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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G01S 7/28 — A1

(11) International Publication Number: WO 90/03584

(43) International Publication Date: 5 April 1990 (05.04.90)

(21) International Application Number: PCT/US89/03526

(22) International Filing Date: 18 August 1989 (18.08.89)

(30) Priority data:
250,675 29 September 1988 (29.09.88) US

(81) Designated States: AU, CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, NL (European patent), NO, SE (European patent).

Published
With international search report.

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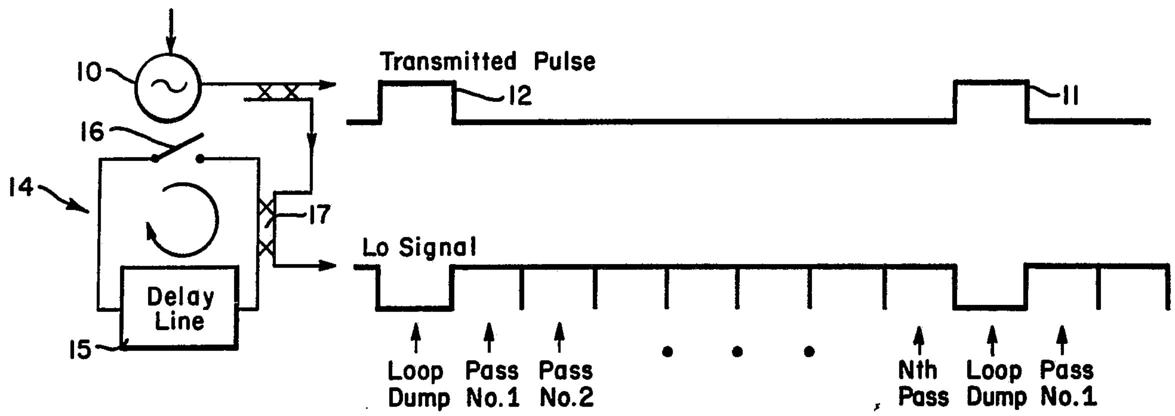
(54) Title: COHERENT RADAR USING RECIRCULATING FIBER-OPTIC DELAY LINE



(57) Abstract

A radar system in which a coupled portion of the transmit pulse (12) is circulated in a closed path delay line (15), each loop (14) of which provides a delay equal to the transmit pulse period. Coupled off signals from the delay line (15) are utilized as a local oscillator for the system and also can be used to make the system coherent-on-receive.

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COHERENT RADAR USING RECIRCULATING FIBER-OPTIC DELAY LINE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a radar system, and, more particularly, to a coherent radar system utilizing a fiber-optic delay line in order to produce pulse-to-pulse coherency and serve as system local oscillator.

2. Description of Related Art

A radar system in its primary major elements may include a radio frequency oscillator which is controlled by a pulse modulator, or pulser, so as to produce periodic pulses of high power but of relatively short duration. These pulses are applied to a highly directional antenna, typically adapted for rotation, and the antenna is controlled to transmit the pulses toward a target or towards a region in which a target is sought. A receiver, which may be interconnected with the same antenna as the transmitter, is controlled by a switching arrangement ("duplexer") to interconnect the antenna to the receiver during the interval between transmitted power pulses in order to receive relected energy from a target. By monitoring the antenna direction and timing of reflected pulse returns, location and range of a target can be obtained.

There are other radar systems for detecting targets and their ranges which rely upon the radiation of unmodulated continuous wave energy. The present invention is not concerned with these continuous wave or "CW" radar systems, but rather with pulse type systems.

One of the earliest forms of oscillators for producing radar pulses was a device called a magnetron, which has an undesirable characteristic in that the phase of each transmitted pulse is randomly related to the phase of previous pulses. The phase problem requires special adjustment and control when the radar is being used as a moving target indicator (MTI). That is, a primary use of radar, for either domestic or military applications, is to detect a moving target amid echoes obtained from adjacent fixed objects, the latter frequently being referred to as "ground clutter" or just "clutter".

More particularly, it is necessary for a radar to act as a satisfactory MTI that the phase of a transmitted pulse be made coherent with the system local oscillator (LO) and to the phase of previous pulses, and it is this coherence that we are primarily concerned with here and in connection with which the described invention achieves its primary utility and advantages.

For example, in air-to-surface missile guidance seekers, coherent processing is extrememly valuable for finding and tracking targets (e.g., tanks) amid ground clutter. However, conventional coherent radar systems have not been considered affordable for this class of weapons, and it is, therefore, highly desirable to find reduced cost alternatives for air-to-surface seekers.

In the case of air-to-air missile seekers, they usually use medium pulse RF or high pulse RF, both of which are ambiguous in range necessitating maintaining pulse-to-pulse coherence. Also, air-to-air seekers require large power-aperture components in order to achieve sufficient acquisition range, and for that reason they usually operate in the X-band (i.e., center of frequency band is 9,000 MHz).

The early radar systems, generally operating at lower frequencies than used now, achieved coherency between the LO and the transmit pulse by locking the LO to the transmit phase and maintaining the locked phase during the listen interval. This technique, however, did not provide pulse-to-pulse coherence. At the present time, fully satisfactory coherent radar seekers having pulse-to-pulse coherence require a relatively expensive frequency reference unit (FRU) that also must be stable over the operational temperature range. This necessity for an FRU is considered to make some missile radar seeker systems prohibitively expensive.

It has been suggested for shipboard use to detect low flying targets over the sea surface that a high resolution radar be provided with a noncoherent delay line canceller, the delay line being of the fiber optic variety. C. T. Chang, D. E. Altman, D. R. Wehner, D. J. Albares, "Noncoherent Radar Moving Target Indicator Using Fiber Optic Delay Lines," IEEE Trans. on Circuits and Systems, Vol. CAS-26, No. 12, Dec. 1979, pp. 1132-1135.

SUMMARY OF THE INVENTION

It is a primary aim and object of the present invention to provide an improved coherent-on-receive (COR) radar system utilizing a delay line which serves as a local oscillator for the system.

Another object is the provision of a coherent radar system as in the previous object that eliminates the need for a frequency reference unit.

A still further object is the provision of a coherent radar system in which pulse-to-pulse coherency is obtained by locking each transmit pulse to the previous pulse delayed in time by a RF delay line.

Yet another object is the provision of a coherent radar system as in the previous objects in which the delay line is a fiber optic delay line.

In accordance with a first embodiment of this invention, a coherent-on-receive radar system is provided having an optical delay line including a fiber-optic transmitter which converts a microwave radar signal into an optical signal, an optical fiber of predetermined length for carrying and delaying the optical signal, and a fiber-optic receiver for converting the optical signal once again into a microwave signal. A microwave switch or directional coupler couples a part of the transmitted signal during a transmitted radar pulse into the fiber-optic delay line. At the end of the radar pulse, the microwave switch is transferred to another connective mode forming a closed loop to cause recirculation of the stored signal. In addition, part of the recirculating signal is continuously coupled off the delay line to serve as the radar local oscillator (LO). Each cycle in the delay line loop, the microwave signal is converted into an RF modulated optical signal which is delayed in accordance with the physical characteristics of the fiber loop, the optical signal is converted back to microwave form, amplified, and the sequence is repeated. The amplification for the delay line recovers signal loss incurred by the signal transmission through the delay line.

The optical fiber of the delay line is cut to a predetermined length so as to delay a pulse making one passage around the delay line by an amount precisely equal to the duration of a radar transmitted pulse. In this manner, repeated replicas of the radar transmitted pulse are continuously coupled off, amplified and mixed with the radar echoes or received signals. At the end of the listen interval, the microwave switches return to the original connective mode directing the recirculated pulse to the radar transmitter for injection locking of a new pulse. As before, a part of the new pulse is coupled into the delay line and the operation continues as already described.

An alternate form of the invention uses an all optical recirculating delay line thereby avoiding the requirement of the first embodiment of converting the delayed transmit pulse from a microwave signal to an optical signal and then once again back to a microwave signal, each time the pulse circulates around the delay line loop. Specifically, this eliminates conversion noise buildup associated with the microwave and optoelectronic components inside the delay loop.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 is a schematic representation of the radar system of this invention using a recirculated pulse in a delay line as system local oscillator (LO).

FIG. 2 is a function block circuit schematic of a first embodiment of this invention for producing a system LO.

FIG. 3 depicts in block form a homodyne radar system with a recirculating delay incorporated therein.

FIG. 4 shows a recirculating delay line incorporated into a heterodyne radar system in accordance with the present invention.

FIG. 5 is a circuit schematic of a coherent-on-receive radar system according to this invention which also serves as system local oscillator.

FIG. 6 is a timing graph of certain signal waveforms in the circuit of FIG. 5.

FIG. 7 is an alternative embodiment employing purely optical recirculating delay line.

FIG. 8 is a graph of an optical delay signal output wave form compared with conventional radar waveforms.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the ensuing description of preferred embodiments of this invention, reference is now made to the drawings and particularly to FIG. 1 thereof. Since the general operation of a radar system is well-known in the art, a detailed description of the more generalized aspects of a radar system will not be given. In a way well-known in the radar art, a high-frequency oscillator 10 is modulated (arrow) to provide a series of transmit pulses 11 and 12 of predetermined constant duration. A portion of, say, the transmit pulse 11 is coupled at 13 into a recirculating delay line 14 including a delay medium or line 15 which is selectively arranged into a closed loop by closing a switch 16. More particularly, on closing the switch the signal is "stored" and circulates in the delay line closed loop. The loop delay is set to precisely equal the transmit pulse duration, i.e., the closed loop is "filled" when the trailing edge of the transmit is reached. The stored signal circulates around the closed loop and is coupled off at 17 to provide the system local oscillator (LO). With the loop delay equaling the transmit pulse duration, then a continuous LO signal is obtained. On arrival of the next transmit pulse 12, the switch is opened allowing the new pulse to be stored and the previously stored pulse 11 to be dumped.

FIG 2 shows that a portion of the transmit pulse is inserted into the recirculating delay line 14 via a suitable coupling means 18 (e.g., switch or directional coupler). The delay medium or delay line 15 can optionally be a coaxial delay line, SAW delay, or fiber-optic delay line. Also, optionally an amplifier/limiter 19 and band pass filter 20 can be incorporated into the recirculating delay line 14 for replacing losses and removing noise, respectively. Coupling of the delayed recirculated pulses to the radar receiver is accomplished via directional coupler 17.

FIG. 3 depicts the incorporation of the recirculating delay line 14 (RDL) in a homodyne radar system. Thus, a radar transmitter 21 is modulated by pulse modulator 22 to provide a pulse output which in conventional manner uses the same antenna 23 for both the transmitter

21 and phase detector 24 through the action of duplexer 25. As described, the RDL produces the LO signal for receiver use. Also, as will be more particularly described the pulses in the RDL can be re-injected along line 26 into the transmitter to achieve coherency.

FIG. 4 shows the incorporation of the RDL 14 of FIG. 3 into a heterodyne radar system.

FIG. 5 depicts in somewhat more detail a schematic block diagram of a coherent-on-receive radar system of the present invention in which radar pulses are maintained in a prescribed phase relationship and stored signals from the LO. An optical delay line 27 is provided having as its general purpose to delay received or echo pulses from a target, the delayed pulses are then subsequently mixed with other pulses to achieve increased noise cancellation which is a desirable and advantageous aspect of the invention. The delay line includes a prescribed length of optical fiber 28 cut to a length for delaying a signal pulse making one full traversal of the delay line a predetermined amount of time, which will be discussed in some detail later.

A fiber-optic transmitter 29 converts a microwave signal, namely, a radar pulse, into a corresponding microwave modulated optical signal which is injected into the optical fiber 28. A complementary set of apparatus is a fiber-optic receiver and limiter 30 interconnected with the opposite end of the delay line fiber 28 and which converts optical signals traversing the delay line into a corresponding microwave signal pulse.

First and second microwave switches 31 and 32 interconnect with the respective ends of the delay line and have two connective aspects identified as A and B, which, in a way well known in the electrical art, are simultaneously switched to either A or B. More particularly, during the transmission of radar pulse, the microwave switches are both located in position B at which time microwave energy is coupled via a microwave directional coupler 33 and through the microwave switch 32 to the fiber-optic transmitter 29 where a corresponding optical pulse is generated and inserted into the delay line fiber 28. At the end of the transmitted pulse, the microwave switches are switched to connective aspect A which forms a closed loop in the delay line allowing the transmitted signal inserted into the line to recirculate. For each cycle or recirculation around the closed loop, the microwave pulse is converted into an optical signal, the optical signal is delayed in the optical fiber, the optical signal is converted back to a microwave signal in the fiber optic receiver which is amplified, and the cycle is repeated. The amplifier 34 in the recirculation loop recovers signal loss which is incurred in the fiber optic delay line. The amplifier may limit the recirculating signal to suppress noise buildup.

The optical fiber 28 of the delay line is cut to provide a length for delaying the circulating pulse an amount precisely equal to the duration of the transmitted radar pulse. In this manner, repeated replicas of the transmitted signal are continuously coupled off by the microwave directional coupler 35 and amplified at 36 prior to mixing with the radar signals, as will be more particularly described. That is, part of the recirculating signal is continuously coupled off and can serve as the local oscillator for the radar system. At the termination of the listen interval, the switches 31 and 32 once again return to position B directing the recirculating pulse to the transmitter for injection locking of a new pulse. Meanwhile, a part of the new transmitted pulse is coupled off into the optical delay line in the same manner as has been described.

A high Q oscillator 37 serially interconnected with the B output of switch 31 in the transmit line prevents the buildup of feedback noise in the transmitted pulse, and, in this way, cleans up phase noise which may be present in the signal. As already indicated, the amplifier 34 suppresses amplitude noise, and also the limiter in the fiber optic receiver 30 aids this same purpose.

The local oscillator signal (LO) which is coupled at 35 after amplification at 36 is split into two parts by a 90° hybrid 38, namely, an in phase or 0° video signal and a quadrature or 90° video signal. These signals are mixed with similar in phase and quadrature signals from radar returns in a conventional manner at 39 and 40, respectively, to provide the necessary radar processing information identified in the drawing as VIDEO-I and VIDEO-Q. If desired, the system could be readily extended to multiple channels to accommodate sum and difference signals from the antenna processor.

FIG. 6 shows in graphical form the local oscillator waveform available at 35 and its time relation to the radar transmitted pulses.

In recapitulation, the described coherent-on-receive radar system mixes radar return signals with delayed transmit signals producing video baseband signals at the target relative Doppler frequency. Pulse-to-pulse coherency is achieved by locking each transmit pulse to the preceding transmit pulse delayed in time.

The described radar system is particularly advantageous in not requiring a stable continuous wave oscillator which is a relatively expensive item. Magnetrons and IMPATT (silicon or gallium arsenide semiconductors) oscillators, although sufficiently modestly priced, are not used in conventional radar systems as a stable frequency source because both have a short coherence interval (i.e., time during which the reference oscillator is coherent). However, in the present invention either of these oscillators can be used (i.e., oscillator 37) in the pulse mode to provide both the reference frequency as well as the high power transmit pulses.

Reference is now made to FIG. 7 showing a circuit schematic of a further embodiment primarily differing from the previously described embodiment in utilizing a purely optical delay line. An advantage of this pure optical delay is that since the delayed transmit pulse is not converted from a microwave signal to an optical signal, and then back again, this eliminates noise buildup associated with the microwave components inside the delay loop. As before, the basic optical fiber delay line 41 includes a length of optical fiber 42 which is precisely cut to provide a delay corresponding to the length of a transmitted radar pulse. First and second optical switches 43 and 44 have A and B connective aspects, the switches being simultaneously both set to A or B. A portion of the transmitted signal is coupled at 45 and converted in a fiber-optic transmitter 46 into an optical signal, which on the switch 44 being set to B condition is inserted into the optical delay line. The opposite end, or switch 43 end, of the delay line when the switch is set to B, feeds the delayed optical signal to a fiber-optic receiver and limiter 47 for conversion to a wave signal.

On adding the delayed pulse to the microwave oscillator 48, a coherent transmit signal is then sent to the antenna or transmitter of the radar along line 49. Similarly, a portion of the optical signal is coupled at 50 where it is converted in a further fiber-optic receiver 51, amplified at 52 and inserted into a 90° hybrid for producing the 0° and 90° video processing signals. Processing is as in the first described embodiment.

It is highly desirable in an air-to-ground missile to be able to function a radar system at millimeter wave frequencies (MMW) which provides the seeker with the ability to resolve rather small targets such as a tank with a relatively small diameter antenna. The essential modification from the FIG. 7 version for this purpose would be to use the coupled radar pulse to actuate a laser beam, the optical output of which is then treated by a modulator to produce the desired pulse optical signal for insertion into the delay line. Otherwise, the system would operate in the same manner and include the same components as shown in FIG. 7 and, therefore, will not be described in detail. In explanation of operation, there is a fundamental limitation on the maximum direct modulation that may be applied to a laser in view of the laser relaxation resonance. Accordingly, indirect amplitude modulation of the laser beam must at the present time be relied upon.

A number of optical modulators provide a satisfactory external modulator for a laser beam, such as Mach-Zehnder interferometric and directional coupler modulators in Ti·$LinbO_3$ and GaAs, and electro-absorption modulators in GaAs.

Increased performance has been obtained in certain sophisticated air-to-ground missiles (e.g., the AMRAAM missile) by employing pulse coding techniques. As already alluded to earlier herein, a difficulty arises in use of the described coherent radar when high resolution is required along with relatively large range capability (e.g., 7.5m for 6.5km range) since this would normally require an excessively large number of circulations in the delay line to obtain the necessary delay. This difficulty can be obviated by phase coding the transmit pulse which reduces the requisite number of circulations in the delay line. This phase coding may be accomplished here by serially inserting a digital phase shifter 53 in the pulse transmit line as shown in dotted line representation in FIG. 5. It is to be noted that pulses to be delayed are coupled off before the phase shifter so as not to include phase coding. This arrangement also results in phase coded information being extracted from the video baseband signal.

Furthermore, other types of coding can be used achieving the same advantageous results. For example, linear frequency modulation can be used to increase the pulse length while maintaining high resolution. Still further, standard pulse compression techniques can be employed with the same beneficial results.

Although the different embodiments of the invention have been described using an optical fiber delay line, it is contemplated that other delay media can be employed with advantage, such as, for example, coaxial delay lines and SAW delay devices.

Review of the coherent radar system described herein establishes not only that it has the ability to utilize less expensive oscillatory power sources (e.g., magnetron, IMPATT oscillator), but also shows a greater degree of noise correlation, or outright cancellation, in the receiver.

The following are commercially available items for certain of the more unusual radar system components described herein:

1. Fiber-optic transmitter 29--TSL-1000, Ortel Corporation;
2. Fiber-optic receiver 30--RSL-25, Ortel Corporation;
3. Coupler 50--2020-6621-IO, Omni-Spectra;
4. External laser beam modulator--MZ313P, Crystal Technology.

The remaining system components are all deemed well-known to those skilled in the appertaining art.

Although the invention has been described in certain preferred embodiments, it is to be understood that one skilled in appertaining art could effect further modifications without departing from the spirit of the invention.

CLAIMS

What is Claimed is:

1. In a radar system having a high-frequency transmit pulse generator, an antenna for radiating transmit pulses toward a target, means for receiving reflected transmit pulses, and means for processing the received pulses, the improvement comprising:

means for coupling a portion of a transmit pulse;

means for converting the coupled transmit pulse portion to a corresponding optical signal;

means for delaying the optical signal a period of time equal to that of a transmit pulse duration;

means for converting the delayed optical pulse to a high-frequency pulse;

first means for interconnecting one terminal of the delaying means to the transmit pulse generator; and

second interconnecting means for interconnecting the means for coupling a portion of a transmit signal to the means for converting the coupled transmit signal to an optical signal.

2. A radar system as in claim 1, in which the first and second interconnecting means include switches actuatable to interconnect the means for converting the transmit pulse to an optical signal, the delaying means and the means for converting the optical signal to a high-frequency pulse into a closed path.

3. A radar system as in claim 1, in which the delaying means includes a predetermined length of an optical fiber.

4. A radar system as in claim 2, in which the switches are actuated at the end of a transmit pulse to maintain the closed loop path until the beginning of the next subsequent transmit pulse.

5. A radar system as in claim 2, in which a low-noise amplifier is serially related in the closed loop.

6. A radar system as in claim 1, in which the means for coupling a portion of a transmit pulse includes a high-frequency directional coupler.

7. A radar system as in claim 1, in which a digital phase shifter is serially interconnected between the high-frequency transmit pulse generator and the antenna.

8. A radar system as in claim 7, in which the means for coupling a portion of a transmit pulse is coupled between the pulse generator and the phase shifter.

9. A radar system as in claim 2, in which further means are provided for coupling off pulses between the means for converting the coupled transmit portion and the second interconnecting means.

10. In a radar system having a high-frequency radio wave oscillator for producing a train of transmit pulses to an antenna, and a receiver for receiving a reflection of the pulses from a target, the improvement comprising:

a high-frequency radio wave directional coupler for coupling off a portion of a transmit pulse;

means for converting the coupled off portion of the transmit signal to a corresponding optical signal;

an optical delay line having an imput and an output;

a first optical switch interconnecting the converting means and the delay line input;

means for converting an optical signal to a corresponding high-frequency radio wave signal fed to the oscillator;

a second optical switch interconnecting the delay line output and the means for converting an optical signal to a corresponding high-frequency radio wave signal;

said first and second switches being simultaneously and periodically actuable to form the delay into a closed loop recirculating path;

an optical directional coupler for coupling off the optical signals in said delay line; and

means responsive to the coupled off optical signals for providing corresponding high-frequency radio wave signals.

11. A radar system as in claim 10, in which a delayed optical pulse from the delay is converted to a high-frequency radio wave signal and locked to the next in time transmit pulse.

12. A radar system as in claim 10, in the delay line has a delay equal to that of one transmit pulse.

13. A radar system as in claim 10, in which the means for converting the coupled off portion of the transmit signal to an optical signal includes a laser and an indirect modulator for modulating the laser beam to form a corresponding optical pulse.

14. A local oscillator generator for a radar system having a transmit pulse generator, a reflected pulse receiver, and received pulse processing apparatus,

comprising:

a delay medium;

a recirculating delay line interconnected with said delay medium and selectively actuatable to form a closed path;

means for coupling a portion of a transmit pulse into the recirculating delay line; and

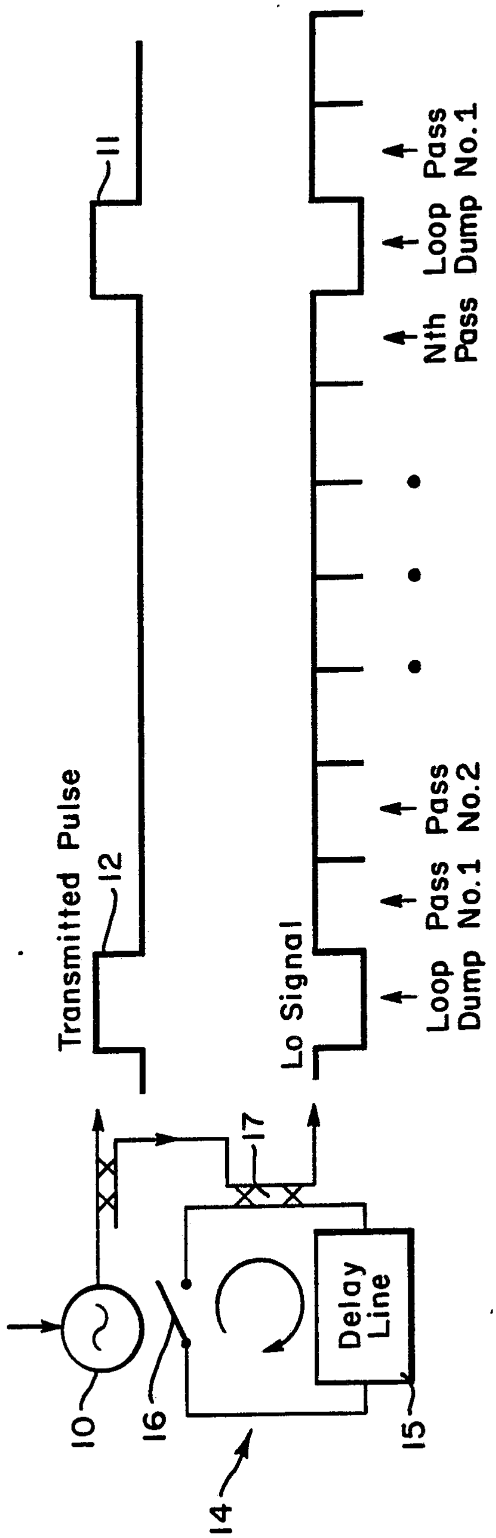
means for coupling the recirculating delayed signal off the delay line to form a pulse local oscillator signal.

15. A local oscillator generator as in claim 14, in which the delay medium is an optical fiber and the recirculating delay line with delay medium provide a one cycle delay equal to the length of a transmit pulse.

16. A local oscillator generator as in claim 14, in which the delay medium includes a coaxial transmission line.

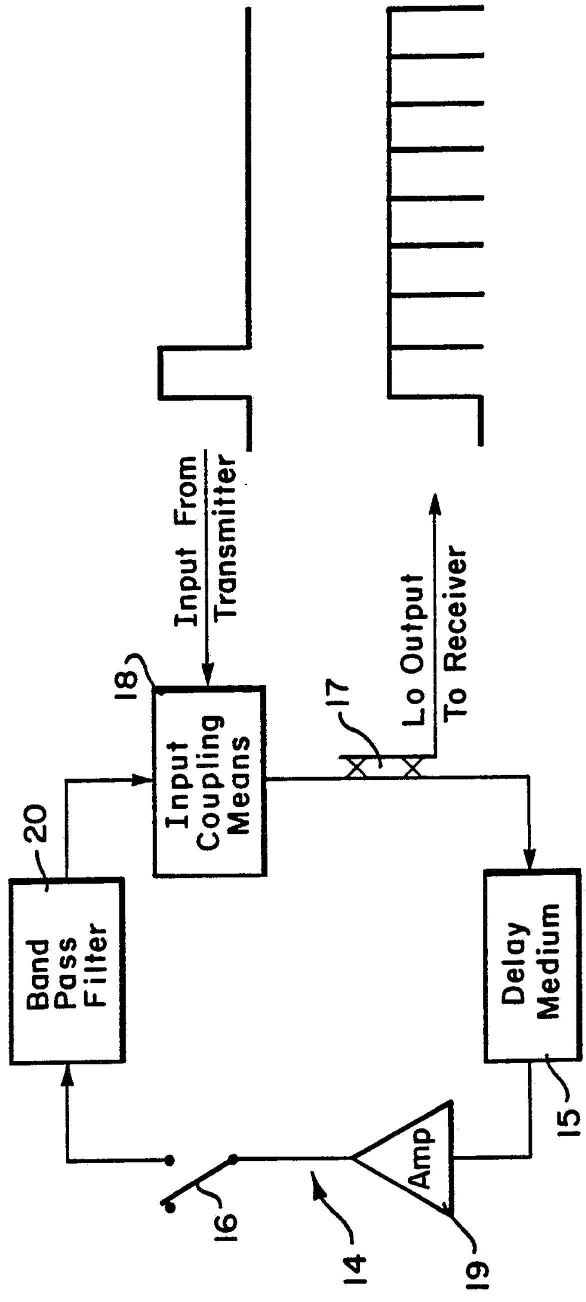
17. A local oscillator generator as in claim 14, in which the delay medium is SAW delay means.

18. A local oscillator generator as in claim 14, in which a switch is interconnected in said recirculating delay line and is selectively actuatable to form a closed path.



Transmitted Pulse
12
11
Lo Signal
Loop Dump
Pass No.1
Pass No.2
Nth Pass
Loop Dump
Pass No.1
Delay Line
10
16
14
15
17

FIG. 1



Input From Transmitter
18
Input Coupling Means
20
Band Pass Filter
17
Lo Output To Receiver
Delay Medium
15
Amp
19
14
16

FIG. 2

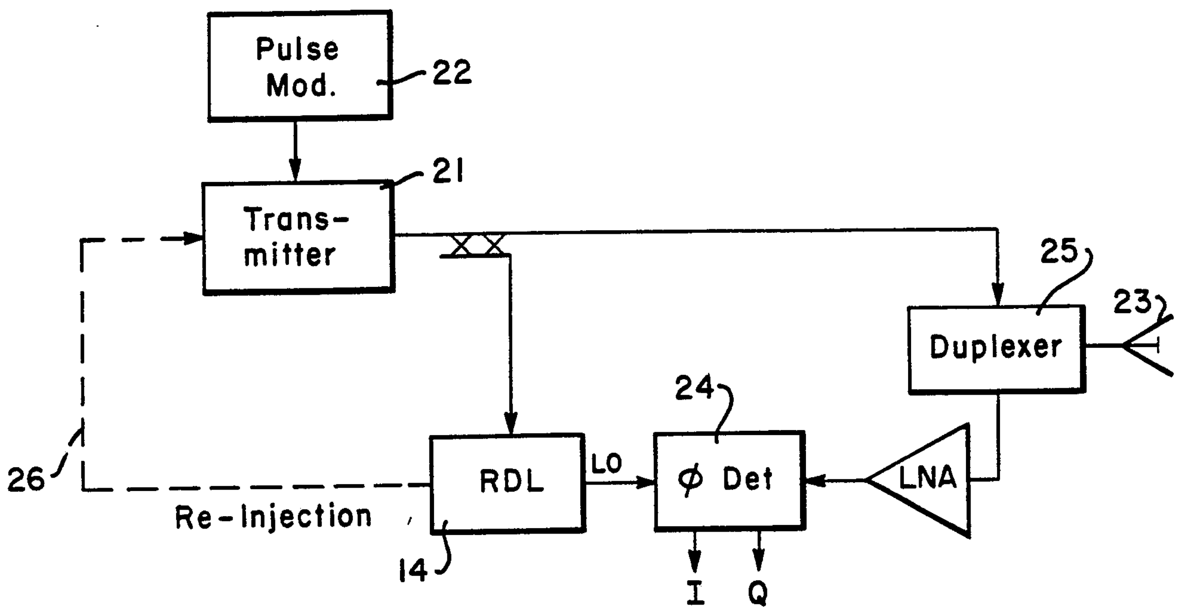

Pulse Mod.
22
21
Trans-mitter
25
23
Duplexer
24
26
RDL
LO
ϕ Det
LNA
Re-Injection
14
I
Q

FIG. 3

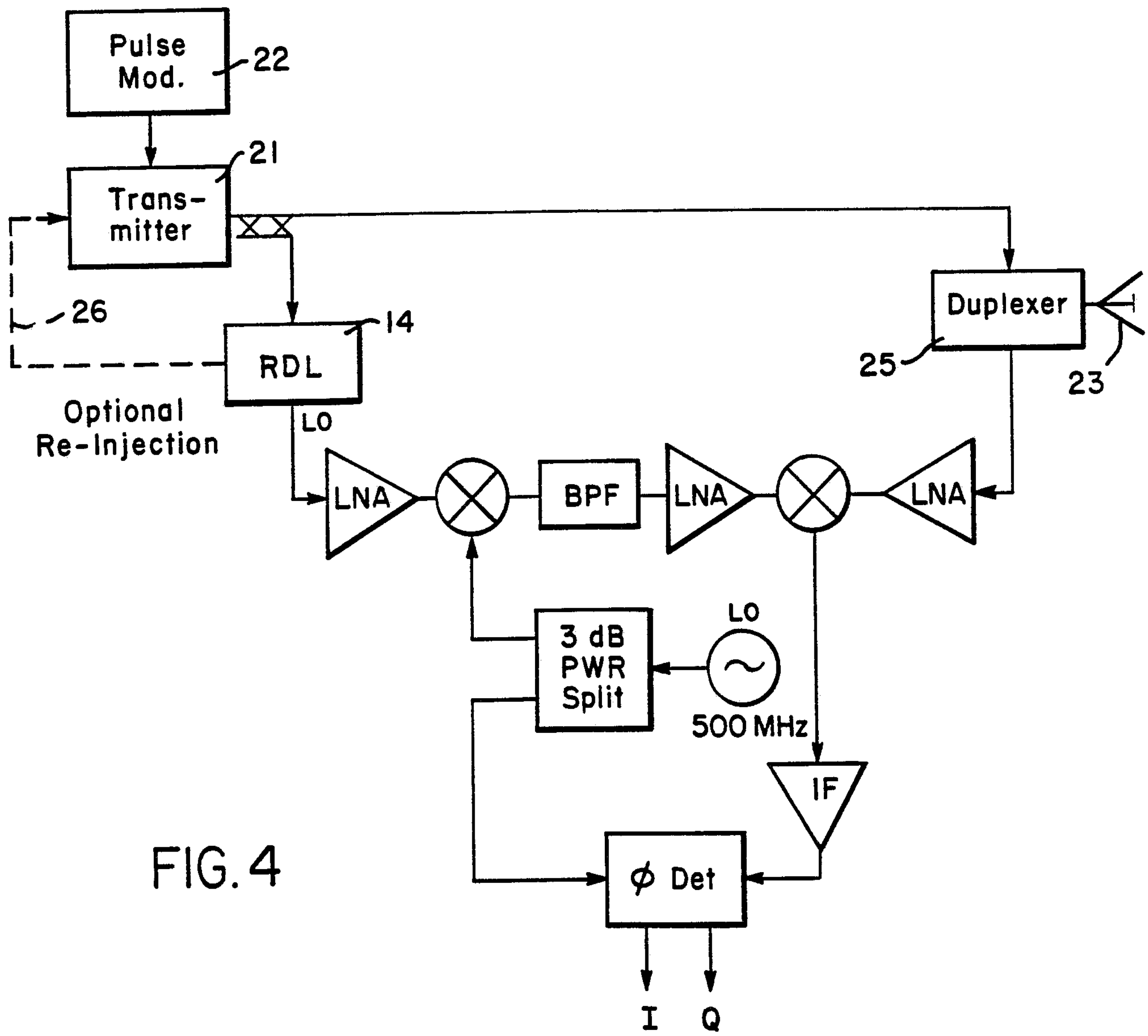

Pulse Mod.
22
21
Trans-mitter
Duplexer
26
14
RDL
25
23
Optional Re-Injection
LO
LNA
BPF
LNA
LNA
LO
3 dB PWR Split
500 MHz
IF
ϕ Det
I
Q

FIG. 4

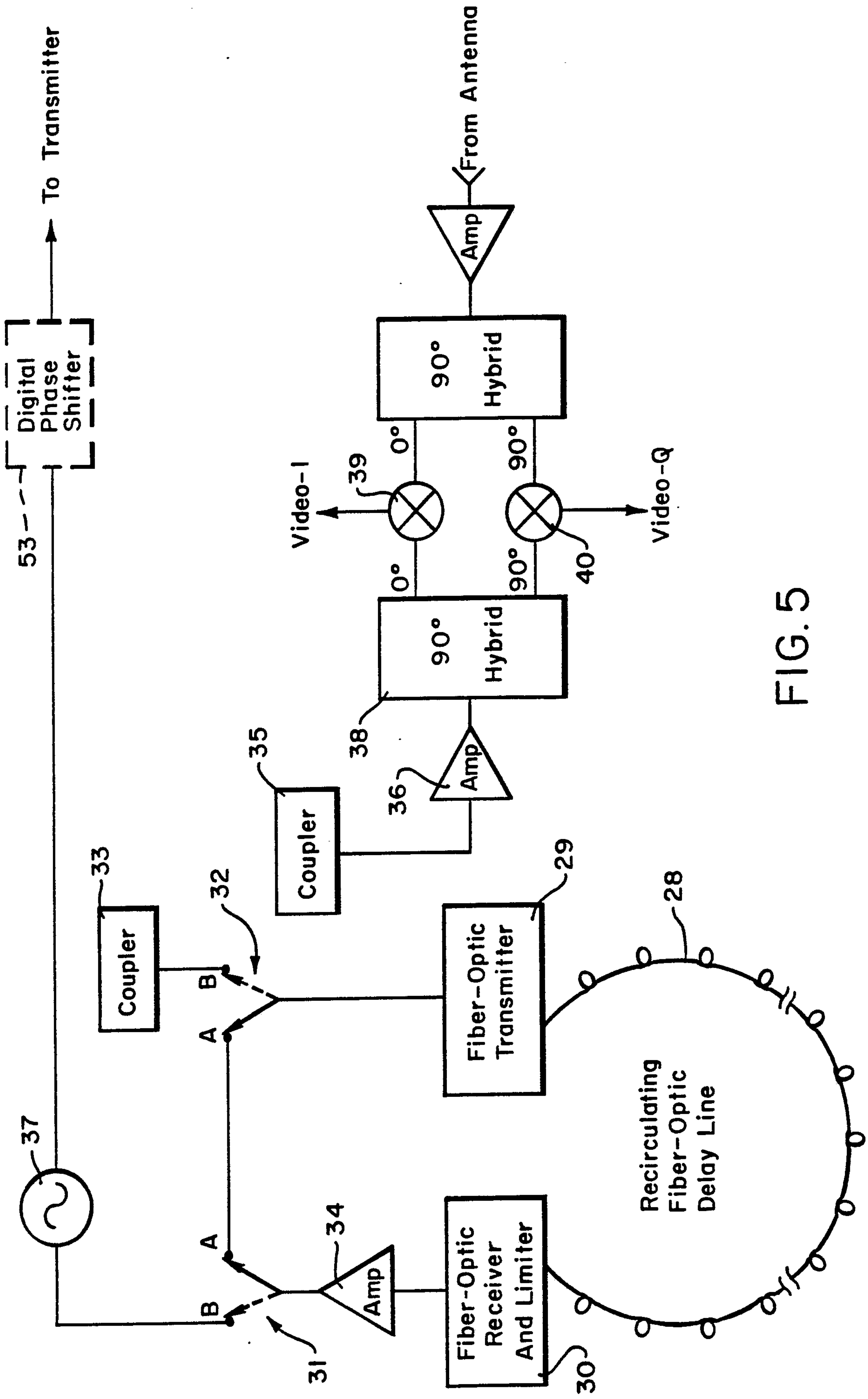

To Transmitter
Digital Phase Shifter
53
From Antenna
Amp
90° Hybrid
0°
90°
Video-I
39
Video-Q
40
0°
90°
90° Hybrid
38
35
Coupler
36
Amp
33
Coupler
32
B
A
29
Fiber-Optic Transmitter
28
Recirculating Fiber-Optic Delay Line
37
A
34
Amp
B
31
Fiber-Optic Receiver And Limiter
30

FIG. 5

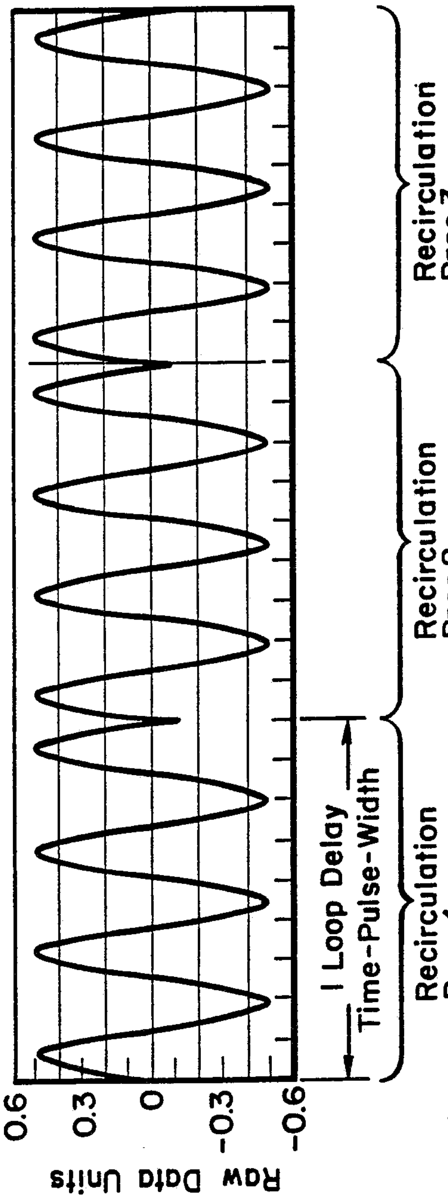

0.6
0.3
0
-0.3
-0.6
Raw Data Units
I Loop Delay
Time-Pulse-Width
Recirculation
Pass 1
Recirculation
Pass 2
Recirculation
Pass 3

FIG.8

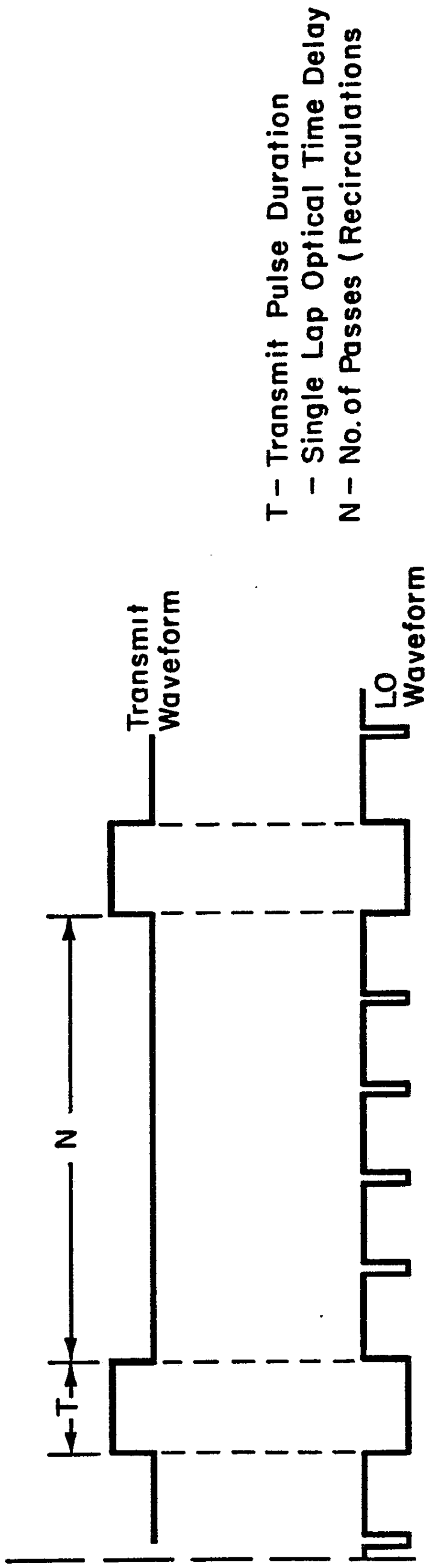

T – Transmit Pulse Duration
– Single Lap Optical Time Delay
N – No. of Passes (Recirculations
Transmit
Waveform
LO
Waveform
T
N

FIG.6

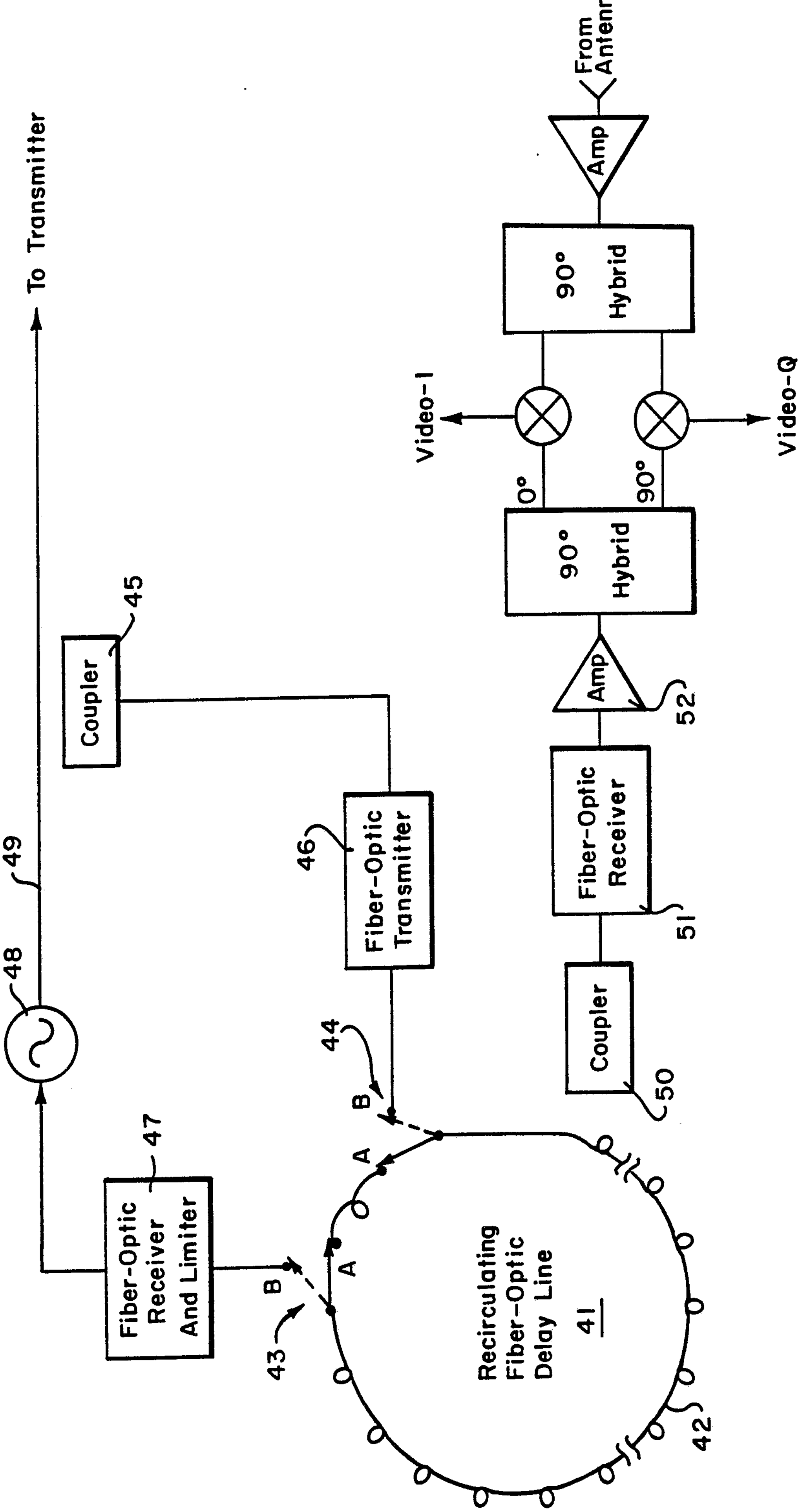

To Transmitter
From Antenna
Amp
90° Hybrid
Video-I
Video-Q
0°
90°
90° Hybrid
Amp
52
Coupler
45
49
48
Fiber-Optic Transmitter
46
Fiber-Optic Receiver
51
Coupler
50
Fiber-Optic Receiver And Limiter
47
44
B
A
A
B
43
Recirculating Fiber-Optic Delay Line
41
42

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 89/03526

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^5: G 01 S 7/28

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^5	G 01 S, H 03 H, H 03 B

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	US, A, 4089001 (T.H. DONAHUE et al.) 9 May 1978 see column 2, line 59 - column 5, line 37; figures 1,2	1-4,6,10-12,14-18
Y	US, A, 4166212 (A.J. JUDENSTEIN) 28 August 1979 see column 1, lines 11-17; column 2, line 20 - column 3, line 68; figures 1-3	1-4,6,10-12,14-18
Y	US, A, 3218561 (D.E. MOELLER) 16 November 1965 see column 1, lines 9-37; column 1, line 65 - column 2, line 64; figure 1	1-4,6,11,12
A	Electro/81 Conference Record, volume 6, 7-9 April 1981, (New York, US), A.E. Popa: "Fiber optics implications for radar equipment design", pages 1-6 (8C/1) see the whole article ./.	1,10,13

* Special categories of cited documents: [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
11th November 1989	17. 01. 90
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	T.K. WILLIS

International Application No. PCT/US 89/03526

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	US, A, 3792344 (J. GUYOT) 12 February 1974 see abstract; figure 1	1,10,14

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 8903526 SA 31144

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 12/01/90
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4089001	09-05-78	DE-A,C 2819043	16-11-78
		FR-A,B 2389904	01-12-78
		GB-A- 1574675	10-09-80
		SE-A- 7804885	07-11-78
US-A- 4166212	28-08-79	None	
US-A- 3218561		None	
US-A- 3792344	12-02-74	FR-A,B 2129949	03-11-72
		BE-A- 781117	17-07-72
		DE-A- 2214195	28-09-72
		GB-A- 1389321	03-04-75

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