PHILIPS OC 170

HIGH-FREQUENCY GERMANIUM TRANSISTOR

for application as oscillator-mixer in short-wave receivers and as I.F. amplifier in F.M. receivers

INTRODUCTION TO THE PHILIPS ALLOY-DIFFUSED TRANSISTOR

Up till now all Philips transistors were of the germanium p-n-p alloy type. The new Philips alloy-diffused transistor OC 170 is the first type in which, as its name indicates already, also the new diffusion principle has been applied.

In practice it is very difficult to make alloy transistors with an average frequency cut-off above 20 Mc/s, because the base layer thickness required for obtaining higher cut-off frequencies is too small to be realized by alloying techniques which at the same time must be suitable for mass production.

Diffusion, being a slow process, makes it possible to obtain very thin layers, because this process can be controlled very accurately by proper choice of diffusion temperature and time.

Due to the diffusion a gradient of impurities is built in the layer which is going to serve as the base layer. This gradient gives rise to the so-called drift effect, adding another improvement to the cut-off frequency.

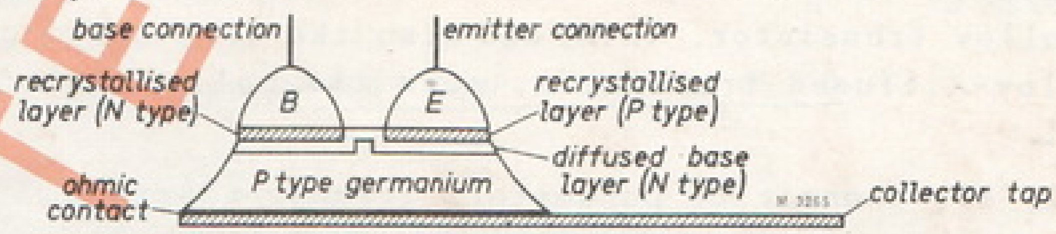
Furthermore the diffusion offers the possibility of obtaining a very small value of the collector capacitance even together with a relatively low value of the base resistance.

The problem of alloying an emitter junction and a base contact on the thin base layer obtained by diffusion is solved by carrying out the alloying and diffusion simultaneously.

CONSTRUCTION OF THE PHILIPS ALLOY-DIFFUSED TRANSISTOR

The construction of the OC 170 is quite different from the alloy types as can be seen in the schematic drawing below.

The transistor is built up on a piece of *p*-type germanium on which two small metal pellets are placed. Pellet *B* contains only an *n* type impurity, whereas pellet *E* contains both a *p* type and an *n* type impurity.



When this assembly is heated up to a certain temperature, germanium will dissolve into the metal pellets until saturation is reached.

Keeping the assembly for a certain time at this temperature, diffusion of the impurities in the pellets *B* and *E* takes place. This means that the impurity atoms penetrate into the solid germanium. However, the element used as *p* type impurity in pellet *E* has such a low diffusion constant, or in other words, penetrates so slowly into the solid germanium, that the diffusion of this element may be neglected.

The *n* type impurity in pellet *E* and *B* has a much greater diffusion constant. These atoms penetrate from the molten pellets into the solid germanium, thus providing an *n* type layer underneath the pellets. Because diffusion also takes place via the gas atmosphere in the oven, the free surface of the germanium crystal is also covered with a thin *n* layer.
When now the assembly is cooled down, a layer of germanium recrystallises from the pellets as in the normal alloy technique. The recrystallised layer of pellet *E* contains very many atoms of the *p* type impurity and gives therefore a *p* type germanium layer. The germanium layer recrystallised from pellet *B* is of course of the *n* type because there are no other impurities in the pellet. So this layer gives a non-rectifying junction with the diffused *n* type layer.

After suitable etching of the unit and making connections to the germanium and the metal pellets, a p-n-p transistor is obtained, in which the original *p* type germanium is the collector, and pellets *B* and *E* are base and emitter respectively.

SOME PROPERTIES OF THE ALLOY-DIFFUSED TRANSISTOR

Some important features of the above-described alloy-diffused transistor may be summarized as follows:

It is possible to make an *n* type diffused base layer of a few microns only. This means that the transit time of the injected holes from the emitter to the collector is very short.

Furthermore, the concentration of the impurities in the diffused base layer is not homogeneous, but decreases when passing from the emitter to the collector junction. This concentration gradient produces a drift field in the base region, which reduces the transit time. Due to this very thin base layer and the presence of the drift effect, the cut-off frequency of an alloy-diffused transistor is high, e.g. 70 Mc/s in the case of the OC 170.

The collector-to-base capacitance of the alloy-diffused transistor is small, e.g. 1.8 pF with the OC 170 at V_{CB} = -6 V. This capacitance is formed mainly by the depletion layer capacitance of the collector-to-base junction. The thickness of the depletion layer at a given collector voltage, and so the capacitance, depends strongly on the resistivity of the collector germanium material. In the design of the alloy-diffused transistor the resistivity of the collector germanium can be given a high value, compared with the specific resistivity of the collector of a normal alloy transistor. This, and also the very small dimensions of the alloy-diffused transistor, make the collector capacitance very small.

Practically all transistor parameters (transconductance, feedback, input and output admittances, etc.) depend to a smaller or greater extent on the base resistance, which therefore should be as small as possible. As the impurity concentration in the base layer of the alloy-diffused transistor is high close to the emitter junction, a low base resistance is obtained in spite of the very thin base layer. There are various ways to define and measure a base resistance. The so-called feedback base resistance of the OC 170, measured at 3 Mc/s, is approximately 40 Ω.

Tentative technical data of the OC 170

MECHANICAL DATA

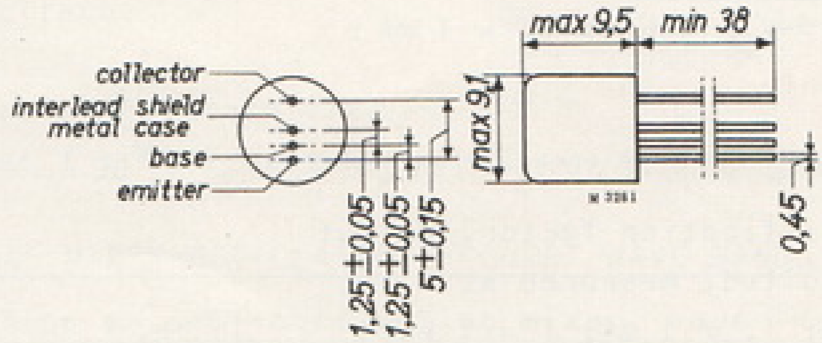


Fig.1. Dimensional outline (im mm) of the OC 170.

THERMAL DATA

junction temperature rise, transistor in free air (from 0-55 °C) — K = max. 0.5 °C/mW

ABSOLUTE MAXIMUM RATINGS

Collector

voltage, base reference

d.c.	$-V_{CB}$	= max. 20 V
peak	$-V_{CBM}$	= max. 20 V

current

d.c.	$-I_{C}$	= max. 10 mA
peak	$-I_{CM}$	= max. 10 mA

dissipation at T_{amb} = 45°C — P_C = max. 60 mW

Emitter

voltage, base reference

d.c.	$-V_{EB}$	= max. 0.5 V
peak	$-V_{EBM}$	= max. 0.5 V

current

d.c.	I_{E}	= max. 10 mA
peak	I_{EM}	= max. 10 mA

Temperature

junction	T_j	= max. 75 °C
storage	T_s	= min. -55 °C = max. +75 °C

CHARACTERISTICS AT AN AMBIENT TEMPERATURE OF 25 °C

Common base circuit

collector current, measured at $-V_{CB}$ = 6 V; I_E = 0 — $-I_{CBO}$ = 2 µA

collector breakdown voltage (= collector-to-base voltage at which $-I_C$ = 50 µA; open emitter) — $-V_{CB}$ = min. 20 V

emitter breakdown voltage (= emitter-to-base voltage at which $-I_E$ = 50 µA; open collector) — $-V_{EB}$ = min. 0.5 V

current amplification cut-off frequency, measured at $-V_{CB} = 6$ V; $I_E = 1$ mA	$f_{\alpha b}$	= avg. 70 Mc/s = min. 40 Mc/s

<u>Common emitter circuit</u>

measured at $-V_{CE} = 6$ V; $I_E = 1$ mA :

base current	$-I_B$	= 20 µA
base voltage	$-V_{BE}$	= 0.3 V
current amplification factor, output short-circuited, measured at $-V_{CE} = 6$ V; $I_E = 1$ mA; f = 1 kc/s	h_{fe}	= 80

<u>Noise figure, measured at</u>

a) $-V_{CE} = 6$ V; $I_E = 1$ mA; $R_s = 500\ \Omega$; f = 1000 c/s	F	= 25 dB
b) $-V_{CE} = 6$ V; $I_E = 1$ mA; $R_s = 200\ \Omega$; f = 0.45 Mc/s	F	= 4 dB
c) $-V_{CE} = 6$ V; $I_E = 1$ mA; $R_s = 150\ \Omega$; f = 10.7 Mc/s	F	= 5 dB

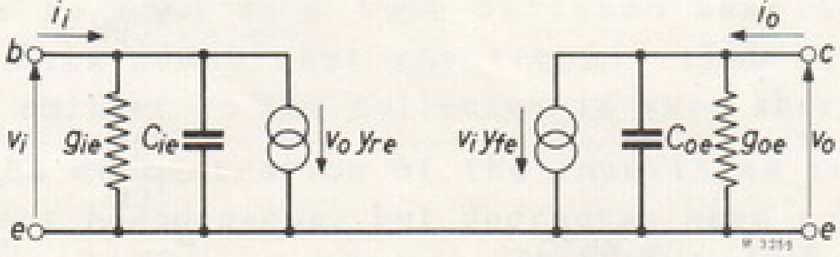


Fig.2. Equivalent transistor circuit.

<u>Small-signal parameters of the equivalent circuit of Fig.2</u>

a) measured at $-V_{CE} = 6$ V; $I_E = 1$ mA; f = 0.45 Mc/s

input conductance	g_{ie}	= 0.5 mA/V
input capacitance	C_{ie}	= 90 pF
feedback conductance	$-g_{re}$	= 0.1 µA/V
feedback capacitance	$-C_{re}$	= 1.8 pF
transfer admittance (absolute value)	$\lvert Y_{fe} \rvert$	= 36 mA/V
output conductance	g_{oe}	= 1 µA/V
output capacitance	C_{oe}	= 5 pF
maximum available unilateralised power gain at f = 0.45 Mc/s	G_a	= 57 dB[1])

b) measured at $-V_{CE} = 6$ V; $I_E = 1$ mA; f = 10.7 Mc/s

input conductance	g_{ie}	= 3 mA/V
input capacitance	C_{ie}	= 65 pF
feedback conductance	$-g_{re}$	= 20 µA/V
feedback capacitance	$-C_{re}$	= 1.6 pF

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1) The maximum available power gain is defined as $G_a = \dfrac{\lvert y_{fe} \rvert^2}{4\, g_{ie} g_{oe}}$

transfer admittance (absolute value)	$\lvert Y_{fe} \rvert$	=	30 mA/V
phase angle of transfer admittance	ϕ_{fe}	=	-30 ^{o}
output conductance	g_{oe}	=	60 µA/V
output capacitance	C_{oe}	=	4.5 pF
maximum available unilateralised power gain at f = 10.7 Mc/s (see note 1 page 4)	G_a	=	31 dB

CHARACTERISTICS AS MIXER-OSCILLATOR AT SHORT-WAVE BANDS

1. Typical operation as self-oscillating mixer, covering the frequency range from 6 Mc/s - 16 Mc/s (19 m - 50 m band)

d.c. collector-to-emitter voltage	$-V_{CE}$	=	7.8 V
d.c. emitter current	I_E	=	1 mA
oscillator voltage (emitter-to-earth):			
at f = 6 Mc/s	V_{osc}	=	0.13 V
at f =16 Mc/s	V_{osc}	=	0.23 V
conversation gain [2]			
at f = 6 Mc/s (approx.)	G_c	=	25 dB
at f = 16 Mc/s (approx.)	G_c	=	20 dB

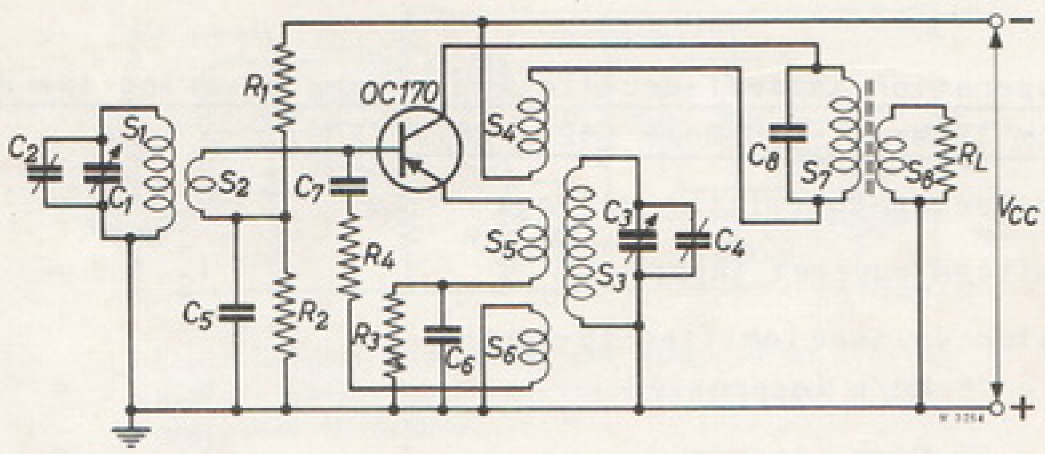

Fig.3. Circuit diagram of a self-oscillating mixer.

Circuit data (see Fig.3)

R_1 = 10 kΩ	$C_1 = C_3$ = 35 - 280 pF; variable
R_2 = 1.8 kΩ	$C_2 = C_4$ = 2 - 8 pF; trimmer
R_3 = 1.2 kΩ	$C_5 = C_6$ = 2.2 kpF; ceramic
R_4 = 56 Ω	C_7 = 39 pF; ceramic
R_L = 1600 Ω	C_8 = 220 pF; ceramic

Interlead shield of the OC 170 connected to earth

Antenna coil (construction see Fig.4)

S_1 = 23 turns of 0.8 ø enamelled copper wire closely wound on a former with a diameter of 10 mm.

Inductance : 2.5 µH

Q (unloaded): 110

S_2 = 3 turns of 0.25 ø enamelled copper wire, wound in S_1

[2] The conversion gain is defined as the ratio between the I.F. power in a 1.6 kΩ load resistor, connected to the output terminals of the I.F. filter and the available H.F. power in the antenna circuit (1.6 kΩ being the average value of the input resistance of the I.F. transistor).

Oscillator coil (construction see Fig.5)

S_3 = 21 turns of 0.8 ⌀ enamelled copper wire closely wound on a former with a diameter of 10 mm.

Inductance : 2.15 μH

Q (unloaded): 100 at f = 6 Mc/s
100 at f = 15 Mc/s

S_4 = 6 turns of 0.25 ⌀ enamelled copper wire, wound in S_3 at earth side

S_5 = 2 turns of 0.25 ⌀ enamelled copper wire, wound in S_3 at earth side

S_6 = 6 turns of 0.25 ⌀ enamelled copper wire

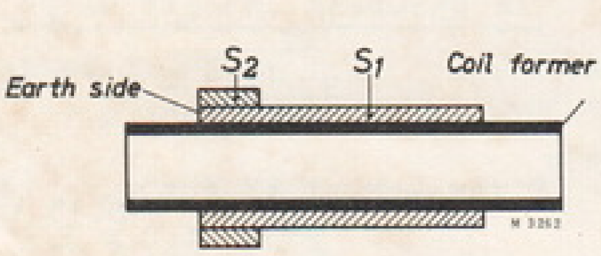

Fig.4. Antenna coil.

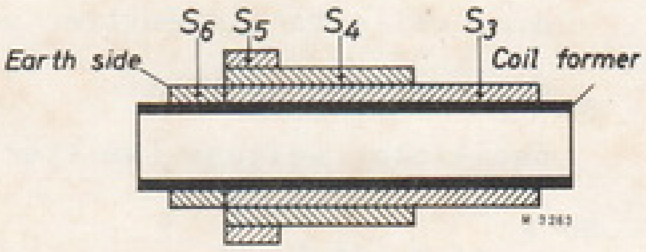

Fig.5. Oscillator coil.

I.F. Transformer

S_7 = 0.55 mH
Q (unloaded) = 160
Transformer ratio S_7 to S_8 = 11.6 : 1

2. Typical operation as self-oscillating mixer, covering the frequency range from 15 Mc/s - 25 Mc/s (12 - 20 m band)

d.c. collector-to-emitter voltage	$-V_{CE}$	=	7.8 V
d.c. emitter current (approx.)	I_E	=	1 mA
oscillator voltage (emitter-to-earth)			
at f = 15 Mc/s (approx.)	V_{osc}	=	0.3 V
at f = 25 Mc/s (approx.)	V_{osc}	=	0.2 V
conversion gain (see note 2 page 5)			
at f = 15 Mc/s (approx.)	G_c	=	10 dB
at f = 25 Mc/s (approx.)	G_c	=	8 dB

Circuit data (see Fig.3)

R_1 = 10 kΩ	C_1 = C_3 = 55 - 180 pF; variable
R_2 = 1.8 kΩ	C_2 = C_4 = 3 - 25 pF; trimmer
R_3 = 1.2 kΩ	C_5 = 2.2 kpF; ceramic
R_4 = 47 Ω	C_6 = C_8 = 220 pF; ceramic
R_L = 1600 Ω	C_7 = 47 pF; ceramic

Interlead shield of the OC 170 connected to earth

Antenna coil (construction see Fig.4)

S_1 = 8 turns of 0.8 ⌀ enamelled copper wire closely wound on a former with a diameter of 10 mm.

Inductance : 0.64 μH

Q (unloaded): 105 at f = 15 Mc/s ; 125 at f = 25 Mc/s

S_2 = 1 turn of 0.25 ⌀ enamelled copper wire wound in S_1

Oscillator coil (construction see Fig.5)

S_3 = 7.5 turns of 0.8 ø enamelled copper wire closely wound on a former with a diameter of 10 mm.

Inductance : 0.58 µH

S_4 = 4 turns of 0.25 ø enamelled copper wire

S_5 = 1 turn of 0.25 ø enamelled copper wire

S_6 = 2 turns of 0.25 ø enamelled copper wire

I.F. transformer

S_7 = 0.55 mH
Q (unloaded): 160
Transformer ratio S_7 to S_8 = 11.6 : 1

CHARACTERISTICS AS I.F. AMPLIFIER AT 10.7 Mc/s

Fig.6 gives one stage of an I.F. amplifier,having four identical stages, for a frequency of 10.7 Mc/s.
The load of the stage (in the practical circuit the input resistance of the following transistor) is 100 Ω; the source resistance(in the practical circuit the output resistance of the preceding transistor) is 5.6 kΩ.

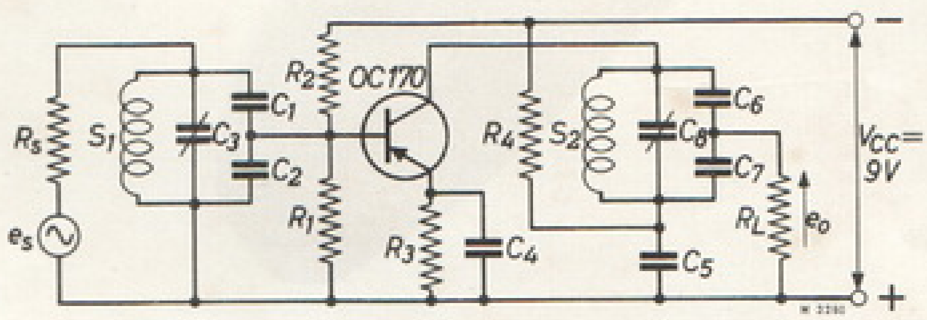

Fig.6.Circuit diagram of one stage of an I.F.amplifier having four identical stages, for a frequency of 10.7 Mc/s.

Circuit data

R_1 = 5.6 kΩ	C_1 = C_6 = 82 pF	S_1 = S_2 = 2.47 µH
R_2 = 22 kΩ	C_2 = C_7 = 470 pF	
R_3 = 1.5 kΩ	C_3 = C_8 = 25 pF	Q (unloaded) = 100
R_4 = 1.5 kΩ	C_4 = 2.2 kpF	
R_s = 5.6 kΩ	C_5 = 2.2 kpF	Q (loaded, nominal transistors) = 35
R_L = 100 Ω		

Interlead shield of the OC 170 connected to earth

Power gain

Ratio of the power, delivered into the load resistance of 100 Ω and the power delivered into the input terminals of the transistor G = 22 dB [3])

[3]) The gain, measured in the circuit of Fig.6 and defined as $\frac{e_o^2}{e_s^2} \cdot \frac{4 R_s}{R_L}$ is 18.2 dB. This figure, however, includes the insertion losses of both the tuned circuits (3.8 dB each).

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