The invention relates to a method of eliminating distortion from signals in a receiver for digitally coded signals transmitted through a channel with multipath reception, in accordance with the generic part of Claim 1.

In radio signal transmission within the higher frequency range the signal sometimes reaches the receiver along different paths. Apart from the direct path reflections from buildings or natural elevations may guide the signal transmitted from the source to the receiver along alternative routes. Since the routes vary in length and attenuation the receiver receives a plurality of signals which all contain the original information but may vary in amplitude, transit time and phase angle. Overlaying of these signals produces a combined signal where the original information is more or less distorted. This may lead to considerable trouble, particularly in the case of digital signals.

A method of eliminating distortion from signals in a receiver for transmitted, digitally coded signals with multipath reception in accordance with the generic part of Claim 1 is already known from DE-A-3 540 716, DE-A-3 246 525 and US-A-4 441 192.

The problem underlying the invention is to provide a method of eliminating distortion from signals, which deals with trouble caused by multipath reception sufficiently to enable the original signal to be read.

In a method in accordance with the generic part of Claim 1, this problem is solved by the features recited in the characterising part.

In the method of the invention the transmission properties of the transmission channel are

determined, the channel being made up of the individual transmission paths at the receiving station. Determination of these properties is repeated at short intervals of time, so that allowance can be made for any changes which have occurred in the interim; these take place particularly with movable receivers.

For this purpose test sequences of agreed structure are transmitted; owing to the multipath reception they are naturally subject to the same distortions as the user data, but in contrast with the user data their construction is known from the start and so inferences can be drawn about the distortions which have taken place in the transmission channel. More specifically, the test sequence stored in the receiver is correlated with the test sequence received, which is distorted by overlaying.

The result, the unit pulse response of the channel, is a correlation spectrum in which the single spectral components represent the path along which the original signal passed from the transmitter to the receiver. This spectrum can then be used to control a filter arrangement which balances the transmission function of the transmission channel largely inversely. When the overlaid signal has been passed through the filter arrangement the distortions which occurred along the transmission path are cancelled. The filter arrangement is set after every test sequence, and the setting is then retained for the user data until the next test sequence, since the transmission properties of the channel thus determined can be expected to remain constant for a certain time.

Developments and advantageous embodiments of the method of the invention are contained in the claims, the remainder of the description and the accompanying drawings, which illustrate an embodiment. In the drawings:

Figure 1 shows a multipath transmission model with distortion at the receiving side

Figure 2 shows the construction of a data frame in which user data and test sequences are transmitted

Figure 3 shows an extract from a data stream to illustrate the cyclic correlation

Figure 4 shows a cyclic correlation spectrum

Figure 5 shows addition sequences and an addition sequence function obtained from them, and

Figure 6 shows a possible filter arrangement for inverse balancing of the transmission function of the channel.

In Figure 1 the transmitted signal U_S reaches a transmission channel which comprises three transmission paths. These paths differ in amplitude a, transit time τ and phase angle ℓ. The indices stand for the ordinal numbers of the transmission channels. The three transmission paths are overlaid linearly at the receiving station. The distortions are then eliminated in the receiver through the provision of two feedback means which have the inverse transmission functions of 2 of the 3 paths. The multipath signal received has its sign reversed, is fed to the inverse transmission paths and added to itself, giving a signal U_S which reaches the receiver along only one path defined by index 1.

To determine the transmission properties of the channel test sequences are transmitted before the actual transmission of user data. Figure 2 shows a frame structure of this data format. A main frame containing e.g. 16 data channels is shown at the bottom of the drawing. The first data channel is drawn again separately and extended through time at the top of the drawing. As will be seen from the enlarged version a test sequence is first transmitted and is then followed by the user data. In accordance with the invention two successive M sequences make a suitable test sequence as they have excellent auto and cross correlation properties.

M sequences are binary sequences of a length 2^n-1 which is the maximum obtainable with a polynomial of ordinal number n. Such polynomials of the expression

$h(x) = h_n \cdot x^n + \ldots + h_1 \cdot x + h_0$ can be obtained by shift registers with feedback. Here

h_n, h_o may be 1 and the other h_i's may be 0 or 1. The degree n of the polynomial also gives the number of registers in the shift register. The register outputs, represented by $h_i = 1$, must together with the output h_0 be linked by EXOR gates and connected to the input H_n. The registers must be set before the shift register runs, and in no event may all the registers be at 0.

If the expression $u_i = (u_o,u_1 \ldots u_{N-1})$ represents an M sequence, then T^iu is the sequence u cyclically delayed by i-cycles:

$$T^iu = (u_i,u_{i+1},\ldots u_{n-1},u_O,\ldots u_{i-1})$$

M sequences generally have the following properties:

a. The period of u is $N = 2^n-1$.

b. There are N different phases of the sequence u:
$u,Tu,T^2u,\ldots T^{N-1}u$.

c. The EXOR link gives:
$T^iu \oplus T^ju = T^ku$ for $i \neq j \neq k \qquad 0<=i,j,k<N$

d. u[q] is formed from the M sequence u through every q_{th} bit from u being used for a new sequence v ($v_i = u_{q.i \bmod N}$). u[q] has the period N/gcd(N,q), i.e. u[q] gives an M sequence only when q is an odd number and gcd(N,q) = 1 becomes (gcd(n,,q).... is the largest common divisor of N and q).

e.g. n = 6, N = 63, q = 3 -> gcd(63,3)=3, period = 63/3 = 21
u[3] is not an M sequence. u[5] with N/gcd(N,q)=63 leads to an M sequence.

e. The reciprocal polynomial of an M sequence also gives an M sequence.

$$h'(x) = x^n \cdot h(x^{-1}) = h_0 \cdot x^n + \ldots h_{n-1} \cdot x + h_n$$

$u = h(x)$ becomes $u[q] = h'(x)$ when $q = 2^{n-1}-1 = (N-1)/2$

f. The autocorrelation spectrum of M sequences has only two values

If -1/1 are used as a pair of binary values

$Q_u(1) = N$ for $1=0 \bmod N$

$Q_u(1) = -1$ for $1=0 \bmod N$

To keep the correlation spectrum free from parts which have been formed by additional overlaying with user data, two M sequences are transmitted as test sequences. The two M sequences are identical. Their length is selected so that the maximum expected differences in transit time along the individual transmission paths are no longer than those of a single M sequence. In the case of the overlaid signal there is then a section in the data stream in which the only part-signals present are those formed by overlaying M sequences, i.e. not containing any additional user data. This happens when the second of the M sequences transmitted reaches the receiver along the transmission path with the shortest transit time, i.e. reaches the receiver first.

This section, defined as M2, is shown in Figure 3. The predetermined M sequence MV1 drawn in below it indicates that the marked section M2 of the data stream is correlated cyclically with the predetermined M sequence. Cyclic correlation is carried out in a plurality of steps which will now be explained. Each byte of the section M2 is first multiplied by the bit or byte of the M sequence MV1 below it. With this section it is therefore a question of the byte, since the additions and subtractions of the part signals

resulting from overlaying are shown accurately in terms of their value. The products obtained in this first step are added, and the result of the addition gives the first single component of the correlation spectrum.

The section M2 is then shifted 1 byte relative to the M sequence MV1 or vice versa. The byte shifted beyond the section is folded over though, as illustrated by the M sequence MV2 drawn in below, and is again multiplied by the first byte of the other data word in section M2, so that all the bytes of the section M2 and M sequence MV2 are again included in the multiplication. The second component of the correlation spectrum is obtained when the products are added. These steps are repeated, through a third step also illustrated with the M sequence MV3 shifted, until all the components have been determined.

The mathematical functions describing the M sequence, the multipath signal, the correlation and the unit pulse responses are summarised again below. A distinction is made between the unit pulse responses according to whether the pair of values of the M sequence is -1/+1 or 0/+1.

$u = (u_0, u_1 \ldots u_{N-1}$ M sequence

$x_i = a_j \cdot u_{(i-j \bmod N)}$ $i,j = 0..N-1$ multipath signal

$Q_{u,x}(1) = u_i \cdot x_{(i+1 \bmod N)}$ correlation

$Q_k = Q_{u,x}(i)$ $i = O \ldots N-1$

$c_j = (Q_{u,x}(j)+Q_k)/2^n$ unit pulse response for pair of values -1/1

$c_j' = (Q_{u,x}(j)+Q_k)/2^{n-2}$ unit pulse response for pair of values 0/1

A possible correlation spectrum which is obtained for an overlaid signal with an M sequence is shown in Figure 4. Here the pairs of values used in the M sequence are -1 and +1.

In practice there is a problem in identifying the aforementioned section M2 for cyclic correlation from the data stream. Cyclic correlation could indeed be carried out permanently but the computing outlay required would not be justified. In theory this is a possibility, for the criterion for the time of correlation with the section M2 could be evaluation of a correlation spectrum containing pronounced single components, while other variations in which correlations with user data are also calculated would not have any pronounced single components.

To allow the section to be identified with a low computing outlay a correlation procedure with far fewer multiplication steps is carried out. The overlaid data stream made up of M sequences and user data is continuously correlated with the stored M sequences over the length of an M sequence, through part of the data stream of the length of an M sequence being multiplied byte by byte by the M sequences stored and through the multiplication results being added. A part shifted by one byte is then selected from the data stream, and the multiplication and addition steps for that and the following parts carried out. This procedure may be termed serial correlation as compared with the cyclic correlation described above.

A possible correlation spectrum obtained when a signal passes to the receiver along two paths is illustrated in Figure 5a. The four projecting single components are produced through the correlation supplying such a unit pulse response each time there is an overlap in time between the M sequences in the data stream and the M sequence stored in the receiver. Since the M sequences are transmitted twice in succession and reach the receiver along two paths there are thus four single components.

The resultant correlation values are multiplied by the correlation values previously determined in the same way but delayed by one M sequence. Products with a negative sign are not considered and are omitted. The product spectrum is shown in Figure 5b, where there are now two single components. The resultant products are then added up over the length of an M sequence.

The result of the addition leads to an addition function which continues like a flight of steps as illustrated in Figure 5c. This function reaches its maximum when pure M sequences are correlated with each other. This property can be utilised to identify the section M2. The exact beginning of the section M2, seen from the negative edge after the maximum value S_{max}, is in fact the length of an M sequence in front of that edge.

When the section M2 has been established in the data stream, the actual cyclic correlation to determine the unit pulse response of the channel may be carried out as described in connection with Figure 3.

In multistage transmission procedures, e.g. quaternary PSK transmission, a phase shift on the transmission path may cause the M sequences transmitted along one channel to appear not in the original one but in the other channel on reception. This happens in quaternary PSK transmission when a phase shift through 90° takes place. In other phase positions parts of the M sequences of the overlaid data stream appear both in the original channel and

the other one. If separate M sequences were transmitted for each channel there might be trouble in assessing them. It is therefore advisable for the M sequences to be transmitted along one channel only at source but for both channels to be evaluated at the receiver.

Figure 6 shows a filter arrangement which can be controlled so that an approximately inverse simulation of the transmission properties of the channel is obtained through control with the components determined in the correlation spectrum. The arrangement firstly comprises a matched filter 1 of the structure illustrated. The unit pulse response x_1 of the not yet distorted transmission channel is assumed to have the structure indicated at the output of the matched filter 1. The filtering characteristic is set by coefficients C_0, C_1 and C_2, corresponding to the single components found in the correlation spectrum. When the individual paths have been totalled a spectrum x_2 is obtained; for three different transmission paths, for example, it includes one projecting main component with smaller secondary components in front and behind. The spectrum x_2 is passed through an equaliser 2, the coefficients of which arise from the modified spectrum x_2 obtained at the output of the matched filter. The spectrum x_3 at the output of the equaliser is then filtered in such a way that the components in front of the main component no longer appear attenuated though the components behind are largely unaltered.

The equaliser 2 is adjoined by a feedback equaliser 3, the structure of which is also illustrated. The coefficients of the feedback equaliser again arise from the components of the spectrum x_3 at the output of the equaliser 2. A spectrum x_4 appears at the output of the feedback equaliser 3, in which there is virtually only the main component, while the following part-components are virtually obliterated and only the part-components in front are still just recognisable. However, the value of the main component is so high compared to the adjacent components that a clear distinction is made and the user data transmitted can be evaluated in a reliable fashion.

* C L M S *

Claims

1. A method of eliminating distortion from signals in a receiver for digital coded signals transmitted along a transmission channel with multipath reception, wherein prior to the transmission of user data test sequences of agreed structure are transmitted, the test sequences received are correlated with a test sequence of the agreed structure stored in the receiver, and the unit pulse response of the channel, received as the result of correlation in the form of a correlation spectrum, is used to control the filter coefficients of a filter arrangement which inversely simulates the transmission function of the transmission channel, characterised in that two identical M sequences are in each case transmitted in immediate succession as test sequences, that the M sequence stored is cyclically correlated with a section of the overlaid data stream made up of user data and M sequences and offset in time in the case of multipath reception, the section being specified by the second M sequence which is in each case the first to reach the receiver, through the M sequence stored being multiplied byte by byte by the section of the data stream and the results of the multiplication added, and that when the section has been shifted one bit relative to the M sequence stored the multiplication and addition steps are repeated until each bit in the section has been multiplied once by each bit in the M sequence stored and a totalled sequence of the same length as the M sequence is arrived at as the correlation spectrum from the results obtained from the addition.

2. A method according to Claim 1, characterised in that to determine the section the data stream made up of M sequences and user data is consecutively correlated continuously with the M sequence stored over the length of an M sequence in each case, through multiplying part of the data stream of the length of an M sequence byte by byte by the M sequence stored and adding the results of the multiplication, a part shifted one byte is selected from the data stream and the multiplication and addition steps are carried

* C L M S *

out for that and the following parts, that the correlation values are multiplied by the correlation values delayed by one M sequence and the resultant products are added up over the length of one M sequence, and that the maximum value of the resultant consecutive totalled function is assessed and the section of the data stream located in front of the negative edge after the maximum value of the totalled function, of a length equal to the length of an M sequence, is selected as a section for cyclic correlation.

3. A method according to Claim 1 or 2, characterised in that the period of the test sequences is selected so that it is greater than the maximum transit time difference in the transmission channel.

4. A method according to any of Claims 1 to 3, characterised in that in multistage transmission procedures such as quaternary PSK transmission the test sequences are transmitted in one channel only, while equal values only, e.g. zeros or ones, are transmitted in the other channel during the same period of time, and while correlation is carried out in both channels.

5. A method according to Claim 4, characterised in that the totalled functions are formed by combined assessment of the correlation values from both channels at the same time.