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(54) Method for the automatic selection of one beam among those formed by a multibeam antenna, in particular for radiomobile systems

(57) The invention relates to a method for the automatic selection of a beam among those set up by a multibeam antenna, in particular for radiomobile systems comprising an equipment for the reception of radio frequency signals provided with an array (10) of radiant and/or receiving elements, a beam former (5) connected downstream of the array and a device for the selection (9) of the best beam linked to the beam former (5). The selection of the best beam is carried out by the selection device (9) choosing the beam presenting the minimum value of an estimation of the decoding error probability of the received signals (Fig. 1).

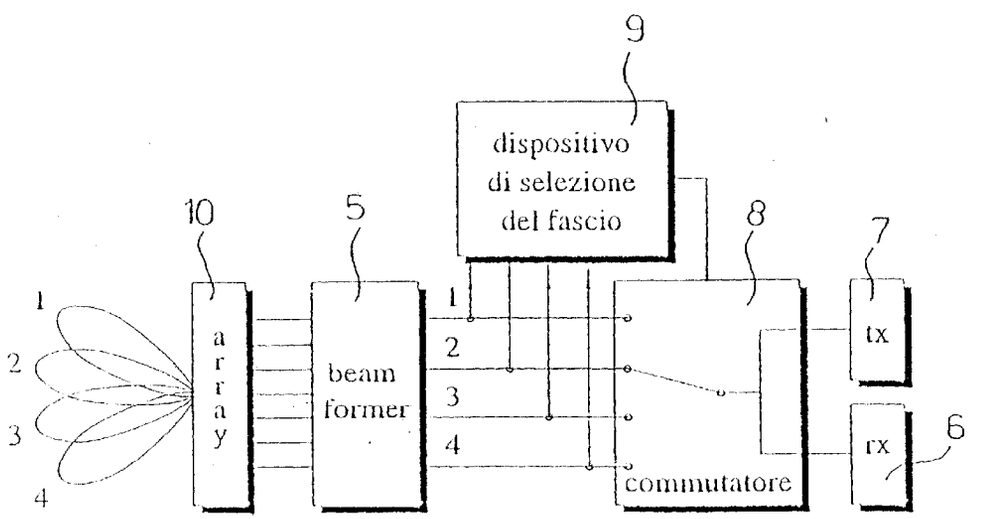


FIG. 1

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Description

Field of the Invention

The present invention relates to a method for the automatic choice of one beam among those set up by a multibeam antenna, in particular for radiomobile systems. In a more specialised way the invention relates to a method to select a beam among those set up by a multibeam antenna, in particular for radiomobile base stations systems comprising a radio receiver set and a directional antenna with steerable beam consisting of a beamformer connected downstream of an array and a device, for the selection of an optimal beam, connected to the beam former.

Background art

As well known a radiomobile telephone system provides for a plurality of portable phone sets, so called cellular phones, in communication with a base station provided with a receiving and transmitting antenna.

The different cellular phones are moving and the antenna of the base station must be able to receive and transmit radio frequency signals from and towards such mobile sets.

For this aim usually omnidirectional or sector antennas with a horizontal width of 120° are used.

This solution causes a significant waste of electric power and a high interference level among the cellular phones belonging to different areas but using the same frequency. In order to remedy these problems so called smart antennas have been proposed enabling the reception and transmission with a radiation diagram which is steerable towards the radiomobile.

In particular we refer to so called switched beams antennas. These antennas are able to receive and transmit with a plurality of radiation diagrams with maximum intensity in different directions, and for which the power assigned by the base stations to a single user is concentrated in a very reduced angular width, even of 20° only, called hereafter beam.

By these directive antennas the total power radiated by the base station is less compared to that needed for an omnidirectional coverage and the global interference level is quite reduced. The smart antenna is composed by a multibeam antenna and a system selecting continuously the best beam for the reception and transmission A possible structure is schematically illustrated in figure 1.

In this figure a block corresponding to a plurality of radiant and/or receiving elements aligned among them by a linear or planar device commonly called array.

The signals 1, 2, 3 and 4 received by the different radiant elements differ only for a phase factor and they are coupled among them by a beam shaper 5 or beam former.

The beam former 5 is a device receiving, as input, signals arriving from the various radiant elements of the array and processing them to supply, as output, the received signals on different beams. Such device may be realised with analog components operating in radio frequency (e.g. the Butler matrix) as well as with a simple digital realisation operating in base band. More particularly the beam former 5 carries out a plurality of linear combinations of the input signals using suitable coefficients. Multiple output gates are provided which may be connected to a receiver by means of a switching unit.

For example connecting a receiver 6 RX to the i-th gate of the beam former, the array 10 radiation diagram is steered in a predetermined direction θi.

Obviously the functioning of the beam former 5 must be considered in a conceptional way as bi-directional i.e. that through a switch block 8 it is also possible to couple the output gates to a transmitter 7 TX in order to be able to transmit signals on a predetermined beam.

The selection of a beam on which to transmit dr receive to and from a predetermined radiomobile is carried out by a selection device 9 which elaborates the signal received on different beams and controls the switching block to connect the receiver 6 or the transmitter 7 to the beam which guarantees the best possible communication with that given radiomobile.

The present invention concerns specifically a new method for the selection of the beam to be implemented in said selection device 9.

In order to understand better the aspects of the invention we should take briefly into consideration the inherent problems in the reception of the signals with different Directions Of Arrival (DOA).

An already known solution suggests to select the communication beam on the basis of the level of received power.

An inconvenience of the method of selecting the beam proposed by this known technique is given by the fact that the possible distortion introduced by the channel will not be taken into consideration.

In fact the presence of echoes reaching the receiver with predetermined delays cause further interferences which for instance one could try to overcome in the GSM receiver using a suitable filtering algorithm known as the Viterbi algorithm.

In this context a channel comprising a plurality of echoes with significant delays among them may turn out to be very distorting, even if the signal is received with a high level.

On the other side a channel with a unique echo does not distort the signal, and it may turn out to be better from the point of view of the quality of the link, even if the signal is received with a lower level.

The technical problem at the basis of the present invention is that to excogitate a method for the selection of an optimum signal beam, in particular for radiomobile systems having the characteristics to making it possible to upgrade the performances of the antennas receiving the signals of the mobiles overcoming the limitations still existing in the solutions according to the known state of the art.

Summary of the invention

The idea of a solution as the basis of the present invention is that of identifying an optimum transmission beam reducing to a minimum an estimation of the decoding error probability of the received signals. Based on this idea of a solution the technical problem has been resolved by a method, of the previously mentioned type, characterised in that the selection of the optimum beam is carried out by selecting a beam having the maximum value of a parameter d_{min}, defined as the minimum distance between received signals related to all combinations of two different transmitted symbols sequences.

Brief description of the drawings

The feature of the present invention which are believed to be novel are set fort with particularity in the appended claims.

The invention, together with further objects and advantages thereof, may be understood with reference to the following description taken in conjunction with the accompanying drawings, and the several figures of which like referenced numerals identify like elements, and in which:

- figure 1 shows a schematic view of a GSM signal transceiver provided with an "intelligent" antenna;
- figure 2 shows a flow scheme of operating phases of the receiver of fig. 1 according to the method according to the present invention;
- figure 3 shows a schematic representation of position, length and period of a training sequence of a normal burst received by the receiver of figure 1;
- figure 4 shows an autocorrelation diagram related to the signal of figure 3.

Detailed description of a preferred embodiment

For the better understanding of the different operating phases of the method we will analyse again the general structure of a GSM receiver set already illustrated with reference to figure 1. It is worth to remind that the equipment of figure 1 is provided with an array 10 set up by a plurality of radiant elements.

The signals arriving from different elements of the array pass through a group of analog components such as: low noise amplifiers (LNA), intermediate frequency converters and the analog filters for channel selection. Such components are schematically shown by the block 11 of figure 2.

The automatic control of the gain will be carried out in a block 12 AGC by measuring the level of the signal during a burst (packet of bits). The gain supplied is a whole multiple of 2 dB.

Then a conversion A/D will be carried out schematically illustrated in block 13. The analog digital converter is a high speed one with a precision of 8 bits (included the sign).

These last two components have an already known structure.

Then a base band conversion of the signal is carried out. the striking signal is a square wave which spectrum is set up by the fundamental frequency (IF) and by the third harmonic.

A filter 15 downstream of the block 13 is used to eliminate the noise components centred on the third harmonic which would otherwise be in base band and in output of the following mixer 16.

A low pass filter 17 is inserted downstream of the mixer 16 and before a decimation block 18. This filter 17 is used to eliminate the noise of the multiple frequencies of the decimation rate which would be again in base band after the decimation and to eliminate the second and fourth harmonic frequencies present at the output of mixer 16.

At the input of the beam former 5 the signals arriving from the elements of the antenna array must have undergone the same amplification, even if the automatic control of the gain has been carried out in an independent way on the signal of each element of the array.

A device 14 compensating the gain of the AGC equalises the gain of the different radiant elements.

Once the gains of the signals arriving from the elements of the antenna have been equalised, the beam former 5

combines them in a linear way in order to form the different beams.

The signals 1, 2, 3, 4 set up in this way are then sent to the selection device 9 which is prepared to carry out the selection of the best beam identifying the one for which the estimation of the decoding error probability of the received signals is at the minimum. The operations carried out by this device for each beam are:

- " the estimation of the impulsive response h(t);
- the calculation of the autocorrelation

$$S_m \equiv \int_{-\infty}^{\infty} h(t)h^*(t - mT)dt$$

- " the calculation of the minimum squared distance

$$d^2_{min} = \min_{\underline{\varepsilon} \neq 0} \left(\sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \varepsilon^*_n \varepsilon_m S_{n-m} \right)$$

where ε is the sequence difference as defined hereafter.

These three options have been schematically illustrated respectively in the blocks 19, 20, 21 and 22. The modality with which the device 9 carries out these operations will be described in details hereafter.

After having calculated the minimum distance for each one of the beams the selection device 9 commands a pair of multiplexers which supply the parameters of the filter and the input signal to a circuit realising a matched filter 23.

The output of the matched filter 23 is therefore sampled in a decimation block 24 with a rate equal to the symbol frequency and the samples obtained in this way are sent to a Viterbi demodulator 25. In a linear modulation system the received signal may be defined as a temporary function r(t) obtained as a summation of a sequence of symbols to be transmitted a_k:

$$r(t) = r_a(t) + n(t) = \sum_{k=-\infty}^{k=+\infty} a_k h(t - kT) + n(t)$$

where T is the duration of a given symbol and h(t) is the impulsive response of the transmission system.

Hereafter transmission system is understood the set of filters in transmission, of the transmission channel (supposed to be linear and stationary) and of filters in reception.

In case of white Gaussian noise the optimum demodulator must be able to calculate for all possible transmitted sequences b_k the distance between the signal really received r(t) and the signal $r_b(t)$ that would have been received in case of transmission of sequence b_k:

$$r_b(t) = \sum_{k=-\infty}^{k=+\infty} b_k h(t - kT)$$

and to choose the sequence b_k to which corresponds the minimum value of this distance.

From this derives that the bigger the distances d_i between the possible received sequences $r_b(t)$ are the smaller will be, with equal noise n(t), the probability of an incorrect decoding.

In particular the decoding error probability of the received signals is very sensible to the minimum value of this distance, we define d_{min} and which turns out, for what said, a function of the impulsive response h(t).

It is also possible to obtain theoretical higher or lower limits to the error probability, in the event of carrying out a

maximum likelihood demodulation. From these limits it is possible to obtain that the parameter d_{min} is a reliable index of the error probability.

Lets now analyse in more details and in a formal way what has been enunciated previously.

a_n and b_n are supposed to be two possible sequences of transmitted symbols, $\tilde{r}_a(t)$ and $\tilde{r}_b(t)$ the complex envelopes of the corresponding received signals, and d_{a-b} the distance between these signals. All these elements are defined in the following way:

$$\tilde{r}_a(t) = \sum_{n=0}^{N-1} a_n h(t - nT)$$

$$\tilde{r}_b(t) = \sum_{n=0}^{N-1} b_n h(t - nT)$$

$$d_{a-b}^2 = \int_0^{NT} |\tilde{r}_a(t) - \tilde{r}_b(t)|^2 dt$$

where h(t) is the complex envelopes of the impulsive response of the transmission system and N is the number of transmitted symbols.

Said ε_n the sequence difference turns out

$$\varepsilon_n \equiv a_n - b_n$$

$$d_{a-b}^2 = \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \varepsilon_n^* \varepsilon_m S_{n-m}$$

$$S_{n-m} \equiv \int_{-\infty}^{\infty} h^*(t - nT) h(t - mT) dt$$

To value the performances of a determined communication channel it will be suitable to estimate the minimum distance among those related to all combinations of two different symbol sequences.

$$d_{min}^2 = \min_{\underline{\varepsilon} \neq \underline{0}} \left(\sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \varepsilon_n^* \varepsilon_m S_{n-m} \right)$$

A multibeam array 10 allowing to receive with n different radiation diagrams makes n different channels available with the same number of impulsive responses $h_l(t)...h_n(t)$. Therefore the selection of the best beam may be made (if all impulsive responses h(t) are known) choosing the one representing the maximum value of the parameter d_{min}.

The GSM transmission standard foresees the transmission, at the centre of every burst, of a training sequence enabling the receiver to estimate precisely the impulsive response h(t).

The estimation of the h(t) is therefore already foreseen to be able to realise the matched filter 23 which is the theoretically optimum receiver.

The method, according to the invention, foresees to carry out this estimation upstream the receiver and to use it both for the selection of the beam and inside of the receiver to implement the matched filter.

In every burst a training sequence c_n is introduced, known at the receiver. On a data or speech channel ("normal burst") this training sequence c_n is inserted at the centre of the burst.

As known from the GSM specifications, the training sequence has a duration L_{tr} equal to 26 bits and is periodical with a period P_{tr} equal to sixteen bits, as illustrated in figure 3.

This sequence is defined in such way that the autocorrelation $R_c(m)$ will be as impulsive as possible (figure 4).

The impulsive response may be estimated correlating the received signal samples with the symbols c_k

In such a way it is possible to estimate with a good validity the impulse h(t) in an interval with a maximum size equal to 6T. Substantially an impulse h(t) with the length 6T is equivalent to an intersymbolic interference on five symbols and it may be considered as a limit situation for a radiomobile channel. Therefore it is possible to obtain a good estimation of the impulsive response of the transmission system in all cases of practical interest

The required computational load for the estimation is absolutely not heavy for the receiver set. As an example it is possible to consider that for each sample of the response fifteen sums are necessary, and in the example taken into consideration four samples for each symbol have been estimated, for a total of six symbols.

Therefore 360 sums among complex numbers have come out for each one of the beams. The calculation of the autocorrelation of the impulsive response is carried out numerically in the device 9 by the following summation:

$$S_m = \sum_{k=0}^{6N_c-1} h(kT_C)h^*(kT_C - mT)$$

where N_c is the number of samples per symbol (four for the proposed realisation) and T_c is the sampling period.

Regarding instead the calculation of the minimum distance d_{min} we proceed with the research of the minimum value of the following function:

$$d^2_{min} = \min_{\bar{\varepsilon} \neq \bar{0}} \left(\sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \varepsilon^*_n \varepsilon_m S_{n-m} \right)$$

In this way the minimum value of a squared form defined positive is sought on a discrete set formed by all the possible length difference sequences N.

From the previous description derives in an evident way that the method according to the invention resolves the technical problem and achieves numerous advantages, of which the most important one is certainly due to the fact that the error probability in the selection of the best beam is reduced to a minimum.

Moreover for the selection of the best beam a modest capacity of data processing is required, and almost all analog and digital components of the receiver set are maintained.

Therefore, while a particular embodiment of the present invention has been shown and described, it should be understood that the present invention is not limited thereto since other embodiments may be made by those skilled in the art without departing from the scope thereof. It is thus contemplated that the present invention encompasses any and all such embodiments covered by the following claims.

In particular, the description made until now refers to the GSM standard. The here described method may anyhow be extended to other radiomobile standards using at the receiver an estimate of the transmission system impulsive response h(t).

Claims

1. Method for the selection of a beam among those formed by a multibeam antenna, in particular radiomobile systems comprising a receiver set of radio frequency signals provided with an array (10) of radiant and/or receiving elements, a beam former (5) connected downstream of the array and a best beam selection device (9) connected to the beam former (5), characterised in that in said selection device (9) of the best beam that beam will be chosen which

presents the minimum value of an estimation of the decoding error probability of the received signals.

2. Method according to claim 2, characterised in that this minimum estimation value of the decoding error probability of the received signals is proportional to a maximum value of a parameter (d_{min}) defined as the minimum distance between the received signals related to all combinations of two different sequences (a_n, b_n) of transmitted symbols.

3. Method according to claim 2, characterised in that operations carried out by the selection device (9) for each beam are:

- an an estimation of the impulsive response h(t) of transmission system;
- a calculation of the autocorrelation of said impulsive response according to the following formula:

$$S_m \equiv \int_{-\infty}^{\infty} h(t)h^*(t - mT)dt$$

- a calculation of said minimum distance to the square according to the following equation:

$$d^2_{min} = \min_{\underline{\varepsilon} \neq 0} \left(\sum_{n=0}^{N-1} \sum_{m=0}^{N-1} \varepsilon^*_n \varepsilon_m S_{n-m} \right)$$

where ε_n is the difference sequence defined as $\varepsilon_n \equiv a_n - b_n$ and N is the number of transmitted symbols.

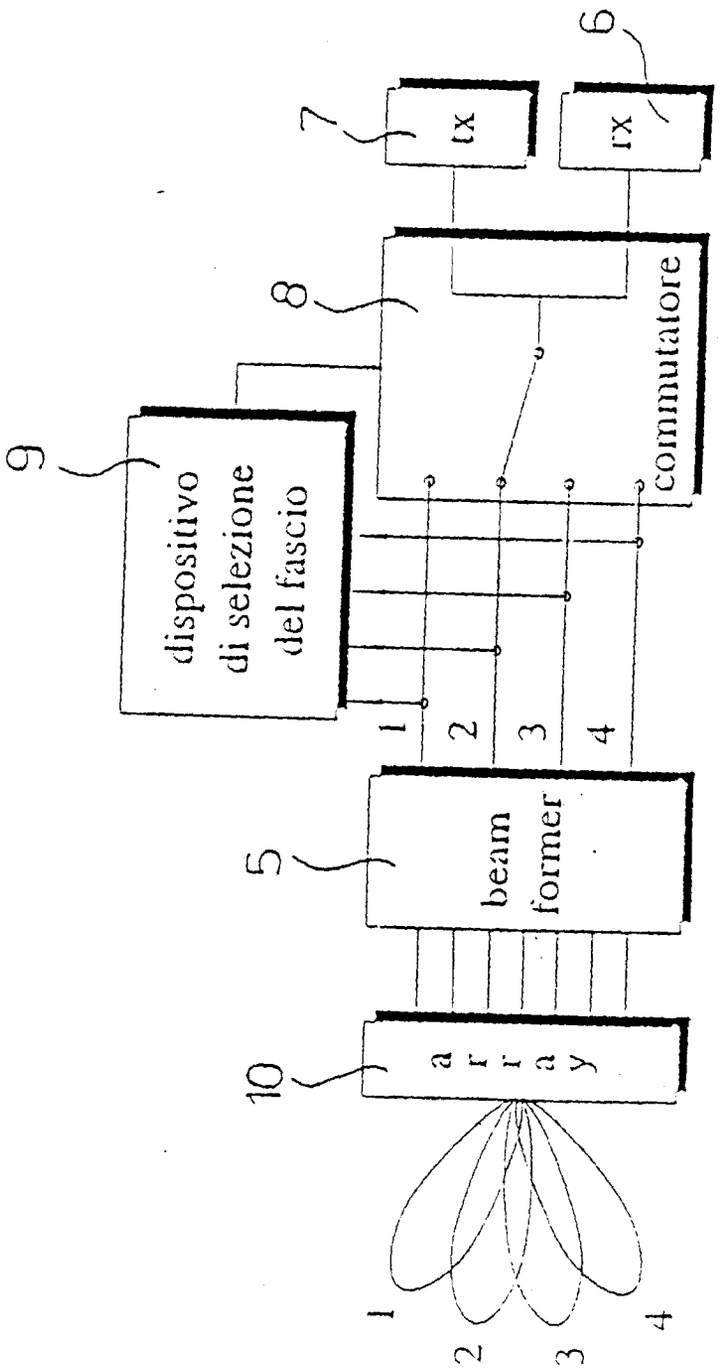

9
dispositivo
di selezione
del fascio
8
commutatore
7
tx
6
rx
5
beam
former
10
array
1
2
3
4

FIG. 1

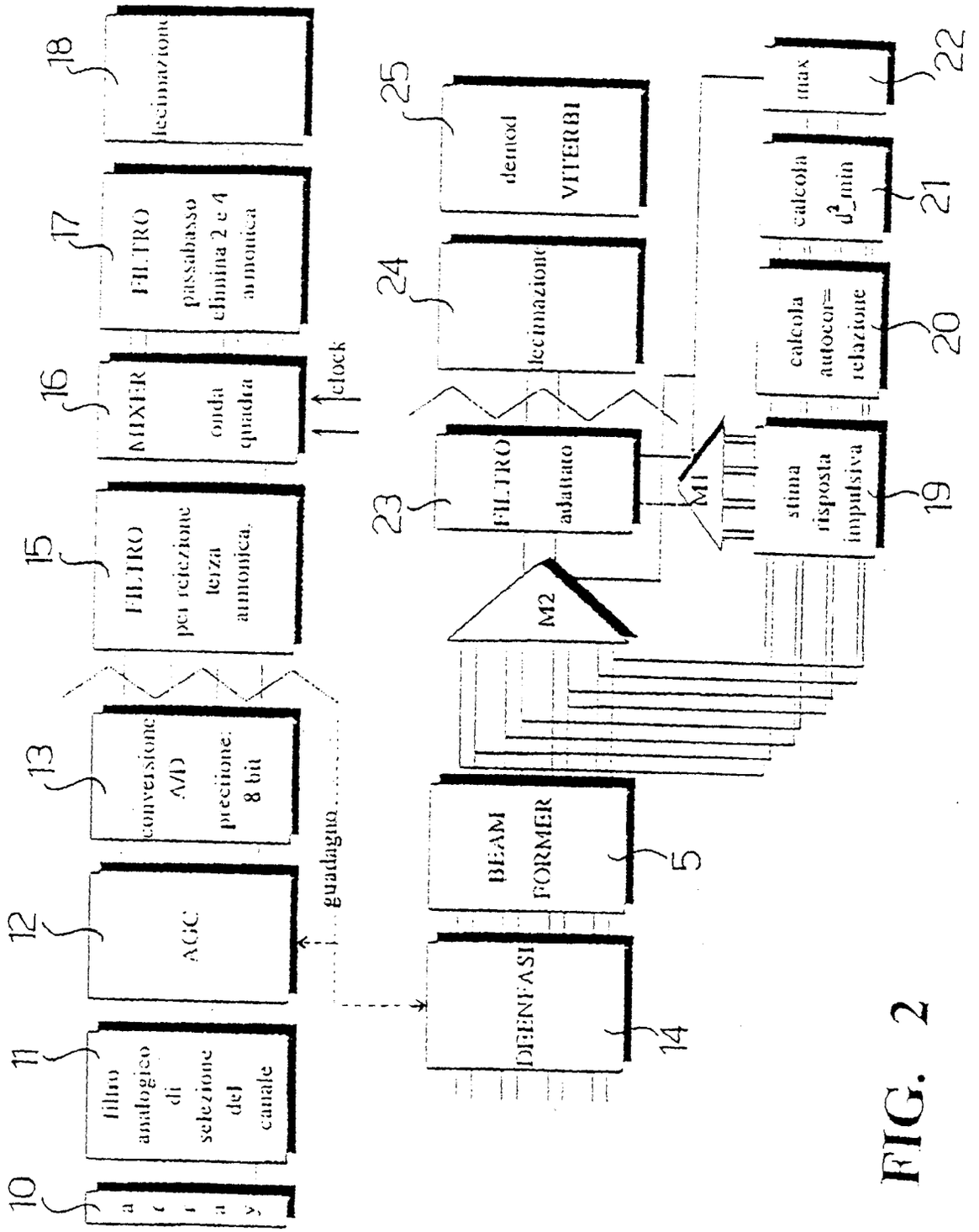

10
11
filtro analogico di selezione del canale
12
AGC
guadagno
13
conversione A/D precisione: 8 bit
15
FILTRO per reiezione terza armonica
16
MIXER onda quadra
clock
17
FILTRO passabasso elimina 2 e 4 armonica
18
decimazione
14
DEINFASI
5
BEAM FORMER
23
FILTRO adattato
M2
M1
24
decimazione
25
demod VITERBI
19
stima risposta impulsiva
20
calcola autocorr= relazione
21
calcola d²_min
22
max

FIG. 2

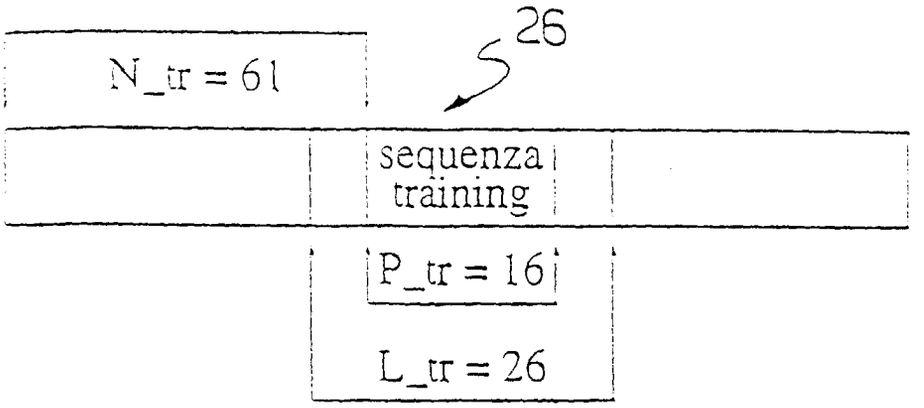


FIG. 3

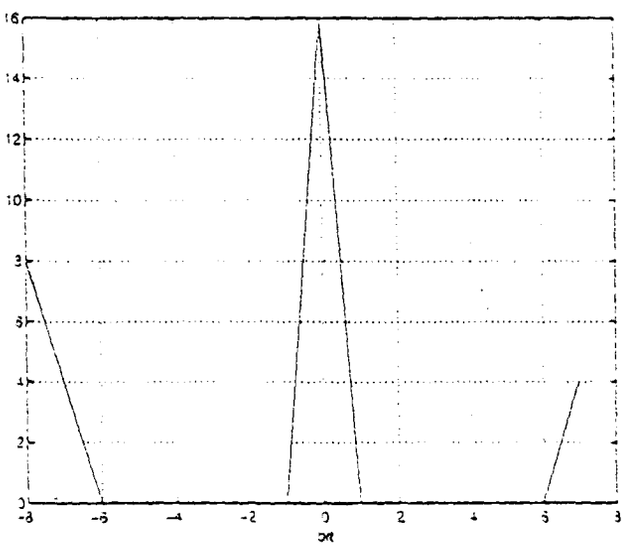


FIG. 4