

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
18 December 2003 (18.12.2003)

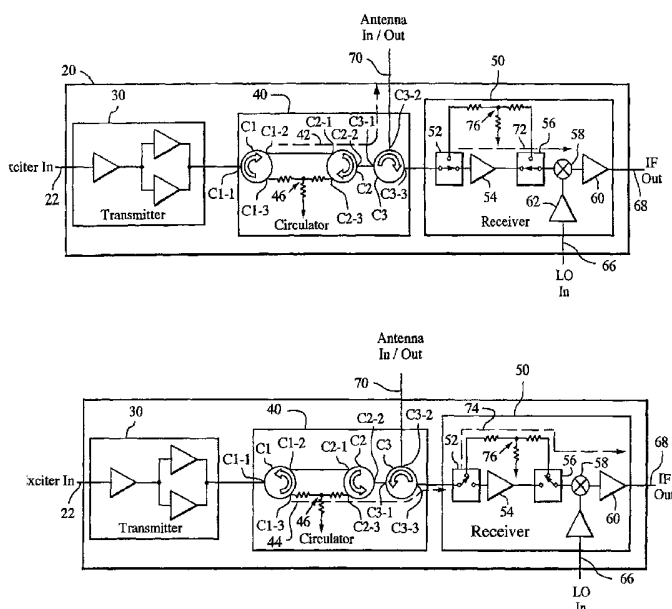
PCT

(10) International Publication Number
WO 03/105272 A1

- (51) International Patent Classification⁷: **H01P 1/39**, 1/383, G01S 13/06, 7/03, 7/40
- (21) International Application Number: PCT/US03/17340
- (22) International Filing Date: 3 June 2003 (03.06.2003)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 10/166,948 11 June 2002 (11.06.2002) US
- (71) Applicant: **RAYTHEON COMPANY** [US/US]; 141 Spring Street, Lexington, MA 02421 (US).
- (72) Inventors: **HUETTNER, Steven, Edward**; 11394 East Prince Road, Tucson, AZ 85749 (US). **REIN, Steven, Craig**; 740 West Calle Alta Loma, Oro Valley, AZ 85737 (US). **BAKER, Douglas, Richard**; 9360 E. Ocotillo Drive, Tucson, AZ 85749 (US).
- (74) Agent: **MURPHY, Cynthia, S.**; Renner, Otto, Boisselle & Sklar, LLP, 1621 Euclid Avenue, Nineteenth Floor, Cleveland, OH 44115-2191 (US).
- (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- Published:**
— with international search report

[Continued on next page]

(54) Title: AN ACCURATE RANGE CALIBRATION ARCHITECTURE FOR PULSED DOPPLER RADAR SYSTEMS



(57) Abstract: A radar system having a tactical mode and a calibration mode includes a transmitter section (30) for providing high-power amplification of an RF pulsed waveform from an exciter during the tactical mode and the calibration mode. A circulator system (40) has an input port connected to an output of the transmitter section and including first, second and third switchable junctions (C1, C2, C3), and a high-power attenuator (46). The circulator system provides a transmit tactical mode signal path (42) and a transmit calibration mode signal path (44) of virtually identical electrical path lengths for a transmitter output signal, the tactical path passing through the first, second and third junctions in a first direction to an antenna I/O port, the calibration path passing through the first, second and third junctions in a second direction and

through the high-power attenuator to an output port. A receiver section (50) is coupled to the output port and includes a receive tactical mode signal path (72) through a low noise amplifier (LNA), mixer, and an intermediate frequency (IF) amplifier to an IF output port for down-converting a radar signal. The receiver section further includes a receive calibration mode signal path (74) through an attenuator which bypasses the LNA and passes through the mixer and IF amplifier to the IF output port.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

AN ACCURATE RANGE CALIBRATION ARCHITECTURE FOR PULSED DOPPLER RADAR SYSTEMS

[0001] This invention was made with Government support under Department of the Navy Contract No. N000024-97-C-5390 CLIN 0001AA TI 416, awarded by the Department of the Navy.

BACKGROUND OF THE DISCLOSURE

[0002] Anti-ballistic missile guidance systems require extremely accurate warhead fuzing. A radar fuze system on a missile uses very short pulse width and extremely fast rise/fall time RF pulses to determine the range and range-rate of the target. A receive/transmit (RX/TX) system is employed to process the RF radar pulse and its target return. In a tactical mode, radar pulses are amplified by a high-power transmitter, then broadcast at the target. The target returns the pulse, which enters the transmitter/receiver through the antenna, and is amplified and down-converted by the receiver.

[0003] For range calibration, the system should provide an alternate signal path from the transmitter to the receiver, which bypasses the antenna, to enable the system to measure its own time delay. In a calibration mode, the alternate signal path should maintain three characteristics. First, it should attenuate the radar pulse signal power dramatically to within a small amplitude window to simulate the small radar return of a target with an acceptable IF output power,

while keeping the receiver well below its saturation level but above the system noise floor. Second, it should preserve the integrity of important radar pulse characteristics, including rise/fall times and pulse width. Third, it should provide a group delay nearly identical to the group delay of a transmitted/received pulse reflected from a theoretical target at a fixed close range. The tolerance versus operating frequency, temperature, exciter power, and from unit-to-unit on the group delay difference between the calibration mode signal path and the tactical mode signal path sets the accuracy to which a target's range can be determined.

[0004] A switchable two-junction circulator has been used to establish a calibration mode path. The first junction was used to attenuate the transmitter output power during the calibration mode, while the second junction bypassed the antenna during calibration and routed the radar pulse directly to the receiver.

This approach allowed the transmit amplifier chain to operate at full output power during calibration, thereby preserving the important pulse characteristic of rise/fall time and pulse width. However, the poor frequency response of the first circulator junction in the calibration mode had an undesirable effect on pulse rise/fall time, since the dominant signal path through this junction in the calibration mode is in the reverse direction of normal signal flow. This reverse-direction signal path has a frequency response similar to that of a notch filter, containing large variations in signal amplitude and group delay over the range of frequencies represented by the pulsed RF signal. This lack of amplitude and delay flatness in the frequency domain translates to poor signal fidelity (e.g. changes in pulse rise/fall time, overshoot, and ringing) in the time domain. A pair of SPST switches within the receiver chain further reduced the calibration mode signal amplitude within the receiver, but had an unpredictable group delay variation due to leakage path effects, resulting from the dominant signal path in the receiver in the calibration mode including the leakage through these SPST switches in their OFF positions. These switches have no requirements for amplitude or delay flatness with respect to frequency in their OFF positions. Typically, in the OFF position, these switches exhibit large variations in

amplitude and group delay with respect to frequency. Similar to the reversed circulator junctions, the amplitude and delay variations that these switches exhibit in the frequency domain translate to poor signal fidelity in the time domain.

[0005] A prior approach by applicants incorporated a bypass path on the transmitter, instead of switching the first junction of the two-junction circulator to attenuate the transmit pulse amplitude. This scheme provides improved group delay accuracy, but does not accurately preserve pulse rise/fall times and pulse width because the transmit chain's non-linear elements are operating at two radically different conditions in the tactical and calibration modes. The accuracy of this approach was found to be highly dependent on temperature and input power. The addition of a controlled attenuation bypass path in the receiver improved the group delay and frequency response characteristics of the RX/TX.

SUMMARY OF THE DISCLOSURE

[0006] An exemplary embodiment of a system in accordance with the invention is a radar system having a tactical mode and a calibration mode. A transmitter section provides high-power amplification of an RF pulsed waveform from an exciter during the tactical mode and the calibration mode. A three-junction circulator system has an input port connected to an output of the transmitter section, and includes a high-power attenuator. The circulator system provides a transmit tactical mode signal path and a transmit calibration mode signal path of virtually identical electrical path lengths for a transmitter output signal. The tactical path passes through the first, second, and third junctions in a first direction to an antenna I/O port. The calibration path passes through the first, second, and third junctions in a second direction and through the high-power attenuator to an output port. A receiver section is coupled to the output port, and includes a receive tactical mode signal path through a low noise amplifier (LNA), mixer, and intermediate frequency (IF) amplifier to an IF output

port for down-converting a radar signal. The receiver section further includes a receive calibration signal path through an attenuator which bypasses the LNA and passes through the mixer and IF amplifier to the IF output port.

BRIEF DESCRIPTION OF THE DRAWING

[0007] These and other features and advantages of the present invention will become more apparent from the following detailed description of an exemplary embodiment thereof, as illustrated in the accompanying drawings, in which:

[0008] FIG. 1 is a simplified schematic diagram of an exemplary embodiment of a radar transmitter/receiver system embodying the invention, configured in a tactical mode.

[0009] FIG. 2 is a simplified schematic diagram of the system of FIG. 1, but configured for a calibration mode.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0010] A purpose of an exemplary embodiment of the invention is to provide an accurate range calibration technique for pulsed Doppler radar systems. In a radar ranging system, distance is measured by converting the time it takes for a transmitted RF signal to reflect from a target and return to the radar's receiver. Thus, accuracy in time measurement is converted to accuracy in distance measurement. For a radar system, the time accuracy will be determined through a calibration measurement. For example, with the speed of light being 3×10^{10} centimeters/ second, a radar that is able to resolve a target return to 100 picoseconds will provide a range accuracy of 1.5 centimeters. This is a goal of an exemplary embodiment of the invention, which is illustrated in FIGS. 1 and 2, although other applications embodying the invention may have lesser or greater range accuracy.

[0011] An exemplary embodiment of a transmitter/receiver system 20 is depicted in the schematic diagrams of FIGS. 1 and 2 in respective tactical and calibration modes. The system 20 includes three principal subassemblies. The transmitter 30 provides high-power amplification of the RF pulsed waveform from the radar exciter. The circulator system 40 includes a combination of three switchable junctions C1, C2, and C3 and a high-power attenuator 46. This provides two signal paths for the transmitted signal. One path 42 passes through circulators C1, C2, and C3 to the antenna I/O port 70. The second path 44 passes through C1, the high power attenuator 46, C2 and C3. These paths 42, 44 are for all practical purposes identical in electrical length but one path (42) has nearly zero loss while the other (44) has an appreciable attenuation. The paths 42, 44 also provide nearly identical group delays between the calibration and tactical modes, and a highly stable group delay difference between these modes.

[0012] The system 20 further comprises receiver 50 which includes a receive tactical mode signal path 72 passing through a low noise amplifier (LNA) 54, mixer 58, and IF amplifier 60 for down-converting a radar signal using an LO signal at LO port 66. The receiver 50 also provides a receive calibration bypass signal path 74 of significant attenuation by use of single-pole, double-throw (SPDT) RF switches 52 and 56. The paths 72, 74 also provide nearly identical group delays between the calibration and tactical modes, and a highly stable group delay difference between these modes. Other ancillary functions typically contained in a transmitter/receiver system, including but not limited to transmit frequency upconverters, transmit gating switches and RF filters are not shown, but will typically be included in a system embodying the invention in accordance with requirements of particular applications.

[0013] During a system tactical mode (FIG. 1), the transmitter 30 operates at full power and amplifies the RF pulse from the exciter received at input port 22, and delivers it to the circulator system 40, to port C1-1 of circulator C1. The circulator system 40 is switched so that the low-loss path 42 between

circulator junctions C1 and C2 is chosen, the signal passing from ports C1-1 to C1-2 of circulator junction C1 to port C2-1 of circulator junction C2, to port C3-1 of circulator junction C3 to port C3-2 of circulator junction C3. The signal path 42 is the transmit tactical mode signal path. The signal is output to the antenna I/O port 70 through circulator junction C3 with extremely low power losses. In the time between the transmit pulses, the signal is reflected from the target and reenters the antenna port 70, where circulator junction C3 delivers it to the receiver 50, the signal passing from port C3-2 to port C3-3 of circulator junction C3. Within the receiver, RF switches 52 and 56 steer the received signal through the high-gain/low-noise-amplifier path 72 and it is down-converted at mixer 58 and output at the IF Out port 68. The signal path 72 is a receive tactical mode signal path.

[0014] During a system calibration mode illustrated in FIG. 2, all of the circulator junctions are reversed compared to the tactical mode, and switches 52 and 56 are in the opposite state. Exactly as in the tactical mode, the transmitter 30 operates at full power, amplifies the RF pulse at port 22 from the exciter, and delivers it to the circulator system 40. Within the circulator system 40, junctions C1 and C2 steer the signal through the transmit calibration mode path 44 to the high-power attenuator 46, where it is significantly attenuated. Thus, the signal passes from port C1-1 to C1-3 of circulator junction C1, through attenuator 46 to port C2-3 to port C2-2 of circulator junction C2, to port C3-1 of circulator junction C3 to port C3-3 of circulator junction C3. Junction C3 thus bypasses the antenna port 70 and delivers the reduced (attenuated) transmit waveform directly to the receiver 50. Within the receiver, the switches 52 and 56 are set to bypass the signal around the LNA 54 through receive calibration mode signal path 74 and attenuator 76, which prevents receiver saturation and contributes to a much-reduced receiver gain so that an acceptable calibration mode IF output power is provided.

[0015] Switchable circulator junctions suitable for the purpose as junctions C1, C2 and C3 are commercially available. For example, EMS Technologies, Norcross, GA, markets waveguide circulators with switchable junctions.

[0016] The exemplary embodiment of the invention provides an extremely accurate range calibration because of the following features:

1. The transmit high-power amplifier 30 is operated at full RF power during tactical and calibration modes, thereby preserving the transmit pulse rise/fall and pulse width characteristics.

2. The triple-junction switchable circulator system 40 provides a high-power attenuation bypass path 44 in calibration mode to accurately attenuate the transmit pulse with no compromise in frequency response, and it provides near identical group delay between the tactical and calibration signal paths 40, 42. The system 40 also routes the attenuated transmit (TX) signal directly to the receiver during calibration mode.

3. A bypass path 74 in the receiver is used to further reduce RX/TX path gain, and is designed to produce a negligible group delay difference between the tactical and calibration modes and an accurate IF output power level during calibration.

4. The amplitude and delay flatness of the bypass paths in both the triple-junction circulator and the receiver can be controlled, thereby preserving signal fidelity in the calibration mode. Path amplitude and delay flatness are controlled by specifying a flat frequency bandwidth over a sufficient bandwidth. Within the circulator and receive bypass paths, a flat frequency response over a wide bandwidth is easily attainable by those skilled in the art of producing RF attenuators. Further the tolerance of the group delay difference between tactical and calibration states is well controlled by employing tight dimensional tolerances during construction of the circulator and receiver.

[0017] It is understood that the above-described embodiments are merely illustrative of the possible specific embodiments which may represent principles of the present invention. Other arrangements may readily be devised in accordance with these principles by those skilled in the art without departing from the scope and spirit of the invention.

CLAIMSWhat is claimed is:

1. A radar system having a tactical mode and a calibration mode, comprising:

a transmitter section (30) for providing high-power amplification of an RF pulsed waveform from an exciter during the tactical mode and the calibration mode;

a circulator system (40) having an input port connected to an output of the transmitter section and including first, second and third switchable junctions (C1, C2 C3), and a high-power attenuator (46), the circulator system providing a transmit tactical mode signal path (42) and a transmit calibration mode signal path (44) of virtually identical electrical path lengths for a transmitter output signal, the transmit tactical mode path passing through the first, second and third junctions in a first direction to an antenna I/O port (70), the transmit calibration mode signal path passing through the first, second, and third junctions in a second direction and through the high-power attenuator to an output port; and

a receiver section (50) coupled to the output port including a receive tactical mode signal path (72) through a low noise amplifier (LNA) (54), mixer (58), and intermediate frequency (IF) amplifier (60) to an IF output port for down-converting a radar signal, the receiver section further including a receive calibration mode signal path (74) through a receiver attenuator (76) which bypasses the LNA and passes through the mixer and IF amplifier to the IF output port.

2. A system according to Claim 1, wherein said high-power attenuator is connected between ports of said first and second circulator junctions (C1, C2) in said transmit calibration mode signal path (44).

3. A system according to Claim 1 or Claim 2, wherein a second port (C1-2) of said first circulator junction is connected to a first port (C2-1) of said second circulator junction by a first transmission line segment forming a portion of said transmit tactical mode signal path, and a third port (C1-3) of said first circulator junction is connected to a third port (C2-3) of said second circulator junction through said high-power attenuator and a second transmission line segment.

4. A system according to any preceding claim, wherein the transmit tactical mode signal path and the transmit calibration signal path provide nearly identical group delays between the calibration and tactical modes.

5. A system according to any preceding claim, wherein the receiver section includes a first RF switch (52) and a second RF switch (56) for selectively bypassing the receive tactical mode signal path and selecting the receive calibration mode signal path during the calibration mode, said receive calibration mode signal path providing a nearly identical group delay to a group delay of the receive tactical mode signal path.

6. A system according to Claim 5, wherein said receiver attenuator is connected in said receive calibration mode signal path between said first RF switch and said second RF switch.

7. A system according to Claim 5 or Claim 6, wherein said first RF switch is disposed in an input signal path leading to an input of the LNA, and the second RF switch is disposed in an output signal path leading from an output of the LNA to an input to said mixer.

8. A system according to any of Claims 5-7, wherein said first RF switch is a first single-pole-double-throw (SPDT) switch, and said second RF switch is a second SPDT switch.

9. A system according to any preceding claim, wherein the calibration node is a range calibration mode, and the transmitter section is a non-linear high-power transmitter section for providing high power amplification of an RF pulsed waveform, the transmitter section operated at full RF power during the actual mode and the range calibration mode, thereby preserving transmit pulse rise/fall time and pulse width characteristics.

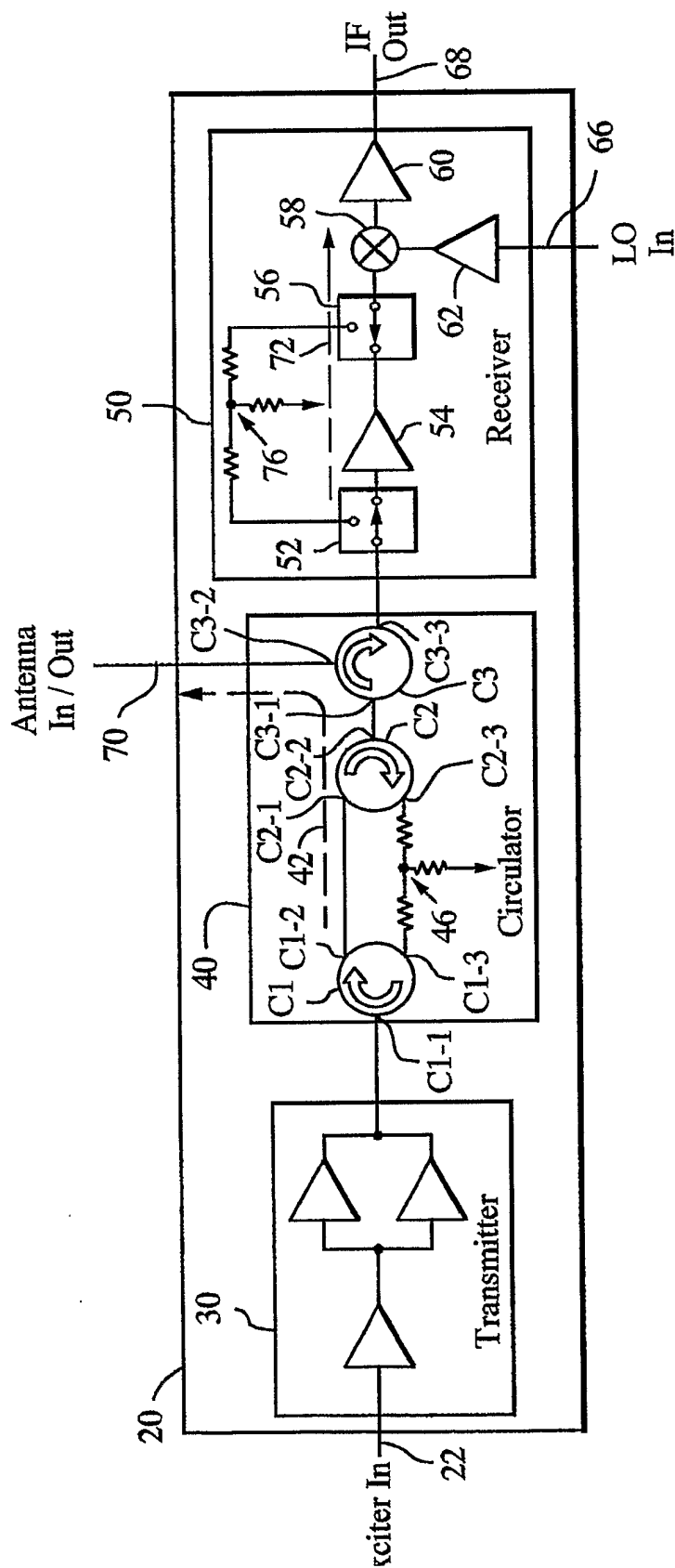


Fig. 1

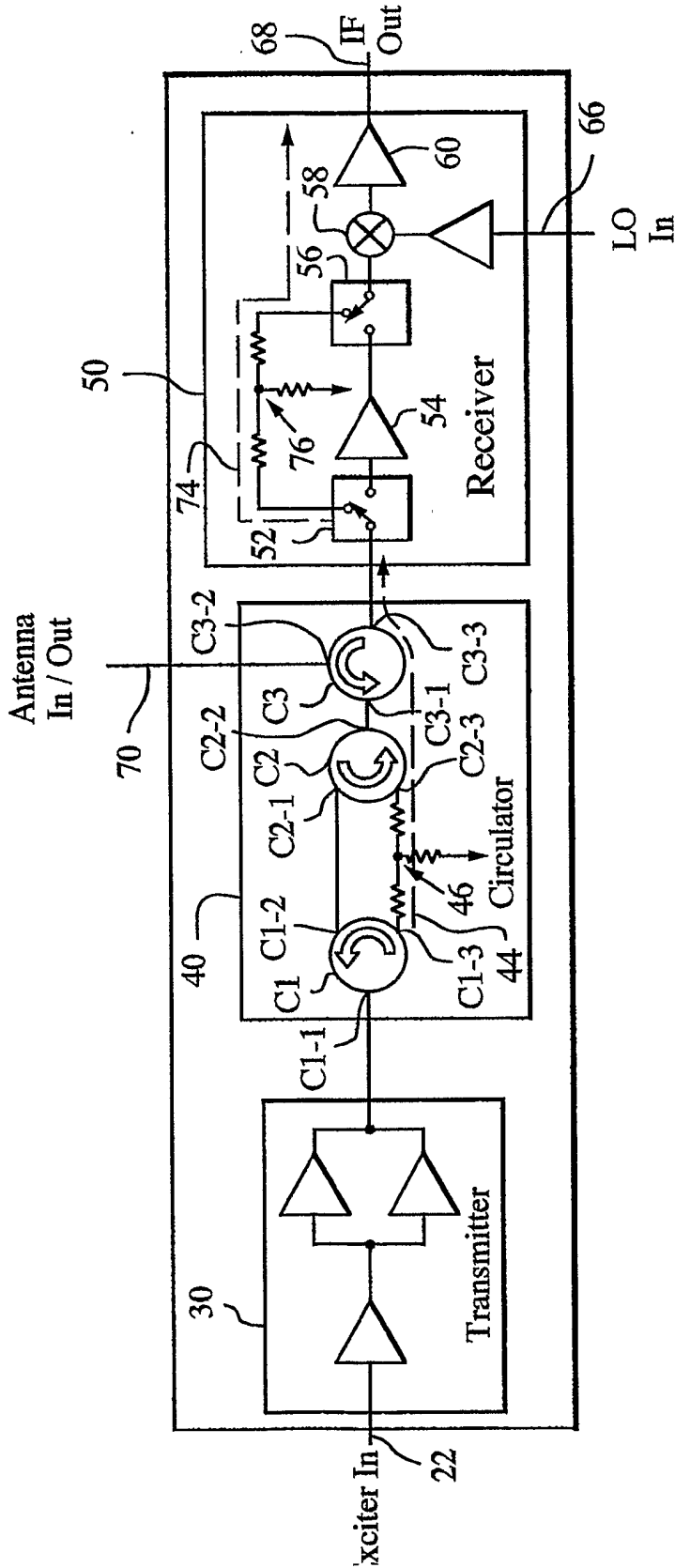


Fig. 2

INTERNATIONAL SEARCH REPORT

Int nal Application No
PCT/US 03/17340

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H01P1/39 H01P1/383 G01S13/06 G01S7/03 G01S7/40

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 7 H01P G01S

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, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 590 477 A (SAVAGE EDWARD ET AL) 20 May 1986 (1986-05-20) abstract column 1, line 59 -column 2, line 13 ---	1-9
A	US 3 491 357 A (STERZER FRED) 20 January 1970 (1970-01-20) abstract figures 1,2 ---	1-9
A	US 4 904 965 A (BLIGHT RONALD F ET AL) 27 February 1990 (1990-02-27) column 1, line 1 -column 1, line 39 column 6, line 26 -column 7, line 56 ---	1-9
A	US 3 582 831 A (SIEKANOWICZ WIESLAW W ET AL) 1 June 1971 (1971-06-01) the whole document --- -/--	1-9

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

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

E earlier document but published on or after the international filing date

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

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

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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.

Z document member of the same patent family

Date of the actual completion of the international search

10 September 2003

Date of mailing of the international search report

16/09/2003

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

van Norel, J

INTERNATIONAL SEARCH REPORT

Inventor's Application No.

PCT/US 03/17340

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3 063 024 A (DAVIS JR LUTHER) 6 November 1962 (1962-11-06) column 1, line 68 -column 2, line 29 column 4, line 8 -column 4, line 17 figures 1-3 -----	1-9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 03/17340

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4590477	A	20-05-1986	NONE	
US 3491357	A	20-01-1970	NONE	
US 4904965	A	27-02-1990	NONE	
US 3582831	A	01-06-1971	NONE	
US 3063024	A	06-11-1962	NONE	