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:

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

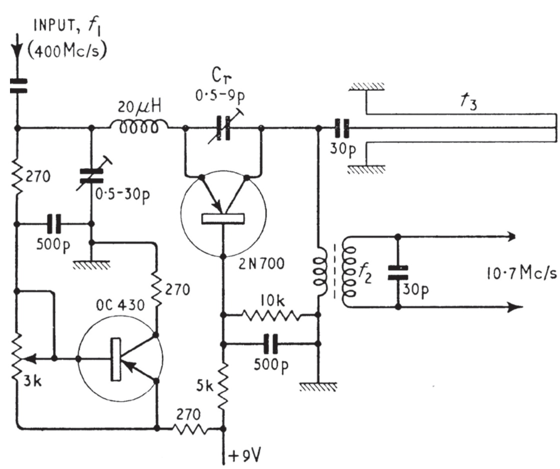
where W = width of the base, D = diffusion constant of the holes in a p–n–p transistor, and I_e = emitter current.

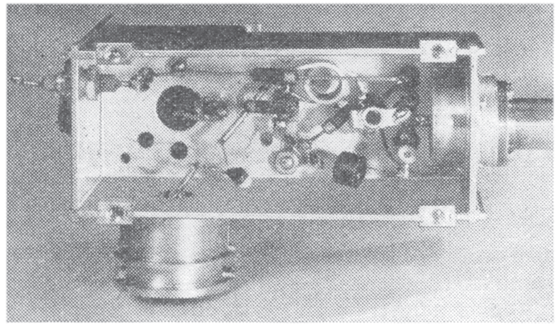
The input cut–off frequency is given by:—

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

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

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

where K = Bolztmann's Constant, T_o = absolute temperature, q = charge of an electron and α = 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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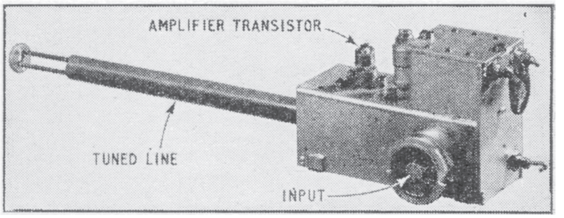

nitude of the first part of equation (3) becomes zero.

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 band–width was 500kc/s and the intermediate frequency 10.7Mc/s.)

In conclusion I should like to thank Dr. Rüchardt of the development department of Siemens' semi–conductor factory and Dr. Engbert, of the semi–conductor 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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