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Map-aware adaptive automotive RADAR

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(54) **MAP AWARE ADAPTIVE AUTOMOTIVE RADAR**

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G01S 13/86 (2006.01)
G01S 13/93 (2006.01)
G01S 13/00 (2006.01)

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CPC ***G01S 13/931*** (2013.01); *G01S 13/86* (2013.01)

(58) **Field of Classification Search**
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USPC 342/13, 16–20, 27, 28, 70–72, 73, 342/82–103, 175, 192–197, 52; 701/1, 701/23–36, 400, 408, 409, 514, 522, 300, 701/301
See application file for complete search history.

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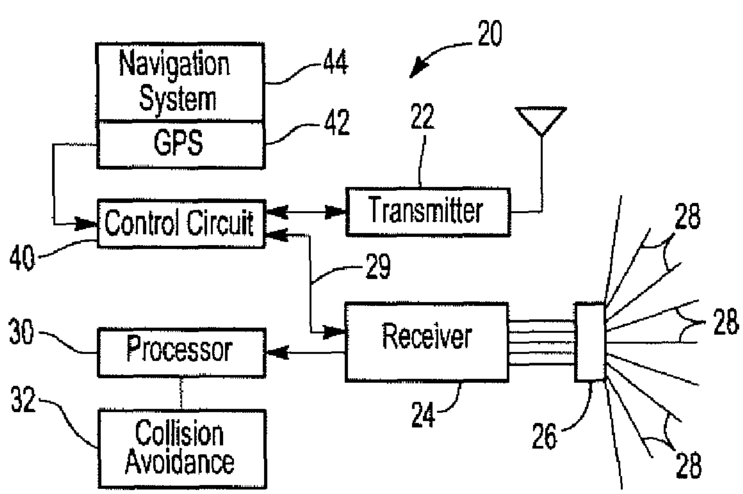
(57) **ABSTRACT**

A dedicated short range radar system is provided for use with a GPS system. The radar system includes a transmitter which transmits a microwave radio signal. A receiver is coupled to a horizontally scanning receiver antenna array which receives an echo, if present, from the radio signal transmitted by the transmitter. The radio receiver then generates an output signal representative of the echo. A control circuit then receives the output signal from the antenna array as well as the output signal from the GPS system. The control circuit then varies the mode of operation of the receiver and/or the transmitter as a function of the type of roadway for optimal radar performance.

15 Claims, 3 Drawing Sheets



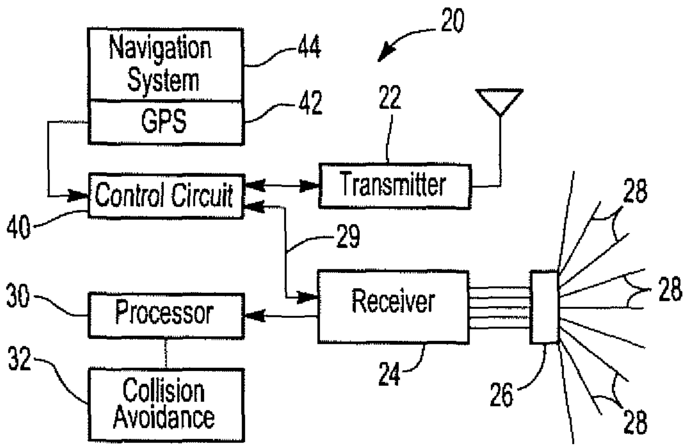


Fig-1

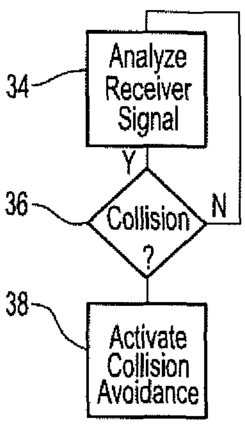


Fig-2

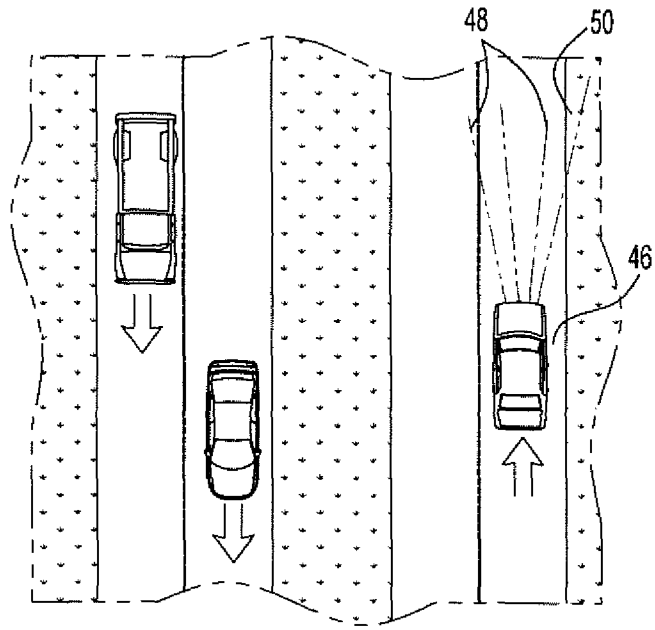


Fig-3

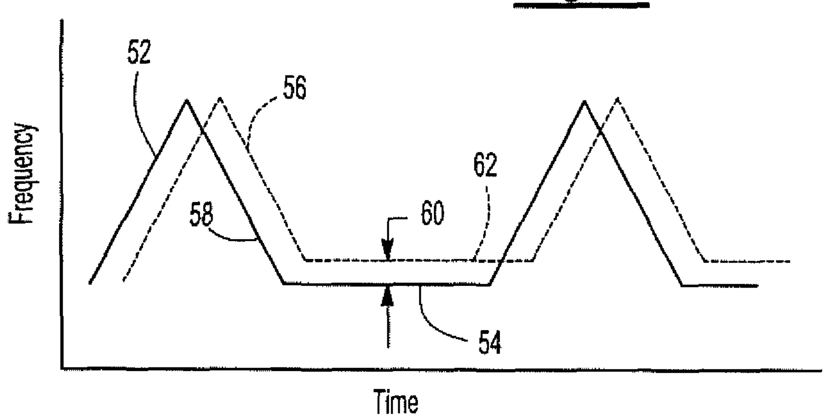


Fig-4

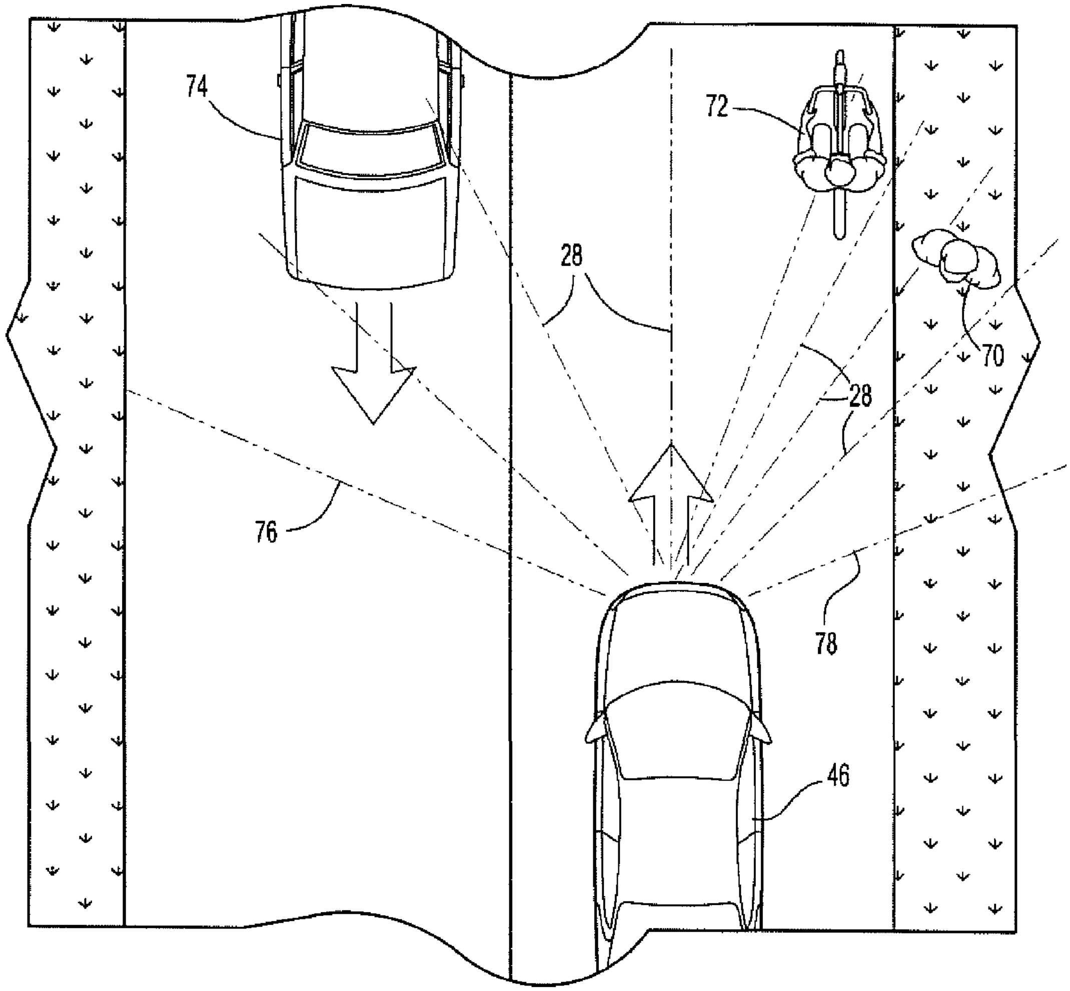


Fig-5

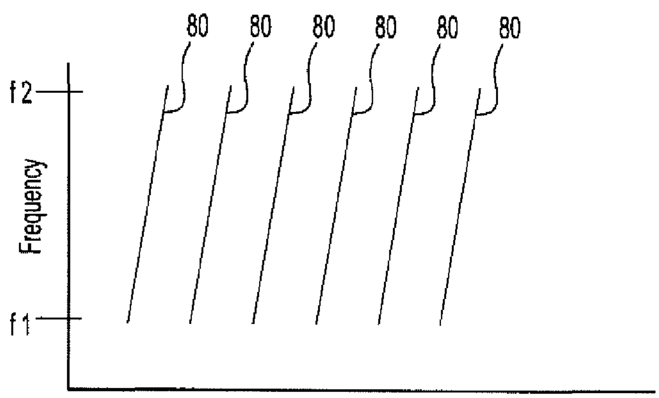


Fig-6

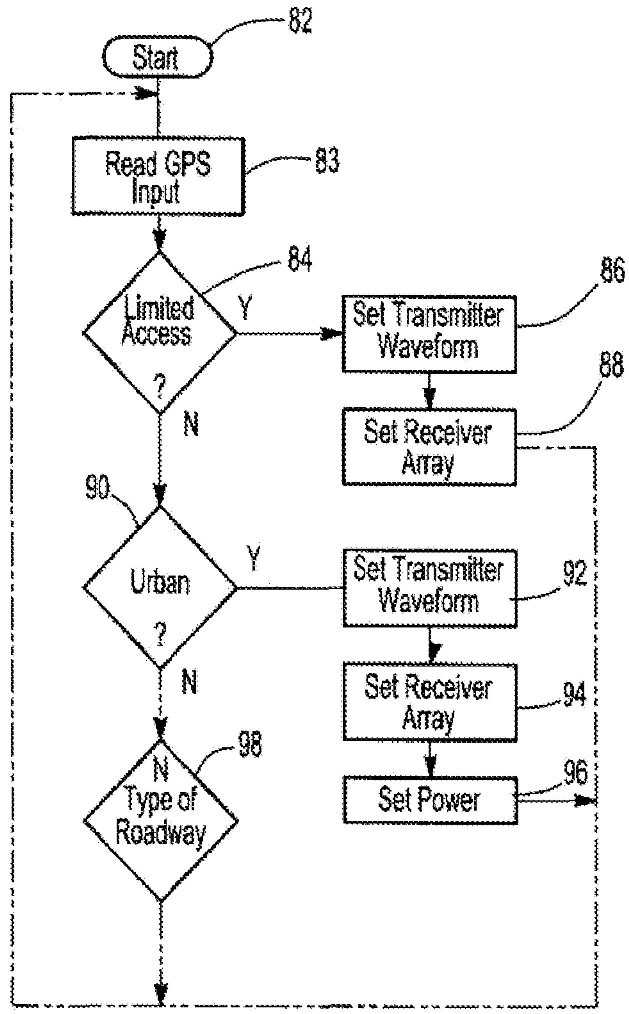

82
Start
Read GPS Input
83
84
Limited Access ?
Y
N
Set Transmitter Waveform
86
Set Receiver Array
88
90
Urban ?
Y
N
Set Transmitter Waveform
92
Set Receiver Array
94
Set Power
96
N Type of Roadway
98

Fig-7

MAP AWARE ADAPTIVE AUTOMOTIVE RADAR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to radar systems and, more particularly, to an automotive dedicated short range radar system.

2. Description of the Related Art

Dedicated short range radar systems for automotive vehicles have enjoyed increased popularity in the United States and elsewhere. Such automotive radar systems have been allotted bandwidth centered at 76.5 gigahertz in the United States by the federal government. Such automotive radar systems are used primarily, but not exclusively, in collision avoidance systems within the automotive vehicle.

Although there are different types of radar systems, many automotive radar systems utilize a continuous wave frequency modulated (CWFM) radar system. In a CWFM radar system, a transmitter transmits a microwave signal, e.g. at a center frequency of 76.5 gigahertz, so that the transmitted radio signal repeatedly sweeps between two frequencies. In the event that there is an object within the range of the vehicle, the transmitted radio frequency is reflected back as an echo towards the vehicle transmitting the radio signal.

In order to receive the echo from the transmitted signal, a horizontally steerable antenna array is also provided on the vehicle. This horizontally steerable array includes a preset number of horizontal scan positions which are horizontally angularly spaced from each other. For example, an antenna array having 16 horizontal scan positions with the first horizontal position directed to the left side of the vehicle, the central horizontal scan position directed straightforwardly of the vehicle, and the 16^{th} horizontal scan position directed towards the right side of the vehicle. The number of horizontal scan positions, furthermore, determines the resolution of the radar system with a higher number of horizontal scan positions resulting in greater resolution.

One disadvantage of these previously known automotive radar systems, however, is that the radar system operates in a constant mode of operation which is selected or designed as a compromise between the various different types of road conditions that will be encountered by the vehicle. For example, during operation of the vehicle on a divided highway limited access roadway, also known as expressways or freeways, the most important information for the operator of the vehicle is relatively long range radar directed forwardly and towards the right side of the vehicle. Furthermore, during such operation, high resolution of the radar system is not required but the accurate measurement of speed changes between the vehicle and the forward vehicles detected by the radar system is of high importance.

Conversely, in an urban or neighborhood environment, the vehicle as well as other objects around the vehicle moves at a much slower rate so that accurate measurement of the speed difference between the vehicle and the surrounding objects is less important than on a divided highway. However, in an urban or neighborhood roadway it is important to detect objects other than vehicles, such as pedestrians, animals, bicycle riders, and the like. Consequently, a much wider range and higher resolution for the radar system is highly desirable. Furthermore, since some objects, such as pedestrians and animals, reflect a lower power density signal back to the vehicle than an automotive vehicle, it would be advantageous to increase the power of the radar system to ensure detection of such pedestrians, animals, etc.

The previously known automotive radar systems, however, do not adapt their mode of operation as a function of the type of roadway. Consequently, a compromised fixed operation of the radar system has been employed with less than optimal operating results for different operating conditions and different types of roadways.

SUMMARY OF THE PRESENT INVENTION

The present invention provides an automotive radar system which automatically adapts the mode of operation for optimal operation as a function of the type of roadway currently traveled by the automotive vehicle.

In brief, the radar system is used in conjunction with a GPS system which generates an output signal of the type of roadway currently traveled by the automotive vehicle or from which the type of roadway can be determined. The GPS system itself may be either self-contained within the radar system, or may be contained within a navigation system on an automotive vehicle which is coupled to the radar system.

A transmitter transmits a CWFM radio signal which repeatedly sweeps between two different frequencies. A radio receiver is then coupled to a horizontally scanning receiver antenna array which receives an echo, if present, from the radio signal transmitted by the transmitter.

A control circuit then receives the output signal from the receiver as well as the output signal from the GPS system. The control circuit then varies the mode of operation of the receiver and/or transmitter as a function of the type of roadway.

For example, in the event that the vehicle is currently traveling on a multilane divided highway, i.e. a limited access divided roadway, the control system reduces the number of horizontal scan positions of the antenna array to a number of horizontal positions slightly left, facing forwardly, and to the right side of the vehicle since radar information on the far left side of the vehicle, i.e. from oncoming traffic on the opposite side of the divided highway, contains little useful information. In addition, the control system varies the signal transmitted by the transmitter to a sawtooth pattern followed by a tail and this waveform is repeated for each horizontal scan position employed by the antenna array. Such a waveform is highly advantageous for a limited access roadway since it provides accurate range detection as well as accurate measurement of velocity differences, i.e. delta velocity, between the vehicle and vehicles forwardly of the vehicle.

Conversely, in an urban or neighborhood environment where automotive speeds are much lower, a wide range radar resolution as well as accurate detection of pedestrians, animals, and the like is highly desirable. Consequently, when the vehicle is traveling on such a roadway, the control system controls the receiver and its horizontal scanning receiver antenna array into a wide scanning pattern with maximum resolution of the number of horizontal scan positions. Such a mode of the radar operation, furthermore, is able to detect even relatively small objects, such as small animals.

Simultaneously, the control system modifies the transmitter to transmit a repeating ramp which repeatedly scans between two fixed frequencies. Such a mode of operation for the transmitter increases the resolution of the radar system but also is less accurate in determining delta velocity between the vehicle itself and the detected objects. However, in an urban or neighborhood roadway, velocity detection or the delta velocity detection between the vehicle and such objects is much less important than on a multilane limited access roadway.

Lastly, in an urban or neighborhood environment, the control system preferably increases the power of the transmitter to ensure that small objects, such as pedestrians and animals, will produce an acceptable echo back to the antenna array.

Still other different types of roadways, such as a winding highway, will cause the control system to generate still different modes of operation for the radar system to provide optimal radar performance.

BRIEF DESCRIPTION OF THE DRAWING

A better understanding of the present invention will be had upon reference to the following detailed description when read in conjunction with the accompanying drawing, wherein like reference characters refer to like parts throughout the several views, and in which:

FIG. **1** is a block diagram view illustrating a preferred embodiment of the present invention;

FIG. **2** is a simplified flowchart illustrating a portion of the operation of the present invention;

FIG. **3** is a top plan view illustrating a vehicle on a multilane divided highway;

FIG. **4** is a transmission waveform used by the radar system on multilane or limited access roadways;

FIG. **5** is a top plan view illustrating the radar system on an urban or neighborhood roadway;

FIG. **6** is a view similar to FIG. **4**, but illustrating the transmission waveform on an urban or neighborhood roadway; and

FIG. **7** is a flowchart illustrating the exemplary operation of the present invention.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE PRESENT INVENTION

With reference first to FIG. **1**, a preferred embodiment of a radar system **20** in accordance with the present invention is shown. The radar system is preferably a continuous wave frequency modulated (CWFM) radar system for use in an automotive vehicle. The radar system **20** thus preferably operates at a frequency of approximately 76.5 gigahertz, i.e. the frequency band allotted by the federal governmental for automotive radar applications.

The radar system **20** includes a transmitter **22** which transmits a microwave signal which repeatedly varies in frequency in a repeating waveform in the automotive radar band. The actual configuration of the waveform transmitted by the transmitter **22** will, however, vary in dependence upon the type of roadway currently traveled by the automotive vehicle as will be described.

Still referring to FIG. **1**, the radar system **20** includes a microwave receiver **24** which receives an input signal from an antenna array **26**. The antenna array **26** includes a predetermined number of horizontal scan positions **28** which are selected under the control of the receiver **24** and a control circuit **40**. In the well-known fashion, the receiver **24** receives echoes of the transmitted microwave signal from the transmitter **22**, if present, in the direction of the horizontal scan position **28** currently selected by the receiver **24**. In the well-known fashion, the resolution of the received microwave signal by the receiver **24** increases with the number of horizontal scan positions **28** of the scanning receiver antenna array **26**.

The receiver **24** generates an output signal on an output line **29** to a processor **30** which, under software control, generates an output signal to a collision avoidance system **32** in the event of a pending or potential collision. The collision avoidance system **32** may take any conventional form, such as an automatic braking system.

With reference now to FIG. **2**, a simplified flowchart illustrating the operation of the processor **30** is shown. At step **34** the processor analyzes the signal from the receiver **24** to identify objects detected by the radar system **20** and their relative velocity relative to the vehicle **46**. Step **34** then proceeds to step **36**.

At step **36** the program determines if a collision is impending. If not, step **36** branches back to step **36** and the above process is repeated. Otherwise, step **36** branches to step **38** and activates the collision avoidance system **32**.

With reference again to FIG. **1**, the control circuit **40** is preferably microprocessor based and operates under the control of a programmed processor **30**. The control circuit **40** also receives an input from a GPS system **42** indicative of the position of the radar system **20**.

The GPS system **42** may be either self-contained with the radar system **20** or may be external to the radar system **20**, e.g. a navigation system **44** for the vehicle **46**. In either event, the GPS system **42** either includes or has access to map data and provides a signal to the control circuit **40** of the type of roadway currently traveled by the radar system **20** and thus currently traveled by the automotive vehicle **46**.

Any conventional system may be employed to determine the type of roadway traveled by the radar system **20**. For example, the map data from the navigation system **44** may have self-contained data indicative of the type of roadway currently traveled by the navigation system **44**. Alternatively, the GPS system **42** or the control circuit **40** may determine the type of roadway from the map data.

There are many different types of roadways that may be traveled by the vehicle. For example, a divided multilane highway or limited access highway or expressway forms one type of roadway. An urban or neighborhood roadway forms another type of roadway while a two lane highway, parking lots, transition zones, and the like all form different types of roadways. The different types of roadways, furthermore, need different modes of operation of both the transmitter **22** and receiver **24** for optimal radar performance. For example, with reference to FIG. **3**, in the event that the type of roadway is a multilane divided highway or a limited access divided highway, high resolution is not required since typically the only objects of interest to the radar system **20** would be relatively large automotive vehicles traveling in the same direction. Likewise, only information forwardly and to the right of the vehicle **46** for merging vehicles is of interest to the radar system **20**.

In this situation, the control circuit **40** identifies the roadway as a divided highway limited access roadway from the input from the GPS system **42** and transmits control signals to the receiver **24** to limit the number of horizontal scan positions **28** of the radar system **20** to only a portion of the available horizontal scan positions **28** and only those positions facing forwardly to the vehicle **46**, as shown at **48**, and optionally to the right side of the vehicle **46** as shown by scan position **50**.

With reference now to FIG. **4**, the control circuit **40** also controls the operation of the transmitter **22** so that the transmitter **22** transmits a sawtooth waveform **52** followed by an elongated tail **54**. An exemplary echo or reflected signal is also shown in FIG. **4** at **56**. The echo **56** follows the same waveform generally as the transmitted waveform **52** but with a time shift representative of the time of flight between the radar system **20** and the detected object.

The frequency shift **58** between the transmitted waveform **52** and the echo **56** provides adequate range detection for the radar system **20**, especially at long range of the type desirable for relatively high vehicle speed of the type expected on a multilane divided highway or limited access roadway. However, the delta speed detection between the radar system **20** and the detected object is relatively difficult to accurately determine during the ramp portion of the waveforms **52** and **56**. However, the frequency shift **58** between the tail **54** of the transmitted signal and the tail **62** of the echo provides an easily detected and accurate delta velocity, i.e. difference in velocity between the radar system **20** and the detected object. The magnitude of the frequency shift **58**, of course, varies as a function of delta velocity.

In operation, the transmitted sawtooth and tail waveform **52** and **54** are repeated during the operation of the radar system **20**. Furthermore, one sawtooth waveform **52** and tail **54** is generated for each horizontal scan position **28** (FIG. **1**) of the antenna array **26**. Consequently, if, for example, the control circuit **40** limits the number of horizontal scan positions **28** to only 10 scan positions out of a total of, for example, 32 scan positions, 10 transmission waveforms **52** followed by the tail **54** would be performed for each complete horizontal scan, i.e. from the left front of the vehicle and to the right of the vehicle. This reduced number of horizontal scan positions **28** utilized by the receiver **24**, however, is not only accurate, but optimal during high speed operation of the vehicle **46** on a multilane or limited access roadway. Furthermore, the lower resolution for the radar system **20** provided by the more limited number of horizontal scan positions **28** is adequate for use on multilane or limited access divided roadways since small objects, such as pedestrians, are rarely, if ever, encountered.

With reference now to FIG. **5**, if the vehicle **46** is traveling in an urban or neighborhood roadway, or even in a parking lot roadway, the vehicle **46** typically travels at a slow speed, e.g. **40** miles per hour or less. While traveling on such a roadway, the vehicle **46** may very well encounter relatively small objects, such as a pedestrian **70**, bicyclist **72**, as well as oncoming vehicles **74**. In this situation, for optimal radar performance, maximum resolution for the radar system is desired whereas the relative velocity difference between the vehicle **46** and the various objects **70**-**74** is less important if important at all.

Consequently, in this situation the control circuit **40** identifies the type of roadway from the GPS system **42** and generates output signals to the receiver **24** (FIG. **1**) to utilize the maximum number of horizontal scan positions **28** available to the scanning radar antenna array **26**. The horizontal scanning positions **28**, furthermore, extend from the far left of the vehicle **46**, as shown at **76**, and to the far right side of the vehicle **46**, as shown at **78**, since the entire area not only in front but also to the left and right of the vehicle **46** is of importance to the radar system **20** and the vehicle **46**.

With reference now to FIG. **6**, the control circuit **40** also controls the operation of the transmitter **22** so that the transmitter **22** transmits repeating ramps **80** which sweep between frequency F**1** and frequency F**2** in the microwave band. In operation, one ramp **80** is used for one horizontal scan position **28** of the antenna array **26**, the next ramp **80** is used for the next horizontal scan position **28** of the antenna array **26**, and so forth. Consequently, if the antenna array contains, for example, 32 horizontal scan positions **28**, 32 frequency ramps **80** will be necessary for a complete horizontal sweep of the antenna array **26**. However, the operation of the radar system **20** is still adequately fast since the tail **54** and **62** (FIG. **4**) used for high speed operation of the vehicle **46** is unnecessary since delta velocity between the vehicle **46** and the objects **70**-**74** is relatively unimportant in an urban or neighborhood roadway.

It is well known that relatively small soft objects, such as pedestrians and animals, reflect relatively low power density back to the radar system **20**. Consequently, in order to further optimize the operation of the radar system **20** in an urban, neighborhood, or parking lot roadway, the control circuit **40** also preferably increases the power of the transmitter **22** to increase the reflection or echo **56** from the pedestrian and ensure detection by the radar system **20**.

It will be understood, of course, that the exemplary roadways thus far described are by way of example only and that other roadways of different types may also require special operation of the radar system **20** in order to optimize operation of the radar system **20**. For example, a winding two lane road may utilize a radar resolution somewhere in between a limited access roadway and an urban roadway. Thus, a number of horizontal scan positions **28** of the antenna array **26** would be employed in between the number used for a limited access roadway and an urban roadway. Similarly, in such a situation, the radar beam may be evenly distributed on the left side and right side of the vehicle **46**.

With reference now to FIG. **7**, a simplified flowchart is shown illustrating the operation of the radar system **20** of the present invention and, particularly, the operation of the processor **30** in the control circuit **40**. After initiation at step **82**, step **82** proceeds to step **83** and reads the input signal from the GPS system **42**. This input signal from the GPS system **42** may include self-contained data indicative of the type of roadway or step **83** may analyze the GPS data to determine the type of roadway. Step **83** then proceeds to step **84**.

At step **84**, the control circuit **40** determines if the vehicle **46**, and thus the radar system **20**, is on a multilane divided highway or limited access roadway. If so, step **84** branches to step **86** and sets the transmitter **22** to the waveform **52** illustrated in FIG. **4**. This ensures not only long range operation of the radar system **20**, but also accurate measurement of the delta velocity between the vehicle **46** and detected objects. Step **86** then branches to step **88**.

At step **88**, the control circuit **40** sets the operation of the receiver **24** to have only a limited number of horizontal scan positions **28** and, optionally, scan positions **28** only forwardly, slightly left, and to the right of the vehicle **46**. Although this reduces the overall resolution of the radar system **20**, such resolution is acceptable for use on multilane divided highways or limited access roadways. Step **88** then branches back to step **83** where the above process is repeated.

Conversely, if the vehicle **46** is not on a limited access roadway, step **84** instead branches to step **90**. At step **90**, the control circuit **40** determines if the vehicle **46** is on an urban roadway. If so, step **90** branches to step **92** where the control circuit **40** sets the radar waveform to the waveform illustrated in FIG. **6**. This waveform ensures high resolution at relatively slow speeds for the vehicle **46** and where delta velocity between the vehicle **46** and detected objects is less important. Step **92** then branches to step **94**.

At step **94**, the control circuit **40** sets the antenna array **26** to scan for the maximum number of horizontal scan positions **28** thus achieving the maximum resolution for the radar system **20** from the left side of the vehicle **46** and to the right side of the vehicle **46**. Such high resolution is desirable in an urban roadway, parking lots, and neighborhood roadways where pedestrians, bicyclists, animals, and the like may be encountered. Step **94** then proceeds to step **96**.

At step **96**, the control circuit **40** increases the power of the transmitter **22** to improve the detection of objects such as animals and pedestrians.

If the roadway is not an urban roadway, step **90** then proceeds to identify other types of roadways at steps **98** and to set the parameters of both the transmitter **22** and receiver **24** and its antenna array **26** to achieve optimal performance for that particular type of roadway.

From the foregoing, it can be seen that the present invention provides an adaptive radar system which controls the operation of the transmitter as well as the receiver and its antenna array to achieve optimal performance automatically as a function of the type of roadway currently traveled by the vehicle. Having described our invention, however, many modifications thereto will become apparent to those skilled in the art to which it pertains without deviation from the spirit of the invention as defined by the scope of the appended claims.

We claim:

1. An automotive radar system comprising:

a GPS system which generates an output signal representative of the type of roadway,

a transmitter which transmits a microwave radio signal,

a horizontally scanning receiver antenna array,

a receiver coupled to said horizontally scanning receiver antenna array which receives an echo, if present, from the radio signal transmitted by said transmitter and generates an output signal representative of the echo,

a control circuit which receives said output signal from said antenna array and the output signal from the GPS system linked with a map database indicative of the type of roadway currently traveled by the automotive radar system, said control circuit varying the mode of operation of said receiver or said transmitter as a function of the type of roadway from the GPS system.

2. The radar system of claim **1** wherein said control circuit varies the transmitter power as a function of the type of roadway.

3. The radar system of claim **2** wherein said control circuit increases the transmitter power when the roadway type is an urban road.

4. The radar system of claim **2** wherein said control circuit decreases transmitter power when the roadway type is a limited access highway.

5. The radar system of claim **1** wherein said control circuit varies the waveform of the microwave radio signal as a function of the type of roadway.

6. The radar system of claim **5** wherein said control circuit controls said transmitter to transmit a sawtooth waveform when the roadway type is a limited access highway.

7. The radar system of claim **5** wherein said control circuit controls said transmitter to transmit a repeating ramp waveform when the roadway type is an urban road.

8. The radar system of claim **1** wherein said antenna array receives echoes at a plurality of horizontal scan positions during a complete horizontal scan of the antenna array and wherein said control circuit varies the number of horizontal scan positions per complete receiver horizontal scan as a function of the type of roadway.

9. The radar system of claim **8** wherein said control circuit utilizes only a portion of the number of scan positions per complete horizontal scan when the roadway type is a limited access highway.

10. The radar system of claim **8** wherein said control circuit utilizes substantially all of the number of scan positions per complete horizontal scan when the roadway type is an urban road.

11. The radar system of claim **1** wherein said antenna array receives echoes at a plurality of horizontal scan positions during a complete horizontal scan of the antenna array and wherein said control circuit varies the selection of horizontal scan positions per complete receiver horizontal scan as a function of the type of roadway.

12. The radar system of claim **11** wherein said control circuit utilizes only scan positions directed forwardly and to one side per complete horizontal scan when the roadway type is a limited access highway.

13. The radar system of claim **1** wherein said control circuit varies the period of a complete horizontal scan of the receiver.

14. The radar system of claim **1** wherein the GPS system is contained in a navigation system of the automotive vehicle.

15. The radar system of claim **1** wherein said radar system is a continuous wave frequency modulated system.

* * * * *