

# Parametric Amplification

OPERATION BEYOND NORMAL CUT-OFF FREQUENCY

AN interesting mode of operation for high-frequency transistors has been developed which gives input characteristics similar to a parametric amplifier and allows useful conversion gains to be obtained beyond the normal cut-off frequency of the transistor.

Normally available high-frequency transistors offer a maximum oscillation frequency of around 1000Mc/s. In this new mode of operation it was possible to use a high-frequency transistor with a normal cut-off frequency of 600Mc/s at 1000Mc/s input frequency in a third harmonic mode mixing circuit. This gave 50dB conversion gain with a noise figure of 7dB for an intermediate frequency of 10.7Mc/s.

The high-frequency behaviour of a transistor is mainly expressed by its cut-off frequency and determined by its emitter capacity, which is formed by the barrier layer capacity  $C_{es}$  and the diffusion capacity  $C_{ed}$ . Theory shows that the current-dependent or diffusion capacity depends in the following manner on the thickness of the base:

$$C_{ed} = 39 (W^2/2D) I_e \quad \dots \quad (1)$$

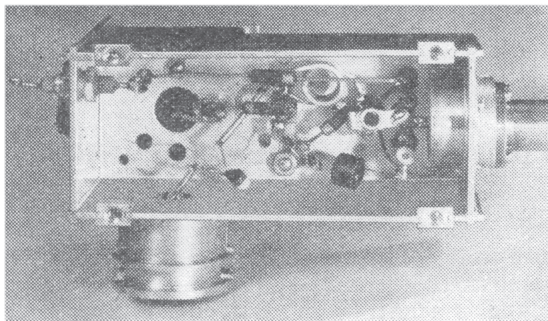
where  $W$  = width of the base,  $D$  = diffusion constant of the holes in a p-n-p transistor, and  $I_e$  = emitter current.

The input cut-off frequency is given by:—

$$f_o = 1/(2\pi r_{bb} C_e) \quad \dots \quad (2)$$

where  $r_{bb}$  = intrinsic base resistance and  $C_e$  = total emitter capacity. The diffusion capacity in the grounded-base circuit appears like an inductance which can be made to cancel the barrier-layer capacity (on the convention that the direction of voltage and current is counted as positive). If by this process  $C_e$  can be made equal to zero,  $f_o$  will reach infinity. In the following part we will call this condition of operation "current-tuned".

The circuit which is to be discussed is shown in the diagram. The 2N700 high-frequency transistor



Underneath view of transistor parametric amplifier

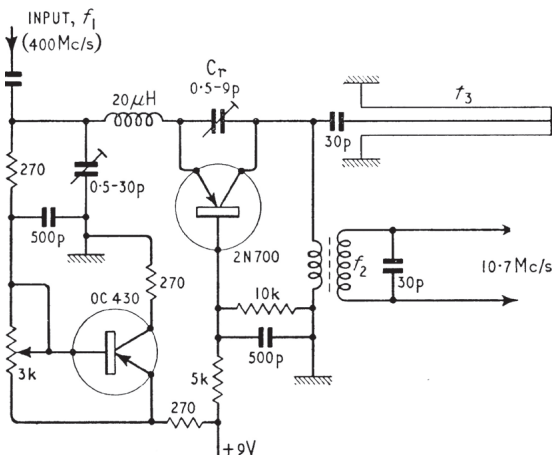
is used as a negative-feedback oscillator in which the oscillation frequency  $f_3$  (smaller than  $f_{max}$ , the frequency at which the gain falls to unity) is determined mainly by the coaxial line. Capacitor  $C_r$  controls the amount of feedback and thereby the conversion gain. From the theory of feedback amplifiers, the output impedance will be transferred by this capacity  $C_r$  to the input as a negative resistance with an inductive component. This capacity forms with the input circuit a capacitive divider and matching network and must be adjustable. For high emitter current and "current-tuned" conditions the input is real and has the value

$$r_e = (KT_o/q) (\alpha/I_e) + r_{bb} \quad \dots \quad (3)$$

where  $K$  = Boltzmann's Constant,  $T_o$  = absolute temperature,  $q$  = charge of an electron and  $\alpha$  = current gain. This is correct even beyond the normal cut-off frequency and will only be limited by the transit time of the minority carriers across the effective base width. To achieve this condition properly it has been found most convenient to use a ZG-Diagraph, since this readily enables the input impedance to be set to the correct resistive value, and it is also necessary to use an electronically regulated source which allows the voltage across the emitter and base to be set, and yet which keeps the emitter current constant when once set.

One can thus consider the input of the transistor as a varactor with a relatively high resistor ( $r_e$ ) in series. Since we are dealing with an oscillating feedback circuit, the series resistor is negative and the input circuit appears to have a high  $Q$  at both the input and oscillating frequencies ( $f_1$  and  $f_3$ ) provided that these only differ by a small amount, e.g., by the magnitude of the intermediate frequency  $f_3$ . This also applies to harmonics of  $f_3$ . For example, taking  $f_2$  as 10Mc/s one can use the third harmonic of a 300Mc/s oscillating frequency to get conversion gain for a 910Mc/s input signal.

The noise is mainly determined by the value of  $r_{bb}$  and is extremely low even up to 2000Mc/s, for at such frequencies and at high currents the mag-



# with Transistors

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nitude of the first part of equation (3) becomes zero.

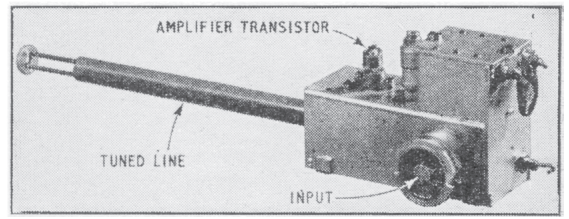
Amplification is produced because, for a properly adjusted transistor, the input circuit appears to have a high Q and is, just like any parametric amplifier, periodically tuned within the needed bandwidth as the transistor impedance is varied from the capacitive to the inductive side by the oscillating frequency (which varies  $C_{ed}$  by modulating the emitter current). Since the intermediate frequency also appears at the input, the transistor can be used to amplify  $f_2$  also.

TABLE

Frequency (Mc/s)	Transistor	Amplification (dB)	Noise-figure (dB)
88-100	OC 615	85	3
88-100	AF 114	88	3.2
*200	OC 615	83	3
*400	OC 615	46	5
*600	OC 615	25	8
600	AF 102	46	6
600	AFY 11	70	5
600	AF 122	47	7
600	AF 106	50	6
1000	AF 106	50	8
1000	2N 1141	60	7
1000	V 122†	55	7
2000	V 122†	35	9
2000	2N 700	30	11

\*Fundamental frequency at 100Mc/s, harmonic mixing.

†Silicon npn transistor, similar to AFY 10 or 2N706.



The table gives practical examples for different frequencies and transistors. (In each case the bandwidth was 500kc/s and the intermediate frequency 10.7Mc/s.)

In conclusion I should like to thank Dr. Röchardt of the development department of Siemens' semiconductor factory and Dr. Engbert, of the semiconductor division of Telefunken for their valuable contributions to the success of this work. The firms, Valvo and Intermetall have helped me by providing high-frequency transistors so that this investigation could be carried out on the broadest basis.

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