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PROCESS FOR TRANSMITTING A DIGITIZED SIGNAL ACCORDING
TO OFDM TYPE MULTICARRIER MODULATION, TRANSMITTER AND
RECEIVER FOR THE IMPLEMENTATION OF THE SAID PROCESS

5 The present invention relates to a process for
transmitting a digitized signal according to OFDM
(Orthogonal Frequency Division Multiplexing) type
multicarrier modulation using N orthogonal channels.
The present invention also relates to a transmitter and
10 a receiver for the implementation of this process.

 In the international Patent Application
PCT/FR 89/00546 filed in the name of THOMSON-CSF, there
is described a particularly high-performance process
for transmission using OFDM type multicarrier
15 modulation making it possible to transmit, with a high
density, a digitized signal. In the transmission
process described, a plurality of orthogonal
frequencies is used and an (amplitude/phase) or (real
part/imaginary part) pair is transmitted on each
20 frequency, the amplitude/phase or real part/imaginary
part pair being one-to-one equivalent to the
information to be sent. Moreover, in order to recover
at the receiver the information sent according to this
process whilst taking into account multiple echoes,
25 various techniques are used such as the associating
with the useful transmission interval of a transition
interval or guard interval, the use of synchronization
signals and especially the use of test-packets which,
on reception, enable equalization of the channels to be
30 performed. However, when wishing to use a very large
number N of channels, for example 1024 channels, there
is in this case a very large spectral occupancy.
Indeed, the frequency band used is at least 16 MHz.
This poses a number of problems in regard, for example,
35 to the frequency of operation of the signal processing
circuits.

 The purpose of the present invention is to
propose a novel process for transmitting a digitized
signal according to OFDM type multicarrier modulation



which enables the frequency band used to be narrowed.

The purpose of the present invention is also to propose a process for transmitting a digitized signal according to OFDM type multicarrier modulation using N
5 orthogonal channels, which can be used equally well with modulation of the type described in international Patent Application PCT/FR 89/00546 as with other OFDM type multicarrier modulations.

Accordingly, the subject of the present
10 invention is a process for transmitting a digitized signal according to OFDM (Orthogonal Frequency Division Multiplexing) type multicarrier modulation using N orthogonal channels, characterized in that the channels are divided into two, $N/2$ channels corresponding to a
15 first frequency band being sent via a first transmission track according to a first polarization and the remaining $N/2$ channels being brought back into the same frequency band and sent via a second transmission track according to a second polarization
20 crossed with respect to the first.

By using this novel transmission process it is possible to have a much larger number of channels for the same frequency band. Moreover, independence between channels is achieved owing to the fact that each
25 channel is orthogonal to the other channels. Thereby, the maximum amplitude of a channel corresponds to the zero of all the other channels as explained in the abovementioned PCT application. Accordingly, if there is coupling between the two polarizations each
30 transporting half of the channels, on decoding, its influence on the channels is minimized.

According to another characteristic of the present invention, the digitized signal transmitted on each track includes, periodically, test-packets
35 allowing the send channel to be equalized on reception.

This feature makes it possible to compensate in particular for the attenuation of one polarization with respect to the other, from the moment when the



variations in the conditions of propagation of a polarization are slower than an equalization cycle.

According to a particular embodiment, two successive test-packets are transmitted per track and the test-packets are chosen in such a way that:

$$\begin{aligned} t_A^1(2q) \neq 0; \quad t_A^2(2q) = 0; \quad t_B^1(2q) = 0; \quad t_B^2(2q) \neq 0 \\ t_A^1(2q+1) = 0; \quad t_A^2(2q+1) \neq 0; \quad t_B^1(2q+1) \neq 0; \quad t_B^2(2q+1) = 0. \end{aligned}$$

The present invention also relates to a transmitter for the implementation of the above process, characterized in that it principally includes a circuit for calculating an inverse fast Fourier transform (FFT^{-1}) for N samples, a first send track for N/2 samples and a second send track for the remaining N/2 samples, the two tracks allowing sending in one and the same frequency band but with cross-polarizations.

The subject of the present invention is also a receiver for receiving signals transmitted according to the above process, characterized in that it includes two reception tracks each able to receive the signals corresponding to N/2 samples, transmitted in one and the same frequency band but with cross-polarizations and a circuit for calculating a fast Fourier transform (FFT) enabling N samples to be processed or, according to a variant embodiment, a circuit for calculating a fast Fourier transform (FFT) enabling N/2 samples to be processed, connected at the output of each track and a circuit for coupling the two circuits for calculating a fast Fourier transform (FFT).

Other features and advantages of the present invention will emerge on reading the description given below of various embodiments, this description being given with reference to the attached drawings in which:

- Figure 1 is a schematic diagram of a transmitter for the implementation of the transmission process according to the present invention;

- Figure 2 is a schematic diagram of a receiver for



receiving signals transmitted according to the process according to the present invention;

- Figure 3 is a simplified schematic diagram explaining the choice of the test-packets, and

- 5 - Figure 4 is a simplified schematic diagram of another embodiment of the send chain according to the present invention.

The transmitter and the receiver which are described below are circuits used to transmit and receive digitized signals, using OFDM (Orthogonal Frequency Division Multiplexing) type multicarrier modulation using N orthogonal channels. In this case and as described in the abovementioned PCT patent application, the digitized signal is chopped up into a succession of packets. The useful part of the signal is therefore made up of N sinusoidal signals each modulated in amplitude and in phase. In the context of the PCT patent described above, in order to take into account the multiple paths due to echoes and to more easily determine the useful signal, a transition interval or guard interval is defined corresponding to the start of the packet followed by the useful part of the signal which alone will be utilized at reception. In order to carry out the modulation in amplitude and in phase, a constellation in the complex plane is used in a known manner. As mentioned in the patent application cited, several types of constellations can be chosen, namely rectangular, hexagonal or circular constellations. Thus, as represented in Figure 1, the binary train issuing from a coder, not represented, and corresponding to the digitized signal to be sent is dispatched at the input of a constellation conversion card 1 which matches the input bits grouped together by N and the points of the constellation which are allocated to each sub-carrier. It is at the constellation/conversion circuit that synchronization information together with test-packets which will be described later and which are used for the equalization



of the channel are also inserted into the signal to be sent. This test-packet inserted in place of a packet conveying information serves on reception by comparison with a reference packet to determine correction
5 coefficients to be applied to the following useful packet. This enables equalization of the channel to be carried out.

The data output by the circuit 1 are dispatched to a circuit for calculating an inverse fast Fourier
10 transform (FFT^{-1})². The circuit for calculating an inverse Fourier Transform has been described in Patent Application PCT/FR 89/00546 to which reference may be made for a more complete description of its operation. The circuit 2 makes it possible to carry out the
15 modulation of N channels on transmission, for example of 1024 channels in 72 microseconds, especially in the case in which it is desired to send television transmissions.

In accordance with the present invention, in
20 order to limit the passband which, in the case of 1024 channels, must be 16 MHz, it is proposed in the present invention to split the channels into two and to dispatch the first 512 channels over a first send track and the last 512 channels over a second send track. As
25 represented in Figure 1, each send track essentially includes a shaping circuit 3A, 3B, a digital/analog converter 4A, 4B, a circuit for transposing the baseband frequency into intermediate frequency 5A, 5B and a transmitter proper 6A, 6B dispatching the signal
30 to be sent to an antenna 7A, 7B.

In more detail, the shaping circuits 3A, 3B serve to put the data issuing from the circuit 2 for calculating an inverse fast Fourier Transform (FFT^{-1}) into the format which can be utilized by the
35 digital/analog conversion circuit and to append the transition interval or guard interval when using a transmission process with a guard interval, as described in the abovementioned patent application. The



data issuing from the shaping circuits 3A, 3B are dispatched to a digital/analog converter 4A or 4B controlled by a sampling frequency F and which makes it possible to obtain an analog signal which it will be possible to modulate. The purpose of the transposition circuits 5A and 5B is to transform the frequency of the analog signal into an intermediate frequency which the transmitter will be able to utilize. Moreover, the transposition circuit 5B makes it possible to reduce the frequency of the analog signal of this track down into the same frequency band as the signal sent via the first track. These signals issuing from the two transposition circuits 5A and 5B are each dispatched to a transmitter proper 6A, 6B of conventional type which dispatches the signal to an antenna 7A and 7B.

In accordance with the present invention, the antennae 7A and 7B transmit the signal according to cross-polarizations. Thus for example, the signal dispatched by the antenna 7A is transmitted with horizontal polarization whilst the signal dispatched by the antenna 7B is transmitted with vertical polarization, these two signals being transmitted in the same frequency band.

An embodiment of a receiver making it possible to receive a signal transmitted according to the process described above will now be described, more particularly with reference to Figure 2. This receiver includes two reception tracks in parallel, each consisting of an antenna 10A, 10B, a receiver 11A, 11B, an intermediate frequency to baseband 1 and intermediate frequency to baseband 2 transposition circuit, 12A, 12B respectively, and an analog/digital converter 13A, 13B. The outputs from the two analog/digital converters are dispatched through an adder 14 at the input of a packet synchronization circuit 15 and of the demodulation circuit 16 which will be described in more detail below. The antennae 10A and 10B are cross-polarization antennae making it



possible to receive the signals transmitted by the two antennae 7A and 7B with cross-polarization. The receivers 11A and 11B are receivers of conventional type which need not be detailed here. The transposition circuits 12A and 12B make it possible to pass from the intermediate frequency in which the baseband signals 1 are transmitted for the first reception track and baseband signals 2 for the second reception track. The transposition circuits consist essentially of a mixer receiving on one of its inputs a signal, at the transposition frequency, issuing from an oscillator. The analog/digital converters 13A, 13B make it possible to transform at the sampling frequency F2 the analog signal into a digital signal. These two signals are added together in an adder 14 before being dispatched to the demodulation part of the system which is identical to that described in the PCT patent application cited above. As represented in Figure 2, this demodulation part includes a packets-synchro circuit 15 the purpose of which is to carry out the temporal chopping of the signal into packets so as to provide a circuit for calculating the fast Fourier Transform (FFT) 16 with only the useful part of the packets by using the synchronization information sent together with the signal. This part also includes at the output of the circuit for calculating the fast Fourier Transform (FFT) 16, a circuit 17 for detecting the test-packets dispatching information to a correction circuit 19 and an equalization circuit 18 charged with the calculations of the correction coefficients which transmits to the correction circuit 19 a correction signal for each packet. The elements issuing from the correction circuit are dispatched to an interface 20 which transforms the information received into a binary train transmitted on the line 21. The use of test-packets makes it possible to carry out equalization and to remedy the attenuation which may exist between the two polarizations.

A way of calculating the value of the test-packets to be dispatched in order to carry out correct equalization of the channels while taking account of coupling of transmission, sending and receiving, will now be described with reference to Figure 3. As represented in Figure 3, at the output of the (FFT⁻¹) circuit 2, the signal R(n) and the signal I(n) which correspond to the real part and to the imaginary part are transmitted on each track respectively.

If account is taken of the couplings which occur respectively at the circuit 2 and at the antennae 7A and 7B, then in transmission, once the steady state is reached, the following equations hold:

FFT⁻¹ coupling

$$r(q) = \frac{1}{2} \left[a(q) + b(q) \right]$$

$$i(q) = + \frac{1}{2j} \left[a(q) - b(q) \right]$$

where

$$r(q) = \text{FFT} \left(R(n) \right)$$

$$i(q) = \text{FFT} \left(I(n) \right)$$

Antenna coupling

$$r'(q) = r(q) + K_{IR} i(q)$$

$$i'(q) = K_{IR} r(q) + i(q)$$

Hence the signals R'(n) are transmitted via the antenna 7A and the signals I'(n) are transmitted via the antenna 7B. Signals R''(n) and I''(n) respectively, which take into account the couplings and the multiple echoes, are received on the reception antennae 10A and 10B. These signals are given by the following equations:



$$R''(t) = \sum_i \alpha_R^i(t) \cdot R'(t - t_i) + \sum_j \alpha_I^j(t) \cdot I'(t - t_j)$$

$$I''(t) = \sum_R \alpha_R^k(t) \cdot R'(t - t_R) + \sum_I \alpha_I^l(t) \cdot I'(t - t_l)$$

or, going over to frequency:

$$r''(q) = r'(q) \left[\sum_i \alpha_R^i(q) e^{-j \varphi(q, t_i)} \right] + i'(q) \left[\sum_j \alpha_R^j(q) e^{-j \varphi(q, t_j)} \right]$$

$$i''(q) = r'(q) \left[\sum_n \alpha_R^n(q) e^{-j \varphi(q, t_R)} \right] + i'(q) \left[\sum_l \alpha_I^l(q) e^{-j \varphi(q, t_l)} \right]$$

5

which can be written in the following form on putting for example

$$C_{RR} = \sum_i \alpha_R^i(q) e^{-j \varphi(q, t_i)}$$

$$\begin{aligned} 10 \quad r''(q) &= C_{RR}(q) r'(q) + C_{IR}(q) i'(q) \\ i''(q) &= C_{RI}(q) r'(q) + C_{II}(q) i'(q) \end{aligned}$$

On reception, these couplings at the antennae 10A, 10B and at the circuit for calculating a fast 15 Fourier Transform 16 can be represented by the following equations:

- Antennae coupling

$$r'''(q) = r''(q) + K'_{IR} i''(q)$$

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$$i'''(q) = K'_{RI} r''(q) + i''(q)$$

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- FFT coupling

$$a'(q) = r'''(q) + ji'''(q)$$

$$b'(q) = r'''(q) - ji'''(q)$$

Thus at the output of the FFT 16, the set can be rewritten in matrix form as follows:

$$\begin{pmatrix} a'(q) \\ b'(q) \end{pmatrix} = \underbrace{\begin{pmatrix} +1 & j \\ +1 & -j \end{pmatrix} \begin{pmatrix} 1 & K'_{IR} \\ K'_{RI} & 1 \end{pmatrix} \begin{pmatrix} C_{RR} & C_{IR} \\ C_{RI} & C_{II} \end{pmatrix} \begin{pmatrix} 1 & K_{IR} \\ K_{RI} & 1 \end{pmatrix} \begin{pmatrix} \frac{1}{2} & +\frac{1}{2} \\ -j/2 & j/2 \end{pmatrix}}_{M(q)} \begin{pmatrix} a(q) \\ b(q) \end{pmatrix}$$

10

or, taking the inverse matrix:

$$\begin{pmatrix} a(q) \\ b(q) \end{pmatrix} = \begin{pmatrix} \alpha(q) & \beta(q) \\ \gamma(q) & \delta(q) \end{pmatrix} \begin{pmatrix} a'(q) \\ b'(q) \end{pmatrix}$$

Moreover, the signals $\hat{a}(q)$, $\hat{b}(q)$ are obtained at the output of the equalization circuit. These signals are such that:

$$\begin{pmatrix} \hat{a}(q) \\ \hat{b}(q) \end{pmatrix} = \begin{pmatrix} \hat{\alpha}(q) & \hat{\beta}(q) \\ \hat{\gamma}(q) & \hat{\delta}(q) \end{pmatrix} \begin{pmatrix} a'(q) \\ b'(q) \end{pmatrix}$$

Now, with the equalization, signals are recovered such that:

$$\begin{pmatrix} \hat{a}(q) \\ \hat{b}(q) \end{pmatrix} = \begin{pmatrix} \hat{a}(q) \\ \hat{b}(q) \end{pmatrix}$$

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We must therefore estimate the matrix

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$$\begin{pmatrix} \hat{\alpha}(q) & \hat{\beta}(q) \\ \hat{\gamma}(q) & \hat{\delta}(q) \end{pmatrix}$$

In accordance with the present invention, in
5 order to estimate this matrix, two test-packets are
transmitted per track, i.e:

$t_A^1, t_B^1, t_A^2, t_B^2$ and we receive $t_A'^1, t_B'^1, t_A'^2, t_B'^2$

10 $t_A^1(q) = \alpha(q) t_A'^1(q) + \beta(q) t_B'^1(q)$

$$t_A^2(q) = \alpha(q) t_A'^2(q) + \beta(q) t_B'^2(q)$$

$$t_B^1(q) = \gamma(q) t_A'^1(q) + \delta(q) t_B'^1(q)$$

15

$$t_B^2(q) = \gamma(q) t_A'^2(q) + \delta(q) t_B'^2(q)$$

$$\text{We put: } \Delta = t_A'^1(q) t_B'^2(q) - t_B'^1(q) t_A'^2(q)$$

20 and it follows that :

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$$\hat{\alpha}(q) = \frac{t_A^1(q) t_B'^2(q) - t_A^2(q) t_A'^1(q)}{\Delta}$$

$$\hat{\beta}(q) = \frac{t_A^2(q) t_A'^1(q) - t_A^1(q) t_A'^2(q)}{\Delta}$$

$$\hat{\gamma}(q) = \frac{t_B^1(q) t_B'^2(q) - t_B^2(q) t_B'^1(q)}{\Delta}$$

$$\hat{\delta}(q) = \frac{t_B^2(q) t_A'^1(q) - t_B^1(q) t_A'^2(q)}{\Delta}$$

The test-packets are then chosen such that:

$$5 \quad t_A^1(2q) \neq 0 ; t_A^2(2q) = 0 ; t_B^1(2q) = 0 ; t_B^2(2q) \neq 0$$

$$t_A^1(2q+1) = 0 ; t_A^2(2q+1) \neq 0 ; t_B^1(2q+1) \neq 0 ; t_B^2(2q+1) = 0$$

We then have:

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$$\hat{\alpha}(2q) = t_A^1(2q) t_B'^2(2q) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\beta}(2q) = t_A^1(2q) t_A'^2(2q) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\gamma}(2q) = t_B^1(2q) t_B'^2(2q) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\delta}(2q) = t_B^2(2q) t_A'^1(2q) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\alpha}(2q+1) = - t_A^2(2q+1) t_B'^1(2q+1) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\beta}(2q+1) = - t_A^2(2q+1) t_A'^1(2q+1) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\gamma}(2q+1) = - t_B^1(2q+1) t_B'^2(2q+1) \times \frac{\Delta^*}{||\Delta||^2}$$

$$\hat{\delta}(2q+1) = - t_B^1(2q+1) t_A'^2(2q+1) \times \frac{\Delta^*}{||\Delta||^2}$$

Thus, with a specific choice of the test-
5 packets it is possible easily to recover the signals
transmitted with cross-polarization in one and the same
frequency band when employing OFDM type modulation.

According to another embodiment represented in
Figure 4, two circuits for calculating a fast Fourier
10 Transform 22A, 22B can be used in reception. Each
circuit is provided on a reception track and yields
signals $r''(q)$ and $i''(q)$ respectively at output. In
this case, it is necessary to recreate the coupling
between the real parts/imaginary parts and the

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wavetrains represented by the signals $a'(q)$, $b'(q)$. This is carried out by the coupling circuit 23 which performs the following operation:

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$$\begin{pmatrix} a'(q) \\ b'(q) \end{pmatrix} = \begin{pmatrix} 1 + j \\ 1 - j \end{pmatrix} \begin{pmatrix} r'''(q) \\ i'''(q) \end{pmatrix}$$

5

In this case also, we can write:

$$\begin{pmatrix} a(q) \\ b(q) \end{pmatrix} = \begin{pmatrix} \alpha(q) & \beta(q) \\ \gamma(q) & \delta(q) \end{pmatrix} \begin{pmatrix} a'(q) \\ b'(q) \end{pmatrix} \text{ where the matrix } \begin{pmatrix} \alpha & \beta \\ \gamma & \delta \end{pmatrix}$$

10 is the same as before.

Figures 3 and 4 have been described whilst referring to the case in which the imaginary parts are transmitted on one track and the real parts on another track. However, the invention applies also to the case in which the signals are simply split into two, the first $N/2$ being transmitted on one track and the last $N/2$ on the other track.

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1. Process for transmitting a digitized signal according to OFDM (Orthogonal Frequency Division Multiplexing) type multicarrier modulation using N orthogonal channels, characterized in that the channels are divided into two, N/2 channels corresponding to a first frequency band being sent via a first transmission track according to a first polarization and the remaining N/2 channels being brought back into the same frequency band and sent via a second transmission track according to a second polarization crossed with respect to the first.

2. Process according to Claim 1, characterized in that the digitized signal transmitted on each track includes, periodically, test-packets allowing the send channel to be equalized on reception.

3. Process according to Claim 2, characterized in that two successive test-packets are transmitted per track.

4. Process according to Claim 3, characterized in that the test-packets are chosen in such a way that:

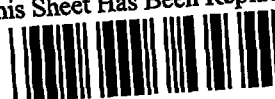
$$\begin{aligned} & t_A^1(2q) \neq 0; \quad t_A^2(2q) = 0; \quad t_B^1(2q) = 0; \quad t_B^2(2q) \neq 0 \\ 25 \quad & t_A^1(2q+1) = 0; \quad t_A^2(2q+1) \neq 0; \quad t_B^1(2q+1) \neq 0; \quad t_B^2(2q+1) = 0. \end{aligned}$$

5. Transmitter for the implementation of the process according to any one of Claims 1 to 4, characterized in that it principally includes a circuit for inverse fast Fourier transform (FFT⁻¹) for N samples, a first send track for N/2 samples and a second send track for the remaining N/2 samples, the two tracks allowing sending in one and the same frequency band but with cross-polarizations.

6. Transmitter according to Claim 5, characterized in that each track includes at least one digital/analog converter, one frequency transposition circuit, one



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transmitter proper and one transmission antenna, each antenna transmitting according to a specific polarization.

7. Receiver for receiving signals transmitted according to the process of Claims 1 to 4, characterized in that it includes two reception tracks each able to receive the signals corresponding to $N/2$ samples, transmitted in one and the same frequency band but with cross-polarizations and a circuit for fast Fourier transform (FFT) enabling N samples to be processed.

8. Receiver for receiving signals transmitted according to the process of Claims 1 to 4, characterized in that it includes two reception tracks each able to receive the signals corresponding to $N/2$ samples transmitted in one and the same frequency band but with cross-polarizations, a circuit for fast Fourier transform (FFT) enabling $N/2$ samples to be processed at the output of each track and a circuit for coupling the two circuits for fast Fourier transform (FFT).

9. Receiver according to either one of Claims 7 and 8, characterized in that each reception track includes at least one antenna receiving according to a specific polarization, one receiver proper, one frequency transposition circuit and one analog/digital converter.

10. Receiver according to any one of Claims 6 to 9, characterized in that it moreover includes means for recognizing the test-packets.



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