Solid State Colour Television Circuits

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Preface

The adoption of solid state design has completely changed c.t.v. circuitry from power supply systems to the signal output stages, implying a new servicing approach based on an understanding of how these circuits operate. These changes have been further complicated by the necessity to stabilise most operating voltages, and to incorporate over-current and over-voltage protection circuits, while the change to wide-angle tubes in some models has prompted the use of active and often complex dynamic convergence and pincushion correction circuits.

Thyristors now perform several major roles in current c.t.v. designs, being used as field oscillators, for line output/l.t. production in many Continental receivers, and to operate overload cut-outs, in addition to their traditional function of providing stabilised h.t. supplies. F.E.T.s, diacs, varicap diodes and other semiconductor devices are now widely used for a variety of purposes, while new i.c.s have been developed for 'touch-button' channel selection, for line generation, switch-mode power supplies and audio output etc., in addition to their well established signal amplifying and processing uses.

In this completely new book, the operating principles of bipolar transistors and other semiconductors are summarised, followed by stage-by-stage coverage of British, Continental and Japanese c.t.v. circuitry, written from a practical angle and illustrated with detailed diagrams.

Sincere thanks are given to Eric Ickinger, Publisher, and Colin Sproxton, Editor, of *Electrical and Electronic Trader,* and to Lionel Howes, Editor, and John Reddihough, Assistant Editor, of *Television,* for permission to reproduce the photograph on the front cover of this book and for permission to reproduce diagrams that originally appeared in these journals.

Sincere thanks are also given to A. E. Thomas, Technical Liaison, ITT Consumer Products Services Ltd., R. J. Ellis, Service Manager, Hitachi Sales (UK) Ltd., D. A. Pike, Technical Publications Dept., Thorn Consumer Electronics Ltd., E. Caldecott, Technical Manager, Grundig (UK) Ltd., L. A. Lammers, Service Manager, Lampitt Electronics Ltd. (Saba Distributors), Barry Russel, Service Manager, Mitsubishi Electric Service Ltd., and R. B. Bernard, GEC Radio & Television Ltd.

Key to Symbols

General

f	Operating frequency
P_{tot}	Total device power dissipation, specified at T_{amb} or T_{case}
T_{amb}	Ambient temperature
T_{case}	Case temperature
T_j	Junction temperature
θ_{amb}	Thermal resistance with device in free air
θ_{case}	Thermal resistance, junction to case

Transistors

C_{ob}	Common base output capacitance at specified V_{cb}
f_T	Common emitter gain-frequency product, at specified V_{ce} and I_c
G_{pe}	Common emitter power gain at specified f, P_o and V_{cc}
h_{fe}	Common emitter small signal gain at specified V_{ce} and I_c
h_{FE}	D.C. gain at specified V_{ce} and I_c
I_c	Collector current
I_e	Emitter current
I_{ceo}	Collector-emitter leakage current, base open-circuited at specified V_{ce}
I_{ces}	Collector-emitter leakage current, base emitter short circuited, at specified V_{ce}
I_{cbo}	Collector-base leakage current, emitter open-circuited at specified V_{cb}
P_o	Output power
V_{cb}	Collector-base voltage
V_{cbo}	Collector-base voltage rating, emitter open-circuited or reverse biased
V_{cc}	Collector operating voltage
V_{ce}	Collector-emitter voltage
V_{ceo}	Collector-emitter voltage rating, base open-circuited or reverse biased
V_{cer}	Collector-emitter voltage rating with resistance (specified) between base and emitter
V_{ces}	Collector-emitter voltage rating with base-emitter short-circuited
$V_{ce\,sat.}$	Collector-emitter saturation voltage, at specified I_c and I_b
V_{cev}	Collector-emitter voltage with emitter-base forward biased at specified V_{eb}
V_{ebo}	Emitter-base voltage with collector open-circuited

Diodes, Zeners and Reference Elements

C	Junction capacitance, at specified V_r and f
C_{tot}	Total device capacitance, at specified V_r
dC/dV	Slope of capacitance/voltage characteristic, at specified V_r
f_o	Series resonant frequency, at specified V_r
f_{Q1}	Frequency at which Q=1, at specified V_r
I_f	Forward current
I_{fm}	Peak forward current
I_r	Reverse current
I_o	Nominal load current, half-wave, resistive load
I_z	Zener current
I_{zm}	I_z parameter for the measurement of other characteristics
L_s	Series inductance, excluding leads
Q	Q factor ($=X_s/R_s$) at specified V_r and f
r_f	Forward slope resistance at I_f and f

Key to Symbols

Δr_f	Incremental change of r_f for specified I_f range		at specified I_z
		$V_{(br)r}$	Reverse breakdown voltage
r_s	Series resistance, at specified V_r	V_f	Forward voltage
r_z	Slope resistance of zener diode	V_r	Reverse voltage
t_{rr}	Reverse recovery time	V_{rm}	Peak reverse voltage
TC	Temperature coefficient of voltage	V_z	Zener voltage

Finally, sincere thanks are also given to the other companies who have kindly assisted with technical information and diagrams etc., namely, Bang and Olufsen (UK) Ltd., Decca Radio & Television, Ltd., Motorola Semiconductor Products Inc., Mullard Ltd., National Panasonic Ltd., Philips Electrical Ltd., Pye Ltd., Rank Radio International Ltd., Rediffusion Vision Ltd., Sanyo Marubeni (UK) Ltd., Sony (UK) Ltd., and Toshiba (UK) Ltd.

G.R.W.

Contents

Chapter 1

Devices and Principles

Although a highly theoretical knowledge of semiconductor principles is not necessary for colour television servicing, a clear understanding of their practical action is most essential. While assuming some familiarity with valved television and transistor radio circuits, the main principles of bipolar and field-effect transistors, thyristors and other semiconductor devices are first summarised, so that their operation in new and often complex c.t.v. applications can be fully appreciated.

Bipolar transistors

Construction

These transistors can be of pnp or npn type, according to the electron (negative n) or hole (positive p) enrichment of their germanium or silicon composition. While npn silicon types are the most widely used in current c.t.v. receivers, the following outline is equally true of pnp types, save that power supply polarity must be reversed.

Physical construction naturally varies widely with transistor purpose, i.e. for small or large a.f., h.f., or u.h.f. amplification, as switches, voltage or current regulators. Bipolar types can be regarded as basically a thin layer of n or p type silicon or germanium (the base) between two layers of the opposite type silicon or germanium, which form the emitter and collector elements or layers.

Bipolar transistors may therefore be considered as two series connected conduction opposed diodes, sharing a common (base) element. When a power supply is connected to the collector/emitter junction only, +ve to collector and −ve to emitter for npn types, only a very small leakage current, I_{co}, will flow between these layers.

However, application of a base current sufficient to overcome the transistor's barrier potential (0.5V–0.7V for silicon types) instigates a much larger collector current I_c, the ratio dI_c/dI_b representing the transistor's 'current amplification factor', designated h_{fe} for the common-emitter mode,

h_{fb} for the common-base mode, and h_{fc} for the common-collector mode.

Emitter current I_e is equal to the sum of I_c and I_b, and as the latter is only a small proportion of the total, I_c/I_e or alpha closely approaches unity, 0.98 being a typical figure.

Transistors are three terminal devices, so that when used as amplifiers and therefore fed from a two terminal input and also supplying output from two terminals, one of the terminals must be common to both the input and output circuits. Depending on which element or layer is common to both circuits, transistor stages operate in common-emitter, common-base or common-collector mode, the last named being more widely referred to as an emitter follower.

Each mode has its own characteristics, which vary widely between modes, and all are used in television applications, but operation in the most generally employed common-emitter mode will be considered first in order to demonstrate basic amplifying action.

As a practical example, *Figure 1.1* shows an npn transistor with an h_{fe} of 50, powered from a 20V rail via a 5k load resistor, and supplied with a base current I_b of 40μA from R_b, (500k).

Ignoring the very small leakage current, negligible in silicon types, I_c will therefore equal $I_b \times 50$ (40μA × 50) or 2mA, which will produce 10V across both load resistor and transistor. Assuming that the transistor is forward biased to the centre of the linear section of its transfer characteristic,

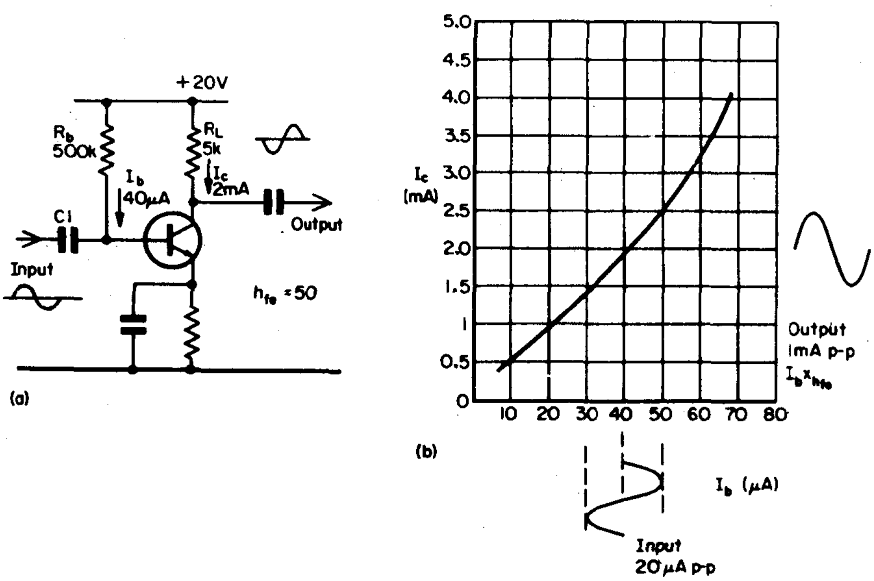

Figure 1.1. (a) Basic common emitter RC amplifier. Ignoring leakage current, negligible in silicon types at normal temperatures, application of 40μA forward bias from Rb instigates a quiescent Ic of 2mA (50.40μA), to produce 10V across both transistor and load resistor. −ve and +ve input swings will then produce magnified Ic and therefore Vc changes in opposite phase to that of the input. (b) Current amplification shown by transfer characteristic, Ic/Ib. A 20μA peak-to-peak sine-wave input produces a 1mA peak-to-peak Ic output and a 5V peak-to-peak Vc change (a.c. voltage) across the 5k load resistor

then equal amplitude +ve and −ve signal excursions applied to the base via Cl, will produce equal but magnified I_c increases and decreases.

The voltage developed across the load resistor will rise and fall proportionately and as collector load resistance is greater than the total impedance of the input circuit, voltage gain $A_v = (V_{out}/V_{in}) = h_{fe} \times R_L/(R_s + R_i)$ where R_L is load resistor value, R_s is signal source resistance, and R_i is input resistance.

While base/emitter current dictates collector current, it must of course have a driving p.d., but due to transistor input impedance varying somewhat with applied voltage, it is always more expedient and more accurate to directly calculate from actual current inputs.

For i.f. and chrominance amplifiers, the dynamic resistance of a tuned circuit, probably shunted by a loading resistor, will constitute the collector load in place of a single resistor, but the effective load impedance will be less than its nominal value, since it will be shunted by the input impedance of the following stage.

For this reason, impedance matching in multistage tuned amplifiers is often necessary and achieved in one of three ways:

(a) by means of a step-down transformer,
(b) by use of a coil tapping point, in effect acting as a step-down autotransformer,
(c) by feeding the following stage from the junction of two series connected fixed trimmers, their combined value tuning the associated coil and their ratio determining the degree of step-down.

Cut-off and saturation

If signal strength is strong enough to reduce collector current to zero at peak −ve values, i.e. when the instantaneous −ve signal value reduces the +ve forward bias to below the transistor's barrier potential, the cessation of collector current (cut-off) will result in flattening or clipping of the peak +ve output excursions, the phase reversal being caused by normal collector/emitter action. At such times, collector/emitter voltage will equal supply voltage, there being no voltage drop across the collector and emitter resistors.

Conversely, if the +ve base signal excursions are sufficiently high, they can drive collector current to saturation point, after which further increases in +ve drive fail to produce further increases in I_c, and the transistor is bottomed.

The heavy collector current then reduces V_c below V_b, so that both junctions become forward biased. As the small voltages then developed across the junctions are in series opposition, the net $V_{ce(sat)}$ represents the difference between them, usually a small fraction of a volt. Clearly, the higher the value of collector load resistor, the more easily a transistor can be driven to saturation.

In some receivers therefore, the square wave required for operating the PAL switch is obtained by alternately driving a transistor from cut-off to saturation by means of a high amplitude ident sine wave, as shown in *Figure 1.2*.

Transistors can therefore function extremely well as switches, for when cut-off, leakage current in modern silicon types is usually so small that virtually the full supply voltage is developed across them and they equate with a high value resistor. When saturated or bottomed, $V_{ce(sat)}$, as mentioned, is a very small potential indeed and the device equates with a low value resistor, in the region of 50 ohms for medium power types.

However, even though current is at a maximum when transistors are bottomed, the wattage dissipated is quite small, and they can safely operate in this condition indefinitely.

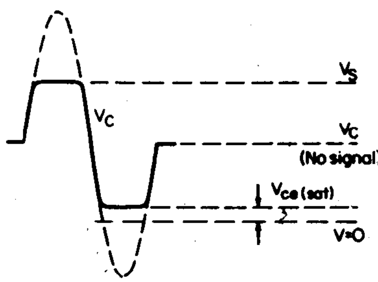

Figure 1.2. Production of a near square wave by a high amplitude sine wave driving a transistor alternately from cut-off to saturation

Mode characteristics

Common emitters *(Figure 1.3a)*

(a) High current gain, h_{fe}, ranging from 40 to 200, giving a high voltage gain with output phase reversed.
(b) A medium value input resistance, h_{ie}, 0k5 to 2k5, which decreases with increases in load resistor value.
(c) A markedly higher output resistance, which reduces with reducing signal source resistance.

Due to their high current and voltage gains, implying higher power gains, plus their medium value input and output impedances which facilitate interstage coupling, common emitters are the most widely used type of amplifier except at u.h.f., where common-base types give a better performance.

Voltage amplification, $A_v = (V_{out}/V_{in}) = h_{fe} \times R_L/(R_s + R_i)$, but as signal source resistance is usually large compared to R_i, this formula can be reduced with little loss in accuracy to $A_v = h_{fe} \times (R_L/R_s)$, and where the emitter resistor is undecoupled, or only partially so, as in many luminance stages, $A_v = (R_L/R_e)$.

Common base *(Figure 1.3b)*

(a) Gives less than unity current gain, but a high voltage gain, with output in phase with input.
(b) Has a very low input impedance, h_{ib}, averaging about 50 ohms, which rises with increases in load resistor value.

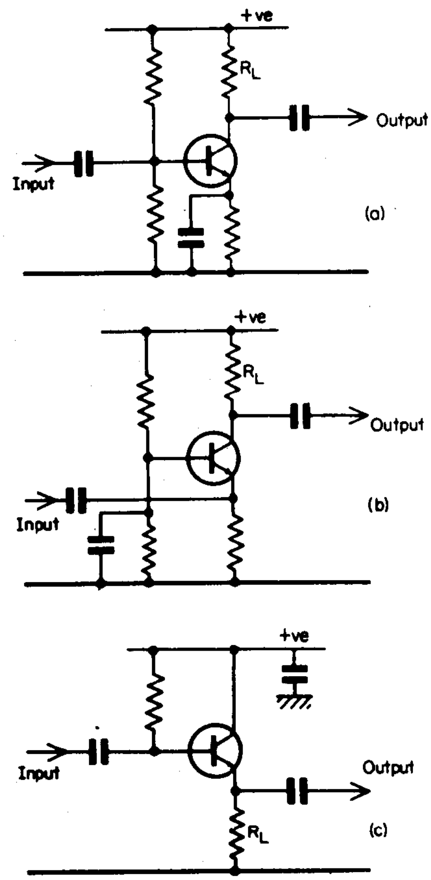

Figure 1.3. The three transistor modes. (a) Common emitter. (b) Common base—the base being signalwise at chassis potential, input is applied across emitter and chassis and output taken from collector and chassis. (c) Common collector (emitter follower)—since the collector is signalwise at chassis potential, input is applied across base and chassis while output is taken from emitter and chassis

(c) High output impedance, 100k–500k, which increases with increases in signal source resistance.

Multistage design is naturally greatly hampered by the extreme disparity of input/output impedance values, but the low input impedance of common-base stages and their ability to operate at very high frequencies make them particularly suitable for use as r.f. amplifiers and mixer/oscillators.

As current gain is almost unity, $A_v = V_{out}/V_{in} = R_L/R_s$.

Common collector (emitter follower) *(Figure 1.3c)*

(a) Gives a high current gain, similar to that of common emitters, i.e. from 40 to 200, but slightly less than unity voltage gain, output being in phase with input.
(b) High input resistance, which increases with increases of load resistor and h_{fe} values, ranging from 10k to 0.5M.
(c) Low output impedance, which increases as signal source impedance approaches about 1k, ranging from 20 to 100 ohms.

Due to their ability to reproduce an output voltage similar to that of the input, but across a much lower value load resistor, emitter followers are widely used as buffer and/or impedance matching stages in many c.t.v. applications, in particular (a) after luminance detectors, to isolate the load resistor from the input capacitance of the nominal first amplifying stage; (b) between reference oscillators and synchronous detectors; and (c), between timebase generators and driver or output stages. They are also used in some Saba models to isolate input capacitance of the shadowmask cathodes from the luminance output load resistor.

Since emitter followers are so widely used, it becomes important to appreciate how this high input impedance is developed. As the emitter load resistor is unbypassed, variations of signal input, V_{in}, produce similar but slightly smaller voltage variations across it, so that the effective base/emitter potential is $V_{in} - V_e$. The resulting base current will therefore be that produced by this fraction of input voltage and not V_{in}.

If $V_{in} - V_e$ is assumed to be only 0.1 of V_{in}, the resulting base current I_b will also be one tenth of that if V_{in} was directly connected across the transistor base/emitter junction, so that the impedance presented to the input signal appears to be ten times its nominal value. An emitter follower with a current gain of 70 and a load resistor of 300 ohms would have an input impedance of 70 × 300 or 21k. Output impedance is approximately R_s/h_{fc} where R_s is the signal source resistance, in shunt with the value of the emitter load.

With the same transistor as before, signal fed from a detector load resistor of 4k2, then output impedance equals 4200/70 or 60 ohms, reduced to a net figure of 50 ohms by its 300 ohm emitter resistor.

The basic emitter-follower circuit and a typical practical example are shown in *Figure 1.4*, forward bias for the latter being supplied from the junction of potential divider R1/R2, decoupled by C1, and to which the earthy end of the detector load R3 is returned.

Applying forward bias in this manner prevents R1 and R2 from shunting the detector load. As the detector diode is arranged to give a −ve output, collector current reduces on signal application, minimum values occurring at sync pulse tips to control the a.g.c. amplifier.

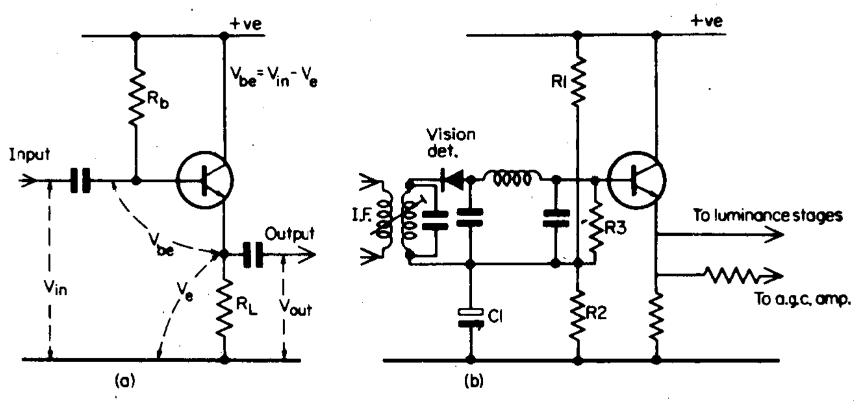

Figure 1.4. (a) Basic emitter-follower circuit. (b) Practical design, forward bias from the junction of potential divider R1/R2 being applied via detector load R3 to the transistor base, decoupler C1 returning the earthy end of the detector circuit to chassis

Darlington pairs

While transistor pairs can be used in a variety of arrangements, as cascode i.f. amplifiers, noise-gated sync separators, for a.g.c. or a.c.c. control, signal matrixing and beam limiting etc., the classic dual transistor combination, the Darlington pair, is becoming increasingly used in colour receivers, particularly as the first luminance stage. This combination is also referred to as the super alpha pair, since their combined current gain commonly reaches 0.9995, and when in the common-collector mode, also as the double emitter follower.

Both arrangements are shown in *Figure 1.5,* (a) in the more widely used emitter-follower mode, and (b) in the common emitter mode, the distinguishing feature in both instances being that the emitter current of Tr1 is the base current of Tr2, so that $I_{b2} = h_{fe1} \times I_{b1} + I_{b1}$. Overall gain equals the product of their individual values, so for individual h_{fe} figures of 50, overall current gain is 2500.

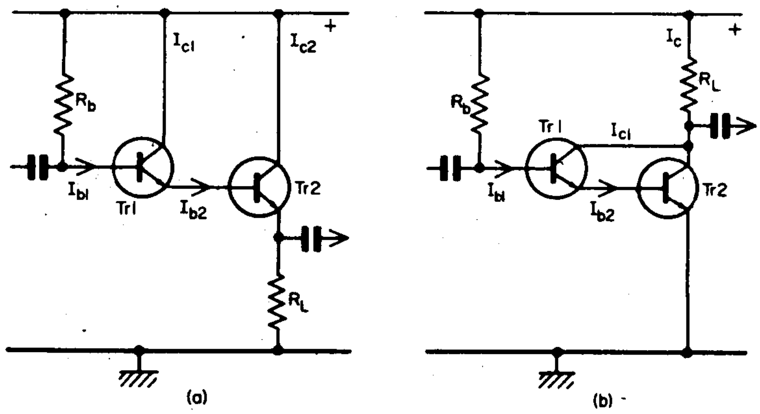

Figure 1.5. Super alpha or Darlington pairs.
(a) In common-collector mode, and (b) in common-emitter mode, the emitter current of Tr1 in both examples being the base current of Tr2. Overall current gain therefore closely approximates to $h_{f1} \times h_{f2}$, with the alpha figure being almost unity. 0.9996 a typical figure

Input impedance, especially for the double emitter follower, is very high, so forward bias to Tr1 is usually via a single resistor from the l.t. rail and not from the usual potential divider to maintain this high input figure.

For all practical purposes therefore, both arrangements can be viewed as a single transistor of high current gain and high input impedance, and in fact, various combinations can be obtained in a single encapsulation.

Working characteristics

Graphs are used in considerable variety to show the operating characteristics of transistors, i.e. maximum voltage ratings, thermal variations on I_c, base/emitter and collector/emitter capacitance with variations in applied voltage, cut-off frequency, and changes in current gain with V_{ce} etc. The three most widely used to illustrate their practical capability are (a), the *input characteristic, V_{be}/I_b*; (b), the *transfer* or *mutual characteristic* (current gain) I_c/I_b; and (c), the *output characteristic, V_{ce}/I_c*.

These three characteristics for a typical npn h.f. transistor, the BF115, are shown in *Figure 1.6.*

The *input characteristic* shows that the base/emitter junction is almost non-conductive until the barrier potential, 0.5–0.7V for silicon types, is exceeded, after which very small increases in V_{be} produce large increases in I_b, indicating a fairly low input resistance for the common-emitter mode employed. Since I_b instigates I_c, V_{be} must exceed the barrier potential before the transistor becomes operative.

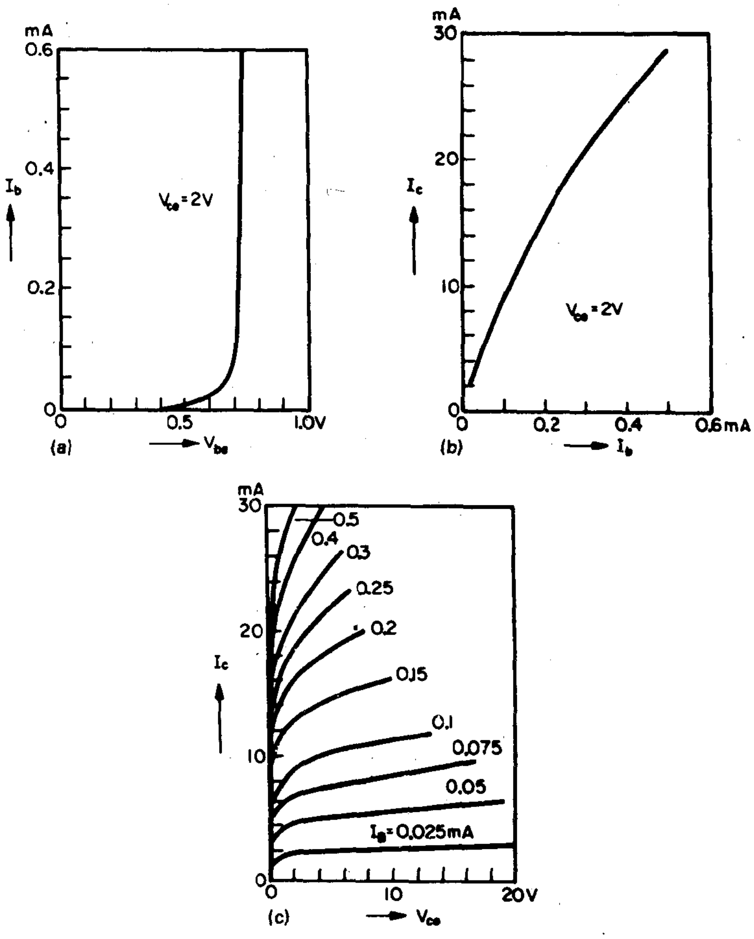

Figure 1.6. Main characteristics of a typical npn h.f. transistor, the BF115.
(a) Input characteristics, V_{be}/I_b with V_{ce} constant, and showing negligible base current till the base/emitter barrier potential is exceeded. (b) Mutual or transfer characteristic (current gain) I_c/I_b with V_{ce} constant. (c) Output or transfer characteristic, V_{ce}/I_c, for fixed I_b values

The *transfer* or *mutual characteristic* shows a fairly linear rise throughout its length, the linearity further improving at higher collector currents, while the *output characteristic* shows that especially at small base currents, large changes in collector voltage produce only small changes in collector current, indicating a relatively high output resistance.

Thermal effects

Transistor leakage currents between collector and emitter and therefore barrier potential vary with temperature changes, the leakage current doubling for every 8°C increase in germanium types, and for every 5° increase in silicon types. However, as the leakage current of silicon types is only about 1% of that for comparable germanium types, the use of silicon types greatly helps circuit design.

Nevertheless, for power types, bias stabilising/current limiting circuitry and heat sinks are still essential to prevent maximum power dissipation figures being exceeded and avoid the risk of thermal runaway.

h Parameters

These are widely used to indicate transistor parameters in numerical values, and termed hybrid or *h* parameters, since the terms employed are of mixed character, i.e. expressed in ohms, as a ratio, or as an admittance, as follows:

- h_i, input impedance, $= V_{in}/I_{in}$ with output short circuited and measured in ohms.
- h_r, reverse feedback factor, i.e. the fraction of output voltage fed back in opposition to the input signal, equal V_{in}/V_o with input open circuited, and therefore a voltage ratio.
- h_f, forward current gain, equalling I_{out}/I_{in}, with output short circuited, and therefore a current ratio.
- h_o, output admittance, equal I_{out}/V_{out} with input open circuited and measured in siemens, or more usually µS.

  As admittance is the reciprocal of impedance, a transistor with an output resistance of 50k would have an output admittance of 20 µS.

In *h* notation, a second subscript letter (b, c or e) is added to indicate the mode of the transistor referred to, so that h_{fe} indicates the current gain of a transistor in the common-emitter mode, while h_{ic} represents the input impedance of a transistor in the common-collector mode.

In the transistor 'black box' common emitter representation of *Figure 1.7*, the input circuit comprises the input impedance h_{ie} in series with a voltage generator developing the h_{re} fraction of output voltage fed back in opposition to the input signal.

The constant current generator develops h_{fe} times the input current, with the resistor representing the output impedance of $1/h_{oe}$, i.e. the reciprocal of the output admittance of the transistor.

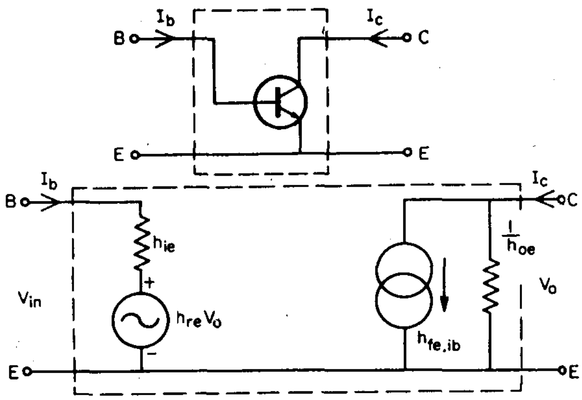

Figure 1.7. h-parameter 'black box' equivalent circuit for common-emitter mode

Stabilisation

In almost all instances, forward bias for signal amplifying transistors is applied from the junction of a potential divider across the power supply rail and chassis to stabilise their operations against thermal drift, for if emitter current tends to rise with rising ambient temperature, a proportional voltage increase develops across its emitter resistor, and as potential divider junction voltage is reasonably constant, the net base/emitter potential reduces. The lower the value of resistors used in the potential divider, the more effectively is V_b held constant, and the better the stability factor.

Stabilisation can be further improved by shunting the bottom resistor of the potential divider with a miniature thermistor, so that if ambient temperature increases, thermistor resistance decreases to reduce V_b and so maintain a closely constant no-signal I_c. This method is widely used in sound and field output stages, where temperature changes and their effects can be most marked *(Figure 1.8a)*. Operation can also be stabilised by supplying

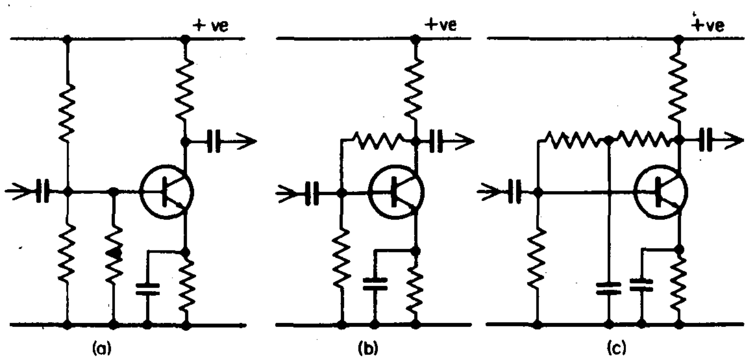

Figure 1.8. Bias stabilisation methods.
(a) With an n.t.c. resistor (thermistor) shunted across the lower potential-divider resistor. (b) With forward bias supplied from the collector. (c) Similar to (b), but using two resistors, decoupled to chassis at their junction to eliminate signal negative feedback