(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 July 2010 (22.07.2010)

PCT

(10) International Publication Number
WO 2010/083177 A1

(51) International Patent Classification:
H04L 27/20 (2006.01) *H03F 1/32* (2006.01)

(21) International Application Number:
PCT/US2010/020832

(22) International Filing Date:
13 January 2010 (13.01.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
12/353,318 14 January 2009 (14.01.2009) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) Title: TRANSMITTER WITH REDUCED SPECTRAL REGROWTH AND ASSOCIATED METHODS

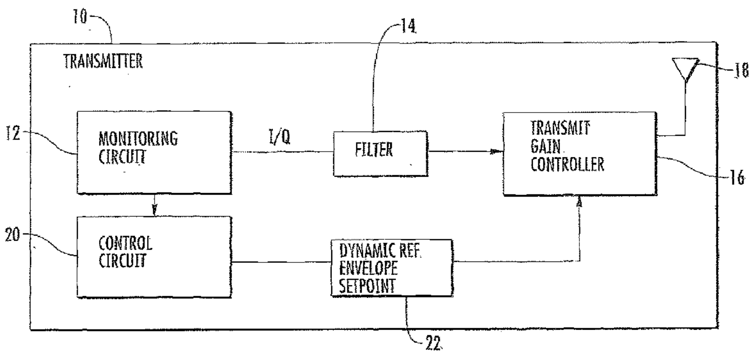

FIG. 1

(57) Abstract: A transmitter includes a monitoring circuit for monitoring phase transitions of in-phase and quadrature components of an input phase modulated signal. A filter is downstream from the monitoring circuit for generating a filtered phase modulated signal within an allocated bandwidth. A transmit gain controller is downstream from the filter for adjusting an amplitude of the filtered phase modulated signal based on a dynamic reference envelope control signal. A control circuit cooperates with the monitoring circuit and the transmit gain controller for generating the dynamic reference envelope control signal so that phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within the allocated bandwidth.

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TRANSMITTER WITH REDUCED SPECTRAL REGROWTH AND ASSOCIATED METHODS

The present invention relates to the field of communications devices, and more particularly, to a transmitter transmitting an output signal within an allocated channel and associated methods.

Transmitters are typically designed to transmit output signal within allocated channels. A transmitted output signal extending beyond its allocated channel may cause interference with an adjacent channel. This is known as adjacent channel emission.

For a phase modulated (PM) transmitter, for example, rapid phase transitions of a phase modulated waveform can create a wide bandwidth signal that is then forced through low-pass analog filters to provide rejection of the sampling artifacts. The low-pass filter bandwidth is much narrower than the bandwidth of the original signal. This may result in a substantial amplitude component on the filtered phase modulated signal.

The filtered phase modulated signal is then typically applied to a transmit gain controller. The transmit gain controller operates based on a transmit gain control (TGC) loop that applies a fixed DC value as a reference envelope control signal to reduce envelope variations in the filtered phase modulated signal. However, the TGC loop has a wider bandwidth than the filter bandwidth allowing the high frequency components to be re-introduced. This leads to high frequency components being introduced while “flattening” the envelope of the filtered phase modulated signal during phase transitions.

The remaining amplitude components and introduction of high frequency components result in extra energy in the adjacent channels, i.e., adjacent channel emission. In other words, the TGC loop is creating spectral regrowth by introducing the high frequency components while attempting to “flatten” the output transmit signal during phase transitions.

One approach for reducing spectral regrowth is to modify the transmitter by adding a filter to the output of the TGC loop. While effective in terms of performance, this approach may not be cost effective for existing transmitters already fielded since hardware modifications are needed.

Yet another approach for reducing spectral regrowth is disclosed in U.S. Patent Application No. 2004/0017859. A transmitter includes a pre-distorter to improve linearity of a power amplifier providing an amplified transmission signal. The amplified transmission signal is conditioned into a narrowband feedback signal that is responsive to a logarithm of the power appearing in the out-of-band components of the amplified transmission signal. The feedback signal is processed in a pre-distortion processor that implements an algorithm to adapt pre-distortion functions implemented in the pre-distorter, which is to improve linearity over time. The algorithm tests a population of randomly-generated pre-distortion functions. A baseline component of the coefficients from pre-distortion functions used in a subsequent population tracks the best-fit pre-distortion function from the current population. New populations are generated from old populations. While this approach is effective in terms of performance, it also is not cost effective for existing transmitters already fielded since hardware modifications are needed.

In view of the foregoing background, it is therefore an object of the present invention to provide a cost effective approach for reducing spectral regrowth in a transmitter.

This and other objects, features, and advantages in accordance with the present invention are provided by a transmitter comprising a monitoring circuit for monitoring phase transitions in in-phase and quadrature components of an input phase modulated signal, a filter downstream from the monitoring circuit for generating a filtered phase modulated signal within an allocated bandwidth, and a transmit gain controller downstream from the filter for adjusting an amplitude of the filtered phase modulated signal based on a dynamic reference envelope control signal. A control circuit may cooperate with the monitoring circuit and the transmit gain controller for generating the dynamic reference envelope control signal so that phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within the allocated bandwidth.

The transmit gain controller is advantageously used to adjust the amplitude of the filtered phase modulated signal based on the dynamic reference envelope control signal. Instead of a fixed value reference envelope control signal, as is typical in the prior art, the dynamic reference envelope control signal may vary between a nominal value and a suppressed value. The suppressed value may be applied to the phase transitions of the filtered phase modulated signal to reduce spectral regrowth.

By reducing spectral regrowth, this advantageously allows the filtered phase modulated signal that is to be transmitted to remain within an allocated bandwidth, which helps to avoid interference with an adjacent channel. In addition, since the dynamic reference envelope control signal may be changed via software, a cost effective approach is provided since hardware modifications to existing transmitters may be avoided.

The transmit gain controller may adjust the amplitude of the filtered phase modulated signal to correspond with an amplitude of the dynamic reference envelope control signal. The transmit gain controller may adjust the amplitude of the dynamic reference envelope control signal to vary between the nominal value and the suppressed value, with the suppressed value corresponding to the phase transitions of the filtered phase modulated signal.

The control circuit may adjust the dynamic reference envelope control signal according to a profile based on a modulation type and data rate of the filtered phase modulated signal. The profile of the dynamic reference envelope control signal may comprise at least one of nominal and suppressed amplitude values, a duration of the suppressed amplitude value, and a delay corresponding to application of the suppressed amplitude value by the transmit gain controller after detection of a phase transition by the monitoring circuit. The profile may be programmable.

The transmitter may comprise a digital signal processor (DSP) for generating the input phase modulated signal having the in-phase and quadrature components. The monitoring circuit and the control circuit may be configured as part of a field programmable gate array (FPGA).

Another aspect is directed to a method for suppressing a filtered phase modulated signal to be transmitted. The method may comprise monitoring phase transitions of in-phase and quadrature components of an input phase modulated signal with a monitoring circuit, and generating a filtered phase modulated signal within an allocated bandwidth with a filter downstream from the monitoring circuit. An amplitude of the filtered phase modulated signal may be adjusted based on a dynamic reference envelope control signal with a transmit gain controller downstream from the filter. The method may further comprise generating the dynamic reference envelope control signal using a control circuit cooperating with the monitoring circuit and the transmit gain controller so that the phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within the allocated bandwidth.

FIG. 1 is a block diagram of a transmitter including a transmit gain controller operating with a dynamic reference envelope control signal in accordance with the present invention.

FIG. 2 is a more detailed block diagram of the transmitter illustrated in FIG. 1.

FIG. 3 is a time domain plot of a filtered phase modulated signal prior to application of the dynamic reference envelope control signal in accordance with the present invention.

FIG. 4 is a time domain plot of a reference envelope control signal and a transmit output signal after application of the reference envelope control signal to a filtered phase modulated signal in accordance with the prior art.

FIG. 5 is a time domain plot of a dynamic reference envelope control signal and a transmit output signal after application of the dynamic reference envelope control signal to a filtered phase modulated signal in accordance with the present invention.

FIG. 6 is a flow chart illustrating a method for suppressing a filtered phase modulated signal in accordance with the present invention.

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout.

Referring initially to FIG. 1, a transmitter **10** comprises a monitoring circuit **12** for monitoring phase transitions of in-phase (I) and quadrature (Q) components of an input phase modulated signal, and a filter **14** is downstream from the monitoring circuit **12** for generating a filtered phase modulated signal within an allocated bandwidth. A transmit gain controller **16** is downstream from the filter for adjusting an amplitude of the filtered phase modulated signal based on a dynamic reference envelope control signal prior to transmission via antenna **18**.

A control circuit **20** cooperates with the monitoring circuit **12** and the transmit gain controller **16** for generating the dynamic reference envelope control signal so that phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within the allocated bandwidth. The transmit gain controller **16** manages the amplitude of the transmit signal in an effort to achieve a constant envelope by integrating against a dynamic reference envelope setpoint **22** as provided by the control circuit **20**.

As will be explained in greater detail below, the transmit gain controller **16** is advantageously used to adjust the amplitude of the filtered phase modulated signal based on the dynamic reference envelope control signal. Instead of a fixed value reference envelope control signal, the dynamic reference envelope control signal is adjusted by the control circuit **20** so that it varies between a nominal value and a suppressed value. The suppressed value is to be applied to the phase transitions of the filtered phase modulated signal to reduce spectral regrowth.

The input phase modulated signals having the in-phase and quadrature components may be provided by a digital signal processor (DSP) **30**, as illustrated in

FIG. 2. Still referring to FIG. 2, the monitoring circuit **12** and the control circuit **20** may be configured as part of a field programmable gate array (FPGA). The in-phase and quadrature components generated by the monitoring circuit **12** are serially provided to a pair of digital-to-analog converters (DAC) **34**. The analog in-phase and quadrature components from the digital-to-analog converters **34** are then passed through respective analog low-pass filters **14** to remove sampling artifacts.

The transmit gain controller **16** mixes the filtered analog in-phase and quadrature components, i.e., the filtered phase modulated signal, to generate the output transmit signal. In doing so, the transmit gain controller **16** adjusts the amplitude of the filtered phase modulated signal to correspond with an amplitude of the dynamic reference envelope control signal.

The control circuit **20** may adjust the dynamic reference envelope control signal according to a profile based on a modulation type and data rate of the filtered phase modulated signal. The profile is initially stored in the DSP **30**, and is loaded into the control circuit **20** during each transmit session.

More particularly, the profile of the dynamic reference envelope control signal includes the following: nominal and suppressed amplitude values, a duration of the suppressed amplitude value, and a delay corresponding to application of the suppressed amplitude value by the transmit gain controller **16** after detection of a phase transition by the monitoring circuit **12**.

Referring now to FIGS. 3-5, various time domain plots will be discussed to better illustrate the advantages of the transmit gain controller **16** applying a dynamic reference envelope control signal to a filtered phase modulated signal **40**. The filtered phase modulated signal **40** has not yet been driven to a constant amplitude by the transmit gain controller **16**. The phase transitions **42** in the filtered phase modulated signal **40** are where the spectral regrowth occurs when the transmit gain controller **16** applies a fixed reference envelope control signal **44** having a fixed DC value, as illustrated in FIG. 4.

Still referring to FIG. 4, after the transmit gain controller **16** applies the fixed reference envelope control signal **44** to the filtered phase modulated signal **40**, the resulting output transmit signal **46** includes spectral regrowth **48**. Since the low-pass filter bandwidth **14** is much narrower than the bandwidth of the signal prior to being filtered, there is a substantial amplitude component on the output transmit signal **46**. Spectral regrowth **48** in the form of high frequency components are introduced while "flattening" the output transmit signal **46** during phase transitions **42**. The remaining amplitude components and introduction of high frequency components result in extra energy in the adjacent channels.

For illustration purposes, the transmitter **10** operates in the UHF band, with 25 kHz channel spacings. However, the transmitter **10** is not limited to this band, and may operate at other frequency bands, as readily appreciated by those skilled in the art.

Referring now to FIG. 5, the transmit gain controller **16** operates with a dynamic reference envelope control signal **50**. The amplitude of the dynamic reference envelope control signal **50** varies between a nominal value **52** and a suppressed value **54**, with the suppressed value corresponding to the phase transitions **42** of the filtered phase modulated signal **40**. The resulting output transmit signal is indicated by reference **56**. The suppressed value **54** of the dynamic reference control envelope **50** reduces spectral regrowth that would typically be added by the transmit gain controller **16** when using a fixed value reference envelope control signal **44**. In the phase transitions **58** of the output transmit signal **56**, the transmit gain controller **16** advantageously reduces unwanted spectral content rather than stabilize power during the phase transitions.

As noted above, the control circuit **20** adjusts the dynamic reference envelope control signal **50** according to a profile based on a modulation type and data rate of the filtered phase modulated signal **40**. The modulation type may be binary phase shift keying (BPSK) or differential phase shift keying (DPSK), for example. Other modulation types may be used as long as the phase modulated signal has a constant envelope, as readily appreciated by those skilled in the art. In addition, the modulation type may also be quadrature amplitude modulation (QAM), as readily appreciated by those skilled in the art. The profile of the dynamic reference envelope control signal **50** can be manually configured for each modulation type and data rate to achieve the best results.

The profile includes a nominal value corresponding to a desired transmit gain control reference value, and a suppressed value corresponding to a transmit gain control reference value applied during phase/symbol transitions. The profile includes a delay which corresponds to an offset between when a phase/symbol transition is detected and when the transmit gain control profile is to be applied. The delay takes into account the time it takes for the filtered phase modulated signal **40** to travel from the monitoring circuit **12** to the transmit gain controller **16**.

The profile can be manually adjusted to modify or balance performance based on specification requirements of the transmitter **10**. This also allows new phase modulated waveform types to be added to fielded radios without changing hardware while meeting strict adjacent channel emission requirements.

By reducing spectral regrowth in the output transmit signal **56**, this advantageously allows the filtered phase modulated signal **40** to remain within its allocated bandwidth, which helps to avoid or reduce interference with an adjacent channel. In addition, since the dynamic reference envelope control signal **50** is changed via software, a cost effective approach is provided since hardware modifications to existing transmitters are avoided.

Referring now to FIG. 6, a flow chart **80** illustrating a method for suppressing a filtered phase modulated signal **40** to be transmitted so that the filtered phase modulated signal remains within an allocated bandwidth will be discussed. From the start (Block **82**), the method comprises monitoring phase transitions of in-phase and quadrature components of an input phase modulated signal with a monitoring circuit **12** at Block **84**. A filtered phase modulated signal **40** is generated within an allocated bandwidth at Block **86** with a filter **14** downstream from the monitoring circuit **12**. An amplitude of the filtered phase modulated signal **40** is adjusted at Block **88** based on a dynamic reference envelope control signal **50** with a transmit gain controller **16** downstream from the filter **14**. The dynamic reference envelope control signal **50** is generated at Block **90** using a control circuit **20** cooperating with the monitoring circuit **12** and the transmit gain controller **16** so that the phase transitions are suppressed in the filtered phase modulated signal **40** and so that the filtered phase modulated signal **40** remains within the allocated bandwidth. The method ends at Block **92**.

CLAIMS

1. A transmitter comprising:

a monitoring circuit for monitoring phase transitions of in-phase and quadrature components of an input phase modulated signal;

a filter downstream from said monitoring circuit for generating a filtered phase modulated signal within an allocated bandwidth;

a transmit gain controller downstream from said filter for adjusting an amplitude of the filtered phase modulated signal based on a dynamic reference envelope control signal; and

a control circuit cooperating with said monitoring circuit and said transmit gain controller for generating the dynamic reference envelope control signal so that phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within the allocated bandwidth.

2. The transmitter according to Claim 1 wherein said transmit gain controller adjusts the amplitude of the filtered phase modulated signal to correspond with an amplitude of the dynamic reference envelope control signal.

3. The transmitter according to Claim 1 wherein said transmit gain controller adjusts an amplitude of the dynamic reference envelope control signal to vary between a nominal value and a suppressed value, with the suppressed value corresponding to the phase transitions of the filtered phase modulated signal.

4. The transmitter according to Claim 1 wherein said control circuit adjusts the dynamic reference envelope control signal according to a profile based on a modulation type and data rate of the filtered phase modulated signal.

5. The transmitter according to Claim 4 wherein the profile of the dynamic reference envelope control signal comprises at least one of nominal and suppressed amplitude values, a duration of the suppressed amplitude value, and a delay corresponding to generation of the suppressed amplitude value by said transmit gain controller after detection of a phase transition by said monitoring circuit.

6. A method for suppressing a filtered phase modulated signal to be transmitted, the method comprising:

monitoring phase transitions of in-phase and quadrature components of an input phase modulated signal with a monitoring circuit;

generating a filtered phase modulated signal within an allocated bandwidth with a filter downstream from the monitoring circuit;

adjusting an amplitude of the filtered phase modulated signal based on a dynamic reference envelope control signal with a transmit gain controller downstream from the filter; and

generating the dynamic reference envelope control signal using a control circuit cooperating with the monitoring circuit and the transmit gain controller so that the phase transitions are suppressed in the filtered phase modulated signal and so that the filtered phase modulated signal remains within an allocated bandwidth.

7. The method according to Claim 6 wherein the transmit gain controller adjusts the amplitude of the filtered phase modulated signal to correspond with an amplitude of the dynamic reference envelope control signal.

8. The method according to Claim 6 wherein the transmit gain controller adjusts an amplitude of the dynamic reference envelope control signal to vary between a nominal value and a suppressed value, with the suppressed value corresponding to the phase transitions of the filtered phase modulated signal.

9. The method according to Claim 6 wherein the control circuit adjusts the dynamic reference envelope control signal according to a profile based on a modulation type and data rate of the filtered phase modulated signal.

10. The method according to Claim 9 wherein the profile of the dynamic reference envelope control signal comprises at least one of nominal and suppressed amplitude values, a duration of the suppressed amplitude value, and a delay corresponding to generation of the suppressed amplitude value by the transmit gain controller after detection of a phase transition by the monitoring circuit.

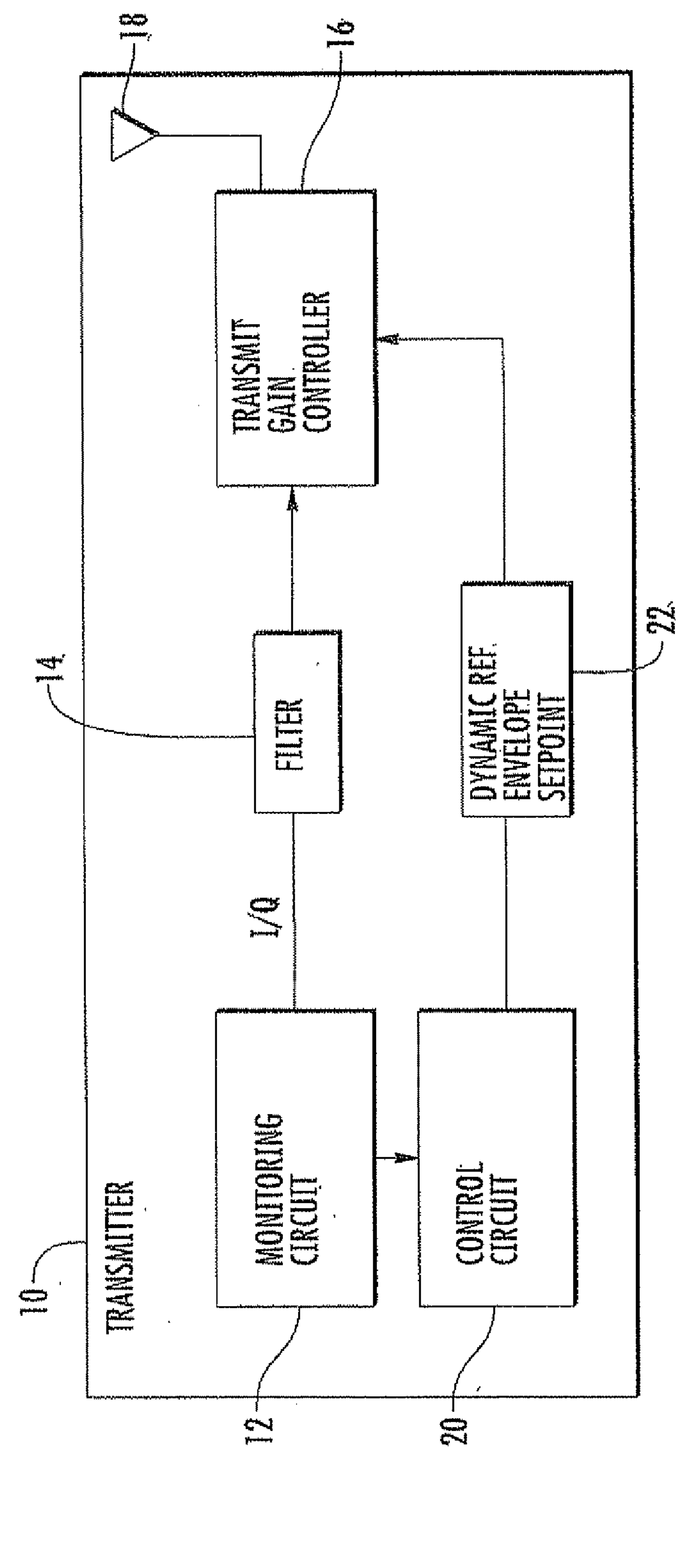
TRANSMITTER
10
MONITORING CIRCUIT
12
CONTROL CIRCUIT
20
I/Q
FILTER
14
DYNAMIC REF. ENVELOPE SETPOINT
22
TRANSMIT GAIN CONTROLLER
16
18

FIG. 1

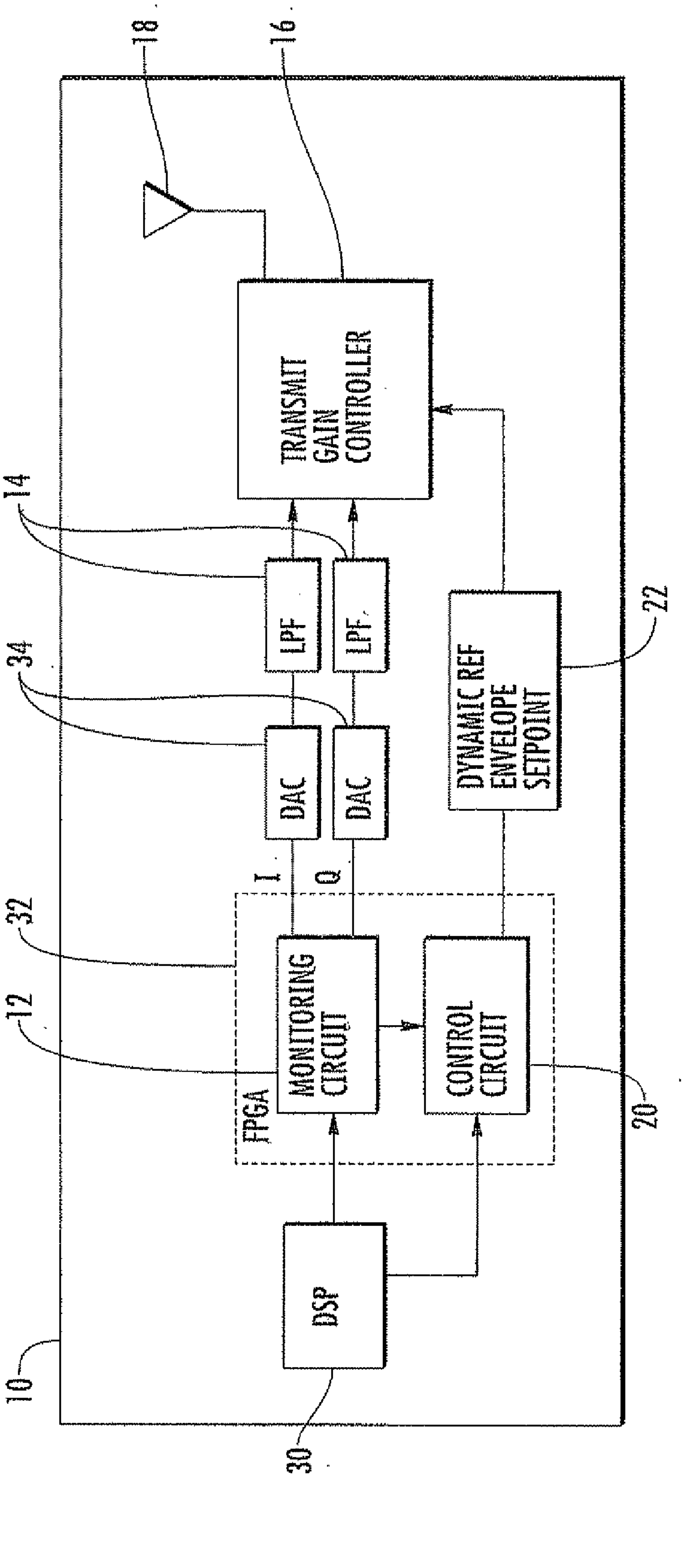
18
16
TRANSMIT
GAIN
CONTROLLER
14
34
LPF
LPF
DAC
DAC
DYNAMIC REF
ENVELOPE
SETPOINT
22
I
Q
32
12
MONITORING
CIRCUIT
CONTROL
CIRCUIT
FPGA
20
DSP
10
30

FIG. 2

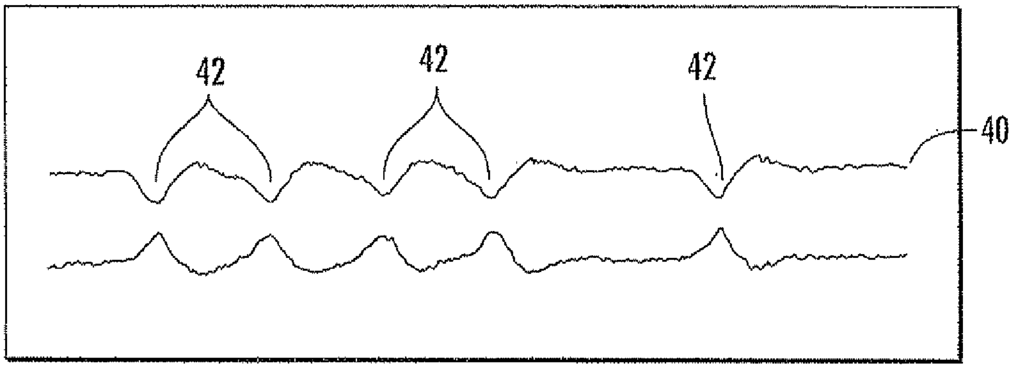

FIG. 3

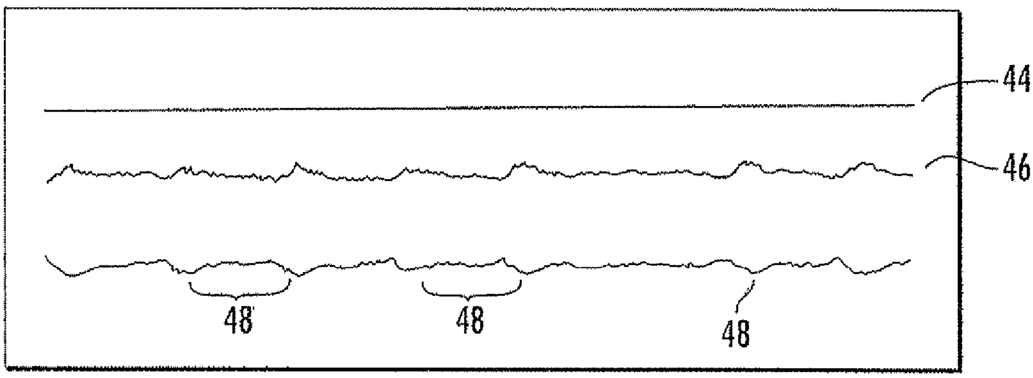

FIG. 4
(PRIOR ART)

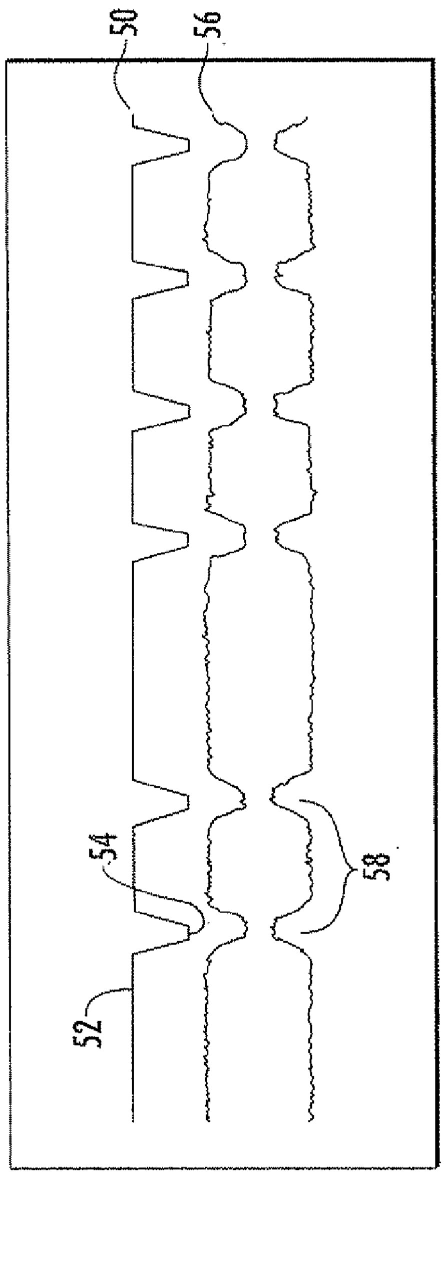

FIG. 5

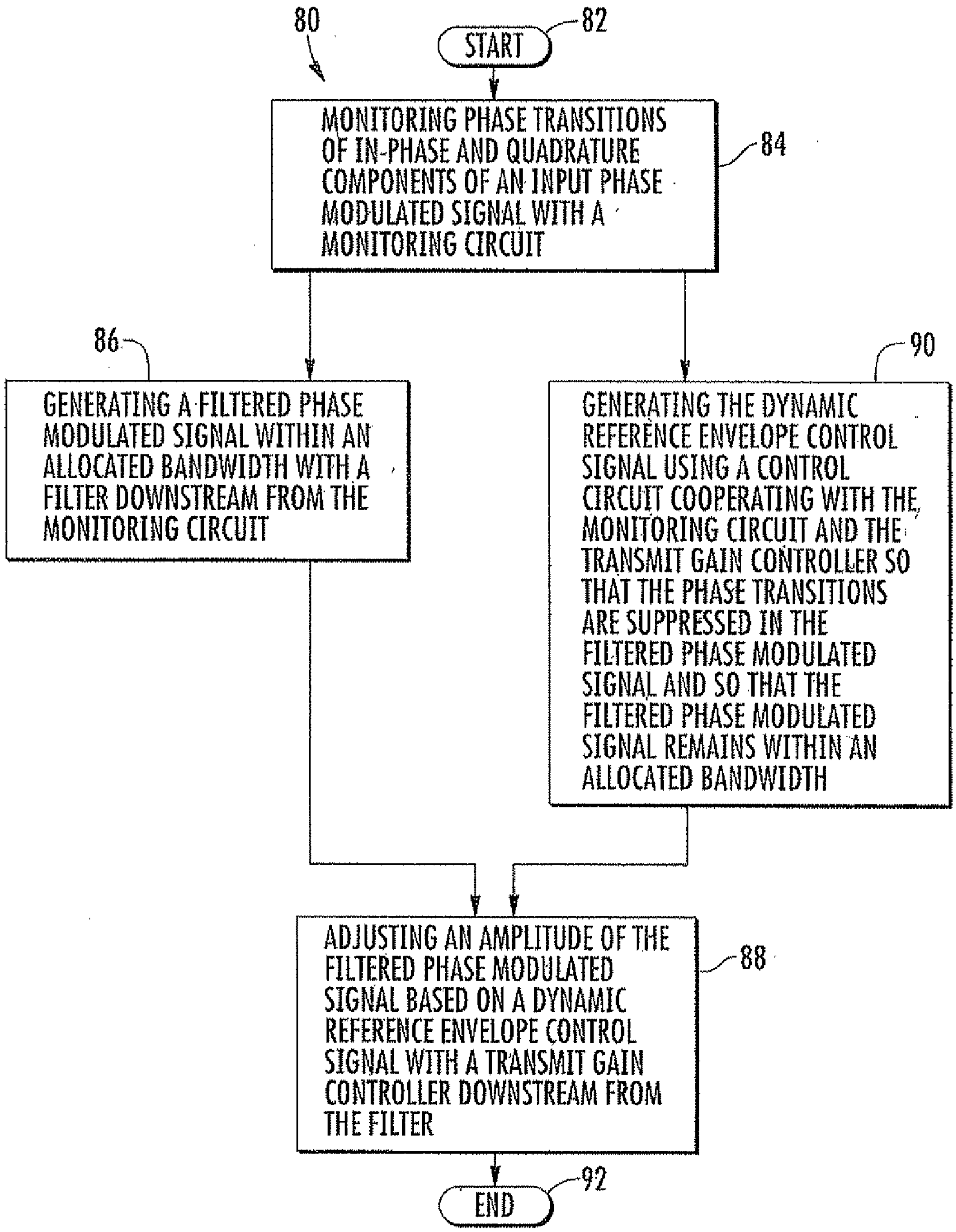
80
START
82
MONITORING PHASE TRANSITIONS OF IN-PHASE AND QUADRATURE COMPONENTS OF AN INPUT PHASE MODULATED SIGNAL WITH A MONITORING CIRCUIT
84
86
GENERATING A FILTERED PHASE MODULATED SIGNAL WITHIN AN ALLOCATED BANDWIDTH WITH A FILTER DOWNSTREAM FROM THE MONITORING CIRCUIT
90
GENERATING THE DYNAMIC REFERENCE ENVELOPE CONTROL SIGNAL USING A CONTROL CIRCUIT COOPERATING WITH THE MONITORING CIRCUIT AND THE TRANSMIT GAIN CONTROLLER SO THAT THE PHASE TRANSITIONS ARE SUPPRESSED IN THE FILTERED PHASE MODULATED SIGNAL AND SO THAT THE FILTERED PHASE MODULATED SIGNAL REMAINS WITHIN AN ALLOCATED BANDWIDTH
ADJUSTING AN AMPLITUDE OF THE FILTERED PHASE MODULATED SIGNAL BASED ON A DYNAMIC REFERENCE ENVELOPE CONTROL SIGNAL WITH A TRANSMIT GAIN CONTROLLER DOWNSTREAM FROM THE FILTER
88
END
92

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/020832

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04L27/20 H03F1/32

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)
H04L H03F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 360 178 A2 (HUGHES NETWORK SYSTEMS [US]) 28 March 1990 (1990-03-28) abstract column 1 - column 6 claim 6 figure 2 -----	1-10
X	EP 1 119 902 B1 (ERICSSON TELEFON AB L M [SE]) 20 August 2003 (2003-08-20) paragraph [0001] paragraph [0006] - paragraph [0007] paragraph [0009] paragraph [0012] paragraph [0017] - paragraph [0018] paragraph [0022] - paragraph [0023] figure 3 -----	1-10

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 March 2010	12/03/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Murcia Martinez, J

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2010/020832

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