.

Component changes

Resistor R_6 permits adjustment of threshold level V_1. Useful ratio R_2/R_3 is in the range 0.5 to 2.0, giving control of trip level and hysteresis range of 0.2 to 0.8V.

Useful C_1 range: 1nF to 100pF. Optimum 100pF at a source frequency of 1MHz.
Rise time: 150 to 100ns using oscilloscope probe.
For R_4 = 1kΩ, R_1 = 100Ω, R_2/R_3 = 0.5, output swing at 1MHz is 3 to 5V, for load capacitance up to 33pF.



Circuit modifications

The emitter resistor may be replaced by a zener diode[1] (left). This means the emitter potential variation is less dependent on current flow through each transistor. Typical performance:

V_{CC} = 10V, D: 5.1V zener diode. R_1: 680Ω, R_2, R_4: 1.5kΩ, R_3: 3.3kΩ. Drive signal: 2V pk-pk; output swing: 5.2 to 10V. Hysteresis: 110mV.

On right,: useful range of R_3: 10 to 500Ω. Useful range of R_2 1 to 2kΩ. R_1: 1kΩ. Typical performance:

V_{CC} = 5V, R_E = 10Ω, R_1 = R_2 = 1kΩ. Minimum sinusoidal drive signal at 100kHz: 2V pk-pk. Output swing: 0.8 to 5V.

Frequency may be increased to 300kHz if drive voltage is increased to 4V pk-pk.

Reference

1. Zero-hysteresis Schmitt trigger, in Electronic Circuit Design Handbook, 4th edition. 1971 p.108.

Further reading

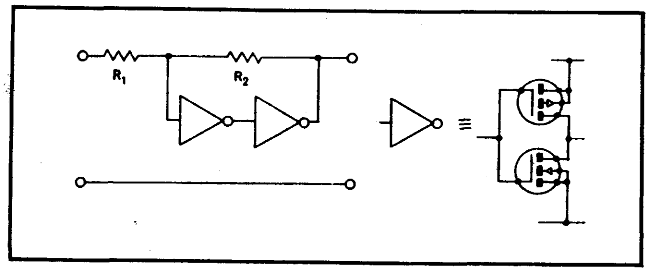
Crump, A. E., Design of Schmitt trigger circuits, *Wireless World*, vol. 73, 1967, pp.122-7 and 175-7.
Circuit Consultant's Casebook, Hemingway, T. K., Business Books, 1970, pp.129-37.

Cross references

Series 2, cards 3, 7 & 8.

Wireless World Circard Series 2: Comparators & Schmitts 3

Complementary m.o.s. Schmitt



Typical performance

IC: CD4007AE (connected as triple inverter)
Supply: 10V
R_1: 1MΩ
R_2: 10MΩ
V_1: 5.9V
V_2: 5.1V
Output swing: 10V
Input current: ±0.5μA

Circuit description

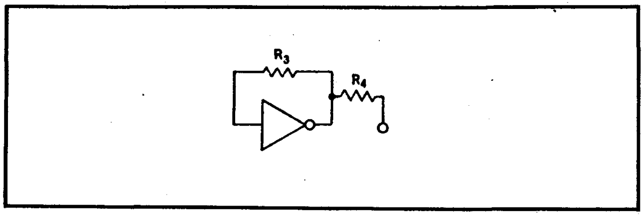
Two c.m.o.s. inverters are cascaded with positive feedback defined by ratio R_2/R_1. Provided this ratio is less than the forward gain in the inverters' linear region, switching follows the appropriate input changes. Output swing approaches supply lines and current from source is small as very high input resistance of inverter allows R_1, R_2 to be large. With small hysteresis switching levels are near supply mid-point.

Component changes

- Any combination of inverters, gates or buffers giving voltage gain > + 1 may be used. Examples: RCA CD4001AE, Motorola MC14001 quad 2-input NOR gates; CD4049AE hex buffer inverters.
- Supply voltage + 3 to + 15V (special versions down to 1.5V).
- R_2/R_1 may be varied between 1 and 100. At upper end of range positive feedback may be too little to guarantee switching. At lower end hysteresis is comparable to supply voltage.
- To minimize capacitive effects/hum pickup reduce R_1, R_2 to ~ 10kΩ. Lower values reduce output swing and accuracy of hysteresis, while increasing current from source.

Circuit modifications

- Buffer input with third inverter/gate increasing input resistance (typical input current ~ 10pA). Resistor R_1 may be dispensed with, the output resistance of buffer taking its place, with R_2 reduced to range 1 to 30kΩ. Resulting hysteresis in range 2.5 to 0.2V.
- Use spare inverter self-biased by large resistor (~ 10MΩ) (see Fig.) to bias input terminal of first inverter via second resistor (~ 10MΩ). This sets mean potential near to centre of linear region, assuming well-matched inverters. Signals may now be a.c. coupled and 200mV pk-pk typically triggers circuit over a range of supply voltage and temperature with no adjustment of bias level.



Further reading

Dean, J. A. & Rupley, J. P., Astable and monostable oscillators using RCA COSMOS digital integrated circuits, RCA application note ICAN-6267.
Schmidt, B., Schmitt trigger design uses CMOS logic, *Electronic Design*, Vol. 20, 27 April 1972, p.72.

Cross reference

Series 2, cards 1, 2 & 8.

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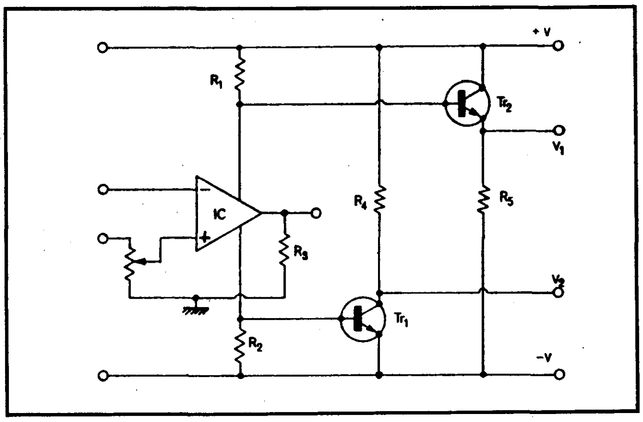
High-power comparator/Schmitt



Performance data

IC: 741; Supplies ±5V
Tr_1: BFR41, Tr_2: BFR81
R_1, R_2: 220Ω, R_3: 270Ω
R_4, R_5: 68Ω, 3W

Minimum V_{in} = 800mV pk-pk.
Max. ±V = ±7V, for full output swing into 68Ω loads

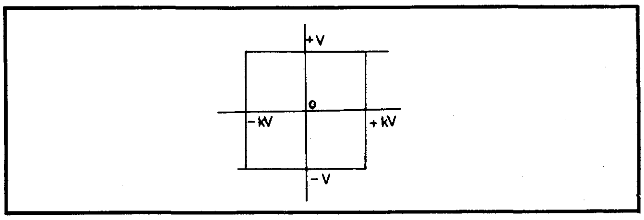
With maximum permissible sinusoidal input of 8V pk-pk, V_1 and V_2 are both square waves swinging between -5 and +4.8V, and -5 and +5V respectively. V_1 and V_2 are in-phase while the currents in R_4 and R_5 are in anti-phase. Max. frequency 1kHz—waveform squareness is lost at higher frequencies.

Circuit description

The output swing of standard op-amps is significantly less than the supply voltage, particularly when the latter is low. The current available is also low. With some op-amps the current in the positive supply lead is large when the output voltage is positive and the output current is large but is small when the output voltage is negative. The negative supply current behaves similarly. The change in supply current as the input signal varies can be used to drive following transistors which may supply currents of several hundred milliamperes at a voltage very close to the supply voltage.

Component changes

- To maximize output voltage swings Tr_1 and Tr_2 must be driven into saturation i.e. base currents of 5 to 10% of load current are required. Reducing R_3 will increase base current.
- Resistors R_1 and R_2 may need to be reduced for some op-amps having larger off-load currents (180Ω was found satisfactory for a 748).



Circuit modifications

The circuit can be altered to give a Schmitt characteristic with controllable hysteresis by connecting either V_1 or V_2 via the pot. shown to the non-inverting input of the op-amp. Using V_2 we obtain the characteristic shown right in which k is the pot tapping and V the supply voltage (5V). This hysteresis is not dependent on the saturation level of the amplifier as it would be if the amplifier output were fed back. Hysteresis width is controllable up to about 0.1V of the pk-pk value of the input provided the input is kept below about 5V pk-pk.

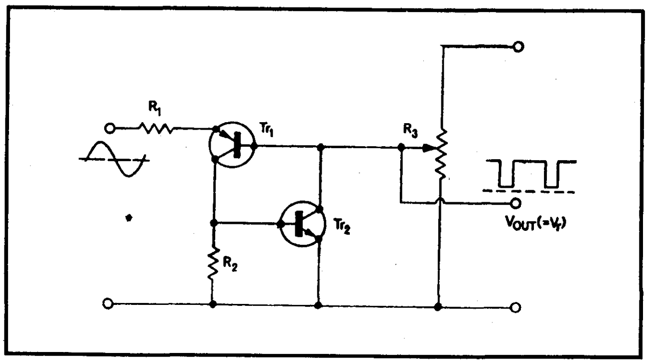
Further reading

Campbell, D. L. and Westlake, R. T. Build a high current servoamplifier with i.cs. *Control Engineering*, December 1969, p.91.
Widlar, R. J., IC op-amp beats f.e.ts on input current, National Semiconductor application note AN-29, 1969, p.15.

Cross references

Series 2, card 9.

Unijunction-equivalent Schmitt



Typical performance

Supply: +5V
Tr_1: BC126 Tr_2: BC125
R_1, R_2: 1kΩ R_3: 4.7kΩ
V_{out} (on) = 0.04V
V_{out} (off) = V_r = 2.5V
V_{in} (on) = 3.8V
V_{in} (off) = 3.0V
Supply current: 8mA (on), 1mA (off)
V_{in} (on) = $V_r + (n+1) V_{be}$ (on).
where $n = R_1/R_2$

Circuit description
The transistors together have properties similar to those of a unijunction transistor. When V_{in} is low Tr_1 and Tr_2 do not conduct and V_r is defined by R_3. For $V_{in} \approx V_r + 1.3V$, Tr_1 and Tr_2 begin to conduct, regenerative switching via Tr_2 clamping V_{out} close to 0V. Reversal of switching occurs when V_{in} falls. Significant current is drawn from the source unless a limiting resistor (R_1) is included.

Component changes
Tr_1: any general purpose p-n-p silicon transistor.
Tr_2: any general purpose n-p-n silicon transistor.
Maximum useful frequency ≈ 100kHz.
Range of V_r source resistance (seen by Tr_1 base): about 2.2kΩ to 33kΩ.
R_1 (max) ≈ 3.3kΩ. For large R_1 values V_r source resistance must be increased for rapid switching action. The output can only be lightly loaded with large V_r source resistance.

Circuit modifications
If the input voltage is fed directly to Tr_1 emitter the circuit may be used to clamp it to a low level (about 0.7V with a 5V supply) when it exceeds some maximum permissible level. For example, V_r could be the output from a voltage regulator and V_{in} its input voltage. If V_{in} (regulator input) rises excessively the circuit will rapidly clamp the regulator input to a low value protecting the regulator and the circuitry it supplies during the time taken for the supply fuse to blow. The transistors require a current rating greater than the supply peak current on s.c. loading. R_2 and R_3 may then need to be reduced.

Further reading
General Electric transistor manual, 1964, Chapter 13.
Unijunction transistor timers and oscillators, Motorola application note AN-294 (appendix), 1967.

Cross references
Series 2, cards 2 & 12.

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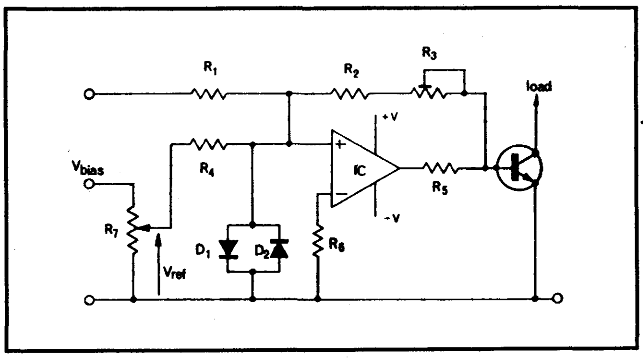
Variable hysteresis level detector



Component data

Supplies: ±15V
R_1, R_4: 2.2kΩ
R_2: 100kΩ
R_3: 100MΩ
R_5: 3.3kΩ
R_6: 1kΩ
R_7: 1kΩ

D_1, D_2: general-purpose diodes.
IC: 741
Tr: ME4103 (in general determined by load current requirements)
All resistors ±5%.

Circuit description

V_{ref} adjusts the level at which the output switches without affecting hysteresis. Positive feedback path R_2 and R_3 provides hysteresis controllable by R_3. Sensitivity can be modified by changing input resistance R_1. Positive output swing is determined by the base-emitter voltage of the transistor and the negative output by the particular operational amplifier used. Diodes on the input provide breakdown protection of the op-amp against excessive input voltages.

Component changes

IC: 748 or LM301A.
For V_{ref} of -1V to -14V, R_3 = 0, supplies: ±15V;
hysteresis: 180mV ±2%;
trip level: V_{ref} + 200mV.
For V_{ref} of -1V to -4V, R_3 = 0, supplies: ±5V;
hysteresis: 700mV ±5%;
trip level: V_{ref} + 100mV;
Hysteresis: 10mV, R_3 = 1MΩ, supplies: ±10→±15V; trip level: V_{ref} + 100mV.
In general, hysteresis may be further increased by reducing $R_2 + R_3$.

Circuit modifications

- If output voltage swing required at lower currents, Tr may be omitted and R_5 reduced to zero. Hysteresis is then controlled by op-amp output swing.
- Alternative methods of defining output swing and hence hysteresis include series back-to-back zener diode or diode limiting circuits.
- For higher speed operation, IC may be any comparator.
- For higher output currents, Tr may be replaced by a Darlington pair. If only an indication of output state is required, most op-amps can deliver sufficient current to drive small light-emitting diodes.

Further reading

Linear Integrated Circuits Handbook, Marconi-Elliott Microelectronics, pp.167/8.
Smith, J. I., Modern Operational Circuit Design, Wiley, 1971, pp.186/7.

Cross references

Series 2, cards 9–11.

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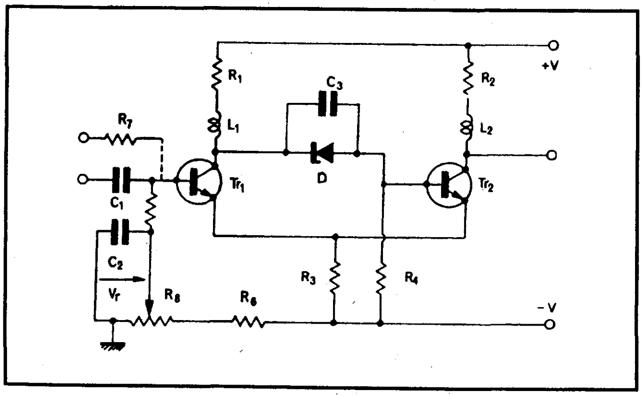
High-speed Schmitt circuit



Typical performance

Supplies: ±5V
Tr_1, Tr_2: BSX20
D_1 = BZX55, C3V9
R_1, R_2, R_3, R_5, R_7: 100Ω
R_4 10kΩ.
R_6: 3.3kΩ; R_8: 1kΩ
C_1, C_2: 0.1μF; C_3: 27pF
L_1, L_2: 0

V_r = -1.0V; V_{in} (Tr_2on) = -2.02V; V_{in}(Tr_2off) = -0.31V
Hysteresis: 1.71V
V_{out}(on) = 0.2V
Supply current
+40mA, -50mA Tr_2off
+43mA, -51.5mA Tr_2on

Circuit description

For maximum speed, Schmitt trigger circuits should operate with the transistors out of saturation at all times. A zener diode in the bias network can assist this. In this circuit, current levels are higher than in the basic Schmitt to maximize gain-bandwith product. The inductors compensate for capacitive loading to optimize rise time. The upper and lower thresholds are negative and the hysteresis is variable but is not independent of the threshold levels.

Component changes

Useful range of V_r: 0 to -1.47V
Corresponding hysteresis range: 2.9 to 1.64V.
L_1 and L_2 can be adjusted to produce a required rise time with a defined overshoot for given capacitive loading. The same principle applies to the complementary Schmitt. With $L_1 = L_2 = 0.11\mu H$, rise time < 8ns with 5% overshoot at low switching rates.
The circuit functions to at least 40MHz with defined output levels although the waveform is rounded at high frequencies. Careful printed circuit layout is necessary for good high-frequency operation.

Circuit modifications

Precise adjustment of the negative rail voltage allows the output to be made truly t.t.l.-compatible with levels of 0V and +5V. The output from Tr_2 may be used to feed a high-speed t.t.l. gate or an e.c.l. gate to "square up" the waveform at high frequencies. Circuits of this type may be useful in conjunction with t.t.l. or e.c.l. circuitry as they provide alternative options of switching levels and hysteresis. To assist supply decoupling at high frequencies, ferrite beads can be added to the supply line wiring.

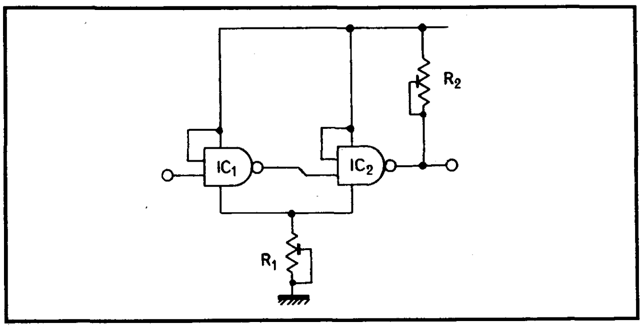
Further reading

E-Line Transistors Applications, Ferranti, 1969. p.20.
MECL Integrated Circuit Schmitt Triggers, Motorola application note AN-239.

Cross references

Series 2, card 2 & 8.

TTL Schmitt circuit

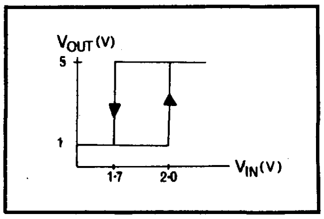


Performance data

Graph obtained with R_2: 250Ω, R_1: 30Ω
Supply: 5V
ICs: 7400
Frequency 0 to 1MHz.
Threshold values and hence hysteresis may be changed slightly by varying R_1 and R_2.

Lower limit (1V as shown) is affected by R_1 and R_2.

With $R_1 = 0$ there is no positive feedback and switching is not clean. With $R_2 = \infty$ upper limit is reduced from 5V.



Circuit description

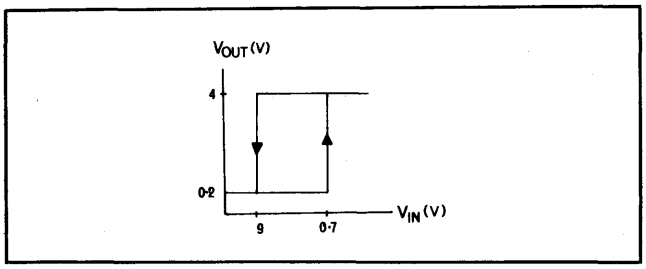
Each NAND gate with one input gate disabled behaves as an inverter. The circuit with positive feedback via R_1 is very similar to the basic Schmitt trigger as each gate is essentially identical. This results in the potential across R_1 being constant and independent of which inverter is enabled. This results in an offset voltage compensated by R_2.

Component changes

Any t.t.l. inverter may be used.

Circuit modifications

An alternative t.t.l. Schmitt is SN7413, produced by Texas, and has two in a single package. Typical characteristics are shown below. Frequencies up to several MHz can be handled, but ringing may occur beyond 100kHz if the circuit layout is poor.



Further reading

Electronic Circuit Design Handbook, Tab Books, 4th edition, p.129.
Designing with t.t.l. Integrated Circuits, McGraw-Hill, 1971. pp.53-7.
MECL Integrated Circuit Schmitt Triggers, Motorola application note AN-239, 1967.

Cross references

Series 2, cards 2, 3 & 7.

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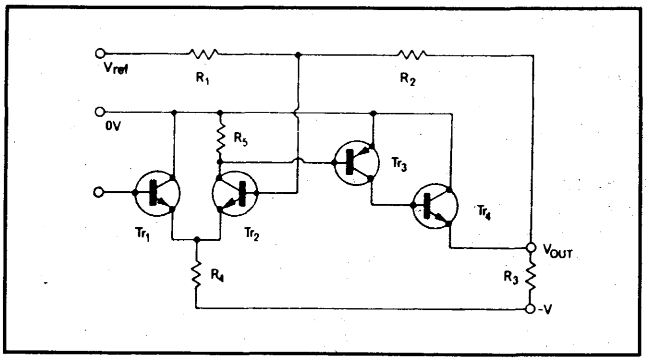
Low-voltage level sensor



Typical performance

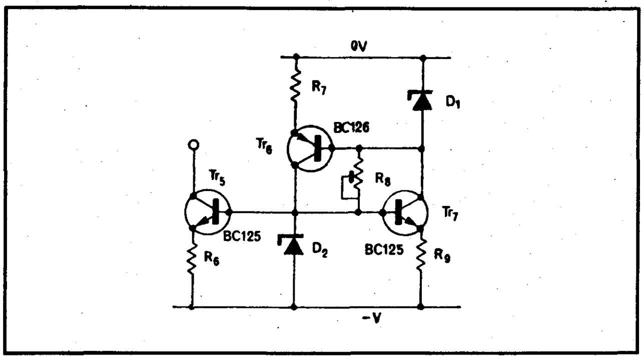
Supply: –12V	R_1: 3.3kΩ
V_{ref}: –1V	R_2: 100kΩ
Tr_1, Tr_2, Tr_4: BC125	R_3: 470Ω
Tr_3: BC126	R_4: 82kΩ
Switching levels	R_5: 10kΩ
on: –1.35V	
off: –1.03V	

Circuit description

Operation from single-ended supplies makes level-sensing of low voltages difficult (lower limit usually set by transistor V_{be}). Taking signal and reference voltages with respect to opposite side of supply as shown allows much reduced triggering voltages. A long-tailed pair drives an inverting stage with positive feedback from the output to the non-inverting input. Input current is small, reducing to zero after switching. For positive-going signals, a complementary version using a positive supply voltage gives comparable results.

Component changes

- Supply voltage –5 to –25V, upper value depending on transistor breakdown. At lower voltages, switching levels become more supply sensitive. Reduce R_4 at lower supply voltages to keep current in it to ~ 120μA.
- Reference voltage –200mV to –5V.
- Load currents up to 100mA possible with no change in circuit. Replacing Tr_4 by higher rating transistor, and scaling all resistors down by factor of 5 allows load currents of up to 0.5A (BFR41, BFY50 etc).
- Tr_1—Tr_4 replaced by any general-purpose silicon planar transistors results in comparable performance: matched pair at input reduces drift.



Circuit modifications

- Reference and signal inputs may be interchanged if minimum current drain from reference is required.
- Replacing R_4 by constant-current circuit minimizes shift of switching levels with varying supply voltage. Fig. shows a ring-of-two reference circuit biasing constant-current stage, and providing stable voltage across R_7 to act as switching-level reference. Replaced by potentiometer for variable reference.
- Tapping R_2 with a zener diode to 0-V line stabilizes hysteresis without limiting output voltage swing.
- For light loading Tr_4 may be omitted.

Further reading

Williams, P., Low-voltage level-sensing circuit, *Electronic Engineering*, 1968, pp.517-9.
Callahan, M. J., Integrated level detector, *IEEE Journal of Solid-State Circuits*, vol. SC-7, 1972, pp.185-8.

Cross reference

Series 2, cards 6, 10 & 11.

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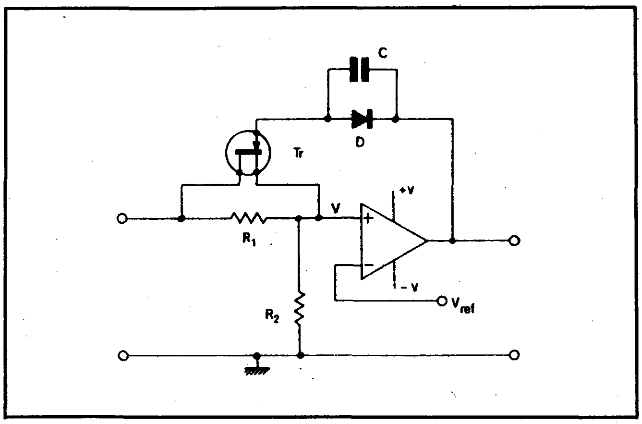
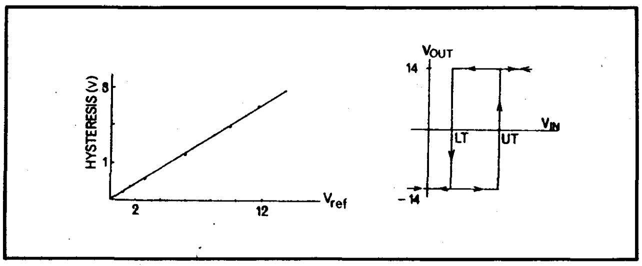
Reference-controlled hysteresis circuit



Typical performance

Graphs obtained with Supplies: ±15V
Tr: Motorola 2N4092
D: 1N914, IC: 741
R_1: 5.6kΩ ±5%
R_2: 27kΩ ±5%
C: 100pF

Lower threshold (l.t.): V_{ref}
Upper (u.t.): $V_{ref}\,.\,(R_1 + R_2)/R_2$
Hysteresis: $V_{ref}\ R_1/R_2$
Max. frequency: 300Hz
V_{ref} must remain positive.

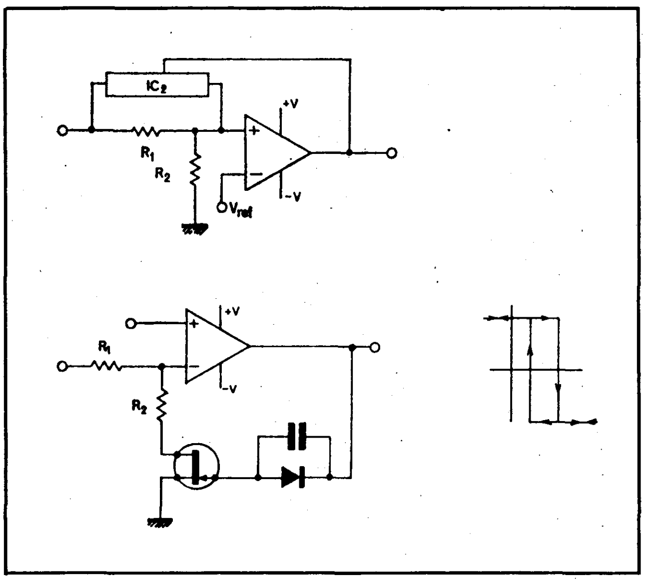


Circuit description

With a low V_{in}, V_{out} is initially negative and the f.e.t. switch if off. V' is then given by $V_{in}.R_2/(R_1 + R_2)$. Increasing V_{in} until V' is just greater than V_{ref} causes V_{out} to change sign, the f.e.t. then conducts and shorts out R_1 making V' equal to V_{in} and forcing V_{out} to become even more positive. V_{out} will only become negative again when V_{in} is reduced below V_{ref}. The positive feedback does not come into action immediately V_{out} starts to leave its saturated condition, so the output may lie between the saturated levels.

Component changes

Using a 748 op-amp the maximum frequency can be extended to 4kHz. National Semiconductor f.e.t. 2N3819/7127 may be used. R_1 is chosen such that the f.e.t. on-resistance is much lower than R_1 and the off-resistance is much higher than R_1. Varying R_1 and R_2 hysteresis of $0.1\,V_{ref}$ and $10\,V_{ref}$ can easily be obtained. Choice of diode and capacitor is not critical.



Circuit modifications

● With a negative V_{ref}, V' should be connected to the inverting input and V_{ref} to the non-inverting input to obtain the positive feedback switching action.
● With a low reference voltage and low supply voltage (e.g. <1V with ±5V supply), f.e.t. pinch-off voltage causes unsatisfactory switching. The f.e.t. and its associated diode and capacitor may be replaced by a c.m.o.s. switch, top. The switch used was CD4016AE, the minimum R_1 in this case being about 10kΩ.
● For applications where V_0 is required to be positive, for positive V_{ref} and small V_{in}, one may use the circuit at bottom, the resulting characteristic being as shown on right The formulae for the upper and lower thresholds and the hysteresis are the same as those for the original circuit.

Further reading

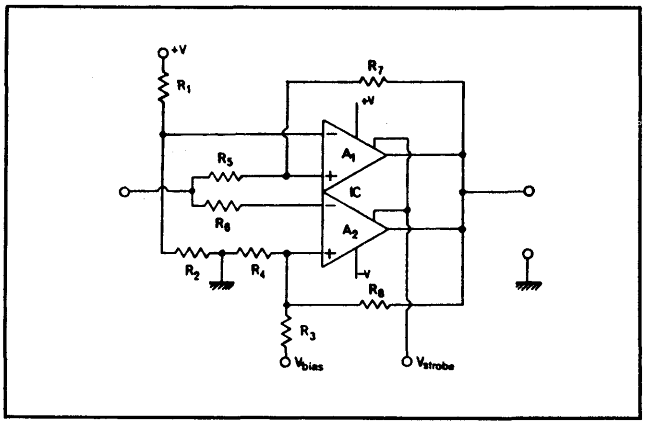
G. S. Oshiro, *Electronic Design*, June 1972.

Cross reference

Series 2, cards 4 & 6.

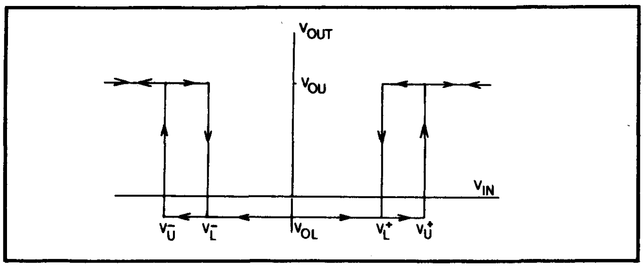
Wireless World Circard Series 2: Comparators & Schmitts 11

'Window' detector



Typical performance

IC: 711
Supplies +12V, -6V
V_{strobe} = +5V; V_{bias}-12V
R_1, R_3: 5.6kΩ
R_2, R_4, R_5, R_6: 470Ω
R_7, R_8: 22kΩ
V^{+}_{U} = 953mV; V^{+}_{L} = 886mV (i.e. V_{OU} hysteresis = 67mV)
V^{-}_{U} = -946mV; V^{-}_{L} = -879mV (i.e. V_{OL} hysteresis = 67mV)
V_{OU} = +4.4V; V_{OL} = -0.4V (inputs commoned)
Supply current: +11.5mA, -5mA
Strobe current: 76μA
Bias current: 2.2mA



Circuit description

A_1 is a non-inverting comparator having a positive reference level (V_{r_1}) set by R_1 and R_2. Amplifier A_2 is an inverting comparator having a negative reference (V_{r_2}) set by R_3 and R_4. V_{out} remains at a low level when $V_{r_2} < V_{in} < V_{r_1}$ and A_2 is capable of switching its output to $+V_{OU}$ when $V_{in} < V_{r_2}$. As the outputs of A_1 and A_2 are common, $V_{out} = +V_{OU}$ when $V_{in} < V_{r_2}$, or when $V_{in} > V_{r_1}$. Hysteresis is introduced by the positive feedback on A_1 (by R_7 and R_5) and A_2 (by R_8 and R_4). See transfer characteristic above. From an output level viewpoint the circuit is t.t.l. compatible.

Component changes

Maximum useful frequency ≈ 1MHz.
V_{OU} may be varied over the range +0.4 to 4.4V by setting V_{strobe} in the range +1 to +5V. V_{OL} remains fixed at -0.4V.
Variation of R_1 and/or R_3 provides independent control of the positive and negative threshold levels. Minimum useful value of R_1 and/or R_3 ≈ 700Ω.
Minimum load resistance (for 10% reduction of V_{OU}) ≈ 680Ω.

Circuit modifications

- Where hysteresis is not required the positive feedback resistors may be omitted.
- A visible-light-emitting diode connected to output terminal through a limiting resistor gives visual indication when the input signal is outside the limits set by V_{r_1} and V_{r_2}. Typically a resistance of 470Ω provides 5mA which is sufficient to illuminate the l.e.d. without excessively loading the IC.

Further reading

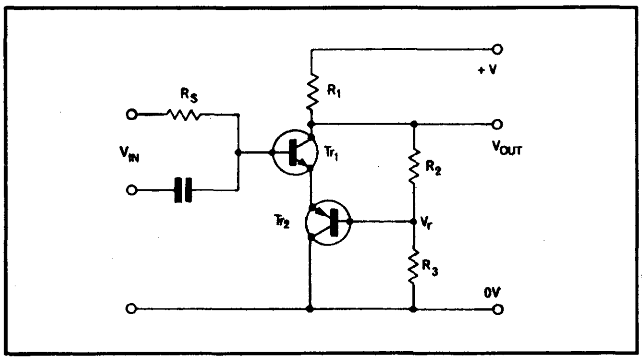
Application of linear microcircuits, SGS, 1969. pp.105-6.
Op-amp circuit collection, National Semiconductor application note AN-31, 1970, p.3.
Measurement of burst ("popcorn") noise in linear integrated circuits, RCA application note ICAN-6732, 1971. p.6.
Cole, H. A., Differential discriminator circuits, *Wireless World*, 1971, pp.603-4.

Cross references

Series 2, card 6.

Wireless World Circard Series 2: Comparators & Schmitts 12

Complementary Schmitt



Typical performance

V_{in} (on) = $V_r + 2V_{be}$
Supply: +12V
Tr_1: BC125; Tr_2: BC126
R_1, R_3: 1kΩ; R_2: 10kΩ
R_s: 100Ω; C_1: 0.1μF
V_{in}(on) = 2.16V
V_{in}(off) = 1.59V
hysteresis = 0.57V
V_O (on) = 1.0V
V_O(off) = 11V
Supply current:
10.5mA (on), 1mA (off)

Circuit description
This is a complementary form of circuit using emitter coupling, as in the classic Schmitt. Neither transistor conducts for low input voltages. When V_{in} exceeds $V_r + 2V_{be}$, both transistors conduct causing the output voltage to fall regeneratively. With suitable resistance values, the supply current in the off state can be made much less than in the on state.

Component changes
● Varying R_2 in the range 5 to 20kΩ allows the hysteresis to be adjusted within the range 1.16 to 0.21V, without significantly changing V_{in} (off).
V_n(on) correspondingly varies in the range 2.81 to 1.74V.
● If Tr_2 is a high-current-gain transistor V_{in} (off) ≈ $2V_{be}$; with a lower gain transistor V_{in} (off) will be increased due to the significant p.d. across R_3 produced by Tr_2 base current.
● A speed-up capacitor of about 27pF across R_2 improves the turn-on time from about 90ns to 30ns. Turn-off time is typically 90ns. Maximum useful frequency is typically 2MHz.

Circuit modifications
A 47-Ω resistor included in series with the 'free collector' of Tr_2 provides a complementary pulse output. These pulses typically have an amplitude of 0.6V (with a 12-V supply) i.e. sufficient to drive a following transistor or thyristor. Tr_1 will still saturate and Tr_2 will remain unsaturated. The value of this resistor may be considerably increased if it is returned to a separate negative supply. With a value $\leqslant R_1$ a second output is then available without significantly changing the circuit action.

Further reading

Hemingway, T. K., Electronic Designer's Handbook, Business Books, 1970, 2nd edition, pp.177-181.
Feinberg, R., Handbook of Electronic Circuits, Chapman and Hall, 1966, p.52.

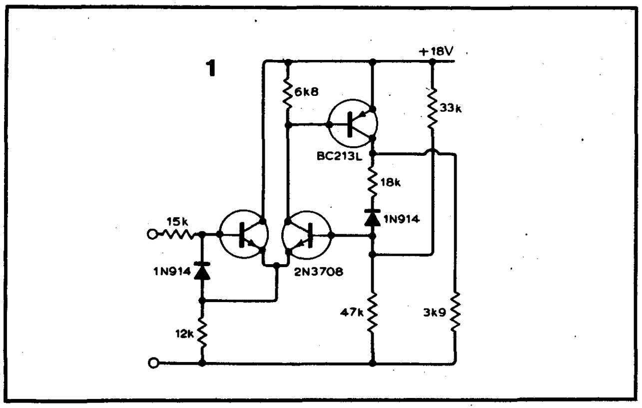
Cross references
Series 2, cards 2 & 5.

Wireless World Circard

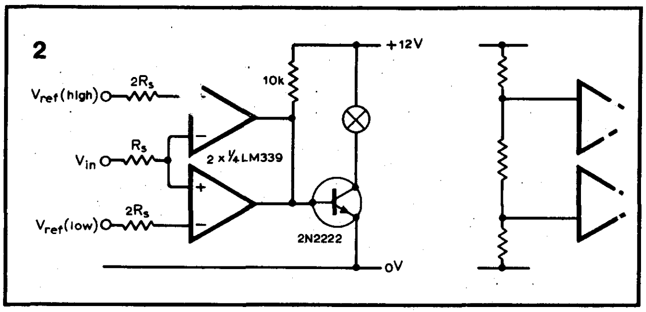
Series 2: Up-date

Schmitts and comparators

1. The circuit shown is a modification of the standard Schmitt circuit in which the input transistor is replaced by long-tailed pair allowing for better temperature compensation. Signal outputs are available from either collector, and the use of common-emitter output stage is helpful in getting a large output swing. Positive feedback is heavy, because the system of which the circuit is part can suffer from spurious triggering due to contact-bounce.
Orr, T. and Thomas, D. W. Electronic sound/synthesizer: part 3, *Wireless World*, vol. 79, 1973, pp.485–90.



2. Recently-developed comparators such as the LM339, MC3402 can be operated from a single polarity supply voltage, with the zero supply line included within their common mode range. Minimum supply voltage can be as low as 2V, the output is an open collector device and the whole circuit can be t.t.l./d.t.l./c.m.o.s. compatible. In addition there are four such comparators in a single package allowing complete subsystems to be constructed with the minimum of interconnections. The example shown has the output devices of both comparators off when V_{in} lies between the reference voltages i.e. the transistor receives base current, illuminating the lamp. For inputs $> V_{REF\,(high)}$ or $< V_{REF\,(low)}$ the lamp is off. The reference voltages can be provided by a simple potential divider chain across the supply.
Smathers, R. T., Frederiksen, T. M. and Howard, W. M. LMI39/LM239/LM339 A quad of independently functioning comparators, National Semiconductor application note AN74, 1973, p.5.



3. The simplest Schmitt trigger circuit using c.m.o.s. has positive feedback across a single non-inverting stage or a cascaded pair of inverters. In these circuits the thresholds are defined by paralleling inputs of multi input gates e.g. for two inputs high the threshold of the third is $\approx 5V$ for a 15V supply. For three inputs in parallel the threshold is 8.5V. For output C high, the threshold for A is 8.5V and for B is 5V. The absence of resistive feedback keeps the input impedance extremely high, while gates C and B form a set – reset flip-flop with rapid switching once the thresholds are reached. The second circuit adds a variable bias which allows the hysteresis to be varied from zero to 50%.
Halligan, J. Schmitt trigger with c.m.o.s. gates, *Semiconductors* (Motorola) 1974/1, pp.29–30.