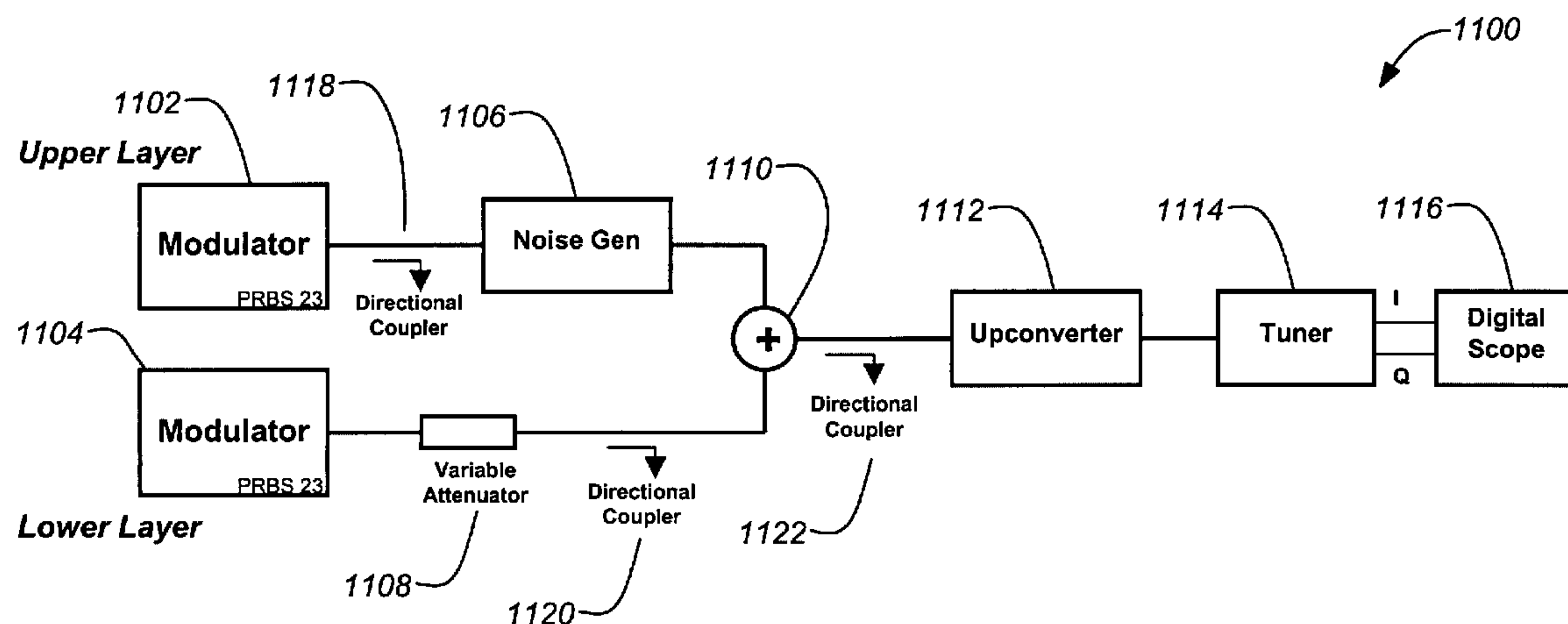




(86) Date de dépôt PCT/PCT Filing Date: 2003/07/03
(87) Date publication PCT/PCT Publication Date: 2004/01/15
(45) Date de délivrance/Issue Date: 2013/09/17
(85) Entrée phase nationale/National Entry: 2004/12/29
(86) N° demande PCT/PCT Application No.: US 2003/020847
(87) N° publication PCT/PCT Publication No.: 2004/006455
(30) Priorité/Priority: 2002/07/03 (US60/393,437)

(51) Cl.Int./Int.Cl. *H04L 27/34* (2006.01),
H04L 27/18 (2006.01)
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(54) Titre : PROCEDE ET APPAREIL DE MODULATION EN COUCHES
(54) Title: METHOD AND APPARATUS FOR LAYERED MODULATION



(57) **Abrégé/Abstract:**

Improvements to a layered modulation (LM) implementation are disclosed. The present invention discloses two implementations of LM, using single and multiple transponders per signal frequency, respectively. Layered hierarchical 8PSK (H-8PSK) is a special case of LM. By re-encoding the high-priority (HP) portion of an H-8PSK signal, LM can improve carrier-to-noise ratio (CNR) or a H-8PSK signal. LM can be computer-simulated and a two-layered signal can be sequentially demodulated with a predict CNR performance. An LM signal can be simulated using live signals for off-line processing. In addition, a signal processing apparatus can process in real time LM signals emulated from live satellite signals.



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METHOD AND APPARATUS FOR LAYERED MODULATION

ABSTRACT

Improvements to a layered modulation (LM) implementation are disclosed. The present invention discloses two implementations of LM, using single and multiple transponders per signal frequency, respectively. Layered hierarchical 8PSK (H-8PSK) is a special case of LM. By re-encoding the high-priority (HP) portion of an H-8PSK signal, LM can improve carrier-to-noise ratio (CNR) of an H-8PSK signal. LM can be computer-simulated and a two-layered signal can be sequentially demodulated with a predicted CNR performance. An LM signal can be simulated using live signals for off-line processing. In addition, a signal processing apparatus can process in real time LM signals emulated from live satellite signals.

METHOD AND APPARATUS FOR LAYERED MODULATION

BACKGROUND OF THE INVENTION

5 1. Field of the Invention

[0001] The present invention relates generally to systems and methods for transmitting and receiving digital signals, and in particular, to systems and methods for broadcasting and receiving digital signals using layered modulation techniques.

10

2. Description of the Related Art

[0002] Digital signal communication systems have been used in various fields, including digital TV signal transmission, either terrestrial or satellite.

15

[0003] As the various digital signal communication systems and services evolve, there is a burgeoning demand for increased data throughput and added services. However, it is more difficult to implement either improvement in old systems and new services when it is necessary to replace existing legacy hardware, such as transmitters and receivers. New systems and services are advantaged when they can utilize existing legacy hardware. In the realm of wireless communications, this principle is further highlighted by the limited availability of electromagnetic spectrum. Thus, it is not possible (or at least not practical) to merely transmit enhanced or additional data at a new frequency.

25

[0004] The conventional method of increasing spectral capacity is to move to a higher-order modulation, such as from quadrature phase shift keying (QPSK) to eight phase shift keying (8PSK) or sixteen quadrature amplitude modulation (16QAM). Unfortunately, QPSK receivers cannot demodulate conventional 8PSK or 16QAM signals. As a result, legacy customers with QPSK receivers must upgrade their receivers in order to continue to receive any signals transmitted with an 8PSK or 16QAM modulation.

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[0005] Layered modulation techniques have been identified and developed to increase capacity, both in backwards compatible and non-backwards compatible implementations. Hierarchical modulation, particularly hierarchical 8PSK (H-8PSK), is also a special type of layer modulation that has been developed directed to a backwards compatible layered modulation implementation.

[0006] What is needed are systems and methods that improve layered modulation implementation, including hierarchical modulation implementations. Further, there is need for systems and methods that simulate the performance of layered modulation systems. The present invention satisfies these and other needs.

SUMMARY OF THE INVENTION

[0007] Improvements to a layered modulation (LM) implementation are disclosed. The present invention relates to two implementations of LM, using single and multiple transponders per signal frequency, respectively. Layered hierarchical 8PSK (H-8PSK) is a special case of LM. By re-encoding the high-priority (HP) portion of an H-8PSK signal, LM can improve carrier-to-noise ratio (CNR) of a H-8PSK signal.

[0008] In addition, LM can be computer-simulated and a two-layered signal can be sequentially demodulated with a predicted CNR performance. An LM signal can be emulated using live signals for off-line processing.

[0009] In addition, a signal processing apparatus can process in real time LM signals emulated from live satellite signals. Embodiments of the invention comprise systems and methods for simulating a layer-modulated signal, including a hierarchically modulated signal. Such systems and methods are useful in the development of layer modulated systems because they allow convenient testing of proposed implementations and adjustments to existing systems and provide performance indicators at low cost.

[0010] A typical method for simulating a layer modulated signal having a first modulation of an upper layer and a second modulation of a lower layer, comprises

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providing an upper layer signal comprising a first modulated bit stream, providing a lower layer signal comprising a second modulated bit stream, attenuating the lower layer signal and combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal. The upper and lower layers
5 can be separately modulated in a laboratory environment or received from distinct antennas.

[0011] A first exemplary layer modulated system simulator comprises a first modulator for modulating a bit stream of the upper layer to produce an upper layer
10 signal, a noise generator for adding noise to the upper layer signal, a second modulator for modulating a bit stream of a lower layer to produce a lower layer signal, an attenuator for attenuating the lower layer signal and a combiner for combining the noise-added upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal. This embodiment of the invention can
15 be used for emulating a composite layer modulated signal entirely within a laboratory.

[0012] A second exemplary layer modulated system simulator comprises a first antenna for receiving the upper layer signal from a first satellite transponder, a first amplifier for amplifying the received upper layer signal, a second antenna for
20 receiving the lower layer signal from a second satellite transponder, a second amplifier for amplifying the received lower layer signal, an attenuator for attenuating the received lower layer signal and a combiner for combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal. This embodiment of the invention can be used for emulating a composite
25 layer modulated signal from existing satellite signals.

[0013] In accordance with an aspect of the present invention, there is provided a method for simulating a layer modulated signal, comprising the steps of:

providing an upper layer signal comprising a first bit stream modulated by a
30 first carrier;

providing a lower layer signal comprising a second bit stream modulated by a second carrier not coherent with the first carrier;

attenuating the lower layer signal; and

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combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal;

wherein at least one directional coupler is used to tap the composite layer modulated signal.

5

[0014] In accordance with another aspect of the present invention there, is provided a signal simulator for simulating a layer modulated signal having an upper layer and a lower layer not coherent with the upper layer, comprising:

- 10 a first modulator for modulating a bit stream of the upper layer according to a first carrier to produce an upper layer signal;
- a noise generator for adding noise to the upper layer signal;
- a second modulator for modulating a bit stream of the lower layer according to a second carrier not coherent with the first carrier to produce a lower layer signal;
- an attenuator for attenuating the lower layer signal; and
- 15 a combiner for combining the noise-added upper layer signal and the attenuated lower layer signal to produce a composite layer modulated signal.

[0015] In accordance with a further aspect of the present invention there, is provided a receiver system for simulating reception of a layer modulated signal, 20 comprising:

- a first antenna for receiving an upper layer signal from a first satellite transponder;
- a first amplifier for amplifying the received upper layer signal;
- a second antenna for receiving a lower layer signal from a second satellite 25 transponder wherein the lower layer signal is not coherent with the upper layer signal;
- a second amplifier for amplifying the received lower layer signal;
- an attenuator for attenuating the received lower layer signal; and
- a combiner for combining the upper layer signal and the attenuated lower layer signal to produce a composite layer modulated signal.

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[0016] In accordance with another aspect of the present invention, there is provided a method for simulating a layer modulated signal having an upper layer and a lower layer not coherent with the upper layer, comprising the steps of:

- providing an upper layer signal comprising a first bit stream modulated
- 5 according to a first carrier;
- providing a lower layer signal comprising a second bit stream modulated according to a second carrier not coherent with the first carrier;
- attenuating the lower layer signal; and
- combining the upper layer signal and the attenuated lower layer signal to
- 10 produce the composite layer modulated signal;
- tuning the composite layer modulated signal;
- evaluating the composite layer modulated signal performance based upon the in-phase and quadrature components of the layer modulated signal.

- 15 [0017] In accordance with a further aspect of the present invention there, is provided a signal simulator for simulating a layer modulated signal having a first modulation of an upper layer and a second modulation of a lower layer, comprising:
- a first modulator for modulating a bit stream of the upper layer according to a first carrier to produce an upper layer signal;
 - 20 a noise generator for adding noise to the upper layer signal;
 - a second modulator for modulating a bit stream of the lower layer according to a second carrier not coherent with the first carrier to produce a lower layer signal;
 - an attenuator for attenuating the lower layer signal;
 - a combiner for combining the noise-added upper layer signal and the
 - 25 attenuated lower layer signal to produce the composite layer modulated signal; and
 - a directional coupler, for tapping the composite layer modulated signal.

- [0018] In accordance with another aspect of the present invention, there is provided a signal simulator for simulating reception of a layer modulated signal having a first
- 30 modulation of an upper layer and a second modulation of a lower layer, comprising:
- a first antenna for receiving the upper layer signal from a first satellite transponder;
 - a first amplifier for amplifying the received upper layer signal;

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a second antenna for receiving the lower layer signal from a second satellite transponder wherein the lower layer signal is not coherent with the upper layer signal;

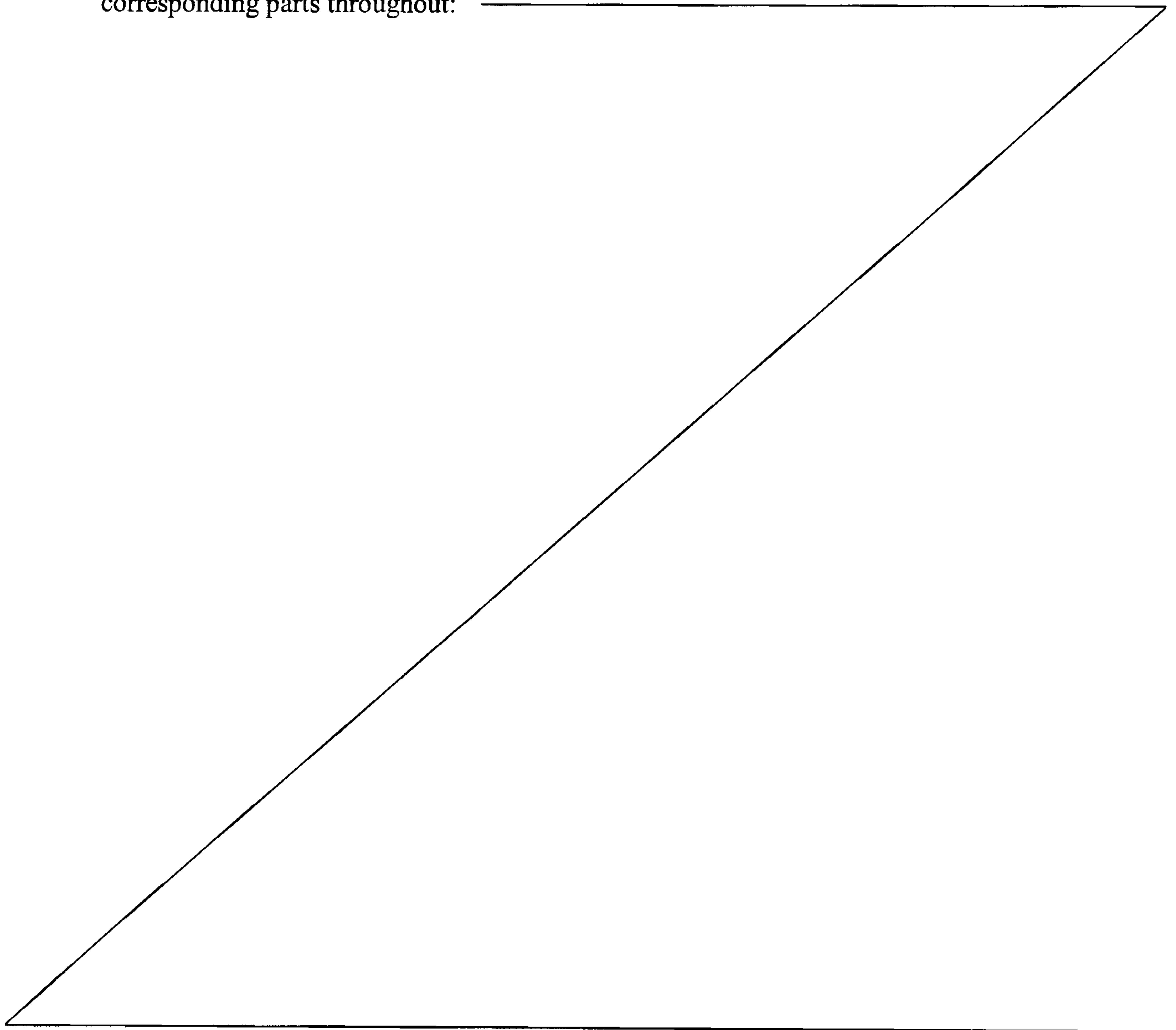
a second amplifier for amplifying the received lower layer signal;

an attenuator for attenuating the received lower layer signal; and

5 a combiner for combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal.

BRIEF DESCRIPTION OF THE DRAWINGS

10 [0019] Referring now to the drawings in which like reference numbers represent corresponding parts throughout:



[0020] FIGS. 1A-1C illustrate the relationship of signal layers in a layered modulation transmission;

[0021] FIGS. 2A-2C illustrate a signal constellation, along with its phase characteristics, of a second transmission layer over a first transmission layer non-coherently;

[0022] FIG. 3A is a diagram illustrating a QPSK signal constellation;

[0023] FIG. 3B is a diagram illustrating a non-uniform 8PSK signal constellation achieved through layered modulation;

[0024] FIG. 4A is a block diagram illustrating a layered modulation system using a single transponder;

[0025] FIG. 4B is a block diagram illustrating a layered modulation system using two transponders;

[0026] FIG. 5 is a block diagram of an exemplary receiver of a layered modulation signal;

[0027] FIG. 6 is a plot illustrating channel capacity shared between upper and lower layers;

[0028] FIGS. 7 is a block diagram of an exemplary receiver for hierarchical modulation;

[0029] FIGS. 8 is a block diagram of a second exemplary receivers for hierarchical modulation;

[0030] FIG. 9 is a block diagram of an exemplary layer modulated signal simulator;

[0031] FIG. 10 is a GUI of an exemplary layer modulated signal simulator showing BER test results;

[0032] FIG. 11A is a block diagram of an exemplary system for simulating a layer modulated signal in a laboratory;

[0033] FIG. 11B is a block diagram of an exemplary system for simulating a layer modulated signal using satellite signals;

5 [0034] FIG. 12 is flowchart of an exemplary method for simulating a layer modulated signal;

[0035] FIG. 13 is a flowchart of exemplary processing for a layer modulated signal;

[0036] FIG. 14 is power spectrum plot of an exemplary layer modulated signal;

10 [0037] FIGS. 15A-15C are plots illustrating upper layer symbol timing recovery for an exemplary layer modulated signal;

[0038] FIGS. 15D-15F are plots illustrating an upper layer symbol timing recovered signal for an exemplary layer modulated signal;

[0039] FIGS. 16A-16C are plots illustrating upper layer carrier recovery for an exemplary layer modulated signal;

15 [0040] FIGS. 16D-16F are plots illustrating an upper layer carrier recovered signal for an exemplary layer modulated signal;

[0041] FIG. 17A is a plot of uncoded upper layer bit errors at the demodulator output for an exemplary layer modulated signal;

20 [0042] FIG. 17B is a plot of upper layer byte errors at the Viterbi decoder output for an exemplary layer modulated signal;

[0043] FIG. 17C is a plot of upper layer byte errors at the de-interleaver output for an exemplary layer modulated signal;

[0044] FIG. 17D is a plot of upper layer errors correctable by a Reed-Solomon decoder for an exemplary layer modulated signal;

[0045] FIG. 18 is a plot of power level matching for an exemplary layer modulated signal;

5 [0046] FIG. 19 is power spectrum plot of an extracted lower layer signal of an exemplary layer modulated signal;

[0047] FIGS. 20A-20C are plots illustrating lower layer symbol timing recovery for an exemplary layer modulated signal;

10 [0048] FIGS. 20D-20F are plots illustrating a lower layer symbol timing recovered signal for an exemplary layer modulated signal;

[0049] FIGS. 21A-21C are plots illustrating lower layer carrier recovery for an exemplary layer modulated signal;

[0050] FIGS. 21D-21F are plots illustrating a lower layer carrier recovered signal for an exemplary layer modulated signal;

15 [0051] FIG. 22A is a plot of uncoded lower layer bit errors at the demodulator output for an exemplary layer modulated signal;

[0052] FIG. 22B is a plot of lower layer byte errors at the Viterbi decoder output for an exemplary layer modulated signal;

20 [0053] FIG. 22C is a plot of lower layer byte errors at the de-interleaver output for an exemplary layer modulated signal;

[0054] FIG. 22D is a plot of upper layer errors correctable by a Reed-Solomon decoder for an exemplary layer modulated signal;

[0055] FIG. 23A is a plot of uncoded bit error rates for upper and lower layers of an exemplary layer modulated signal; and

[0056] FIG. 23B is a plot of Viterbi decoder output bit error rates for upper and lower layers of an exemplary layer modulated signal.

5 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0057] In the following description, reference is made to the accompanying drawings which form a part hereof, and which show, by way of illustration, several embodiments of the present invention. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of
10 the present invention.

LAYERED AND HIERARCHICAL MODULATION/DEMODULATION

[0058] FIGS. 1A-1C illustrate the basic relationship of signal layers in a layered modulation transmission. FIG. 1A illustrates a first layer signal constellation 100 of a transmission signal showing the signal points or symbols 102. FIG. 1B illustrates the
15 second layer signal constellation of symbols 104 over the first layer signal constellation 100 where the layers are coherent. FIG. 1C illustrates a second signal layer 106 of a second transmission layer over the first layer constellation where the layers may be non-coherent. The second layer 106 rotates about the first layer constellation 102 due to the relative modulating frequency of the two layers in a non-
20 coherent transmission. Both the first and second layers rotate about the origin due to the first layer modulation frequency as described by path 108.

[0059] FIGS. 2A-2C illustrate a signal constellation of a second transmission layer over the first transmission layer after first layer demodulation. FIG. 2A shows the constellation 200 before the first carrier recovery loop (CRL) and FIG. 2B shows the
25 constellation 200 after CRL. In this case, the signal points of the second layer are actually rings 202. FIG. 2C depicts a phase distribution of the received signal with

respect to nodes 102. A relative modulating frequency causes the second layer constellation to rotate around the nodes of the first layer constellation. After the second layer CRL this rotation is eliminated. The radius of the second layer constellation is determined by its power level. The thickness of the rings 202 is
 5 determined by the carrier to noise ratio (CNR) of the second layer. As the two layers are non-coherent, the second layer may also be used to transmit analog or digital signals. A special case of layered modulation is found in hierarchical modulation, such as hierarchical non-uniform 8PSK.

[0060] FIG. 3A is a diagram illustrating a signal constellation for a QPSK HP data
 10 signal. The signal constellation includes four possible signal outcomes 302 for A and B wherein $\{A,B\} = \{0,0\}$ (point 302A in the first quadrant), $\{1,0\}$ (point 302B in the second quadrant), $\{1,1\}$ (point 302C in the third quadrant), and $\{0,1\}$ (point 302D in the fourth quadrant). An incoming and demodulated signal mapped to one of quadrants (I-IV) and the value for $\{A,B\}$ (and hence, the value for the relevant portion
 15 of the HP data stream) is determined therefrom.

[0061] FIG. 3B is a diagram illustrating an 8PSK constellation created by addition of an LP data stream (represented by "C"). The application of hierarchical modulation adds two possible data values for "C" ($C = \{1,0\}$) to each of the outcomes 302A-302D. For example, outcome 302A ($\{A,B\} = \{0,0\}$) is expanded to an outcome pair
 20 304A and 304A' ($\{A,B,C\} = \{0,0,1\}$ and $\{0,0,0\}$), respectively, with the members of the pair separated by an angle Θ from $\{A,B\}$. This expands the signal constellation to include 8 nodes 104A-104D (each shown as solid dots).

[0062] If the angle Θ is small enough, a legacy QPSK signal will receive both $\{A,B,C\} = \{0,0,1\}$ and $\{0,0,0\}$ as $\{A,B\} = \{0,0\}$. Only receivers capable of
 25 performing the second hierarchical level of modulation (LP) can extract the value for $\{C\}$ as either $\{0\}$ or $\{1\}$. This hierarchical signal structure has been termed "non-uniform" 8PSK.

[0063] The choice of the variable Θ depends on a variety of factors. FIG. 3B, for example, presents the idealized data points without noise. Noise and errors in the transmission and/or reception of the signal vary the actual position of the nodes 304A-304D and 304A'-304D' in FIG. 3B. Noise regions 306 surrounding each node indicate areas in the constellation where the measured data may actually reside. The ability of the receiver to detect the symbols and accurately represent them depends on the angle Θ , the power of the signal (e.g. the carrier), represented by r_c , and the noise (which can be represented by r_n). As can be seen by inspecting FIG. 3B, interference of LP into HP is reduced as signal power increases, or as Θ decreases. The performance of this hierarchical modulating system can be expressed in terms of its carrier to interference ratio (C/I).

[0064] With a layered-type demodulation as in this invention, the noise contributed by UL symbol errors to the extracted LL signal is avoided. With a Layered modulation mapping, the LP bit value for the 8 nodes alternates between 0 and 1 around the circle, i.e., {0,1,0,1,0,1,0,1}. This is in contrast with the {0,0,1,1,0,0,1,1} assignment in Figure 3B for the conventional hierarchical modulation. Layered demodulation first FEC-decodes the upper layer symbols with a quasi-error free (QEF) performance, then uses the QEF symbols to extract the lower layer signal. Therefore, no errors are introduced by uncoded lower layer symbol errors. The delay memory required to obtain the QEF upper layer symbols for this application presents a small additional receiver cost, particularly in consideration of the ever-decreasing solid state memory cost over time.

[0065] In a conventional hierarchical receiver using non-uniform 8PSK, the LP signal performance can be impacted by HP demodulator performance. The demodulator normally includes a timing and carrier recovery loop. In most conventional recovery loops, a decision-directed feedback loop is included. Uncoded symbol decisions are used in the prediction of the tracking error at each symbol time of the recovery loop. The tracking loop would pick up an error vector whenever a

symbol decision is in error; the uncoded symbol error rate (SER) could be as high as 6% in many legacy systems. An FEC-corrected demodulator of this invention avoids the degradation.

- 5 [0066] FIG. 4A is a block diagram illustrating a first layered modulation system 400 using a single transponder 402 in a satellite. The uplink signal 406 is processed at the broadcast center 408. Both the upper layer (UL) and lower layer (LL) signals 410, 412 are encoded and mapped and modulated together 414 before frequency upconversion 416. The signals 410, 412 are combined after FEC encoding. A receiver 418 decodes
10 the downlink from the transponder 402. Conventional single traveling wave tube amplifiers (TWTAs) are suitable for constant-envelope signal such as 8PSK and derivatives. This system is suited for layered modulation using coherent UL and LL signals.
- 15 [0067] FIG. 4B is a block diagram illustrating a second layered modulation system 420 using multiple transponders 402A, 402B. The upper layer (UL) and lower layer (LL) signals 410, 412 are separately encoded and mapped and modulated 414A, 414B before separate frequency upconversion 416A, 416B. A separate broadcast center 408 can be used for each layer. The signals 410, 412 are combined in space before
20 downlink. A receiver 418 decodes the downlinked signals simultaneously received from transponders 402A, 402B. Separate TWTAs for the transponders 402A, 402B allow nonlinear TWTAs outputs to be combined in space. The upper layer and lower layer signals 410, 412 can be coherent or non-coherent.
- 25 [0068] FIG. 5 is a block diagram of an exemplary receiver 500 of a layered modulation signal, similar to those described in U.S. Patent No. 7,209,524, filed on April 27, 2001, and entitled "LAYERED MODULATION FOR DIGITAL SIGNALS", by Ernest C. Chen. FEC re-encoding and remodulation may begin prior
30 to the final decoding of the upper layer. In addition, processing is simplified for signals that are coherent between layers, particularly processing of the lower layer.

[0069] The effect of two layered modulation on channel capacity can be demonstrated by the following analysis.

N : Power of thermal noise

S_L : Power of lower-layer signal with Gaussian source distrib.

N_U : Effective power of upper-layer noise ($N_U = S_L + N$)

S_U : Power of upper-layer signal with Gaussian source distrib.

C_{CM} : Channel capacity for Conventional Modulation (bps/Hz)
with the total power

C_{LM} : Channel capacity for Layered Modulation (bps/Hz)

$$C_{CM} = \log_2 \left(1 + \frac{S_L + S_U}{N} \right)$$

$$C_{LM} = \log_2 \left(1 + \frac{S_L}{N} \right) + \log_2 \left(1 + \frac{S_U}{N_U} \right) = \log_2 \left[\left(1 + \frac{S_L}{N} \right) \left(1 + \frac{S_U}{N_U} \right) \right]$$

Since

$$\left(1 + \frac{S_L}{N} \right) \left(1 + \frac{S_U}{N_U} \right) = 1 + \frac{S_L}{N} + \left(1 + \frac{S_L}{N} \right) \frac{S_U}{S_L + N} = 1 + \frac{S_L + S_U}{N}$$

It follows that

$$C_{LM} = C_{CM}$$

Thus, assuming Gaussian source and noise distributions, sharing power between two
5 layers does not reduce the total capacity of a layer modulation system.

[0070] The effect of an additional layer in a layered modulation system on channel capacity can also be demonstrated by the following analysis.

N : Power of thermal noise

S_B : Power sum of bottom 2 signals with Gaussian source distrib.

$$(B \equiv U + L; \quad S_B = S_U + S_L)$$

N_T : Power of top-layer noise ($N_T = S_B + N$)

S_T : Power of top-layer signal with Gaussian source distrib.

C_{CM} : Channel capacity for Conventional Modulation (bps/Hz)
with the total power

C_{LM} : Channel capacity for Layered Modulation (bps/Hz)

$$C_{CM} = \log_2 \left(1 + \frac{S_B + S_T}{N} \right)$$

$$C_{LM} = \log_2 \left(1 + \frac{S_B}{N} \right) + \log_2 \left(1 + \frac{S_T}{N_T} \right) = \log_2 \left[\left(1 + \frac{S_B}{N} \right) \left(1 + \frac{S_T}{N_T} \right) \right]$$

Since

$$\left(1 + \frac{S_B}{N} \right) \left(1 + \frac{S_T}{N_T} \right) = 1 + \frac{S_B}{N} + \left(1 + \frac{S_B}{N} \right) \frac{S_T}{S_B + N} = 1 + \frac{S_B + S_T}{N}$$

It follows that

$$C_{LM} = C_{CM}$$

Thus, again assuming Gaussian source and noise distributions, sharing power among any number of layers does not reduce the total capacity.

[0071] FIG. 6 is a example plot illustrating channel capacity shared between upper
5 and lower layers. This example is for a 11.76 dB total signal power (referenced to thermal noise). The power is shared between upper and lower layer signals. A Gaussian source distribution is assumed for both layers as well as a Gaussian noise distribution. Channel capacity is approximately 4 bps/Hz for CNR of 11.76 dB. As shown, the sum of the two layer capacities always equals the total capacity.

10 [0072] Hierarchical 8PSK can be viewed as a special case of layered modulation. Referring to FIG. 3B, constant power can be applied for all signals. The high priority (HP) data signal, represented by the nodes 302A-302D corresponds to the upper layer. The low priority (LP) signal, represented by the nodes 304A-304D and 304A'-304D', corresponds to the lower layer. The HP and LP signals are synchronous, having

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coherent phase and identical baud timing. The HP layer of an 8PSK hierarchically modulated signal can be demodulated as if the composite signal were QPSK, typically using a decision-direct feedback tracking loop.

- 5 [0073] FIGS. 7 & 8 are block diagrams of exemplary receivers for hierarchical modulation similar to those described in PCT Patent Application Publication No. WO/2004/004193, filed on July 1, 2003, and entitled "IMPROVING HIERARCHICAL 8PSK PERFORMANCE", by Ernest C. Chen et al.

10 LAYERED AND HIERARCHICAL SIMULATION

- [0074] Embodiments of the invention comprise systems and methods for simulating a layer-modulated signal, including a hierarchically modulated signal. The methods and systems presented herein can be used to accelerate the study and development of
15 layered modulation systems while reducing costs. Many different proposed layered modulation implementations can be quickly and inexpensively evaluated.

- [0075] In one exemplary embodiment an end-to-end simulation of communication channel, including satellite distortions, downlink noise, receiver phase noise and
20 receiver implementation errors is developed. The simulator can be developed using a mathematical programming tool such as MATLAB. Standard signals can be incorporated into the simulator for ready application, e.g. DIRECTV and DVB-S signals as well as turbo codes and other signals.

- 25 [0076] The simulator can be used to process computer-simulated signals or data captured from modulators and/or satellites. For example, LM signals can be emulated by RF-combining real-time signals. In addition, cross-check laboratory tests can be performed with synthesized signal performance. A field programmable gate array (FPGA) LM signal processor essentially mimics a LM simulator of the invention, but
30 with real time processing.

[0077] FIG. 9 is a block diagram of a complete simulation 900 of a layer modulated signal. Pseudorandom binary sequence (PRBS) generators 902, 904 are used to create the upper and lower layer data. Data from each layer is then passed through an forward error correction (FEC) encoder 906, 908. After FEC encoding the signals can be processed to simulate either a single or dual-transponder system. See FIGS. 4A and 4B. If a dual-transponder system is being simulated (as in FIG. 4B), the upper and lower layers are processed separately. Each signal layer is separately passed through a signal mapper 910A, 910B, a pulse shaping filter 912A, 912B (e.g., a root raised cosine filter), a baud timing and carrier frequency offset simulator 914A, 914B, and a satellite distortion simulator 916A, 916B. If a single transponder system is being simulated (as in FIG. 4A), the upper and lower layers are combined and passed through the same set of processes together with a weighted summation contained in signal mapper 910. For a dual-transponder system, the upper and lower layers are combined at the output in a weighted summation 918. In either case, modeled channel interference effects 920 (adjacent and co-channel) are added. The composite signal is then processed by adding white Gaussian noise provided by a noise generator 922, phase noise from a phase noise generator 924 and frequency filtering by a receiver front end filter 926 before receiver processing 928. Captured data 930 from laboratory equipment that provide the same functionality as the simulation modules (902, 904...all items in Figure 9 except 930 and 928) can be applied to the receiver processing to evaluate performance.

[0078] FIG. 10 is a graphical user interface (GUI) 1000 of an exemplary layer modulated signal simulator including several blocks of FIG. 9 showing BER test results. The display outlines the simulator signal processing flow. Upper and lower layer signal transmitters 1002, 1004 are shown with signal outputs combined and passed through the additive white Gaussian noise (AWGN) channel 1006. The composite signal then arrives at the receiver 1008. Lower layer outputs are provided to a lower layer performance measurement block 1010 along with the original lower layer signal from the lower layer transmitter 1004. Similarly, upper layer outputs are

provided to an upper layer performance measurement block 1012 along with the original upper layer signal from the upper layer transmitter 1002. An error rate and frame based bit error calculation are performed for each layer to establish a performance measurement. Operational parameters can be set in a dialog box 1014.

5 [0079] FIG. 11A is a block diagram of an exemplary system 1100 for synthesizing a layer modulated signal in a laboratory. A first modulator 1102 is used to modulate a first bit stream, e.g. a PRBS, of the upper layer to produce an upper layer signal. A noise generator 1106 can be used to add noise to the upper layer signal. A second modulator 1104 is used for modulating a second bit stream of a lower layer to produce
10 a lower layer signal. An attenuator 1108, (such as variable attenuator) can be used for appropriately attenuating the lower layer signal. A combiner 1110 is then used to combining the noise-added upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal. (Equivalently, noise generator 1106 with a corresponding output power level may be placed on the lower layer path
15 instead of the upper layer path.) The composite layer modulated signal can then be upconverted 1112 before being communicated to a tuner 1114 to extract the in-phase and quadrature components of the separate signal layers, analyzed using a scope 1116 as desired. If a digitizing oscilloscope is used, the digitized in-phase and quadrature signals can be introduced as the Captured Data 930 in Figure 9. Directional couplers
20 1118, 1120 can be used to tap the upper layer signal (prior to noise addition) and the lower layer signal (after attenuation) to be used in evaluating the relative power levels of the upper and lower layer signals prior to the addition by the combiner 1110.. Similarly, the composite signal can also be tapped by a direction coupler 1122.

[0080] FIG. 11B is a block diagram of an exemplary system 1150 for simulating a
25 layer modulated signal using satellite signals. Distinct satellite signals 1152, 1154 are received at separate antennas 1156, 1158. It is important to note that the two received signals 1152, 1154 are not layered modulation signals. Both signals 1152, 1154 are passed through separate amplifiers 1160, 1162. The satellite signal 1154 to be used as

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the lower layer signal is passed through an attenuator 1164 (such as a variable attenuator) to appropriately attenuate the signal. Both signals are then combined at the combiner 1166 to form the composite layered modulation signal. The composite signal can then be communicated to a tuner 1168 to extract the in-phase and quadrature components of the separate signal layers which may be analyzed using a scope 1176. If a digitizing oscilloscope is used, the digitized in-phase and quadrature signals can be introduced as the Captured Data 930 in Figure 9. Directional couplers 1170, 1172, 1174 can be used to tap the upper layer signal, lower layer signal and the composite signal, respectively. These tapped signal are used to evaluate the signal and/or attenuator performance. This system 1150 requires less expensive equipment than the embodiment of FIG. 11A (particularly, omitting the modulators 1102, 1104). In addition, because actual satellite signals 1152, 1154 are used, real signal effects are included in the composite layer modulated signal.

15 **[0081]** FIG. 12 is flowchart of an exemplary method 1200 for simulating a layer modulated signal. The method applies to the systems of both FIGS. 11A & 11B. The method 1200 simulates a layer modulated signal having a first modulation of an upper layer and a second modulation of a lower layer. At step 1202 an upper layer signal is provided comprising a first modulated bit stream. At step 1204, a lower layer signal is provided comprising a second modulated bit stream. Next at step 1206, the lower layer signal is attenuated. Finally at step 1208, the upper layer signal and the attenuated lower layer signal are combined to produce the composite layer modulated signal. The method can be further modified consistent with the foregoing system embodiments.

25 **[0082]** FIG. 13 is a flowchart of processing for a layer modulated signal. Further detail of layered modulation processing can be found U.S. Patent No. 7,209,524, filed on April 27, 2001, and entitled "LAYERED MODULATION FOR DIGITAL SIGNALS", by Ernest C. Chen. Layered modulation simulation

methods and systems of the invention can be used to evaluate the performance of layered signals as well as receiver processes.

EXEMPLARY LAYERED MODULATION SIMULATION

[0083] An exemplary computer simulation of a layered modulation signal can be defined with the following parameters. Both layers can use a nominal symbol frequency of 20 MHz (not necessarily synchronized to each other in timing frequency and phase). The carrier frequencies are not necessarily coherent with respect to each other either. The excess bandwidth ratio is 0.2. It is assumed that no satellite degradation of the signal occurs; TWTA and filter effects can be modeled separately if necessary. The upper and lower layer signals can each be a convolutional code 6/7, Reed-Soloman (146, 130) signal with an assigned reference power of 0 dB to the upper layer. Upper layer CNR is approximately 7.7 dB. Lower layer CNR is approximately 7.6 dB. Noise (AWGN) of -16 dB can be applied. A turbo-coded signal may alternately be used for the lower layer. Phase noise of the low noise block (LNB) and tuner are included. The following table summarizes the simulation results.

Input CNR (dB)		Output CNR (dB)		
UL	LL	UL	LL	Dynamic Range
7.6	None	7.43	None	7.43
7.7	7.6	7.51	7.22	15.48

The first row applies to processing only the upper layer, which reduces CNR by approximately 0.2 dB (7.6 dB – 7.43 dB). The second row applies to processing both layers. The lower layer CNR is reduced by approximately 0.4 dB (7.6 dB – 7.22 dB). This result compares favorably with nominal 16QAM performance. Further details of the simulation process are shown hereafter.

[0084] FIG. 14 is power spectrum plot of an exemplary layer modulated signal that can be simulated by the method and system previously described. The composite upper and lower layer signals are added with thermal noise. A sampling frequency of

100 MHz is used and a display resolution of 1 MHz is shown. The spectrum peak is scaled to 0 dB, showing a thermal noise floor of approximately -17 dB. A front end receiver filter is used to taper the noise floor.

- [0085] FIGS. 15A-15C are plots illustrating upper layer symbol timing recovery for an exemplary layer modulated signal. FIG. 15A is a plot of the comparator output, based on a zero-crossing method. FIG. 15B is the low pass filter (LPF) output of the loop filter; a decision-directed second order filter is applied. A nominal baud rate of 20 MHz is recovered. FIG. 15C is a plot of the tracked symbol times (indicating a delta baud rate) with a fitted curve overlaid. A small RMS error is exhibited.
- 10 [0086] FIGS. 15D-15F are plots illustrating an upper layer symbol timing recovered signal for an exemplary layer modulated signal. FIGS. 15D and 15E illustrate respectively the upper layer signal before and after the timing recovery loop. FIG. 15F is a plot of the CNR estimate after the timing recovery loop. The estimated output CNR of 7.78 dB, which includes measurement errors, compares very favorably with
- 15 the input CNR of 7.7 dB.

- [0087] FIGS. 16A-16C are plots illustrating upper layer carrier recovery for an exemplary layer modulated signal. FIG. 16A is a plot of the phase comparator output, based on quadrature multiplication. FIG. 16B is a plot of the loop LPF output, using a decision-directed second order scheme. A baud rate of approximately 20 MHz is
- 20 recovered. FIG. 16C is a plot of the phase tracked out for the simulated carrier frequency and phase noise. A small RMS error in phase is exhibited.

- [0088] FIGS. 16D-16F are plots illustrating an upper layer carrier recovered signal for an exemplary layer modulated signal. FIG. 16D illustrates the upper layer signal before the carrier recovery loop. FIG. 16E illustrates the upper layer signal after the carrier recovery loop when the signal constellation is stabilized; the upper layer QPSK
- 25 signal in the presence of the lower layer QPSK and noise are apparent. FIG. 16F is a

histogram of the phase error about a constellation node. The estimated output CNR of 7.51 dB compares well with the input CNR of 7.7 dB.

[0089] FIG. 17A is a plot of uncoded upper layer bit errors at the demodulator output for an exemplary layer modulated signal. The errors at the carrier recovery
5 loop output are shown. The plot identifies 80 R-S packets of data by the "packet" number versus the two-bit symbol number. The plot reports approximately 0.16% of BER at an estimated CNR of 7.5 dB.

[0090] FIG. 17B is a plot of upper layer byte errors at the Viterbi decoder output for an exemplary layer modulated signal. The packet number is displayed versus an
10 eight-bit symbol number, showing 95 packets worth of data. A BER of 0.282% is reported.

[0091] FIG. 17C is a plot of upper layer byte errors at the de-interleaver output for an exemplary layer modulated signal. The packet number is displayed versus an eight-bit symbol number, showing 83 packets worth of data. [0092] FIG. 17D is a
15 plot of upper layer errors correctable by a Reed-Solomon decoder for an exemplary layer modulated signal. Of the 83 packets worth of data, only 3 packets with one R-S correctable error byte each occurred, which is well below the correction threshold of eight errors. Thus, no uncorrectable errors were exhibited in 83 packets at an estimated CNR of 7.5 dB.

20 [0093] FIG. 18 is a plot of upper layer signal matching calculated between received signal and reconstructed signal for an exemplary layer modulated signal. As shown, nearly constant matching coefficients (in magnitude and phase) are exhibited over 300,000 100-MHz samples, despite the presence of the lower layer signal.

[0094] FIG. 19 is power spectrum plot of an extracted lower layer signal of an
25 exemplary layer modulated signal. A sampling frequency of 100 MHz is used and a display resolution is 1 MHz. The spectrum peak is scaled to 0 dB with a thermal

noise floor of approximately -9 dB after canceling out the upper layer signal. The plot can be compared with the power spectrum of the composite signal shown in FIG. 14.

[0095] FIGS. 20A-20C are plots illustrating the extracted lower layer symbol timing recovery for an exemplary layer modulated signal. FIG. 20A is a plot of a lower layer comparator output, based on a zero-crossing method. FIG. 20B is the loop low pass filter (LPF) output; a decision-directed second order filter is applied. A nominal baud rate of 20 MHz is extracted. FIG. 20C is a plot of the tracked symbol times (indicating a delta baud rate) with a fitted curve overlaid. A small RMS error is exhibited.

[0096] FIGS. 20D-20F are plots illustrating a lower layer symbol timing recovered signal for an exemplary layer modulated signal. FIGS. 20D and 20E illustrate respectively the upper layer signal before and after the timing recovery loop. The lower layer forms a ring in signal constellation. FIG. 20F is a plot of the CNR estimate after the timing recovery loop. The estimated output CNR of 7.22 dB compares well with the input CNR of 7.6 dB.

[0097] FIGS. 21A-21C are plots illustrating lower layer carrier recovery for an exemplary layer modulated signal. FIG. 21A is a plot of the lower layer phase comparator output, based on quadrature multiplication. FIG. 21B is a plot of the loop LPF output, using a decision-directed second order scheme. A nominal baud rate of 20 MHz is extracted. FIG. 21C is a plot of the phase tracked out for the simulated carrier frequency and phase noise. A nominal RMS error in phase is exhibited.

[0098] FIGS. 21D-21F are plots illustrating an lower layer carrier recovered signal for an exemplary layer modulated signal. FIG. 21D illustrates the upper layer signal before the carrier recovery loop. FIG. 21E illustrates the upper layer signal after the carrier recovery loop when the signal constellation is stabilized; the lower layer QPSK signal in the presence of noise are apparent. FIG. 21F is a histogram of the phase

error about a constellation node. The estimated output CNR of 7.22 dB compares reasonably well with the input CNR of 7.6 dB.

[0099] FIG. 22A is a plot of uncoded lower layer bit errors at the demodulator output for an exemplary layer modulated signal. The errors at the carrier recovery
5 loop output are shown. The plot identifies 80 R-S packets of data by the "packet" number versus the two-bit symbol number. The plot reports approximately 1.1% of BER at an estimated CNR of 7.2 dB.

[0100] FIG. 22B is a plot of lower layer byte errors at the Viterbi decoder output for an exemplary layer modulated signal. The packet number is displayed versus an
10 eight-bit symbol number, showing 95 packets worth of data. A BER of 0.297% is reported.

[0101] FIG. 22C is a plot of lower layer byte errors at the De-interleaver output for an exemplary layer modulated signal. The packet number is displayed versus an eight-bit symbol number, showing 83 packets worth of data.

15 [0102] FIG. 22D is a plot of upper layer errors correctable by a Reed-Solomon decoder for an exemplary layer modulated signal. Of the 83 packets worth of data, only 11 packets with one R-S correctable error byte each occurred, which is well below the correction threshold of eight errors. Thus, no uncorrectable errors were exhibited in 83 packets at an estimated CNR of 7.2 dB.

20 [0103] FIG. 23A is a plot of uncoded bit error rates for upper and lower layers of an exemplary layer modulated signal. The plot identifies the lower layer and upper layer simulation results relative to a theoretical result based on additive white gaussian noise (AWGN) curve, illustrating the result of 65K samples (130K bits) of data. The
25 lower layer at the estimated CNR is shown with a BER right on the AWGN curve. The upper layer shows a BER below the curve equaling a 2.1 dB increase. Thus, QPSK interference is more benign than AWGN of the same power.

[0104] FIG. 23B is a plot of Viterbi decoder output bit error rates for upper and lower layers of an exemplary layer modulated signal. The plot identifies the lower layer and upper layer simulation results relative to the AWGN curve, illustrating the result of 65K samples (130K bits) of data. In this case, the estimated CNR and BER
5 for both upper and lower layers occur close to the AWGN curve.

[0105] The foregoing description including the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is
10 intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto. The above specification, examples and data provide a complete description of the manufacture and use of the invention. Since many embodiments of the invention can be made without departing from the scope of the invention, the invention resides in the claims hereinafter appended.

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WHAT IS CLAIMED IS:

1. A method for simulating a layer modulated signal, comprising the steps of:
 - 5 providing an upper layer signal comprising a first bit stream modulated by a first carrier;
 - providing a lower layer signal comprising a second bit stream modulated by a second carrier not coherent with the first carrier;
 - attenuating the lower layer signal; and
 - 10 combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal;
 - wherein at least one directional coupler is used to tap the composite layer modulated signal.
- 15 2. The method of claim 1, further comprising:
 - adding noise to the upper layer signal; and
 - upconverting the composite layer modulated signal;
 - wherein providing the upper layer signal comprises modulating the first bit stream and providing the lower layer signal comprises modulating the second bit stream.
- 20 3. The method of claim 1, further comprising:
 - amplifying the upper layer signal; and
 - amplifying the lower layer signal;
 - wherein providing the upper layer signal comprises receiving the first modulated
 - 25 bit stream from a first satellite transponder and providing the lower layer signal comprises receiving the second modulated bit stream from a second satellite transponder.
4. The method of claim 1, wherein at least one directional coupler is used to tap the upper layer signal.
- 30 5. The method of claim 1, wherein at least one directional coupler is used to tap the attenuated lower layer signal.

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6. The method of claim 1, further comprising: tuning the composite layer modulated signal;

evaluating the composite layer modulated signal performance based upon the in-phase and quadrature components of the layer modulated signal.

5

7. A signal simulator for simulating a layer modulated signal having an upper layer and a lower layer not coherent with the upper layer, comprising:

a first modulator for modulating a bit stream of the upper layer according to a first carrier to produce an upper layer signal;

10 a noise generator for adding noise to the upper layer signal;

a second modulator for modulating a bit stream of the lower layer according to a second carrier not coherent with the first carrier to produce a lower layer signal;

an attenuator for attenuating the lower layer signal; and

15 a combiner for combining the noise-added upper layer signal and the attenuated lower layer signal to produce a composite layer modulated signal.

8. The signal simulator of claim 7, wherein the attenuator comprises a variable attenuator.

20 9. The signal simulator of claim 7, further comprising an upconverter for upconverting the composite layer modulated signal.

10. The signal simulator of claim 7, further comprising a tuner for tuning the composite layer modulated signal.

25

11. A receiver system for simulating reception of a layer modulated signal, comprising:

a first antenna for receiving an upper layer signal from a first satellite transponder;

30 a first amplifier for amplifying the received upper layer signal;

a second antenna for receiving a lower layer signal from a second satellite transponder wherein the lower layer signal is not coherent with the upper layer signal;

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a second amplifier for amplifying the received lower layer signal;
an attenuator for attenuating the received lower layer signal; and
a combiner for combining the upper layer signal and the attenuated lower layer
signal to produce a composite layer modulated signal.

5

12. The receiver system of claim 11, wherein the attenuator comprises a
variable attenuator.

13. The receiver system of claim 11, further comprising a tuner for tuning
the composite layer modulated signal.

10

14. A method for simulating a layer modulated signal having an upper layer
and a lower layer not coherent with the upper layer, comprising the steps of:

providing an upper layer signal comprising a first bit stream modulated
according to a first carrier;

15

providing a lower layer signal comprising a second bit stream modulated
according to a second carrier not coherent with the first carrier;

attenuating the lower layer signal; and

combining the upper layer signal and the attenuated lower layer signal to
produce the composite layer modulated signal;

20

tuning the composite layer modulated signal;

evaluating the composite layer modulated signal performance based upon the in-
phase and quadrature components of the layer modulated signal.

25

15. The method of claim 14, further comprising:

adding noise to the upper layer signal; and

upconverting the composite layer modulated signal;

wherein providing the upper layer signal comprises modulating the first bit
stream and providing the lower layer signal comprises modulating the second bit stream.

30

16. The method of claim 14, further comprising amplifying the upper layer
signal; and

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amplifying the lower layer signal;

wherein providing the upper layer signal comprises receiving the first modulated bit stream from a first satellite transponder and providing the lower layer signal comprises receiving the second modulated bit stream from a second satellite transponder.

5 17. The method of claim 14, wherein at least one directional coupler is used to tap the upper layer signal.

10 18. The method of claim 14, wherein at least one directional coupler is used to tap the attenuated lower layer signal.

15 19. The method of claim 14, wherein at least one directional coupler is used to tap the composite layer modulated signal.

20 20. A signal simulator for simulating a layer modulated signal having a first modulation of an upper layer and a second modulation of a lower layer, comprising:
 a first modulator for modulating a bit stream of the upper layer according to a first carrier to produce an upper layer signal;
 a noise generator for adding noise to the upper layer signal;
 a second modulator for modulating a bit stream of the lower layer according to a
20 second carrier not coherent with the first carrier to produce a lower layer signal;
 an attenuator for attenuating the lower layer signal;
 a combiner for combining the noise-added upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal; and
 a directional coupler, for tapping the composite layer modulated signal.

25 21. The signal simulator of claim 20, wherein the attenuator comprises a variable attenuator.

30 22. The signal simulator of claim 20, further comprising an upconverter for upconverting the composite layer modulated signal.

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23. The signal simulator of claim 20, further comprising a tuner for tuning the composite layer modulated signal.

24 A signal simulator for simulating reception of a layer modulated signal having a first modulation of an upper layer and a second modulation of a lower layer, comprising:

a first antenna for receiving the upper layer signal from a first satellite transponder;

a first amplifier for amplifying the received upper layer signal;

10 a second antenna for receiving the lower layer signal from a second satellite transponder wherein the lower layer signal is not coherent with the upper layer signal;

a second amplifier for amplifying the received lower layer signal;

an attenuator for attenuating the received lower layer signal; and

15 a combiner for combining the upper layer signal and the attenuated lower layer signal to produce the composite layer modulated signal.

25. The signal simulator of claim 24, wherein the attenuator comprises a variable attenuator.

20 26. The signal simulator of claim 24, further comprising a tuner for tuning the composite layer modulated signal.

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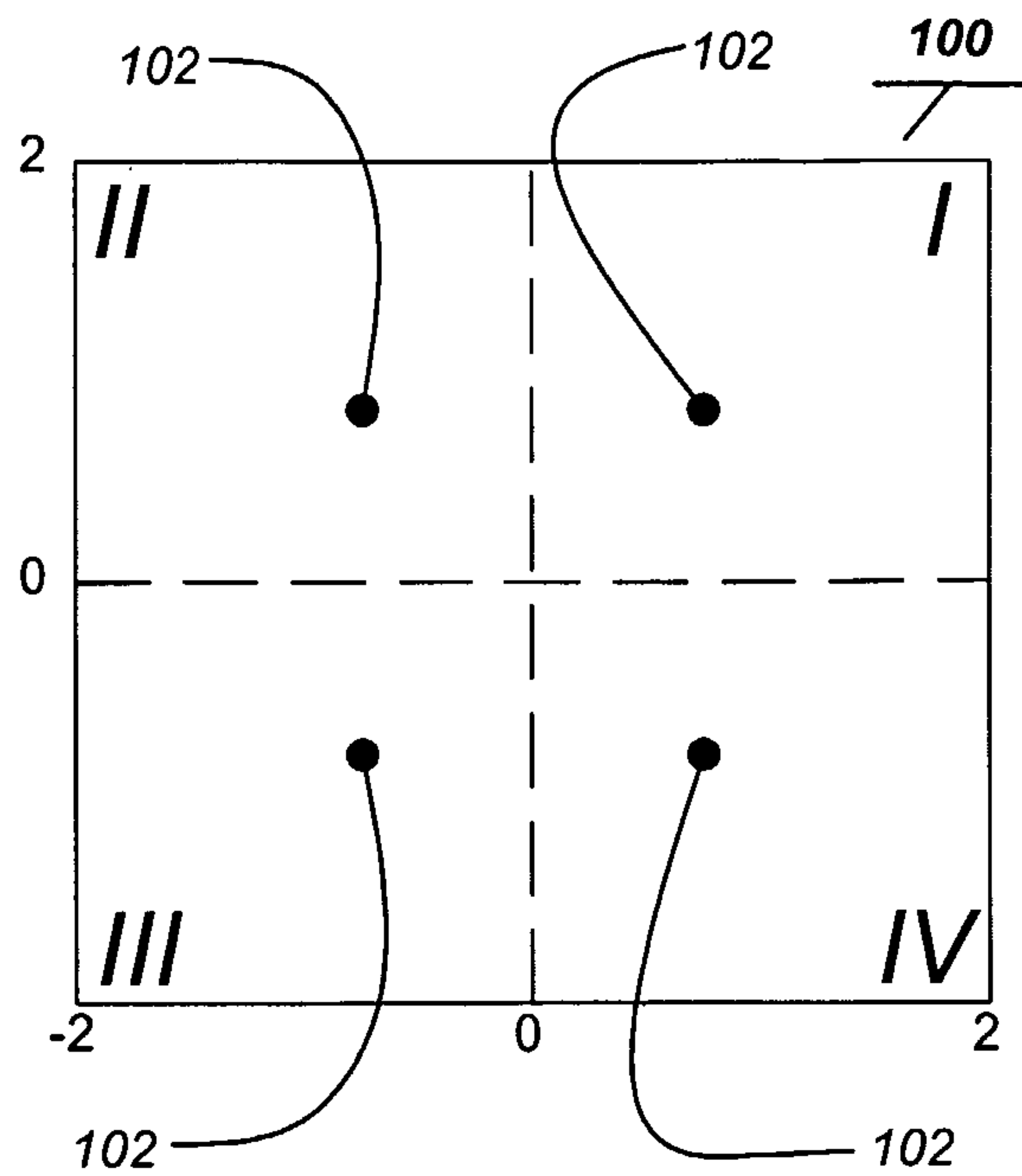


FIG. 1A

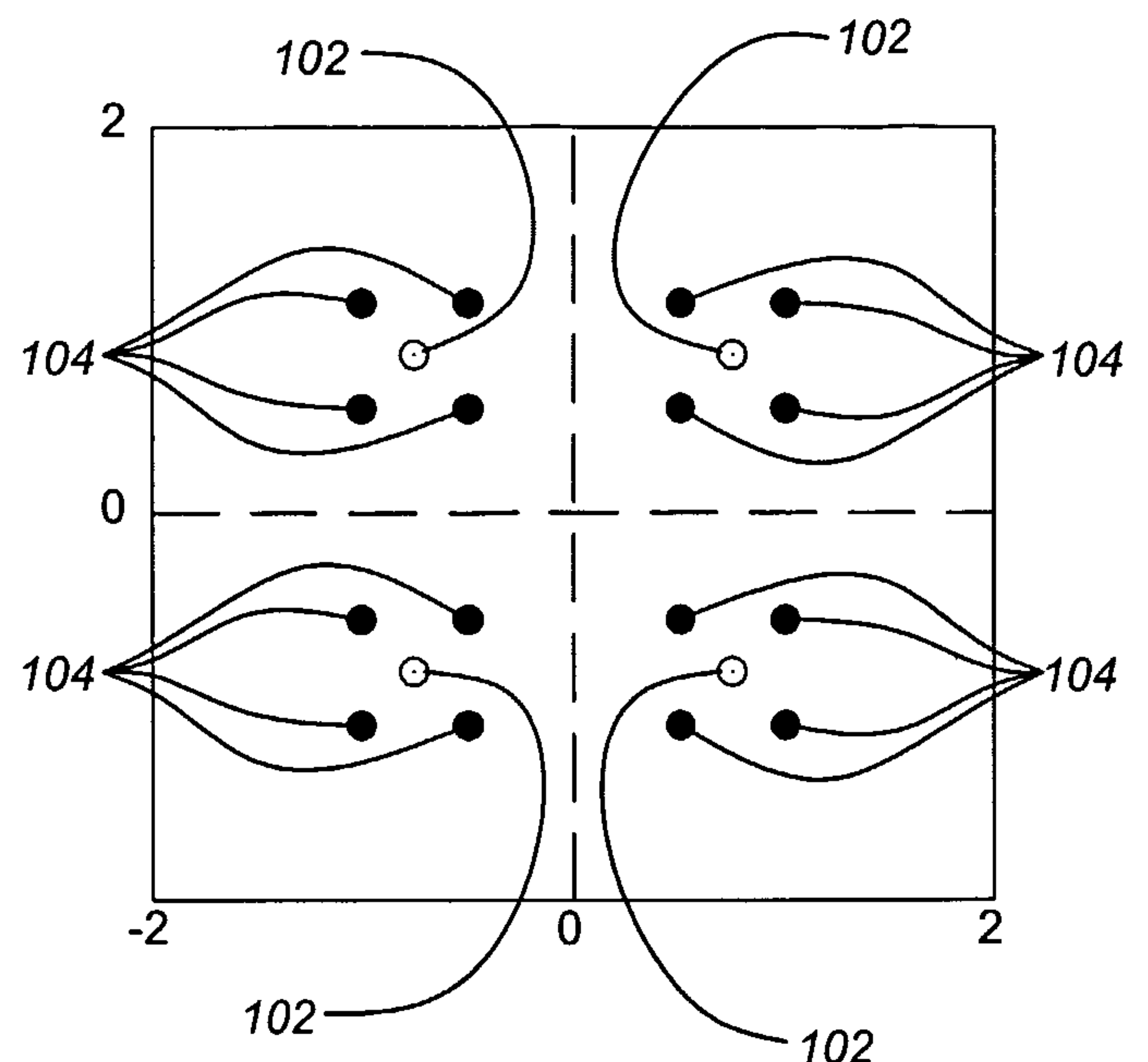


FIG. 1B

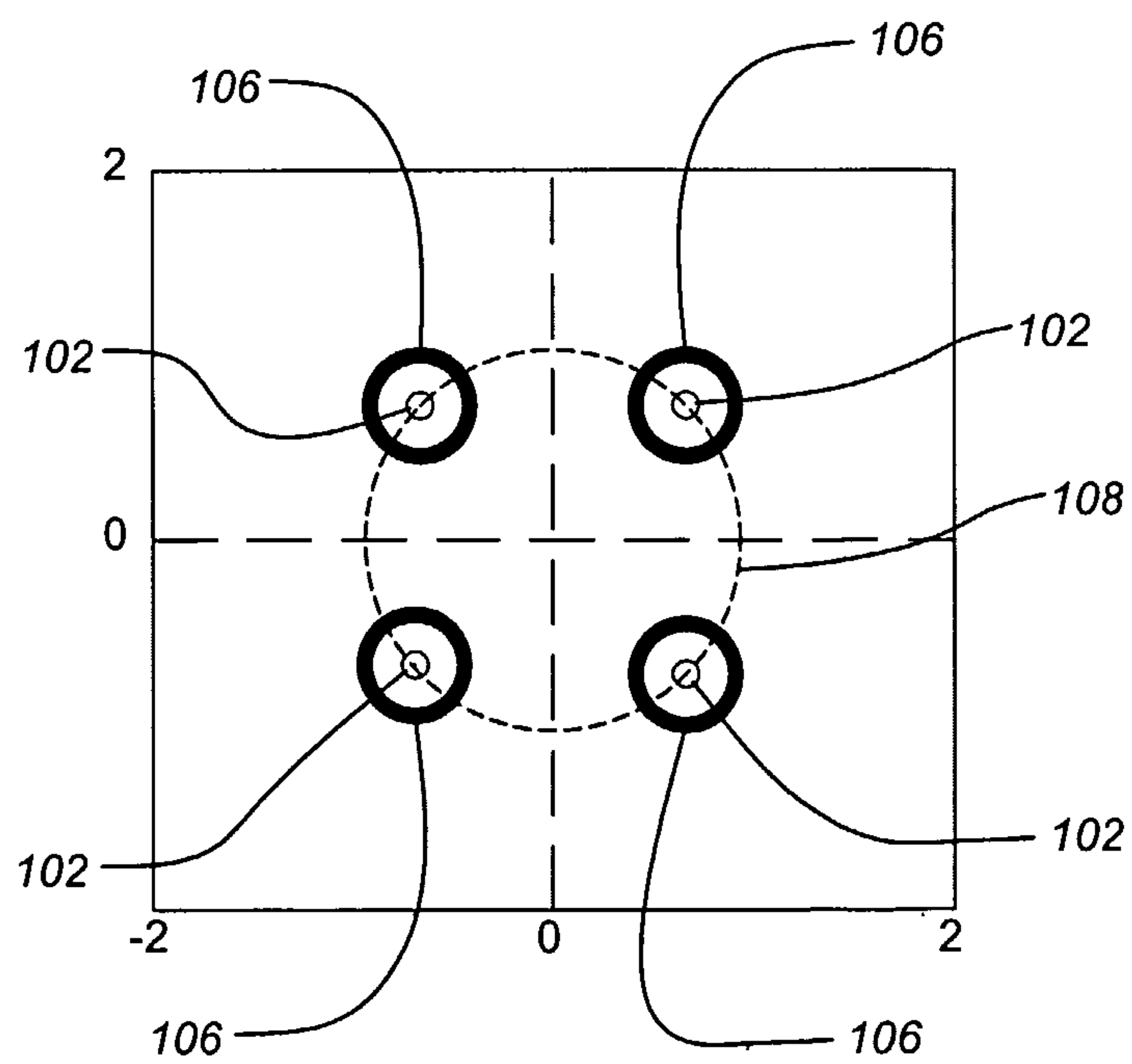
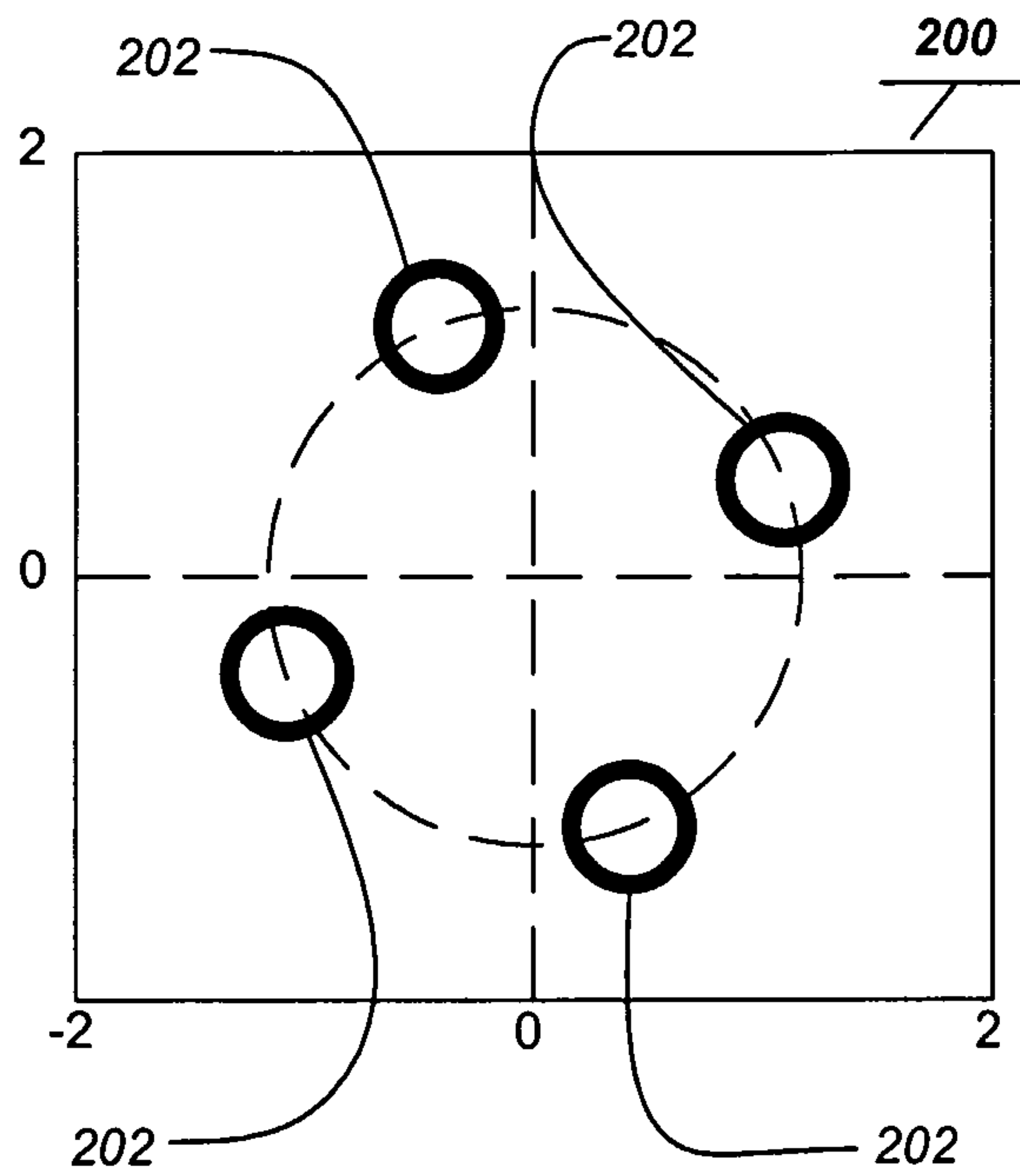
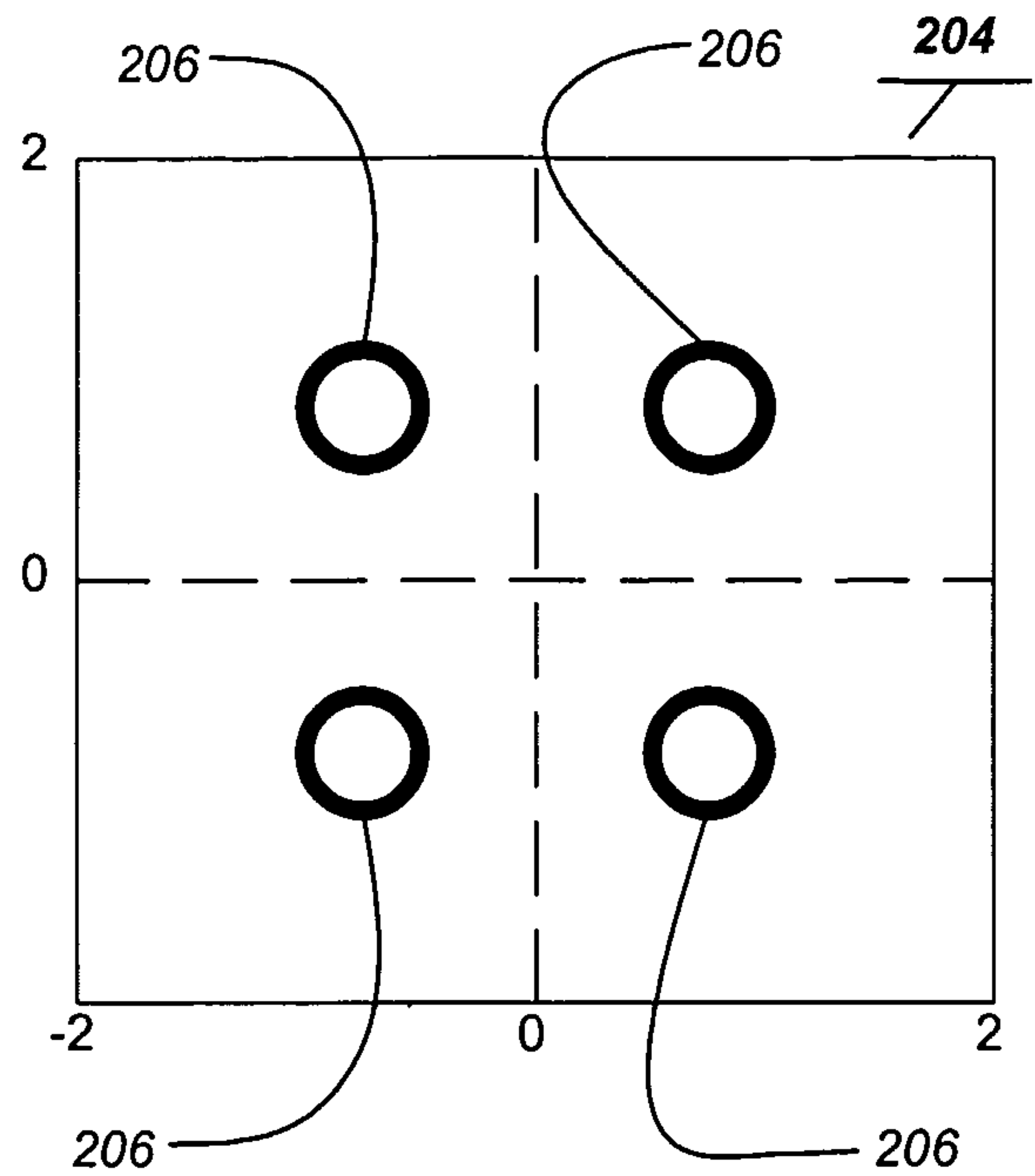
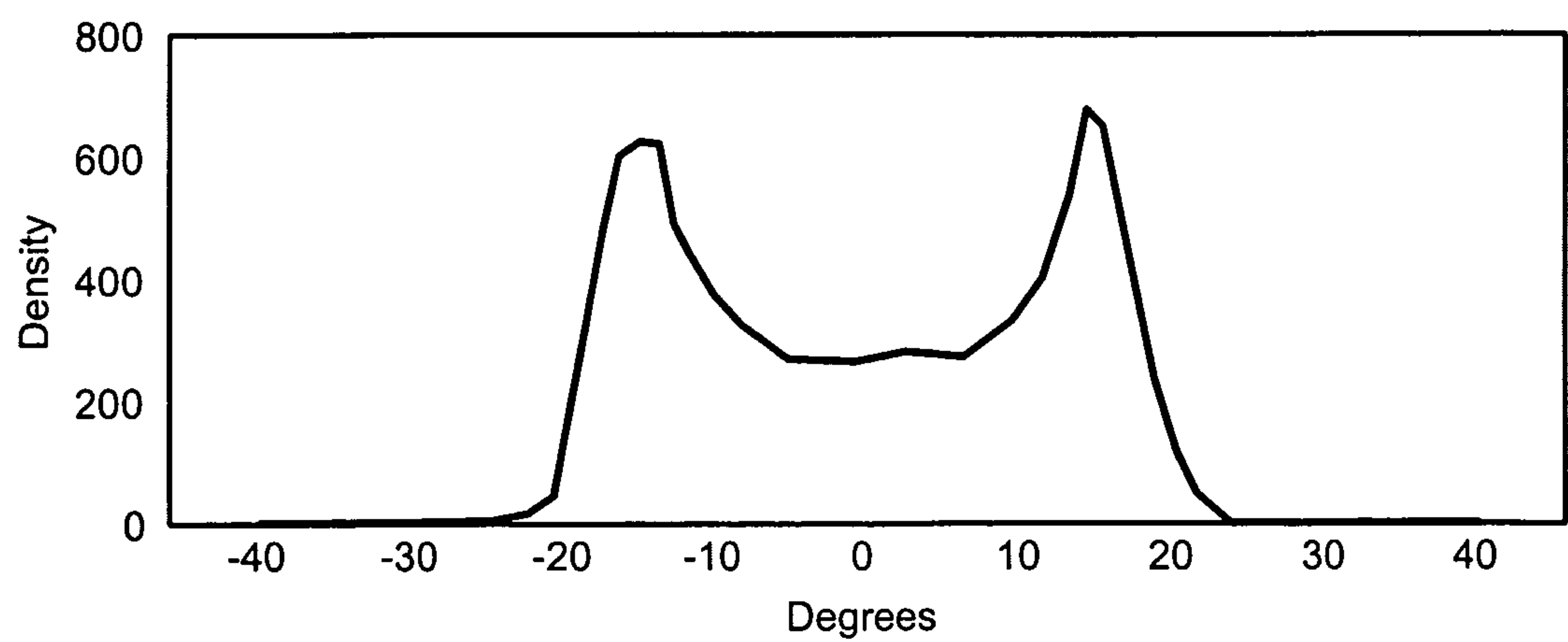


FIG. 1C

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*FIG. 2A**FIG. 2B*

Phase Error Distribution

*FIG. 2C*

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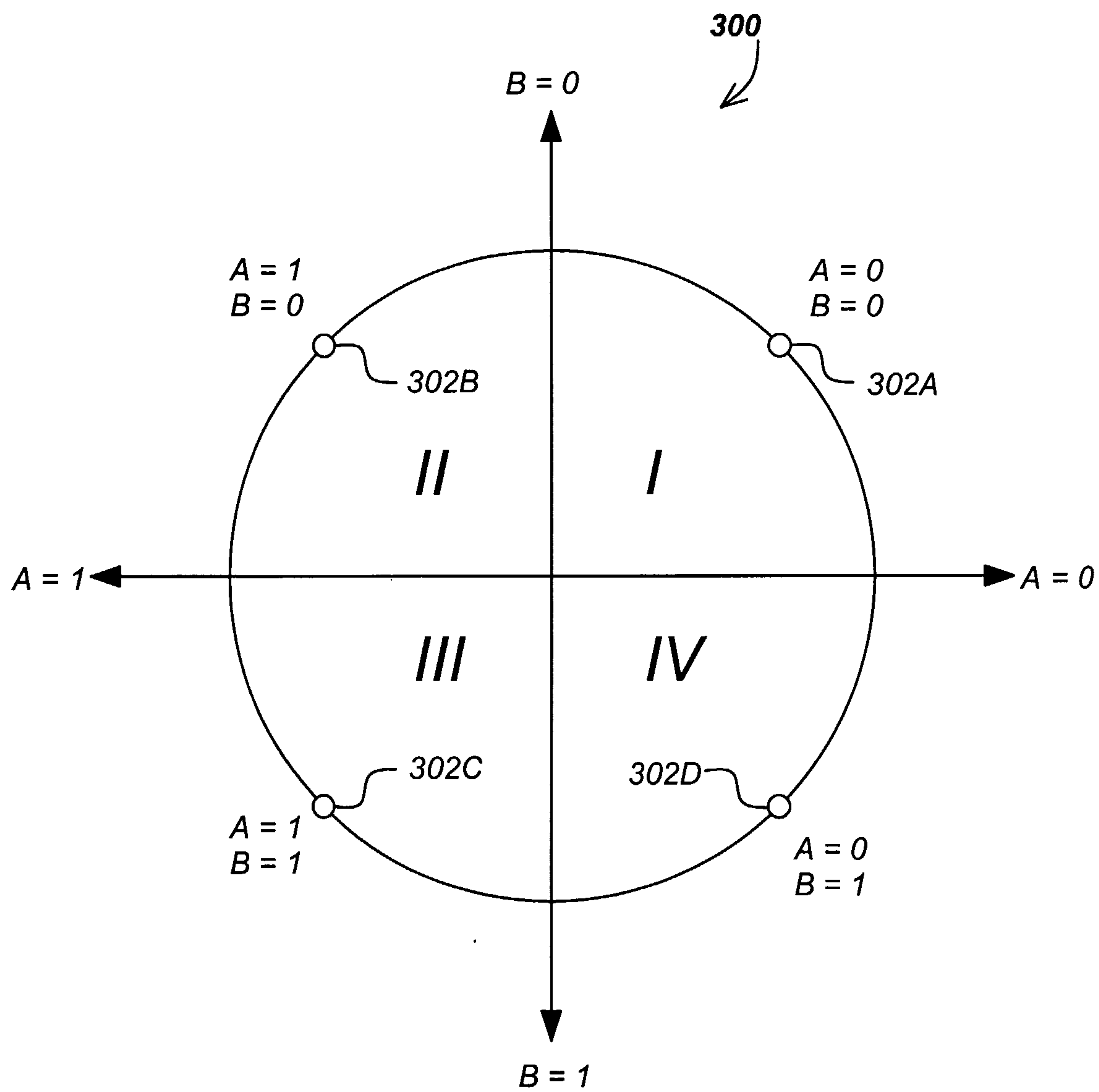


FIG. 3A

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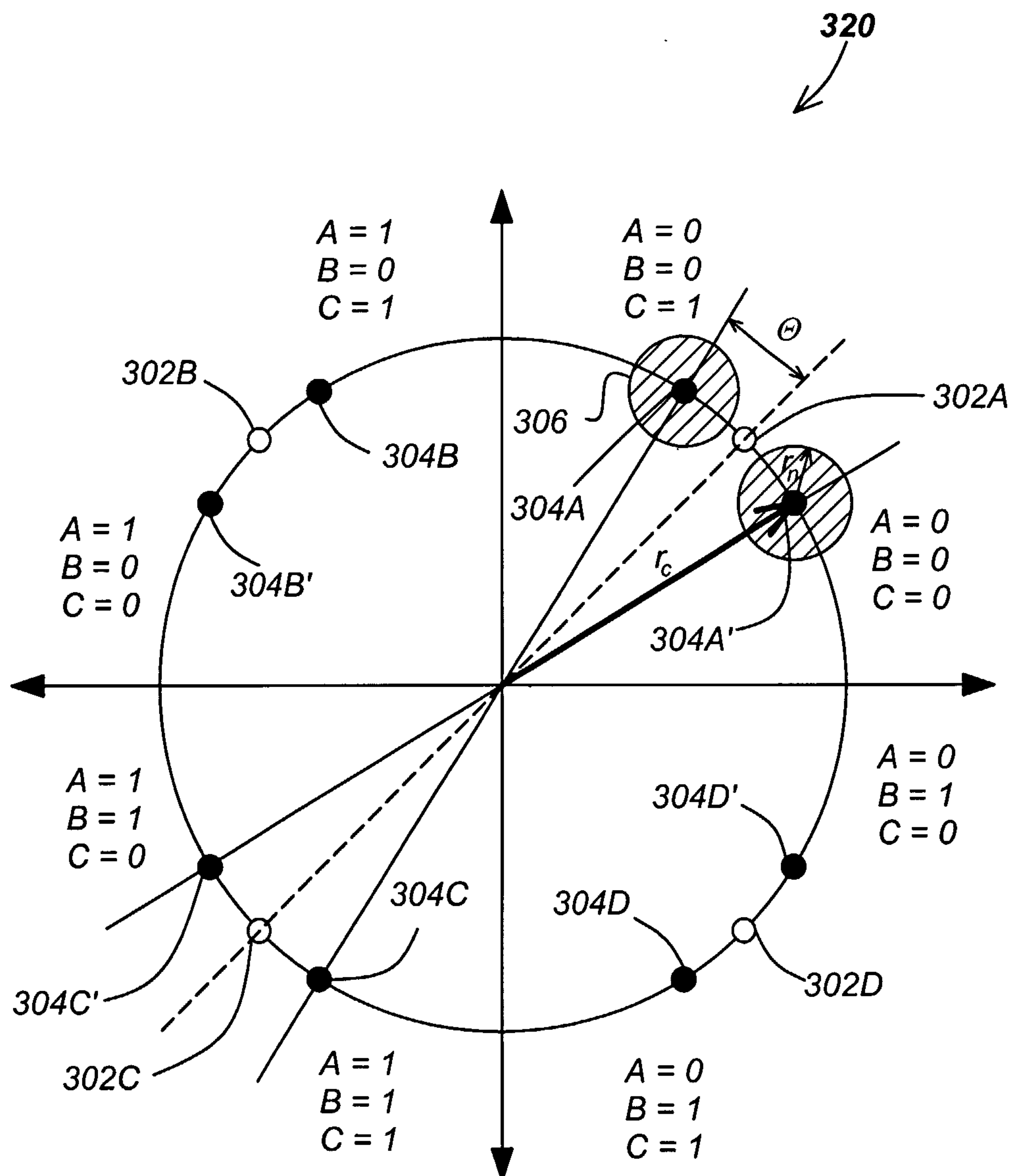


FIG. 3B

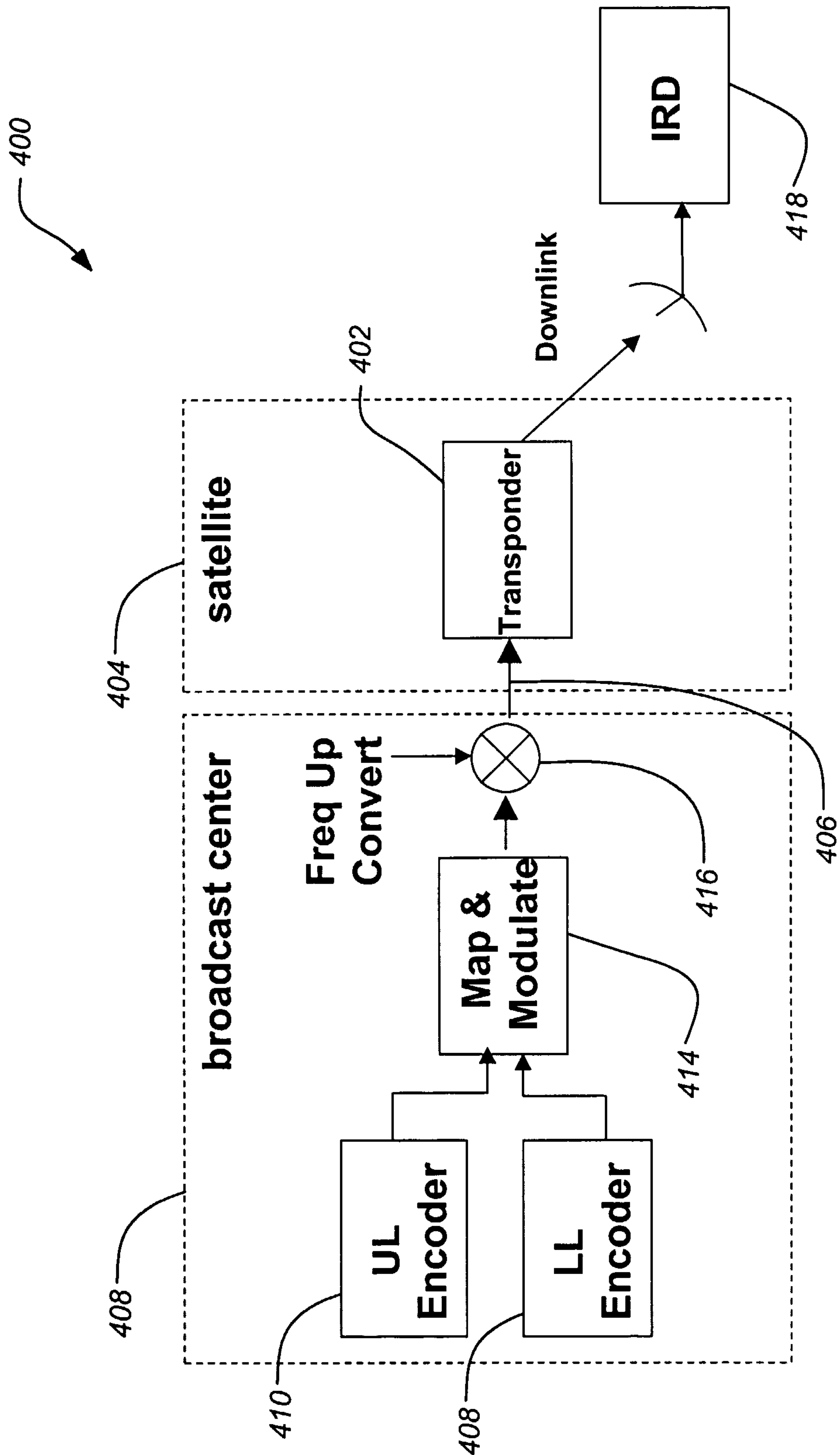


FIG. 4A

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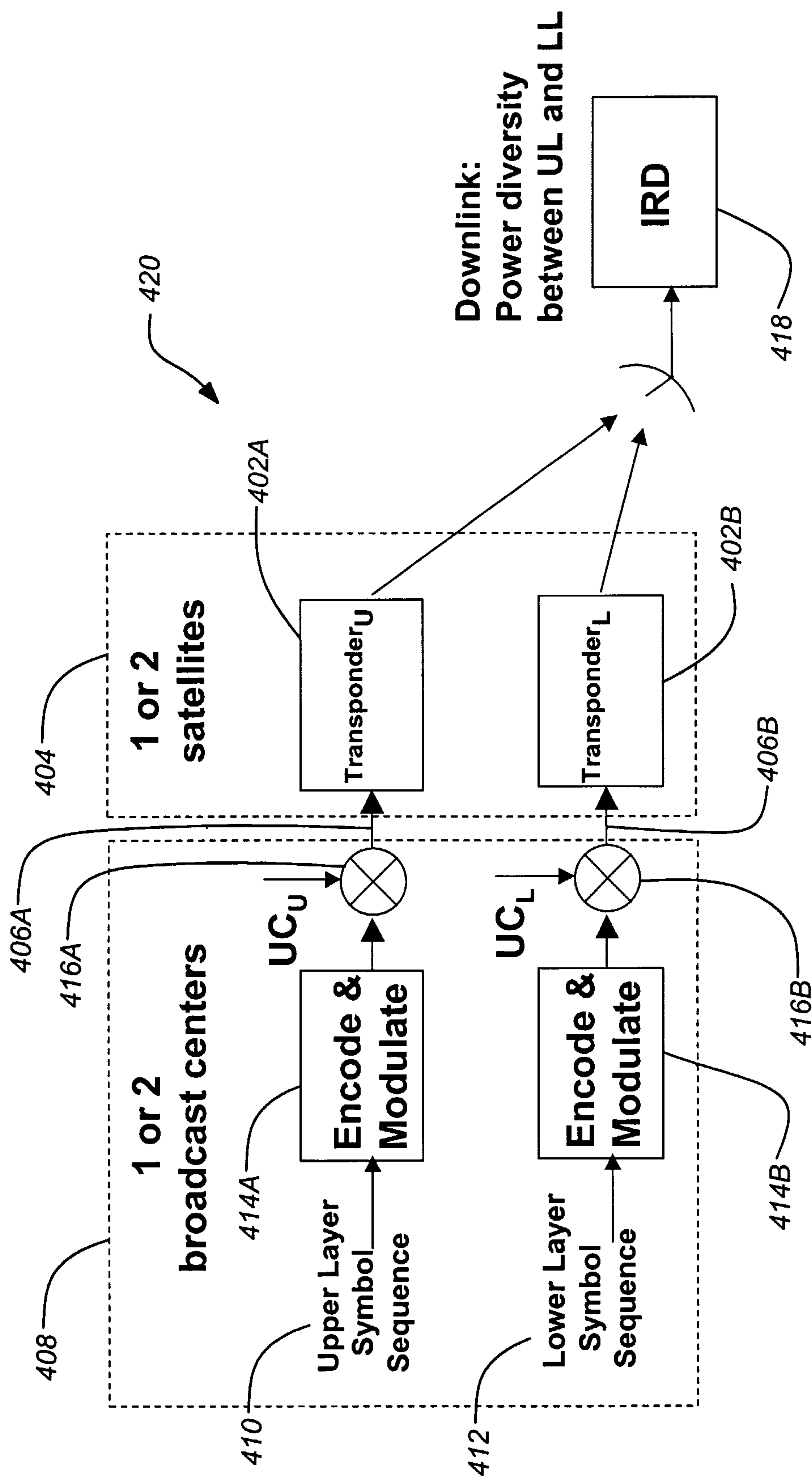


FIG. 4B

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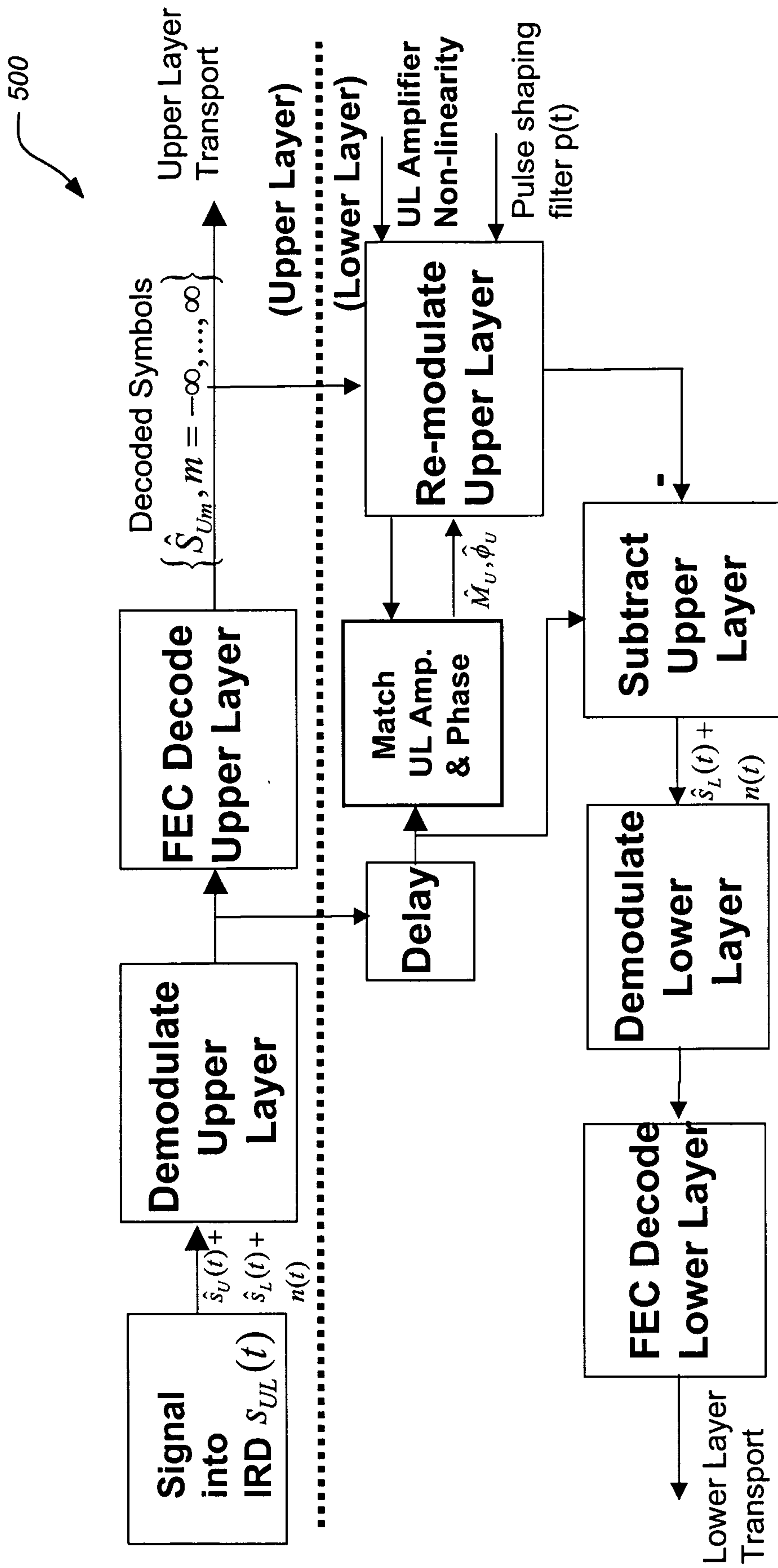


FIG. 5

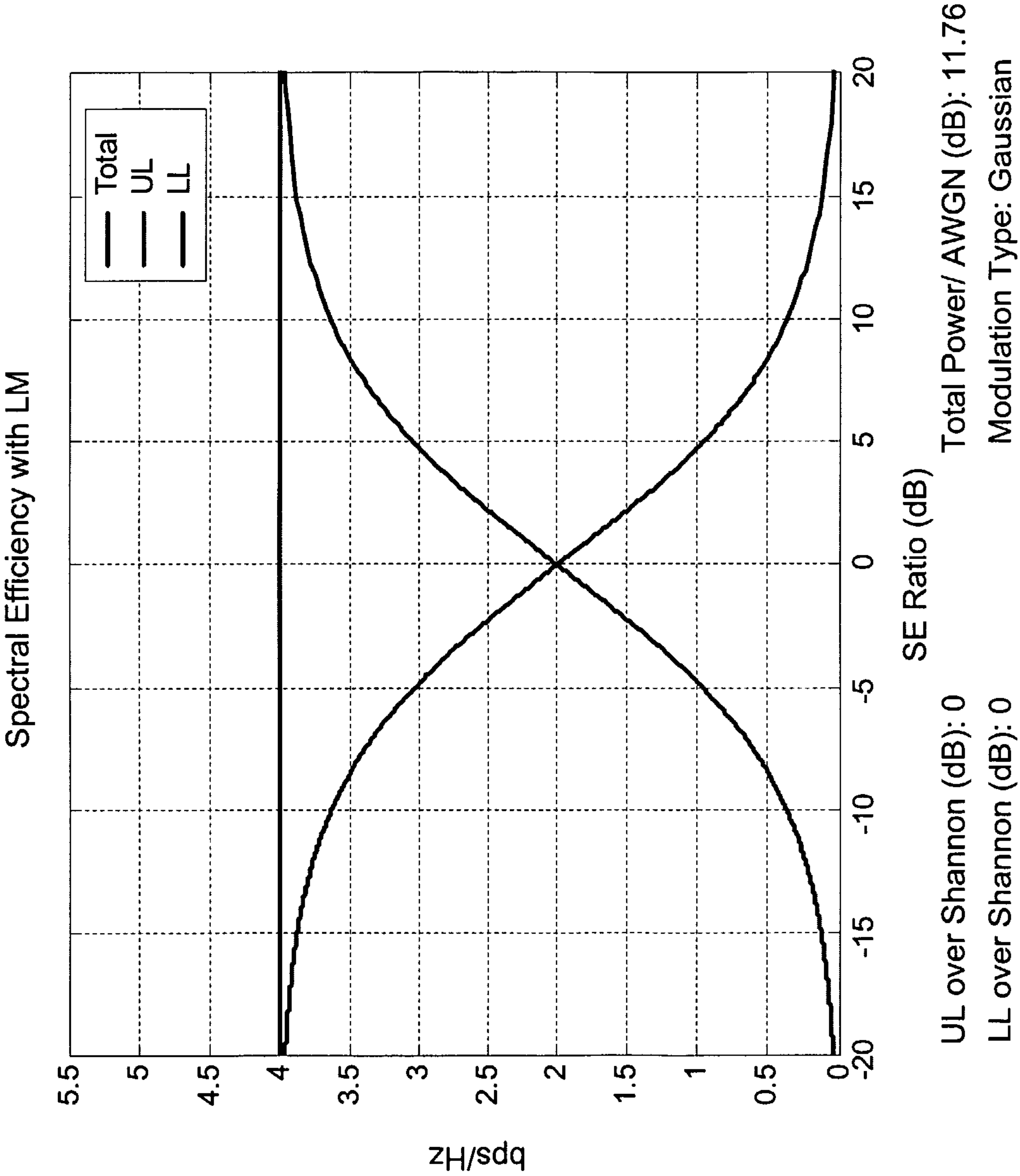


FIG. 6

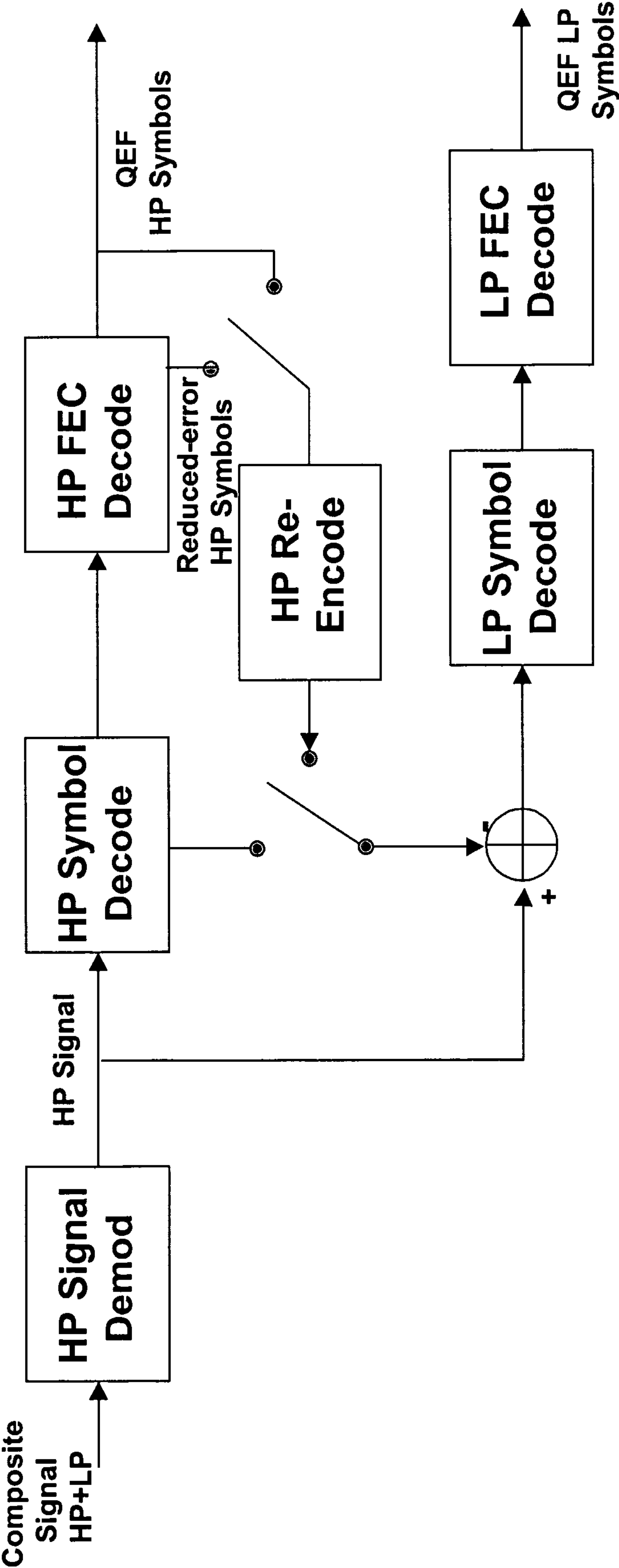


FIG. 7

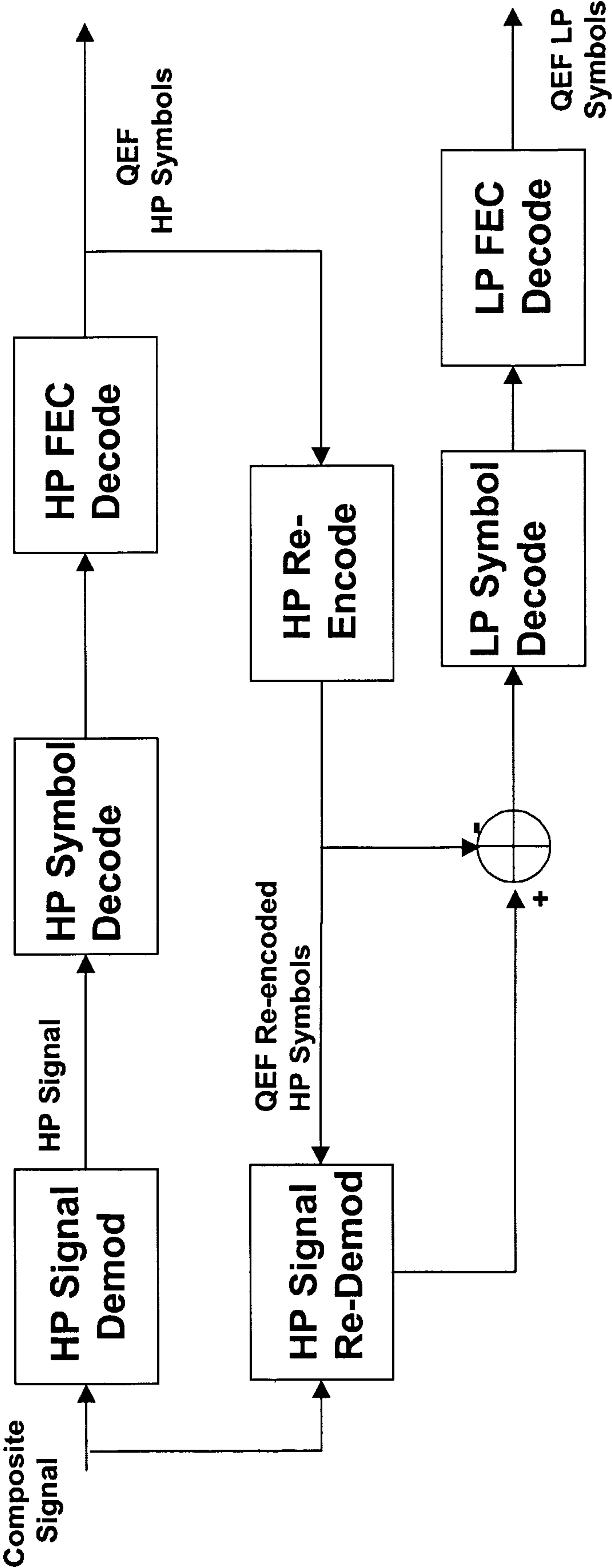


FIG. 8

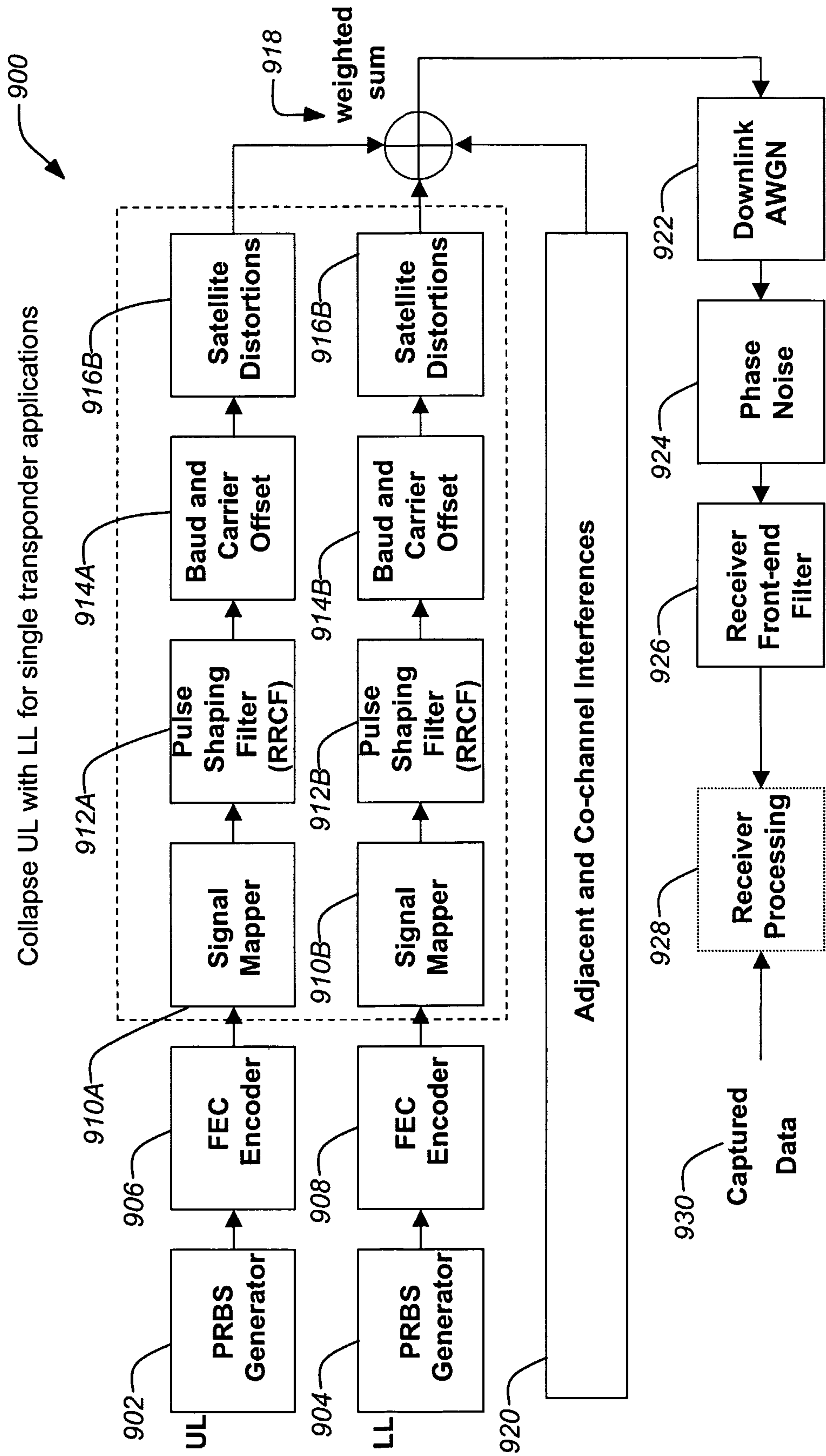


FIG. 9

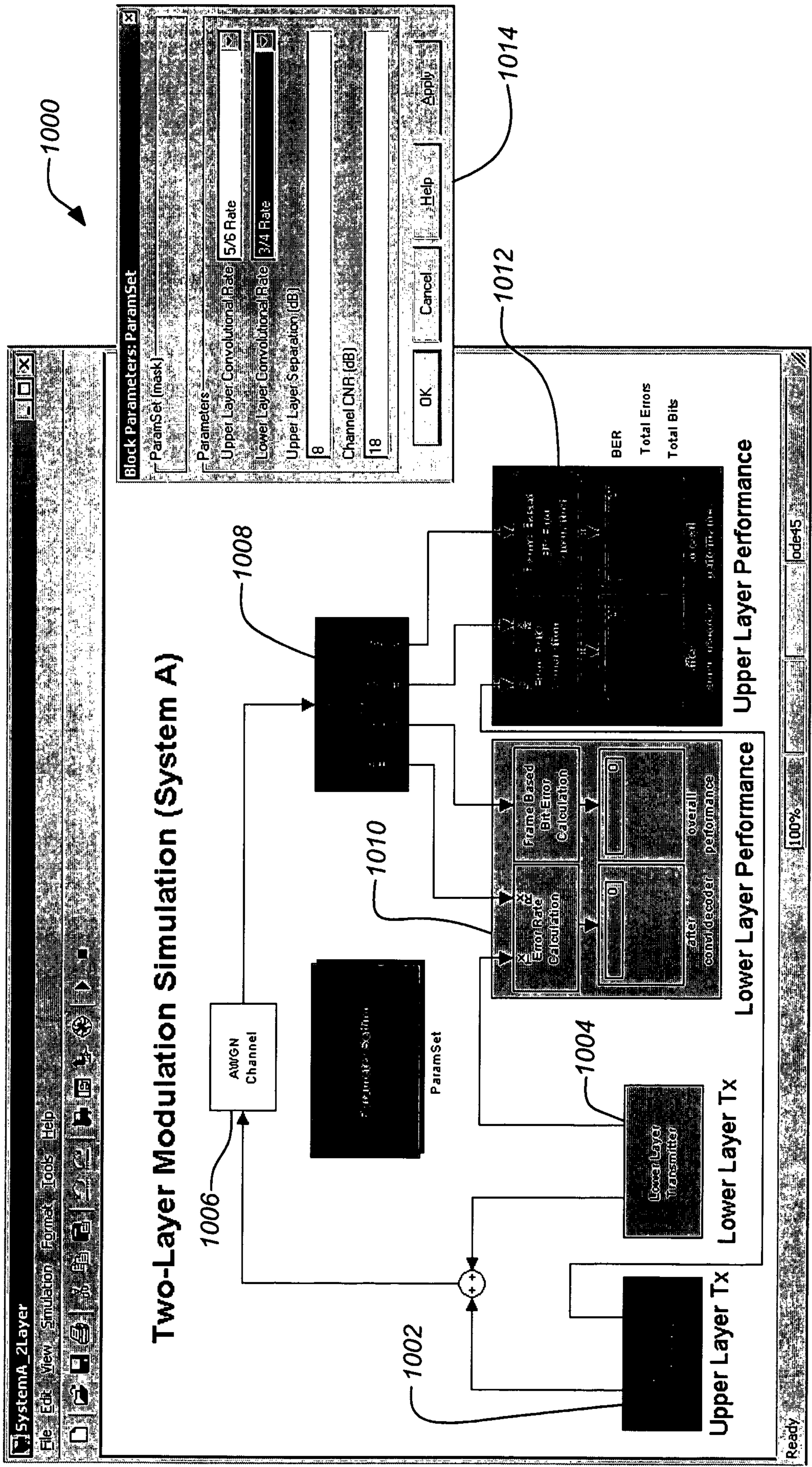


FIG. 10

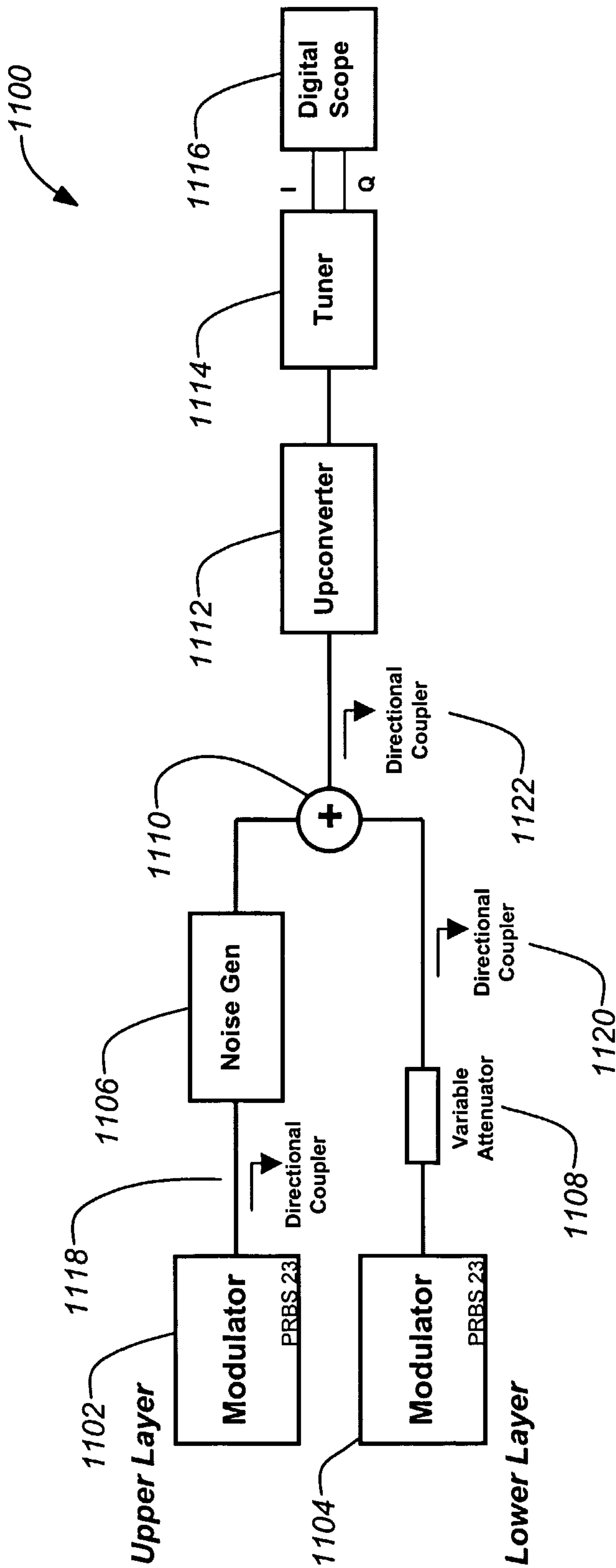


FIG. 11A

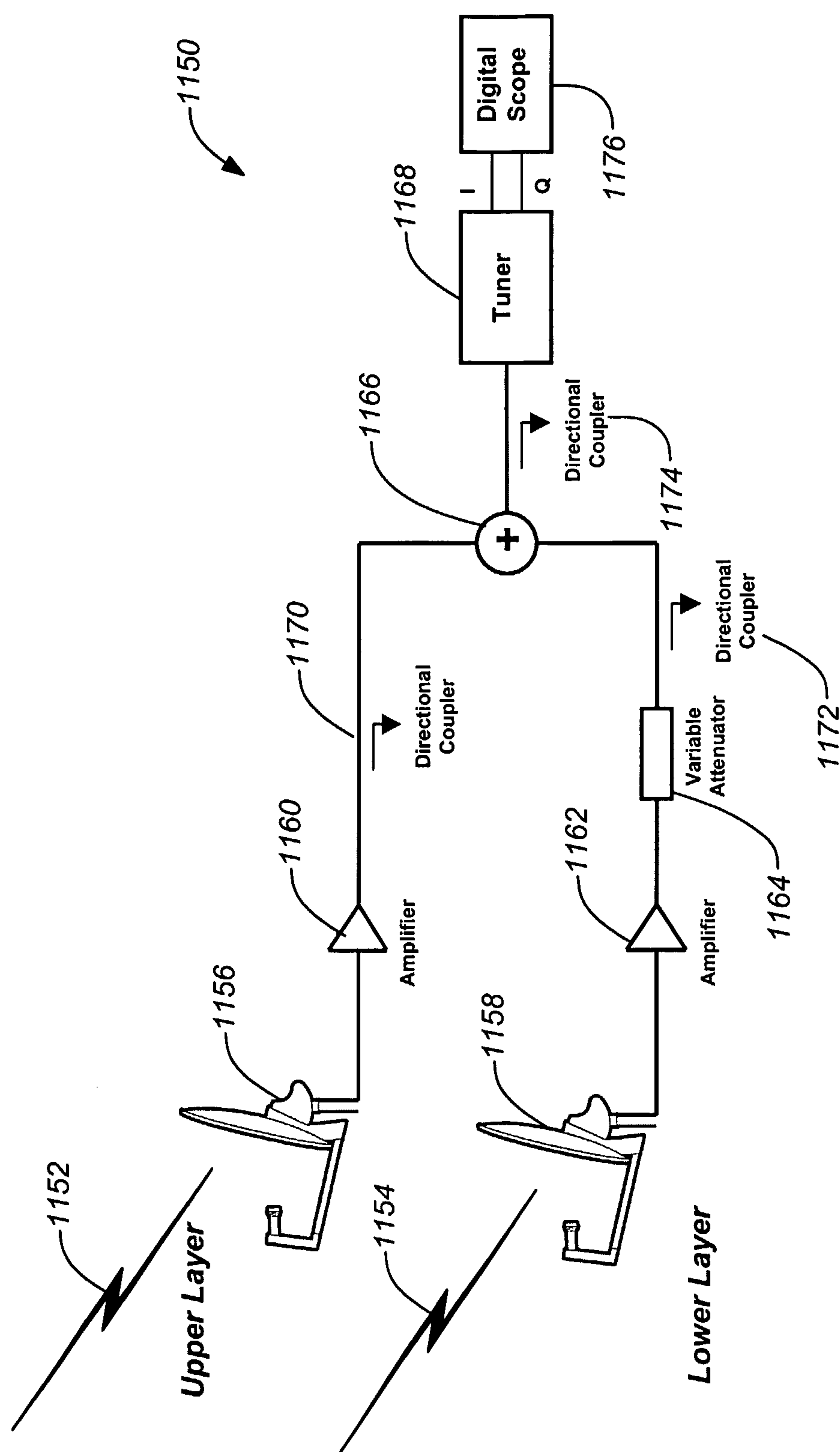
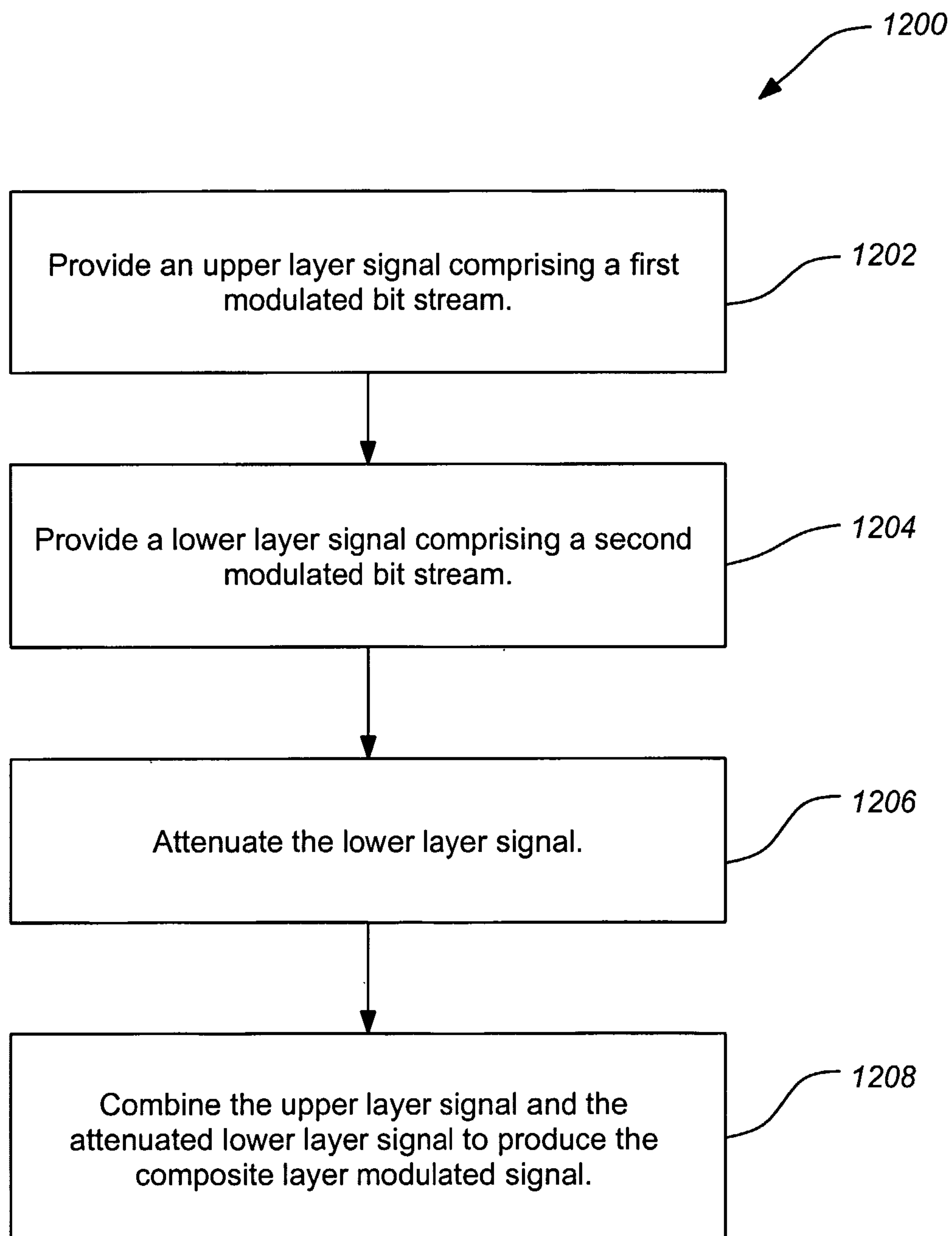


FIG. 11B

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**FIG. 12**

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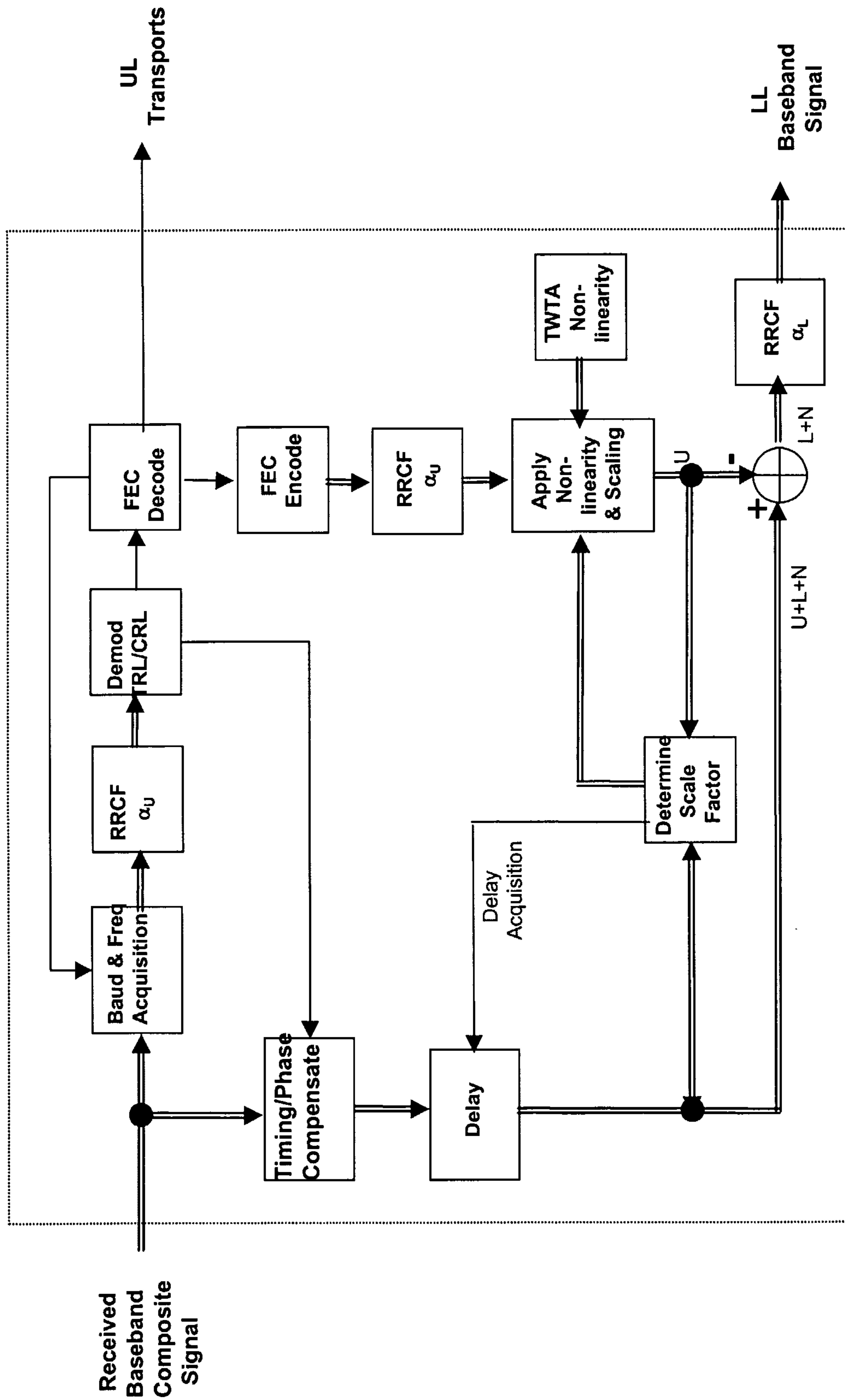
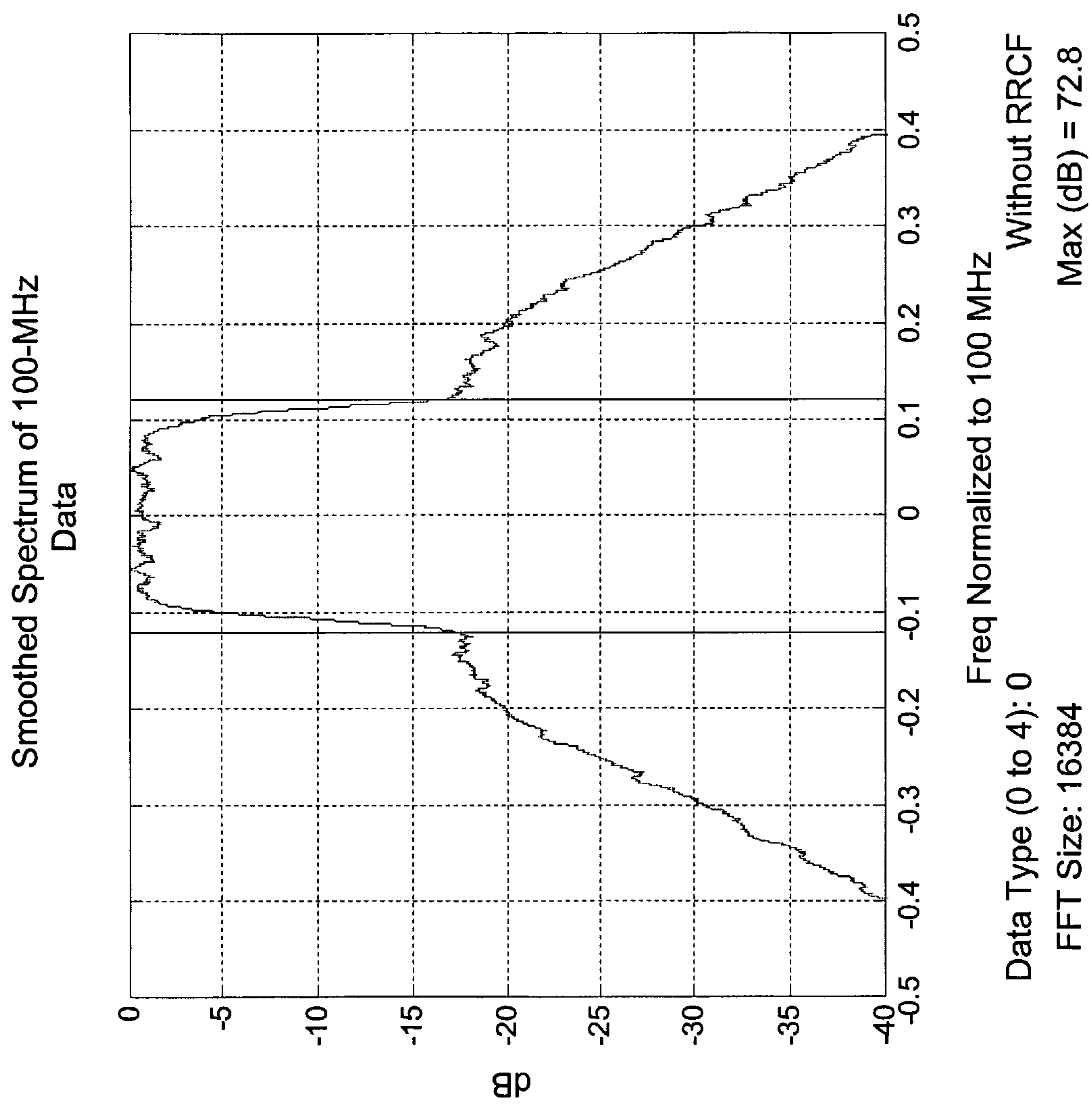
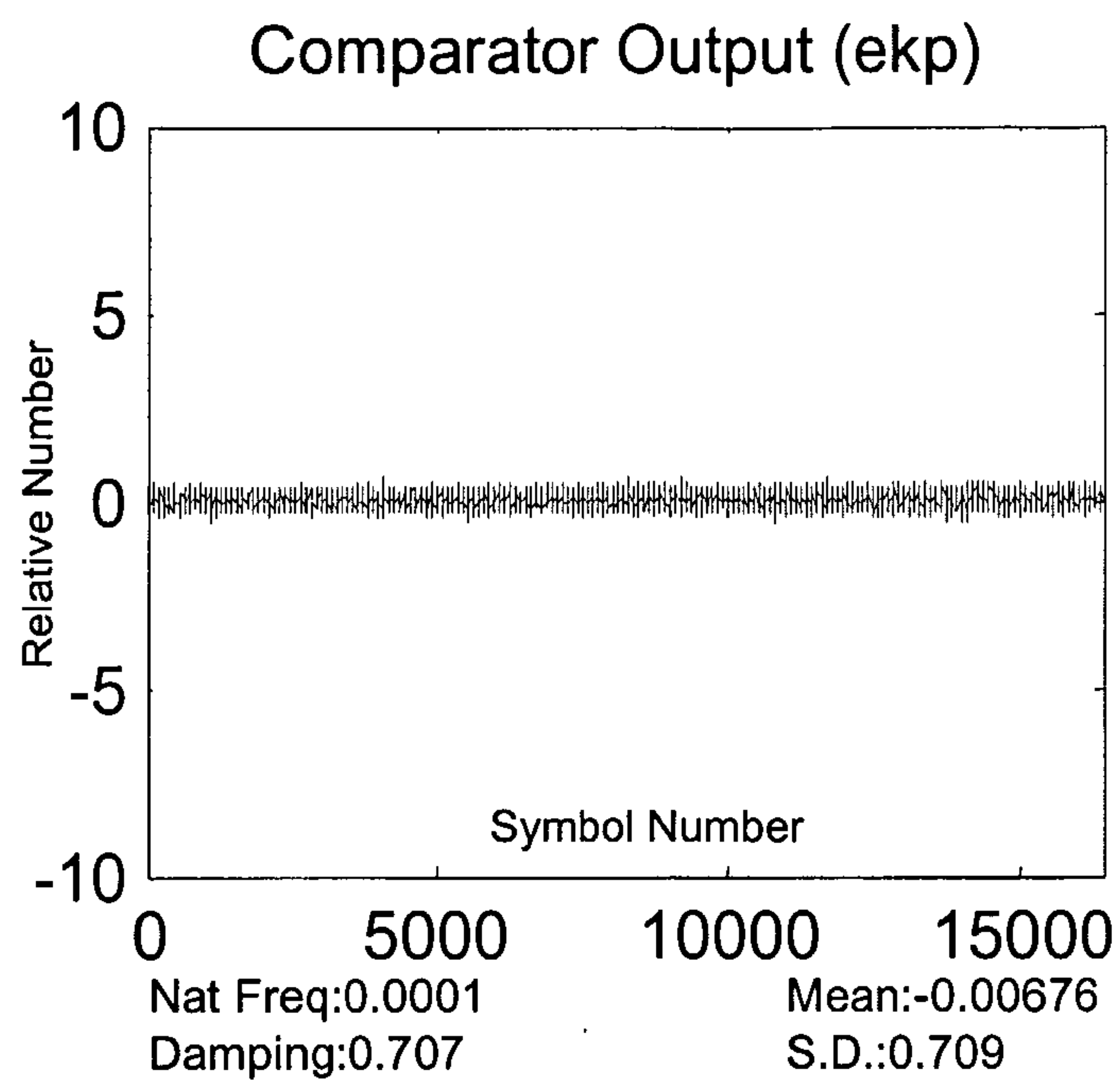
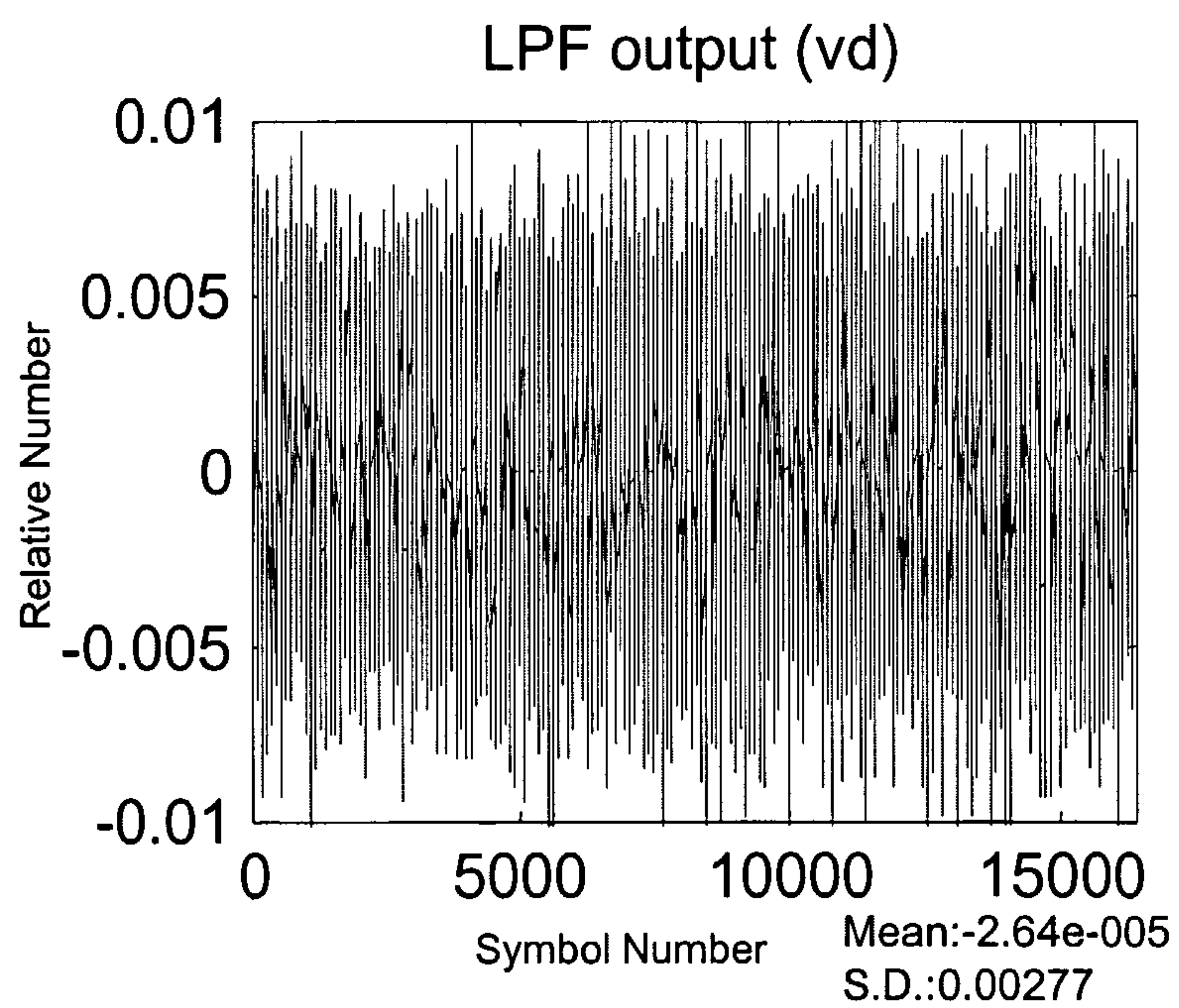


FIG. 13

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**FIG. 14**

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*FIG. 15A**FIG. 15B*

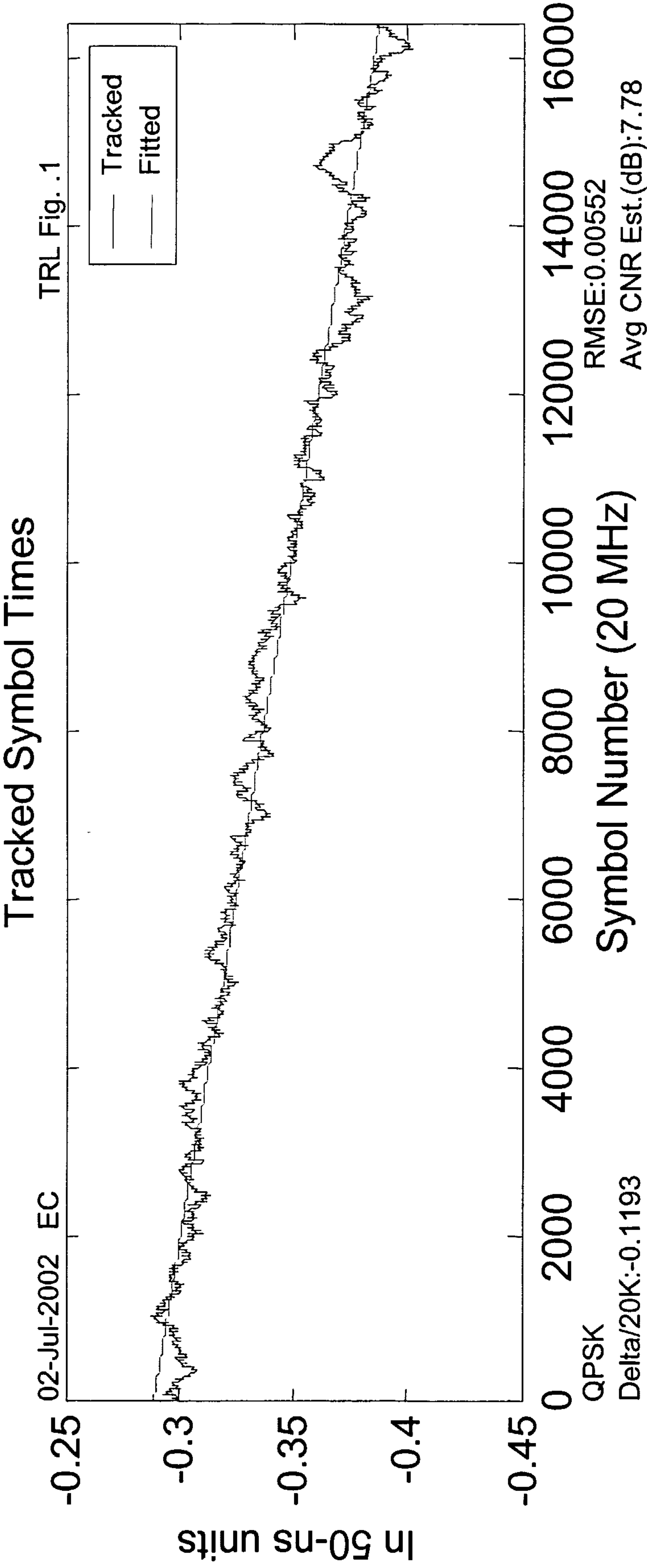
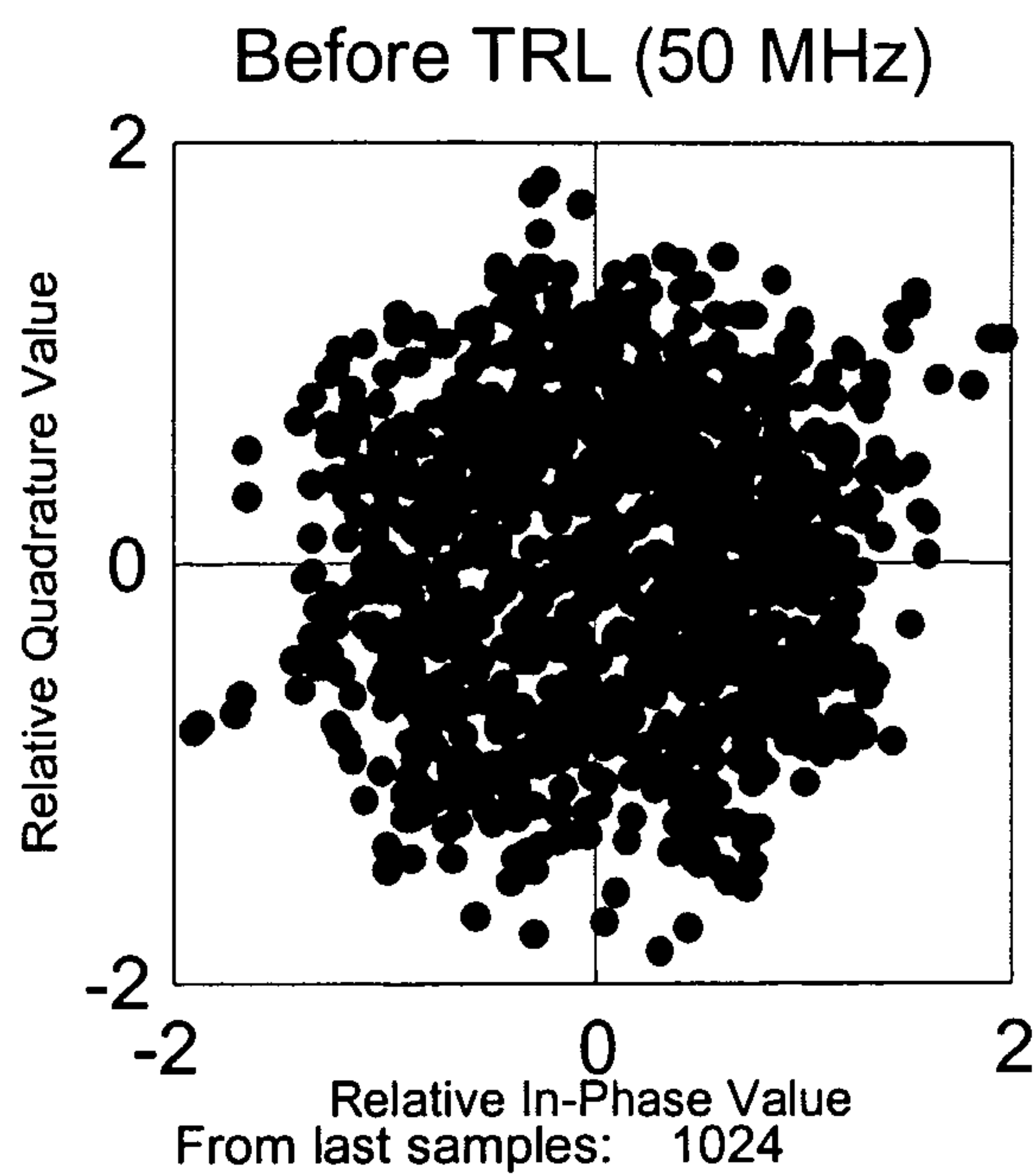
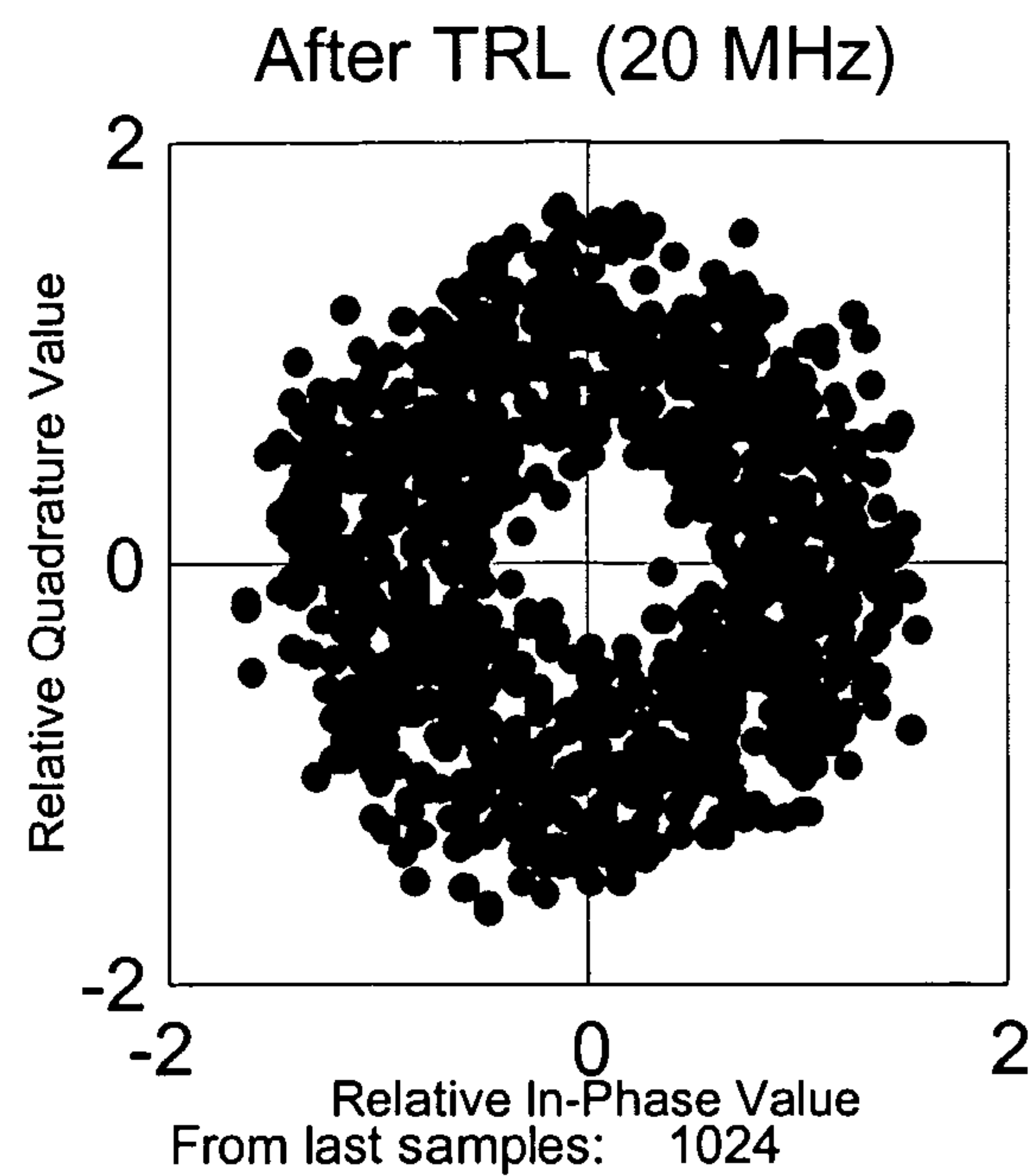
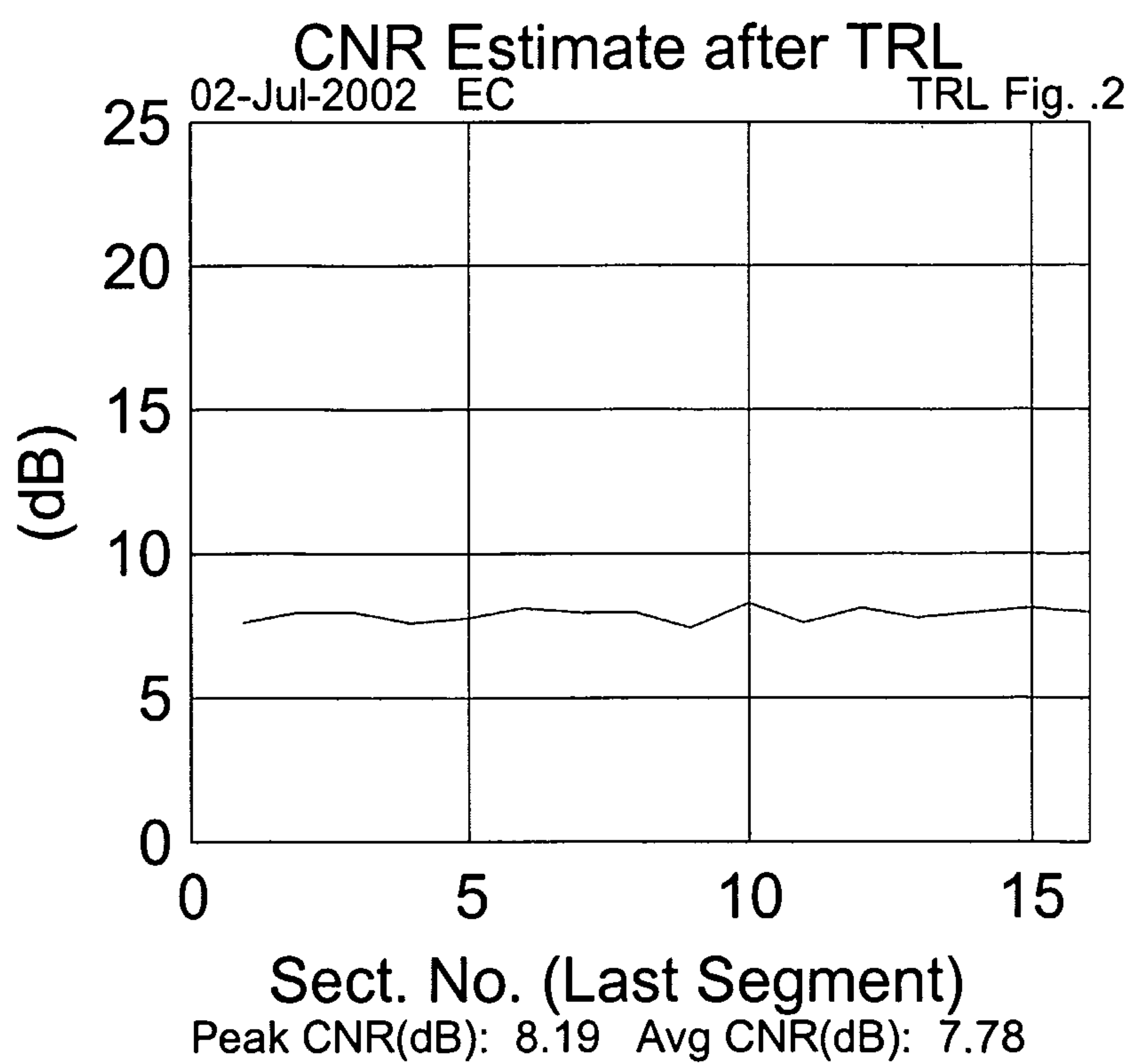
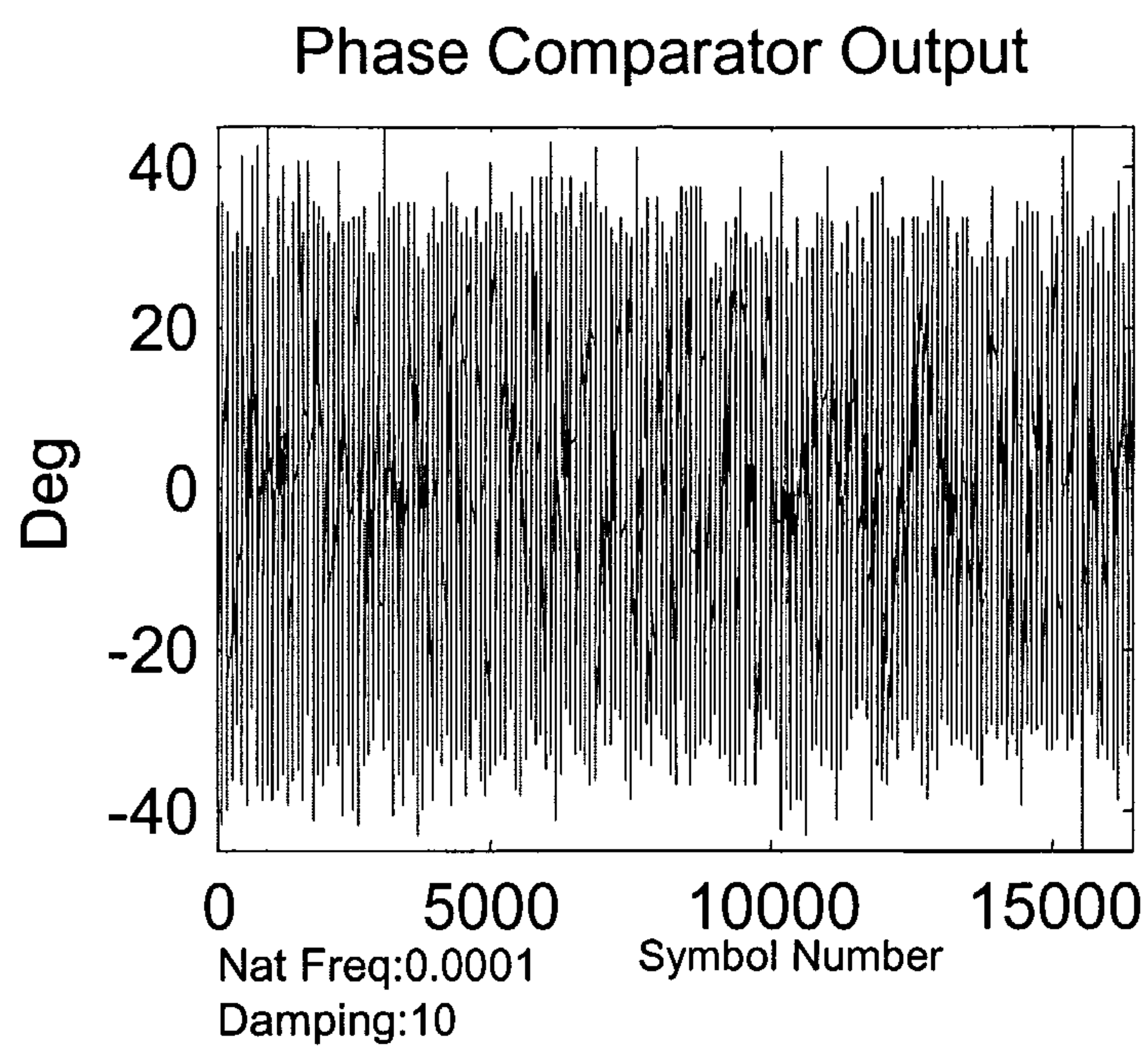
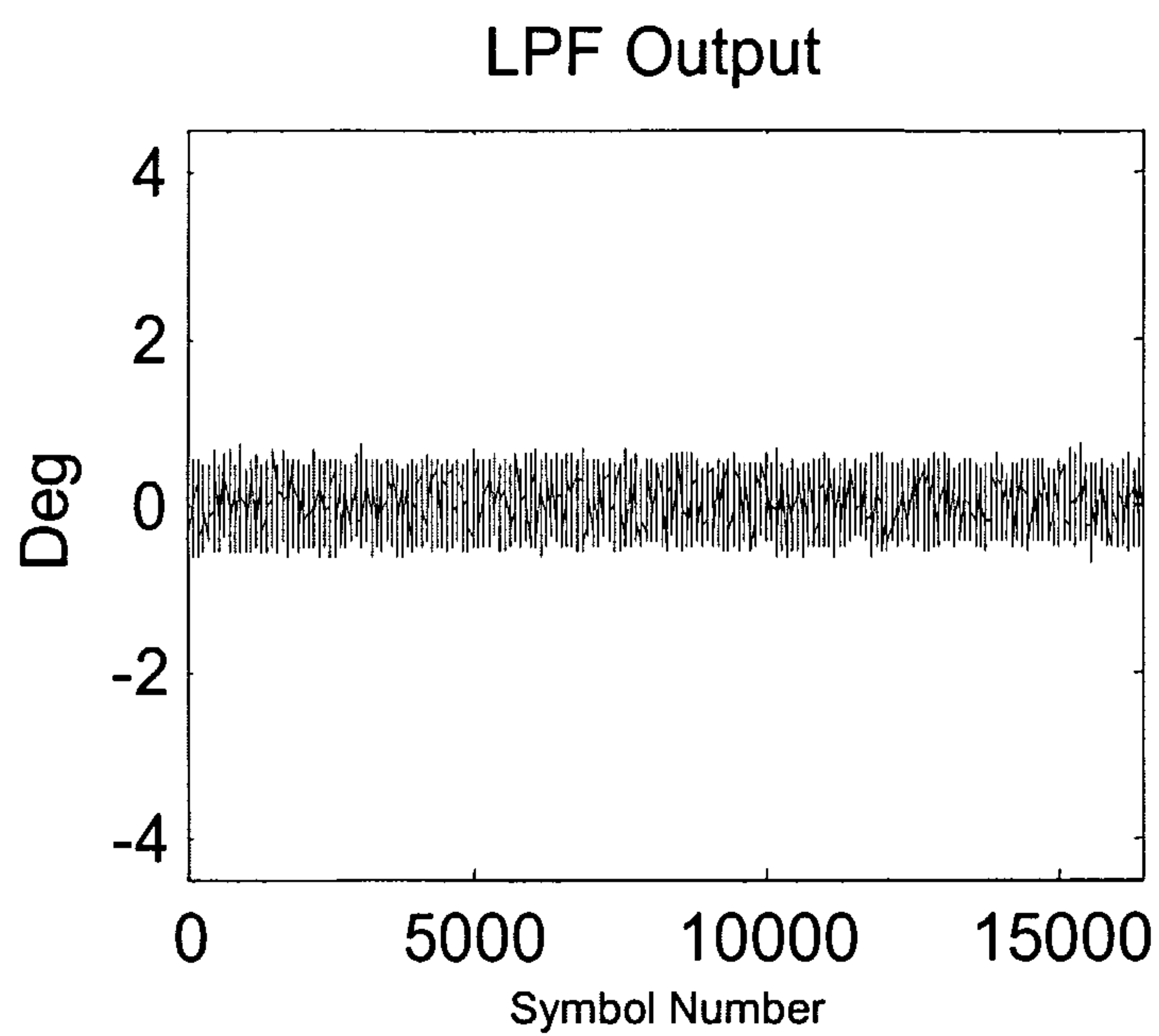


FIG. 15C

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*FIG. 15D**FIG. 15E**FIG. 15F*

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*FIG. 16A**FIG. 16B*

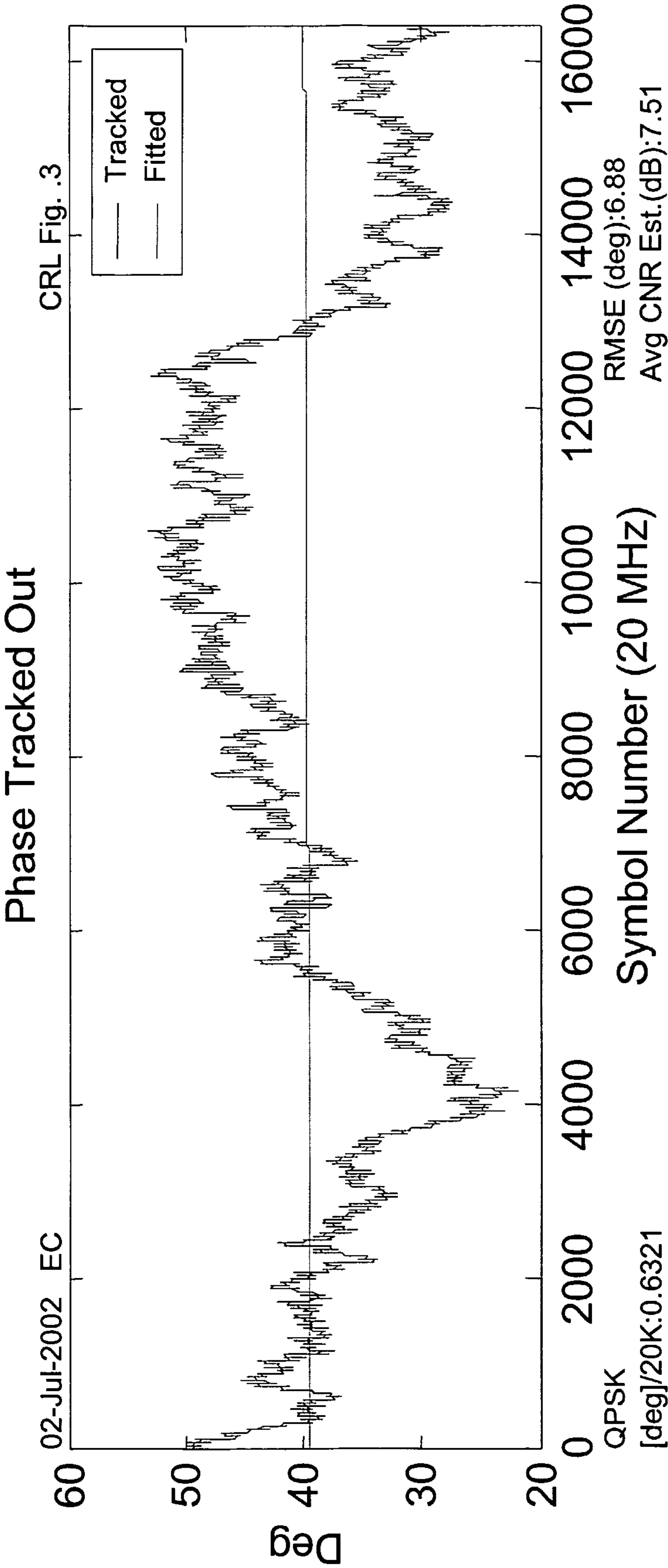


FIG. 16C

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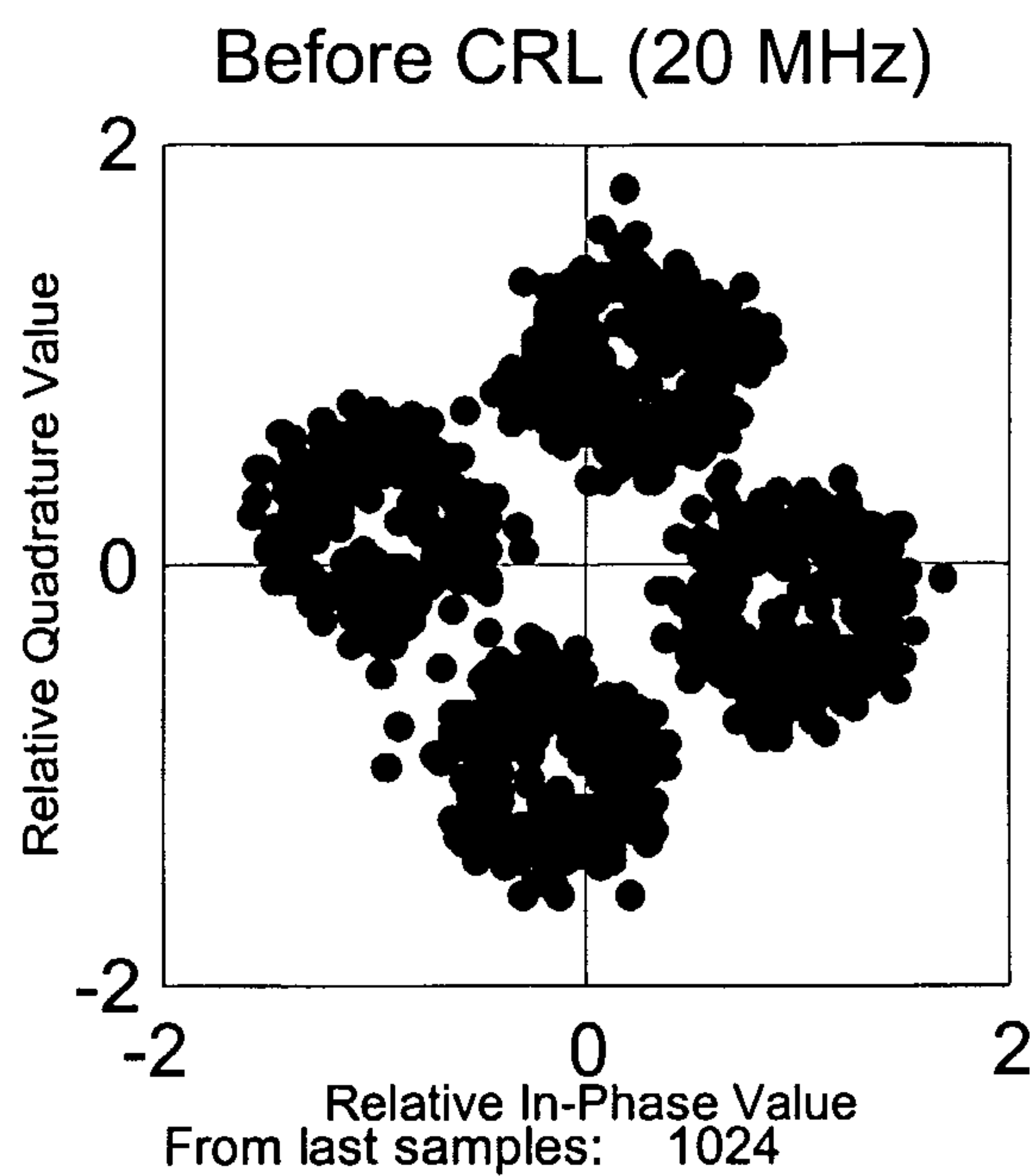


FIG. 16D

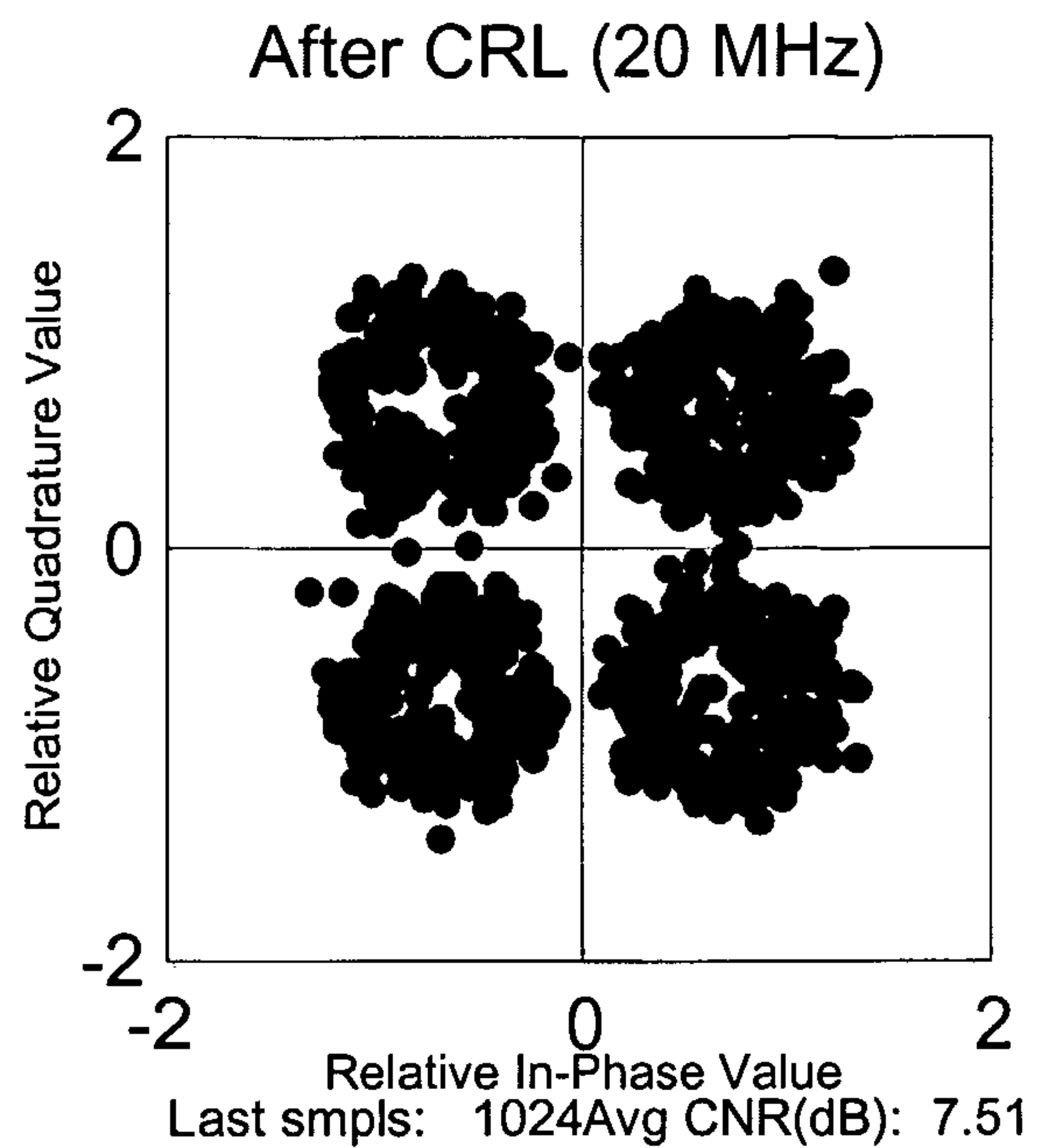


FIG. 16E

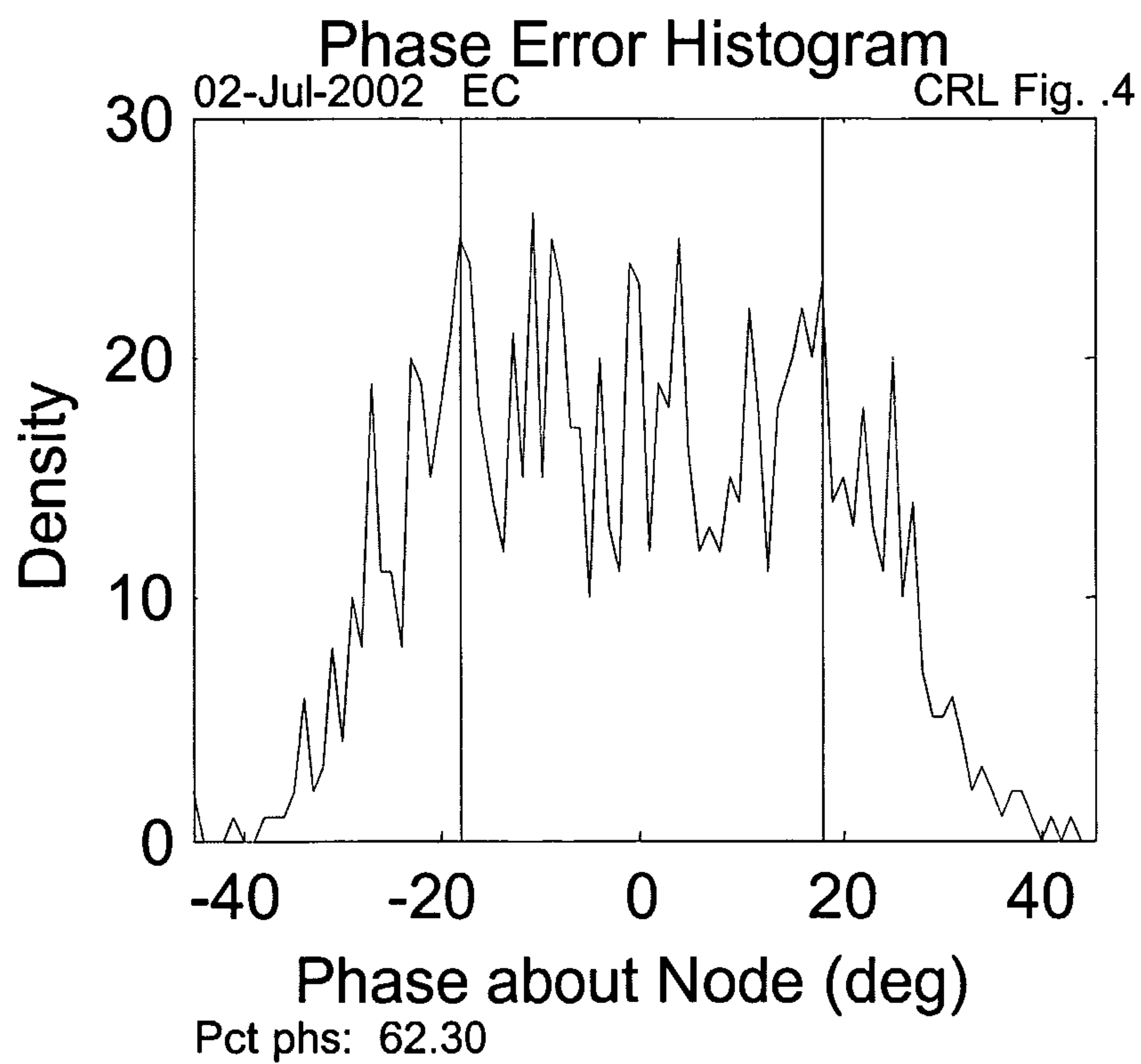
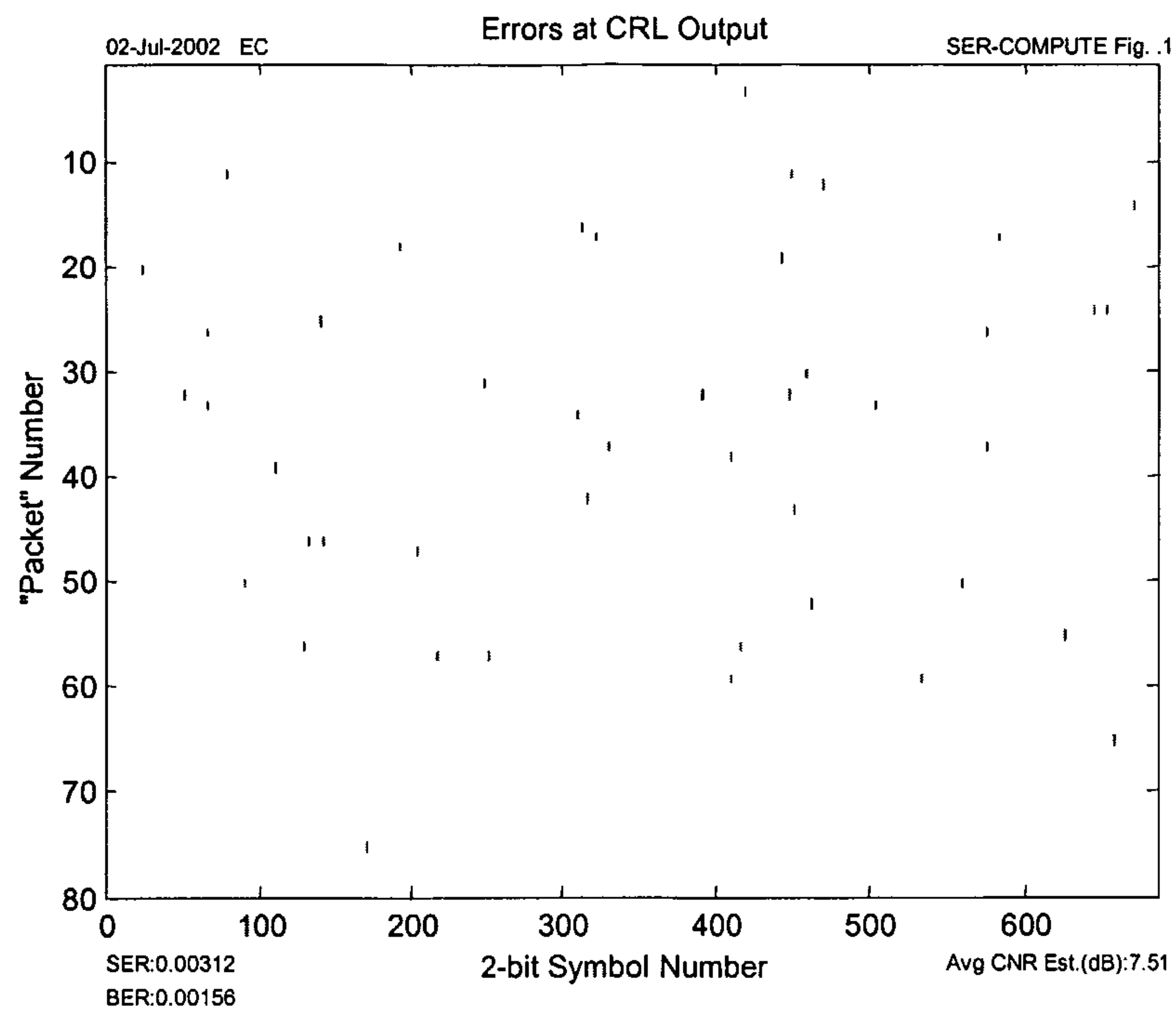
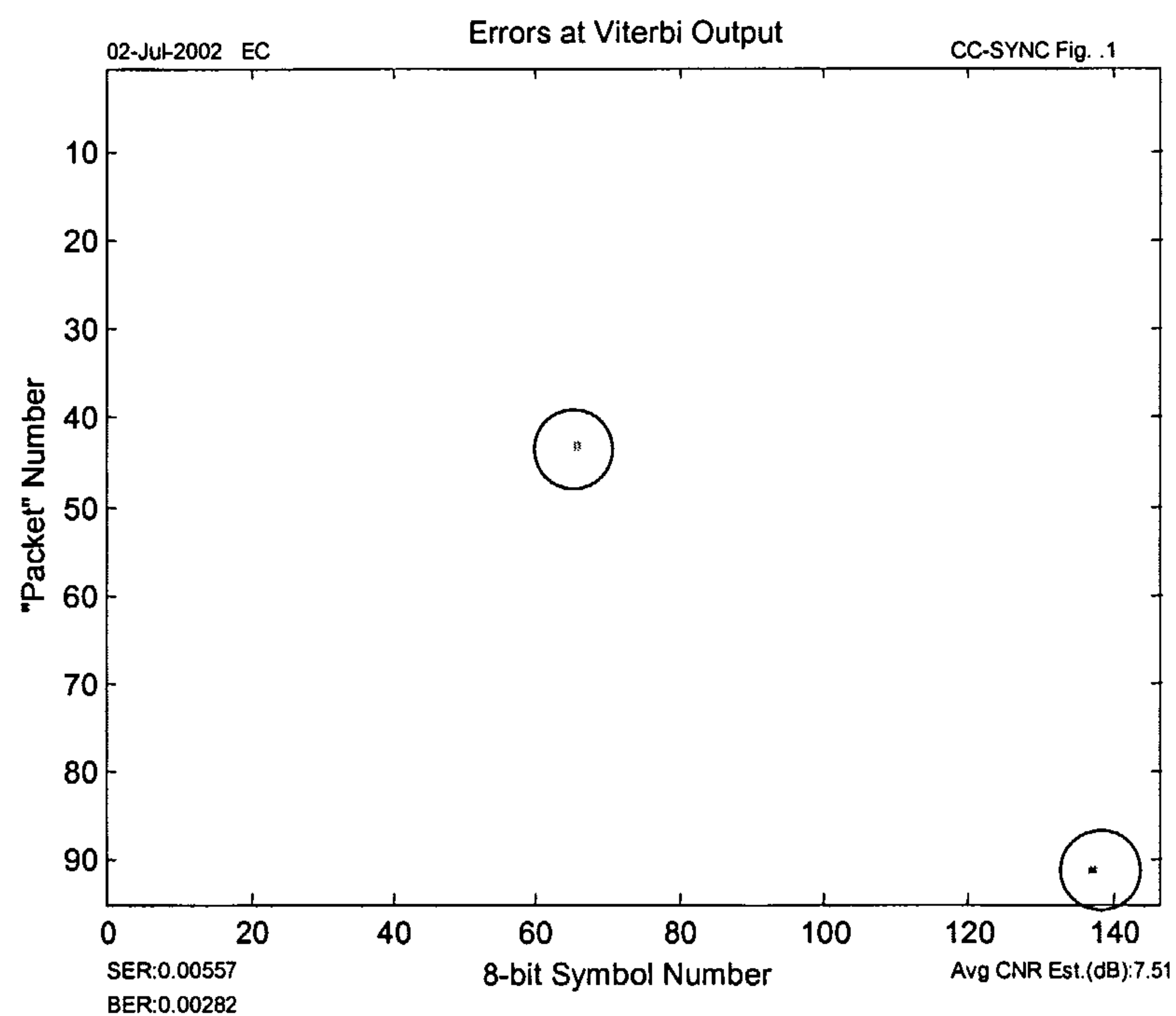


FIG. 16F

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*FIG. 17A**FIG. 17B*

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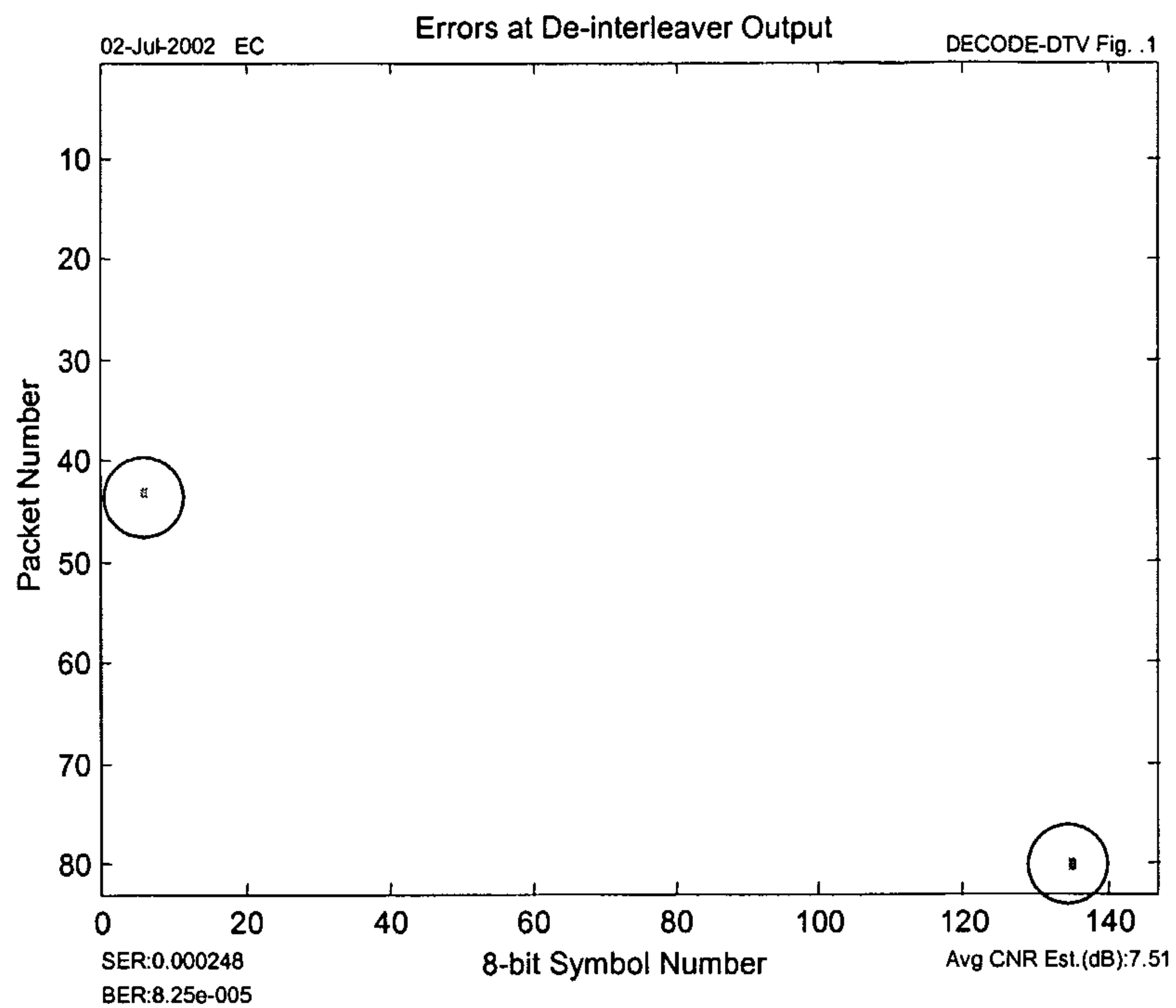


FIG. 17C

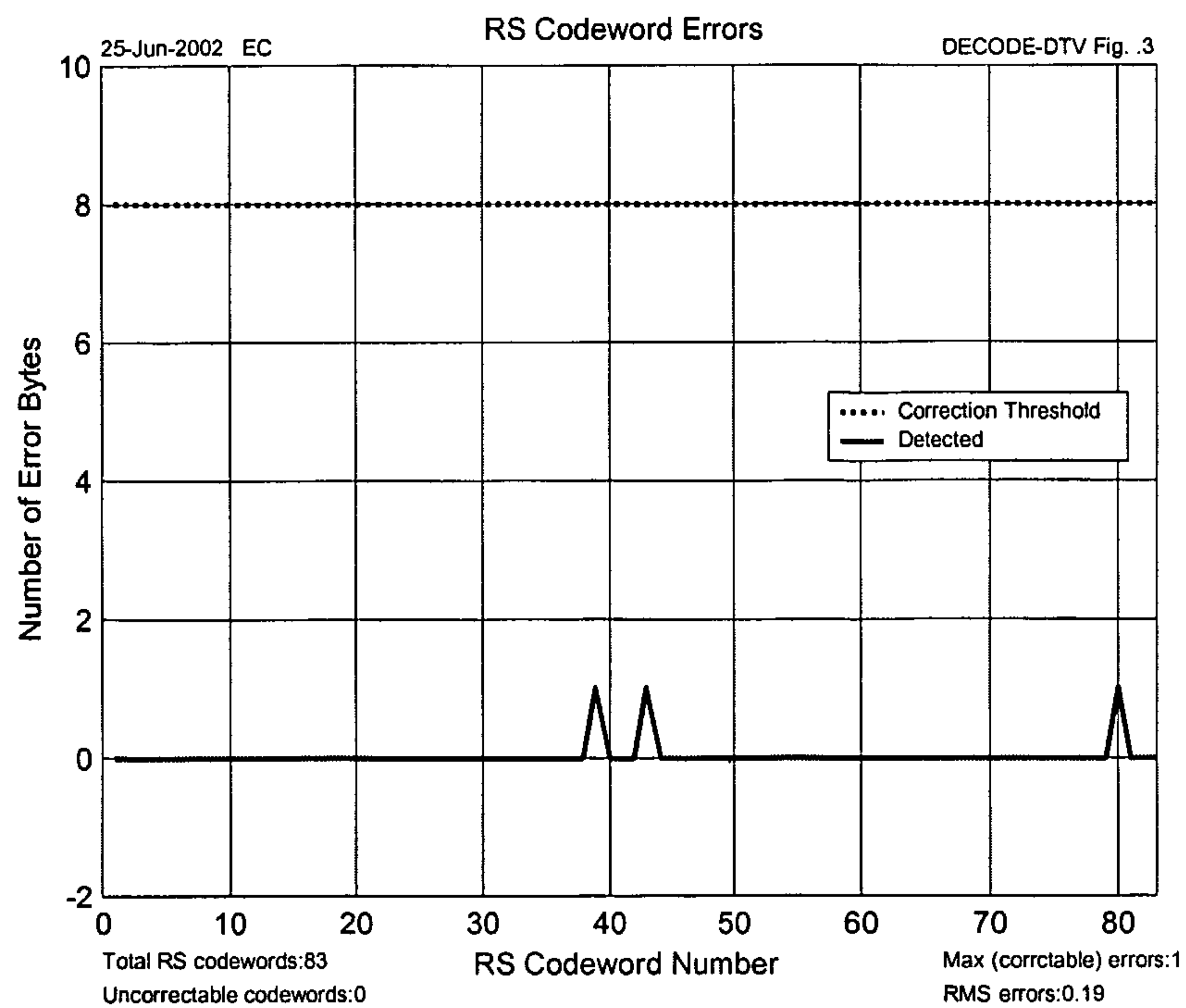


FIG. 17D

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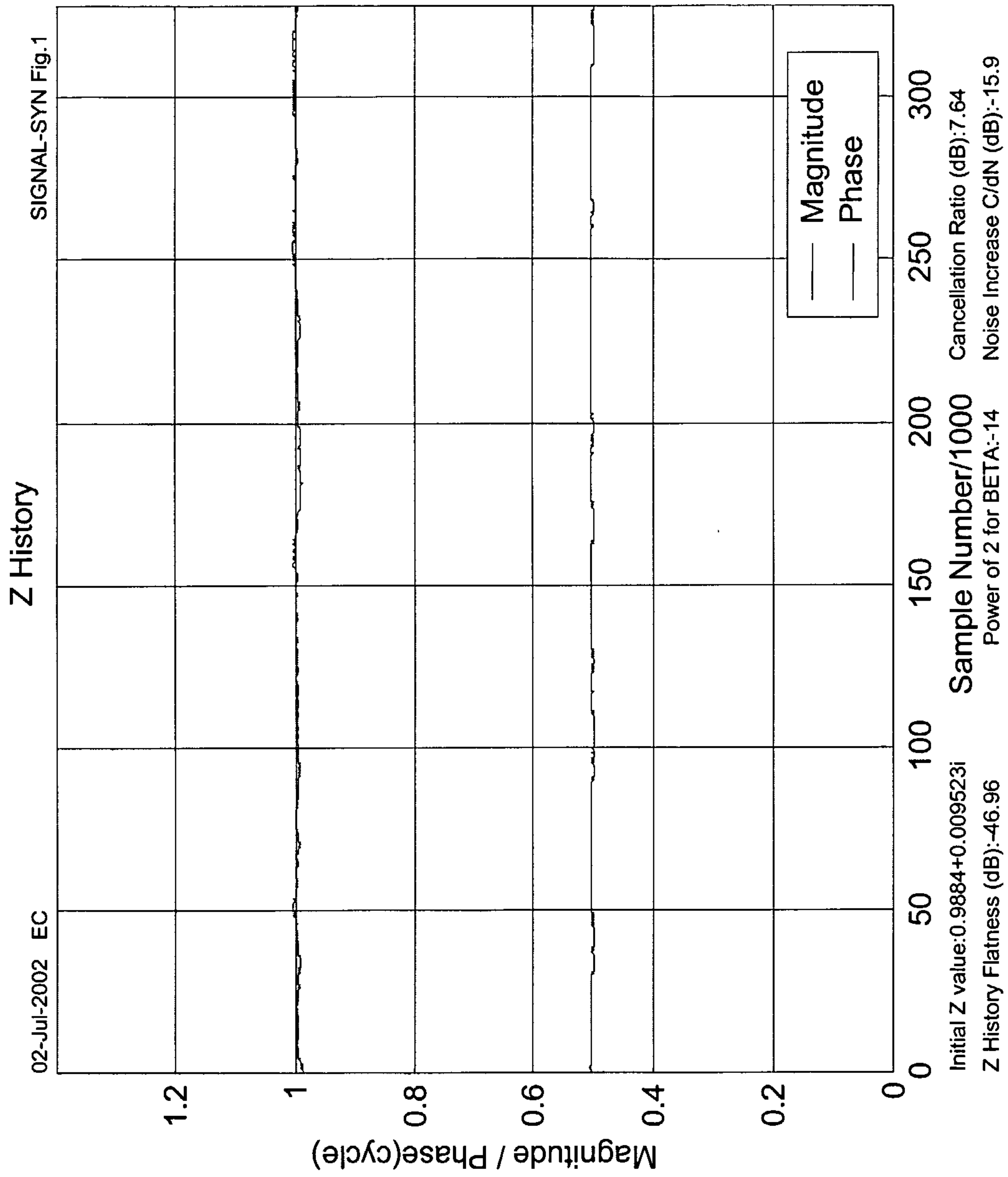


FIG. 18

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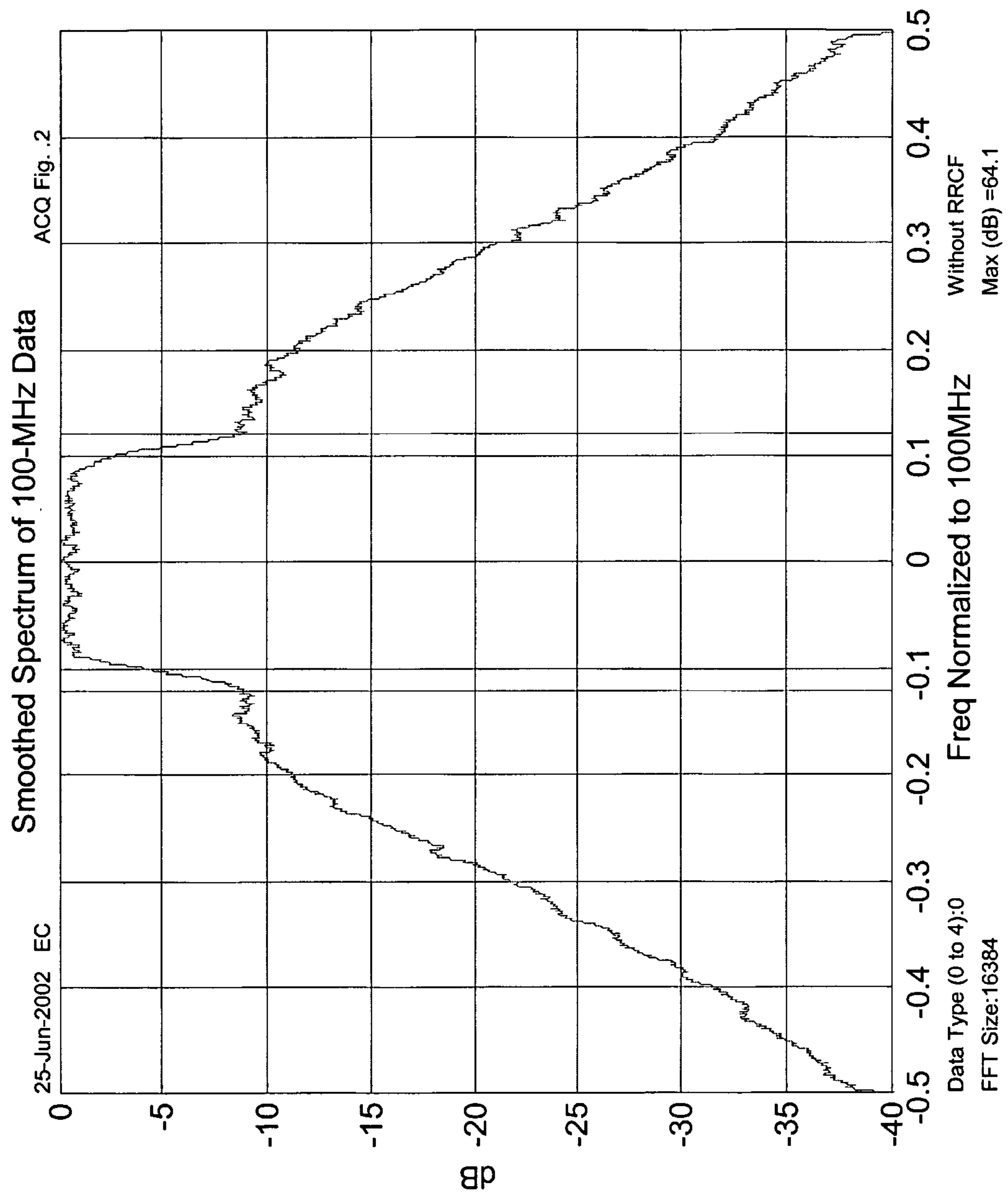
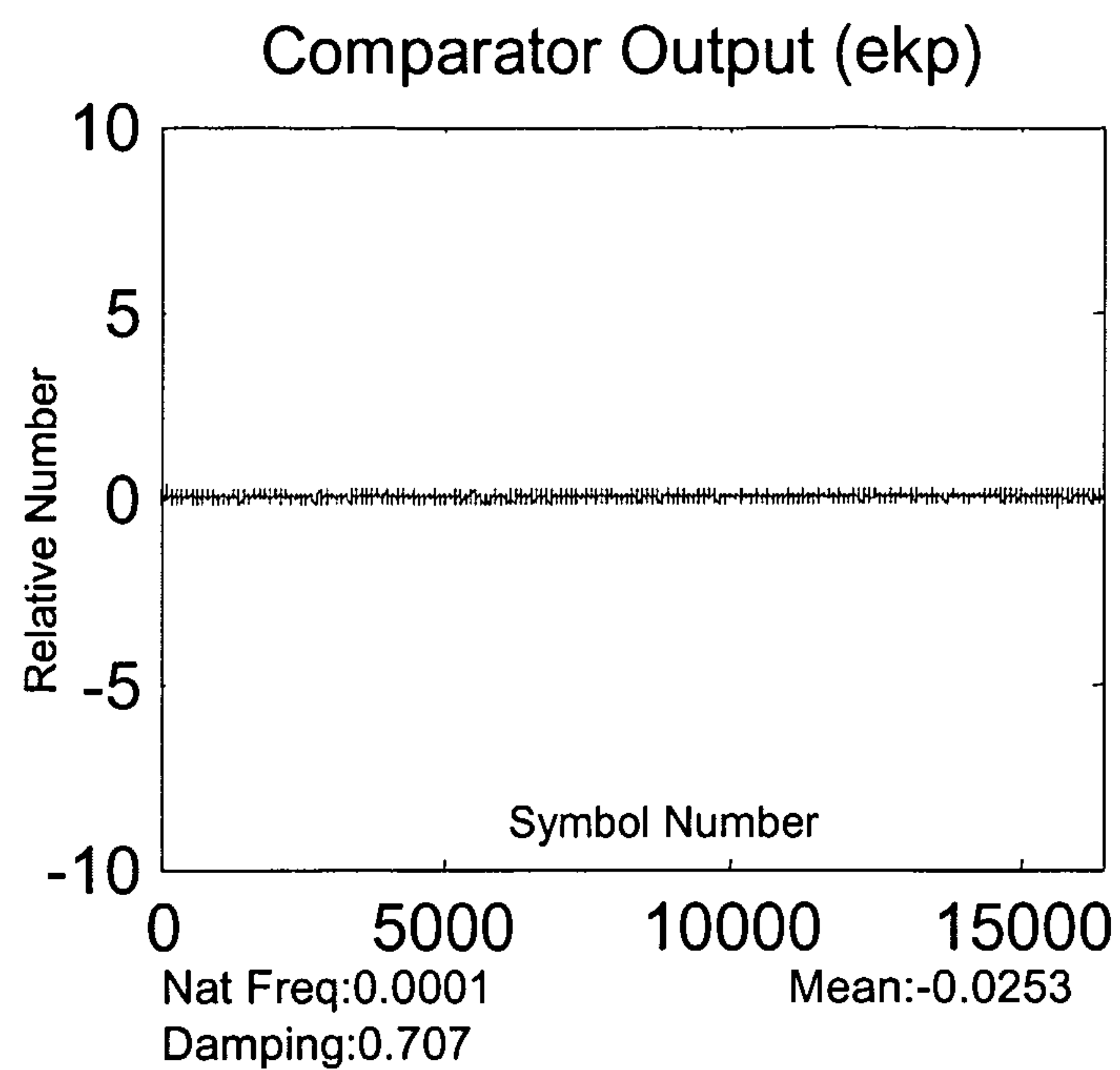
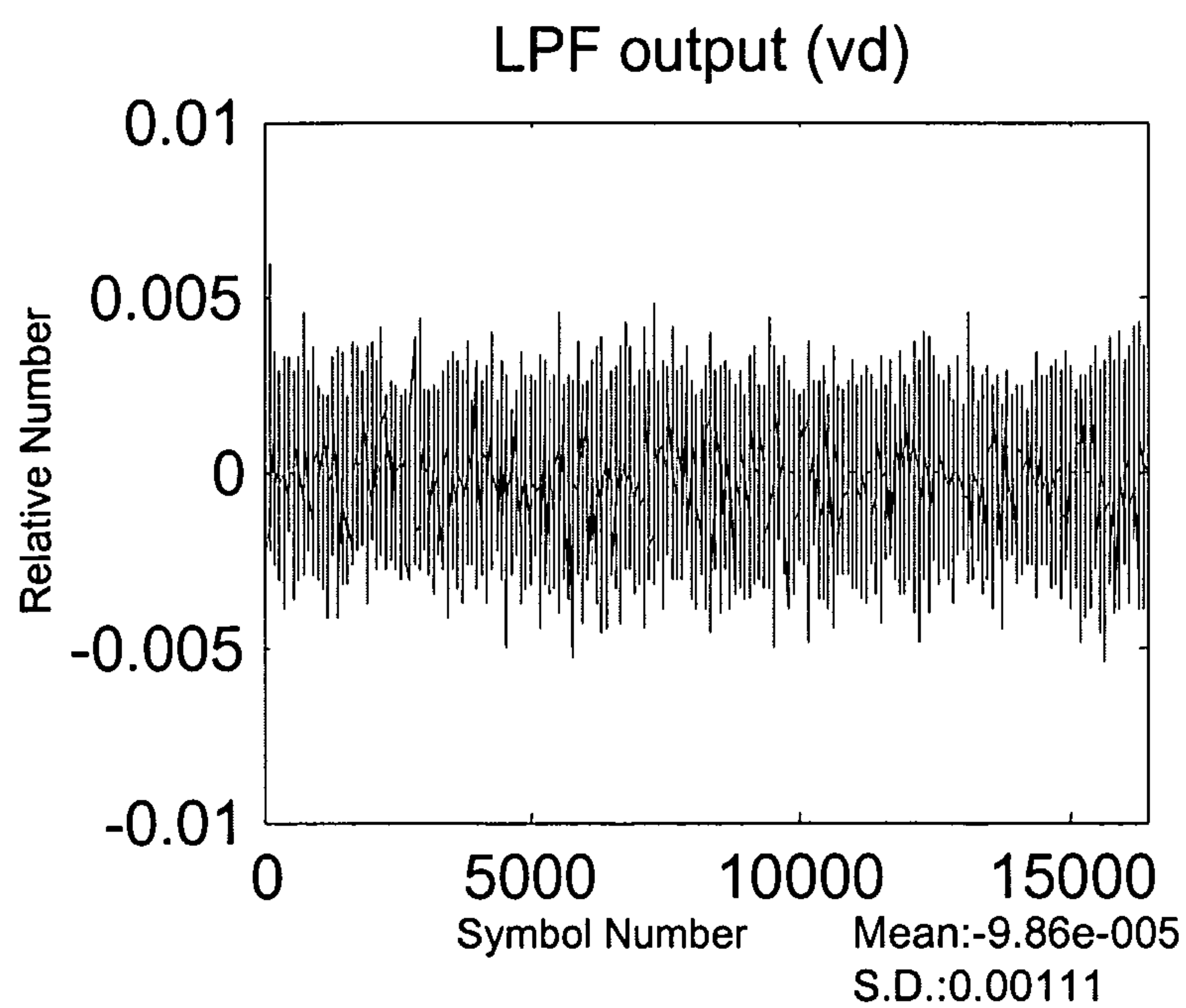


FIG. 19

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*FIG. 20A**FIG. 20B*

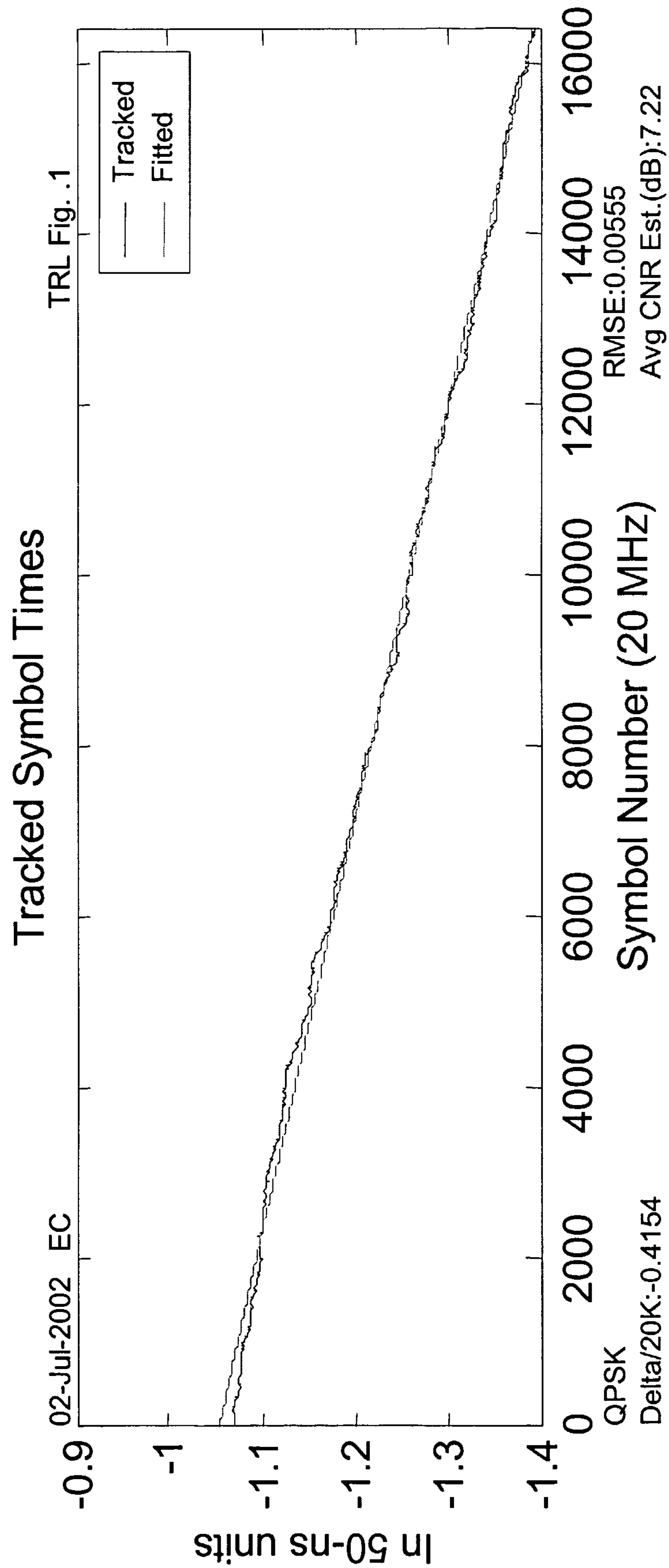
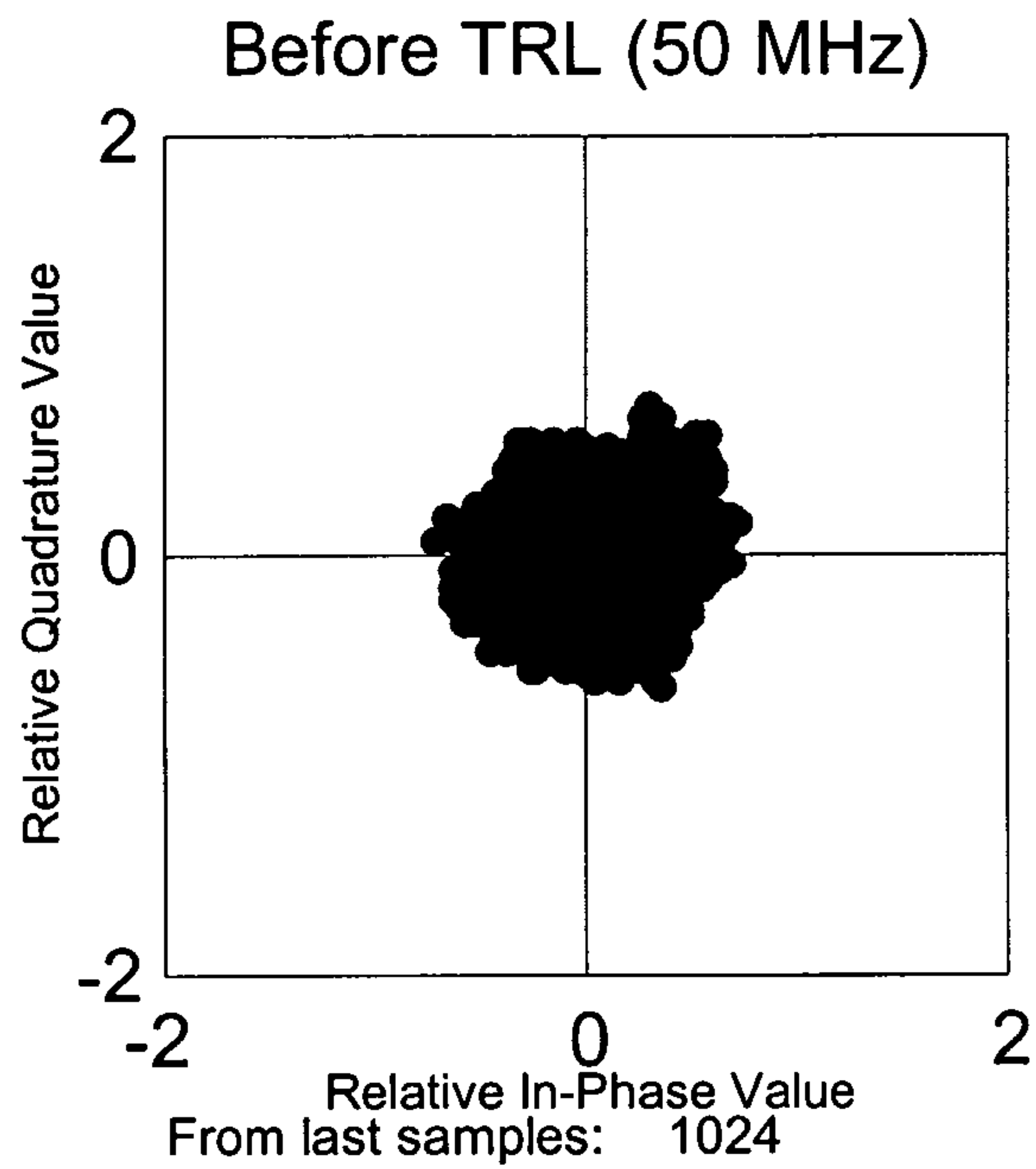
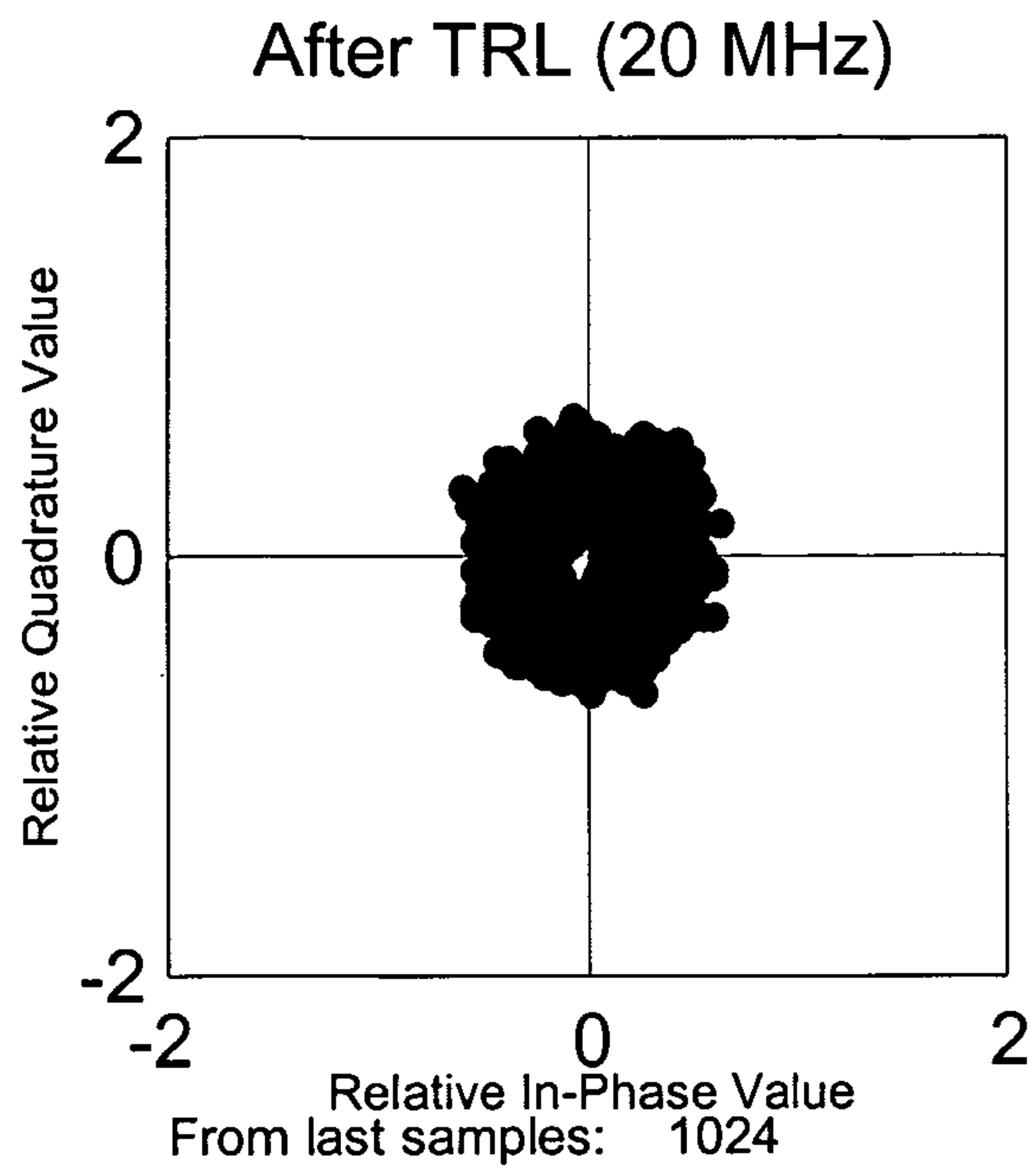
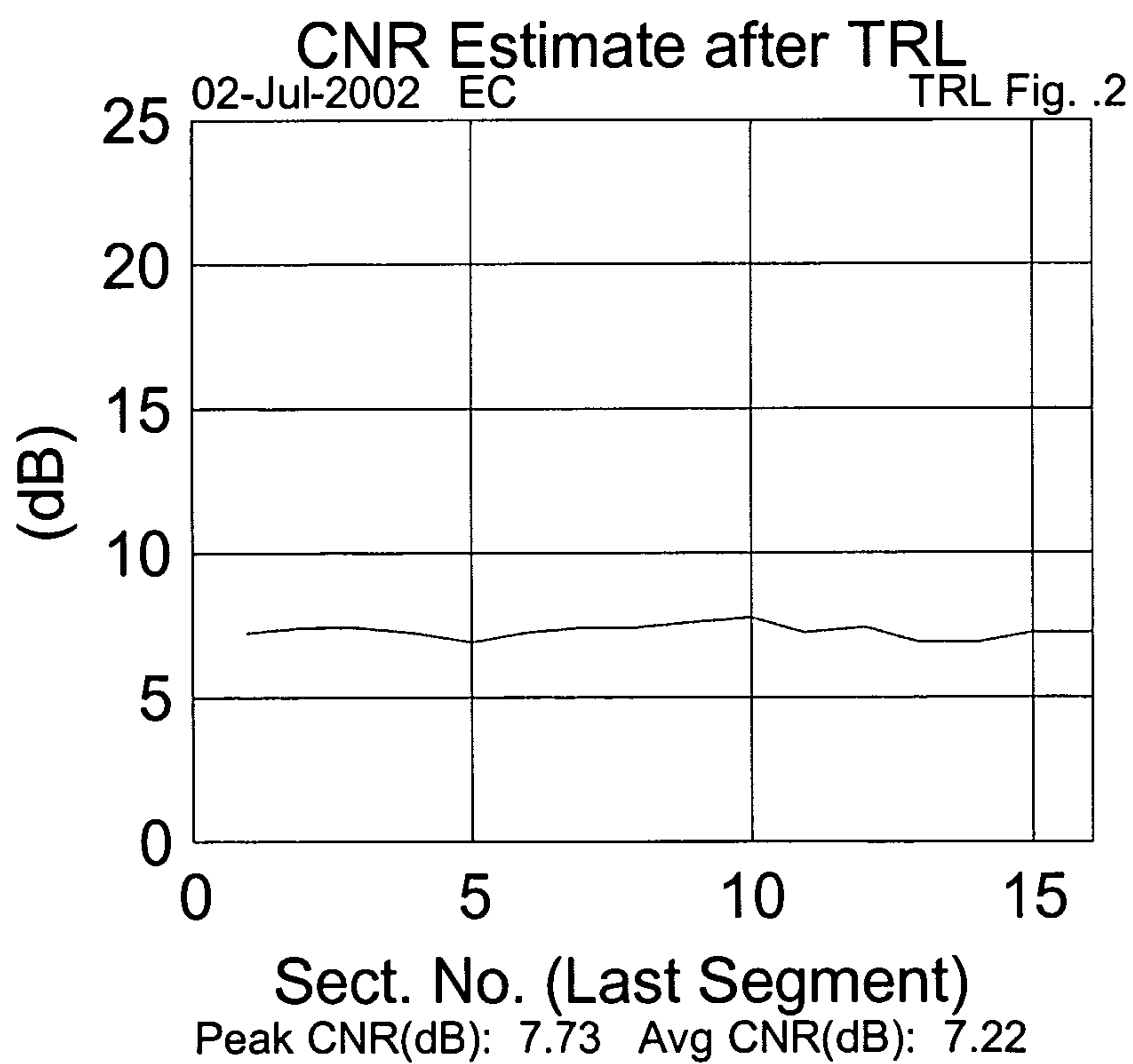
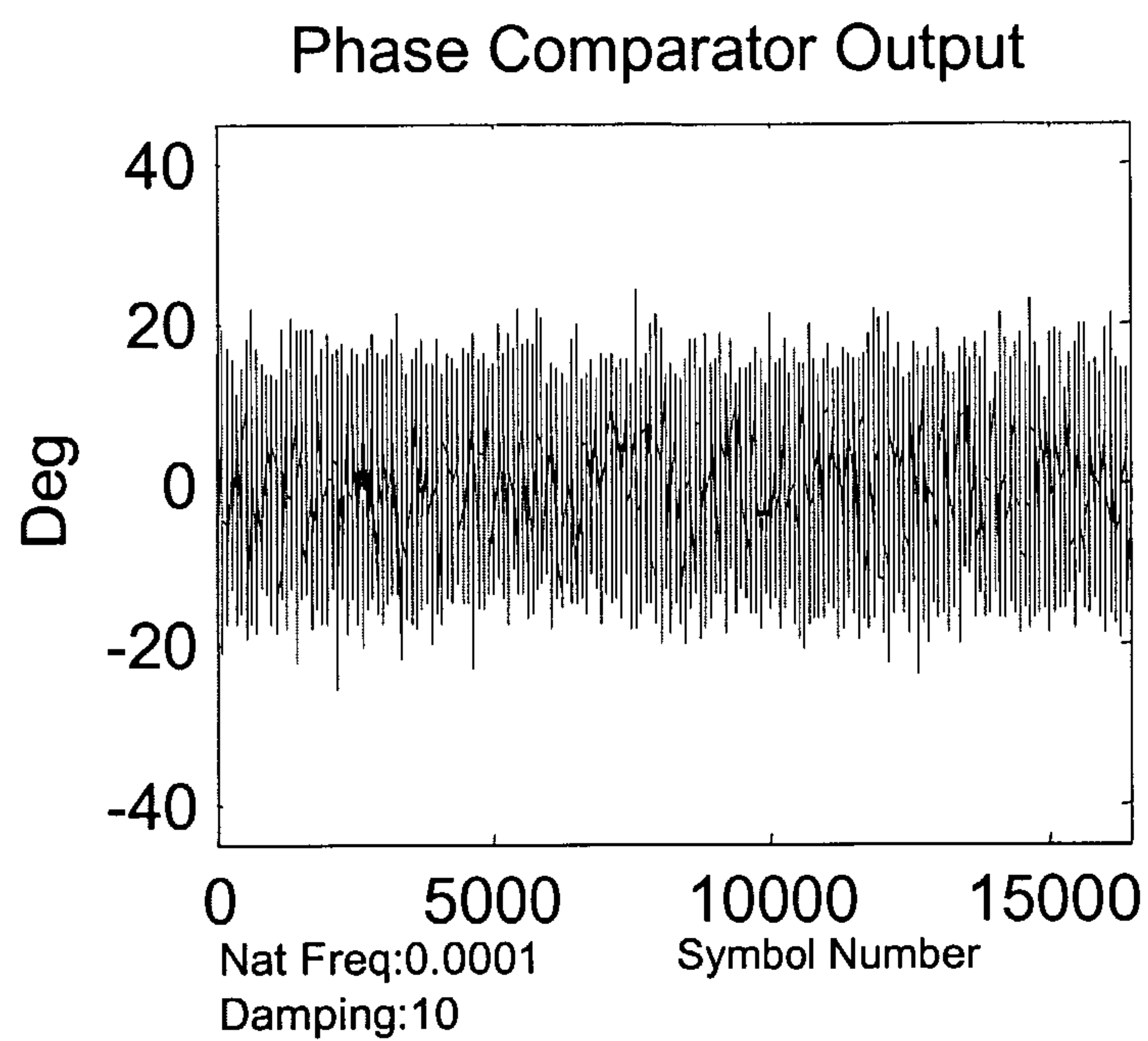
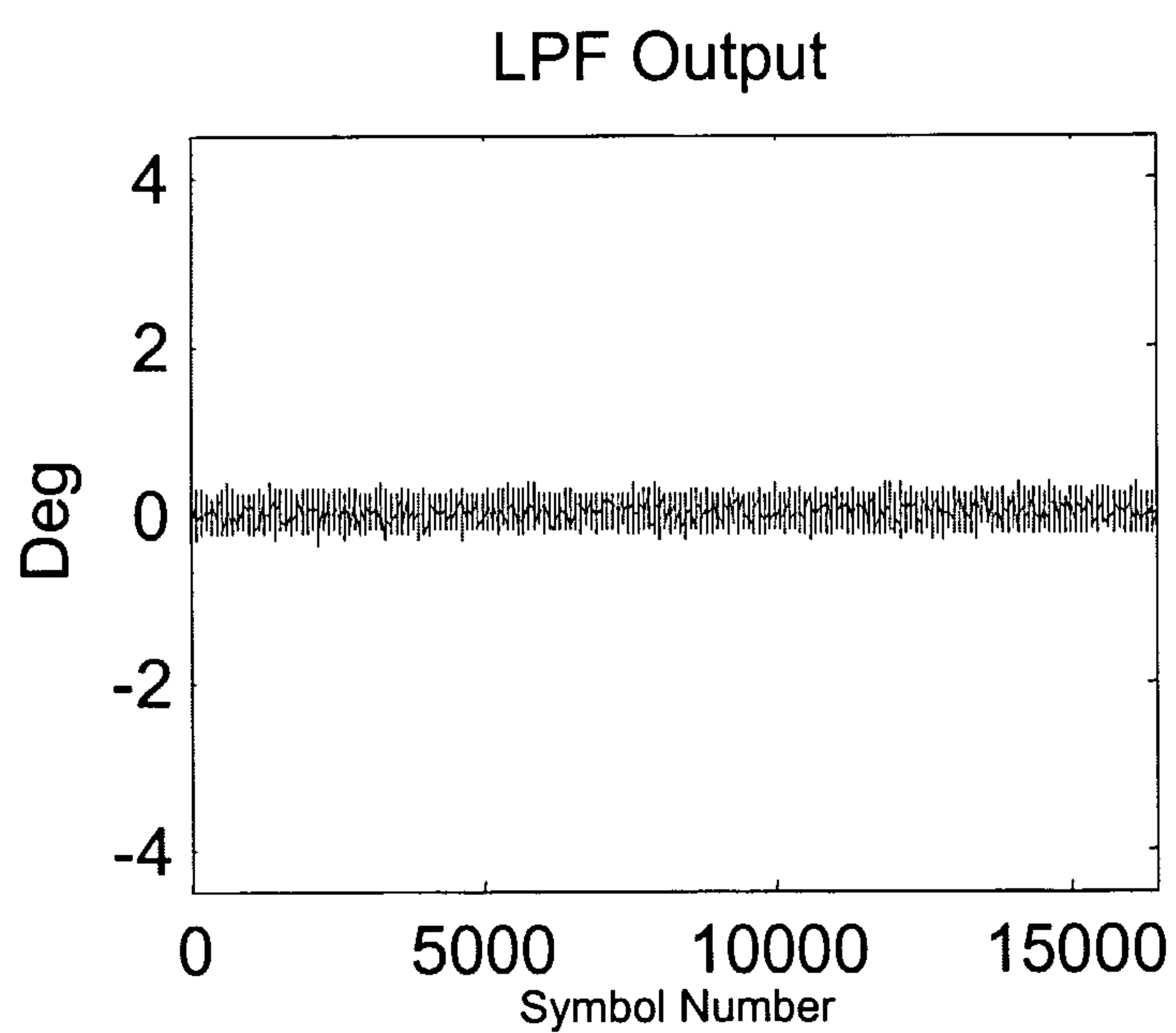


FIG. 20C

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*FIG. 20D**FIG. 20E**FIG. 20F*

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*FIG. 21A**FIG. 21B*

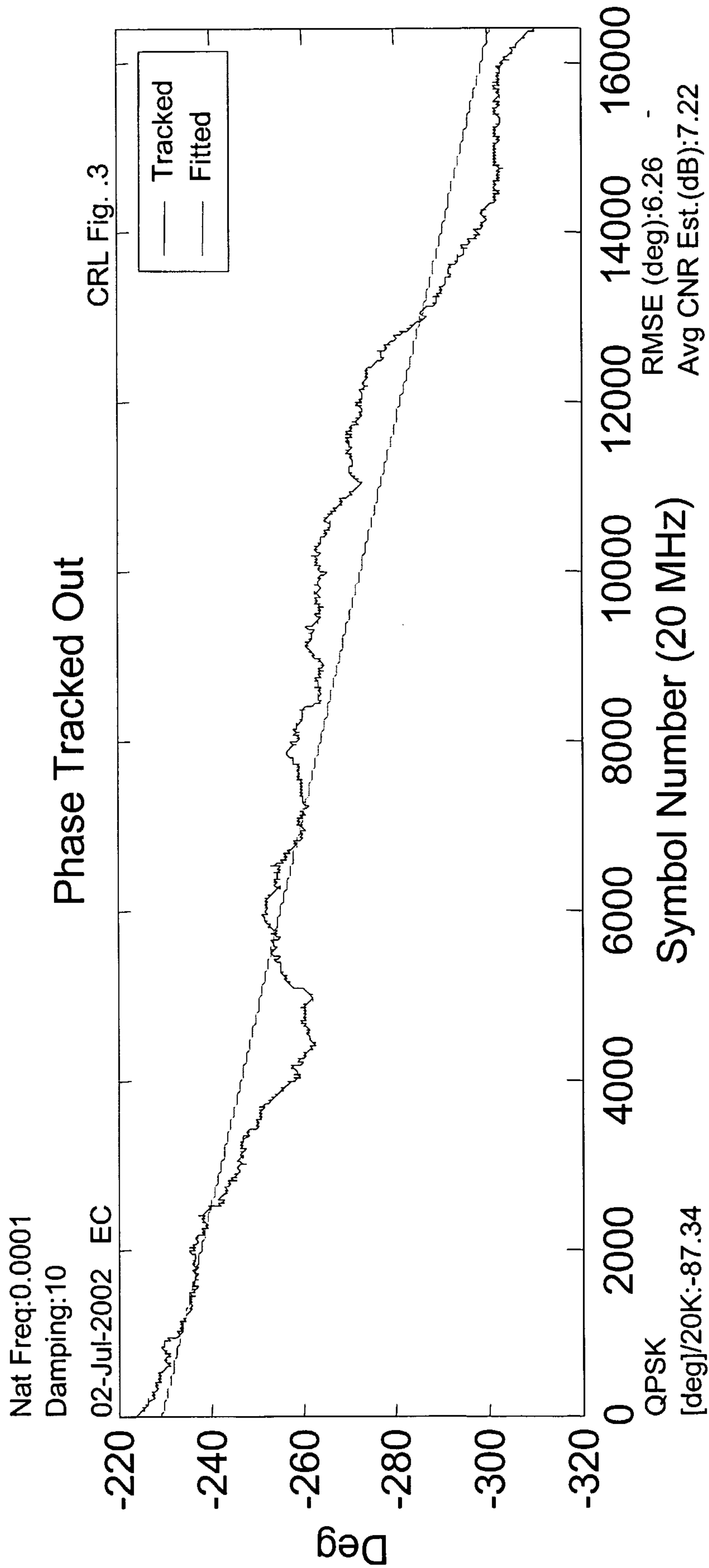
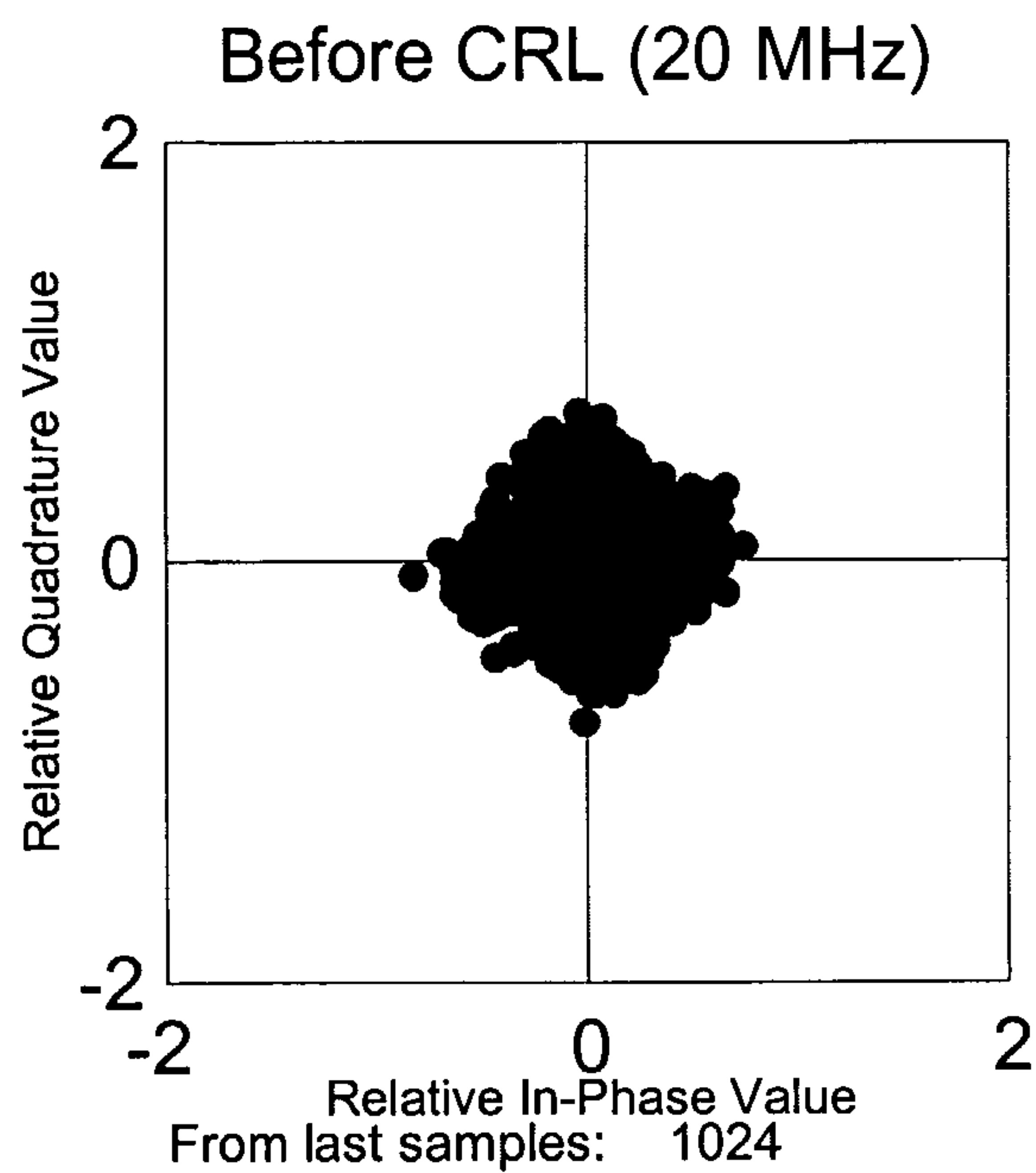
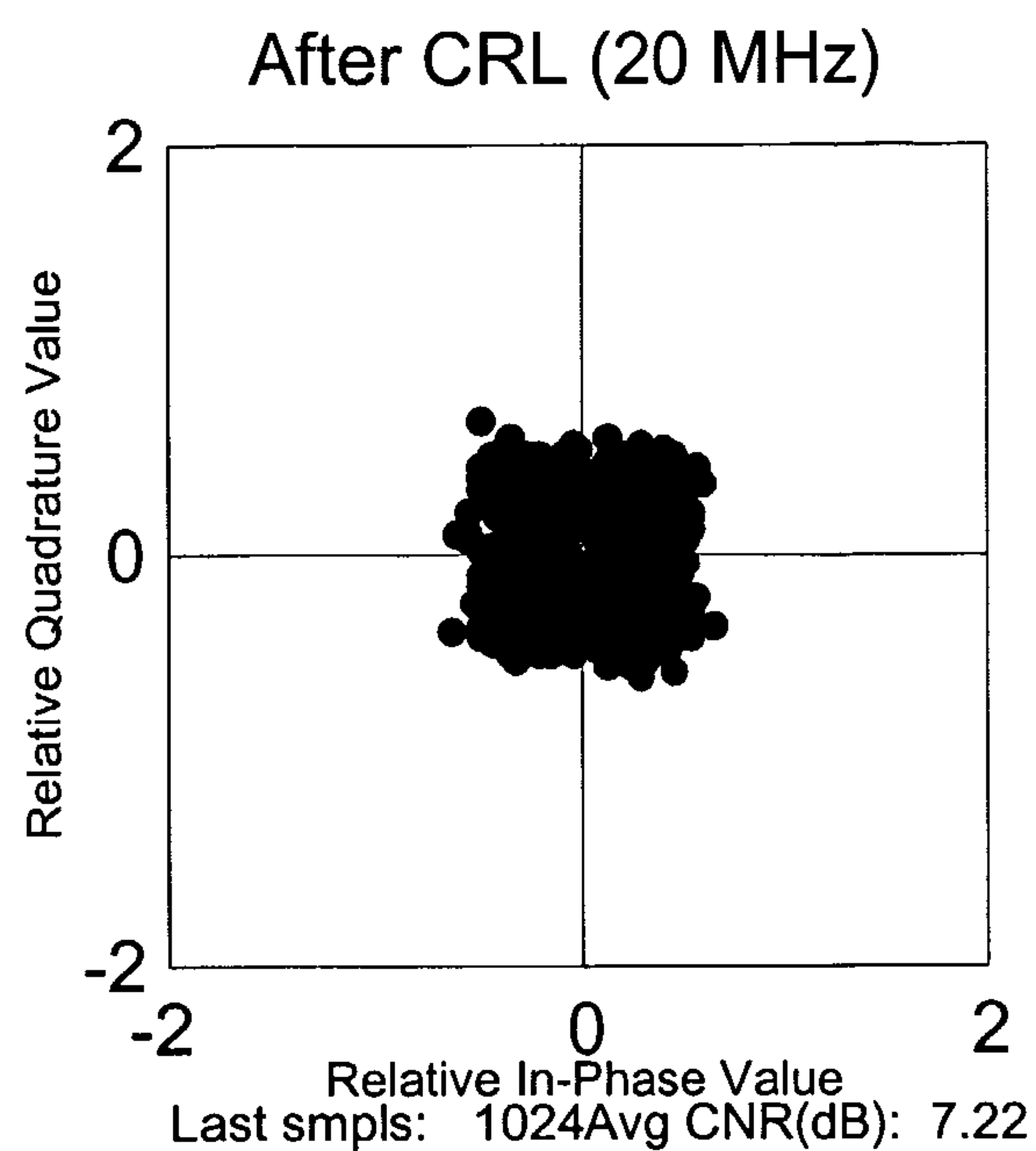
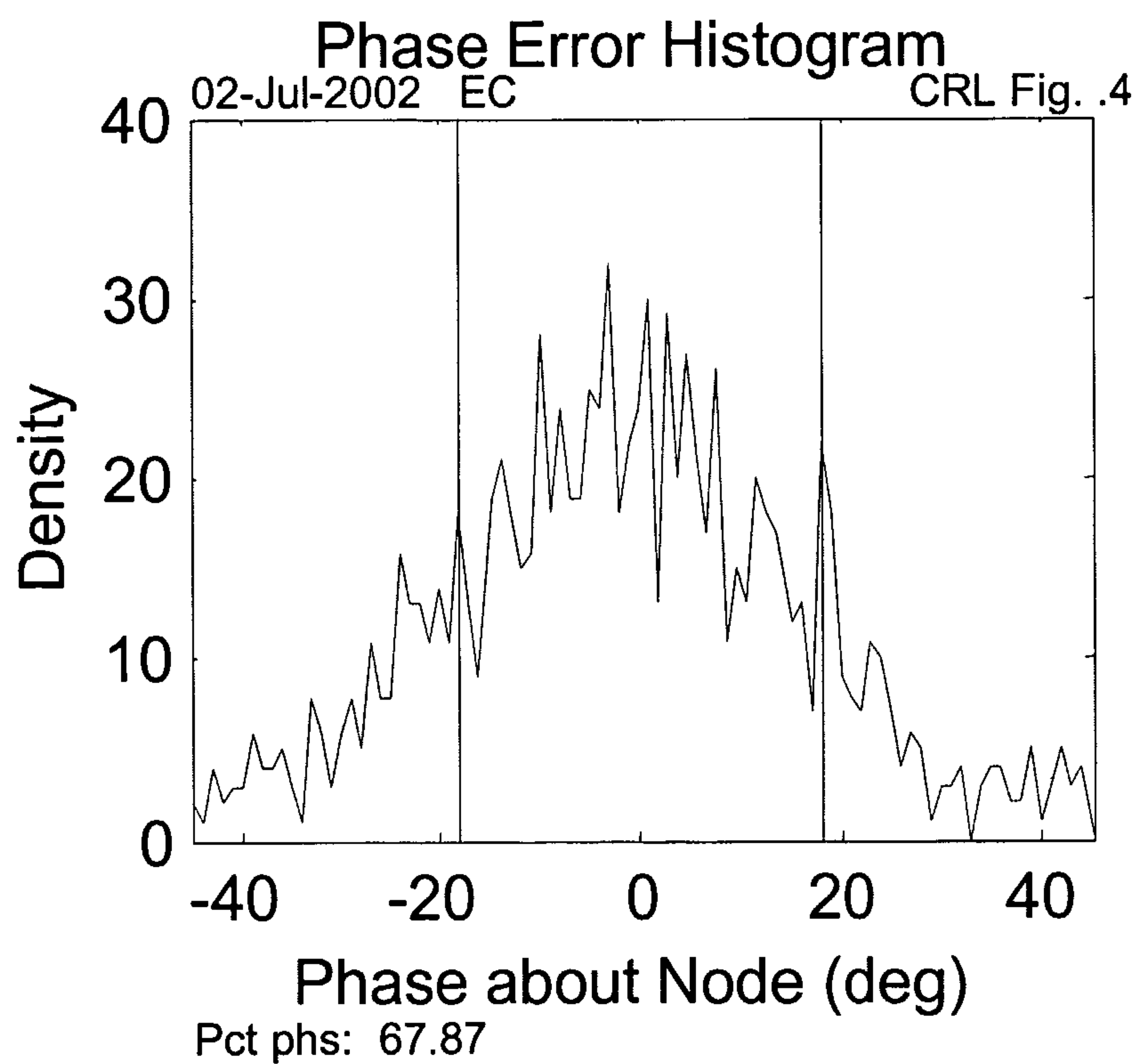
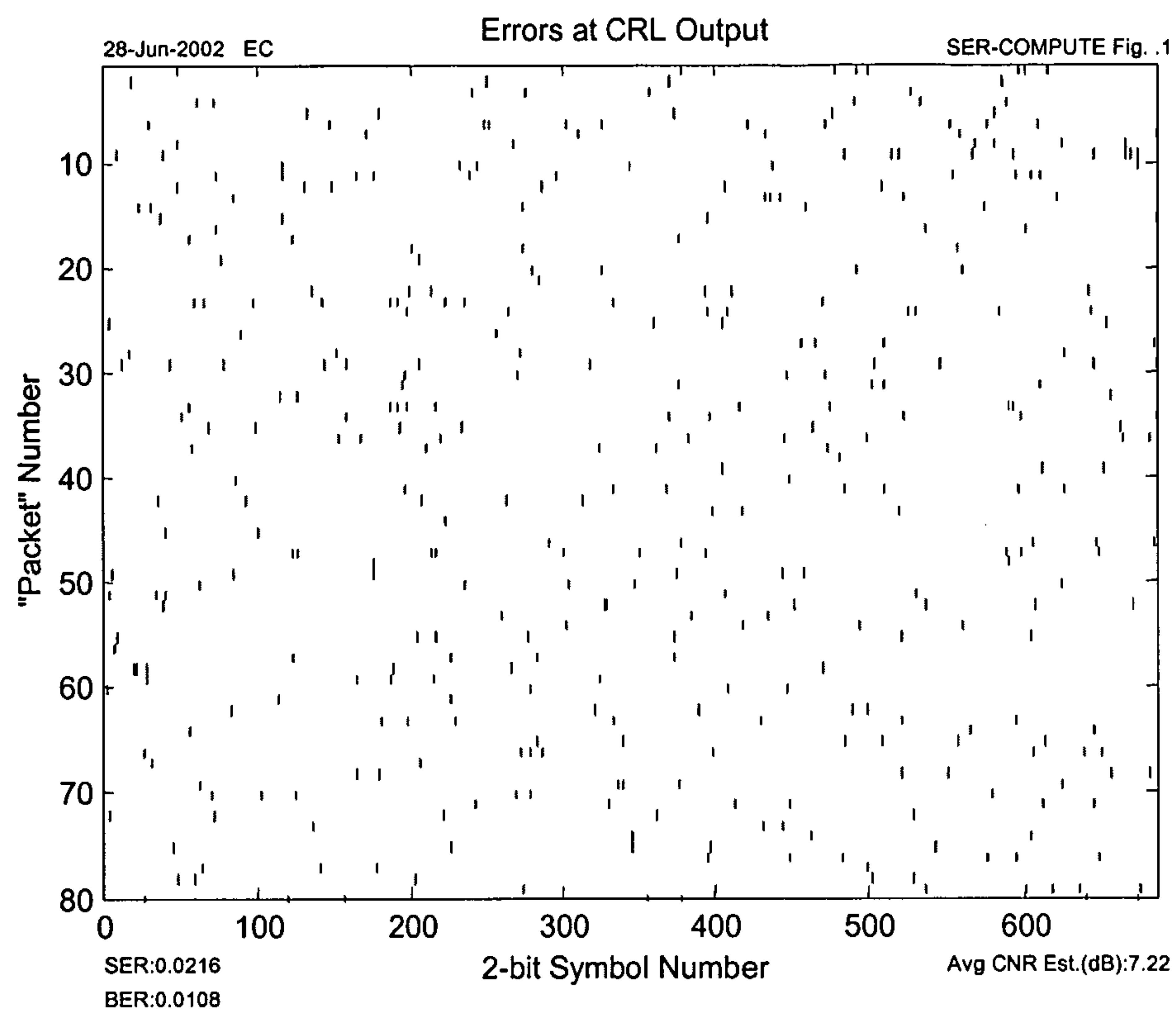
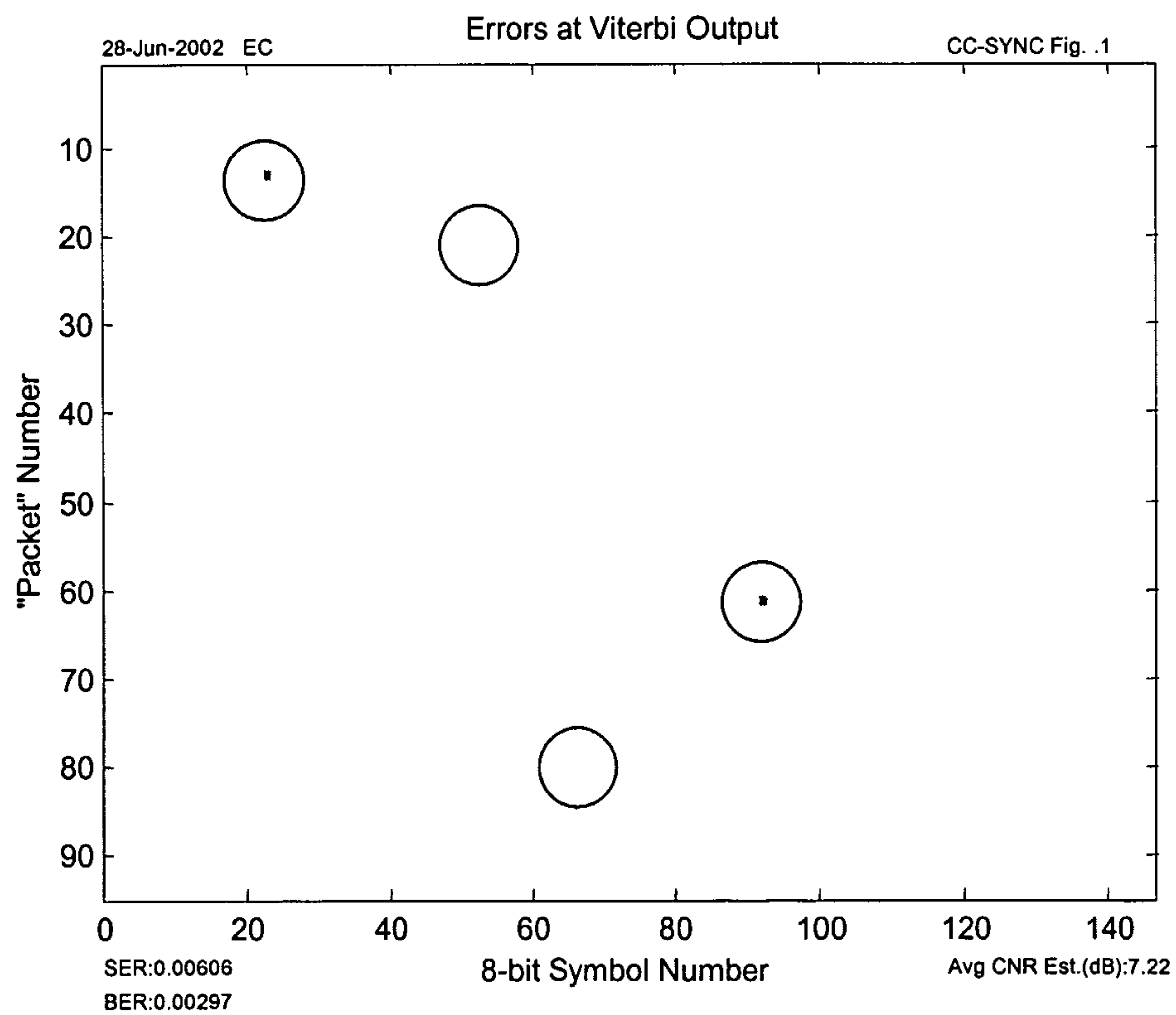


FIG. 21C

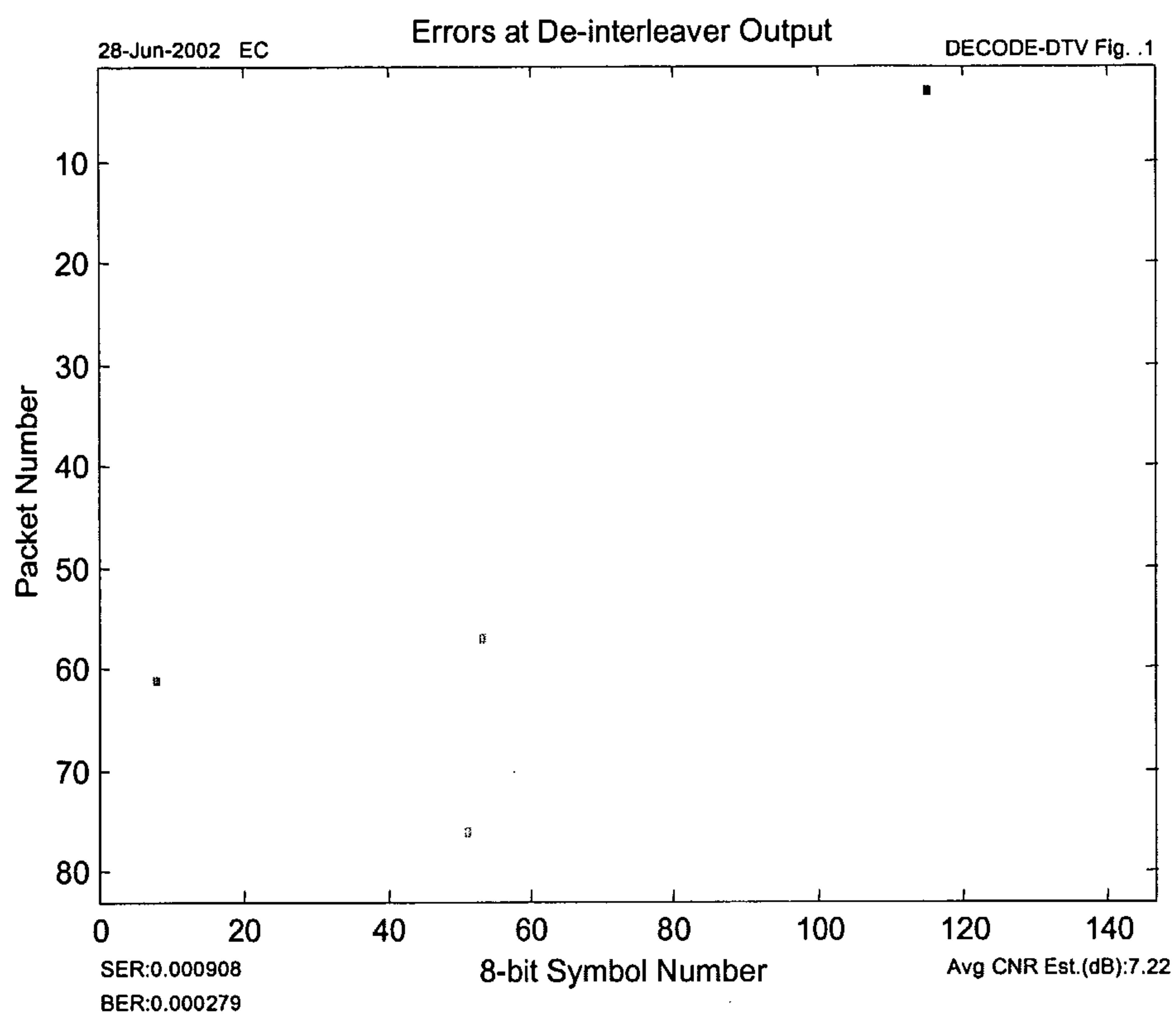
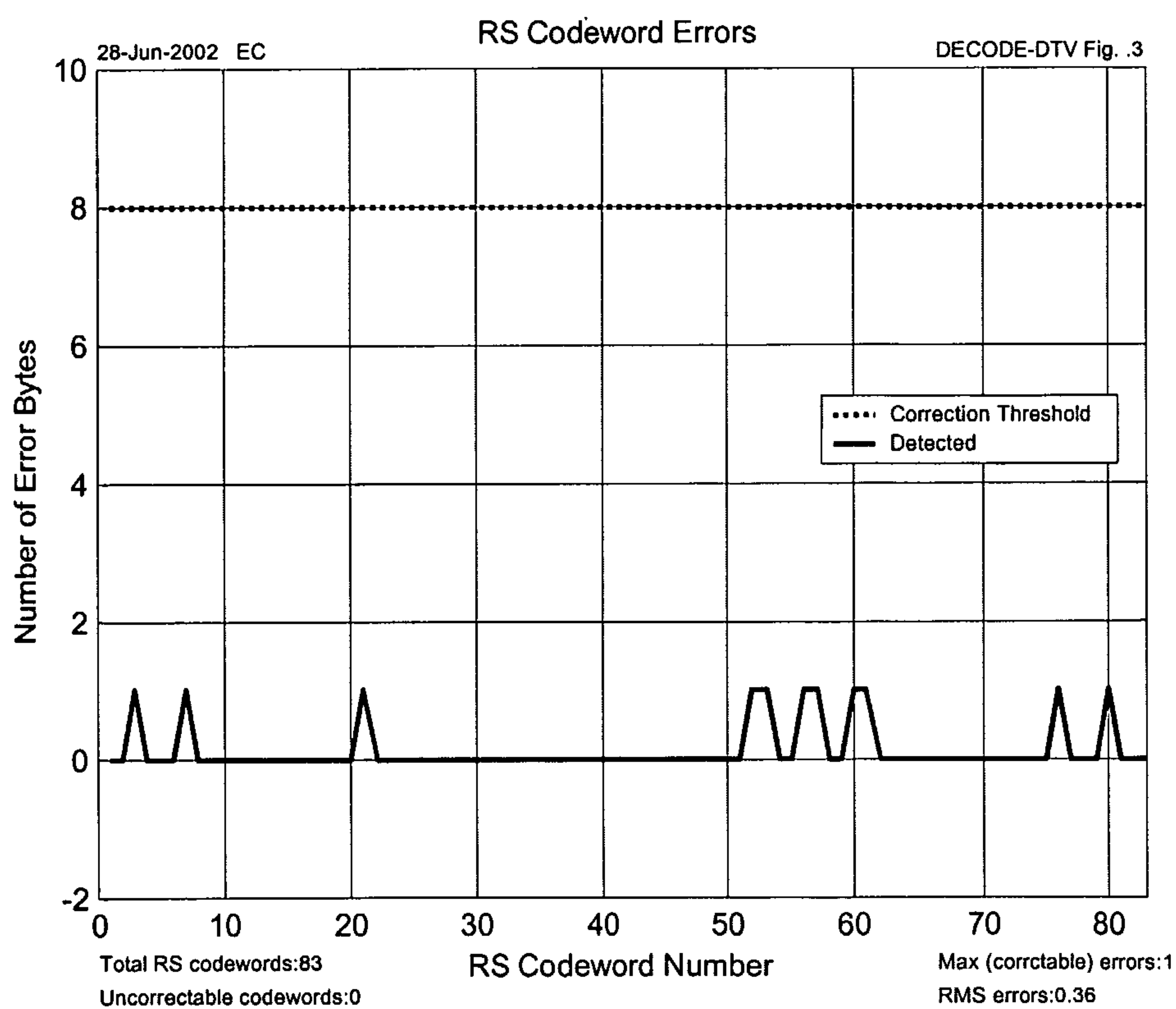
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**FIG. 21D****FIG. 21E****FIG. 21F**

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*FIG. 22A**FIG. 22B*

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**FIG. 22C****FIG. 22D**

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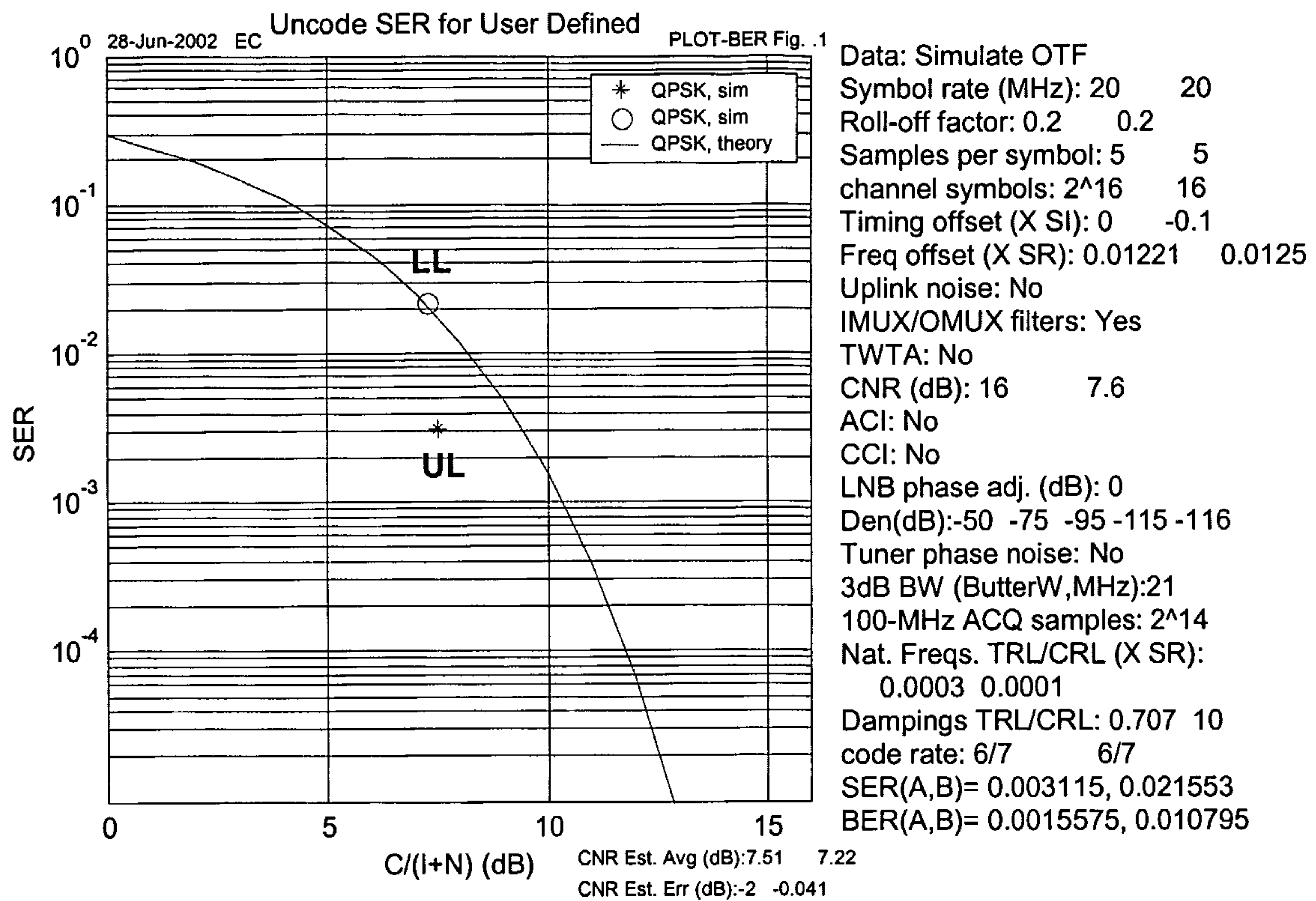


FIG. 23A

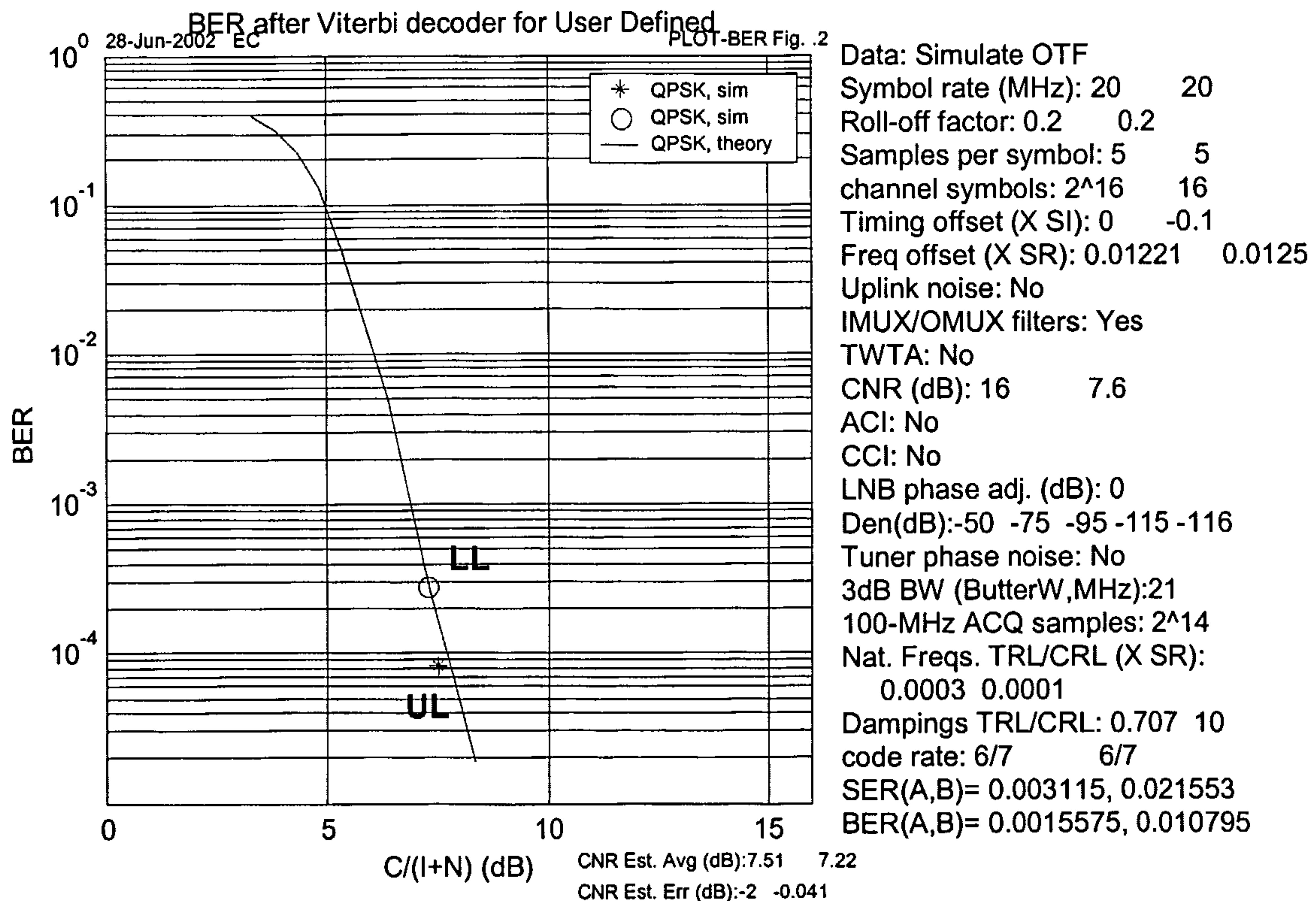


FIG. 23B

