

**DESCRIPTION**

Radio receiver comprising analog dynamic compression and digital expansion.

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The invention relates to a radio receiver for a phase or frequency modulated information signal, comprising an analog receiving section which provides a non-linear dynamic compression, an analog-to-digital converter and a digital signal processing section.

- 5                Radio receivers of this type can be used, for example, in the Pan-European mobile radio system GSM. In this mobile radio system speech signals in digitized form are transmitted together with other digital signals in a Time-Division Multiple Access mode (TDMA).

- DE 39 25 305 A1 has disclosed a radio receiver of the type mentioned in  
10 the opening paragraph. In that document the frequency of the received information signal is selected in an analog receiving section of the radio receiver and converted into an intermediate frequency by means of a mixer. An IF amplifier which performs non-linear dynamic compression is connected to the IF mixer. As a result, the output signal of the IF amplifier is either compressed or limited, depending on the input signal level.  
15 The output signal of the IF amplifier is applied to a baseband converter which produces therefrom two quadrature components. These quadrature components are sampled and applied to an analog-to-digital converter. Subsequently, the sampled digital values are buffered in a digital signal processing section, a channel estimate is made and an equalization and a decoding is performed. The non-linear dynamic compression and  
20 limitation achieve that a more cost-effective analog-to-digital converter can be used which has a small number of quantization steps, whereas even at the largest possible input levels of the information signal there is no overload of the analog-to-digital converter, and, nevertheless, even at the smallest possible input levels usable sample values are still produced. In practice is found that the output signal of the digital signal  
25 processing section has bit errors.

It is an object of the invention to improve a radio receiver of the type mentioned in the opening paragraph so that the bit error rate of the output signal of the

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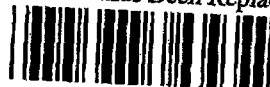
digital signal processing section is small.

This object is achieved in a radio receiver of the type mentioned in the opening paragraph, in that the digital signal processing section comprises an expansion section to compensate for the non-linear dynamic compression of the analog receiving  
5 section.

The invention is then based on the recognition that on account of the dynamic compression the radio receiver is capable of processing information signals which have a large dynamic range, but that the dynamic compression also causes non-linear distortions to occur, as a result of which bit errors may be produced in the output  
10 signal of the digital signal processing section. These non-linear distortions may be compensated with the aid of the expansion section accommodated in the digital signal processing section, so that the bit errors caused by the non-linear distortions are compensated in the output signal of the digital signal processing section.

The analog receiving section comprises, for example, an input circuit  
15 which selects the frequency of the received information signal, and includes one or more intermediate frequency mixers for converting the information signal to one or more intermediate frequencies. The analog receiving section further includes an arrangement for non-linear dynamic compression. The input signal to this arrangement for dynamic compression is either compressed or limited, depending on the input signal  
20 level. Such a compression characteristic for dynamic compression is represented and described in, for example, DE 39 25 305 A1. The compression characteristic therein has a logarithmic behaviour in a first region, and a limiting behaviour in a succeeding second region. Then there is a conversion to the baseband where two quadrature signal components are produced. These components are then subjected to analog-to-digital  
25 conversion, and the thus obtained digitized quadrature components are processed in the digital signal processing section. In order to compensate for the non-linear distortions caused by the dynamic compression, the analog-to-digital conversion in the expansion section is followed by an expansion of the two digitized quadrature components. The thus produced expanded quadrature components are subsequently processed in known  
30 fashion by the digital signal processing section which is formed, for example, by a channel estimator and an equalizer. Consequently, it is possible to use a cost-effective analog-to-digital converter to process information signals which have a large dynamic range, without causing disturbing non-linear distortions to occur. As a result of the

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expansion, the distortions caused by the dynamic compression are cancelled and thus also the bit errors are prevented from occurring in the output signal of the digital signal processing section, which bit errors would have resulted in the absence of an expansion.

In an advantageous embodiment, pairs of inverse values which are  
5 inversely proportional to the characteristic of the non-dynamic compression are determined in the expansion section for each pair of sample values of digitized quadrature components of the information signal, and are used for the linear equalization of digitized quadrature components. The non-linear characteristic of the analog dynamic compression is described, for example, by a mathematic function for  
10 which also the inverse value may be determined. In the expansion section the pairs of inverse values may thus, for example, be calculated on the basis of the pairs of sample values of the digital quadrature components. With the aid of these pairs of inverse values a linear equalization of the pairs of sample values of the digitized quadrature components may be effected in the expansion section, so that the non-linear distortions  
15 of the dynamic compression are cancelled.

In an advantageous embodiment the expansion section comprises a Table in which a pair of inverse values can be stored for each pair of sample values of the digitized quadrature components resulting from the non-linear dynamic compression. This is advantageous in that for each pair of sample values the inverse value need not  
20 be calculated each time, because the pair of inverse values for each pair of sample values of the digitized quadrature components is stored in the Table of the expansion section. This certainly results in a relatively large need for storage capacity for the Table.

In one embodiment, the expansion section comprises a Table in which an  
25 expansion factor can be stored for each pair of sample values of the digitized quadrature components. Since the non-linear dynamic compression affects the value of the information signal, for each pair of sample values, only one expansion factor need be stored in the Table instead of a pair of inverse values. The expanded quadrature components at the output of the expansion section are then shown as the product of the  
30 relevant expansion factor and each digitized quadrature component. Consequently, the need for memory capacity for the Table may be considerably reduced.

In a further embodiment the memory cells of the Table can be addressed by a pair of sample values of the digitized quadrature components. The pair of sample

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values of the digitized quadrature components are thus simultaneously used for addressing each memory cell of the Table, in which either the pairs of inverse values themselves or the expansion factors are stored.

In a further advantageous embodiment the memory cells of the Table can  
5 be addressed by only a predeterminable number of most significant bits of a pair of sample values of the digitized quadrature components. The address of a specific memory cell is thus not obtained from the full word size of the pair of sample values of the digitized quadrature components, but only from the most significant bits of each digitized quadrature component value. As a result, the size of the Table is considerably  
10 reduced without resulting in appreciable distortions of the information signal.

The invention will be further explained in the following with reference to the exemplary embodiments shown in the drawing Figures, in which

Fig. 1 shows a radio receiver;

15 Fig. 2 shows a digital information transmission system comprising a radio receiver; Figs. 3a, 3b each show an exemplary embodiment for an expansion section of a radio receiver; and

Fig. 4 shows a compression characteristic of a non-linear dynamic compression.

20 The radio receiver represented in Fig. 1 comprises an analog receiving section 10, an analog-to-digital converter 25 and a digital signal processing section 30. A phase or frequency modulated information signal  $e$  is applied to the analog receiving section 10. The analog receiving section 10 comprises an input section 20 for frequency selection, an IF mixer 21, an IF amplifier 22 having non-linear dynamic compression, a  
25 baseband converter 23, and a sample-and-hold circuit 24. Quadrature signal components  $I$  and  $Q$  available at the output of the sample-and-hold circuit 24 are applied to the analog-to-digital converter 25, at whose output digitized quadrature components  $I_d$ ,  $Q_d$  are available. The digitized quadrature components  $I_d$  and  $Q_d$  are applied to the digital signal processing section 30, which comprises an expansion section 29, a random-access  
30 memory 26, a channel estimator 27 as well as an equalizer 28. At the output of the expansion section 29 expanded quadrature components  $I_{ex}$  and  $Q_{ex}$  are available, whereas the output of the equalizer 28 presents a decoded information signal.

In the input circuit 20 the information signal  $e$  received from the radio

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receiver shown in Fig. 1 is first frequency selected and then converted to an intermediate frequency by means of the IF mixer. The signal thus converted is subsequently subjected to a non-linear dynamic compression in the IF amplifier 22. The variation of such a dynamic compression characteristic is denoted in block 22 of the IF amplifier. The IF amplifier has in a first region I of its power transmission characteristic a dynamic compression, and in a subsequent region II a limitation, of the input signal. Such a dynamic compression characteristic has been shown and described in DE 39 25 305 A1 (as well as in Fig. 4) already mentioned in the introduction of the description. As a result of the non-linear dynamic compression of the IF amplifier 22 it is possible to utilize a cost-effective analog-to-digital converter while, nevertheless, processing signals which have a large dynamic range, but at the cost of introducing non-linear distortions. In the analog receiving section 10, subsequent to the dynamic compression, the information signal is subdivided by the baseband converter 23 into two quadrature components I and Q, which are finally sampled in the sample-and-hold circuit 24 and applied to the analog-to-digital converter 25.

For equalizing the distortions caused by the dynamic compression in amplifier 22, the digitized quadrature components  $I_d$  and  $Q_d$  are expanded in the expansion section 29. A first possibility is that in the expansion section pairs of inverse values are determined for each pair of sample values of the digitized quadrature components  $I_d$ ,  $Q_d$  which will linearly equalize the digitized quadrature components  $I_d$ ,  $Q_d$ . The pairs of inverse values may then be calculated from the inverse value of the non-linear characteristic of the IF amplifier 22 as described by a mathematical function. The expansion is then effected in accordance with the calculated pairs of inverse values. Since the dynamic compression of the amplifier 22 affects the value of the quadrature components I, Q, the inverse value of the dynamic compression characteristic and thus also the pairs of inverse values depend on the values of the quadrature components I and Q.

A recalculation of the inverse value for each pair of sample values  $I_d$ ,  $Q_d$  of the quadrature components requires much calculation circuitry and consequent high cost. For this reason, in a section option, the inverse value is not calculated again for each pair of sample values, but the expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$  for each pair of sample values of the digitized quadrature components  $I_d$ ,  $Q_d$  are stored in the Table in the expansion section 29. The memory cells of the Table are then

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addressable by the pair of sample values of the digitized quadrature components  $I_d$ ,  $Q_d$ . The disadvantage of this solution is the need for an enormous memory capacity. For example, for an 8-bit word size of the analog-to-digital converter 25 and a 16-bit word size of the expanded values  $I_{ex}$ ,  $Q_{ex}$ , the Table has a size of:

$$5 \quad 2^8 * 2^8 * 2 * 16 \text{ bits} = 2\,097\,152 \text{ bits.}$$

This need for memory capacity may be reduced if instead of storing the actual expanded signal values of quadrature components  $I_{ex}$ ,  $Q_{ex}$ , the Table stores only an expansion factor  $F(I_d, Q_d)$  which depends on the values of the quadrature components  $I_d$  and  $Q_d$ . The expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$  are then  
10 calculated according to the following instruction:

$$I_{ex} = F(I_d, Q_d) * I_d$$

$$Q_{ex} = F(I_d, Q_d) * Q_d.$$

Consequently, for example, for an 8-bit word size the analog-to-digital converter 25 and an 8-bit word size of the expansion factor, the size of the Table is:

$$15 \quad 2^8 * 2^8 * 8 \text{ bits} = 524\,288 \text{ bits.}$$

A further reduction of the Table size may be achieved in that the address of the memory cell of the Table is not based on the full word size of the quadrature components  $I$ ,  $Q$ , but only the most significant bits of a pair of sample values of the digitized quadrature component values  $I_d$ ,  $Q_d$  are used for the addressing. The

20 calculation of the expanded signal values is then represented as follows:

$$I_{ex} = F(I_m, Q_m) * I_d$$

$$Q_{ex} = F(I_m, Q_m) * Q_d.$$

In this representation  $I_m$  and  $Q_m$  signify the most significant bits of a pair of sample values of the quadrature components  $I_\alpha$  and  $Q_\alpha$ . A detailed representation of  
25 such a form of instruction is described and represented in Fig. 3. For an 8-bit word size of the analog-to-digital converter 25, and with a calculation of the expansion factor on the basis of the 5 most significant bits ( $m=5$ ), the size of the Table will be:

$$2^5 * 2^5 * 8 \text{ bits} = 8192 \text{ bits.}$$

In this manner there will only be very small residual distortions left of the  
30 information signal which, however, do not have a disturbing effect on the further digital signal processing. The further digital signal processing of the thus expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$  is effected in known fashion by means of buffering in the random-access memory 26 and subsequent channel estimation 27 and equalization 28 as



described, for example, in DE 39 05 305 A1.

Fig. 2 shows a digital radio transmission system in which the information to be transmitted is transmitted in the form of a binary signal  $b$  via a transmitter 1.

Between the transmitter 1 and the receiver 2 there is a radio transmission path denoted by an arrow. The transmitted signal is received by a radio receiver 2. The radio receiver 2 comprises an analog receiving section 20, 21, 22, 23, 24, an analog-to-digital converter 25 and a digital signal processing section 30.

The functions of individual components of the digital transmission system have, in essence, already been described in connection with Fig. 1 and are also contained in DE 39 25 305 A1. In contradistinction to the digital transmission system described in DE 39 25 305 A1, the digital signal processing section 30 comprises an expansion section 29. This effects a compensation for the non-linear dynamic compression 22 of the analog receiving section 20, 21, 22, 23, 24 as this has already been described in connection with Fig. 1.

Figs. 3a, 3b show each an exemplary embodiment of an expansion section 29 used in the digital signal processing section of a radio receiver. The expansion section 29 determines expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$  based on a pair of sample values of digitized quadrature components  $I_d$ ,  $Q_d$ . For this purpose, Fig. 3a show that the digitized quadrature component values  $I_d$ ,  $Q_d$  are applied to the expansion section 29 which, in essence, is constituted by a Table. At the output of the expansion section 29 the expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$  are available. As already described in connection with Fig. 1, the Table of the expansion section 29 stores for each pair of sample values of the digitized quadrature components  $I_d$ ,  $Q_d$  a pair of inverse values, i.e., the expanded quadrature component values  $I_{ex}$ ,  $Q_{ex}$ , or an expansion factor. For addressing the individual memory cells of the Table T, each time the pair of values  $I_d$ ,  $Q_d$  is used.

Fig. 3b shows a further exemplary embodiment of an expansion section 29. The digitized quadrature component values  $I_d$ ,  $Q_d$  have an 8-bit word size in the exemplary embodiment represented in Fig. 3b, i.e., in the radio receiver an analog-to-digital converter with an 8-bit word size is used. This is symbolized in Fig. 3b by means of /8 at the individual signal arrows. To reduce the size of the Table T, only the most significant bits, for example, the 5 most significant bits, are used for addressing the Table T to obtain the expanded quadrature components  $I_{ex}$ ,  $Q_{ex}$  from the 8 bits

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each of the digitized quadrature components  $I_d$ ,  $Q_d$ , whereas the remaining least significant bits are discarded. This is illustrated in Fig. 3b by means of the signal arrows denoted by /5. For each pair of individual digitized quadrature components  $I_d$ ,  $Q_d$  an expansion factor is stored in the Table, which factor can be selected by using the digitized quadrature components  $I_d$ ,  $Q_d$  which also serve as addresses. The expansion factor may only adopt positive values. The expansion factor is multiplied by the digitized quadrature components  $I_d$ ,  $Q_d$  and thus produces the expanded quadrature components  $I_{ex}$ ,  $Q_{ex}$ . The maximum word size of the expansion factor may be selected at random and determines the total word size of the expanded quadrature components  $I_{ex}$ ,  $Q_{ex}$ . In this manner, with an analog-to-digital converter having an 8-bit word size and with a maximum expansion factor of 255 there is a final word size of the expanded quadrature components  $I_{ex}$ ,  $Q_{ex}$  of 16 bits each. As a result, in the exemplary embodiment shown in Fig. 3b the Table T has a size of:

$$2^5 * 2^5 * 8 \text{ bits} = 8192 \text{ bits.}$$

Fig. 4 gives a diagrammatic representation of a characteristic which has a logarithmic behaviour in a specific region for non-linear dynamic compression, as has already been explained with respect to the IF amplifier 22 described in Figs. 1 and 2 and also in DE 39 25 305 A1. The characteristic shows an output signal denoted  $U_a$  of the IF amplifier 22 shown in the Figs. 1 and 2, in mV, plotted against an input signal level denoted  $P_e$  of the IF amplifier 22, in dBm. The characteristic has a linear region III, a logarithmic region I and a limitation region II. On the basis of the selected semi-logarithmic representation, the region II appears to be correctly shown. The characteristic shown in Fig. 4 is also used for calculating the inverse values or expansion values respectively, for storing these values in the Tables shown in the Figs. 3a and 3b. For this purpose, first the equation of the characteristic has to be determined. This corresponds to the calculation of the compression values of the IF amplifier 22 (Figs. 1, 2). Subsequently, its inverse value is calculated, which is additionally digitally approximated and quantized, as required.

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CLAIMS:

1. Radio receiver (2) for a phase or frequency modulated information signal (e), comprising an analog receiving section (10) which provides a non-linear dynamic compression (22), an analog-to-digital converter (25) and a digital signal processing section (30), characterized in that the digital signal processing section (30) comprises an expansion section (29) to compensate for the non-linear dynamic compression (22) of the analog receiving section (10).
2. Radio receiver as claimed in Claim 1, characterized in that inverse values which are inversely proportional to the characteristic of the non-linear dynamic compression (22) are determined in the expansion section (29) for each pair of sample values of digitized quadrature components ( $I_d$ ,  $Q_d$ ) of the information signal (e), and are used for the linear equalization of digitized quadrature components ( $I_d$ ,  $Q_d$ ).
3. Radio receiver as claimed in Claim 1, characterized in that the expansion section (29) comprises a Table (T) in which a pair of inverse values can be stored for each pair of sample values of the digitized quadrature components ( $I_d$ ,  $Q_d$ ).
- 15 4. Radio receiver as claimed in Claim 1, characterized in that the expansion section (29) comprises a Table (T) in which an expansion factor can be stored for each pair of sample values of the digitized quadrature components ( $I_d$ ,  $Q_d$ ), expanded quadrature components ( $I_{ex}$ ,  $Q_{ex}$ ) being formed from the product of each expansion factor and each digitized quadrature component ( $I_d$ ,  $Q_d$ ).
- 20 5. Radio receiver as claimed in one of the Claims 3 or 4, characterized in that the memory cells of the Table (T) can each be addressed by a pair of sample values of the digitized quadrature components ( $I_d$ ,  $Q_d$ ).
6. Radio receiver as claimed in one of the Claims 3 or 4, characterized in that the memory cells of the Table (T) can be addressed by only a predeterminable number of most significant bits of a pair of sample values of the digitized quadrature components ( $I_d$ ,  $Q_d$ ).
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