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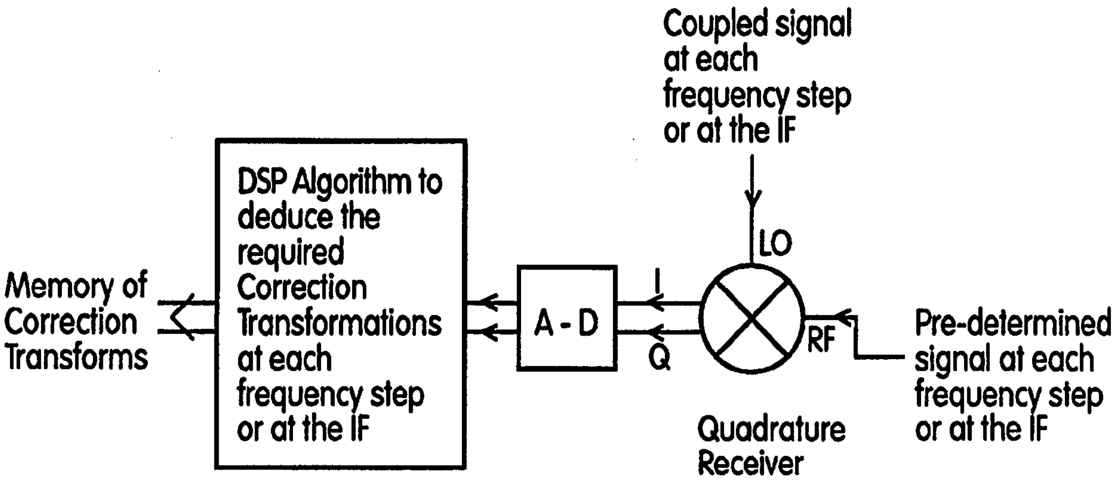
(54) Title: A SYSTEM FOR CORRECTING RECEIVER ERRORS IN RADAR



(57) Abstract

The system involves applying a predetermined signal to a radar receiver at each frequency of stepped frequencies employed or at the intermediate frequency and obtaining digitised quadrature signals. An estimate of a correction transform is obtained from the quadrature signals and stored. The predetermined signal is disconnected and the transform employed to correct for quadrature phase error and quadrature gain error in the received signals at each frequency step or at the intermediate frequency during reception of signals by the receiver.

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TITLE

"A SYSTEM FOR CORRECTING RECEIVER ERRORS IN RADAR"

FIELD OF THE INVENTION

THE INVENTION relates to a system for correcting receiver errors in radar. In particular, the invention concerns correcting receiver errors in step frequency radar.

BACKGROUND OF THE INVENTION

A step frequency radar signal can be used to synthesise a narrow time domain pulse. Receiver errors occur because the quadrature (I, Q) receiver is imperfect in its operation. The errors introduced by the quadrature receiver include phase errors and gain errors in the quadrature signals obtained from the receiver. In addition to this, offset errors and common gain errors are also present.

Correct operation of the receiver requires the reference signals to the quadrature receiver to be exactly 90° out of phase. As well, the quadrature channel gains must be equivalent. If these conditions are not met, spurious range signals are generated in the range signal synthesis process.

In a homodyne system, offset errors may be corrected employing the method suggested by Noon et al in the paper entitled "An Inexpensive Microwave Distance Measuring System" 1993 Microwave and Optical Technology Letters, 6, pages 287 to 292. Correction of offset errors is also required for superheterodyne and heterodyne systems but only at the intermediate frequency (IF).

It is an object of the present invention to provide a system which at least minimises the difficulties referred to above.

DISCLOSURE OF THE INVENTION

According to one aspect, the present invention provides a system for correcting receiver errors in a radar, the system including applying a predetermined signal to a radar receiver at each frequency of stepped frequencies employed or at an intermediate frequency, sampling quadrature signals obtained from the receiver at each frequency step or at the intermediate frequency, forming an estimate of a correction transform for the quadrature signals and storing the transform and then disconnecting the predetermined signal and employing the transform to correct for quadrature phase error and quadrature gain error in received signals at each frequency step or at the intermediate frequency during reception of signals by the receiver.

The quadrature signals are received from I, Q channels made available by the receiver. The signals provided by the I, Q channels may be digitised employing an analogue to digital converter. To secure the correction transform at each of the stepped frequencies employed in the radar system, the stepped frequency signals are progressively coupled to the receiver and mixed with the predetermined signal referred to above. For superheterodyne and heterodyne systems, the intermediate frequency is coupled to the receiver and mixed with the predetermined signal referred to above. System gain errors may be corrected after correction of quadrature phase gain and offset errors in the receiver. Offset error correction may be carried out employing the method disclosed in the Noon et al publication. The predetermined signal employed to secure an estimate of the correction transform may consist of narrow band Gaussian noise and this Gaussian noise signal may be applied to the receiver and mixed with the stepped frequency input coupled to the receiver or with the IF.

It is preferred that the amplitude of the Gaussian noise signal be selected to substantially fill the dynamic range of the A-D converter employed to digitise the signals secured from the I,Q channels. A sufficient number of samples of the noise should be taken at each frequency step or at the IF in order to ensure that an effective estimate of the covariance matrix can be obtained from which the correction transform is secured. This allows optimum transformation to be determined for converting sampled data into uncorrelated data of equal variance. It is preferred that the variance be constrained to be the same at each frequency of the frequency steps or at each intermediate frequency. After the correction transform has been secured, then during actual operation of the radar, the transform may be applied to the I, Q signals at each step frequency signal or at each IF to decorrelate the quadrature channls.

As an alternative to employing a narrow band Gaussian noise signal as the predetermined signal, a sinusoidal signal may be used. Where a sinusoidal signal is employed, the amplitude of that signal should be selected to substantially fill the dynamic range of the A-D converter. It is also preferred that the frequency of the sinusoidal signal be tuned so that it has a slight frequency offset from the transmitted radar frequency at each frequency step or from the IF. The offset should be such that it falls within the instantaneous band width of the receiver and is sufficiently offset from the centre frequency of the receiver to allow more than 2 π radians of rotation during a data sampling period. Where the predetermined signal is a sinusoidal signal, the system of the invention may employ the covariance matrix transform similar to that used where the predetermined signal is narrow band Gaussian noise. As an alternative to this, an ellipse may be fitted to the locii of points formed on a complex plane of the quadrature signals taken at each frequency step or at the IF. The minor and major axes of the ellipse may be determined and allow the correction transform to be determined for converting received data into a circle and hence correct phase and gain errors.

In an alternative to that described above, the predetermined signal employed in the system of the invention may comprise a modulated form of an output from the transmitter. Provided the form of the modulation is known, it is possible to determine the correction transform required to correct for phase and gain errors in the quadrature signals.

As mentioned above, in addition to correcting for quadrature phase and gain errors, the invention may also provide for correction of system gain errors. A correction factor may be secured and applied at each frequency step employed in the transmitter such that the magnitude of the complex signal at the receiver is constant across the transmitter band.

DISCLOSURE OF THE DRAWINGS

A particular preferred embodiment of the invention will now be described by way of example with reference to the drawings in which:

Figure 1 shows a block diagram form of part of a quadrature radar system and how a quadrature phase and gain correction transform may be secured;

Figure 2 shows a block diagram of the way in which the correction transform secured in the system of Figure 1 is used in part of a quadrature radar receiver;

Figure 3 is a block diagram showing a preferred system securing an offset correction transform;

Figure 4 is a block diagram showing a system employing the transform secured in Figure 3 and using it to correct offset errors;

Figure 5 is a block diagram showing a preferred system for securing a system gain correction transform;

Figure 6 is a block diagram of a system employing the transform of Figure 5 in system gain correction;

Figure 7 is a detailed block diagram of a system as shown in Figure 1;

Figure 8 is a detailed block diagram of what is shown in Figure 2; and

Figure 9 is a diagram of a radar receiver showing offset correction, quadrature gain and phase correction and system gain correction in diagrammatic form.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 shows a quadrature receiver which mixes a coupled signal from the transmitter with a received signal at each frequency stop or at the IF to enable the quadrature signals I, Q to be secured for each frequency step employed in the transmitter. The I, Q signals are digitised in an A-D converter and processed in a digital signal processor (DSP) which applies a correction transform at each frequency step or at the IF to the digitised receiver signals to correct for quadrature gain and phase errors. The transform required is stored in a memory and applied to the digital signal processor such that corrected digitised I, Q signals are secured from the digital signal processor at each frequency step or at the IF.

Figure 2 is useful in explaining the manner in which an estimate of the correction transform may be secured and stored in memory. As shown in this Figure, the received signal is disconnected from the receiver and in its place, the predetermined signal previously mentioned is applied to the receiver and mixed with the coupled signal at each frequency step or at the IF. The predetermined signal, as discussed, may consist of narrow band Gaussian noise, a sinusoidal signal, an attenuated and modulated form of the transmitter output or any other suitable signal. The quadrature signals I, Q secured from the receiver are digitised in an analog to digital (A-D) converter and applied to a digital signal processor (DSP). Since the characteristics of the predetermined signal are known, the digital signal processor is able to determine an estimate of a correction transform required to correct for phase and gain errors introduced by the quadrature receiver at each of the frequencies or at the IF. The correction transform is stored in memory and employed as discussed above in relation to Figure 1 to correct for phase and gain errors during actual reception of the signals during use of the radar system.

Figure 3 of the drawings shows a block diagram of a preferred radar system and illustrates the way in which an offset correction transform may be secured. The RF input to the quadrature receiver is terminated with a matched terminator. The coupled signal is applied to the mixer and the resultant I, Q quadrature signals are applied to the input of an analog to digital converter. The digitised I, Q signals are then processed for each frequency or at the IF to provide an offset correction transform in memory which may be used during operation of the radar system as shown in Figure 4 to provide for offset correction in an operational system. In Figure 4, the received signal and the coupling signal are mixed in the quadrature receiver to provide I, Q signals at each frequency step or at the IF. These I, Q signals are digitised in the A-D converter and the digitised signal applied to a digital signal processor in which those signals are modified in line with the transform stored in memory to provide resultant I, Q signals at each of the frequency steps or at the IF which have been corrected for offset error.

Figure 5 of the drawings shows a block diagram of one way in which system gain error may be corrected. System gain correction or pre-whitening correction may be achieved by directly mixing the output of the transmitter for each of the frequency steps with the coupled signal at each frequency step or at the IF to provide I, Q signals for application to the analog-to-digital converter. The digitised I, Q signals so produced are applied to the digital signal processor and a correction transform stored in memory. In Figure 6, that correction transform can then be applied to the digitised I, Q signals secured during actual use of the radar system to produce at the output of the digital signal processor, I, Q signals which have been corrected for system gain errors.

Figure 7 of the drawings is a more detailed block diagram form of what is shown in Figure 1. The signal from the wideband Gaussian noise generator is mixed with the coupled signal at each frequency step or at the IF in the quadrature receiver. The resultant I, Q signals are then passed through a low pass filter. The nett effect of this is the same as if a narrow band Gaussian noise signal was mixed with the coupled signal and the resultant I, Q signals were not low pass filtered. The narrow band signals secured from the low pass filter are digitised in the analog to digital converter and samples of the I, Q signals are taken at each frequency step and a covariance matrix is secured at each frequency step or at the IF. The matrix at each frequency step or at the IF is then processed to determine transforms which will decorrelate the I, Q signals and a scaling transform is produced to equalise the I, Q channel gains. A memory is then employed to store each of the transforms for each frequency step or at the IF.

Figure 8 of the drawings is a more detailed block diagram form of what is shown in Figure 2 and shows the manner in which the stored correction transform may be employed to correct I, Q signals for phase and gain errors. This is achieved by mixing the received signal with the coupled signal at each frequency step or at the IF in the receiver, low pass filtering the I, Q signals and then digitising those signals in an analog to digital converter. Samples are taken of the I, Q signals for each frequency step employed in the transmitter and then the correction transform is applied at each step to correct the quadrature gain and phase errors to provide corrected I, Q signals.

Figure 9 shows a simplified block diagram form which illustrates the manner in which I, Q signals received from the quadrature receiver may be corrected for offset gain, quadrature gain and phase errors and system gain errors to provide I, Q signals corrected for all of these errors.

CLAIMS:

1. A system for correcting receiver errors in a radar, the system including applying a predetermined signal to a radar receiver at each frequency of stepped frequencies employed or at an intermediate frequency, sampling quadrature signals obtained from the receiver at each frequency step or at the intermediate frequency, forming an estimate of a correction transform for the quadrature signals and storing the transform and then disconnecting the predetermined signal and employing the transform to correct for quadrature phase error and quadrature gain error in received signals at each frequency step or at the intermediate frequency during reception of signals by the receiver.

2. The system of Claim 1 wherein the quadrature signals are sampled employing an analogue to digital converter.

3. The system of Claim 1 or 2 wherein the correction transform is secured by progressively coupling the stepped frequency signals to the receiver and mixing the stepped frequency signals with the predetermined signal.

4. The system of Claim 1 or 2 wherein the correction transform is secured by coupling the intermediate frequency to the receiver and mixing the intermediate frequency with the predetermined signal.

5. The system of any one of Claims 1 to 4 wherein the predetermined signal is a Gaussian noise signal.

6. The system of any one of Claims 1 to 4 wherein the predetermined signal is a sinusoidal signal.

7. The system of Claim 5 wherein a predetermined number of samples of the noise signal is taken at each of the stepped frequencies or at the intermediate frequency to ensure that an effective estimate of a covariance matrix is obtained from which the correction transform is secured for allowing the transform to be determined for converting sampled data into uncorrelated data of equal variance.

8. The system of Claim 7 wherein the variance of is constrained to be the same at each of the stepped frequencies or at each intermediate frequency.

9. The system of Claim 6 wherein the frequency of the sinusoidal signal is tuned so that it has a slight frequency offset from the transmitted radar frequency at each frequency step or from the intermediate frequency.

10. The system of Claim 5 or 6 employing an ellipse fitted to locii of points formed on a complex plane of the quadrature signals taken at each frequency step or at the intermediate frequency and determining the major and minor axes of the ellipse and the correction transform for converting received data into a circle and hence correct for phase and gain errors.

11. The system of Claim 7 or 10 wherein the output from a transmitter of the system is modulated and input into the receiver to determine the correction transform.

12. The system of Claim 1 including correcting for system gain errors by determining a correction factor and applying that factor at each frequency step employed in a transmitter of the system so that the magnitude of the complex signal at the receiver is constant across the transmitter band.

AMENDED CLAIMS
[received by the International Bureau on 15 August 1995 (15.08.95); original claims 1-12 replaced by amended claims 1-9 (2 pages)]

1. A system for correcting receiver errors in a radar, the system including applying a Gaussian noise signal to a radar receiver at each frequency of stepped frequencies employed or at an intermediate frequency, sampling quadrature signals obtained from the receiver at each frequency step or at the intermediate frequency, forming an estimate of a correction transform for the quadrature signals and storing the transform and then disconnecting the Gaussian noise signal and employing the transform to correct for quadrature phase error and quadrature gain error in received signals at each frequency step or at the intermediate frequency during reception of signals by the receiver.

2. The system of Claim 1 wherein the quadrature signals are sampled employing an analogue to digital converter.

3. The system of Claim 1 or 2 wherein the correction transform is secured by progressively coupling the stepped frequency signals to the receiver and mixing the stepped frequency signals with the Gaussian noise signal.

4. The system of Claim 1 or 2 wherein the correction transform is secured by coupling the intermediate frequency to the receiver and mixing the intermediate frequency with the Gaussian noise signal.

5. The system of Claim 1 wherein a predetermined number of samples of the noise signal is taken at each of the stepped frequencies or at the intermediate frequency to ensure that an effective estimate of a covariance matrix is obtained from which the correction transform is secured for allowing the transform to be determined for converting sampled data into uncorrelated data of equal variance.

6. The system of Claim 5 wherein the variance of is constrained to be the same at each of the stepped frequencies or at each intermediate frequency.

7. The system of Claim 5 employing an ellipse

fitted to locii of points formed on a complex plane of the quadrature signals taken at each frequency step or at the intermediate frequency and determining the major and minor axes of the ellipse and the correction transform for converting received data into a circle and hence correct for phase and gain errors.

8. The system of Claim 5 or 7 wherein the output from a transmitter of the system is modulated and input into the receiver to determine the correction transform.

9. The system of Claim 1 including correcting for system gain errors by determining a correction factor and applying that factor at each frequency step employed in a transmitter of the system so that the magnitude of the complex signal at the receiver is constant across the transmitter band.

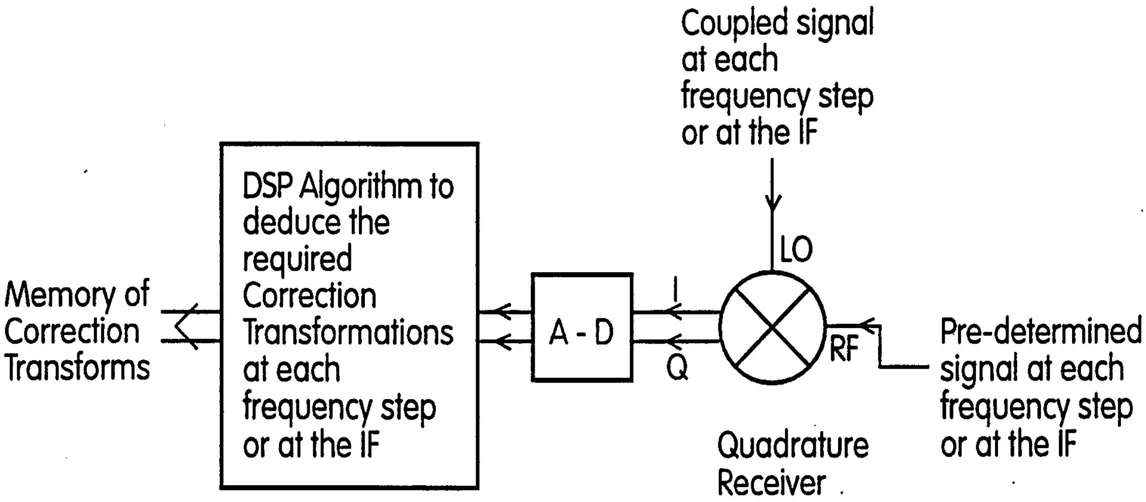
Coupled signal at each frequency step or at the IF
LO
DSP Algorithm to deduce the required Correction Transformations at each frequency step or at the IF
Memory of Correction Transforms
A - D
I
Q
RF
Pre-determined signal at each frequency step or at the IF
Quadrature Receiver

FIG.1

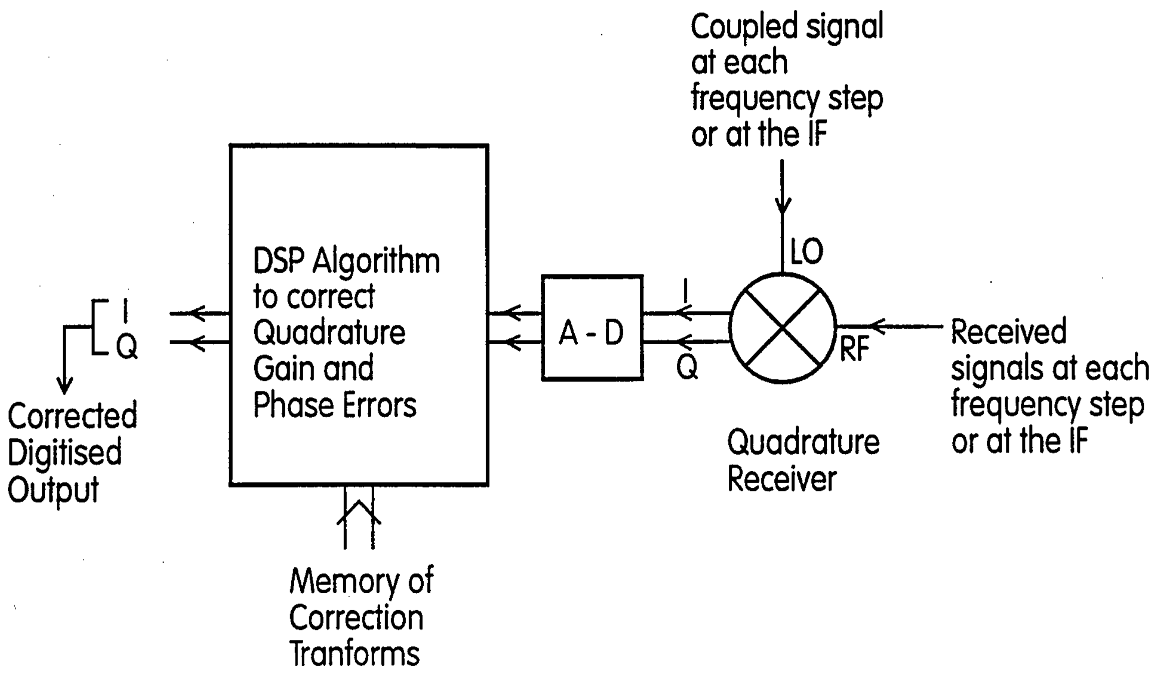
Coupled signal at each frequency step or at the IF
LO
DSP Algorithm to correct Quadrature Gain and Phase Errors
I
Q
Corrected Digitised Output
A - D
RF
Received signals at each frequency step or at the IF
Quadrature Receiver
Memory of Correction Tranforms

FIG.2

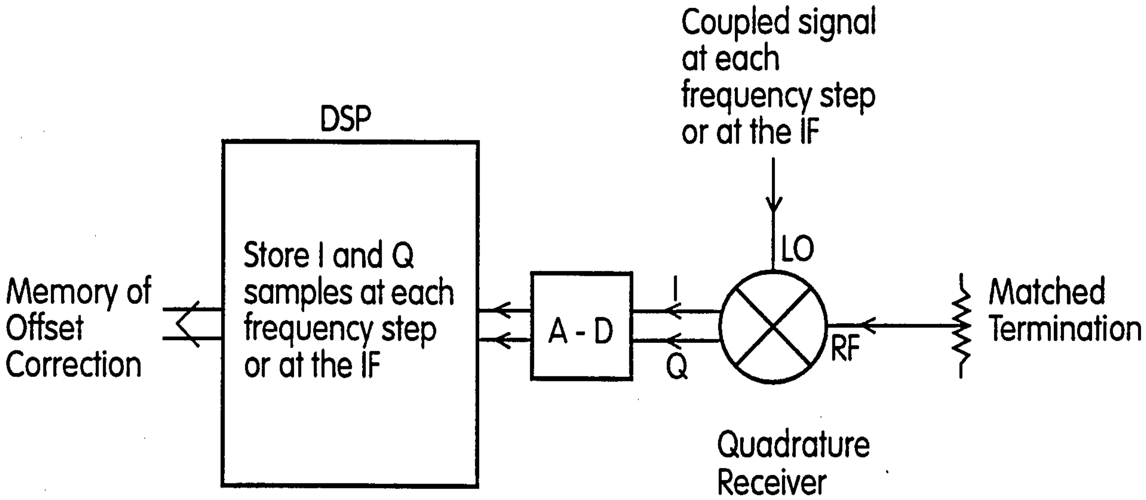
Coupled signal
at each
frequency step
or at the IF
DSP
LO
Store I and Q
samples at each
frequency step
or at the IF
Memory of
Offset
Correction
A - D
I
Q
RF
Matched
Termination
Quadrature
Receiver

FIG.3

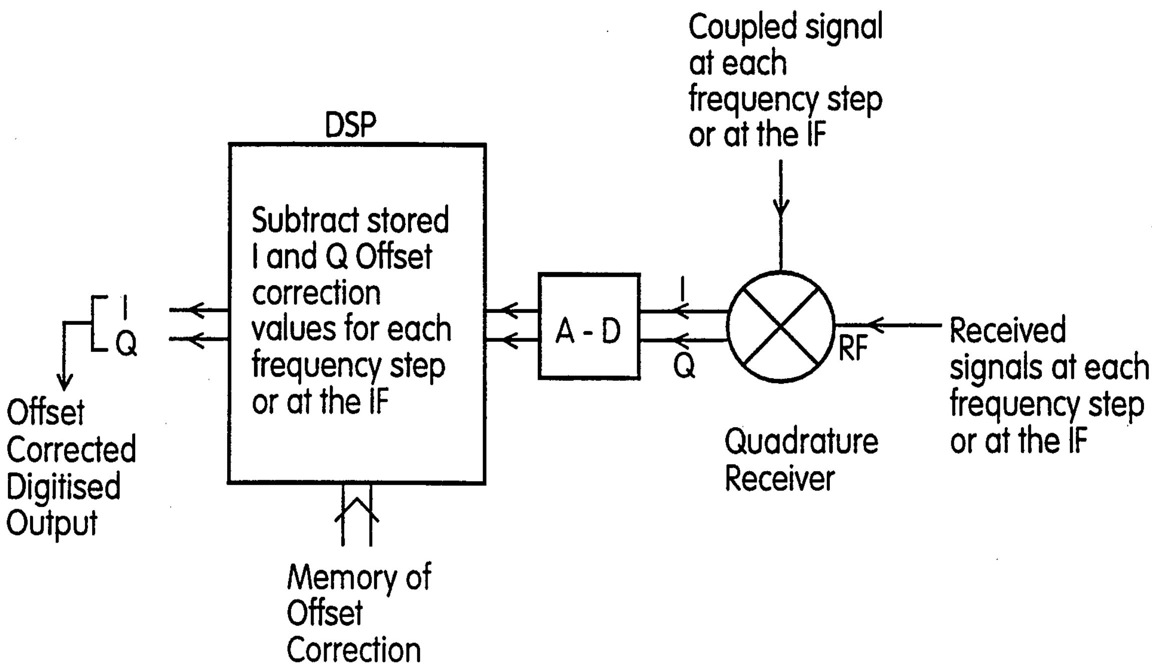
Coupled signal
at each
frequency step
or at the IF
DSP
Subtract stored
I and Q Offset
correction
values for each
frequency step
or at the IF
I
Q
Offset
Corrected
Digitised
Output
A - D
I
Q
RF
Received
signals at each
frequency step
or at the IF
Quadrature
Receiver
Memory of
Offset
Correction

FIG.4

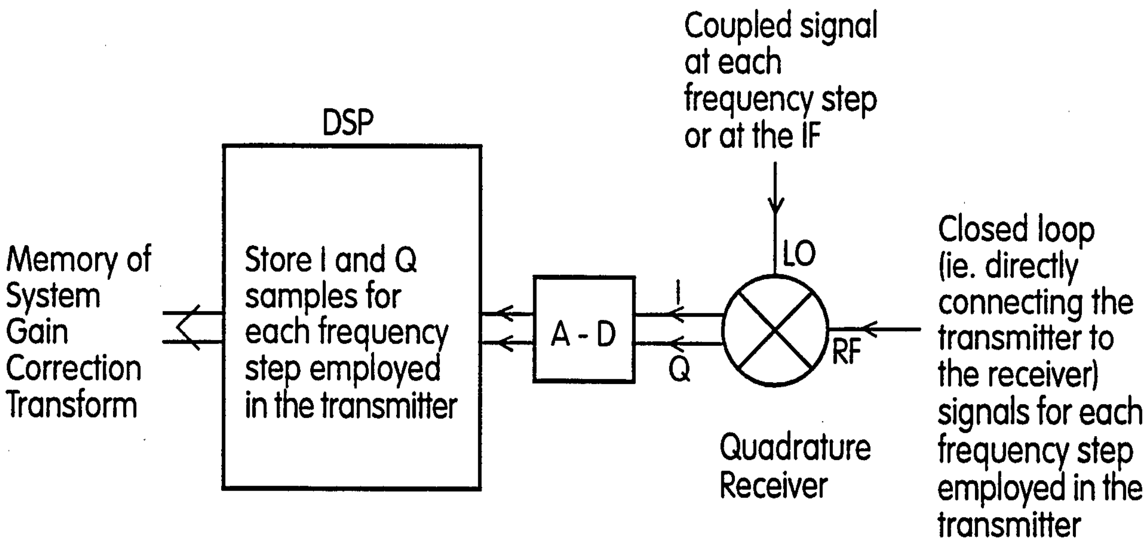
Coupled signal at each frequency step or at the IF
DSP
Memory of System Gain Correction Transform
Store I and Q samples for each frequency step employed in the transmitter
A - D
I
Q
LO
RF
Closed loop (ie. directly connecting the transmitter to the receiver) signals for each frequency step employed in the transmitter
Quadrature Receiver

FIG.5

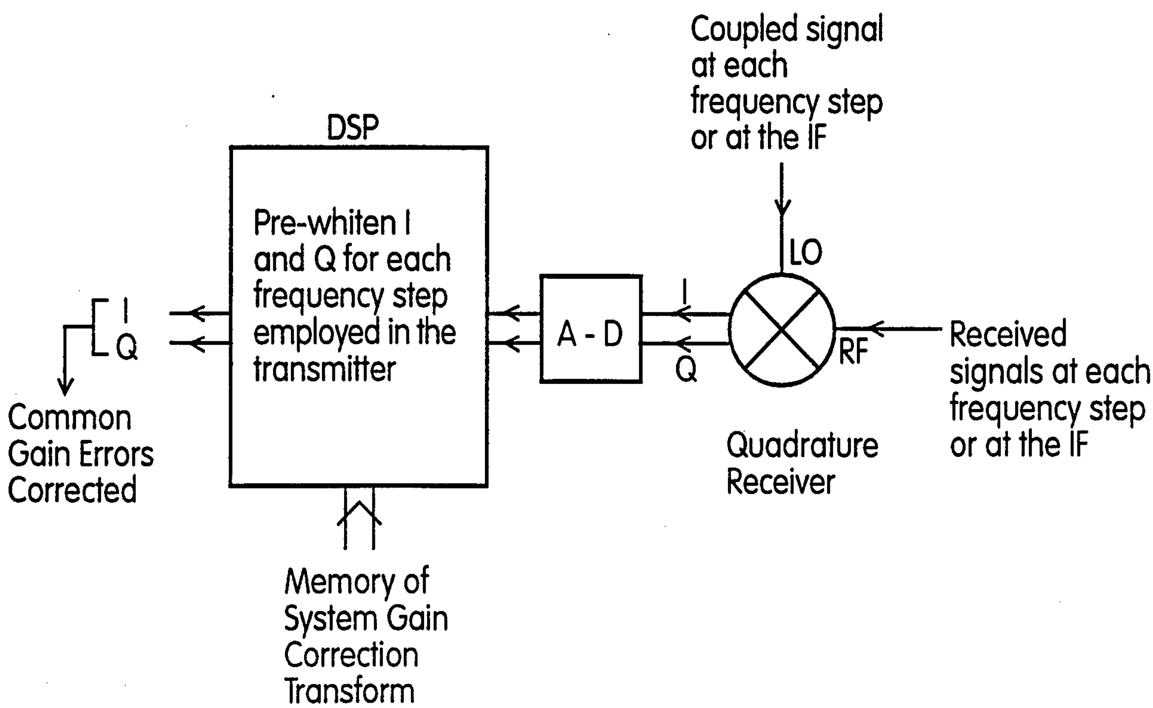
Coupled signal at each frequency step or at the IF
DSP
Pre-whiten I and Q for each frequency step employed in the transmitter
I
Q
Common Gain Errors Corrected
A - D
LO
RF
Received signals at each frequency step or at the IF
Quadrature Receiver
Memory of System Gain Correction Transform

FIG.6

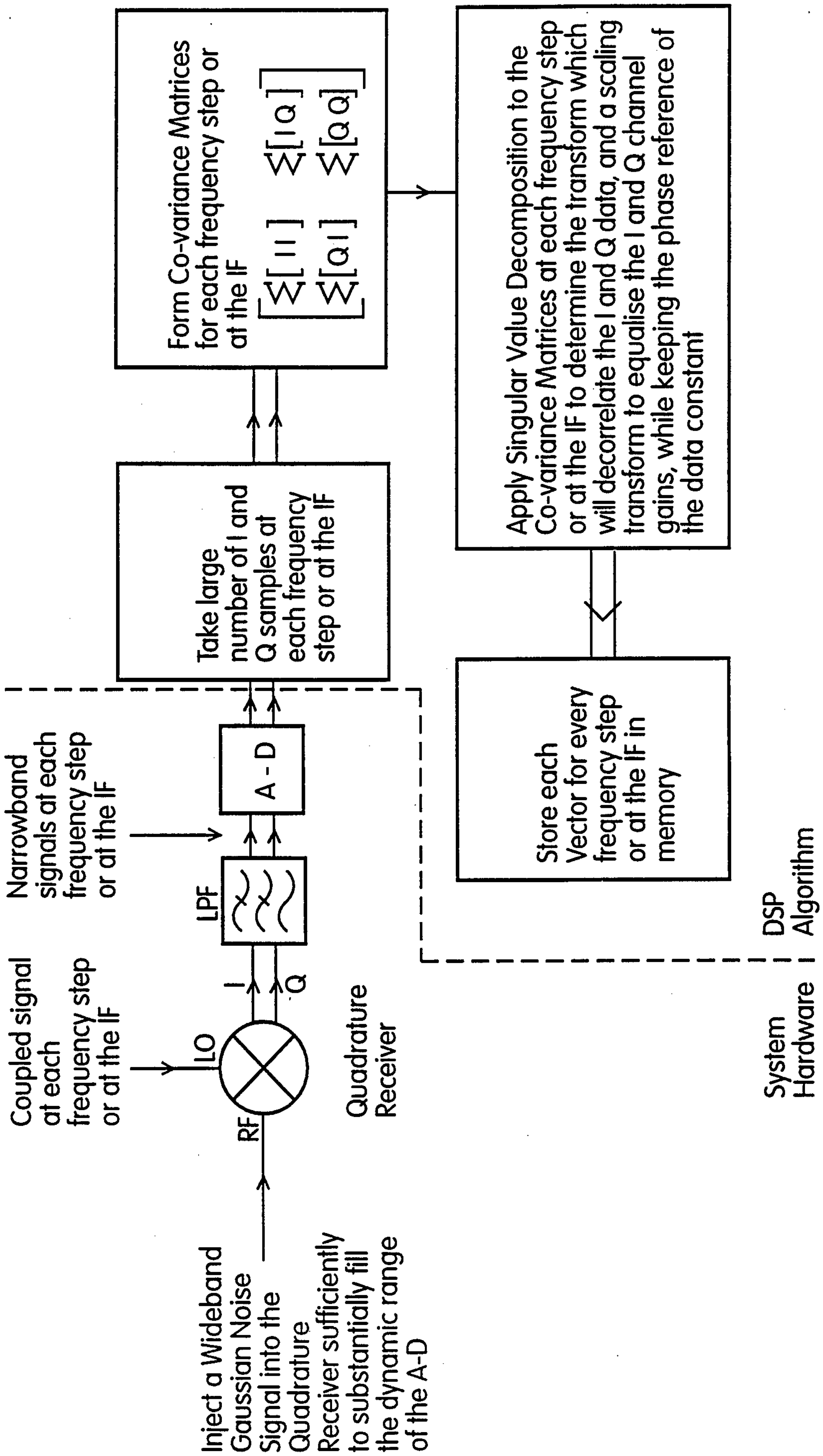
Inject a Wideband Gaussian Noise Signal into the Quadrature Receiver sufficiently to substantially fill the dynamic range of the A-D
RF
LO
Coupled signal at each frequency step or at the IF
Quadrature Receiver
I
Q
LPF
Narrowband signals at each frequency step or at the IF
A - D
Take large number of I and Q samples at each frequency step or at the IF
Form Co-variance Matrices for each frequency step or at the IF
Σ[I I] Σ[I Q]
Σ[Q I] Σ[Q Q]
Apply Singular Value Decomposition to the Co-variance Matrices at each frequency step or at the IF to determine the transform which will decorrelate the I and Q data, and a scaling transform to equalise the I and Q channel gains, while keeping the phase reference of the data constant
Store each Vector for every frequency step or at the IF in memory
System Hardware
DSP Algorithm

FIG.7

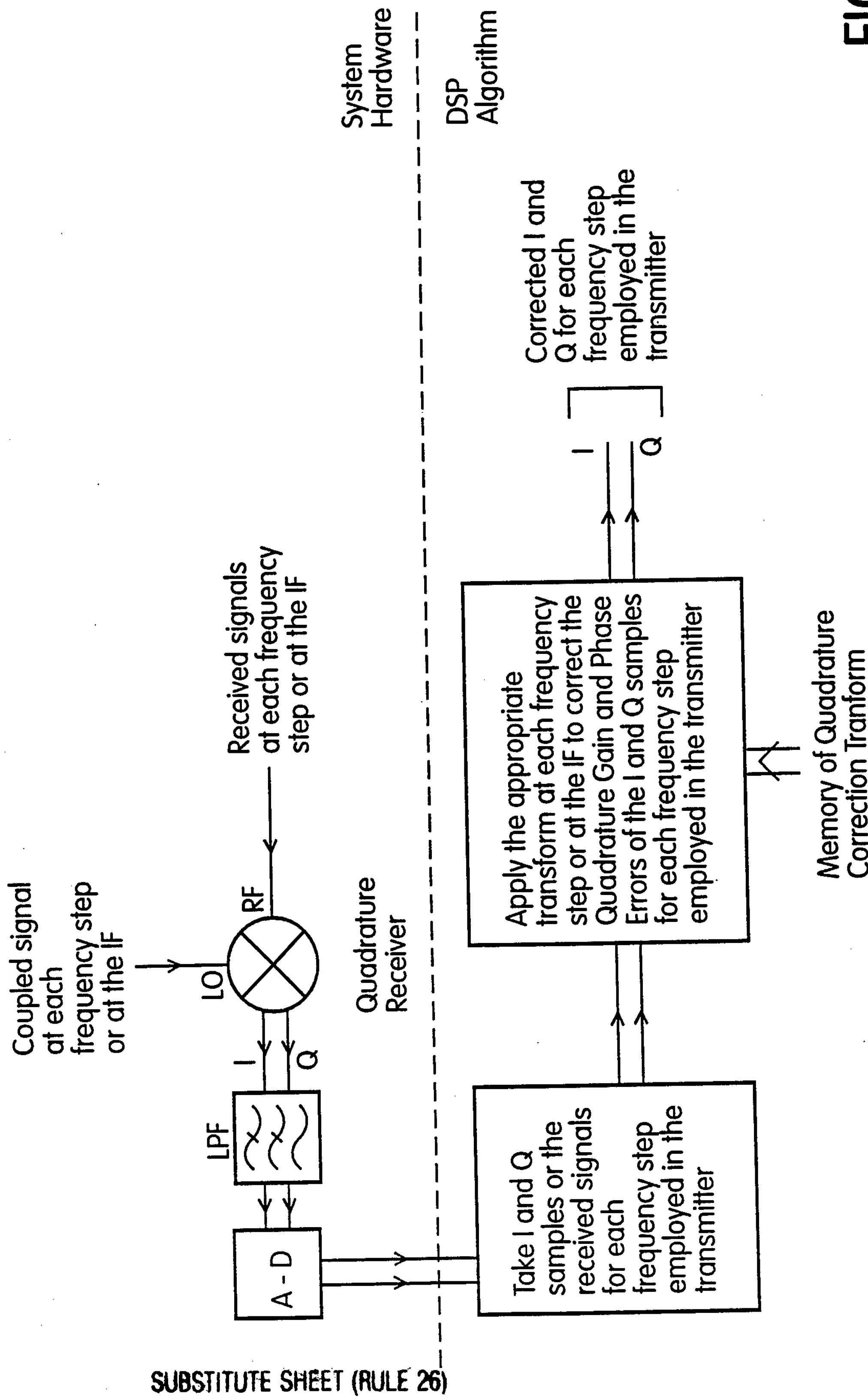
System Hardware
DSP Algorithm
Coupled signal at each frequency step or at the IF
LO
RF
Received signals at each frequency step or at the IF
I
Q
LPF
A - D
Quadrature Receiver
Take I and Q samples or the received signals for each frequency step employed in the transmitter
Apply the appropriate transform at each frequency step or at the IF to correct the Quadrature Gain and Phase Errors of the I and Q samples for each frequency step employed in the transmitter
Memory of Quadrature Correction Tranform
I
Q
Corrected I and Q for each frequency step employed in the transmitter

FIG.8

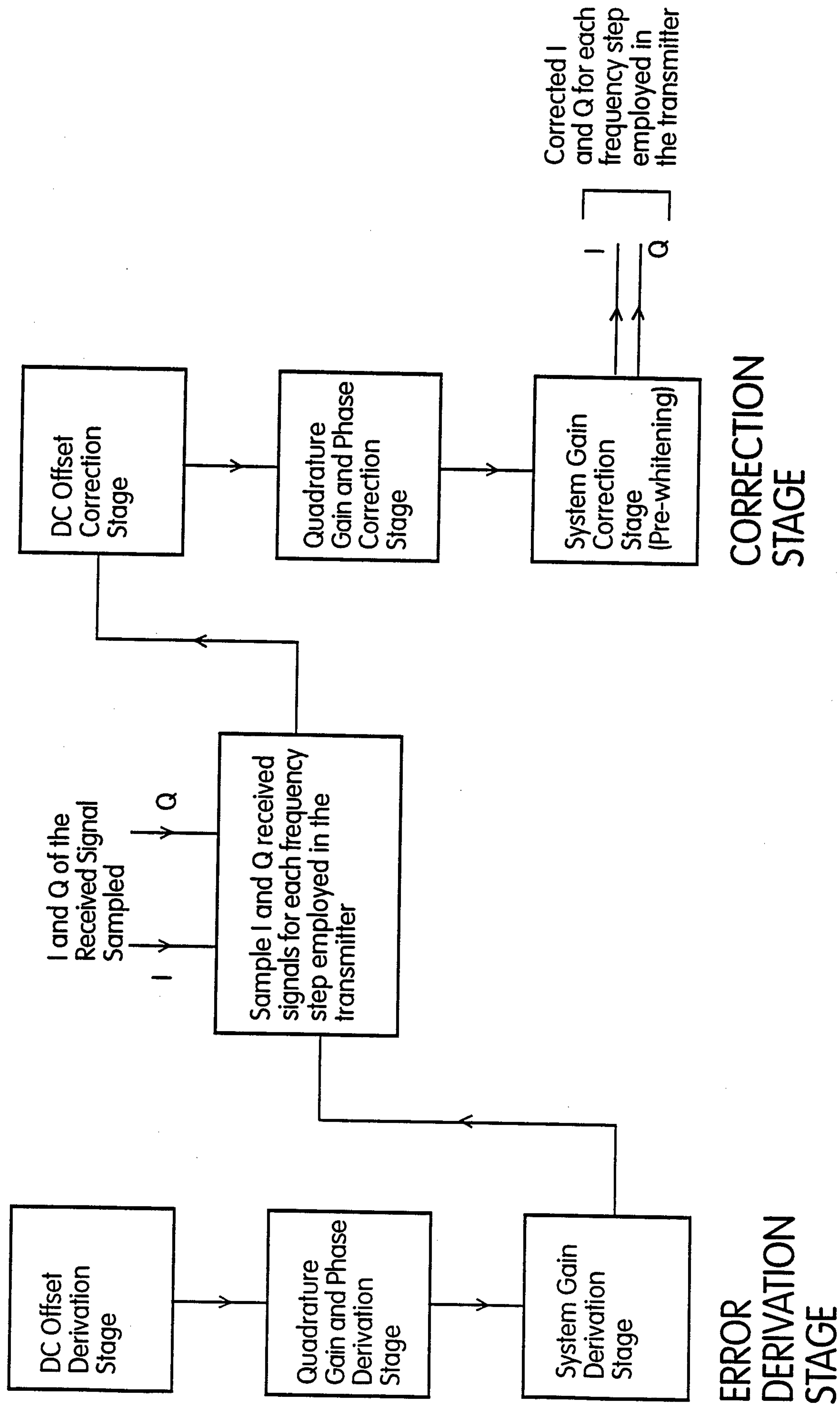
I and Q of the Received Signal Sampled
I
Q
Sample I and Q received signals for each frequency step employed in the transmitter
DC Offset Correction Stage
Quadrature Gain and Phase Correction Stage
System Gain Correction Stage (Pre-whitening)
I
Q
Corrected I and Q for each frequency step employed in the transmitter
CORRECTION STAGE
DC Offset Derivation Stage
Quadrature Gain and Phase Derivation Stage
System Gain Derivation Stage
ERROR DERIVATION STAGE

FIG.9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 95/00217

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl.6 G01S 7/40

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: G01S 7/40

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC AS ABOVE

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)
WPAT, JOPAL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	US 5063529 A (CHAPOTON) 5 November 1991 Abstract Column 1 lines 27/35 Column 2 lines 46/68 Column 3 lines 1/2 Column 4 lines 17/24	1-12

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 May 1995	19 JUNE 1995 (19.06.95)

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION PO BOX 200 WODEN ACT 2606 AUSTRALIA	R STOPFORD
Facsimile No. 06 2853929	Telephone No. (06) 2832177

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to claim No.
X	US 4994810 A (SINSKY) 19 February 1991 Abstract Column 2 lines 27/52 Column 3 lines 52/54, 61/68 Column 4 lines 15/34 Column 6 lines 42/63 Column 9 lines 29/63	1-12
X	US 4931800 A (WARD) 5 June 1990 Abstract Column 1 lines 28/55	1-12
X	US 4646093 A (POSTEMA et al) 24 February 1987 Column 1 lines 54/68 Column 2 lines 1/39 Column 4 lines 20/23 Column 5 lines 50/60 Column 7 lines 13/17 Column 8 lines 12/31 Column 10 lines 58/61	1-12
X	US 4616229 A (TAYLOR,Jr) 7 October 1986 Abstract Column 4 lines 8/37, 56/62 Column 6 lines 51/68 Column 7 lines 1/3, 57/68	1-12
X	US 4003054 A (GOLDSTONE) 11 January 1977 Column 1 lines 30/60, 67/68 Column 2 lines 1/45 Column 3 lines 24/31 Column 4 lines 29/36, 48/54 Column 6 lines 38/46	1-12
X	US 3950750 A (CHURCHILL et al) 13 April 1976 Abstract Column 1 lines 9/13 Column 2 lines 11/21 Claim 1	1-12
X	EP 110260A1 (HOLLANDSE SIGNAALAPPARATEN B.V.) 13 June 1984 Abstract Page 1 lines 2/15, 29/36 Page 2 lines 17/25 Page 4 lines 24/36 Page 5 lines 1/22	1-12
X	IEEE, Transactions on Aerospace and Electronic Systems, Vol AES-17, No 1, January 1981.FE Churchill et al, "THE CORRECTION OF I AND Q ERRORS IN A COHERENT PROCESSOR" Pages 131-137 Abstract Conclusion	1-12

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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