United States Patent Application Publication	20250266598
Kind Code	A1
Publication Date	August 21, 2025
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SYNCHRONIZATION OF DISTRIBUTED RADAR SYSTEM USING DIELECTRIC WAVEGUIDE

Abstract

A distributed radar system includes a management unit, a plurality of distributed radar units, and a dielectric waveguide network comprising a plurality of dielectric waveguides coupling the management unit to the plurality of distributed radar units. The management unit is configured to generate a reference signal for synchronization of operations of the plurality of distributed radar units. At least one of the distributed radar units may be configured to generate a digital data signal representative of results of a radar sensing operation of the distributed radar unit, the dielectric waveguide network may be configured to propagate a representation of the digital data signal to the management unit, and the management unit may be configured to control at least one operation of the distributed radar system based on the digital data signal.

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Family ID: **1000007743229**

Appl. No.: **18/582770**

Filed: **February 21, 2024**

Publication Classification

Int. Cl.: **H01P3/16** (20060101); **G01S7/03** (20060101); **G01S13/931** (20200101); **H01P5/08** (20060101)

U.S. Cl.:

CPC **H01P3/16** (20130101); **G01S7/032** (20130101); **G01S13/931** (20130101); **H01P5/08**

(20130101);

Background/Summary

BACKGROUND

[0001] Radar systems generally operate on the basis of the transmission of a signal (often referred to as an “illumination signal”) and processing of a resulting received signal (often referred to as a “reflected signal”) that is a representation of the signal as reflected or scattered by one or more objects in the environment. Coherent radar systems utilize the frequency difference between the illumination signal and the resulting reflected signal to determine a distance metric for the detected object. Phase differences of the reflected signal between receive antennas is used to determine a metric for the direction of arrival (DoA) of the reflected signal. As such, accurate measurement of the frequency difference and phase differences, and thus accurate measurement of the distance metric and the DoA metric, is often dependent on accurate synchronization between generation of the illumination signal and processing of the reflected signal.

[0002] Distributed radar systems, such as Advanced Driver Assistance System (ADAS)-based automotive radar systems, utilize multiple radar units for environmental object detection. Sufficient synchronization can be difficult to achieve in such distributed radar systems, in which multiple radar units ideally would be driven using the same fully-synchronized reference signals; that is, reference signals with the same frequency, phase, and time base. However, conventional mechanisms for distributing a common reference signal to multiple radar units, such as coaxial cable-based networks or optical fiber-based networks, typically introduce additional phase noise, which can render the distributed system insufficiently synchronized to maintain coherency. Moreover, such conventional approaches can be complex to implement and consume excess power. These obstacles often lead designers to implement a distributed radar system so that the individual radar units generate a local reference signal from a local crystal oscillator or other signal source, with the resulting distributed radar system thus being non-coherent.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The present disclosure is better understood, and its numerous features and advantages made apparent to those skilled in the art, by referencing the accompanying drawings. The use of the same reference symbols in different drawings indicates similar or identical items.

[0004] FIG. **1** is a block diagram of a distributed radar system utilizing a dielectric waveguide network for distribution of a reference signal in accordance with some embodiments.

[0005] FIG. **2** is a block diagram of an alternative implementation of the distributed radar system of FIG. **1** utilizing a different network topology for the dielectric waveguide network in accordance with some embodiments.

[0006] FIG. **3** is a hardware diagram of a radar management unit of the distributed radar system of FIGS. **1** and **2** in accordance with some embodiments.

[0007] FIG. **4** is a hardware diagram of a distributed radar unit of the distributed radar system of FIGS. **1** and **2** in accordance with some embodiments.

[0008] FIG. **5** is a flow diagram illustrating a method of operation of the distributed radar system of FIGS. **1-4** in accordance with some embodiments.

DETAILED DESCRIPTION

[0009] Some conventional distributed radar systems use coaxial cables or optical fibers to distribute a reference signal to multiple radar units. However, a coaxial cable-based solution typically is impractical for use in transmitting a reference signal at the same carrier frequency as the illumination signal as it requires additional mixers and other circuitry at the receiving radar units, which can introduce additional unpredictable phase noise. Optical fiber-based distribution solutions require electrical-to-optical conversion circuitry at the transmit side and optical-to-electrical conversion circuitry at the receive side, and this circuitry increases complexity and power consumption, and may be prone to introducing additional phase noise. With the additional phase noise introduced by such conventional solutions, significant uncertainty in the time base is introduced, and thus either coherency is effectively lost or additional mechanisms, such as phase offset estimation, is utilized to attempt to mitigate for the additional time base uncertainty, thereby increasing the complexity, cost, and inefficiency of such systems. Moreover, this conversion circuitry often is not capable of being fabricated on the same chip or module as the other circuitry, and thus requiring a less compact, more complex multi-module approach.

[0010] FIGS. **1**-**5** depict systems and methods for reference signal distribution in a distributed radar system using a network of one or more dielectric waveguides for transmission of a reference signal from a management unit to one or more destination radar units, wherein the management unit may be a centralized control unit that does not perform any radar illumination or radar sensing operations directly or the management unit may be another radar unit (that is, a leader radar unit) that also performs radar operations. The one or more dielectric waveguides, in embodiments, are implemented as a dielectric core (e.g., a polymer fiber) and may be surrounded by one or more cladding layers (which may be dielectric or conductive), and which utilize total internal reflection (TIR) for transmitting an electromagnetic (EM) signal along the length of the dielectric core. At the transmit side, the management unit utilizes one or more launchers and associated circuitry to launch the reference signal into a transmit side of the dielectric waveguide network in the form of a radio frequency (RF) signal, whereupon the RF signal is conveyed along one or more dielectric waveguides via total internal reflection of the corresponding polymer fiber to one or more of radar units. At a receive side of the dielectric waveguide network, a distributed radar unit uses a corresponding launcher/antenna to receive the RF signal from a connected dielectric waveguide and then utilize the received signal as a local reference signal.

[0011] The reference signal, in implementations, is a continuous waveform (CW) signal, such as a sine wave. In other implementations, the reference signal is a modulated radar signal that is to be used by the radar units as the illumination signal, such as a frequency-modulated continuous wave (FMCW) signal or a pulsed (or chirp) signal. In either approach, the frequency of the reference signal may be at the “radar frequency” of the illumination signals to be generated from the reference signal, or below or above this radar frequency, and subsequently converted to the radar frequency using frequency multipliers or dividers, but with a lower multiplier factor, and thus less potential phase noise introduced, due to the higher-frequency transmission capabilities of the dielectric waveguide. Moreover, the waveform of the reference signal may be modulated, in either or both of frequency or amplitude, in order to provide time stamping signaling, which may be used by the radar units in order to synchronize start times or other time bases.

[0012] In at least one embodiment, the dielectric waveguide network utilizes a branched star topology in which a single dielectric waveguide is coupled to the management unit, and this single dielectric waveguide branch in turn is connected to multiple other dielectric waveguide branches, each of which terminates at a corresponding radar unit. In another embodiment, the dielectric waveguide network utilizes a parallel star topology, in which multiple dielectric waveguides extend between the management unit and the multiple radar units, with each dielectric waveguide terminating at the management unit at one end and terminating at a corresponding radar unit at the other end. In still other embodiments, the dielectric waveguide network utilizes a ring topology.

[0013] Further, in some implementations, in addition to utilizing the dielectric waveguide network for distributing the reference signal to the radar units, the dielectric waveguide network also is used to communicate data, either unidirectionally from the radar units to the management unit or vice versa, or bidirectionally between the radar units and the management unit, such as radar sensing data from the radar units representing the results of processing of the received signals reflected from object(s) in the environment or control data from the management unit for use by the radar units in configuring or controlling their operation.

[0014] FIG. **1** illustrates a distributed radar system **100** employing a dielectric waveguide (DWG) network **102** for distribution of reference signaling in accordance with some implementations. The distributed radar system **100** ("system **100**" for brevity) includes a radar management unit **104** connected to a plurality of distributed radar units **106** ("radar units **106**" for brevity) via the DWG network **102**. For ease of illustration and description, the system **100** is depicted as having three radar units **106**, enumerated radar unit **106-1**, **106-2**, and **106-3**. However, in other implementations two radar units **106** may be employed or more than two radar units **106** may be employed. The radar units **106** are configured to operate as distributed radar units for the system **100** by performing radar operations, including one or both of an illumination operation by which a radar illumination signal is emitted into the local environment of the radar unit **106** via a corresponding antenna array (e.g., antenna array **110** for radar unit **106-1**) or a radar sensing operation in which one or more reflected signals resulting from reflection of a radar illumination signal by one or more objects in the local environment are received via the corresponding antenna array and processed by the radar unit **106** to generate digital signaling (that is, digital data) representative of a distance metric (e.g., distance, speed, or position) for some or all of the received reflected signals.

[0015] In some embodiments, the radar management unit **104** is also one of these radar units **106**, but with additional reference signal generation and distribution responsibilities as described herein. In other embodiments, the radar management unit **104** operates as a central control unit for the system **100** and does not have any direct radar illumination or radar sensing capabilities; that is, the radar management unit **104** is not one of the distributed radar units **106**. In such embodiments, the radar management unit **104** operates to control the overall operation of the distributed radar units **106** as well as to process the radar sensing data provided by the distributed radar units **106** from corresponding radar sensing operations to provide environmental characterization data that can be acted upon by other components within the system **100** (not shown). For example, in some embodiments, the system **100** is part of an ADAS for an automobile or other vehicle, with the radar units **106** distributed at the periphery of the vehicle for the purposes of detecting objects in the local environment of the vehicle using radar illumination/reflection, and processing received reflected signals to determine data representative of one or more of a distance, position, speed, or shape of one or more objects, and the ADAS further includes one or more processors executing software that utilize this resulting data to control one or more operations of the vehicle, such as displaying radar imagery of detected objects, controlling one or more driving aspects of the vehicle (e.g., emergency braking or adaptive cruise control), and the like.

[0016] In implementations, the system **100** is a coherent distributed radar system in which the radar illumination operations and the radar sensing operations of the radar units **106** are highly correlated from the use of effectively synchronized reference signaling. This synchronized reference signaling is used for both radar illumination signal generation and processing of received reflected signals to extract object distance/speed metrics. The synchronization of this reference signaling is facilitated by the transmission of the reference signal **108** from the radar management unit **104** to each of the radar units **106** via the DWG network **102**. In the illustrated implementation of FIG. **1**, the DWG network **102** has a parallel star topology **112** in which a separate dielectric waveguide (DWG) **114** connects a corresponding radar unit **106** to the radar management unit **104**. Thus, in the depicted implementation, the parallel star topology **112** includes a DWG **114-1** connecting the radar management unit **104** and the radar unit **106-1**, a DWG **114-2** connecting the radar management unit **104** and the radar unit **106-2**, and a DWG **114-3** connecting the radar management unit **104** and the radar unit **106-3**. Each DWG **114** is configured to facilitate propagation of electromagnetic (EM) signaling with relatively low magnitude loss and low insertion loss at millimeter wave (mmW) frequencies (30 GHz to 300 GHz) or even higher frequencies.

[0017] As shown by enlarged cross-sections **116** and **118**, in some implementations, each DWG **114** may be implemented in a cable form factor composed of a dielectric core **120**, which may be solid or hollow. In some embodiments, the dielectric core **120** is enclosed by at least one cladding layer **122** (that is, a jacket) partially or fully enclosing the dielectric core **120**, whereas in other embodiments, cladding layers are omitted. The dielectric core **120** may be extruded, laminated, cast, or otherwise formed, with a solid or hollow core, and may be composed of any of a variety of polymers or other suitable dielectric materials, such as polytetrafluoroethylene (PTFE, also known by the trade name "Teflon"), polyethylene (PE), polypropylene (PP), polystyrene (PS), and the like. Typically, the material of the dielectric core fiber **120** has a relatively low dielectric constant (Dk) and a relatively low insertion loss (e.g., around 5 decibels (dB) or less) and is suited for the propagation of an EM signal at microwave frequencies or higher (that is, at the same or similar frequencies employed for the radar illumination signal(s)). The at least one cladding material may be composed of one or more dielectric materials (e.g., open-cell or closed-cell foam, such as expanded PTFE, PP, PE, PS, and the like), one or more metals (e.g., copper (Cu) or silver (Ag)), one or more metal alloys (copper alloy), or a combination thereof. As shown by cross-section **116**, the DWG **114** may have a circular or ovoid cross-section, with the dielectric core **120** comprising a dielectric core fiber with a circular or otherwise ovoid cross-section and at least one cladding layer **122** with a similar circular or otherwise ovoid cross-section. As shown by cross-section **118**, the DWG **114** instead may have a rectangular cross-section, with the dielectric core **120** comprising a dielectric core fiber with a rectangular cross-section and the one or more cladding layers **122** with rectangular or ovoid cross-sections. One additional aspect of a DWG **114** with dielectric core **120** having a rectangular cross-section is that either or both orthogonal polarizations for the transmitted signaling may be employed. Other cross-sections, such as triangular or another n-sided polygon, likewise may be employed. One such example implementation of the DWG **114** includes a polymer microwave fiber (PMF) DWG.

[0018] In the parallel star topology **112** of the DWG network **102** of FIG. **1**, the radar management unit **104** distributes the reference signal **108** (or duplicate representations thereof) to the proximal end of each corresponding DWG **114** via a signal splitter or other signal distribution component (see FIG. **3**). As described in greater detail with reference to FIG. **3**, for each of the DWGs **114-1**, **114-2**, and **114-3**, the radar management unit **104** utilizes a corresponding set of one or more launchers (i.e., antennas) to convert the reference signal **108** to an EM signal that is emitted into the proximal end of the corresponding DWG **114**, whereupon the DWG **114** conveys the EM signal to the distal end of the DWG **114** via TIR. As described in greater detail below with reference to FIG. **4**, at the distal end (relative to the unit **104**) of the DWG **114**, the corresponding radar unit **106** utilizes a set of one or more launchers (i.e.., antennas) to receive the EM signal as a received reference signal, which is then utilized by the radar unit **106** for use in performing one or both of radar illumination operations or radar sensing operations.

[0019] Turning briefly to FIG. **2**, an alternative implementation of the DWG network **102** is shown in accordance with various embodiments. In the depicted implementation, the DWG network **102** connecting the radar management unit **104** to the radar units **106** has a branched star topology **212** in which the DWG network **102** has a single endpoint at the radar management unit **104** and single endpoints at each of the radar units **106-1**, **106-2**, and **106-3**. For example, with the branched star topology **212**, the DWG network **102** may comprise a DWG **214-2** connecting the radar management unit **104** at one end to the radar unit **106-2** at the other end, as well as a DWG **214-1** electromagnetically coupled and otherwise coupled to the DWG **214-2** via a splitter **216-1** (that is, a tap) at one end and to the radar unit **106-1** at the other end, and a DWG **214-3** electromagnetically coupled and otherwise coupled to the DWG **214-2** via a splitter **216-2** at one end and to the radar unit **106-3** at the other end. The splitters **216-1** and **216-2** operate to distribute signaling conducted via the DWG **214-2** from the radar management unit **104** to the radar units **106-1** and **106-3**, respectively, and to distribute signaling conducted from the radar units **106-1** and **106-3**, respectively, via the DWGs **214-1** and **214-3** to the radar management unit **104** via the DWG **214-2**. Note that although two splitters **216-1** and **216-2** are shown to provide a 1-to-3 and 3-to-1 connection, in other embodiments a single 3-way splitter may be employed to connect both the DWG **214-1** and DWG **214-3** to the DWG **214-2**, and vice versa.

[0020] In the branched star topology **212** of FIG. **2**, the radar management unit **104** converts the reference signal **108** to a EM signal via one or more launchers at the proximal end of the DWG **214-2**, and the resulting EM signal is then propagated to the distal ends (relative to the radar management unit **104**) of the DWGs **214-1**, **214-2**, and **214-3** via TIR and the splitters **216**. At each distal end, the corresponding radar unit **106** utilizes a set of one or more launchers (i.e., antennas) to receive the EM signal as a received reference signal, which is then utilized by the radar unit **106** for use in performing one or both of radar illumination operations or radar sensing operations.

[0021] Ideally, the path lengths between the radar management unit **104** and each radar units **106** via the DWG network **102** are equal regardless of particular topology employed, such that there is no relative time delay in receipt of the propagated representation of the reference signal **108** received at one radar unit **106** relative to receipt of a propagated representation of the reference signal **108** at another radar unit **106**. However, in implementation various constraints may result in different path lengths between the radar management unit **104** and the radar units **106**. In such instances, should the path length differences result in timing differences for receipt of the propagated representations of the reference signal **108** that may risk satisfactory operation of the system **100**, then in some embodiments the radar units **106** may employ timing delay circuitry so as to compensate for the timing differences introduced by different path lengths, as described below.

[0022] Returning to FIG. **1**, operation of the system **100** is further described. It will be appreciated that the reference signal **108** may take any of a variety of forms. For example, the radar management unit **104** may generate the reference signal **108** as a continuous wave (CW) signal or a frequency modulated continuous wave (FMCW) signal as is known in the art. Because the DWGs employed in the DWG network **102** typically are capable of mmW frequencies, the carrier frequency (or frequency range) of the CW signal or FMCW signal may be set to the radar frequency employed by the illuminating radar units **106** for the radar illumination signals launched by these radar units **106**. For example, if the illuminating radar units **106** employ a radar frequency of 77 GHz for the radar illumination signal(s), then the radar management unit **104** may generate the reference signal **108** as a CW signal or FMCW signal having a carrier frequency of 77 GHz. In other embodiments, the carrier frequency may be set to lower than the radar frequency or higher than the radar frequency, in which case the radar units **106** may employ frequency multipliers or dividers to convert the reference signal **108** to the radar frequency.

[0023] In addition to generating the reference signal **108** and distributing the same reference signal **108** via the DWG network **102** in a manner such that the frequency, time-base, and phase noise is substantially preserved, the radar management unit **104** also may utilize modulation of the reference signal **108** to convey additional information. For example, coherent distributed radar sensing often relies on accurate time base synchronization in addition to accurate phase/frequency synchronization. For example, start times for radar illumination signal generation often are synchronized across multiple distributed illuminating radar units. As such, the radar management unit **104** may use one or both of amplitude modulation or frequency modulation to introduce time stamping into the reference signal **108** using any of a variety of known techniques, and the radar units **106** may operate to detect the time stamping present in this additional modulation and synchronize the timing of their respective operation accordingly.

[0024] Moreover, in addition to distribution of the reference signal **108**, the DWG network **102** is also utilized to facilitate data communications. For example, the radar data generated by each sensing radar unit **106** may be transmitted to the radar management unit **104** via the DWG network **102** as EM data signaling **124** using any of a variety of network protocols or data transmission protocols. Further, control or configuration information may be transmitted from the radar management unit **104** to one or more of the radar units **106** as EM data signaling **124** using the DWG network **102**. For example, the DWG network **102** and associated physical interfaces at the radar management unit **104** and the radar units **106** may be implemented as the physical (PHY) layer of an Ethernet-based communications network between the units **104** and **106**.

[0025] FIG. **3** illustrates a hardware configuration of the radar management unit **104** of the system **100** of FIG. **1** in accordance with some embodiments. In the depicted example, the radar management unit **104** includes a digital processing system **302**, a reference signal generator **304**, a RF front end **306**, a replicator **307**, and a plurality of waveguide interfaces **310**, one for each of the parallel DWGs **114** of the parallel star topology **112**, such as a waveguide interface **310-1** for the DWG **114-1**, a waveguide interface **310-2** for the DWG **114-2**, and a waveguide interface **310-3** for the DWG **114-3**. In other implementations with more or fewer DWGs **114** in the DWG network **102**, the radar management unit **104** would implement more or fewer waveguide interfaces **310**.

[0026] The digital processing system **302** includes one or more processors, memories, input/output (I/O) devices, and other processing components configured to facilitate execution of one or more sets of instructions that, when executed, cause the digital processing system to operate to manage the overall operation of the radar management unit **104**, as well as the system **100**. For example, the digital processing system **302** may operate to generate configuration/control data for transmission to the radar units **106** to configure or control their operation, such as by specifying radar illumination/sensing parameters, timing parameters, and the like. The digital processing system **302** further may operate to receive radar sensing data from the radar units **106** and process the radar sensing data to control one or more operations of the system **100**, such as the display of graphical information pertaining to sensed objects in the radar sensing data, to control one or more autonomous driving operations, and the like.

[0027] The reference signal generator **304** operates to generate the reference signal **108** and includes any of a variety of circuitry or other components known in the art for generating such a reference signal, such as a crystal oscillator, frequency multipliers or dividers, a phase locked loop (PLL), a delay locked loop (DLL), and the like. The reference signal generator **304** may modify one or more aspects of the reference signal **108**, such as frequency or amplitude (e.g., for purposes of frequency modulation or amplitude modulation for time stamping) based on a control signal **312** provided by the digital processing system **302**. The reference signal generator **304** further may generate a clock signal **315** used by the RF front end **306** for timing/synchronization. For example, the clock signal **315** may be used for timing/synchronization for the transmission or receipt of data signaling via the DWGs **114**.

[0028] The RF front end **306** comprises various circuitry for facilitating conversion of digital data from the digital processing system **302** to analog signaling for transmission via the DWGs **114** and for conversion of analog signaling received from the DWGs **114** to digital data for processing by the digital processing system **302** as is known in the art. Such circuitry may include one or more of a baseband processor, a modem, a digital-to-analog converter (DAC), an analog-to-digital converter (ADC), amplifiers, filters, mixers, frequency multipliers, dividers, and the like.

[0029] The replicator **307** comprises circuitry configured to receive the reference signal **108** as an input and to output multiple representations of the reference signal **108** (that is, duplicates of the reference signal **108**) as reference signals **308-1**, **308-2**, and **308-3** having substantially the same frequency, phase noise, and time base, such as, for example, an amplifier with multiple replicated outputs. As such, the circuitry implementing the replicator **307** is configured to introduce relatively minimal frequency, phase, and phase noise differences in the process of outputting reference signals **308-1**, **308-2**, and **308-3** from reference signal **108**. The reference signal **308-1** is provided to the waveguide interface **310-1**, the reference signal **308-2** is provided to the waveguide interface **310-2**, and the reference signal **308-3** is provided to the waveguide interface **310-3**.

[0030] The waveguide interfaces **310-1**, **310-2**, and **310-3** each comprises the physical interface between the radar management unit **104** and the DWG **114-1**, **114-2**, and **114-3**, respectively. As such, each waveguide interface **310** includes a set of one or more launchers **314** and, in some implementations, one or more amplifiers **316** (and other circuitry, such as one or more filters) for converting an input analog signal **318** (e.g., reference signal **308-1** or an analog signal representing digital data) to an EM signal **320** that is then emitted (or "launched") into the proximal end of the corresponding DWG **114** and then propagated to the distal end via TIR. The waveguide interface **310** also can include a set of one or more launchers **322** for receiving an EM signal propagated from the distal end of the DWG **114** (that is, transmitted by the corresponding radar unit **106**) and one or more amplifiers **324** and other circuitry (e.g., one or more filters) and converting the EM signal to an analog signal **326** for processing by the RF front end **306** (e.g., for conversion from an analog signal to a digital signal that is then processed by the digital processing system **302**). The launcher(s) **314** for launching an EM signal and the launcher(s) **322** for receiving an EM signal may be the same or different launcher(s). The waveguide interfaces **310** further may include physical fasteners to maintain a mechanical connection with the corresponding DWG **114** as well as to properly align the proximal end of the DWG **114** with the sets of one or more launchers **314** and **322**.

[0031] While FIG. **3** illustrates a hardware configuration for the radar management unit **104** using the parallel star topology **112** for the DWG network **102**, a similar approach may be implemented for different topologies for the DWG network **102**. For example, for the branched star topology **212** of FIG. **2** for the DWG network, the radar management unit **104** instead may utilize a single waveguide interface **310** for coupling to the single DWG **214** terminating at the radar management unit **104**, and may omit the replicator **307** as the reference signal **108** does not need to be split/duplicated into multiple synchronized representations.

[0032] FIG. **4** illustrates a hardware configuration of the radar unit **106** of the system **100** of FIG. **1** in accordance with some embodiments. In the depicted example, the radar unit **106** includes a digital processing system **402**, a radar controller **404**, the antenna array **110**, an RF front end **406** and a waveguide interface **410**. The digital processing system **402** includes one or more processors, memories, I/O devices, and other processing components configured to facilitate execution of one or more sets of instructions that, when executed, cause the digital processing system **402** to operate to manage the overall operation of the radar unit **106**. For example, the digital processing system **402** may operate to generate configuration/control data for controlling the radar controller **404**, to process radar sensing data from the radar controller **404** (e.g., for performing the distance/speed calculations based on signaling provided by the radar controller **404**), to format digital data for transmission via the corresponding DWG **114** (e.g., DWG **114-1** for radar unit **106-1**) via the RF front end **406** and waveguide interface **410** (e.g., to operate as the data link layer and higher layers in accordance with an Ethernet protocol), and the like.

[0033] The radar controller **404** operates to perform one or both of radar illumination operations or radar sensing operations based on configuration information provided by the digital processing system **402**, as known in the art. The wireless aspects of these operations, such as emitting a radar illumination signal or receiving a reflected signal, are performed by the antenna array **110**, which may include one or more antennas, such as in a multiple input multiple output (MIMO) antenna configuration. The timing and synchronization of these operations is based on a received reference signal **412**, which in turn is based on a received representation of the reference signal **108** as described in more detail below.

[0034] The RF front end **406** comprises various circuitry for facilitating conversion of digital data from the digital processing system **402** to analog signaling for transmission via the corresponding DWG **114** and for conversion of analog signaling received from the DWG **114** to digital data for processing by the digital processing system **402** as is known in the art. Such circuitry may include one or more of a baseband processor, a modem, a digital-to-analog converter (DAC), an analog-to-digital converter (ADC), amplifiers, filters, mixers, frequency multipliers, dividers, and the like.

[0035] The waveguide interface **410** comprises the physical interface between the radar unit **106** and the corresponding DWG **114**. Thus, the waveguide interface **410** includes a set of one or more launchers **414** and one or more amplifiers **416** (and other circuitry, such as one or more filters) for converting an input EM signal (e.g., EM signal **320**, FIG. **3**) propagated from the distal end of the DWG **114** (that is, transmitted from the distal end via TIR) to the proximal end of the DWG **114** to an analog signal **420**. The waveguide interface **410** also can include one or more amplifiers **422** and other circuitry (e.g., one or more filters) and a set of one or more launchers **424** for receiving an analog signal **426** from the RF front end **406** and converting the analog signal **426** to an EM signal that is launched (that is, transmitted) into the proximal end of the DWG **114** for propagation to the radar management unit **104** at the distal end of the DWG **114** via TIR. The analog signal **426** may be, for example, an analog representation of a digital signal provided by the digital processing system **402** or by the radar controller **404**, and this digital signal may represent, for example, radar sensing data obtained by the radar controller **404**. The launcher(s) **424** for launching an EM signal and the launcher(s) **414** for receiving an EM signal may be the same or different launcher(s). The waveguide interface **410** further may include physical fasteners to maintain a mechanical connection with the corresponding DWG **114** as well as to properly align the proximal end of the DWG **114** with the set of one or more launchers **414** and **424**.
[0036] The waveguide interface **410** (or the RF front end **406**) further may include a timing reference extraction module **428** having circuitry configured to extract the reference signal **412** from the analog signal **420** when the incoming EM signal **320** represents the reference signal **108** generated by the radar management unit **104**. For example, the timing reference extraction module **428** can include one or more amplifiers (which may include the amplifier **416**), one or more filters, and the like. Further, in embodiments in which the carrier frequency of the reference signal **108** (as represented in the received EM signal **320**) is not the radar frequency, the timing reference extraction module **428** further may include frequency multiplier or a frequency divider to increase or decrease the frequency of the extracted reference signal **412** to match the radar frequency used by the radar controller **404**. Further, as noted above, there may be path length differences between the various DWGs, and thus the timing reference extraction module **428** also may include circuitry for calibrating or otherwise compensating for the time delays introduced by these path length differences between the different radar units. The radar controller **404** then utilizes the reference signal **412** to control its operation. For example, the frequency and phase of the reference signal **412** is used to generate a radar illumination signal emitted by the antenna array **110** and/or is used to extract distance/speed information from a reflected signal received by the antenna array **110** so as to generate radar sensing data. Moreover, as described above, the reference signal **108**, and thus the extracted reference signal **412**, may include further amplitude modulation or further frequency modulation for inserting time stamp information, and this further modulation may be interpreted thusly by the radar controller **404** as time stamp information for use in synchronizing the timing of its radar illumination/sensing operations with other radar units **106** receiving their own representation of the reference signal **108** concurrently.
[0037] FIG. **5** illustrates an example method **500** of operation of the system **100** for parallel distribution of a reference signal to distributed radar units via a DWG network and return of radar sensing data from the radar units via the same DWG network in accordance with some embodiments. For case of description, the method **500** is described in the example context of the system **100** of FIGS. **1-4**, but is not intended to be limited to these particular implementations. The method **500** initiates at block **502** with the reference signal generator **304** of the radar management unit **104** initiating generation of the reference signal **108**, which as noted above may be, for example a CW signal or FMCW signal and may have a carrier frequency at, above, or below the radar frequency utilized by the radar units **106**, and further may be modulated to include time stamp information or other control information. At block **504**, a representation of the reference signal **108** is concurrently launched into each DWG **114**/**214** of the DWG network **102** that is

coupled to the radar management unit **104**. For the parallel star topology **112** of FIG. **1**, this includes using the replicator **307** to generate a plurality of reference signals **308** from the reference signal **108**, with each reference signal **308** being launched into a corresponding DWG **114**/**214**. For the branched star topology **212** of FIG. **2**, this includes launching the reference signal **108** (or a single representation thereof) into the DWG **214** directly coupled to the radar management unit **104**. The launching of a reference signal into the proximal end of a corresponding DWG **114**/**214** includes using the amplifier(s), launcher(s) and other RF circuitry of a corresponding waveguide interface **310** to convert the reference signal to an EM signal (e.g., EM signal **320**) that is injected into the proximal end of the corresponding DWG **114**/**214** and then is propagated toward the distal end of the DWG **114**/**214** via TIR.

[0038] At block **506**, each radar unit **106** receives the corresponding EM signal via the corresponding DWG **114**/**214** and the launcher(s), amplifiers, and other circuitry of the waveguide interface **410** of the radar unit **106** converts the EM signal to an analog signal (e.g., analog signal **420**). The timing reference extraction module **428** then extracts a reference signal **412** from the analog signal and provides the extracted reference signal **412** to the radar controller **404** of the radar unit **106**.

[0039] At block **508**, the radar controller **404** performs one or more radar operations that are timed and otherwise synchronized based on the reference signal **412**. These radar operations can include, for example, one or both of launching a radar illumination signal generated based on the reference signal **412** or receiving one or more reflected signals from one or more objects in the local environment based on one or more radar illumination signals (block **512**). For example, in some configurations, each of the radar units **106** is configured to both emit a radar illumination signal and to sense reflected signals. For example, in an ADAS system, each of the radar units **106-1**, **106-2**, and **106-3** may be configured to emit a corresponding radar illumination signal (which may be different from the radar illumination signals emitted by the other radar units **106**) and also sense reflected signals, not only from its own illumination signal but from the other radar illumination signals emitted by the other radar units **106**. In other configurations, some radar units **106** are operated to only emit radar illumination signals while other radar units are operated to only sense reflected signals.

[0040] For example, in an ADAS system the radar unit **106-2** may be configured as an illumination-only radar unit while radar units **106-1** and **106-3** are configured as sense-only radar units. For the radar sensing operation (block **510**), this operation typically includes receiving the reflected signal and comparing the reflected signal to the corresponding emitted radar illumination signal (e.g., by comparing phase offset) in order to determine one or more metrics for the reflecting object, such as distance and/or speed. The reference signal **412** may be used to control the radar operations in various ways. For example, the radar controller **404** may generate the radar illumination signal directly from the reference signal **412**, and thus the reference signal **412** likewise is indirectly used to determine distance/speed metrics based on, for example, phase comparisons between the radar illumination signal and a received reflected signal. As another example, as explained above the reference signal **108** may be amplitude modulated or frequency modulated so as to represent time stamp information, and this modulation thus is present in the extracted reference signal **412**. This time stamp information then may be used by the radar controller **404** for controlling the timing of the start of emission of a radar illumination signal (e.g., the start of a “chirp”) so that the radar illumination signals of all illuminating radar units **106** are time-base synchronized as well as phase and frequency synchronized.

[0041] As explained above, the DWG network **102** further can be used as a data communications network for transmitting data from the radar management unit **104** to the radar units **106** or from the radar units **106** to the radar management unit **104**. Accordingly, in implementations in which the radar unit **106** performs radar sensing operations, at block **510** the radar controller **404** can process a sensed reflected signal in view of the radar illumination signal that led to the reflected signal (e.g., by determining a phase shift) to determine one or more metrics, such as distance or speed, and the digital processing system **402** or the radar controller **404** then may convert these metrics to digital data (identified as "radar sensing data"). At block **512**, a representation of this radar sensing data is transmitted to the radar management unit **104** via the DWG network **102**. In embodiments, this process includes the digital processing system **402** encapsulating the radar sensing data into an appropriate data container for the network protocol used by the system **100** (e.g., in an Ethernet frame) and the RF front end **406** converting the data container and the radar sensing data contained therein into an analog signal that is then launched into the proximate end of the DWG **114**/**214** as an EM signal by one or more launchers of the waveguide interface **410**. The EM signal is then propagated to the distal end of the DWG network **102** for reception by the radar management unit **104**.

[0042] At block **514**, the radar management unit **104** receives the EM signal from the DWG network **102** via one or more launchers at the corresponding waveguide interface **310** and the RF front end **306** converts the resulting analog signal to a digital data signal. At block **516**, the digital processing system **302** receives the digital data signal and takes one or more actions in response, such as displaying distance/speed information represented in the digital data signal, controlling one or more autonomous driver functions based on the digital data signal, and the like.

[0043] In some embodiments, certain aspects of the techniques described above may be implemented by one or more processors of a processing system executing software. The software comprises one or more sets of executable instructions stored or otherwise tangibly embodied on a non-transitory computer readable storage medium. The software can include the instructions and certain data that, when executed by the one or more processors, manipulate the one or more processors to perform one or more aspects of the techniques described above. The non-transitory computer readable storage medium can include, for example, a magnetic or optical disk storage device, solid state storage devices such as Flash memory, a cache, random access memory (RAM) or other non-volatile memory device or devices, and the like. The executable instructions stored on the non-transitory computer readable storage medium may be in source code, assembly language code, object code, or other instruction format that is interpreted or otherwise executable by one or more processors.

[0044] A computer readable storage medium may include any storage medium, or combination of storage media, accessible by a computer system during use to provide instructions and/or data to the computer system. Such storage media can include, but is not limited to, optical media (e.g., compact disc (CD), digital versatile disc (DVD), Blu-Ray disc), magnetic media (e.g., floppy disc, magnetic tape, or magnetic hard drive), volatile memory (e.g., random access memory (RAM) or cache), non-volatile memory (e.g., read-only memory (ROM) or Flash memory), or microelectromechanical systems (MEMS)-based storage media. The computer readable storage medium may be embedded in the computing system (e.g., system RAM or ROM), fixedly attached to the computing system (e.g., a magnetic hard drive), removably attached to the computing system (e.g., an optical disc or Universal Serial Bus (USB)-based Flash memory), or coupled to the computer system via a wired or wireless network (e.g., network accessible storage (NAS)).

[0045] Note that not all of the activities or elements described above in the general description are required, that a portion of a specific activity or device may not be required, and that one or more further activities may be performed, or elements included, in addition to those described. Still further, the order in which activities are listed are not necessarily the order in which they are performed. Also, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present disclosure as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present disclosure.

[0046] Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any feature(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as a critical, required, or essential feature of any or all the claims. Moreover, the particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. No limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope of the disclosed subject matter. Accordingly, the protection sought herein is as set forth in the claims below.

Claims

1. A distributed radar system comprising: a management unit; a plurality of distributed radar units; and a dielectric waveguide network comprising a plurality of dielectric waveguides coupling the management unit to the plurality of distributed radar units; wherein the management unit is configured to generate a reference signal for synchronization of operations of the plurality of distributed radar units; and the dielectric waveguide network is configured to propagate a representation of the reference signal to each of the distributed radar units of the plurality of distributed radar units.

2. The distributed radar system of claim 1, wherein the reference signal comprises one of a continuous waveform (CW) signal or a frequency modulated continuous waveform (FMCW) signal.

3. The distributed radar system of claim 2, wherein the reference signal has a carrier frequency equal to a frequency of a radar illumination signal generated by at least one distributed radar unit based on the reference signal.

4. The distributed radar system of claim 1, wherein each dielectric waveguide includes a dielectric core at least partially surrounded by at least one cladding layer.

5. The distributed radar system of claim 4, wherein the dielectric core is composed of at least one of: polytetrafluoroethylene, polyethylene, polypropylene, or polystyrene.

6. The distributed radar system of claim 4, wherein the at least one cladding layer is composed of at least one of a polymer, a metal, or a metal alloy.

7. The distributed radar system of claim 1, wherein the management unit is further configured to introduce time stamp information into the reference signal through modulation of the reference signal.

8. The distributed radar system of claim 7, wherein at least one distributed radar unit of the plurality of distributed radar units is configured to determine the time stamp information from the received representation of the reference signal and to control a timing of at least one radar operation of the distributed radar unit based on the time stamp information.

9. The distributed radar system of claim 1, wherein the dielectric waveguide network has a parallel star topology having a plurality of dielectric waveguides, each dielectric waveguide terminating at the management unit at one end and terminating at a corresponding distributed radar unit at an opposing end.

10. The distributed radar system of claim 9, wherein the management unit comprises: a splitter having an input to receive the reference signal and a plurality of outputs, each output to provide a representation of the reference signal; and a plurality of waveguide interfaces, each waveguide interface coupled to a corresponding output of the plurality of outputs of the splitter and further coupled to a first end of a corresponding dielectric waveguide of the plurality of dielectric waveguides, the waveguide interface having at least one launcher for launching an analog signal corresponding to a received representation of the reference signal as an electromagnetic signal for propagation to a proximal end of the dielectric waveguide.

11. The distributed radar system of claim 1, wherein the dielectric waveguide network has a branched star topology having a first dielectric waveguide having one end coupled to the management unit and an opposing end coupled to one of the distributed radar units, and a plurality of second dielectric waveguides, each of the other dielectric waveguides having one end coupled to the first dielectric waveguide and an opposing end coupled to a corresponding distributed radar unit.

12. The distributed radar system of claim 11, wherein the management unit comprises: a waveguide interface coupled to a proximal end of the first dielectric waveguide, the waveguide interface having at least one launcher for launching an analog signal corresponding to a representation of the reference signal as an electromagnetic signal for propagation to a proximal end of the dielectric waveguide.

13. The distributed radar system of claim 1, wherein each distributed radar unit comprises: a waveguide interface coupled to a proximal end of a corresponding dielectric waveguide of the dielectric waveguide network and comprising at least one launcher and at least one amplifier to convert an electromagnetic signal received from the dielectric waveguide to a corresponding analog signal; and wherein the distributed radar unit is configured to control at least one radar operation of the distributed radar unit based on a representation of the reference signal generated from the analog signal.

14. The distributed radar system of claim 1, wherein: at least one distributed radar unit is configured to generate a digital data signal representative of results of a radar sensing operation of the distributed radar unit; the dielectric waveguide network is configured to propagate a representation of the digital data signal to the management unit; and the management unit is configured to control at least one operation of the distributed radar system based on the digital data signal.

15. A vehicle comprising an advanced driver assistance system having the distributed radar system of claim 1.

16. A method in a distributed radar system, the method comprising: generating, at a management unit, a reference signal; transmitting a representation of the reference signal from the management unit to each of a plurality of distributed radar units via a dielectric waveguide network comprising a plurality of dielectric waveguides; and receiving, at each distributed radar unit, the representation of the reference signal from the dielectric waveguide network and controlling one or more radar operations of the distributed radar unit based on the received representation of the reference signal.

17. The method of claim 16, further comprising: modulating, at the management unit, the reference signal to introduce time stamp information into the reference signal; and controlling, at a distributed radar unit, a timing of at least one radar operation of the distributed radar unit based on time stamp information from a received representation of the reference signal.

18. The method of claim 16, wherein: the dielectric waveguide network has a parallel star topology having a plurality of dielectric waveguides, each dielectric waveguide terminating at the management unit at one end and terminating at a corresponding distributed radar unit at an opposing end; and transmitting a representation of the reference signal from the management unit to each of the distributed radar units comprises: generating a plurality of representations of the reference signal at the management unit; and launching, at a corresponding waveguide interface of a plurality of waveguide interfaces of the management unit, an electromagnetic signal representative of a corresponding representation of the reference signal into a corresponding dielectric waveguide of the plurality of waveguides using at least one launcher of the waveguide interface.

19. The method of claim 16, wherein: the dielectric waveguide network has a branched star topology having a first dielectric waveguide having one end coupled to the management unit and an opposing end coupled to one of the distributed radar units, and a plurality of second dielectric waveguides, each of the other dielectric waveguides having one end coupled to the first dielectric waveguide and an opposing end coupled to a corresponding distributed radar unit; and transmitting a representation of the reference signal from the management unit to each of the distributed radar units comprises: launching, at a waveguide interface of the management unit, an electromagnetic signal representative of the reference signal into the first dielectric waveguide using at least one launcher of the waveguide interface.

20. The method of claim 16, further comprising: generating, at a distributed radar unit, a digital data signal representative of results of a radar sensing operation of the distributed radar unit; propagating a representation of the digital data signal to the management unit via the dielectric waveguide network; and controlling, at the management unit, at least one operation of the distributed radar system based on a received representation of the digital data signal.