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20546

Reply to Attn of: GP-4

TO: NIT-44/Scientific and Technical Information Division
Attn: Shirley Peigare

FROM: GP-4/Office of Assistant General Counsel
for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP-4 and Code NST-44, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 4,439,766

Issue Date : March 27, 1984

Government or
Contractor Employee: U.S. Gov't

NASA Case No. : MSC-18,675-1

NOTE - If this patent covers an invention made by a contractor employee under a NASA contract, the following is applicable:

YES [ ]   NO [X]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the specification, following the words "...with respect to an invention of...."

(NASA-Case-MSC-18675-1) DOPPLER RADAR HAVING PHASE MODULATION OF BOTH TRANSMITTED AND REFLECTED RETURN SIGNALS Patent (NASA) 8 p CSCL 17I   N84-22820
Unclas
00/32 15829

MSC-18,675-1

United States Patent [19]

Kobayashi et al.

[11] **4,439,766**

[45] **Mar. 27, 1984**

[54] **DOPPLER RADAR HAVING PHASE MODULATION OF BOTH TRANSMITTED AND REFLECTED RETURN SIGNALS**

[75] Inventors: **Herbert S. Kobayashi**, Webster; **Paul W. Shores; Patrick Rozas**, both of Houston, all of Tex.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics & Space Administration**, Washington, D.C.

[21] Appl. No.: **266,687**

[22] Filed: **May 22, 1981**

[51] **Int. Cl.**^{3} **G01S 9/44**

[52] **U.S. Cl.** .... **343/9 R**; 343/17.5

[58] **Field of Search** .... 343/5 BD, 9 R, 17.2 R, 343/17.5, 8, 17.2 PC, 5 R, 112 CA, 14; 367/90, 91, 99, 909

[56] **References Cited**

U.S. PATENT DOCUMENTS

2,991,471	7/1961	Pritchard	343/5 R X
3,388,398	6/1968	Kratzer et al.	343/8 X
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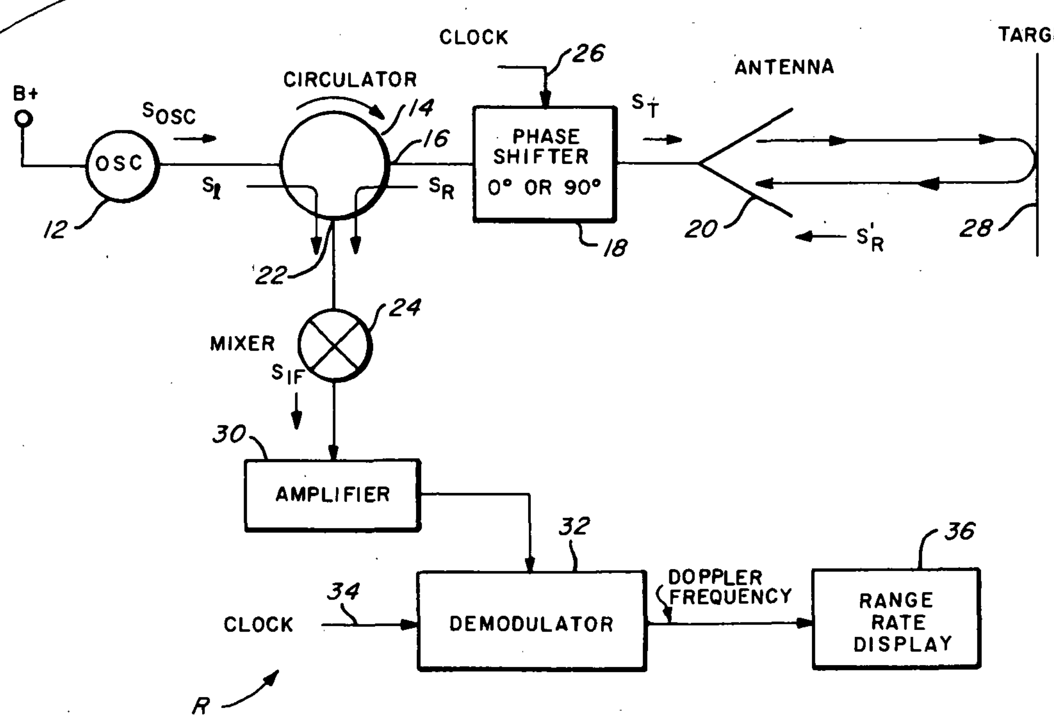
3,750,171	7/1973	Faris	343/14 X
3,750,172	7/1973	Tresselt	343/9 R X
4,019,185	4/1977	Morgan	343/17.5 X
4,042,925	8/1977	Albanese et al.	343/14
4,184,154	1/1980	Albanese et al.	343/9 R
4,241,347	12/1980	Albanese	343/9 R

Primary Examiner—Maynard R. Wilbur
Assistant Examiner—M. Gordon
Attorney, Agent, or Firm—Marvin F. Matthews; John R. Manning

[57] **ABSTRACT**

A microwave radar signal is generated **(12)** for transmission through an antenna **(20)**. Before transmission, the signal is phase modulated **(18)** by 0° or 90° amounts during each alternate half-cycles of an intermediate frequency (IF) clock signal **(26)**. After transmission and return, the signal is again phase modulated **(18)** the same amounts during each alternate half-cycles. The return phase modulated signal is mixed **(24)** with a leakage signal component of the microwave signal, leaving an IF doppler. The IF doppler signal may then be amplified **(30)**, removing any requirement that direct current level signals be amplified and also removing the effect of detector noise from the doppler signal.

10 Claims, 6 Drawing Figures



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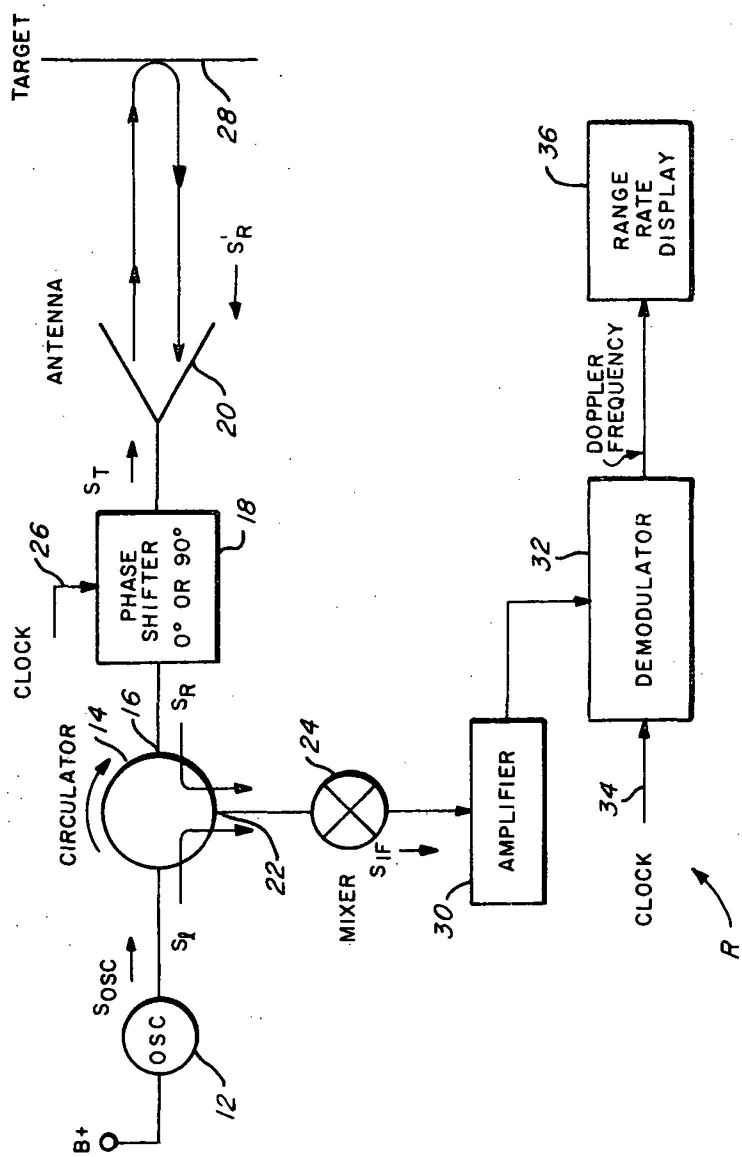

TARGET
28
ANTENNA
20
CLOCK
26
PHASE SHIFTER 0° OR 90°
18
CIRCULATOR
14
16
22
OSC
12
B+
MIXER
24
AMPLIFIER
30
DEMODULATOR
32
CLOCK
34
DOPPLER FREQUENCY
RANGE RATE DISPLAY
36
R

FIG. 1

FIG. 2

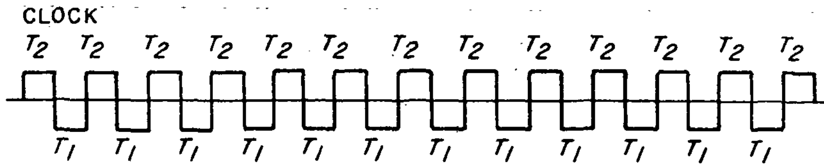


FIG. 3

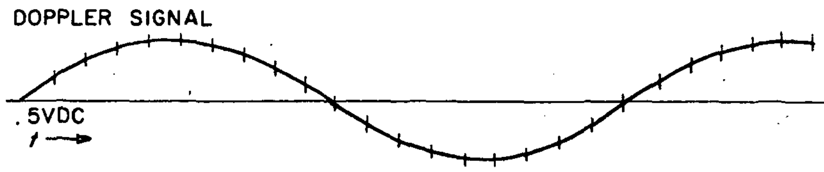


FIG. 4

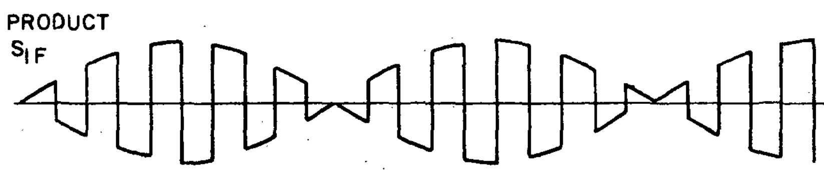


FIG. 5

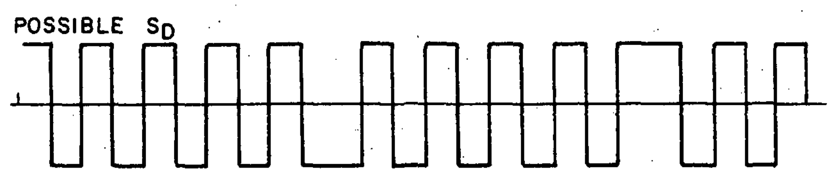
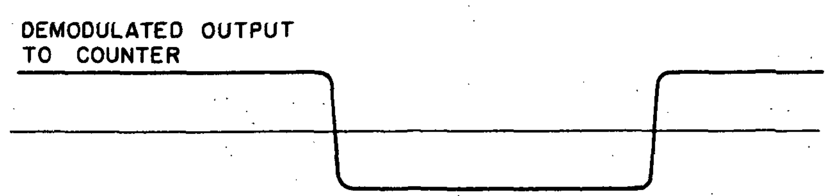


FIG. 6



DOPPLER RADAR HAVING PHASE MODULATION OF BOTH TRANSMITTED AND REFLECTED RETURN SIGNALS

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the U.S. Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

The present invention relates to doppler radar, particularly the measurement of velocities at near zero doppler frequencies.

BACKGROUND ART

Generally, in the past three types of radar have been used—pulse radar, continuous wave (CW) radar and doppler radar. The first two types are expensive and may not measure distances at close range. The third type, or doppler radar, is often used by law enforcement officers in checking motor vehicle speed. It has been generally inexpensive, reliable and accurate and has worked at close ranges. However, doppler radar has had problems measuring low velocity targets. In order for doppler radar to measure low velocities (near zero), certain circuit components including a mixer, filter amplifier and read-out circuit had to be directly coupled. However, in measuring velocities near zero, a problem existed in the amplifier and filter portion since the amplifier was required to have a direct current response and the filter was required to track down to zero frequency.

In the detector circuit of the doppler radar, a direct current was formed by diode circuitry together with an alternating current signal resulting from the reflected return doppler signal.

Due to the requirement of compensation for propagation losses, the detector signal often had to be amplified by a factor of as much as 10^6. In addition to this sort of gain, to allow for wide variations in speed an amplifier was required to amplify low doppler counts, often near zero, for relatively little relative movement. An amplifier having such a magnitude of gain and operating at very low frequencies presents severe design problems. Further, the detector often had an offset on the order of one-half volt. Amplifying this extraneous voltage by a factor of 10^6 could obscure the meaningful information in the doppler signal. Further, as frequencies decreased, detector noise (also known as 1/f noise) became greater. Amplification of this noise again could often mask doppler information.

Certain prior art patents relating to radar have utilized some form of phase modulation in portions of their systems. In U.S. Pat. Nos. 3,388,398; 4,019,185; 4,042,925 and 4,184,154, the transmitted radar signal was phase modulated by a pseudo-random code and the returned radar signal was cross-correlated with the pseudo-random code, apparently either in order to increase the effective detection ranges of the radar or to eliminate range ambiguities. One other patent, U.S. Pat. No. 3,750,172, used multiple frequencies rather than phase modulation in order to render the radar insensitive to targets beyond a preselected range. So far as is known, however, none of these radar systems have dealt with the problem of close ranges or near zero velocities, situations which can occur in aircraft or spacecraft.

DISCLOSURE OF INVENTION

Briefly, the present invention relates to a microwave doppler radar system for detecting, with transmitted radar signals, the range rate of an object at close range from returned signals reflected from the object. Both the transmitted and returned signals are periodically phase modulated, preferably by a like amount of predetermined phase shift, during the same one of two alternate half cycles of an established operating frequency. The returned signal is multiplied with the transmitted signal to form an intermediate frequency signal. The intermediate frequency signal is then amplified and demodulated to form a doppler signal indicative of the range rate of the object.

With the present invention the intermediate frequency signal which could vary, for example, in amplitude from one hundred millivolts to as low as one microvolt can be easily amplified without requiring a direct current amplifier with its attendant drift problems. Further, the intermediate frequency (IF) signal can be filtered for less noise around the IF frequency rather than in base band as was done in prior doppler radar.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic electrical circuit diagram of a doppler radar system according to the present invention; and

FIG. 2 is the waveform of the clock signal

FIG. 3 is the Doppler signal with 0° phase shift

FIG. 4 is the product signal, S_{IF} with 0° and 90° phase shift

FIG. 5 is the IF signal amplified into saturation

FIG. 6 is the demodulated output.

DESCRIPTION OF PREFERRED EMBODIMENT

In the drawings, a doppler radar system R (FIG. 1) with phase modulation of both the transmitted and reflected return signal is shown. In the radar system R, a radar signal is generated by the application of a low direct current voltage, such as ten volts, from a power supply to an oscillator **12**. The oscillator **12** may be, for example, a Gunn diode or any other suitable oscillator which generates a microwave signal, on the order of around ten GHz. The microwave signal formed in the oscillator **12** is passed through a circulator **14** to two ports. A first port **16** is the transmit-receive port and leads through a phase shifter **18** to an antenna **20** through which a transmitted microwave radar signal S_T is transmitted and received. A second port **22** serves as a signal detecting port and conducts the returned radar signals to a mixer **24**. The port **22** further conducts a leakage signal S_1, in the form of a portion of the signal formed in the oscillator **12**, to the mixer **24** so that a product signal is formed between the leakage signal S_1 and a returning signal S_R, for reasons to be set forth.

The phase shifter **18** receives a clock signal (FIG. 2) of an established operating frequency. As can be seen in FIG. 2, the clock signal is composed of alternating half-cycles T_1 and T_2. In the phase shifter **18**, each of the signals presented thereto from the port **16** and antenna **20**, representing both the transmitted signal S_T and the returned signal S_R have no, or 0°, phase shift imposed thereon during the first one T_1 of the alternate half-cycles of the clock signal present on input **26**. Conversely, during the other of the alternate half-cycles T_2, each of the signals S_T and S_R have a $\pi/2$ or 90° phase shift imposed thereon.

The transmitted signal S_T then passes from the phase shifter **18** to the antenna **20**, from which it travels to and is reflected by a target, if one is present, designated symbolically at **28**. The microwave radar signal S'_R reflected from the target **28** then returns to the antenna **20**, from which it passes as the reflected signal S'_R to the phase shifter **18**, undergoing phase shift in the manner set forth above depending upon the half-cycle of the clock signal.

The return signal S_R passes from the phase shifter **18** through the circulator **14** and port **22** to the mixer **24**. As has been set forth above, the circulator **14** additionally provides the signal S_1 from the oscillator **12** to the mixer **24**. The mixer **24** forms a product signal S_{IF} (FIG. 4) which is then provided to an amplifier **30** for amplification and filtering about a center intermediate frequency (IF) signal corresponding to the clock signal provided to the phase shifter **18** over input **26**. The output of the amplifier **30** for an example doppler signal (FIG. 3) is shown at FIG. **5**. The output of the amplifier **30** is then furnished to a demodulator **32**. The demodulator **32** further receives the clock signal provided to the phase shifter **18** at an input terminal **34** so that the doppler signal present in the output of the amplifier **30** may be demodulated, forming an example signal shown in FIG. **6** which is provided to a suitable display indicator **36**.

With the present invention, it is possible to phase modulate the path of both the transmitted signal S_T and the reflected return signal S_R in the phase shifter **18** by electronically changing the path by ± one-fourth wave length at a suitable intermediate frequency signal, for example ten-thousand times per second. This causes the reflected return signal S_R entering the mixer **24** to be phase modulated $\pm\pi/2$ radians at an intermediate frequency of ten-thousand times per second. The circulator **14** forms a sum of the transmitter leakage signal S_1 and the reflective signal S_R which is fed to the diode mixer **24**. As has been set forth above, the mixer **24** forms an output signal which has a direct current term proportional to the sum of the RMS values of the leakage signal S_1 and the reflective signal S_R. In addition to this direct current term, the output of the mixer **24** contains noise and the product of the leakage signal S_1 and the return signal S_R. The doubled frequency terms formed by multiplication of the leakage signal and the return signal in the mixer **24** are removed by filtering in the amplifier **30**.

For situations where:

(a) the period of the clock signal very greatly exceeds the roundtrip delay time between antenna and target, or

Period of clock>>roundtrip delay time; and

(b) the maximum doppler frequency is very much less than the clock frequency, or

Max doppler freq<<clock frequency

with the present invention it can be shown that the output signal from the amplifier **30** is a bi-phase modulated signal containing a noise component, a clock signal and a doppler component introduced by relative motion of the target **28** with respect to the antenna **20**. This type of signal according to the present invention can be amplified and filtered to reduce the noise component much more easily than a base band signal of the type produced by prior doppler radars.

Thus, with the present invention, the alternating doppler signal is translated to an intermediate frequency (IF) where such signal has less noise. This IF signal further can be filtered and demodulated at a high level so that the doppler signal can be displayed for velocity values as low as zero. Further, at the intermediate frequency level, the direct current signal formed in the mixer **24** is filtered out and thus does not affect the doppler information.

For ease and understanding the present invention, the following explanation of the operation is set forth:

DEFINITIONS

A_1—amplitude constant which depends on transmitting power, etc.

A_2—amplification

ω_0—$2\pi\times 10$ GHz

t—time

α_1—attenuation in waveguide

α_2—attenuation of the reflected return signal

θ—phase shift of signal return

t_d—total time delay between transmitted and reflected return signal

D—distance between transmitter-receiver and target

C—speed of wave

B—reference leakage signal amplitude

T_1, T_2: T_1 low and T_2 high clock

IF—intermediate frequency

S_{IF}—IF signal

S_D—high level doppler signal

Based on the foregoing definitions, the following signals are present in the radar system R:

Oscillator signal

$$S_{osc}=A_1 \sin \omega_o t$$

Transmitted signal

$$S_T=A_1\alpha_1 \sin [\omega_o t+(0(T_1),\pi/2(T_2))]$$

The reflected return signal

$$S_R=A_1\alpha_1\alpha_2 \sin [\omega_o t-\theta-\omega_o t_d+(0(T_1),\pi(T_2))]$$

Reference leakage signal

$$S_1=A_1 B \sin \omega_o t$$

The mixer detector output signal

$$S_{IF}=(S_R+S_1)^2$$

$$S_{IF}=(A_1\alpha_1\alpha_2 \sin [\omega_o t-\theta-\omega_o t_d+(0(T_1),\pi(T_2))])^2+(A_1 B \sin \omega_o t)^2+2A_1 B \sin \omega_o t x A_1\alpha_1\alpha_2 \sin [\omega_o t-\theta-\omega_o t_d+(0(T_1),\pi(T_2))]$$

As has been set forth above, in the amplifier **30**, the direct current term in the mixer detector output signal S_{IF} and the double frequency $2\omega_o$ are filtered out of the mixer detector output signal. Further, the remaining portions of the mixer detector output signal can be categorized as a modified signal S'_{IF} in the form of the product of two signals at the microwave frequency ω_o as follows:

$$S'_{IF}=2A_1B \sin \omega_o t x A_1\alpha_1\alpha_2 \sin [\omega_o t-\theta-\omega_o t_d+(0(T_1),\pi(T_2))]$$

By performing this multiplication operation in the mixer **24** and filtering out the $2\omega_O$ frequency term in the amplifier **30**, the resultant signal presented to the demodulator **32** is a signal which can be characterized as follows:

$$S'_{IF}=A_1^2B\alpha_1\alpha_2 \text{ COS } [\theta+\omega_o t_d-(0(T_1),\pi(T_2))]$$

As has been set forth above, this signal can be amplified to a high level without losing the doppler information since it is at an intermediate frequency, in effect substituting the amplification A_2 for the initial amplitude constant A_1.

In the demodulator **32**, the doppler signal S_D is formed as follows:

$$S_D = A_2^2B\alpha_1\alpha_2 \text{ COS}[\theta + \omega_o t_d - (0(T_1), \pi(T_2)] \times \text{COS}(0(T_1), \pi(T_2))]$$

$$= \tfrac{1}{2} A_2^2B\alpha_1\alpha_2[\text{COS}(\theta\ \omega_o t_d) + \text{COS}(\theta + \omega_o t - 2(0(T_1), \pi(T_2))]$$

The last component of frequency of the preceding equation represents twice the clock signal (FIG. 2) which is a much higher frequency than the other two components of the doppler signal S_D, which can also be filtered out in demodulator **32**, forming the output doppler frequency signal S_D expressed as follows:

$$S'_D=\tfrac{1}{2}A_2^2B\alpha_1\alpha_2 \text{ COS } (\theta+\omega_o t_d)$$

which is presented to the range rate display **36**.

For a constantly moving target, the doppler frequency is represented by the time derivative of the preceding expression, and since θ is a constant, the doppler frequency F_D is defined as follows:

D = distance to target

$$td = \frac{2D}{C}$$

$$W_{doppler}\, t = \theta + \omega_o \frac{2D}{C}$$

$$\frac{d}{dt} W_{doppler}\, t = \frac{d}{dt}\left(\theta + \omega_o \frac{2D}{C}\right)$$

Distance is function of time

$$F_D = 0 + F_0\, 2\, \frac{V_r}{C}$$

where F_O is the oscillator frequency, V_r is the radial velocity and $W_{doppler}$ is 2π times the doppler frequency.

With the present invention, the low level detected signal which can vary from 0.1 volt to one microvolt can be easily amplified at the intermediate frequency (FIG. 4). This signal can then be filtered for less noise around the center frequency at the intermediate frequency rather than having to be filtered in the base band as with prior art doppler type radars. This intermediate frequency signal can then be demodulated at a high level and the doppler frequency can be displayed for velocity values beginning at zero.

The foregoing disclosure and description of the invention are illustrative and explanatory thereof, and various changes in the size, shape, materials, components, circuit elements, wiring connections and contacts, as well as in the details of the illustrated circuitry and construction may be made without departing from the spirit of the invention:

We claim:

1. A doppler radar system for detecting the range rate of an object at close range comprising:

(a) Local oscillator means for generating a radar signal;

(b) a single antenna for transmitting and receiving radar signals;

(c) means for phase modulating both the transmitted and returned signals with the same modulator and wherein said modulation occurs prior to any signal mixing;

(d) means for mixing the returned signal with the local oscillator signal to form an intermediate frequency signal;

(e) means for amplifying the intermediate frequency signal; and

(f) means for demodulating the amplified intermediate frequency signal to form a doppler signal indicative of the range rate of the object.

2. The radar system of claim **1**, wherein said means for phase modulating comprises:

phase shift means.

3. The radar system of claim **2**, wherein said phase shift means operates on alternate half cycles of an established operating frequency and further comprises:

(a) means for imposing no phase shift in one of the alternate half cycles; and

(b) means for imposing a predetermined phase shift in the other of the alternate half cycles.

4. The radar system of claim **3**, wherein said means for imposing a predetermined phase shift comprises:

means for imposing a 90° phase shift.

5. The radar system of claim **3**, wherein the established operating frequency is an intermediate frequency signal and further including:

clock means for forming the intermediate frequency signal.

6. The radar system of claim **1**, further including:

means for displaying the demodulated signal to indicate the range rate of the object.

7. A method of detecting the range rate of an object at close range comprising the steps of:

(a) forming a radar signal with oscillator means;

(b) transmitting and receiving said signals with the same antenna;

(c) phase modulating both the transmitted and returned signals with the same modulator prior to any signal mixing;

(d) mixing the returned signal with the oscillator signal to form an intermediate frequency signal;

(e) amplifying the intermediate frequency signal; and

(f) demodulating the amplified intermediate frequency signal to form a doppler signal indicative of the range rate of the object.

8. The method of claim **7**, wherein said step of phase modulating is performed during alternate half cycles of an established operating frequency and comprises the steps of:

(a) imposing no phase shift in one of the alternate half cycles; and

(b) imposing a predetermined phase shift in the other of the alternate half cycles.

9. The method of claim 8, wherein said step of imposing a predetermined phase shift comprises the step of: imposing a 90° phase shift.

10. The method of claim 7, further including the step of:

displaying the demodulated signal to indicate the range rate of the object.

* * * * *