

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
22 June 2006 (22.06.2006)

PCT

(10) International Publication Number
WO 2006/064466 A2

(51) International Patent Classification: **Not classified**

(21) International Application Number:
PCT/IB2005/054211

(22) International Filing Date:
13 December 2005 (13.12.2005)

(25) Filing Language: Dutch

(26) Publication Language: English

(30) Priority Data:
1027745 14 December 2004 (14.12.2004) NL

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

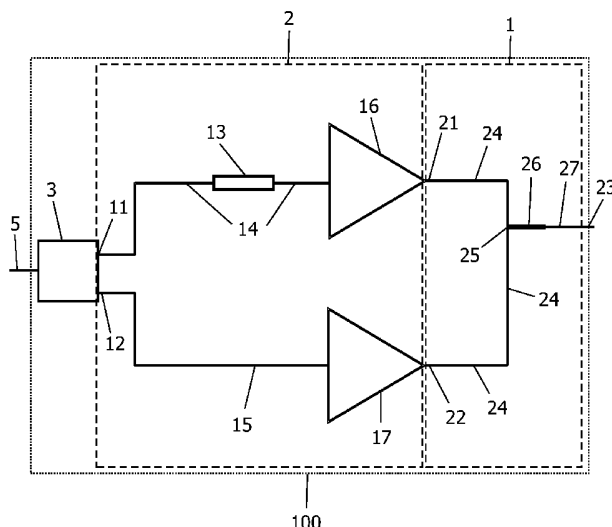
(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: LOW-LOSS, ASYMMETRICAL COMBINER FOR PHASE DIFFERENTIAL SYSTEMS AND ADAPTIVE RF AMPLIFIER COMPRISING AN ASYMMETRICAL COMBINER



(57) Abstract: A low-loss combiner for phase differential systems, wherein the combiner does not have an output resistor and wherein the outcoupling point is asymmetrically positioned with respect to the two inputs of the combiner. In particular, the location is such that the combiner has an input impedance suitable for input signals thereof with a large range of mutual phase difference. This input impedance advantageously has a very small reactive component. Additionally, the real part of the input impedance increases as the phase difference between the input signals of the combiner increases. Furthermore, a (preferably adaptive) RP amplifier is disclosed, in which the input signal is amplified by an active splitter and split into a first and a second signal with a mutual phase difference in a manner that is dependent on the amplitude of the input signal. The two signals are combined again after further amplification by the low-loss combiner.

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Low-loss, asymmetrical combiner for phase differential systems and adaptive RF amplifier comprising an asymmetrical combiner

The invention relates to a combiner and to an amplifier system comprising such a combiner.

5 Third generation telephone systems are based on the Universal Mobile Telecommunications System, UMTS, which uses 5 Megahertz Wideband Code Division Multiple Access. The total bandwidth is 60 MHz and ranges from 2110 MHz to 2170 MHz for base station to mobile traffic. A UMTS network comprises a large number of base station transmitters for transmitting the UMTS radio signal. Each of these base station transmitters
10 comprises linear output amplifiers. Due to the composition of the UMTS signal, said transmitters produce an output signal whose average output power is much less than the maximum output power for which these transmitters are dimensioned. As a result, these transmitters exhibit high power consumption and produce a great deal of heat in relation to the actual output power. In other words: the efficiency of these transmitters is low. This
15 problem can be alleviated by using known adaptive amplifier systems in which the behavior of the amplifier is dependent on the input signal, as is the case with a Doherty system, for example. These known systems, however, require relatively complex designs, which are difficult to produce. In other systems two separate, identical signals with a mutual phase difference are generated. The two signals are each amplified by a separate amplifier, and
20 finally the two signals are "added" together again in a so-termed combiner. If phase differences exist between the two signals that are to be combined, a significant loss of power will occur, however. Conventional combiners provided with an output resistor (load) exhibit advantageous properties as regards the combining of signals. In the case of phase differences between the two signals to be added together, however, this type of combiner will allow a
25 great deal of power to dissipate in the load, resulting in considerable losses. Conventional combiners not provided with an output resistor do not have this drawback, of course, but in the case of phase differences between the two input signals, power reflections generate a reactive component in the input impedance, likewise resulting in considerable losses. This

occurs in particular when the output transistors of the amplifiers operate close to their cut-off frequency, which is generally the case with UMTS.

5 The combiner of the present invention avoids these drawbacks and combines two signals with a mutual phase difference without any significant losses. This makes it possible to obtain an improved amplifier system having a relatively great bandwidth. At the same time this amplifier system has this advantage that it can be produced in a relatively simple manner, without the stability problems that are encountered with Doherty systems.

10 An advantage of the combiner for phase difference systems is that it is low-loss. This advantage is obtained in part because an output resistor is not needed. The point of outcoupling from the combiner is asymmetrically positioned with respect to the two inputs, such that the combiner has a desired input impedance for input signals with a large range of mutual phase difference. This desired input impedance has a very small reactive component,
15 whilst the real part of the input impedance increases as the phase difference between the input signals increases.

 The combiner according to the present invention can be used very advantageously in an adaptive amplifier system. This makes it possible to realize an amplifier system, which, in the case of input signals of varying amplitude, exhibits a high degree of
20 efficiency over a wide amplitude range.

 Furthermore, an adaptive RF amplifier is disclosed in which the input signal is amplified by an active splitter and split into two or more signals with a mutual phase difference in a manner that is dependent on the amplitude of the input signal. After further amplification, said two or more split signals are combined again by the low-loss combiner. In
25 the case of small signal sizes the amplifier functions as a linear amplifier with enhanced efficiency, and in the case of large signal sizes the amplifier functions as an LINC (Linear amplification using Non-linear Components) amplifier. The overall result of these combined processes is a linear amplification system with enhanced efficiency over the entire range of signal sizes.

30 The amplifier system and the combiner according to the invention can be realized by using varying transistor production technologies as known to those skilled in the art. Furthermore it is possible to integrate the combiner and the amplifiers into a monolithic solution. A discrete solution or a system-in-package solution is by no means excluded, however.

The resulting amplifier system is very suitable for amplifying in particular identical RF signals, for example in a mobile telephone or in a base station. Although the invention is very suitable for wider bands, such as the UMTS band, it can also be used advantageously with other bands, such as GSM, CDMA, T-CDMA, W-CDMA, W-LAN, 802.11 and the like.

Although the invention will be explained below on the basis of an amplifier system comprising two amplifiers, it is not excluded that the amplifier system comprises a larger number of amplifiers. Besides pre-amplifiers, it is also possible to connect more amplifiers in parallel. Said amplifiers may be connected to combiners in pairs, for example, via a hierarchy.

The above and further aspects of the combiner and the amplifier system according to the invention will be explained in more detail with reference to the figures, in which:

Fig. 1 schematically shows the combiner in combination with a non-adaptive amplifier system;

Fig. 2 shows a graph in which the relative impedance and the relative efficiency are plotted as a function of the drive angle;

Fig. 3 schematically shows the combiner in combination with an adaptive amplifier system; and

Fig. 4 schematically shows the operation of the adaptive amplifier system as a function of the signal size.

Phase difference RF amplifier system with low-loss combiner

The low-loss combiner is realized in that the outcoupling point is selected to be asymmetrically positioned with respect to the two combiner inputs. The combiner in combination with a non-adaptive amplifier system is schematically shown in Fig. 1. In the figure, numeral 1 indicates the combiner and numeral 2 indicates the non-adaptive amplifier system. The combiner 1 comprises combiner inputs 21 and 22 and a combiner output 23. A signal conductor 24 interconnects the combiner inputs 21 and 22. The signal conductor 24 is of a type that has a specific characteristic impedance. The length of the signal conductor 24 is about a whole multiple of a half wavelength of the RF signals that are to be combined. Unlike

the prior art, the outcoupling point 25, where the combined signal is coupled out, is selected to be asymmetrically positioned on the signal conductor 24 in the present invention, at an unequal distance from each of the combiner inputs 21 and 22. Since the signals to be combined must travel an unequal path length between the respective combiner inputs 21 and 22 on the one hand and the outcoupling point 25 on the other hand, a phase shift occurs between the two signals. The outcoupling point 25 is connected to the combiner output 23 via signal conductors 26 and 27. The amplifier system 2 comprises inputs 11 and 12. The input 11 is connected to the input of an amplifier 16 by means of a signal conductor 14 and the input 12 is connected to the input of an amplifier 17 by means of a signal conductor 15. A delay circuit 13 is incorporated in the signal conductor 14. Like the signal conductor 14, the signal conductors 14, 15, 26 and 27 and the delay circuit 13 have a specific characteristic impedance. The combiner 1 combines the output signals of the amplifiers 16 and 17. The outputs of the amplifiers are to that end directly connected to the combiner inputs 21 and 22. The aforesaid desired length of a whole multiple of a half wavelength between the two amplifier outputs needs to be present between the respective output transistors of the amplifiers 16 and 17. In practice, the output of an amplifier will usually comprise an adapter circuit of a certain path length. Corrections need to be made for this by adapting the length of the signal conductor 24, so that the path length between the two output transistors is a whole multiple of a half wavelength. The wavelength is dependent on the frequency of the signals to be combined, so that a combiner functions optimally at a certain design frequency and a frequency range thereabout. The outcoupling point 25 and the delay circuit 13 are selected so that the phase shifts they introduce will be of identical magnitude but of opposite sense, so that said phase shifts will offset each other.

The signal conductors are microstrip lines, for example. In order to ensure a correct operation, the two amplifiers are given the same nominal output impedance, and a value equal to said nominal output impedance is selected for the characteristic input impedance of the microstrip line 24, which impedance also forms the terminal impedance for the amplifiers 16 and 17. The combiner 1 does not comprise an additional output resistor (load). A usual value for the nominal output impedance of the amplifiers is 50Ω , so that the characteristic impedance of the microstrip line must also be 50Ω . In this case the characteristic impedance at the outcoupling point is only 25Ω , however, because two branches of the microstrip line 24, each having a value of 50Ω , are connected in parallel. If an output impedance of 50Ω is required at the output 27, this can be realized by connecting a so-termed transformer to the outcoupling point 25, with the transformer being a microstrip

line 26 having a length of $\frac{1}{4}$ wavelength and a characteristic impedance of $(25 \times 50)^{\frac{1}{2}} = 35.3\Omega$. Subsequently, the free end of the microstrip line 26 is connected to the output 23 by a microstrip line 27 having a characteristic impedance of 50Ω . It will be apparent that it is also possible to select a different output impedance, as long as a transformer is arranged between the two microstrip lines not having the same impedance in the case of impedance transitions, in which case the transformer must have a length of $\frac{1}{4}$ wavelength and a characteristic impedance that is the root of the product of the two mutually different impedances. If an impedance transition is not required, the transformer 26 can be left out and the microstrip line 27 having a characteristic impedance of 25Ω can form the direct connection between the outcoupling point 25 and the output 23. It will be apparent that other values for the characteristic impedances of the microstrip lines 24, 26 and 27 may be selected in dependence on the output impedances of the amplifiers 16 and 17 and the desired output impedance on the output 23.

The behavior of a combiner having an asymmetrical outcoupling point has been simulated, and the results of the calculations are shown in Fig. 2. The curves that are shown in Fig. 2 represent the characteristics of the combiner with three different asymmetric selections of the outcoupling point 25, resulting in a phase shift of 30, 35 and 40 degrees, respectively. The phase angle is the difference of phase between the two input signals, in which connection it is noted that the phase angle applies between the inputs 11 and 12. Furthermore, Real is the real part and Reac is the reactive part of the input impedance of the combiner that is set as the standard. For the standardization, the real part of the input impedance at a phase angle of zero has been set at 1. From the calculations as shown in Fig. 2 it appears that when asymmetry of the outcoupling point 25 is selected so that a phase shift of about 30 - 40 degrees results, a special condition arises: the reactive part of the input impedances, Reac, remains very small over a large range of phase angles, whereas the real part of the input impedance increases approximately proportionally with the phase angle. In the case of an asymmetrical outcoupling point resulting in a phase shift of less than 30 degrees, the reactive part of the input impedance exhibits a significant increase with phase angles in the middle of the usable range, which is undesirable. In the case of an asymmetrical outcoupling point resulting in a phase shift of more than 40 degrees, the attainable increase in the impedance decreases as a function of the phase angle, with the increase of the reactive part of the input impedance remaining at an acceptable level, below a factor of 2.5. This is the reason why the system no longer functions at a value a few degrees outside this range, and the asymmetry of the outcoupling point 25 must be selected so that it will result in a

phase shift of about 25 to 45 degrees, preferably about 30 to 40 degrees. Fig. 2 furthermore shows that in the case of an asymmetry of the combiner of 30 degrees, the efficiency level of the combiner remains above 98% with a phase angle of up to 80 degrees. In the case of an asymmetry of 35 degrees and 40 degrees, respectively, the efficiency level remains above 99.5% with a phase angle of up to 60 degrees and a value of 99.9% with a phase angle of up to 40 degrees.

Adaptive phase difference controlled RF amplifier comprising a low-loss combiner.

The adaptive RF amplifier will now be described with reference to Fig. 3. Like parts are indicated by the same numerals as in Fig. 1. In Fig. 3, the adaptive amplifier system is indicated as a whole at 100, comprising a combiner 1, an amplifier system 2 and an active signal splitter 3. In this figure, numeral 5 indicates the input and numeral 23 indicates the output of the amplifier system. The input signal is amplified in the active signal splitter 3 and split into two separate signals, which are taken off via splitter outputs 11 and 12. The signal splitter 3 may be an analog or a digital splitter. In the latter case, the signal on the input 5 might be digitally encoded; with the splitter 3 comprising D/A converters for converting the two split digital signals into analog signals on the outputs 11 and 12. Signal conductors 14 and 15 carry the split signals to amplifiers 16 and 17, respectively, in which signal conductor 14 a delay circuit 13 is incorporated. The outputs of the amplifiers 16 and 17 are connected to the inputs 21 and 22 of the combiner 1.

The behavior of the active signal splitter 3 is dependent on the amplitude of the input signal. In the case of a maximum signal size at the input 5, the output power at the output 23 likewise has a maximum value $P_{\max}$. In the case of small signal sizes, below a certain threshold value corresponding to an output power of about -7 dB $P_{\max}$, or 20% of the maximum output power, the split signals are amplified with a fixed amplification factor by the signal splitter 3, whilst a constant mutual phase difference of about 60 - 80 degrees is generated between the two split signals. The selection of the precise value of this phase difference is dependent on the optimum adaptation to the transistors that are used in the amplifiers 16 and 17. When the signal size at the input rises to a value above the threshold value, the phase difference between the two split signals will decrease continuously until the phase difference has decreased to 0 degrees with a maximum signal size. In the case of a maximum phase difference, the average phase of the two split signals approximately equals zero. In the case of a decreasing phase difference between the two signals, the average phase can remain approximately zero or be given a value slightly different from zero so as to offset a possible phase shift in the amplifiers 16 and 17. Furthermore, the amplification factor of the

signal splitter 3 has increased by a factor of 4 over this range, dependent on the output transistors that are used in the amplifiers 16 and 17. The desired output power of the transmitter is generated by the amplifiers 16 and 17 generate, which are so dimensioned that the signal splitter 3 will operate with a small signal size and that the power consumption of the signal splitter 3 will not influence the efficiency of the total system to an appreciable extent.

The operation of the adaptive amplifier system will now be explained with reference to Fig. 4. First, the situation in the case of maximum signal sizes will be described. In the case of maximum signal sizes, the phase difference between the split signals is 0 degrees. The output transistors are driven to full output and the combiner has a characteristic input impedance equal to the nominal impedance of the amplifiers. This is a common design, which provides an optimum efficiency. Now the condition in the case of small signal sizes will be described. In the case of small signal sizes, from zero to the threshold value, the split signals exhibit a constant mutual phase difference of about 60 to 80 degrees. The combiner has a constant input impedance but, due to the asymmetrical design, said constant input impedance is a factor of about 5 higher than the nominal impedance of the amplifiers. As a result, the efficiency of the amplifiers 16 and 17 is significantly higher than that of a conventional amplifier system. Furthermore, the amplification factor of the output amplifiers 16 and 16 is a factor of about 4 higher than with nominal impedance. The result is that less control signal is needed, so that less power needs to be supplied by the pre-amplifiers of the amplifiers 16 and 17, so that they require less electric current, as a result of which an additional improvement of the overall efficiency is achieved. The system operates as a linear amplifier in this range, albeit with a significantly improved efficiency. If the signal sizes increase to a value above the threshold value, the phase difference between the split signals, or the phase angle, decreases and the input impedance of the combiner decreases, and thus also the amplification factor of the output amplifiers 16 and 17. In the case of signal sizes from the threshold value to the maximum signal size, the output transistors are driven to full output. Furthermore, the amplification factor of the splitter 5 increases with a factor of about 4 for signal sizes from the threshold value to the maximum signal size so as to offset the decrease in the amplification factor of the output amplifiers 16 and 17 resulting from the lower terminal impedance (= input impedance of the combiner). The result is that the system functions as an LINC (Linear amplification using Non-linear Components) system for output signals above the threshold value, in which the amplifiers are driven to full output at all times, therefore, so that a higher efficiency level is achieved also with these input signals,

compared to conventional amplifiers. In practice there will be a transition range between the range of linear operation and the range of full output in many cases. In said transition range, the phase angle between the two split signals already decreases, but the output amplifiers 16 and 17 are not driven to full output yet.

5 At maximum power, the efficiency of the amplifier system according to the present invention equals the efficiency of a conventional amplifier. At lower generated power levels, this high efficiency level is in principle maintained up to the threshold value of about 20% of maximum power, whereas the efficiency level of conventional amplifiers will already have decreased to less than half at that stage. At power levels that are even lower, lower than
10 the threshold value, the efficiency level of the amplifier system of the present invention remains a constant factor higher than that of a conventional amplifier.

 To achieve a variation in the terminal impedance of a factor of 4 to 5, the splitter must be able to generate a variation in the phase difference between the two split signals of 0 - 80 degrees. Some transistors no longer function optimally with a terminal
15 impedance that is a factor of 4 to 5 higher than the nominal terminal impedance of the amplifier, however. In such cases it may be decided to use a lower a maximum phase difference from the splitter, so that the variation in the terminal impedance will also be less large.

 In the example as described above, the signal conductors of the combiner are
20 microstrip lines. It will be understood that the invention is not limited to this embodiment. Thus it is possible to select strip lines or coax lines. In an alternative embodiment, the signal conductor comprises one or more passive components, such as a capacitor. A capacitor is not an electrical conductor, to be true, but it is capable of passing an RF signal at the high frequencies that are usual in the RAF applications.

CLAIMS:

1. A combiner for combining two RF signals, comprising two combiner inputs and one combiner output, a first signal conductor having a characteristic impedance, which interconnects the two combiner inputs, wherein the path length of said first signal conductor is approximately a whole multiple of a half wavelength of the RF signals that are to be
5 combined at the design frequency of the combiner, and wherein a second signal conductor having a characteristic impedance connects an outcoupling point on the first signal conductor to said output, characterized in that the outcoupling point is asymmetrically positioned, at an unequal distance from the two combiner inputs.

10 2. A combiner as claimed in claim 1, wherein the outcoupling is asymmetrically positioned, in such a manner that the difference in path length between the outcoupling point and each of the two combiner inputs corresponds to a phase shift between the two signals to be combined of about 25 to 45 degrees.

15 3. A combiner as claimed in claim 2, wherein the outcoupling point is asymmetrically positioned, in such a manner that the difference in path length between the outcoupling point and each of the two combiner inputs corresponds to a phase shift between the two signals to be combined of about 30 to 40 degrees.

20 4. A combiner as claimed in any one of the preceding claims, characterized in that the combiner does not comprise an output resistor.

5. A combiner as claimed in any one of the preceding claims, wherein the signal conductors are configured as microstrip lines or as strip lines.

25

6. A combiner as claimed in any one of the preceding claims, wherein the second signal conductor connects the outcoupling point to the output via a third signal conductor having a characteristic impedance, and wherein the second signal conductor has a length amounting to about $\frac{1}{4}$ wavelength and a characteristic impedance that is the root of the

product of the characteristic impedance of the first signal conductor, divided by two, and the characteristic impedance of the third signal conductor.

7. A combiner as claimed in any one of the preceding claims, wherein said signal
5 conductors are coax lines.

8. An amplifier system comprising a first and a second amplifier and the combiner as claimed in any one of the preceding claims.

10 9. An amplifier system as claimed in claim 8, which is in particular suitable for amplifying two identical RF input signals that may exhibit a variable phase shift relative to each other, comprising a first input, which is connected to the input of a first amplifier by means of a first amplifier signal conductor, and a second input, which is connected to the input of a second amplifier by means of a second amplifier signal conductor, and wherein the
15 respective amplifiers are connected to the inputs of a combiner for combining the two amplified signals, wherein the output of the combiner is also the output of the amplifier system.

10. An amplifier system as claimed in claim 8 of 9, wherein a delay circuit is
20 incorporated in the amplifier signal conductor, wherein the asymmetry of the combiner and the size of the delay circuit are selected so that the phase shifts they introduce will be of identical magnitude and of opposite sense, so that said phase shifts offset each other.

11. An amplifier system as claimed in claim 10, wherein the magnitude of the
25 phase shift caused by the asymmetry of the combiner and the delay circuit is 25 to 45 degrees.

12. An amplifier system as claimed in claim 11, wherein the magnitude of the
30 phase shift caused by the asymmetry of the combiner and the delay circuit is 30 to 40 degrees.

13. An amplifier system as claimed in claim 8, 9 of 10, wherein the two amplifiers have the same nominal output impedance and wherein the characteristic input impedance of the combiner equals the nominal output impedance of the amplifiers.

14. An adaptive amplifier system for amplifying RF signals, comprising an active signal splitter at the input of the system, which functions to amplify and split an input signal into two amplified and split signals, said splitter comprising one splitter input and two splitter outputs, wherein the input of the system is connected to or coincides with the input of the splitter, and wherein the manner in which the splitter amplifies and splits the input signal is dependent on the size of the input signal, characterized in that the outputs of the splitter are connected to the inputs of the amplifier system as claimed in claim 8.

15. An adaptive amplifier system as claimed in claim 14, wherein the splitter effects a constant phase shift between the split signals and the signals amplified with a constant amplification factor in the case of input signals below the threshold value, whereas the phase shift between the split signals decreases continuously to a value of about zero and the amplification factor increases continuously in the case of signals from the threshold value to the maximum value, so that the system behaves as a conventional linear amplifier with enhanced efficiency in the case of small signal sizes and as a conventional LINC (Linear amplification using Non-linear Components) amplifier in the case of large signal sizes, with the output transistors being driven to full output at all times.

16. An adaptive amplifier system as claimed in claim 15, wherein the splitter effects a phase difference between the split signals of 60 to 80 degrees in the case of small input signals.

17. An adaptive amplifier system as claimed in claim 15 of 16, wherein the amplification factor of the splitter is about four times larger in the case of a maximum signal size than in the case of a small signal size.

18. An adaptive amplifier system as claimed in any one of the claims 14-17, wherein the splitter is an analog splitter.

19. An adaptive amplifier system as claimed in any one of the claims 14-17, wherein the splitter is a digital splitter.

20. Use of the amplifier system as claimed in any one of the claims 8-19 for amplifying one or more RF signals.

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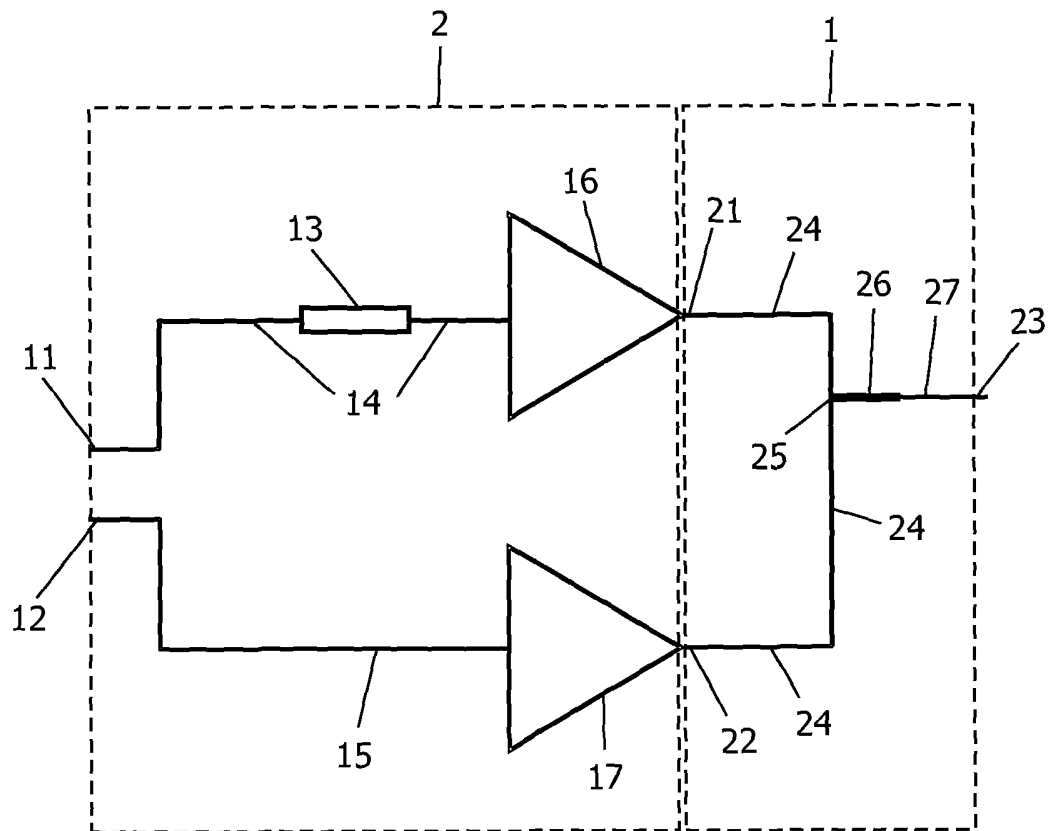


FIG. 1

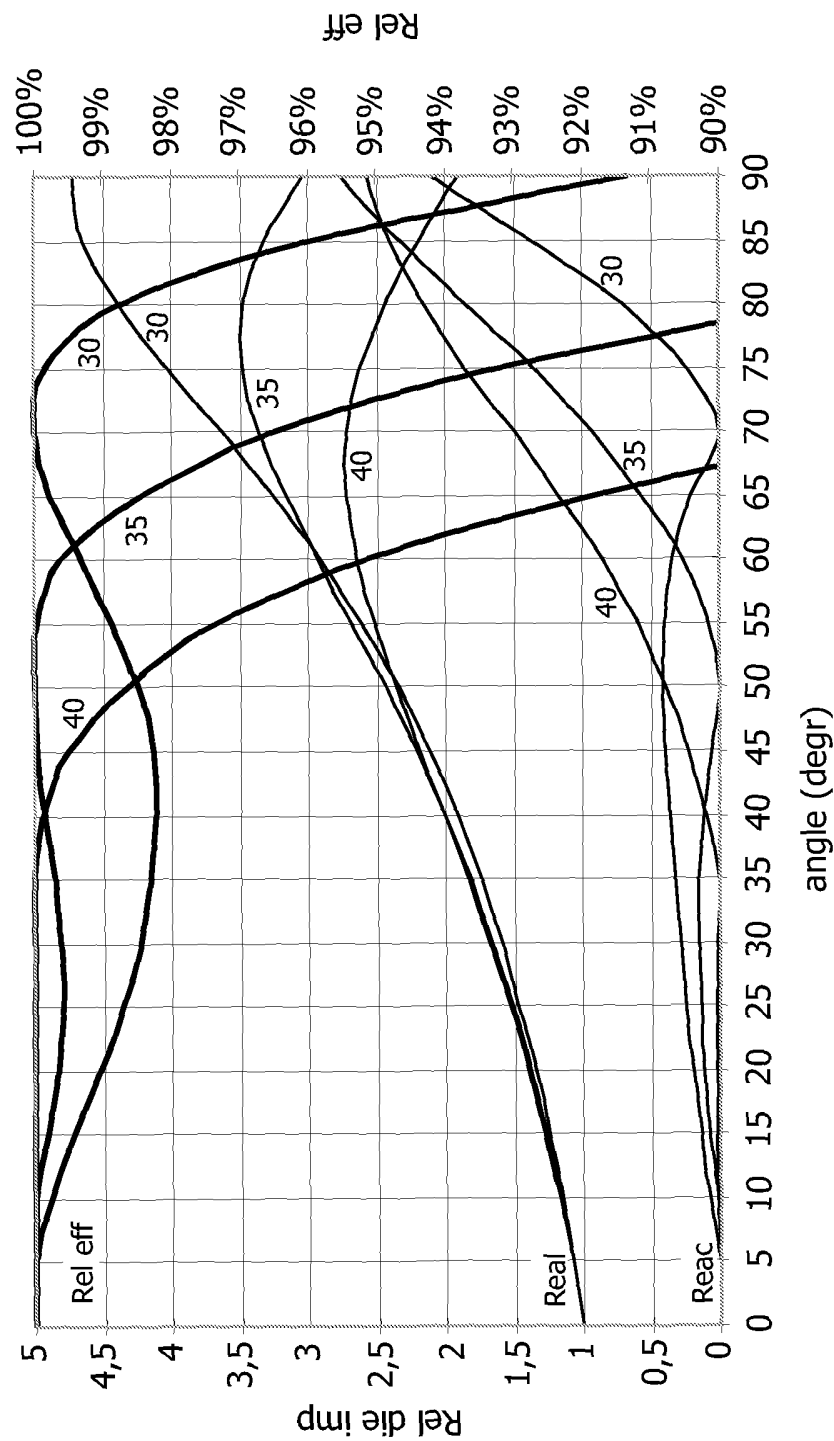


FIG. 2

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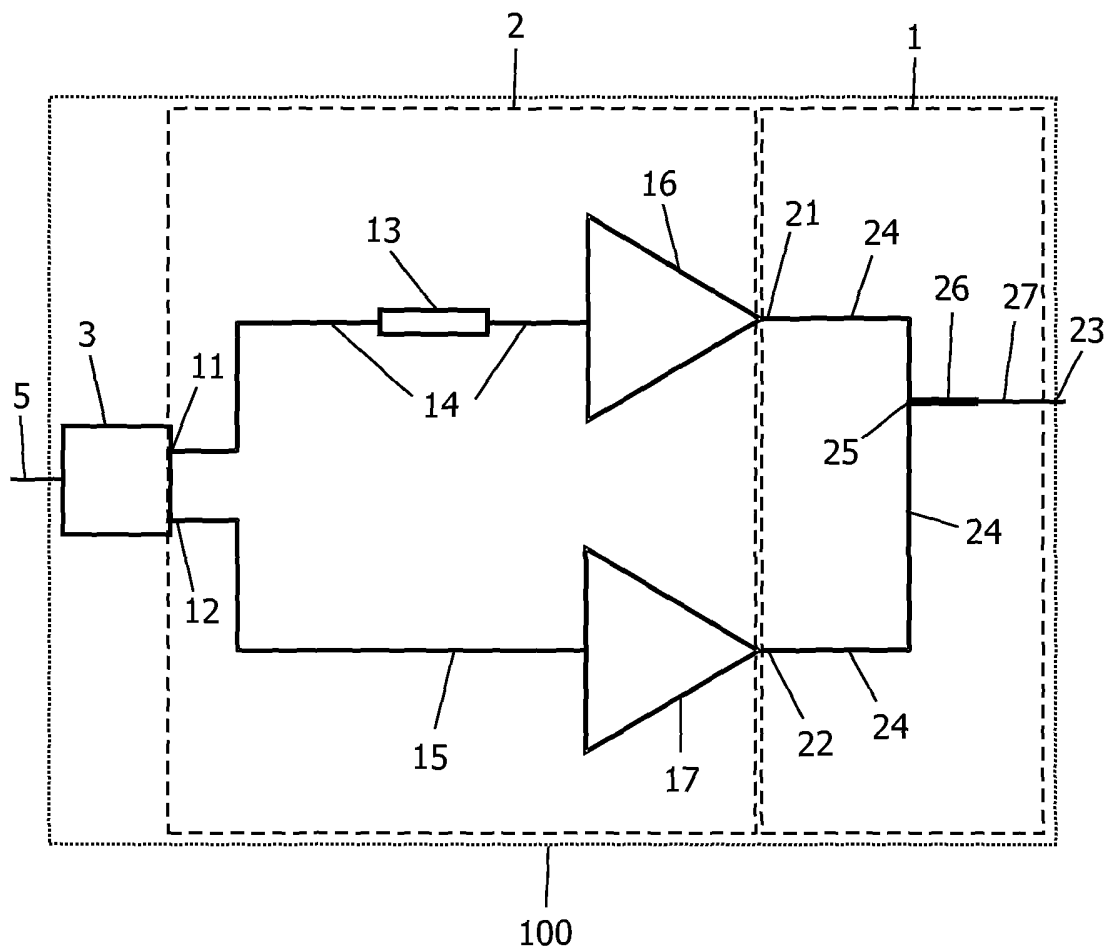


FIG. 3

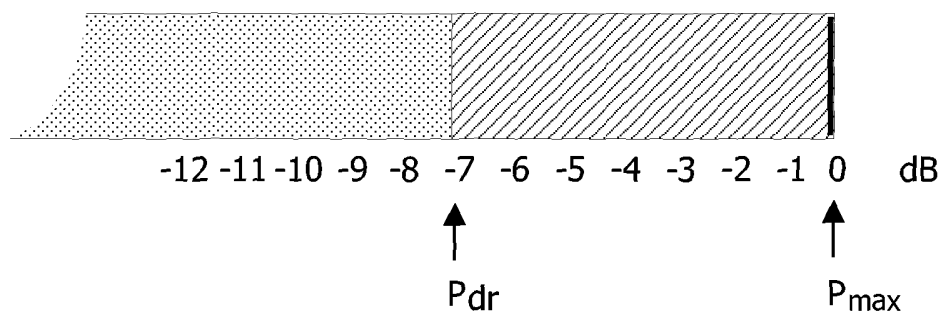


FIG. 4