(54) A DISTORTION CORRECTOR FOR WIDE-BAND TRANSISTORIZED AMPLIFICATION STAGES

(71) We, THOMSON-CSF, a French Body Corporate, of 173, Boulevard Haussmann, 75008 - Paris - France, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to distortion correctors for wide-band amplifiers and particularly for coaxial cable repeaters.

The transmission of information by carrier currents over large distances necessitates the cascading of a large number of line amplifiers (up to several hundred) which are intended to compensate the attenuation of coaxial cables.

These amplifiers have to satisfy very stringent requirements in order to reach the quality objectives recommended by the CCITT, particularly in regard to the intermodulation distortion including that of order 3 which is particularly troublesome, particularly because it increases with the square of the number of repeaters.

One of the major causes of intermodulation distortion in transistorized amplifiers is the varactor effect of the transistors, which is reflected in a variation in the base-collector capacitance of the transistors according to the amplitude of the amplified signal, and creates an intermodulation distortion which increases in dependence upon the frequency and power level; this latter is important in the case of the transistors of the output stages of high-capacity line repeaters.

It is known that these deficiences can be overcome by using transistors specially designed for that. They operate with high currents and biassing voltages and by simultaneously effecting a global correction of the amplifier either by negative feedback or by a so-called "feed-forward" circuit which corrects the amplified signal by reinjecting the sole products of distortion into the output signal in phase opposition.

These arrangements are attended by the drawback of involving the use of special, and therefore expensive, transistors which increase the consumption of the repeater whilst at the same time reducing its reliability correlatively, and the use of a correction circuit which is made difficult by the phasing necessities which it involves, quite apart from the problems of stability which arise if the correction circuit is of the negative feedback type.

The object of the present invention is considerably to reduce these requirements both in regard to the special performances of the transistors and their consumption and in regard to the number of corrections which may remain necessary and which therefore become easier to effect, this reduction being made possible by carrying out a simple correction at the actual level of at least one of the transistorized stages responsible for all the distortions.

According to the invention, there is provided a distortion corrector for a wide-band transistorized amplifier having at least a transistor, the base collector junction capacitance C of which is variable in dependence upon the amplitude of the current passing through it, comprising at least one circuit having a capacitive impedance in parallel with a resistance, said circuit being inserted into said amplifier in such a way that it is traversed by the current amplified by said amplifier from a source impedance which is low by comparison with the impedance of said circuit, and said capacitive impedance being formed by first and second varactors connected head-to-tail and having a capacitance which is variable in dependence upon the voltage established at its terminals according to a law determined to obtain compensation for the distortion introduced by said capacitance C.

The invention will be better understood from the following description in conjunction

with the accompanying drawing, wherein:

- *Figure 1* is a circuit diagram of one example of application of the corrector, according to the invention, to an amplifier stage equipped with a transistor having a common emitter circuit.

- *Figure 2* shows a variant of Figure 1 applied to a stage having a common collector circuit followed by a stage having a common base circuit.

In Figure 1, an NPN transistor 1 receives at its base 2 an a.c. voltage delivered by a generator 3 of internal resistance R_1. Its collector 4 is connected to an output terminal 5 and to a positive biassing voltage B_1 through a resistor R_2. Its emitter 6 is connectd to earth through a resistor R_5 and to one of the plates of capacitors C_1 and C_2 of which the others are connected to earth respectively through the anode-cathode junction of a varactor 10 and the cathode-anode junction of a varactor 11. A negative biassing source B_2 supplies the anode of the varactor 10 through a resistor R_3 whilst a positive biassing source B_3 supplies the cathode of the varactor 11 through a resistor R_4.

This amplifier stage, having a common emitter circuit, delivers the signals applied to its base 2 in amplified form at its output 5.

Its base-collector junction is the seat of a parasitic varactor effect which may be represented by an equivalent circuit diagram formed by a variable parasitic capacitor C_p varying in the opposite direction to the voltage of the signal which is applied to it through a resistance R_p.

With respect to a transmitted signal of pulsation ω, this network has a transfer function T_p such that

$$(1) \quad T_p = \frac{1}{1+jR_pC_p\,\omega}$$

where C_p has a law of variation in dependence upon the voltage V which is at its terminals and which is a characteristic peculiar to the transistor used. It has the following form:

$$C_p = C_o\,(1+aV+bV^2+\ \ldots)$$

where C_o is the value of the capacitance C_p at rest in the absence of an a.c. signal, a and b parameters representative of the non-linearity of the system, which are respectively responsible for the intermodulation distortion of order 2 by linear variation of the capacitance in dependence upon the amplitude of the signal and for the intermodulation distortion of order 3 by variation, at the second degree, of this same capacitance.

These distortions are compensated by a correction circuit according to the invention inserted into the emitter circuit of the transistor 1. In this circuit, the capacitors C_1 and C_2 have an insulating function with respect to the biassing by d.c. voltages B_2 and B_3, they show a negligible impedance to the amplified alternating currents. The resistors R_3 and R_4 are selected with very high values by comparison with the impedances of the varactors 10 and 11 to these same currents which therefore see an impedance Z_E of the emitter circuit formed by the resistor R_5 in parallel with a variable capacitance C_V formed by the varactors 10 and 11 connected head-to-tail, thus giving the following relation:

$$Z_E = \frac{1}{1+jR_5C_v\,\omega}$$

where ω is the pulsation of the alternating current transmitted.

If the current gain β of the transistor is very much greater than one and if the internal resistance R_1 of the generator 3 is negligible by comparison with the product βZ_E, the gain of the stage. i.e. the ratio of the voltage collected at the terminals of the load resistor R_2 to that supplied by the generator 3 is given by

$$b = \frac{R_2}{Z_E} = \frac{R_2}{R_5}\,(1+jR_5C_v\,\omega)$$

There is thus obtained a transfer function

$$(2) \quad T_v = \frac{1}{R_5}(1+jR_5C_v\,\omega)$$

of the current flowing through this correction network which is the opposite of the transfer function T_p of the distorting network expressed by relation (1) above.

The transfer functions T_v and T_p are in series in the circuit and the resulting transfer function T_R is expressed by the product $T_v \times T_p$, i.e.

$$T_R = K\frac{1+jR_5C_v\ \omega}{1+jR_pC_p\ \omega}$$

The distortion will be eliminated if T_R is independent of C_v and C_p which will be the case if $R_5 = R_p$ and if $C_v = C_p$, this latter equality determining the choice of the varactors 10 and 11 and their operating points ensured by the voltages B_2 and B_3.

The following Figure shows a different circuit in which the correction network according to the invention acts as a connection between an input transistor having a common collector circuit and an output transistor having a common base circuit.

In Figure 2, an NPN transistor 11 receives at its base 12 an a.c. voltage supplied by a generator 13 of internal resistance R_{11}. Its collector 14 is connected to a positive voltage source B_4 and its emitter 16 is connected, through a resistor R_{15}, to the emitter 26 of a PNP transistor 21 of which the base is connected to earth and of which the collector 24 is connected to an output terminal 25 and to a positive voltage source B_5 through a load resistor R_{12}. A correction circuit, similar to that shown in the preceding figure, comprises in parallel, between the emitters 16 and 26, the cathode-anode space of a varactor 30 in series with a capacitor C_{11}, and a capacitor C_{12} in series with the anode-cathode space of a varactor 31 in addition to the already mentioned resistor R_{15}. Finally, the anodes of the varactors 30 and 31 are respectively connected to negative voltage sources B_{11} and B_{12} through corresponding resistors R_{13} and R_{14}.

If the current gains of each transistor are significantly greater than one, if the source resistance R_{11} is negligible, and taking into account the fact that the input impedance of the transistor 21, having a common base circuit, is low by comparison with that of the correction circuit, the voltage gain may be expressed as follows:

$$G = \frac{R_{12}}{Z_F}$$

where Z_F is the impedance of the emitter circuit of the transistor 11 which, under the assumptions made, is limited to that of the correction circuit, namely:

$$Z_F = \frac{R_{15}}{1+jR_{15}C'_v\ \omega}$$

where C'_v is the capacitance formed by the varactors 30 and 31 connected head-to-tail.

Accordingly, the conditions here are the same as in the circuit shown in Figure 1, C'_v having, in this case, to be selected to compensate the varactor effect resulting from the two transistors 11 and 21.

The circuits described have been tested with type 2N5109 and 2N5583 transistors and with type MV1404 hyperabrupt varactors MOTOROLA (registered Trade Mark). These types of transistors have resulted in two varactors connected head-to-tail being included in the correction circuit.

Other types of varactors might be necessary with different transistors.

Similarly, it is pointed out that, if the feed of the corrector by an emitter circuit readily enables the need for a low internal source resistance to be satisfied, the corrector may also be differently connected, in particular between the collector of a first transistor and the base of a second transistor, provided that the first transistor has a sufficiently low load resistance and that the second transistor is a transistor operating with high currents so that it has a low input impedance.

Experience has shown that the circuits described above enable the intermodulation power to be decreased by 10 dB for all the frequencies of the range of applications of the wide-band amplifiers thus equipped.

WHAT WE CLAIM IS:

1. A distortion corrector for a wide-band transistorized amplifier having at least a transistor, the base collector junction capacitance C of which is variable in dependence upon the amplitude of the current passing through it, comprising at least one circuit having a capacitive impedance in parallel with a resistance, said circuit being inserted into said amplifier in such a way that it is traversed by the current amplified by said amplifier from a source impedance which is low by comparison with the impedance of said circuit, and said capacitive impedance being formed by first and second varactors connected head-to-tail and having a capacitance which is variable in dependence upon the voltage established at its terminals according to a law determined to obtain compensation for the distortion introduced by said capacitance C.

2. A corrector as claimed in claim 1 applied to a transistor having a common emitter

circuit, wherein the anode of said first varactor and the cathode of said second varactor are grounded, the cathode of said first varactor being connected to the emitter of said transistor through an insulating capacitor and coupled to a first adjustable biassing source, and the anode of said second varactor being connected to the emitter of said transistor through an insulating capacitor and coupled to a second adjustable biassing source, said first and second biassing sources being opposite in sign.

3. A corrector as claimed in claim 1 applied to two cascaded amplification stages comprising a first transistor which has a common collector circuit and of which the emitter circuit is coupled with that of a second transistor having a common base circuit, wherein the cathodes of said first and second varactors are respectively connected to the emitters of said first and second transistors, each anode of said first and second varactors being respectively connected on the one hand to the emitter of said second and first transistors through an insulating capacitor and on the other hand to two adjustable biassing sources.

4. A distortion corrector substantially as described herein with reference to Figure 1 or to Figure 2 of the accompanying drawing.

5. A wide band transistorized amplifier including distortion corrector as claimed in any preceding claim.

FIG.1

FIG.2