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Aker

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(54) **VEHICULAR TRAFFIC SURVEILLANCE DOPPLER RADAR SYSTEM**

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(51) **Int. Cl.**
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G01S 13/58 (2006.01)
G01S 13/91 (2006.01)

(52) **U.S. Cl.** **342/107**; 342/114

(58) **Field of Classification Search** 342/70, 342/107, 127, 146, 109, 114
See application file for complete search history.

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Primary Examiner — Daniel Pihulic

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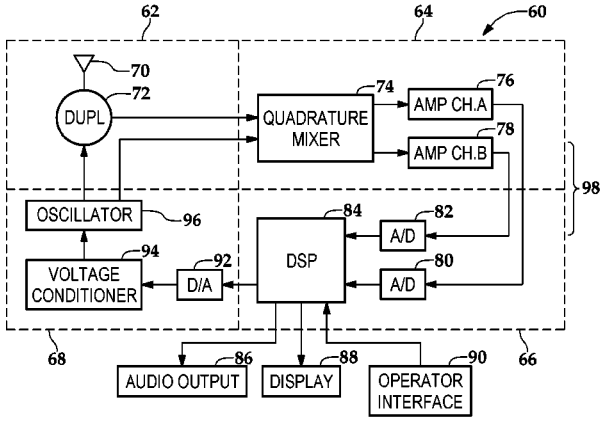
(57) **ABSTRACT**

A vehicular traffic surveillance Doppler radar system and method for use of the same are disclosed. In one embodiment, the system comprises a modulation circuit portion for generating modulated FM signals. An antenna circuit portion transmits the modulated FM signals to a target and receives the reflected modulated FM signals therefrom. A ranging circuit portion performs a quadrature demodulation on the reflected modulated FM signals and determines a range measurement based upon phase angle measurements derived therefrom.

16 Claims, 9 Drawing Sheets



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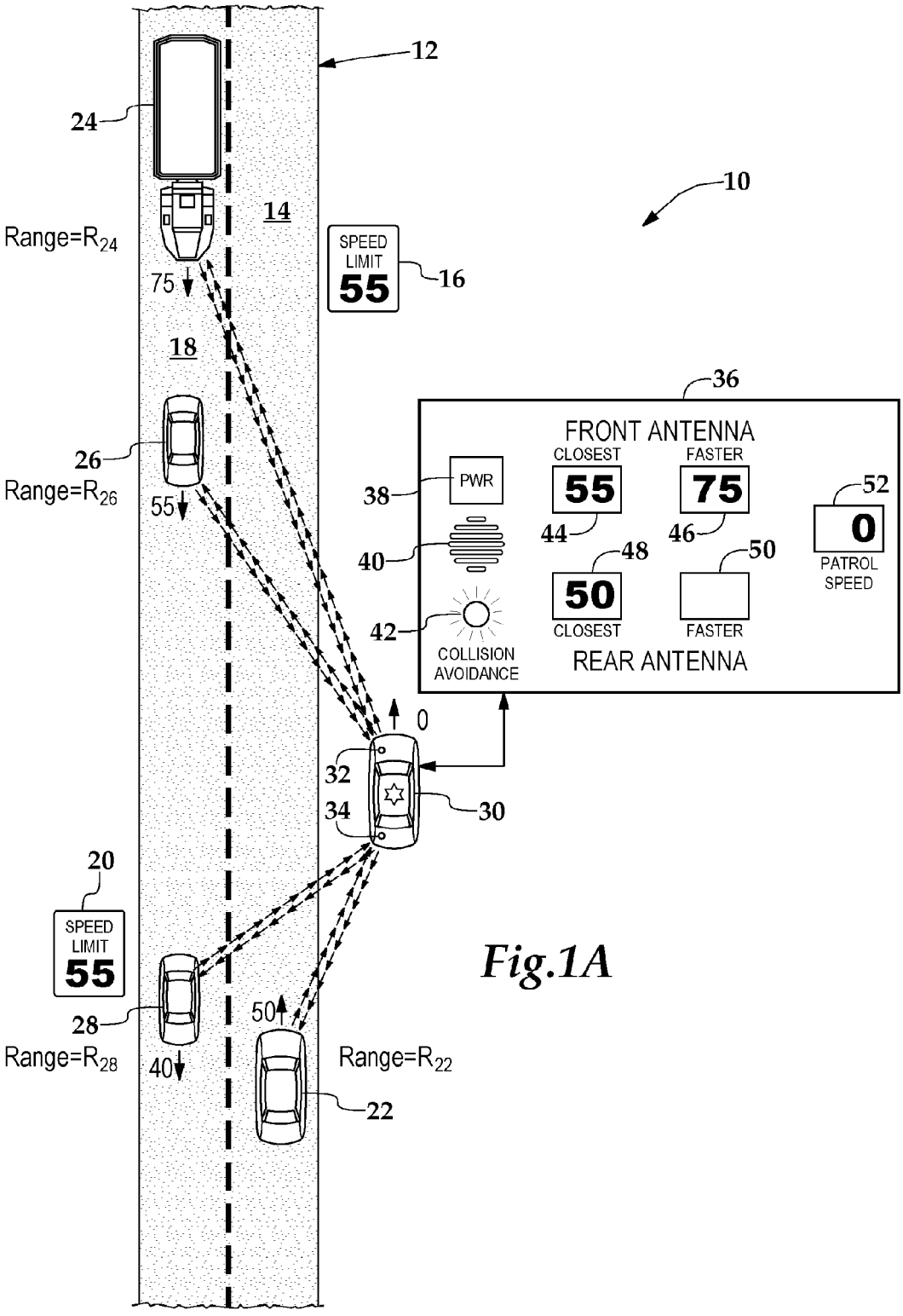
12
24
10
14
Range=R_{24}
SPEED LIMIT 55
16
75
18
36
FRONT ANTENNA
CLOSEST
FASTER
26
Range=R_{26}
38
PWR
55
75
52
0
PATROL SPEED
55
44
46
40
48
50
50
CLOSEST
FASTER
42
COLLISION AVOIDANCE
REAR ANTENNA
0
32
34
30
20
SPEED LIMIT 55
28
Range=R_{28}
40
50
Range=R_{22}
22

Fig.1A

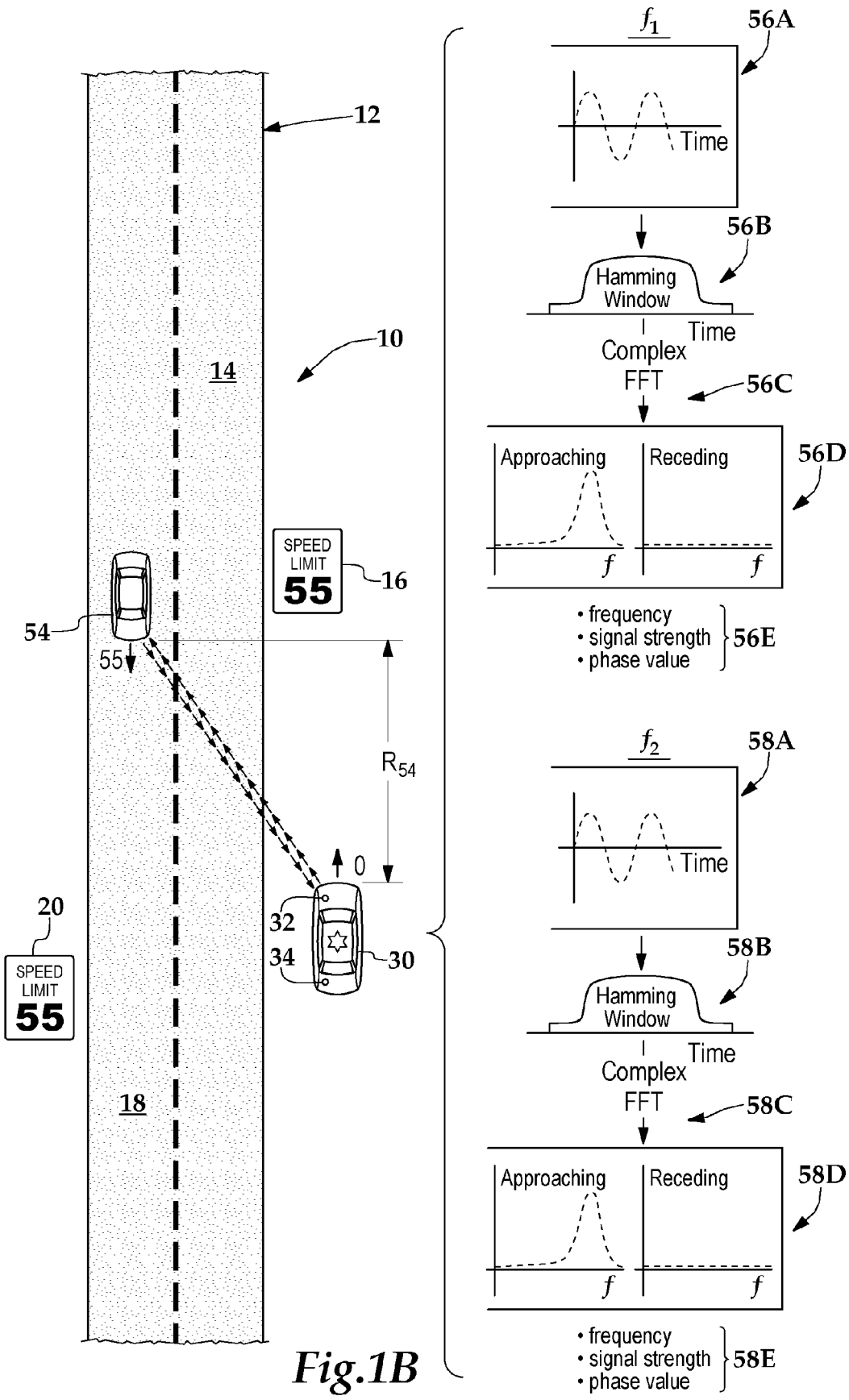
12
10
14
SPEED LIMIT 55
16
54
55
R_{54}
0
20
SPEED LIMIT 55
32
34
30
18
f_1
56A
Time
56B
Hamming Window
Time
Complex FFT
56C
Approaching
Receding
56D
f
f
• frequency
• signal strength
• phase value
56E
f_2
58A
Time
58B
Hamming Window
Time
Complex FFT
58C
Approaching
Receding
58D
f
f
• frequency
• signal strength
• phase value
58E

Fig.1B

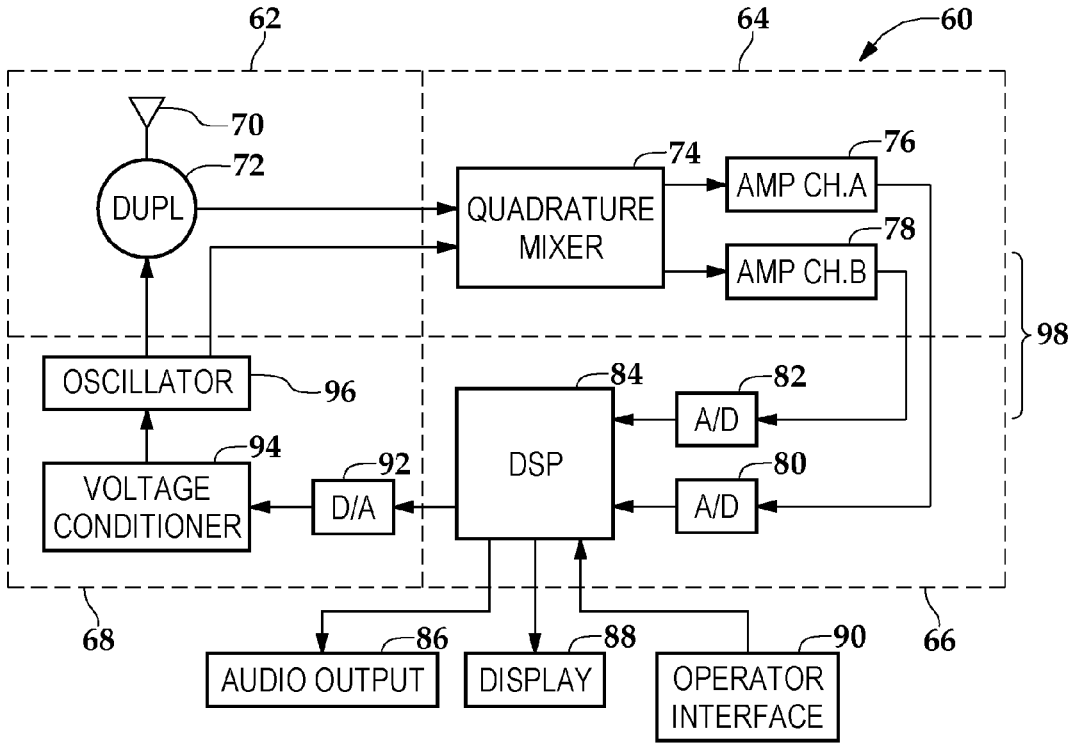
62
64
60
70
72
DUPL
74
QUADRATURE MIXER
76
AMP CH.A
78
AMP CH.B
98
OSCILLATOR
96
84
DSP
82
A/D
94
VOLTAGE CONDITIONER
92
D/A
80
A/D
68
66
86
AUDIO OUTPUT
88
DISPLAY
90
OPERATOR INTERFACE

Fig.2

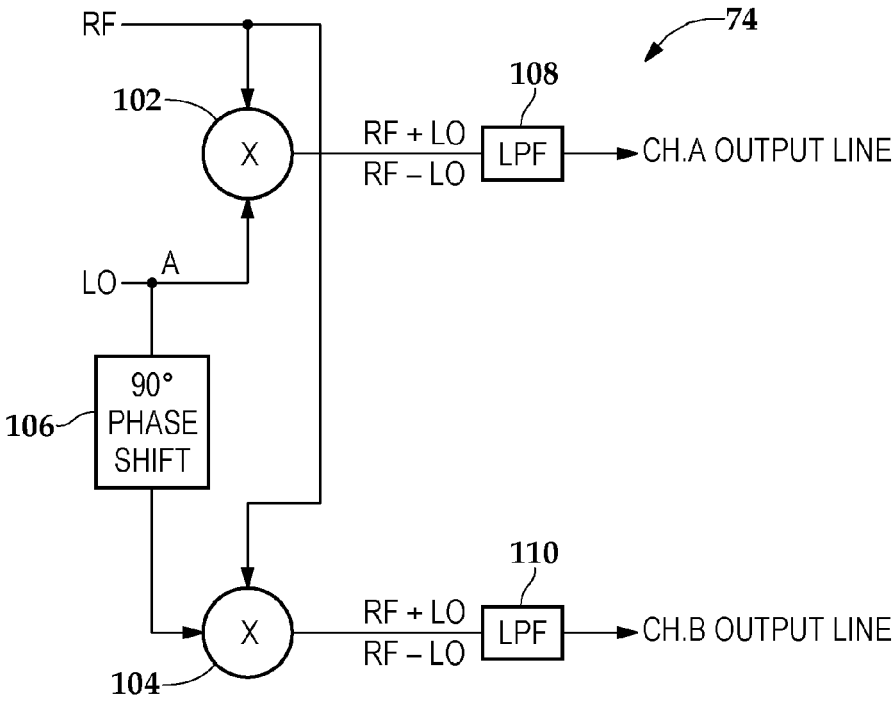
RF
74
102
108
X
RF + LO
RF – LO
LPF
CH.A OUTPUT LINE
LO
A
90°
PHASE
SHIFT
106
110
X
RF + LO
RF – LO
LPF
CH.B OUTPUT LINE
104

Fig.3

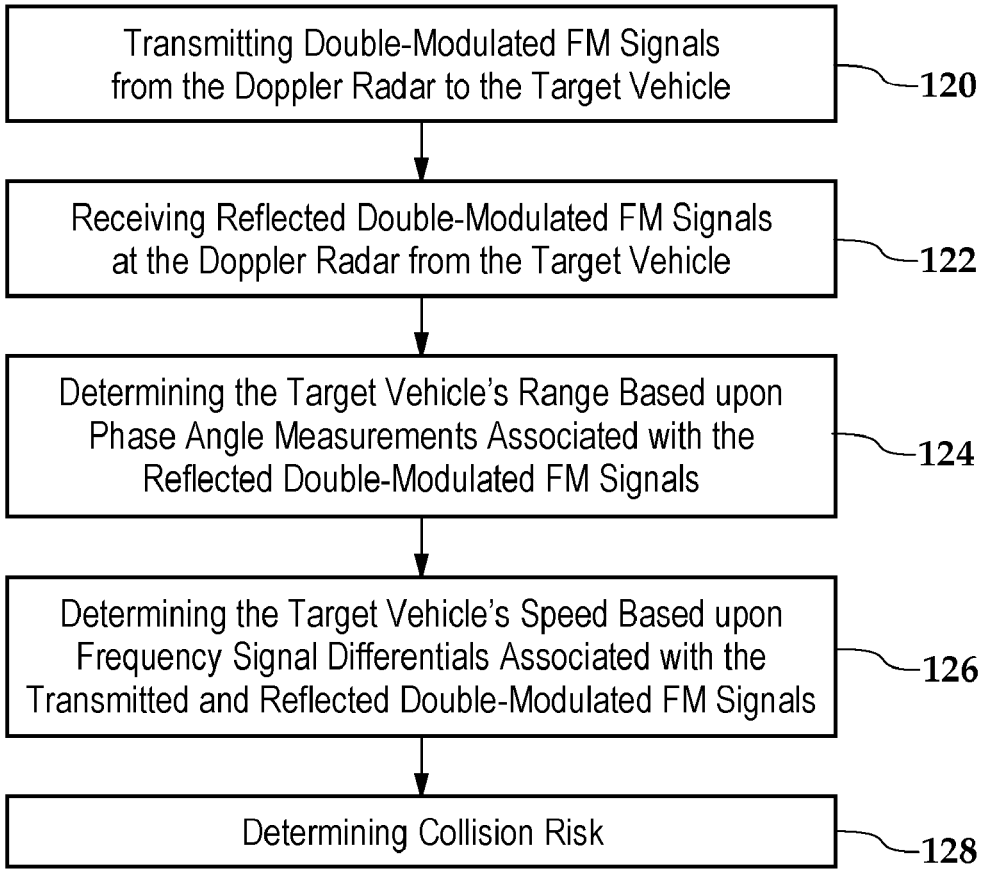
Transmitting Double-Modulated FM Signals from the Doppler Radar to the Target Vehicle
120
Receiving Reflected Double-Modulated FM Signals at the Doppler Radar from the Target Vehicle
122
Determining the Target Vehicle's Range Based upon Phase Angle Measurements Associated with the Reflected Double-Modulated FM Signals
124
Determining the Target Vehicle's Speed Based upon Frequency Signal Differentials Associated with the Transmitted and Reflected Double-Modulated FM Signals
126
Determining Collision Risk
128

Fig.4

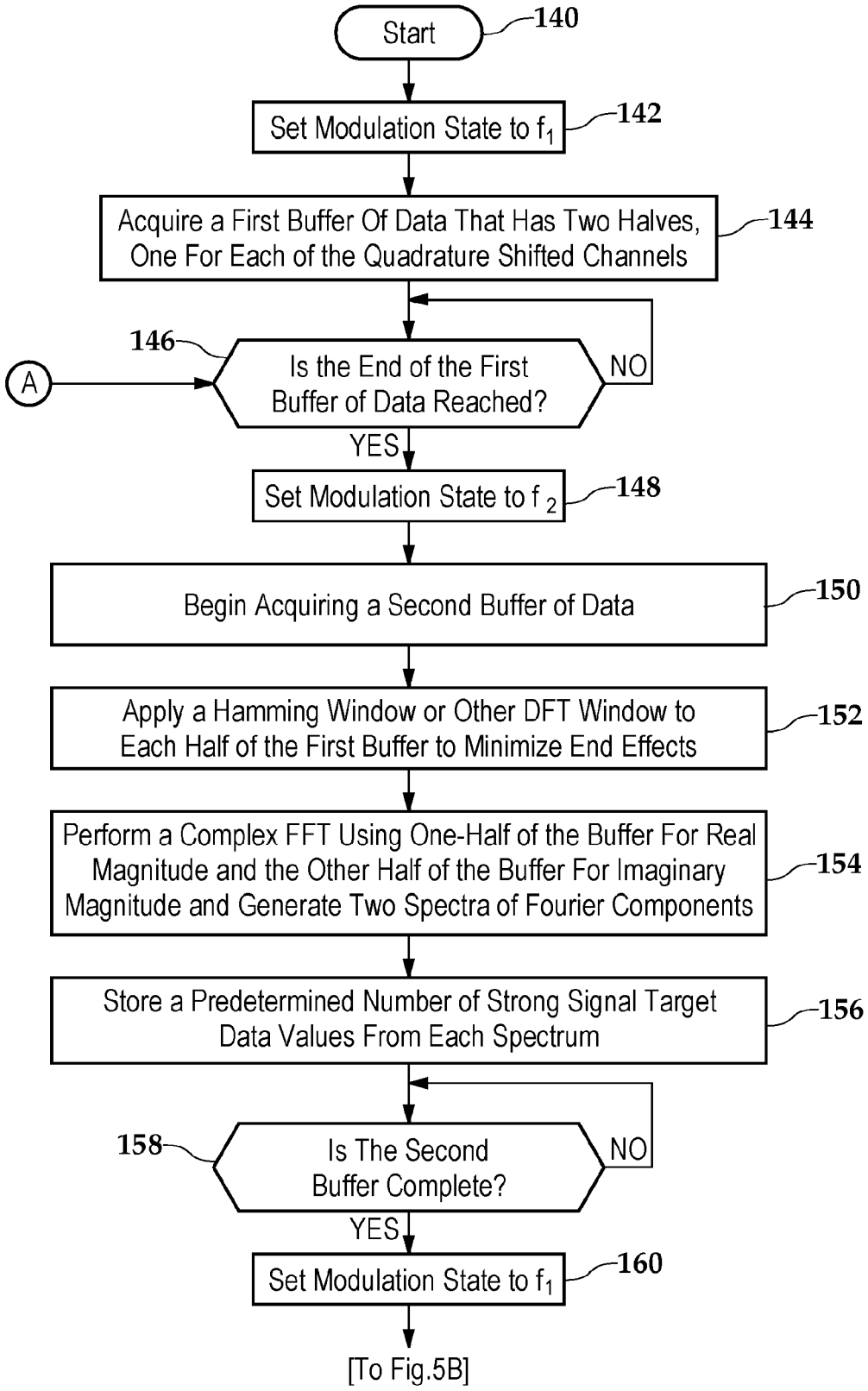
Start
140
Set Modulation State to f_1
142
Acquire a First Buffer Of Data That Has Two Halves, One For Each of the Quadrature Shifted Channels
144
146
A
Is the End of the First Buffer of Data Reached?
NO
YES
Set Modulation State to f_2
148
Begin Acquiring a Second Buffer of Data
150
Apply a Hamming Window or Other DFT Window to Each Half of the First Buffer to Minimize End Effects
152
Perform a Complex FFT Using One-Half of the Buffer For Real Magnitude and the Other Half of the Buffer For Imaginary Magnitude and Generate Two Spectra of Fourier Components
154
Store a Predetermined Number of Strong Signal Target Data Values From Each Spectrum
156
158
Is The Second Buffer Complete?
NO
YES
Set Modulation State to f_1
160
[To Fig.5B]

Fig.5A

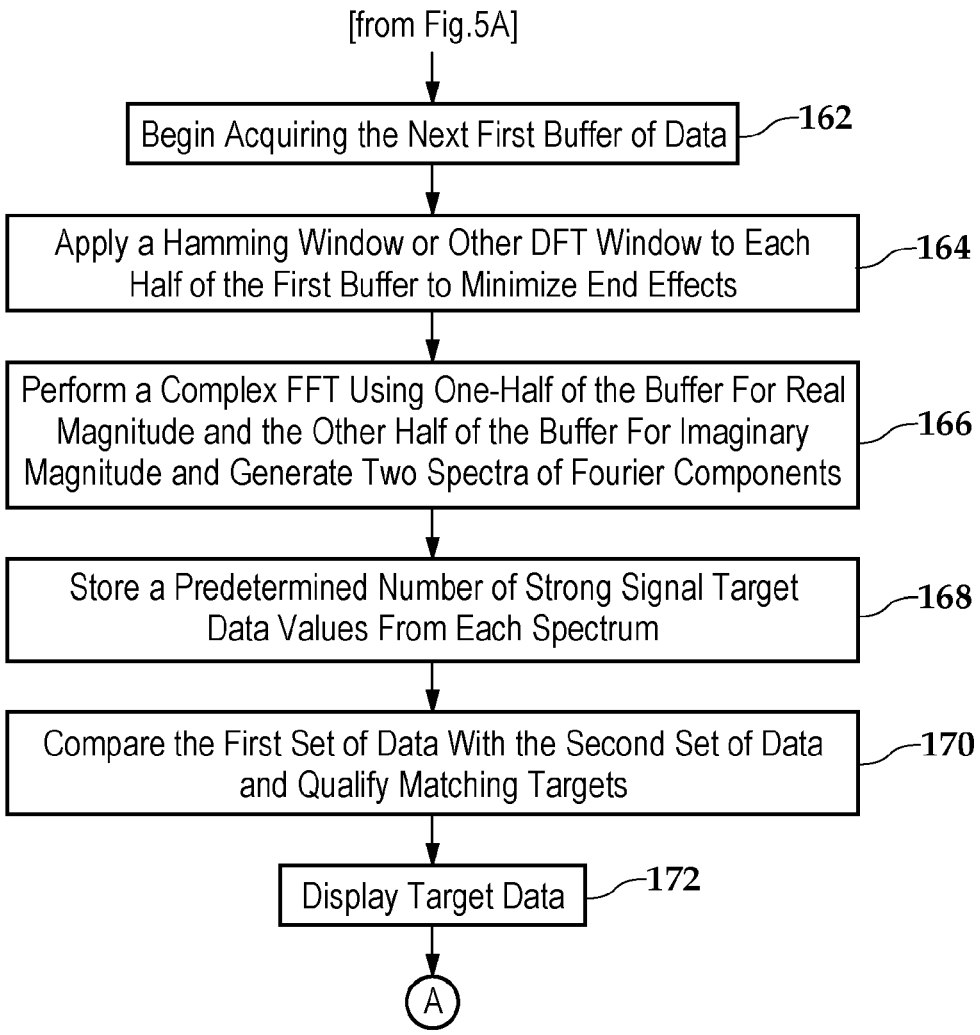
[from Fig.5A]
Begin Acquiring the Next First Buffer of Data
162
Apply a Hamming Window or Other DFT Window to Each Half of the First Buffer to Minimize End Effects
164
Perform a Complex FFT Using One-Half of the Buffer For Real Magnitude and the Other Half of the Buffer For Imaginary Magnitude and Generate Two Spectra of Fourier Components
166
Store a Predetermined Number of Strong Signal Target Data Values From Each Spectrum
168
Compare the First Set of Data With the Second Set of Data and Qualify Matching Targets
170
Display Target Data
172
A

Fig.5B

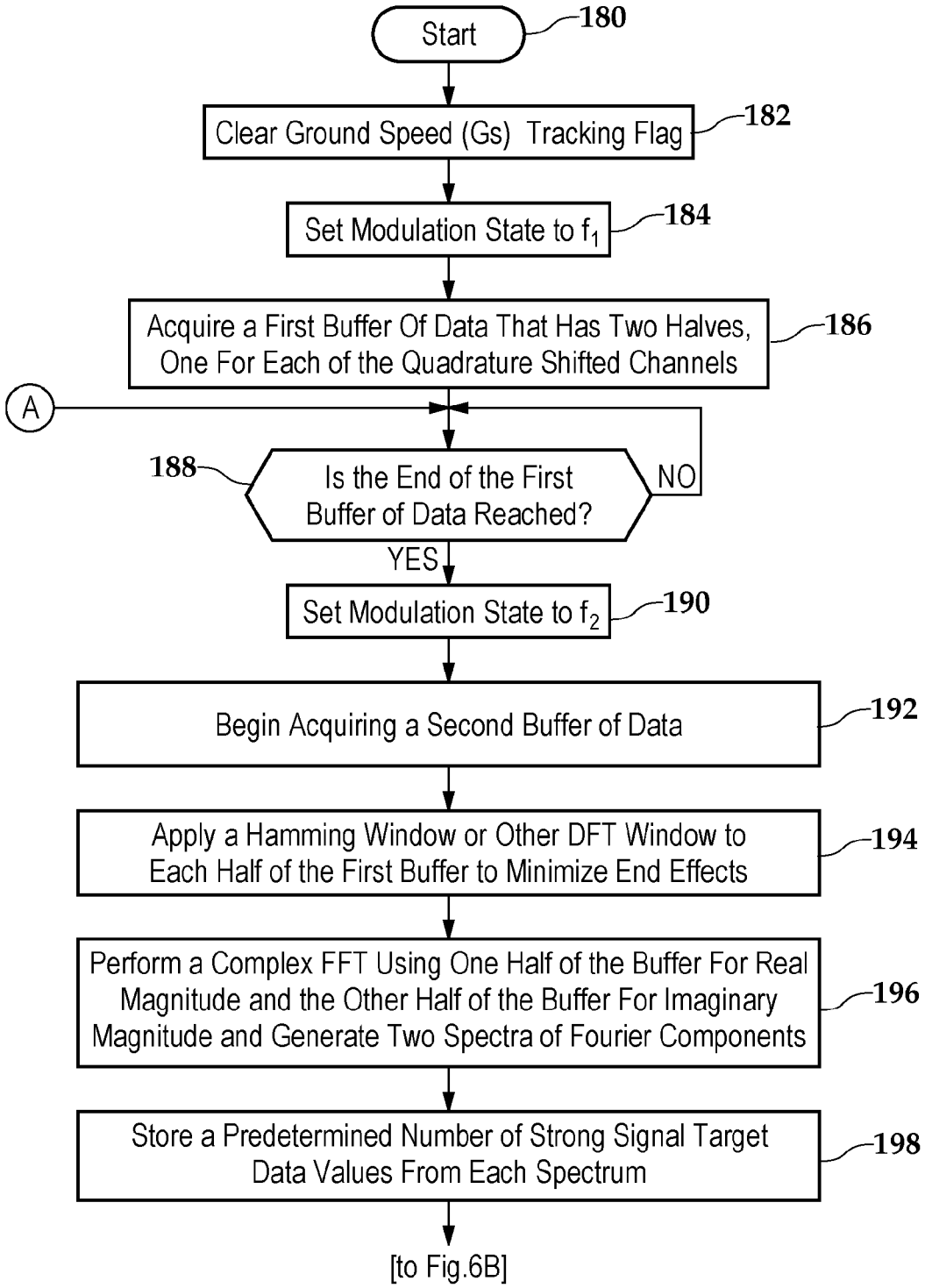
Start
180
Clear Ground Speed (Gs) Tracking Flag
182
Set Modulation State to f_1
184
Acquire a First Buffer Of Data That Has Two Halves, One For Each of the Quadrature Shifted Channels
186
A
188
Is the End of the First Buffer of Data Reached?
NO
YES
Set Modulation State to f_2
190
Begin Acquiring a Second Buffer of Data
192
Apply a Hamming Window or Other DFT Window to Each Half of the First Buffer to Minimize End Effects
194
Perform a Complex FFT Using One Half of the Buffer For Real Magnitude and the Other Half of the Buffer For Imaginary Magnitude and Generate Two Spectra of Fourier Components
196
Store a Predetermined Number of Strong Signal Target Data Values From Each Spectrum
198
[to Fig.6B]

Fig.6A

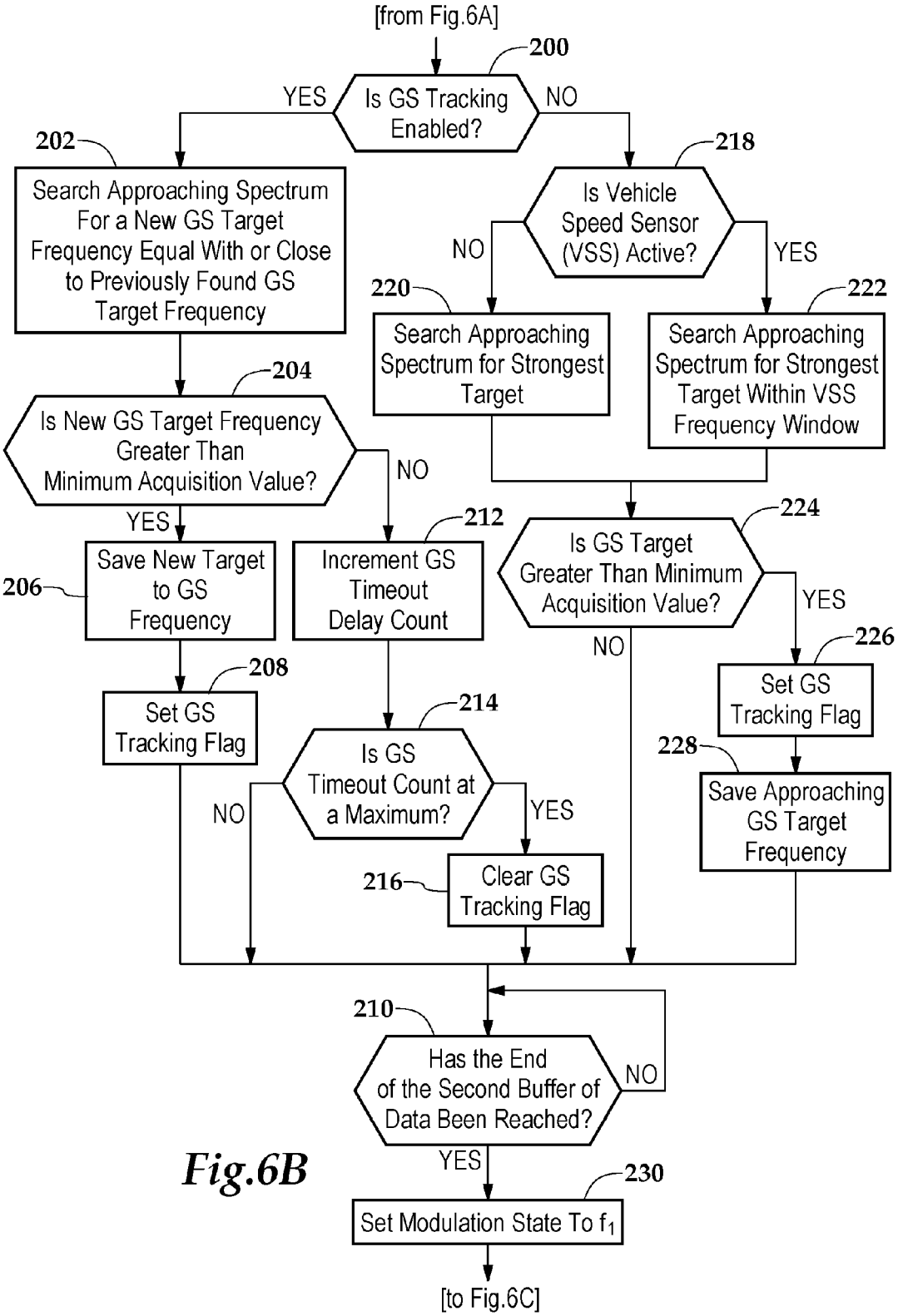
[from Fig.6A]
200
Is GS Tracking Enabled?
YES
NO
202
Search Approaching Spectrum For a New GS Target Frequency Equal With or Close to Previously Found GS Target Frequency
218
Is Vehicle Speed Sensor (VSS) Active?
NO
YES
220
Search Approaching Spectrum for Strongest Target
222
Search Approaching Spectrum for Strongest Target Within VSS Frequency Window
204
Is New GS Target Frequency Greater Than Minimum Acquisition Value?
NO
YES
206
Save New Target to GS Frequency
212
Increment GS Timeout Delay Count
224
Is GS Target Greater Than Minimum Acquisition Value?
YES
NO
226
Set GS Tracking Flag
208
Set GS Tracking Flag
214
Is GS Timeout Count at a Maximum?
NO
YES
228
Save Approaching GS Target Frequency
216
Clear GS Tracking Flag
210
Has the End of the Second Buffer of Data Been Reached?
NO
YES
230
Set Modulation State To f_1
[to Fig.6C]

Fig.6B

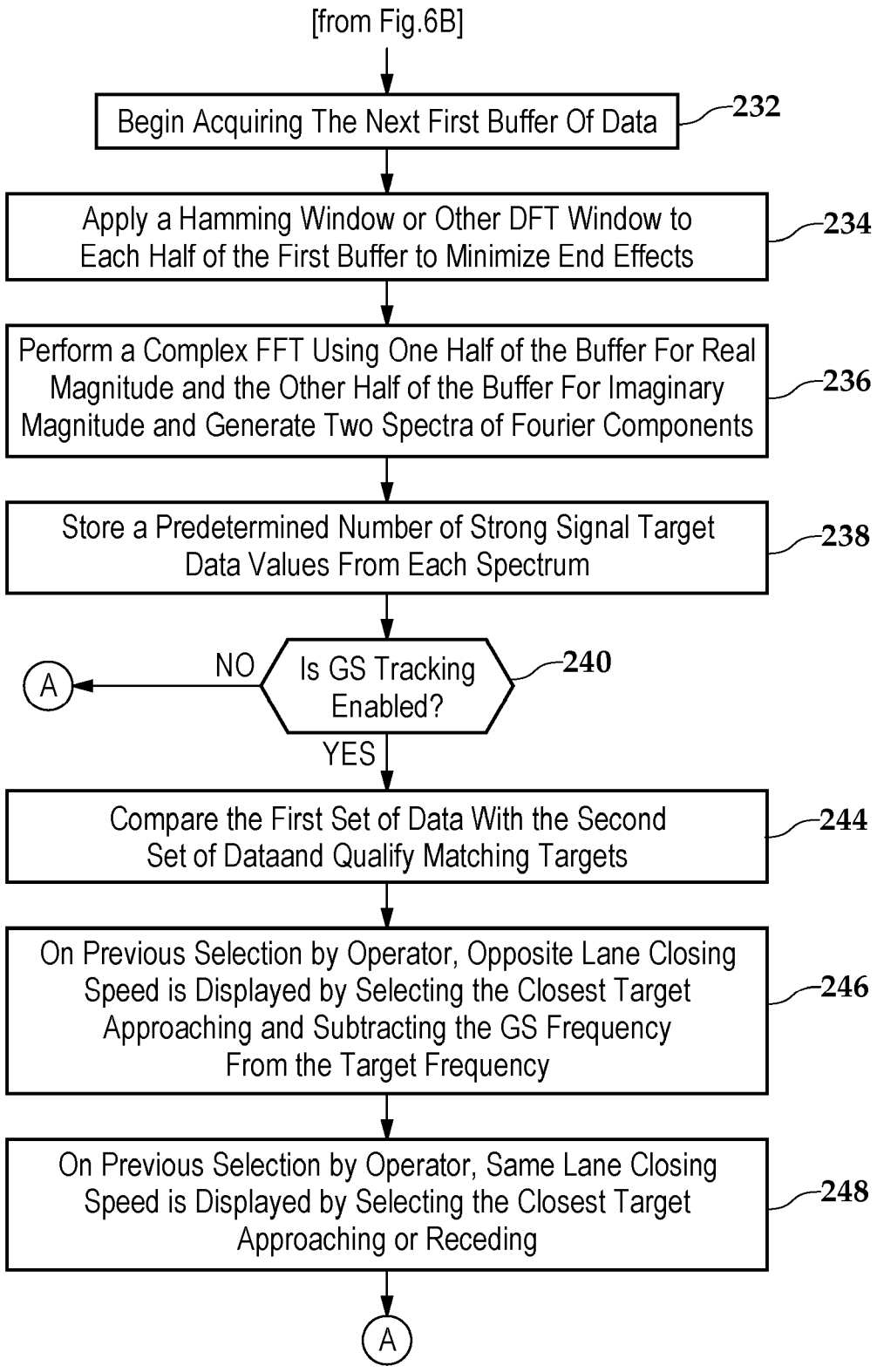
[from Fig.6B]
Begin Acquiring The Next First Buffer Of Data
232
Apply a Hamming Window or Other DFT Window to Each Half of the First Buffer to Minimize End Effects
234
Perform a Complex FFT Using One Half of the Buffer For Real Magnitude and the Other Half of the Buffer For Imaginary Magnitude and Generate Two Spectra of Fourier Components
236
Store a Predetermined Number of Strong Signal Target Data Values From Each Spectrum
238
Is GS Tracking Enabled?
240
NO
A
YES
Compare the First Set of Data With the Second Set of Dataand Qualify Matching Targets
244
On Previous Selection by Operator, Opposite Lane Closing Speed is Displayed by Selecting the Closest Target Approaching and Subtracting the GS Frequency From the Target Frequency
246
On Previous Selection by Operator, Same Lane Closing Speed is Displayed by Selecting the Closest Target Approaching or Receding
248
A

Fig.6C

VEHICULAR TRAFFIC SURVEILLANCE DOPPLER RADAR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/984,577 entitled "Vehicular Traffic Surveillance Doppler Radar System" and filed on Jan. 4, 2011, in the name of John L. Aker, which issued as U.S. Pat. No. 8,138,966 on Mar. 20, 2012; which is a continuation of U.S. patent application Ser. No. 11/757,872 entitled "Vehicular Traffic Surveillance Doppler Radar System" and filed on Jun. 4, 2007, in the name of John L. Aker, which issued on Jan. 4, 2011 as U.S. Pat. No. 7,864,102; which is a continuation of U.S. patent application Ser. No. 11/279,383 entitled "Vehicular Traffic Surveillance Doppler Radar System," filed on Apr. 11, 2006, and issued on Jun. 5, 2007 as U.S. Pat. No. 7,227,494 in the name of John L. Aker; which is a continuation of U.S. patent application Ser. No. 11/059,476, entitled "Vehicular Traffic Surveillance Doppler Radar System", filed on Feb. 16, 2005, and issued on May 2, 2006 as U.S. Pat. No. 7,038,614 in the name of John L. Aker; all of which are hereby incorporated by reference for all purposes.

TECHNICAL FIELD OF THE INVENTION

This invention relates, in general, to police radar systems and, in particular, to a vehicular traffic surveillance Doppler radar system that is operable to determine the range of a target.

BACKGROUND OF THE INVENTION

The role of radar in traffic safety enforcement is widespread throughout the United States and the principal tool for police traffic surveillance is Doppler radar. In a police Doppler radar system, an emitted microwave frequency signal is reflected from a target vehicle, causing a change in the frequency of the signal in proportion to a component of the velocity of the target vehicle. The Doppler radar system measures the frequency differential and scales the measurement to miles per hour, for example, in order to display the velocity of the target vehicle to a policeman or other Doppler radar system operator. Using the existing frequency differential scheme, conventional police Doppler radar systems are capable of a high degree of accuracy with regard to vehicle speed measurements in environments having one target vehicle.

It has been found, however, that the existing police Doppler radar systems are not necessarily successful in environments having multiple vehicles in position to reflect the radar signal. In particular, identification of the vehicle whose speed is being displayed when multiple vehicles are in a position to reflect the radar signal has proven difficult due to "look-past error," which occurs in situations where the intended target vehicle in the foreground has a significantly smaller radar cross-section than an unintended target vehicle in the background. Accordingly, further improvements are warranted in the field of traffic surveillance Doppler radar systems.

SUMMARY OF THE INVENTION

A system and method are disclosed that provide for a vehicular traffic surveillance Doppler radar which substantially eliminates look-past error by determining the range and speed of vehicles in multiple vehicle environments. In particular, the range of the target may be utilized in a comparative fashion in a multi-vehicle environment to determine which vehicle is closer or the closest. Also, the range of the target may be utilized in conjunction with the speed and heading of the target to determine the risk of a collision between the target and a patrol vehicle.

In one embodiment, a system comprises a modulation circuit portion for generating modulated FM signals, such as double-modulated FM signals. An antenna circuit portion transmits the modulated FM signals to a target and receives the reflected modulated FM signals therefrom. A ranging circuit portion, which may include a quadrature circuit portion and a processing circuit portion, performs a quadrature demodulation on the reflected modulated FM signals and determines a range measurement based upon phase angle measurements derived therefrom.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

FIG. **1**A depicts a schematic illustration of a multiple vehicle environment wherein one embodiment of a system for traffic surveillance is being utilized;

FIG. **1**B depicts a schematic illustration of a single vehicle environment wherein one embodiment of a system for determining a range of a target is being utilized;

FIG. **2** depicts a schematic diagram of one embodiment of the vehicular traffic surveillance Doppler radar system;

FIG. **3** depicts a schematic diagram of one embodiment of a quadrature mixer for the vehicular traffic surveillance Doppler radar system;

FIG. **4** depicts a flow chart of one embodiment of a method for determining a range of a target and avoiding a collision;

FIGS. **5**A and **5**B together depict a flow chart of another embodiment of a method for determining a range of a target; and

FIGS. **6**A, **6**B, and **6**C together depict a flow chart of a further embodiment of a method for determining a range of a target.

DETAILED DESCRIPTION OF THE INVENTION

While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and do not delimit the scope of the present invention.

Referring initially to FIG. **1**A, therein is depicted an environment **10** having multiple vehicles wherein one embodiment of the vehicular traffic surveillance Doppler radar system is being utilized. A highway **12** includes a northbound lane **14** having a speed limit of 55 mph as depicted by speed limit sign **16** and a southbound lane **18** having a speed limit of 55 mph as depicted by speed limit sign **20**. A vehicle **22** is traveling in the northbound lane **14** at a speed of 50 mph as indicated by the northbound arrow and number "50" proximate to the front portion of the vehicle **22**. Vehicles **24**, **26**, and **28** are traveling in the southbound lane **18** at speeds of 75 mph, 55 mph, and 40 mph, respectively. A patrol vehicle **30** equipped with a vehicular traffic surveillance Doppler radar

system is stationary and facing north in a location that is proximate to the northbound lane **14**. The vehicle **22** is approaching the patrol vehicle **30** quickly. Additionally, with respect to the position of patrol vehicle **30**, vehicles **24** and **26** are positioned such that conditions are present for look-past error.

A front-facing antenna **32** and a rear-facing antenna **34** are mounted on the patrol vehicle **30** for surveying traffic. A control panel **36** is associated with the patrol vehicle **30** and preferably secured to the dashboard in the interior of the patrol vehicle **30**. The control panel **36** includes a power button **38**, a speaker **40**, and a collision avoidance indicator **42**. Displays **44** and **46** indicate the speeds (in mph) of the closest vehicle and the faster vehicle, respectively, associated with the front-facing antenna **32**. Similarly, displays **48** and **50** indicate the speeds (in mph) of the closest vehicle and the faster vehicle, respectively, associated with the rear-facing antenna **34**. In instances where only one vehicle is associated with the rear-facing antenna **34**, the display **50** is empty. A display **52** indicates the speed (in mph) of the patrol vehicle **30**. It should be appreciated that the displays **44-52** may either be dedicated to displaying the indicators discussed hereinabove or configurable to provide other types of indications. For example, a display may be configured to provide a history of the speed of a particular targeted vehicle.

As illustrated, the patrol vehicle **30** is monitoring the traffic in both the northbound lane **14** and southbound lane **18**. With regard to both antennas **32** and **34**, the vehicular traffic surveillance Doppler radar system is in a stationary, closest and faster, approaching only mode. In this mode, the police vehicle **30** is stationary and monitoring the speeds of both the closest and faster vehicles approaching the police vehicle **30**. It should be appreciated, however, that other modes of operation are within the teachings of the present invention. By way of example, the following table provides a non-exhaustive matrix of the more common operator selectable modes of the multi-mode radar system disclosed herein.

TABLE I

Common Operator Selectable Modes

Patrol Vehicle	Type of Signal(s)	Receding/Approaching
Stationary	Closest and Faster	Approaching
Stationary	Closest and Faster	Receding or Approaching
Stationary	Closest and Faster	Receding
Stationary	Closest	Approaching
Stationary	Closest	Receding or Approaching
Stationary	Closest	Receding
Moving	Closest and Faster	Approaching
Moving	Closest and Faster	Receding or Approaching
Moving	Closest and Faster	Receding
Moving	Closest	Approaching
Moving	Closest	Receding or Approaching
Moving	Closest	Receding

With respect to the forward-facing antenna **32**, the officer operating the vehicular traffic surveillance Doppler radar system is intending to target vehicle **26** which is a small sports car having a relatively small radar cross-section (σ_1). The forward-facing antenna **32** emits double-modulated FM signals that spread less than ten degrees from an axis of the forward-facing antenna **32**. It should be appreciated that although the present invention is described as utilizing double-modulated FM signals, other types of modulated FM signals may be utilized. For example, triple and higher order modulated FM signals may be utilized. In one embodiment, the double-modulated FM signals are a continuous wave signal transmission that is alternated between a first and second frequency, which may be expressed as f_1 and f_2, respectively. The double-modulated FM signals reflect off of the vehicle **26** and the vehicle **24** which is a large truck having a relatively large radar cross-section (σ_2), wherein $\sigma_2 >> \sigma_1$. Hence, the vehicle **24** has a stronger reflected signal than the vehicle **26** even though the vehicle **24** is farther away from the patrol vehicle **30** than the vehicle **26**. The reflected double-modulated FM signals generated by the vehicles **24** and **26** are received by the forward-facing antenna **32** and processed to resolve the multiple targets by determining the direction, speed, and range of the targeted vehicles **24** and **26**.

As will be discussed in further detail hereinbelow, the vehicular traffic surveillance Doppler radar system receives the reflected double-modulated FM signals and performs a quadrature demodulation on the reflected double-modulated FM signals. In one embodiment, homodyne reception is utilized wherein a voltage having the original carrier frequency is generated and combined with the incoming reflected double-modulated FM signals. The quadrature demodulated, reflected FM signals are then converted to digital signals and a fast Fourier transform (FFT) is performed that results in an approaching or closing target spectrum and a receding or opening target spectrum. In one implementation, a complex FFT is performed on the data. Analysis of the resulting spectra using the multi-direction sensing capabilities of the instant police radar indicates that both of the vehicles **24** and **26** are approaching. The frequency signal differentials associated with each target are also analyzed to determine that the vehicle **24** is traveling at 75 mph and the vehicle **26** is traveling at 55 mph. The phase angle signal differentials associated with each of the targets are analyzed to determine that the vehicle **24** is at a range of R_{24} and that the vehicle **26** is at a range of R_{26}. As $R_{26} << R_{24}$, the vehicle **26** is closer to the patrol vehicle **30** than the vehicle **24**. The speed of the closest vehicle, i.e., vehicle **26**, is indicated at the display **44** and the speed of the faster vehicle, i.e., vehicle **24**, is indicated at display **46**.

The police officer operating the vehicular traffic surveillance Doppler radar system uses the displayed information to determine that the closest target, which is vehicle **26**, is traveling at 55 mph and a more distant target, which is vehicle **24**, is traveling at 75 mph. Existing radar systems assume that the strongest target is the closest target; namely, the vehicle **26** in the illustrated example. Accordingly, if patrol vehicle **30** had been equipped with an existing radar system, then the vehicle **26** could have appeared to have been traveling 75 mph in a 55 mph zone. The vehicular traffic surveillance Doppler radar system presented herein avoids this false positive due to look-past error by calculating target ranges based upon the phase angle signal differentials associated with the targets rather than assuming signal strength is indicative of range and, in particular, the strongest signal is from the closest vehicle.

With respect to the rear-facing antenna **34**, the officer operating the vehicular traffic surveillance Doppler radar system is intending to target vehicle **22**. The emitted double-modulated FM signals reflect from the vehicle **22** and the vehicle **28** which is heading south in the southbound lane **18**. The reflected double-modulated FM signals are processed to determine the direction, speed, and range of the targets. The vehicle **28** is receding from the patrol vehicle **30**, so the speed and range of the vehicle **28** are ignored since the vehicular traffic surveillance Doppler radar system is in an approaching only mode. The speed, 50 mph, and range, 300 ft, of the

vehicle **22** are determined and the display **48** indicates that the closest vehicle is traveling at 50 mph. The police officer uses the displayed information to determine that vehicle **22** is traveling at 50 mph.

Further, the vehicular traffic surveillance Doppler radar system includes safety features that determine if conditions are safe for the patrol vehicle **30** to pull-out in front of oncoming traffic based on the speed and range of the oncoming vehicles. Based on the speed (50 mph) and the range (300 ft) of the vehicle **22**, the vehicular traffic surveillance Doppler radar system determines that conditions are hazardous and a collision with vehicle **22** is possible if the patrol vehicle **30** pulls into the northbound lane **14**. In one implementation, to indicate that conditions are hazardous and a collision is possible, the vehicular traffic surveillance Doppler radar system provides a visual indication via collision avoidance indicator **42** and an audio indication via speaker **40** to the police officer operating the vehicular traffic surveillance Doppler radar system. In one embodiment, the visual collision avoidance indicator **42** and the audio indication via speaker **40** are only enabled when the patrol vehicle **30** is in motion. In another embodiment, the operator of the patrol vehicle **30** may turn the collision avoidance system OFF and ON as the system is needed.

FIG. **1**B depicts the environment **10** of FIG. **1**A wherein one embodiment of a system for determining the range of a target vehicle is being utilized. As illustrated, the patrol vehicle **30** is monitoring a vehicle **54** traveling at a speed of 55 mph in the southbound lane **18**. Forward-facing antenna **32** transmits a continuous FM signal to the vehicle **54** and receives a reflected double-modulated signal therefrom. The frequency signal differentials associated with the signals are analyzed to determine that the vehicle is traveling at 55 mph. In particular, when the double-modulated FM signal is reflected from the vehicle **54**, the frequency of the reflected double-modulated FM signal is shifted in proportion to a component of the velocity of the vehicle **54**. The shift or frequency signal differential between the double-modulated FM signal and the reflected double-modulated FM signal provides the speed of vehicle **54**. In instances where triple or higher order modulated FM signals are utilized, mathematical "fold overs" are used to remove phase ambiguities and distinguish between short and long range targets so that target metrics such as speed, heading, and range can be determined.

Further, the phase angle signal differentials associated with the reflected double-modulated signal are analyzed to determine that the vehicle **54** is at a range of R_{54} from the patrol vehicle **30**. More specifically, the range, R_{54}, is related to the change or differential in phase, Δ_{phase}, in the reflected double-modulated signal by the following range equation:

$$R_{54}=(\Delta_{phase}*c)/(4\pi(f_2-f_1)), \text{ where}$$

$\Delta_{phase}=\phi_2-\phi_1$ for the phase angle signals (ϕ) in first and second sets of data (phase angle may be expressed in radians);

f_1 and f_2 are the frequencies utilized in the double-modulated signal (frequency may be expressed in gHz); and

c is the speed of light (186,282 miles/second).

Utilizing the relationships described by the range equation, the traffic surveillance Doppler radar system determines the phase magnitude between the phase angle signals (ϕ) to arrive at a target range. For example, if the change in phase, Δ_{phase}, of the received reflected double-modulated signal is +/−180° and f_1=34.7 gHz and f_2=34.7001 gHz, then the range, R_{54}, of the vehicle **54** is 2,460 ft (0.47 miles). In multi-vehicle environments, such as the environment described in FIG. **1**A, by calculating the range of each vehicle in the multi-vehicle environment, the Doppler radar system described herein is able to determine which vehicle is the closest or which vehicle is closer. Additionally, the range of the target may be utilized in conjunction with the speed and the heading of the target to determine the risk of a collision between the target and a patrol vehicle.

More specifically, to determine the range, speed, and heading of the target vehicle, for example, the Doppler radar system sets the modulation state to frequency f_1 and a processor, such as a digital signal processor (DSP), within the Doppler radar system acquires a full buffer of data **56**A for each of two quadrature demodulated channels. Once the buffer is full, a Hamming window **56**B or other discrete Fourier transform (DFT) window is applied to both channels of data. A complex FFT **56**C is performed and two spectra **56**D of Fourier components are outputed, i.e., one for the approaching targets and one for the receding targets. Targets that are heading towards the Doppler radar are located in the approaching spectra and targets that are heading away from the Doppler radar are located in the receding spectra. The spectra **56**D are searched for the strongest target signals and data **56**E, such as frequency, signal strength, and phase angle value (ϕ_1), is stored for each target signal. For example, with respect to the vehicle **54**, the approaching portion of spectra **56**D is searched and frequency and phase value measurements are stored.

In one embodiment, at the end of the collection of the first buffer of data **56**A and during the processing depicted by numerals **56**B through **56**E, the modulation state is set to frequency f_2 and a second buffer of data **58**A is collected before a sequence of data processing operations **58**B through **58**E are executed which are analogous to the processing operations **56**B through **56**E. In particular, the phase angle value (ϕ_2) for the second set of data is collected. Once the data **58**E is collected, the phase angle values (ϕ_1 and ϕ_2) for the target signals in spectra **56**D and **58**D that correspond to the vehicle **54** are compared and the change in phase angle, Δ_{phase}, is utilized to calculate the range of the vehicle **54** as described by the range equation presented hereinabove. Additionally, to determine the speed of the vehicle **54**, the frequency of the f_1 or f_2 signal is measured since the change in frequency is proportional to a component of the velocity of the target vehicle. It should be appreciated that the speed and the range of the vehicle may be calculated in any order or simultaneously.

FIG. **2** depicts one embodiment of the vehicular traffic surveillance Doppler radar system which is generally designated **60**. The vehicular traffic surveillance Doppler radar system includes an antenna circuit portion **62**, a quadrature circuit portion **64**, a processing circuit portion **66**, and a modulation circuit portion **68**. The antenna circuit portion **62** includes an antenna **70** that transmits outgoing radar waves in the form of double-modulated FM signals and receives reflected double-modulated FM signals from stationary and moving objects including intended and unintended target vehicles. A duplexer **72** guides the outgoing double-modulated FM signals from the modulation circuit portion **68** to antenna **70** and guides reflected radar waves received by antenna **70** to the quadrature circuit portion **64**.

The quadrature circuit portion **64** includes a quadrature mixer **74** coupled to the duplexer **72** in order to receive the reflected double-modulated FM signals. The quadrature circuit portion **64** is also coupled to the modulation circuit portion **68** in order to receive a local oscillator signal. As will be explained in further detail in FIG. **3**, the quadrature mixer **74** performs a quadrature demodulation by mixing the local oscillator signal with incoming RF of reflected radar waves in two separate mixers in two separate channels such that one

channel is shifted by 90° relative to the other channel. The quadrature demodulation results in a channel A signal that is driven to amplifier **76** and a channel B signal that is driven to amplifier **78**. Preferably, amplifiers **76** and **78** are matched, low noise amplifiers. The amplified channel A and B signals are driven to the processing circuit portion **66** and received by analog-to-digital (A/D) converters **80** and **82**, respectively. The A/D converters **80** and **82** sample the analog signals from amplifiers **76** and **78**, respectively, and output the sampled signals as digital data sampled signals on one or more transmission paths, such as busses, infrared (IR) communication paths, or cables, connected to a DSP **84**.

The DSP **84** processes the digital data samples from channels A and B by performing a FFT thereon to develop the aforementioned approaching target Fourier spectrum and receding target Fourier spectrum. The target Fourier spectra are searched for targets and the direction each target is traveling relative to the patrol vehicle is identified. Data associated with the spectra is further analyzed to determine the speeds of the identified targets based upon frequency signal differentials associated with the targets. Additional information regarding the direction and speed sensing capabilities of the radar system of the present invention may be found in the following co-owned United States patents: (1) U.S. Pat. No. 6,198,427, entitled "Doppler Complex FFT Police Radar With Direction Sensing Capability," issued on Mar. 6, 2001 in the names of Aker et al.; and (2) U.S. Pat. No. 6,646,591, entitled "Doppler Complex FFT Police Radar With Direction Sensing Capability," issued on Nov. 22, 2003 in the names of Aker et al.; both of which are hereby incorporated by reference for all purposes.

As previously discussed, the range of the identified target is calculated based upon a phase angle signal differential associated with the target. In particular, the ranging circuit portion **98**, which in one embodiment includes the quadrature circuit portion **64** and the processing circuit portion **66**, determines the heading of the target as well as the range of the target. In one implementation, heading or direction is determined by comparing the phases or lead/lad relationship of two frequencies. For example, a target at 1000 ft. might lead by 70 degrees if closing and lag by 70 degrees if opening. With respect to the range of the target, in regard to a particular target, the phase angle is arbitrary. However, the difference between the phase angle for the particular target with respect to a first set of data and the phase angle for the particular target with respect to a second set of data is indicative of the range between the police Doppler radar of the present invention and the particular target. Accordingly, the vehicular surveillance Doppler radar system described herein permits target discrimination between any two targets including two targets of the same speed traveling in opposite directions.

Target metrics, such as direction or heading, speed, and range, determined by the DSP **84** are provided to the operator via an audio output **86** and a display **88**, which, in one implementation, may be control unit **36** of FIG. **1**. An operator interface **90**, which may include front panel or remote controls, provides for general operation of the system including operator selectability of the aforementioned multiple modes of operation. It should be appreciated that the range measurements may be presented in a comparative fashion where one vehicle is indicated to be closer or the closest relative to one or more other vehicles.

A D/A convertor **92** receives multiple digital signals from the DSP **84** and converts these signals to a voltage which is supplied to a voltage conditioner **94** which may be a voltage regulator or varactor device, for example. Operating in combination with the converter **92**, the voltage conditioner **94** provides two voltages to an oscillator **96** that, in turn, generates the double-modulated FM signals. In particular, a frequency versus voltage characteristic that is associated with the oscillator **96** is utilized to generate two frequencies with only a relatively small difference in the applied voltages. In one embodiment, the DSP **84** determines the required calibration and generates a calibration signal indicative of the voltages required to generate the desired frequencies. The calibration signal is received by the D/A converter **92**, which in combination with the voltage conditioner **94**, applies the two voltages to the oscillator **96** that generate the desired double-modulated frequency.

Further information regarding the target range self-calibrating capabilities of the radar system of the present invention may be found in the following commonly owned, patent application: "System and Method for Calibrating a Vehicular Traffic Surveillance Doppler Radar," filed on Feb. 16, 2005, assigned application Ser. No. 11/059,474, and issued on Jun. 6, 2006 as U.S. Pat. No. 7,057,550 in the name of John L. Aker; which is hereby incorporated by reference for all purposes.

In one implementation, the oscillator **96** comprises a dielectric resonator oscillator (DRO) or a Gunn diode oscillator that utilizes a negative resistance property of bulk gallium arsenide (GaAs) to convert an applied DC voltage into microwave power. Further information regarding the modulation circuit portion **68** may be found in the following commonly owned, patent application: "Modulation Circuit for a Vehicular Traffic Surveillance Doppler Radar System," filed on Feb. 16, 2005, assigned application Ser. No. 11/059,199, and issued on May 23, 2006 as U.S. Pat. No. 7,049,999 in the name of John L. Aker; which is hereby incorporated by reference for all purposes.

It should be appreciated by those skilled in the art that although a particular arrangement of circuitry has been illustrated with respect to the radar system of the present invention, the radar system of the present invention may comprise any combination of hardware, software, and firmware. In particular, each of the circuit portions **62**, **64**, **66**, and **68** of the present invention may comprise any combination of hardware, software, and firmware.

FIG. **3** depicts one embodiment of the quadrature mixer **74**. As previously discussed, the function of the quadrature mixer **74** is to mix local oscillator energy with incoming RF of reflected radar waves in two separate mixers in two separate channels and shift one channel 90° relative to the other channel. Incoming RF from the duplexer **72** is provided to a channel A mixer **102** and a channel B mixer **104**. Local oscillator (LO) energy arrives from oscillator **96** and is provided as a second input to mixer **102**. The local oscillator energy is also coupled to a second input of mixer **104** via a phase shifter **106** which, in the illustrated embodiment, is a 90° phase shifter. The phase shifter **106** shifts the local oscillator signal by 90°, or any integer multiple of 90°, in either direction relative to the local oscillator signal. In an alternative embodiment, instead of shifting the local oscillator signal by 90°, the incoming RF can be shifted by 90° at the input of one mixer relative to the same incoming RF at the input of the other mixer.

The 90° phase shift can be achieved in any known manner associated with quadrature demodulation. In the preferred embodiment, the 90° phase shift is achieved by having a microwave transmission line which is one-quarter wavelength (at the frequency of operation) longer in the path from the local oscillator or RF input to one mixer than it is in the path to the other mixer. By way of example, other techniques such as reactive circuits or delay lines may also be used.

The mixers **102** and **104** modulate the local oscillator signals with the Doppler shifted RF signals reflected from stationary and moving objects and output sum and difference frequencies on a channel A output line and a channel B output line. Low pass filters **108** and **110** are coupled to the channel A and B output lines, respectively, in order to remove the upper sideband (local oscillator plus Doppler shifted RF) signals from each of the spectrum on the channel A and B output lines so that only the difference frequencies are outputed. Preferably, to reduce errors and noise, the mixers **102** and **104** and low pass filters **108** and **110** are matched as closely as possible since amplitude variations between channels A and B may cause noise in the system.

FIG. **4** depicts one embodiment of a method for avoiding collisions between a source vehicle, such as a law enforcement cruiser or motorcycle, having a Doppler radar associated therewith and a target vehicle. At block **120**, double-modulated FM signals are transmitted from the Doppler radar to the target vehicle. The double-modulated signals may be the aforementioned double-modulated f_1 and f_2 FM signals. At block **122**, the Doppler radar receives reflected double-modulated FM signals from the target vehicle. At block **124**, the target vehicle's range is determined based upon phase angle measurements associated with the reflected double-modulated FM signals. As part of determining the range, a quadrature demodulation may be performed on the reflected double-modulated FM signals. At block **126**, the target vehicle's speed is determined based upon frequency signal differentials associated with the transmitted and reflected double-modulated FM signals. It should be appreciated that the operations presented in blocks **124** and **126** may be performed simultaneously or in another order such as reverse order. At this time, the heading or direction of the target vehicle with respect to the source vehicle may also be determined. At block **128**, the risk of collision between the source vehicle and the target vehicle is determined. The risk of collision is related to several variables including the speed of the source vehicle and the speed, heading, and range of the target vehicle. For example, if the source vehicle, i.e., patrol vehicle, is stationary and the target vehicle is approaching at 50 mph at a range of 300 feet then the target vehicle will be passing the patrol vehicle in approximately 4 seconds. Hence, the patrol vehicle does not have enough time to merge into the approaching or oncoming traffic and the Doppler radar notifies the operator that a risk of collision is present. It should be appreciated that the time threshold for safe merger/risk of collision is adjustable. For example, the time threshold may be set for 10 seconds. Further, the time threshold may be adjusted in accordance with the time of day, road conditions, and weather, for example.

FIGS. **5**A and **5**B together depict another embodiment of a method for determining a range of a target. At block **140**, the Doppler radar is operating in a stationary patrol vehicle, closest target, receding or approaching only mode that is implemented utilizing a relative distance measurement process. At block **142**, the modulation state is set to frequency f_1. At block **144**, a first buffer of data is acquired that has two halves; namely, one for each of the quadrature shifted channels. At waiting block **146**, once the end of the first buffer of data is reached, the methodology advances to block **148** wherein the modulation state is set to frequency f_2.

At block **150**, the second buffer of data is collected. While this second buffer of data is being collected, the methodology continues to block **152** where a Hamming window or other DFT window is applied to each half of the first buffer of data in order to minimize end effects. At block **154**, a complex FFT is performed utilizing one-half of the buffer as the real magnitude and utilizing the other half buffer as the imaginary magnitude. This generates two spectra of Fourier components; namely, one spectra for approaching targets and one spectra for receding targets. These two spectra are searched at block **156** in order to find and store a predetermined number of strong signal target data values and relevant parameters such as frequency, signal strength, and phase value for each target signal.

At waiting block **158**, the methodology waits until the second buffer of data is acquired before advancing to block **160** where the modulation state is returned to frequency f_1 and the next first buffer of data is acquired at block **162**. At blocks **164** through **168**, while the data of the first buffer is being collected, the data of the second buffer is analyzed. Briefly, similar to the operations of blocks **152** through **156**, at block **164**, the end effects of the data are minimized. At block **166**, a complex FFT is performed and at block **168**, a predetermined number of strong signal target data values from each spectrum are recorded. At block **170**, the first set of data recorded at block **156** and the second set of data recorded at block **168** are analyzed to determine various target metrics such as the direction, speed, and range of each target. At block **172**, based on the settings the operator has selected, appropriate target data is displayed. For example, the speed of an approaching target may be displayed in miles per hour. The methodology then returns to decision block **146** as indicated by the letter A.

FIGS. **6**A, **6**B, and **6**C together depict a further embodiment of a method for determining a range of a target. At block **180**, the Doppler radar system is operating in a moving patrol vehicle, closest target, receding or approaching mode that is implemented utilizing a relative distance measurement process. At block **182**, the ground speed tracking flag is cleared. At block **184**, the modulation state is set to frequency f_1. At block **186**, a first buffer of data is acquired and once the end of the first buffer is reached, at block **188**, the methodology advances to block **190** where the modulation state is set to frequency f_2. At block **192**, a second buffer of data is collected. While the second buffer of data is being collected, the first buffer of data is processed and analyzed in blocks **194** through **198**. At block **194**, a Hamming window or other DFT window is applied to each half of the first buffer of data in order to minimize end effects. At block **196**, a complex FFT is performed utilizing one-half of the buffer as the real magnitude and utilizing the other half buffer as the imaginary magnitude. This generates approaching and receding spectra of Fourier components. These two spectra are searched at block **198** in order to find and store a predetermined number of strong signal target data values and relevant parameters such as frequency, signal strength, and phase value for each target signal.

In one embodiment, the ground speed of the patrol vehicle is required in order to accurately determine the speed of a target vehicle. At decision block **200**, if ground speed tracking is enabled, then the methodology advances to block **202** wherein the approaching spectrum is searched for a new ground speed target frequency that is equal with or close to the previously found ground speed target frequency. At decision block **204**, if the new ground speed target frequency is greater than the minimum acquisition value, then a new target to ground speed frequency is saved at block **206**. At block **208**, the ground speed tracking flag is set. At block **210**, the methodology waits for the second buffer of data to be completed.

Returning to decision block **204**, if the new ground speed target frequency is not greater than the minimum acquisition value, then the methodology advances to block **212** wherein the ground speed timeout delay count is incremented. At block **214**, if the ground speed timeout count is at a maximum, then the process advances to block **216** where the ground speed tracking flag is cleared before advancing to block **210**. Otherwise, the process continues directly from block **214** to block **210**.

Returning to decision block **200**, if the ground speed tracking is not enabled, then the methodology advances to blocks **218** through **228** in order to determine the ground speed of the patrol vehicle and activate ground speed tracking. In one embodiment, a target that represents the background radar signal is found as a representation of the ground speed of the patrol vehicle. At decision block **218**, if the vehicle speed sensor is not active, then the approaching spectrum is searched for the strongest target at block **220**. The vehicle speed sensor may be a digital output from the patrol car speedometer, for example. On the other hand, if the vehicle speed sensor is active, then the approaching spectrum is searched for the strongest target within the vehicle speed sensor window.

Once the target is acquired in block **220** or block **224**, the target is tracked to monitor for changes in the ground speed of the patrol vehicle wherein at block **224** if the ground speed target is greater than the minimum acquisition value, the process continues to block **226** where the ground speed tracking flag is set and the approaching ground speed target frequency is saved at block **228** before advancing to block **210**. If the ground speed target was not great enough, then the method advances directly to block **210** and the ground speed acquisition of blocks **218** through **228** will have to be performed again.

As previously discussed, at block **210**, once the second buffer is full of data, the modulation state is set to frequency f_1 at block **230** and the next first buffer of data is acquired at block **232**. While the data is being collected, the second buffer of data is processed and analyzed at blocks **234** through **238**. The processing and analysis of blocks **234** through **238** is similar to the processing and analysis described in blocks **194** through **198**, respectively. At block **240**, if the ground speed tracking is enabled, then the methodology advances to block **244**. Otherwise, the methodology returns to block **188**. At block **244**, the data collected at block **198** is compared to the data collected at block **238** to determine qualifying matches and the range and speed of target vehicles. At block **246**, by previous selection by the operator, Opposite Lane closing speed is displayed by selecting the closest target approaching and subtracting the ground speed frequency from the target frequency. At block **248**, by previous selection by the operator, Same Lane closing speed is displayed by selecting the closest target approaching or receding. If the target is approaching, then the speed is displayed by subtracting the target relative approaching frequency from the ground speed frequency. On the other hand, if the target is receding, then the speed is displayed by adding the target receding frequency to the ground speed frequency. The methodology then returns to block **188**.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. A vehicular traffic surveillance Doppler radar comprising:

an antenna circuit portion configured to receive reflected modulated FM signals from a target;

a ranging circuit portion configured to perform a quadrature demodulation on the reflected modulated FM signals; and

the ranging circuit portion configured to:

acquire a first buffer of data associated with a first frequency of the reflected modulated FM signals while analyzing a second buffer of data associated with a second frequency of the reflected modulated FM signals, and

determine, for the target, a range measurement based upon phase values derived from the data of the second buffer.

2. The vehicle traffic surveillance Doppler radar as recited in claim **1**, wherein the ranging circuit portion is further configured to:

acquire the second buffer while analyzing the first buffer; and

determine, for the target, a range measurement based upon phase values derived from the data of the first buffer.

3. The vehicular traffic surveillance Doppler radar as recited in claim **1**, wherein the ranging circuit portion comprises direction-sensing capabilities to determine a heading of the target with respect to the Doppler radar system.

4. A vehicular traffic surveillance Doppler radar for use in a multiple vehicle environment including a plurality of target vehicles, the vehicle traffic surveillance Doppler radar comprising:

a direction-sensing Doppler radar associated with a source vehicle;

the Doppler radar configured to perform a quadrature demodulation on reflected modulated FM signals received from at least a portion of a plurality of target vehicles;

the Doppler radar configured to:

acquire a first buffer of data associated with a first frequency of the reflected modulated FM signals while analyzing a second buffer of data associated with a second frequency of the reflected modulated FM signals, and

determine, for the at least a portion of the plurality of target vehicles, a range measurement based upon phase values derived from the data of the second buffer.

5. The vehicle traffic surveillance Doppler radar as recited in claim **4**, wherein the ranging circuit portion is further configured to:

acquire the second buffer while analyzing the first buffer; and

determine, for the at least a portion of the plurality of target vehicles, a range measurement based upon phase values derived from the data of the first buffer.

6. The vehicular traffic surveillance Doppler radar as recited in claim **4**, wherein the source vehicle comprises a law enforcement vehicle.

7. The vehicular traffic surveillance Doppler radar as recited in claim **4**, wherein the direction-sensing Doppler radar is configured to determine which of the plurality of target vehicles are approaching and which are receding with respect to the source vehicle.

8. The vehicular traffic surveillance Doppler radar as recited in claim **4**, wherein the source vehicle generates modulated FM signals which are transmitted to the at least a portion of the plurality of the target vehicles and reflected therefrom as reflected modulated FM signals.

9. The vehicular traffic surveillance Doppler radar as recited in claim 8, wherein each of the ranges of the at least a portion of the plurality of target vehicles is determined based upon phase angle measurements associated with the reflected modulated FM signals.

10. The vehicular traffic surveillance Doppler radar as recited in claim 8, wherein a speed of each of the at least a portion of the plurality of target vehicles is determined based upon frequency signal differentials associated with the modulated FM signals and reflected modulated FM signals.

11. A method for operating a vehicular traffic surveillance Doppler radar, the method comprising:

receiving first reflected modulated FM signals at the Doppler radar from a first target;

receiving second reflected modulated FM signals at the Doppler radar from a second target;

acquiring a first buffer of data associated with a first frequency of the first reflected modulated FM signals and the second reflected modulated FM signals while transforming data of a second buffer associated with a second frequency of the first reflected modulated FM signals and the second reflected modulated FM signals to target spectrum;

analyzing frequency signal differentials associated with the target spectrum to determine respective speeds of the first and second targets; and

analyzing phase angle signal differentials associated with the target spectrum to determine respective ranges of the first and second targets.

12. The method as recited in claim 11, further comprising acquiring the second buffer of data while transforming the data of the first buffer to target spectrum.

13. The method as recited in claim 11, further comprising determining which of the first and second targets has a faster speed based on the respective speeds of the first and second targets.

14. The method as recited in claim 11, further comprising determining which of the first and second targets is closer based on the respective ranges of the first and second targets.

15. The method as recited in claim 11, further comprising determining the respective ranges of the first and second target vehicles independently of respective radar cross-sections of the first and second target vehicles.

16. The method as recited in claim 11, further comprising avoiding look-past error by calculating the respective ranges of the first and second target vehicles based upon the phase angle signal differentials.

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