

RF POWER AMPLIFIER COMPRISING TWO TRANSISTORS AND PIECE OF RF EQUIPMENT USING SUCH AN AMPLIFIER

5 The present invention relates to an RF power amplifier comprising two transistors, said amplifier preserving its linear modulation properties over a wide range of powers.

It also relates to an RF transmitting and receiving system including such an amplifier.

10 The invention is applicable to any type of RF equipment and especially to portable equipment.

In RF transmitting systems, it is known that power amplifiers are subject to saturation of output power at high input powers. Because of the non-linear behaviour thus produced, harmonic distortion is observed. More particularly,
15 the appearance of "parasitic frequencies" that are linear combinations of the frequency components of the signal to be amplified is observed. This type of effect is highly undesirable in amplifiers handling radioelectric signals, because these parasitic frequencies may degrade RF link quality.

The consequences of a non-linear behaviour, i.e. of nonlinearity, therefore
20 appear when the operating power of an amplifier is increased. For digital modulation of high-amplitude signals (i.e. signals of high peak-to-average power), an amplifier cannot thus be used at its maximum power, in order to preserve its linearity. A loss of efficiency therefore results.

The type of amplifier being set, two classes of operation are possible.

25 If it is desired to use the amplifier at a low power level but to achieve a high level of linearity, the class called the "A" class, which is very linear at low levels but which exhibits rapid power saturation and therefore much less linearity at high power levels, must be used.

If it is desired to use the amplifier at a high power level, the class called
30 the "AB" class must be used, this class allowing power saturation to be delayed and therefore a better linearity to be obtained at high levels; however, at low levels linearity is greatly degraded. It is therefore not possible to use the amplifier with its maximum linearity over a wide power range.

One known way of maintaining linearity performance is to apply a digital pre-distortion, this technique also being known as the DPD technique. However, this solution is bulky because implementation of the DPD requires additional hardware. It is also complex to use in particular because it involves closed-loop control and RF delay management. These constraints also mean that it is costly.

One aim of the invention is especially to mitigate the aforementioned drawbacks, in particular by making it possible to maintain the linearity performance of class AB power amplifiers implementing any digital modulation scheme over a wide power range, for example an output range of possibly as much as 25 dB, in a way that is simple to implement.

To this end, one subject of the invention is an RF power amplifier comprising two transistors, said transistors being field-effect transistors controlled in a push-pull mode, said transistors, during the operation of said amplifier, operating asymmetrically, the drain-source currents (I_{DS1} , I_{DS2}) of said transistors in the on state being different.

In one particular embodiment, said currents being controlled by the gate voltages of said transistors, the values of said voltages are functions of operating parameters, pairs of said values functions of said parameters being stored in a memory accessible to said amplifier.

The values of said gate voltages are for example a function of frequency, of the output power of said amplifier or of temperature.

Said values of the gate voltages are for example determined in a calibrating phase in which, linearity criteria of said amplifier being set in advance, the retained pairs are those that meet said criteria.

EVM measurements or AM/AM and AM/PM measurements are for example used to check whether said criteria are met.

Another subject of the invention is a piece of RF transmitting and receiving equipment using a power amplifier such as described above, this piece of equipment for example being carriable.

5 Other features and advantages of the invention will become apparent from the following description, which is given with regard to the appended drawings, which show:

- Figure 1, a diagram of an RF power amplifier comprising two transistors according to the prior art;
- 10 - Figure 2, a diagram of an RF power amplifier comprising two transistors according to the invention;
- Figure 3, an illustration of the improvement in the compromise between power and linearity provided by the invention.

15 Figure 1 shows a diagram of an RF power amplifier comprising two transistors. It more particularly shows the output stage 1 of a power amplifier including two transistors Q1, Q2 that are arranged to be controlled in a push-pull mode, the transistors preferably being field-effect transistors (FETs).

A power amplifier generally includes a plurality of stages including an input stage, a control stage 2 and the output stage 1, the latter delivering the power. The control stage is represented in Figure 1 by a block 2, it is produced in a way that is conventional and moreover well-known.

Via this control stage, the two transistors are controlled in a push-pull mode. A first transistor Q1 is turned on one half-period in two, the second transistor Q2 being turned on in the other half-period. The same drain-source rest current I_{DS} flows through both transistors. The operation of the two transistors is thus symmetric. These transistors Q1, Q2 are controlled open via their respective gate voltages V_{GS1} , V_{GS2} , which are delivered by the control stage 2.

30 This type of push-pull arrangement is conventionally used in prior-art RF amplifiers.

The RF input signal is delivered by an RF line 3, a coaxial line for example, and the component of the RF signal carried by one conductor 301 activates the gate voltage V_{GS1} via the control stage whereas the component carried by the other conductor 302 activates the gate voltage V_{GS2} . The RF signal

carried by these conductors is amplified by the transistors Q1, Q2, which are supplied as is conventional by a power source of voltage V_{DS0} via coupled inductor coils L_{01} , L_{02} .

The output stage 1 of the amplifier, which is also the power stage, includes,
 5 connected to the output of the transistors, a network the basic components of which are inductors and capacitors. Thus, the transistor Q1 is connected to a conductor 401 of the output RF line 4 via an inductor L_1 and a capacitor C_1 , and the transistor Q2 is connected to a conductor 402 of the output RF line 4 via an inductor L_2 and a capacitor C_2 , the two lines being decoupled by a
 10 capacitor C_3 .

As was described above, this type of amplifier comprising transistors in a push-pull arrangement cannot function linearly over a wide power range. High powers produce non-linear behaviours that themselves cause harmonic
 15 distortion that degrades radiocommunications. More precisely, as is known, the non-linear behaviour of power amplifiers generates amplitude and phase distortion in the transmitted signals. This distortion causes spectral leakage out of the band of the useful signal and deforms the constellations of the modulated signals.

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Figure 2 shows an exemplary embodiment of an RF power amplifier according to the invention. It has the same structure or architecture as the amplifier in Figure 1 but its push-pull operation is asymmetric.

More particularly, the transistors Q1, Q2 again operate in a push-pull control
 25 mode but their biases are asymmetric. In other words, whereas in a conventional amplifier the current I_{DS} flowing through the two transistors is the same, in an amplifier according to the invention, a first current I_{DS1} flows through the first transistor Q1 and a second current I_{SD2} flows through the second transistor Q2, these two currents being different.

30 Thus, by making the biases of the transistors asymmetric, the invention makes it possible to compensate for the effect of self-bias of these transistors, which effect causes nonlinearities.

To make this asymmetry possible i.e. to allow the drain-source currents I_{DS1} and I_{DS2} to be different, the control mode must be modified with respect to a
 35 conventional amplifier of the type shown in Figure 2, in particular as regards

the value of the gate voltages V_{GS1} , V_{GS2} . In particular, it is necessary to be able to control the amplitudes of these voltages independently.

Tests and trials carried out by the Applicant have shown that if the biases are made asymmetric, the transfer functions referred to as the amplitude/amplitude (AM/AM) and amplitude/phase (AM/PM) transfer functions are improved at medium power levels, allowing the results of associated EVM and ACPR measurements characterizing the linearity of the amplifier to be greatly improved.

As mentioned above, the nonlinearity of power amplifiers causes phase and amplitude distortion in the transmitted signals, engendering spectral leakage out of the useful band and deforming the constellations of the modulated signals. It will be recalled that this distortion is especially characterized by:

- adjacent channel power ratio (ACPR), which is the ratio of the power of the signal in the useful band to the power of the signal generated by the distortion in an adjacent channel, or, in other words, the ratio of the power in the desired and undesired spectra; and
- error vector magnitude (EVM), which is the average distance between the points of the ideal constellation and the values of received samples that are subject to the distortion of the amplifier.

The values of the gate voltages V_{G1} , V_{G2} defining the IDS1, IDS2 pair are set in order to obtain the desired linearity conditions. They may be adjusted depending on the transmission frequency. It is thus possible to store a table giving the values of the (V_{G1} , V_{G2}) pair as a function of frequency. This table may be accessible to the control stage 2 that delivers the gate voltages V_{G1} , V_{G2} .

This asymmetric bias pair (V_{G1} , V_{G2}) may be determined using an EVM measurement or using AM/AM and AM/PM measurements. Once this pair has been determined for a prototype amplifier, it may be applied to any other amplifier. More precisely, the various values determined as a function of transmission frequency may be applied.

The asymmetric bias pairs are therefore determined in a calibration phase in which the EVMs or AM/AM and AM/PM coefficients of the power amplifier are measured, at various transmission frequencies, as a function of various

values of the currents I_{DS1} and I_{DS2} , i.e. of the (V_{G1}, V_{G2}) pair. For each frequency, the value of the pair giving the best linearity is retained and stored in a table. The useful frequency band is sampled to obtain a set of representative frequencies for which the pairs are determined. This table may
 5 be stored in the circuit board on which the power amplifier is mounted. Depending on the frequency, the control stage of the amplifier selects the values of the voltages V_{G1} , V_{G2} to be applied to the push-pull transistors Q1, Q2.

10 In practice, the present invention may be implemented very simply. In the phase of setup and calibration, the gate and therefore input voltages V_{G1} , V_{G2} of each constituent transistor Q1, Q2 of the push-pull amplifier are supplied separately and independently.

In this phase of setup and calibration, the values of the DC gate and
 15 therefore input voltages of the push-pull amplifier are scanned, controlled and measured separately. The scan of the values over a given range allows the values giving the best results as regards the linearity of the amplifier to be determined, this linearity in particular being characterized by AM/AM and AM/PM or EVM measurements.

20 A measure of linearity is therefore coupled to a scan of gate-voltage values, for example using two different procedures:

- measurement of EVM, for example with a modulated-signal generator and a modulated-signal analyser; or
- measurement of AM/AM and AM/PM coefficients, for example with a
 25 vector network analyser.

Once these pairs of DC gate voltage values have been determined according to linearity criteria set beforehand, these voltage values are stored in a memory 21 directly accessible by the amplifier in push-pull configuration.

30 These values may be stored in the form of a table or of a polynomial relationship. As was specified above, these values depend on frequency. They may also be determined as a function of power level and of temperature level. A table containing a plurality of entries or a polynomial relationship dependent on a plurality of variables is thus obtained.

During the operation of an amplifier, the DC gate voltage values determined in the calibration phase are applied depending, for example, on the frequency, power and temperature of use of this amplifier in the final piece of equipment, which in particular will be a portable RF transmitting and receiving system. The linear behaviour of the amplifier is thus improved by compensating for the effect of self-bias of the transistors.

Figure 3 illustrates the improvement in linearity obtained with a power amplifier according to the invention. This figure shows by way of two curves 31, 32, the variation in EVM measurements as a function of output power, expressed in dB, for a given frequency equal to 30 MHz.

A first curve 31 represents the EVM measurements from a push-pull amplifier according to the prior art with transistors biased in the conventional way. A rise in the curve 31 at medium power levels characterizes the nonlinearity.

The second curve 32 represents EVM measurements from an amplifier according to the invention, which measurements were obtained with asymmetric rest currents IDS1, IDS2 (different DC gate voltages). With this amplifier, the rise in the curve at medium power levels disappears. Therefore, the linear behaviour of the amplifier is better.

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The invention allows the addressed problem(s) to be solved. In particular, it improves linearity performance at low powers without degrading performance at high powers.

This improvement is obtained at low cost, in particular because parameterisation need be carried out only once in the calibration phase for a single prototype amplifier.

The invention moreover has a number of advantages.

In particular, it may be very easily implemented. It is enough just to make provision to separately adjust the rest current of the two transistors of the amplifier, i.e. the transistors arranged in the push-pull configuration. This adjustment may easily be carried out using a memory containing the values of the gate voltages to be applied to each of the transistors as a function of various parameters that in particular include frequency of use, power or even temperature, other parameters also possibly being taken into account.

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The invention makes it possible to more easily comply with the EVM specifications of software-defined radiocommunication equipment.

It also allows a good reproducibility in performance to be obtained, especially by virtue of the values of pairs of gate voltages to be applied, which values
5 are stored in memory and intended for various amplifiers.

CLAIMS

1. RF power amplifier comprising two transistors, said transistors (Q1, Q2) being field-effect transistors controlled in a push-pull mode, characterized in that, during the operation of said amplifier, said transistors operate asymmetrically, the drain-source currents (I_{DS1} , I_{DS2}) of said transistors in the on state being different.
2. Power amplifier according to Claim 1, characterized in that, said currents being controlled by the gate voltages (V_{G1} , V_{G2}) of said transistors (Q1, Q2), the values of said voltages are functions of operating parameters, pairs of said values functions of said parameters being stored in a memory (21) accessible to said amplifier.
3. Power amplifier according to Claim 2, characterized in that the values of said gate voltages (V_{G1} , V_{G2}) are a function of frequency.
4. Power amplifier according to either one of Claims 2 and 3, characterized in that the values of said gate voltages (V_{G1} , V_{G2}) are a function of the output power of said amplifier.
5. Power amplifier according to any one of Claims 2 to 4, characterized in that the values of said gate voltages (V_{G1} , V_{G2}) are a function of temperature.
6. Power amplifier according to any one of the preceding claims, characterized in that said values of the gate voltages (V_{G1} , V_{G2}) are determined in a calibrating phase in which, linearity criteria of said amplifier being set in advance, the retained pairs are those that meet said criteria.
7. Power amplifier according to Claim 6, characterized in that EVM measurements are used to check whether said criteria are met.
8. Power amplifier according to Claim 6 or 7, characterized in that AM/AM and AM/PM measurements are used to check whether said criteria are met.

9. RF transmitting and receiving system, characterized in that it includes a power amplifier according to any one of the preceding claims.

10. RF transmitting and receiving system according to Claim 9, characterized
5 in that it is carriable.