



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

<p>(51) International Patent Classification⁶ : H04N 5/21, 9/79</p>	<p>A2</p>	<p>(11) International Publication Number: WO 96/02105 (43) International Publication Date: 25 January 1996 (25.01.96)</p>
<p>(21) International Application Number: PCT/IB95/00541 (22) International Filing Date: 6 July 1995 (06.07.95) (30) Priority Data: 08/271,810 7 July 1994 (07.07.94) US (71) Applicant: PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL). (71) Applicant (for SE only): PHILIPS NORDEN AB [SE/SE]; Kottbygatan 5, Kista, S-16485 Stockholm (SE). (72) Inventor: GHOSH, Monisha; 17C Cromwell Place, Mohegan Lake, NY 10547 (US). (74) Agent: KOOIMAN, Josephus, Johannes, Antonius; Internationaal Octrooibureau B.V., P.O. Box 220, NL-5600 AE Eindhoven (NL).</p>		<p>(81) Designated States: JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>Without international search report and to be republished upon receipt of that report.</i></p>
<p>(54) Title: METHOD AND APPARATUS FOR OPTIMAL NTSC REJECTION FILTERING AND TRANSMITTER AND RECEIVER COMPRISING SAME</p>		
<p>(57) Abstract</p> <p>The invention comprises an optimal causal, monic (first coefficient of filter is 1) NTSC rejection filter for use at an ATV receiver which is designed to optimally process the interference caused by an NTSC co-channel signal while keeping the noise enhancement to a desirably low value. In other words, the designed method gives the filter with the BEST NTSC rejection capability for a given noise enhancement.</p>		

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METHOD AND APPARATUS FOR OPTIMAL NTSC REJECTION FILTERING
AND TRANSMITTER AND RECEIVER COMPRISING SAME

BACKGROUND OF THE INVENTION

The Federal Communications Commission and cable television testing organizations such as CableLabs have been evaluating digital television delivery systems in order to choose a new television "standard" which someday will replace NTSC in the United States. These systems all involve digital coding and data compression techniques, for
5 example those utilizing the MPEG algorithms or variations thereof.

The FCC plans to test and approve an advanced television (ATV) standard comprising for example, high definition television (HDTV) and standard definition (SDTV) digital signals for terrestrial broadcasting in 1995, and although the specifics of the standard are yet to be fully tested and agreed upon, the FCC has indicated that the system will
10 initially take the form of a so called "simulcast" approach.

The new ATV signals will have to fit into currently unused television channels (so-called "taboo" channels) and initially co-exist with conventional analog television signals without co-channel interference.

NTSC will be used hereinafter to represent one example of conventional
15 television broadcasting. Other examples would be SECAM and PAL. Although NTSC is exemplified herein, it is not meant to be construed as a limitation and will be used herein synonymously with "conventional" to represent conventional television in general.

In 1995 the FCC will test the so-called "Grand Alliance" system which is a proposed system being cooperatively developed by the corporate sponsors which developed
20 the first round of individual proposals which were tested by the FCC in 1991 and 1992. This Grand Alliance system proposes to take the best features from those systems already tested in order to present a single optimum system for FCC approval as the U.S. standard.

The Grand Alliance has already decided on a coding algorithm which will comply with the source coding standards proposed by MPEG (Motion Pictures Experts
25 Group). In addition, the RF transmission scheme selected by the Grand Alliance is the trellis coded 8VSB system designed and built by Zenith Electronics. Details of the Zenith VSB system are described in "Digital Spectrum Compatible - Technical Details", Sept. 23,

1991 and more recently modified and described in "VSB Transmission System: Technical Details", Feb 18, 1994, which are incorporated by reference herein.

The technique used in the Zenith 8VSB modem to combat co-channel interference is as follows. A comb filter is used in the digital (e.g. HDTV) signal receiver to
5 introduce nulls in the digital spectrum at the frequency locations of the conventional (e.g. NTSC) picture, color and the sound carriers. This provides a significant improvement in performance when conventional television, e.g. NTSC, is broadcast on a co-channel.

When co-channel interference from an NTSC signal is present at the HDTV receiver, the comb filter at the receiver is treated as a partial response channel in
10 cascade with the trellis coder. An optimum decoder can then be developed which uses Viterbi decoding on an expanded trellis, the states of which correspond to the cascade of the states of the comb-filter and the trellis
coder as described in "Principles of Digital Communication and Coding" authored by A.J. Viterbi and J.K. Omura and published by McGraw Hill in 1979, which is incorporated by
15 reference herein.

For a comb-filter with a delay of 12 symbols, the number of trellis states are extremely large. To simplify their design, Zenith converts the MPEG coded and RS coded and interleaved data-stream from serial to parallel, then uses 12 parallel trellis encoders followed by a parallel to serial converter at the transmitter. The trellis decoder for
20 the case when the comb filter is used, implements Viterbi decoding on a trellis with the number of states equal to two or four times the number of states of the trellis encoder. This is described in detail in "VSB Transmission System: Technical Details".

For the case when co-channel conventional television interference is
25 absent, Viterbi decoding is implemented on a trellis with the number of states equal to the number of states of the trellis encoder. This is possible since pre-coding is not used in the transmitter.

The choice between the path afforded by simple trellis decoding or of that using the comb filter and the expanded trellis at the receiver is decided by the measured
30 error-rate of the periodically sent data field sync symbols at the outputs of the post-comb filter and with no post-comb filter.

When both co-channel and AWGN (additive white Gaussian noise) are present however, the performance of the comb filter degrades dramatically. This is because the AWGN after the comb filter does not

remain white, but gets "colored", in other words the noise samples are not independent of each other.

This affects the performance of the trellis decoder which is

optimized for performance in an AWGN channel. Since the co-channel conventional

5 television interference is maximum at the fringe area where the signal power is small and hence the AWGN is large, this is indeed a scenario which must be taken into account. A first objective of the instant invention is therefore

to improve the performance of an ATV receiver when co-channel interference and a high AWGN level are present.

10 The number of states of the trellis encoder is

limited by the fact that the Viterbi decoder for the comb-filter path must operate on a trellis with at least double the number of states of the trellis encoder. This limits the AWGN performance of the trellis encoder/decoder when co-channel television interference is not present. A second object of the instant invention therefore is to improve the AWGN

15 performance of the trellis encoder/decoder in an ATV receiver when cochannel television interference is not present.

The comb filter method of NTSC rejection requires the ATV spectrum to be shifted 45.8khz with respect to the NTSC spectrum in order to align the nulls of the comb filter with the picture and color carriers as described in "VSB Transmission System:

20 Technical Details". This causes the digital spectrum to spill over into the adjacent 6Mhz channel which is undesirable

for adjacent channel rejection. Another object of the invention is to do away with this frequency offset.

Finally, the switching between the use of a comb filter in the receiver or
25 not, suggested by Zenith is cumbersome. A significant number of computations must be performed

to determine whether the comb filter should be used or not. Furthermore the use of the comb filter also specifies the use of 12 parallel encoders and correspondingly 12 parallel decoders which also is cumbersome. Another object of the invention therefore is to avoid the use of a

30 comb filter at the receiver.

In addition to other documents cited herein, this application incorporates by reference the following documents:

U.S. patents 5,086,340, 5,087,975 and 5,121,203 and PCT application

filing No. IB 94/00412 (PHA 21.860) filed December 12, 1994 and PCT application filing No. IB 95/00069 (PHA 21.869) filed February 1, 1995, and any corresponding patents or applications.

5 SUMMARY OF THE INVENTION

The invention comprises an optimal causal, monic (first coefficient of filter is 1) NTSC rejection filter for use at an ATV receiver which is designed to optimally process the interference caused by an NTSC co-channel signal while keeping the noise enhancement to a desirably low value. In other words, the design method gives the filter with
10 the BEST NTSC rejection capability for a given noise enhancement.

The invention described in PCT application filing No. IB 94/00412, provides a design method that attenuates just the picture and sound carriers of the NTSC interference. The method however is not necessarily optimal in reducing NTSC interference. One feature of the instant invention is that it utilizes knowledge of the entire interference
15 spectrum in order to design the rejection filter. The prior art comb filter or the rejection filter described in the '421 PCT application both basically use the knowledge of the position of the picture, sound and color carriers only.

The invention provides the optimum filter performance in terms of NTSC rejection for a given amount of noise enhancement. The embodiment described herein
20 provides an NTSC rejection of about 12.06db for a noise enhancement of about .25db with the NTSC color bar signal. The preferred embodiment described herein is also relatively insensitive to the nature of the input NTSC signal and gives good NTSC rejection for signals other than the color bar signal.

Another feature of the invention is that since the filter is formulated as a
25 predictor, the output will be maximally white. The filter output can be further "whitened" by use of an interleaver as described in the '421 PCT application incorporated by reference herein, as well as any corresponding application.

A further feature of the filter designed in accordance with the invention is that it is causal and monic and can be used to precode the data at the transmitter as suggested
30 in the '773 patent application.

Still another feature of the invention is that the design method it comprises is independent of the modulation format of the digital signal and could be used for non-VSB transmission modalities, for example quadrature amplitude modulation (QAM) transmission as well.

Another feature of the invention is that the digital signal need not be offset by 45.8kHz as is presently required in the 8VSB system designed by Zenith.

BRIEF DESCRIPTION OF THE DRAWINGS

5 Fig. 1 describes a block diagram of a VSB transmitter for use with the invention;

Fig. 2 describes a block diagram of a VSB receiver for use with the invention;

10 Fig. 3 shows the structure of an NTSC interference rejection filter comprising the invention; and

Fig. 4 graphically compares the frequency response of the NTSC rejection filter of Figure 3 and the NTSC color bar spectrum.

Fig. 5 describes the pr-coder located at the transmitter illustrated in Fig. 1.

15 DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

Fig. 1 describes a Zenith VSB transmitter (as described in "VSB Transmission System: Technical Details" which has been modified in accordance with the invention.

20 The MPEG coded data DA (or, more generally, digital television data) is processed by the Reed-Solomon (RS) encoder 5, the byte interleaver 10 and then the trellis encoder 15. These three blocks are well-known and described, for example, in "VSB Transmission System: Technical Details".

The symbol interleaver 20 randomizes the trellis-coded symbols before they are processed by the pre-coder 25. The symbol interleaver 20 can be implemented as a 25 block interleaver or as a convolutional interleaver; both implementations are described in U.S. patent 3,652,998 which is incorporated by reference herein. The implementation of the pre-coder 25 is described in the PCT application filing No. IB 95/00069 which is incorporated by reference herein. A design for pre-coder 25 is shown in Fig. 5. The output of the symbol interleaver 20 is passed through a modulo-M adder 120, 30 which adds its output passed through and NTSC prediction filter 115 like the one at the receiver. The operation of the modulo-M adder 120 is described in "New Automatic Equalizer Employing Modulo Arithmetic", Electronic Letters, pages 138-139, in Mar. 1971, where the value of M is chosen to be greater than or equal to the peak value of the incoming symbol.

The output of the pre-coder 25 is passed through a multiplexer (MUX) 40, which multiplexes with the output of pre-coder 25, any training TS signals that are used.

A pilot signal is inserted into the multiplexed data stream by pilot insertion means 45 and the multiplexed data stream with pilot is then passed through a VSB modulator 50 and RF upconverter 55, after which it is transmitted over a communications path, for example a terrestrial broadcast channel.

The blocks 40, 45, 50, 55 are described in detail in "VSB Transmission System: Technical Details" and "Digital Spectrum Compatible - Technical Details" which are both incorporated by reference herein.

Fig. 2 is a block diagram of a VSB receiver comprising the invention.

Tuner 60 selects the channel of interest and converts the received signal from RF to IF, where the IF filter and down converter 65 can be, for example, a Surface Acoustic Wave (SAW) filter (which shapes the signal spectrum according to the filter used in the VSB modulator 50) followed by a mixer which down converts the shaped signal to a baseband signal as explained in greater detail in "Digital Spectrum Compatible - Technical Details".

Analog-to-digital (A/D) converter 70 samples the down-converted signal from IF filter and down-converter 65 at symbol-rate which is, for example, 10.76 MHz. The interference rejection filter 80, which is described in more detail in Figure 3, then processes the sampled signal and passes it to the equalizer and phase tracker 85.

The soft-decision symbol interleaver 90 essentially performs the inverse operation of the symbol interleaver 20, except that the symbols have "soft" decision information as described in "Principles of Digital Communication and Coding" which is incorporated by reference herein.

The output of the symbol deinterleaver 90 is then passed through a trellis decoder 95, a byte deinterleaver 100 and the RS decoder 105 which are described in "VSB Transmission System: Technical Details". Sync and timing block 110 controls the clocking for each of the digital signal processing blocks and also the A/D converter 70. The output of the RS decoder 105 is supplied to an MPEG decoder (not shown).

An optimal NTSC interference rejection filter in accordance with the

invention for use in a VSB receiver (for example interference rejection filter 80 of Fig. 2) is shown in Fig. 3. It comprises an L-tap delay line 200 where each delay D is equal to one symbol interval, which is the reciprocal of the A/D sampling rate of 10.76Mhz.

The interference rejection filter 80 is a first order predictor, that is the
 5 first tap is 1 and all the other taps
 have a smaller magnitude than the first tap.

The coefficients of the interference rejection filter 80 (g_1 to g_L) are selected as follows. The input signal corrupted with AWGN and cochannel interference, is present at the input to the
 10 A/D converter 70. The digital output signal of the A/D converter 70, which will be denoted hereinafter as r_k , is equal to: $s_k + n_k + w_k$, where s_k is the transmitted symbol of the desired digital signal (pre-coded at the transmitter for example), n_k is the NTSC interference, w_k is the AWGN. σ_w^2 represents the variance of the AWGN which varies inversely to the signal to noise ratio and k represents the time index of the signal sampled at the A/D sampling rate.
 15 The goal of the filtering operation on r_k is to reduce the variance of the interference n_k at the filter output 210, while keeping the noise variance σ_w^2 as small as possible. Assuming n_k to be wide-sense-stationary, we can define the interference correlation matrix R_n as follows:

$$R_n(i,j) = E[n_k n_{k+i-j}].$$

20 In practice E, the ensemble average, are replaced by the time average, in order to form R_n . The filter is denoted by the vector $[g_0 g_1 \dots g_L]^T$ where L+1 is the length of the filter and T denotes transpose. The first coefficient g_0 is intentionally set equal to 1 in order to force the filter to be causal. Causality is a constraint that is important if precoding is essential at the transmitter, for example a precoder 25 for use in a VSB transmitter, which is designed in
 25 accordance with the invention. In accordance with this invention, the coefficients used in the interference rejection filter 80 at the receiver are also used in the pre-coder 25 at the transmitter.

If we us consider the effects of filtering on the interference and noise, in accordance with the invention, the filter can be expressed as the partitioned vector $[1 \ g^T]$
 30 where $g^T = [g_1 \ g_2 \ \dots \ g_L]$. The variance of the NTSC interference, J, at the output of the filter is represented as:

$$J = [1 \ g^T] R_n \begin{bmatrix} 1 \\ g \end{bmatrix}$$

and the variance of the noise at the output of the filter 80 is represented as:

$$\sigma_w^2 (1 + \mathbf{g}^T \mathbf{g}).$$

5 The criterion used for determining the filter \mathbf{g} comprises the following steps:

Minimize J with respect to \mathbf{g} subject to the constraint

$\mathbf{g}^T \mathbf{g} = K$, where K is some constant determining the allowable noise enhancement. For example if a noise enhancement of 0.3db is allowed, the value of K is .07. The minimization of J can be carried out in a straightforward manner by one skilled in the art using Lagrange

10 multipliers. R_n is first rewritten in a partitioned form as follows:

$$R_n = \begin{bmatrix} a & \mathbf{b}^T \\ \mathbf{b} & C \end{bmatrix}$$

where \mathbf{b} is a $L \times 1$ vector and C is a $L \times L$ matrix. Then, the minimization criterion can be written as:

15 Minimize $a + 2\mathbf{g}^T \mathbf{b} + \mathbf{g}^T C \mathbf{g} + \lambda(\mathbf{g}^T \mathbf{g} - K)$ with respect to \mathbf{g} and λ . This minimization reduces to solving the following two equations for \mathbf{g} and λ , where λ is the Lagrange multiplier:

$$\mathbf{g} = (C + \lambda I)^{-1} \mathbf{b}, \text{ and } \mathbf{g}^T \mathbf{g}$$

=K,

20 where I is an $L \times L$ identity matrix.

These equations

cannot be solved in closed form for \mathbf{g} but can be fairly easily solved for a given k by computing

$$f(\lambda) = \mathbf{b}^T (C + \lambda I)^{-2} \mathbf{b} \text{ as a function of } \lambda \text{ and picking a value of } \lambda \text{ for which } f(\lambda) = k.$$

Once λ is known, \mathbf{g} can be calculated from $\mathbf{g} = (C + \lambda I)^{-1} \mathbf{b}$.

25 From the above, it is apparent that the filter coefficients

are heavily dependent on the nature of the correlation matrix R_n and hence the question arises as to what is a representative NTSC signal correlation matrix. For this example, the NTSC color bar signal was chosen. The signal was sampled at 10.76 Mhz which is the symbol frequency for Zenith's 8VSB system. The correlation values were evaluated by time

30 averaging and performing the

the series of steps described above for a filter having a length of 37 (i.e. $L = 36$).

The filter thus obtained has the coefficients shown in Table 1. This filter has a noise enhancement of 0.25 db and NTSC rejection of 12.06 db.

Fig. 4 is a graph of magnitude (MAG) in decibels (dB) against normalized frequency NF. The frequency response FFR of the filter which has the coefficients shown in table 1 is shown in dotted lines in Fig. 4. The NTSC color bar spectrum NCB is shown in solid lines. The frequency response has notches at the picture, chroma and sound carriers where most of the NTSC energy is located. In fact, the rejection with another NTSC signal, the 'text over tulips' signal, is 12.58 db. Hence, even though this filter has been designed for rejecting the color bar signal, its response is general enough to reject other NTSC signals quite well also.

Tap No.	Tap Value
1	1.0000
2	-0.0161
3	-0.0561
4	0.0272
5	0.0289
6	0.0594
7	0.0599
8	0.0444
9	0.0093
10	0.0003
11	-0.655
12	-0.0228
13	-0.0869
14	0.0009
15	-0.0372
16	0.0445
17	0.0275
18	0.0592
19	0.0402
20	0.0283
21	-0.0079
22	-0.0144
23	-0.0627
24	-0.0220
25	-0.0673
26	0.0143
27	-0.0205
28	0.0556
29	0.0254
30	0.0569
31	0.0228
32	0.0159
33	-0.0224
34	-0.0240
35	-0.0598
36	-0.0200
37	-0.0500

Table 1.

Claims:

1. A method for calculating a plurality of coefficients for an interference rejection filter, said method comprising the steps of:
 - a) sampling at a sampling rate, an interference signal providing interference energy, in order to derive signal samples;
 - 5 b) correlating the samples to form a correlation matrix;
 - c) using said correlation matrix to minimize the interference energy present at the output of the interference rejection filter while constraining the enhancement of noise due to said interference rejection filter, to a specified value.
2. A television receiver comprising:
 - 10 a) means for receiving a digital television signal accompanied by noise, and an interference component resulting from a co-channel signal; and
 - b) interference rejection filter for reducing the effect of said interference component on said digital television signal, wherein said interference rejection filter comprises a plurality of coefficients which have been calculated in accordance with the
 - 15 method of Claim 1.
3. A transmitter for transmitting a digital television signal to the television receiver as claimed in claim 2, said transmitter comprising a precoder which precodes said digital signal prior to its transmission using said plurality of coefficients which have been calculated in accordance with the method of Claim 1.
- 20 4. A signal which has been pre-coded using a plurality of coefficients which

have been calculated in accordance with the method of Claim 1.

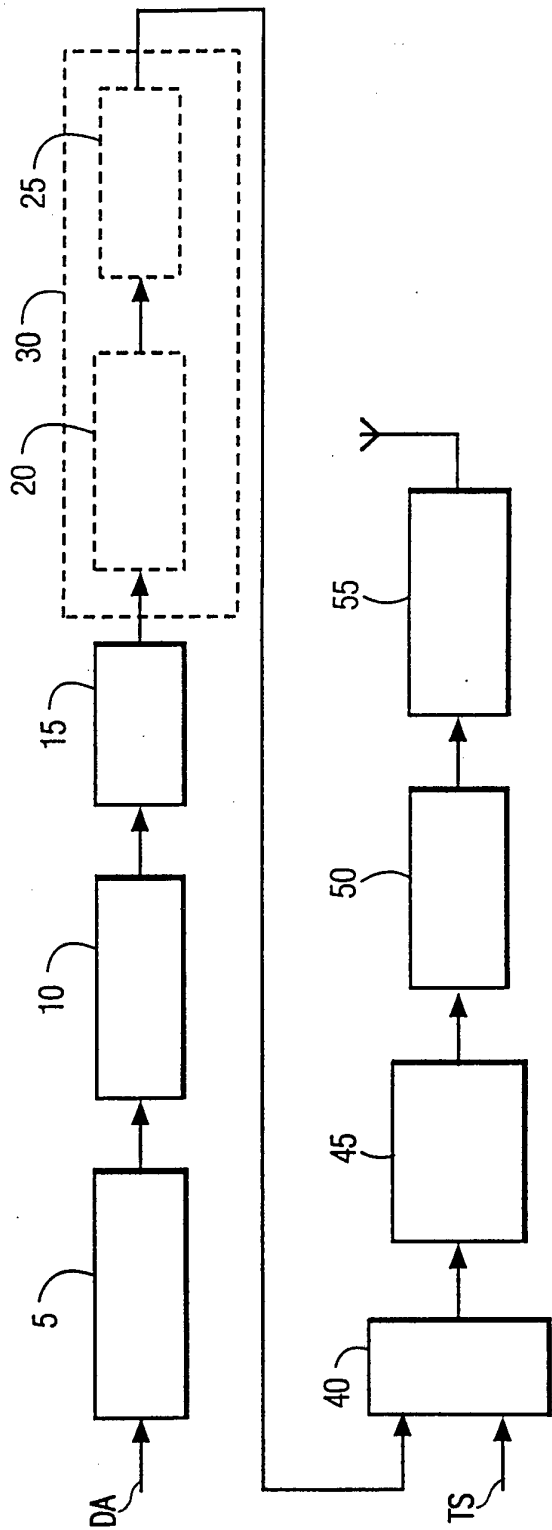


FIG. 1

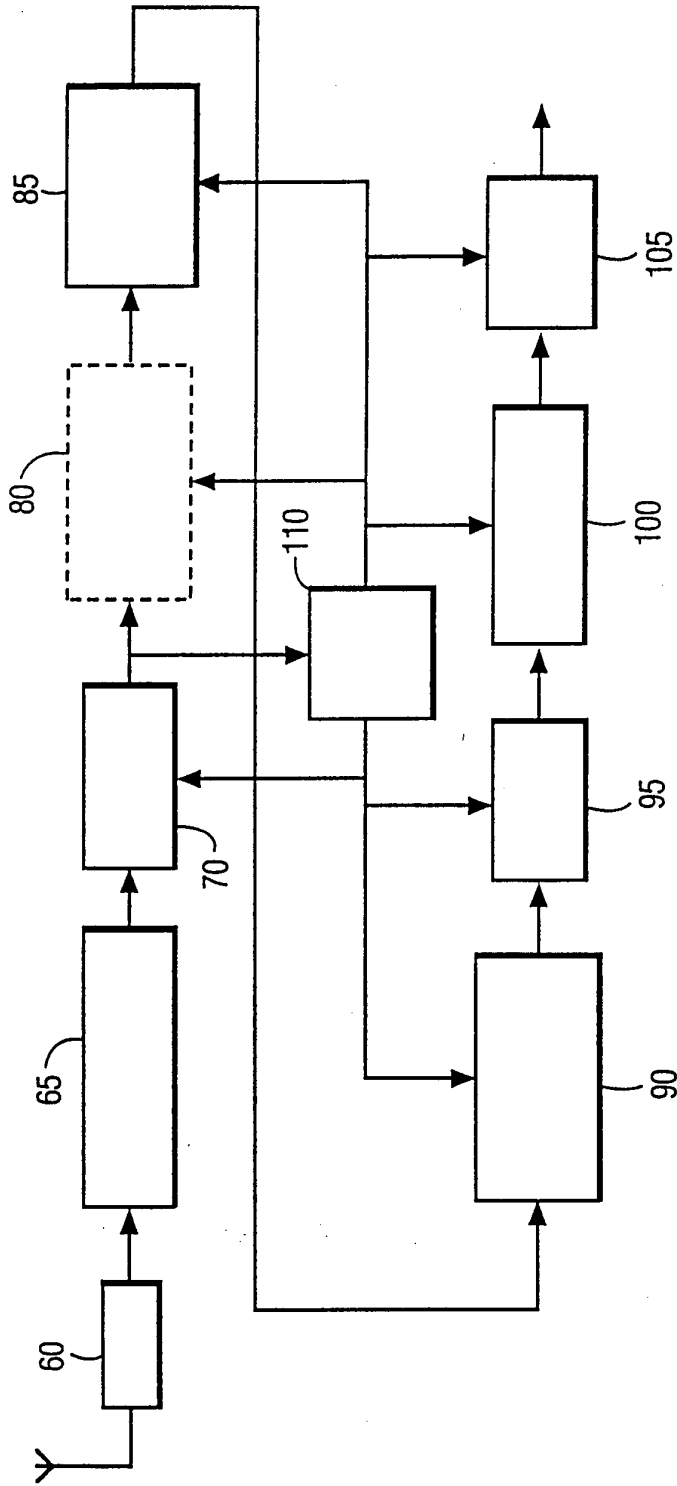


FIG. 2

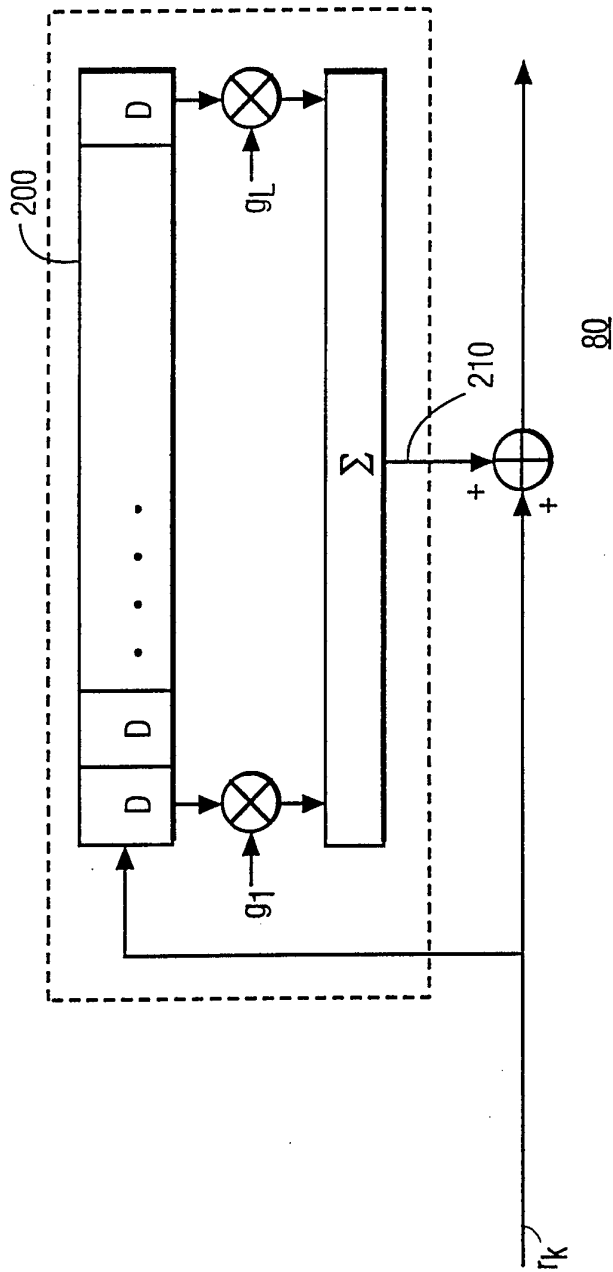


FIG. 3

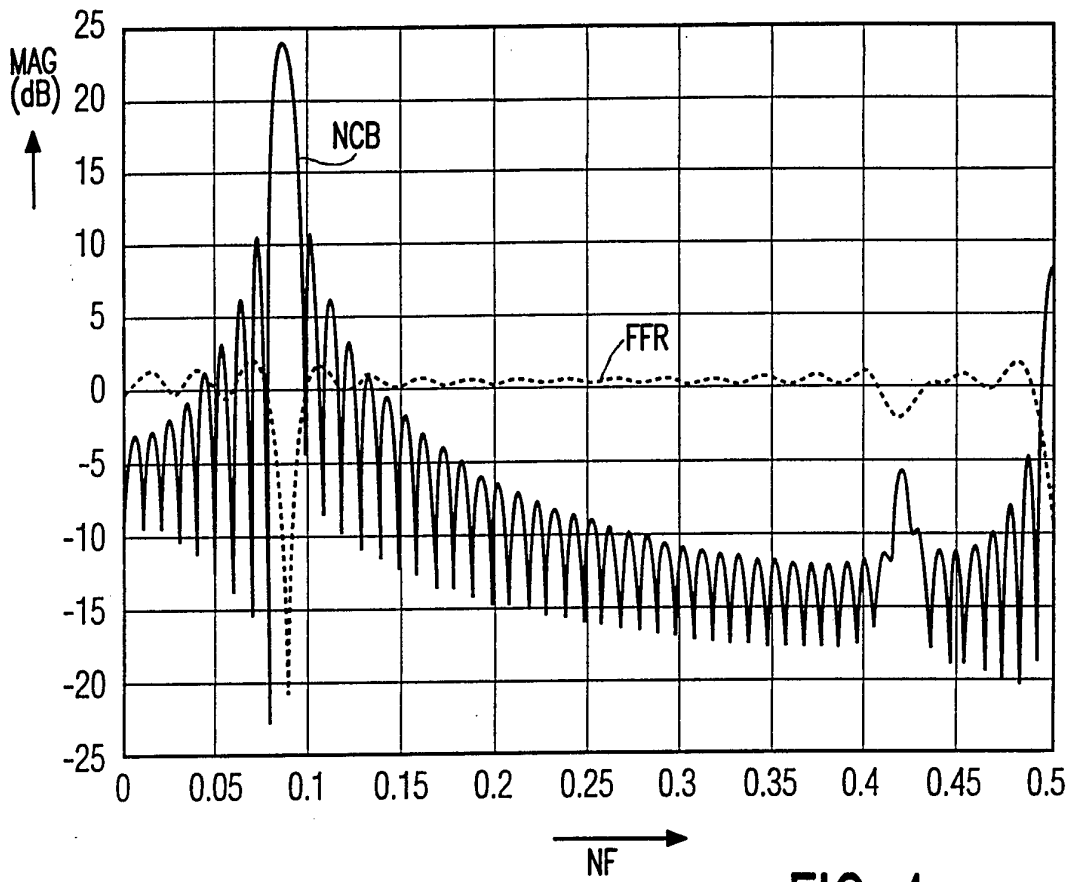


FIG. 4

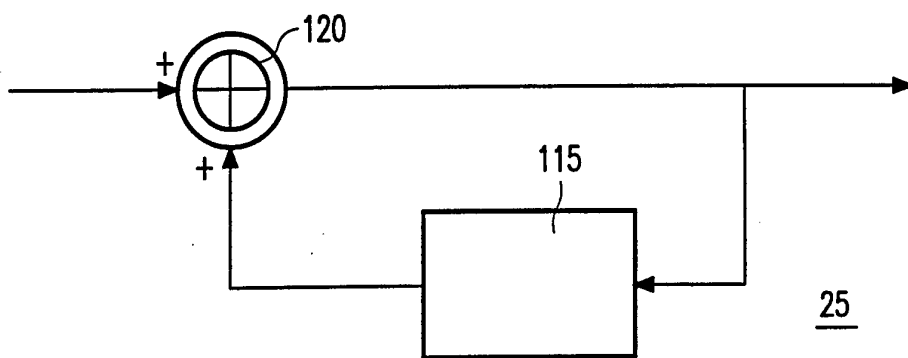


FIG. 5