US 20240248189A1

(19) United States
(12) Patent Application Publication
Esmail

(10) Pub. No.: US 2024/0248189 A1
(43) Pub. Date: Jul. 25, 2024

(54) **TARGETING SYSTEM FOR BISTATIC RADIO WAVE LOCALIZATION**

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(21) Appl. No.: **18/207,767**

(22) Filed: **Jun. 9, 2023**

Related U.S. Application Data

(60) Provisional application No. 63/440,188, filed on Jan. 20, 2023.

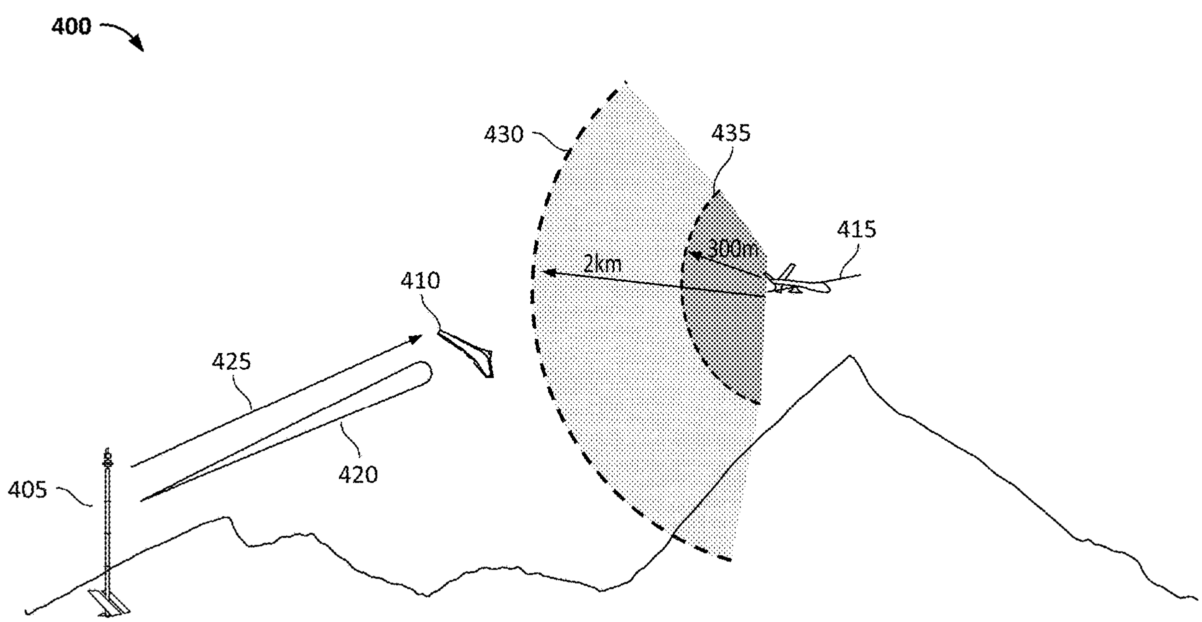
Publication Classification

(51) **Int. Cl.**
G01S 13/00 (2006.01)
F41G 7/22 (2006.01)
G01S 13/72 (2006.01)

(52) **U.S. Cl.**
CPC ***G01S 13/003*** (2013.01); ***F41G 7/2266*** (2013.01); ***F41G 7/2286*** (2013.01); ***G01S 13/723*** (2013.01)

(57) **ABSTRACT**

The present application discloses a method, system, and computer system for tracking a target object. The method includes (i) receiving, by a receiver, an indication regarding a radio frequency (RF) transmitted beam, (ii) receiving a scattered reflection of the RF transmitted beam from a first target object, and (iii) processing the scattered reflection of the RF transmitted beam using the indication.



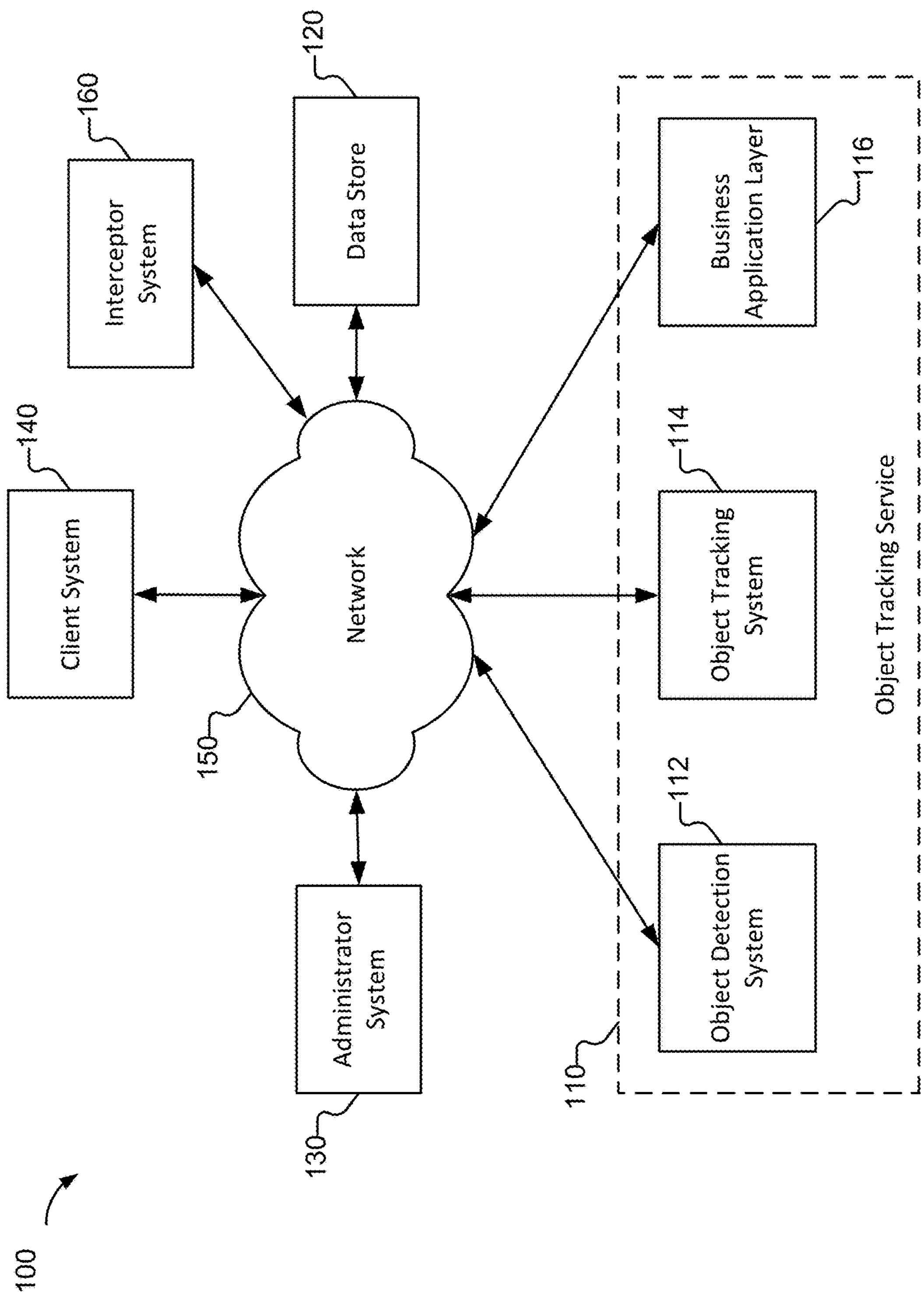

100
Client System
140
Interceptor System
160
Data Store
120
Network
150
Administrator System
130
Business Application Layer
116
Object Tracking System
114
Object Detection System
112
Object Tracking Service
110

FIG. 1

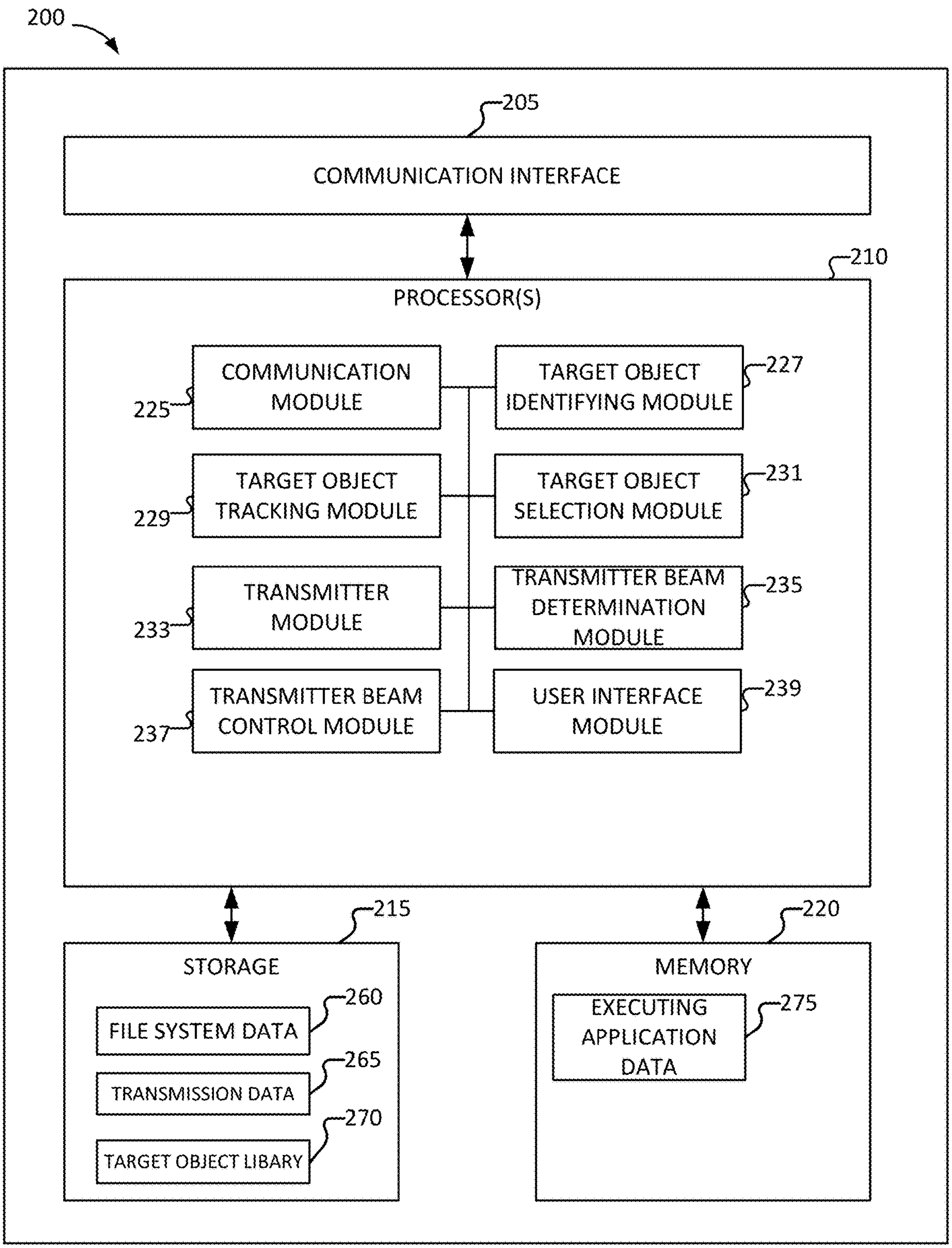

200
205
COMMUNICATION INTERFACE
210
PROCESSOR(S)
COMMUNICATION MODULE
225
TARGET OBJECT IDENTIFYING MODULE
227
TARGET OBJECT TRACKING MODULE
229
TARGET OBJECT SELECTION MODULE
231
TRANSMITTER MODULE
233
TRANSMITTER BEAM DETERMINATION MODULE
235
TRANSMITTER BEAM CONTROL MODULE
237
USER INTERFACE MODULE
239
215
STORAGE
FILE SYSTEM DATA
260
TRANSMISSION DATA
265
TARGET OBJECT LIBARY
270
220
MEMORY
EXECUTING APPLICATION DATA
275

FIG. 2

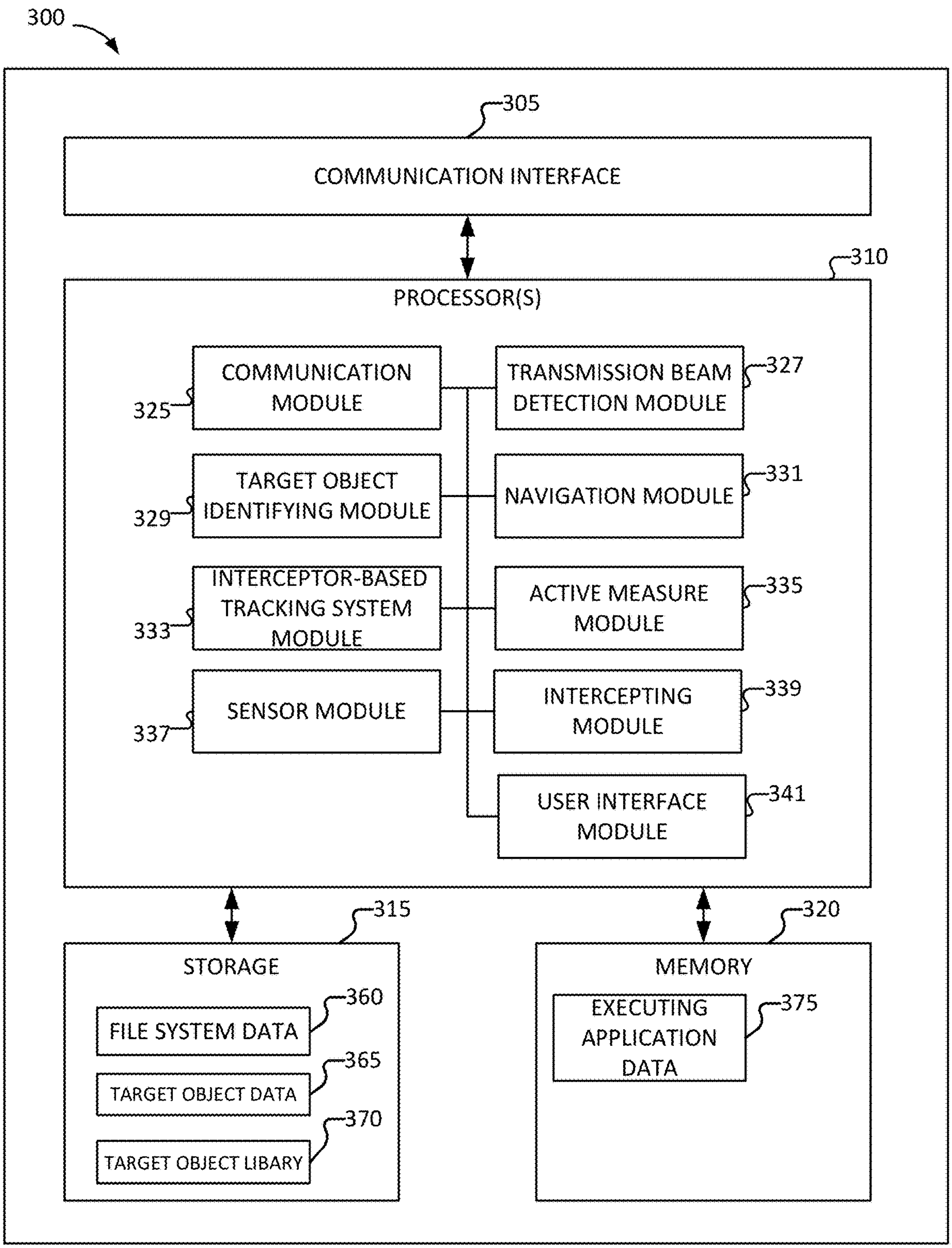

300
305
COMMUNICATION INTERFACE
310
PROCESSOR(S)
COMMUNICATION MODULE
325
TRANSMISSION BEAM DETECTION MODULE
327
TARGET OBJECT IDENTIFYING MODULE
329
NAVIGATION MODULE
331
INTERCEPTOR-BASED TRACKING SYSTEM MODULE
333
ACTIVE MEASURE MODULE
335
SENSOR MODULE
337
INTERCEPTING MODULE
339
USER INTERFACE MODULE
341
315
STORAGE
FILE SYSTEM DATA
360
TARGET OBJECT DATA
365
TARGET OBJECT LIBARY
370
320
MEMORY
EXECUTING APPLICATION DATA
375

FIG. 3

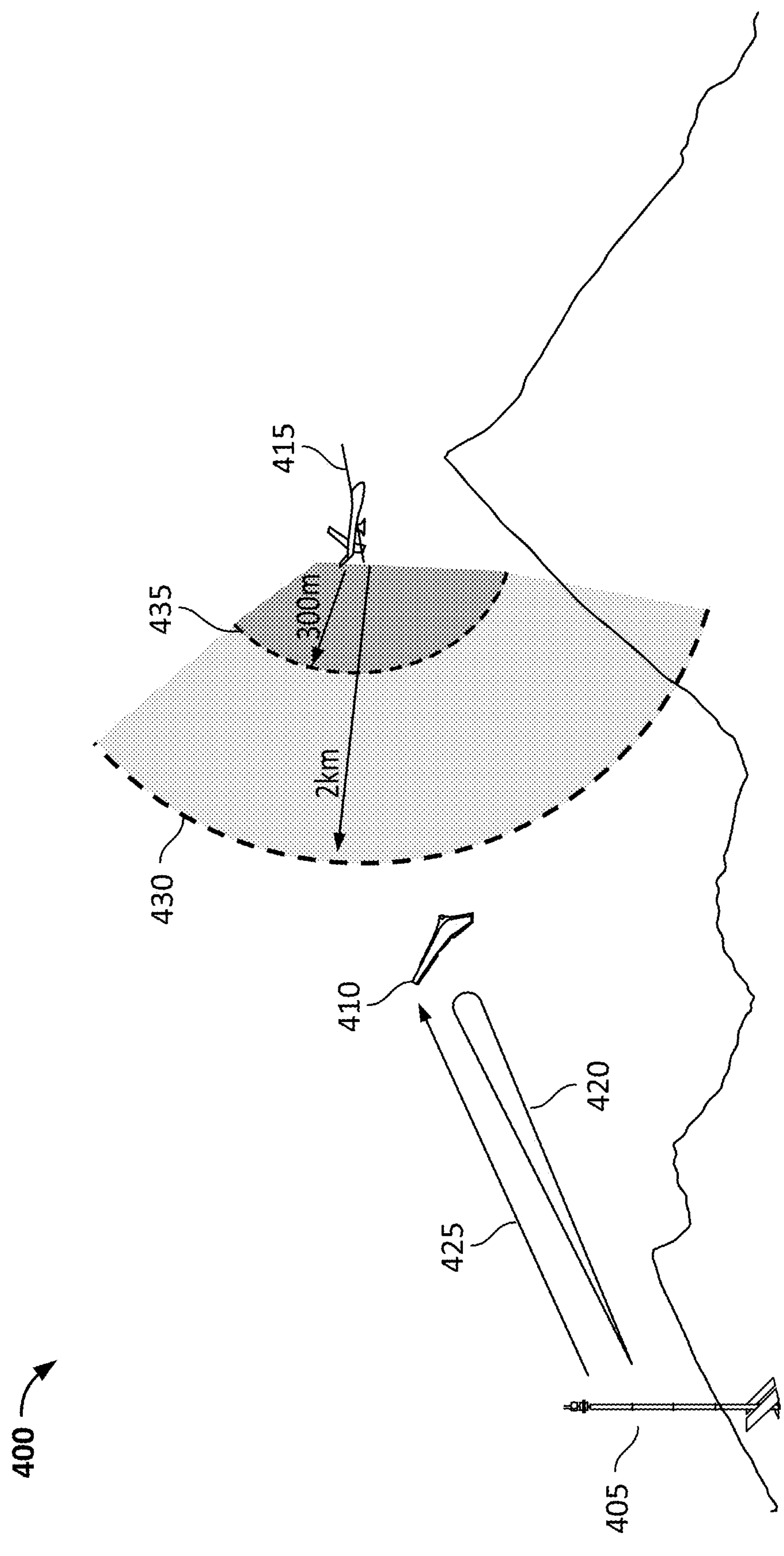


FIG. 4

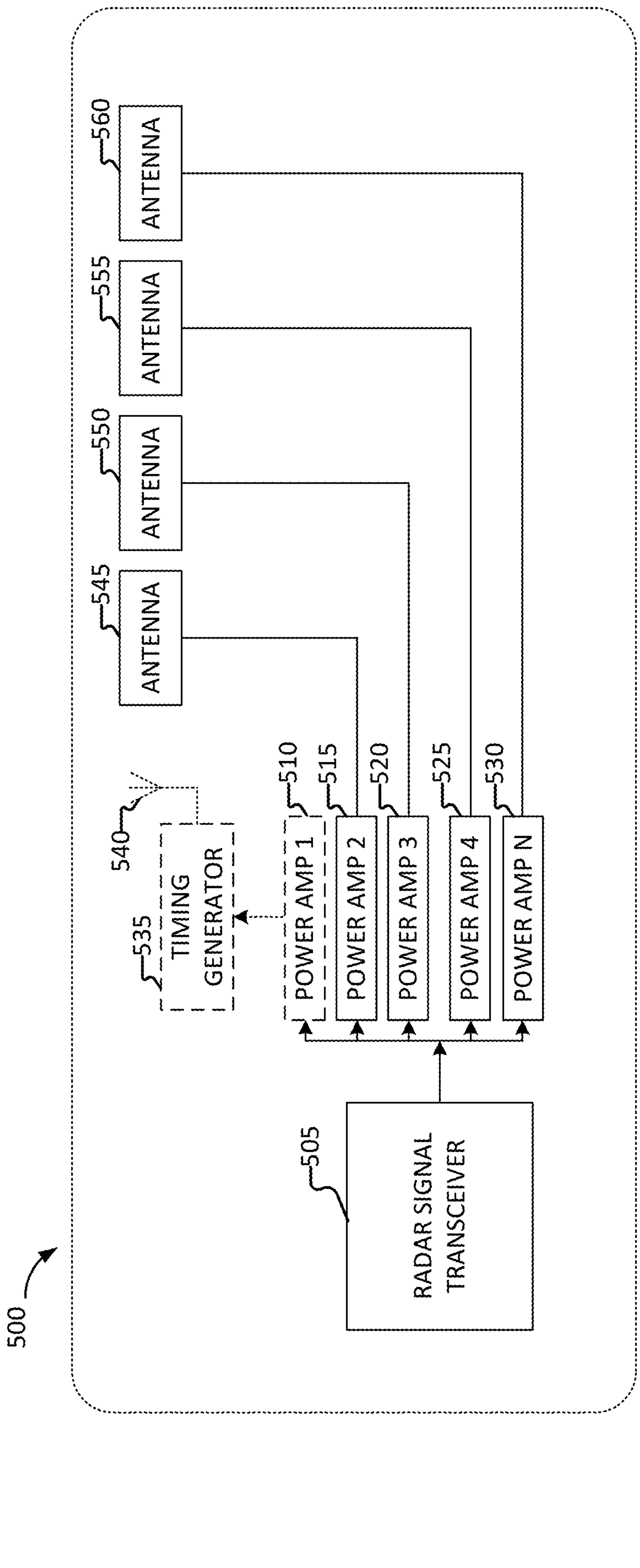

500
505
RADAR SIGNAL TRANSCEIVER
510
POWER AMP 1
515
POWER AMP 2
520
POWER AMP 3
525
POWER AMP 4
530
POWER AMP N
535
TIMING GENERATOR
540
545
ANTENNA
550
ANTENNA
555
ANTENNA
560
ANTENNA

FIG. 5

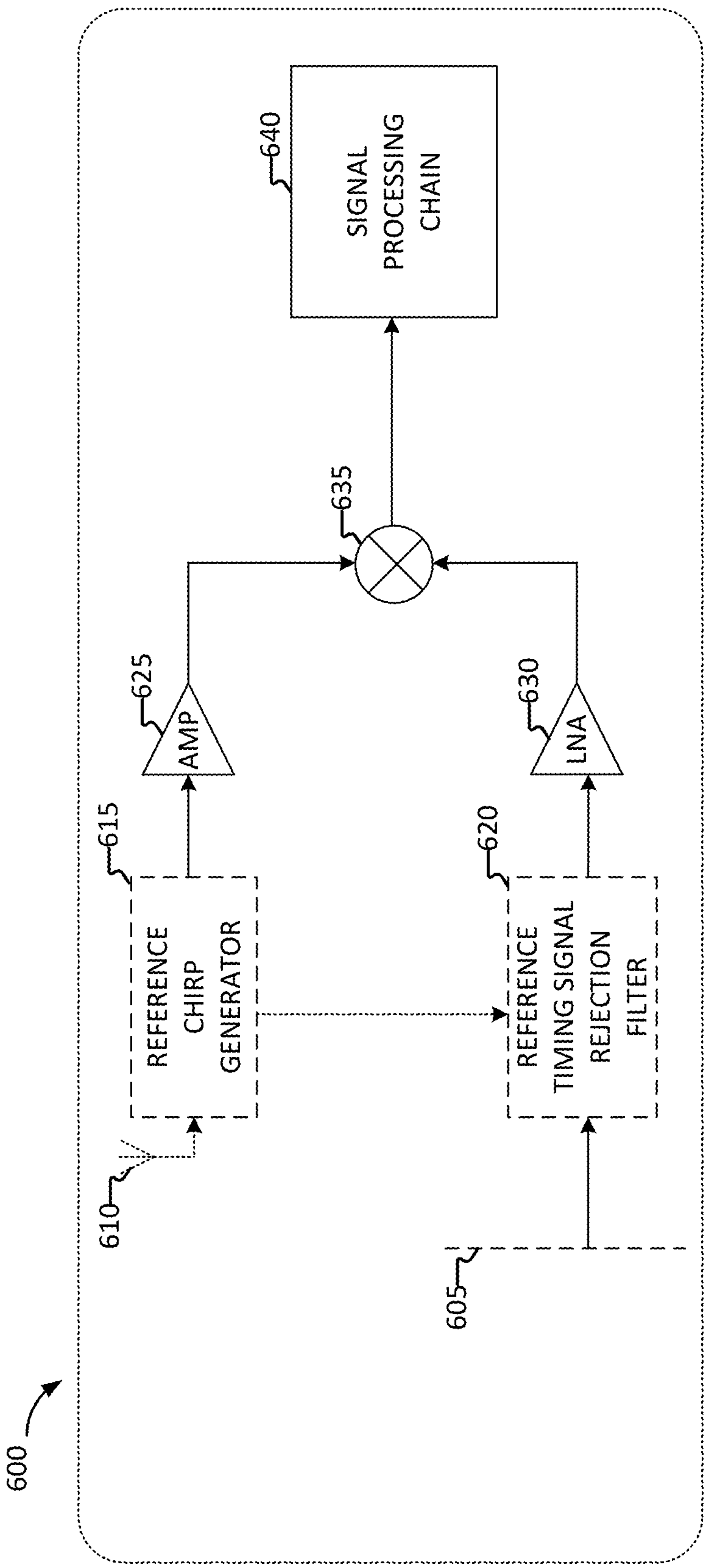

600
605
610
615
REFERENCE CHIRP GENERATOR
620
REFERENCE TIMING SIGNAL REJECTION FILTER
625
AMP
630
LNA
635
640
SIGNAL PROCESSING CHAIN

FIG. 6

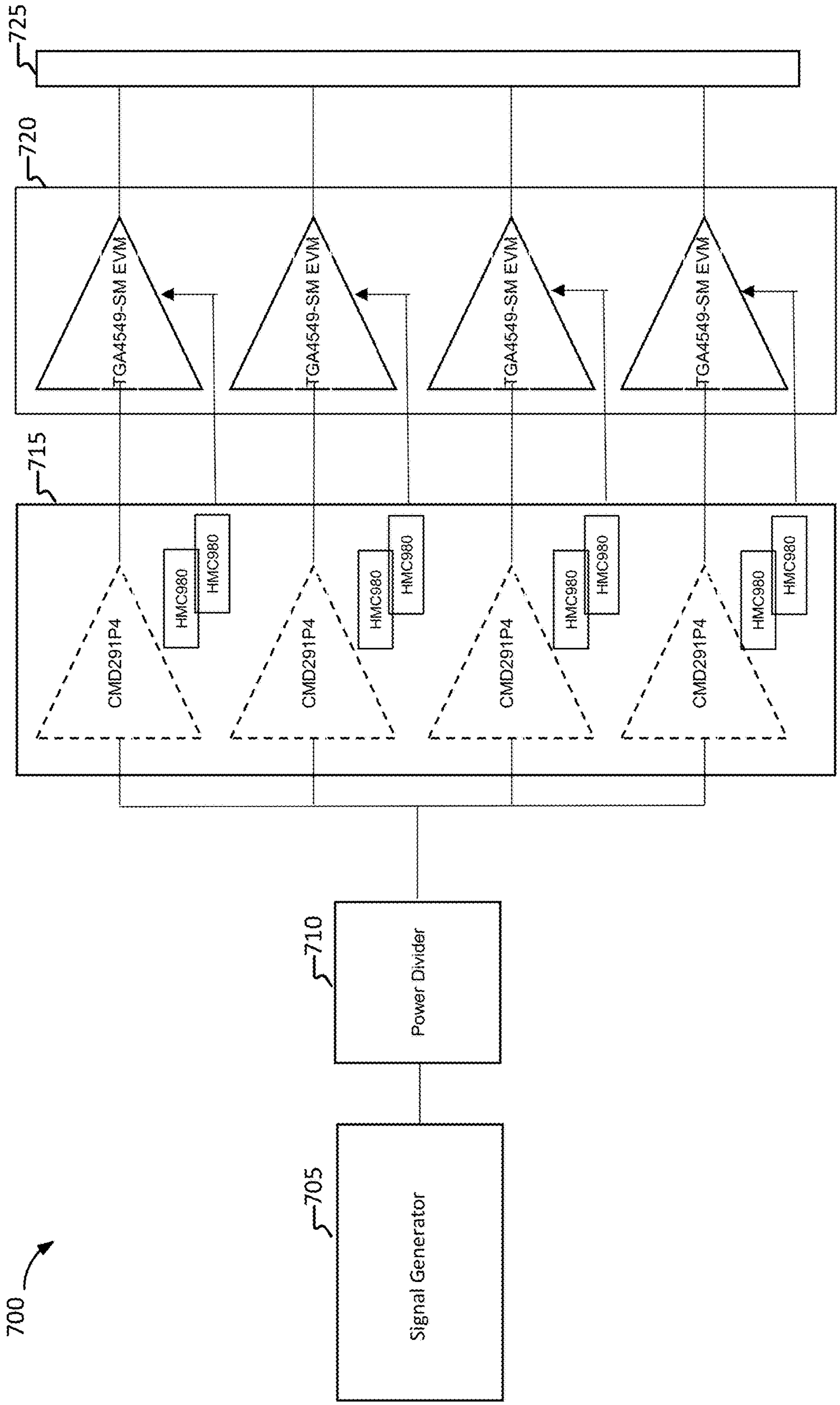

725
720
TGA4549-SM EVM
TGA4549-SM EVM
TGA4549-SM EVM
TGA4549-SM EVM
715
HMC980
HMC980
CMD291P4
CMD291P4
CMD291P4
CMD291P4
710
Power Divider
705
Signal Generator
700

FIG. 7

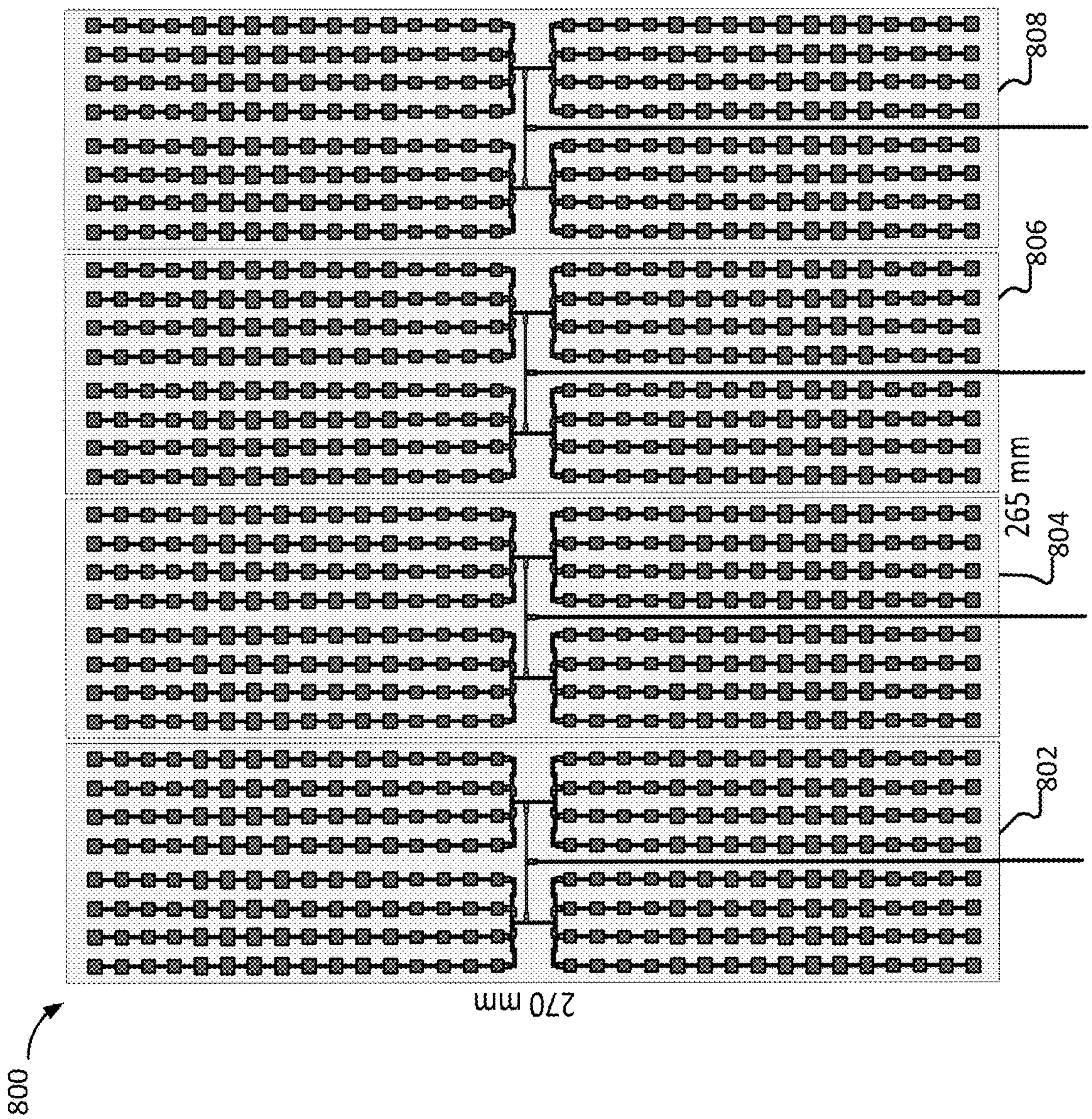


FIG. 8

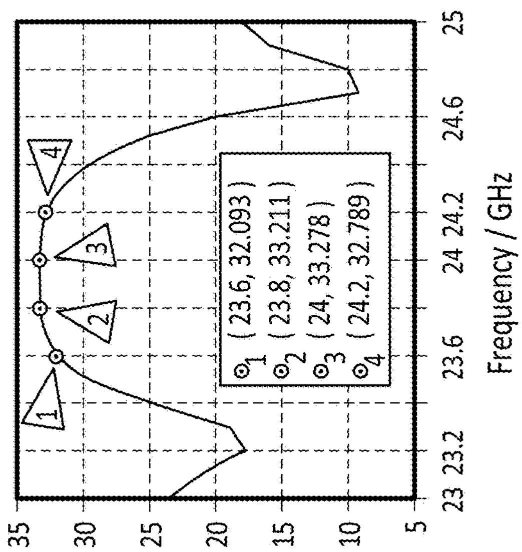


FIG. 9A

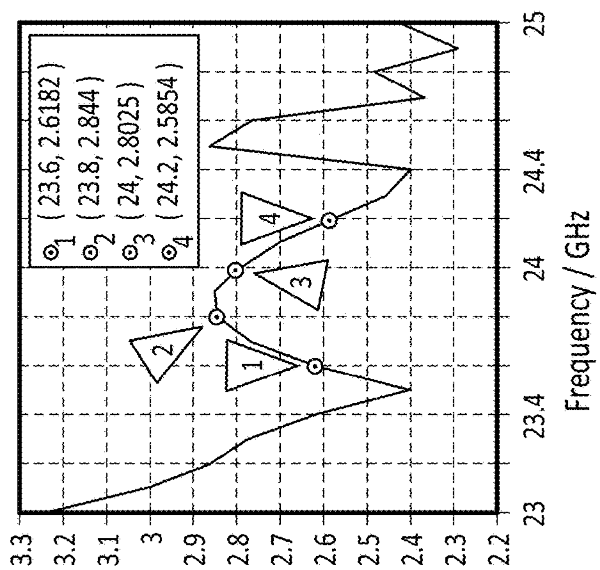


FIG. 9B

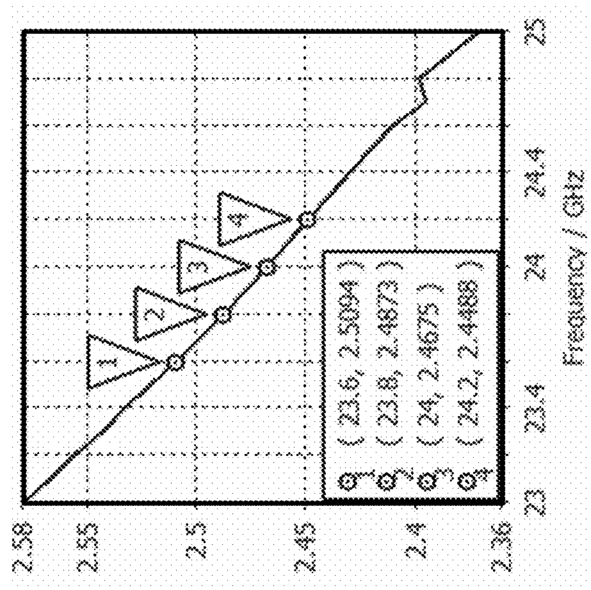


FIG. 9C

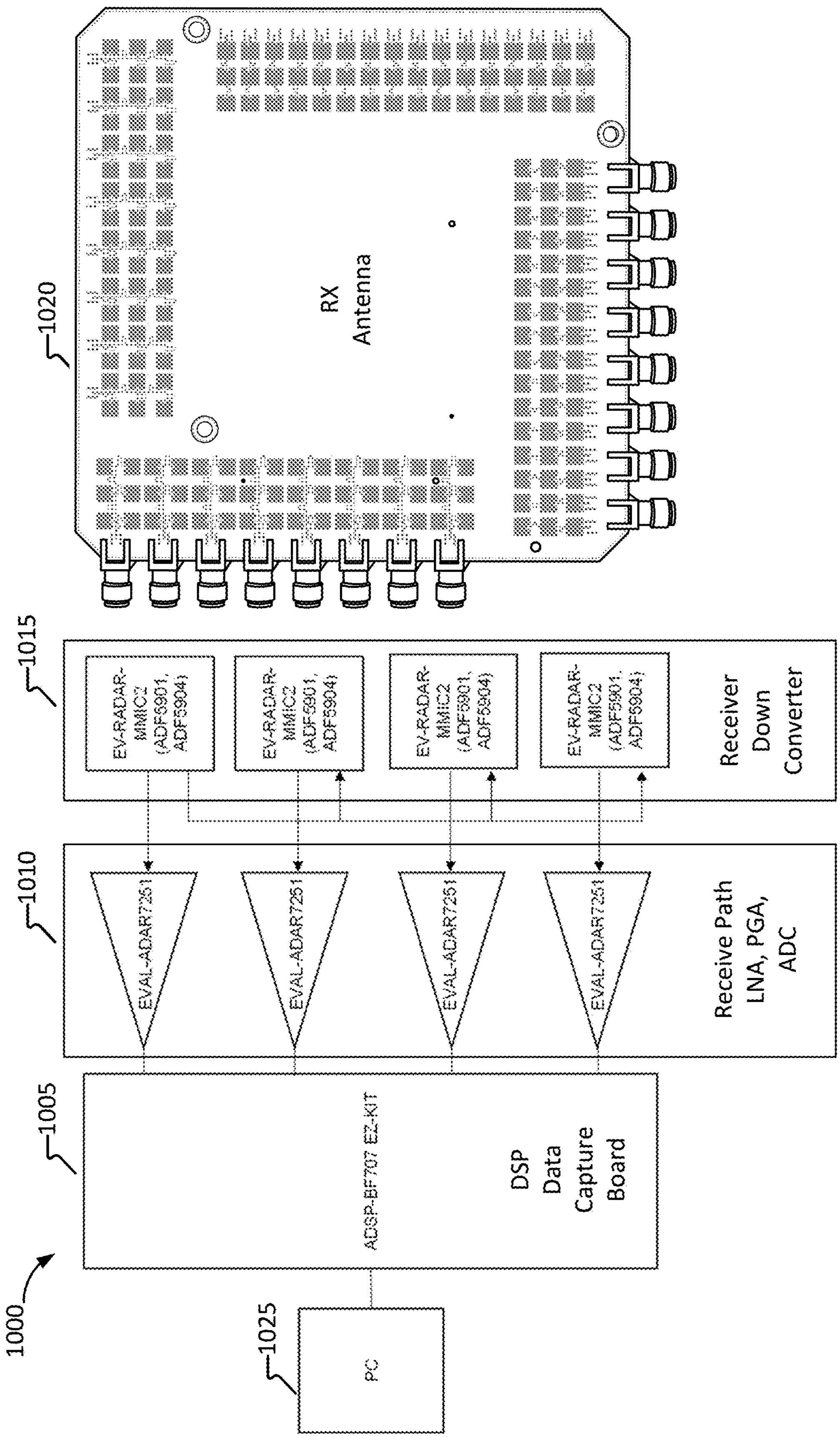
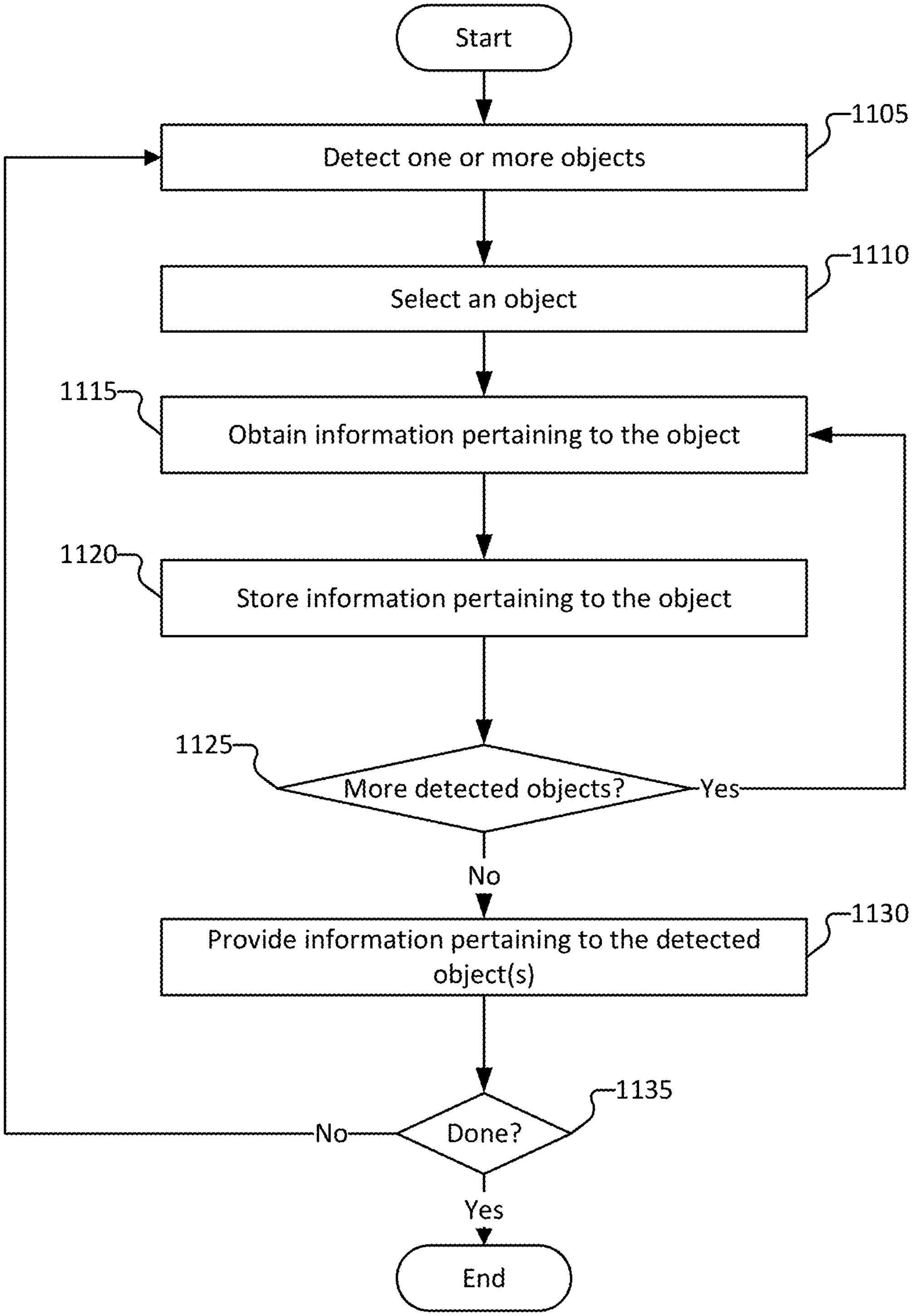
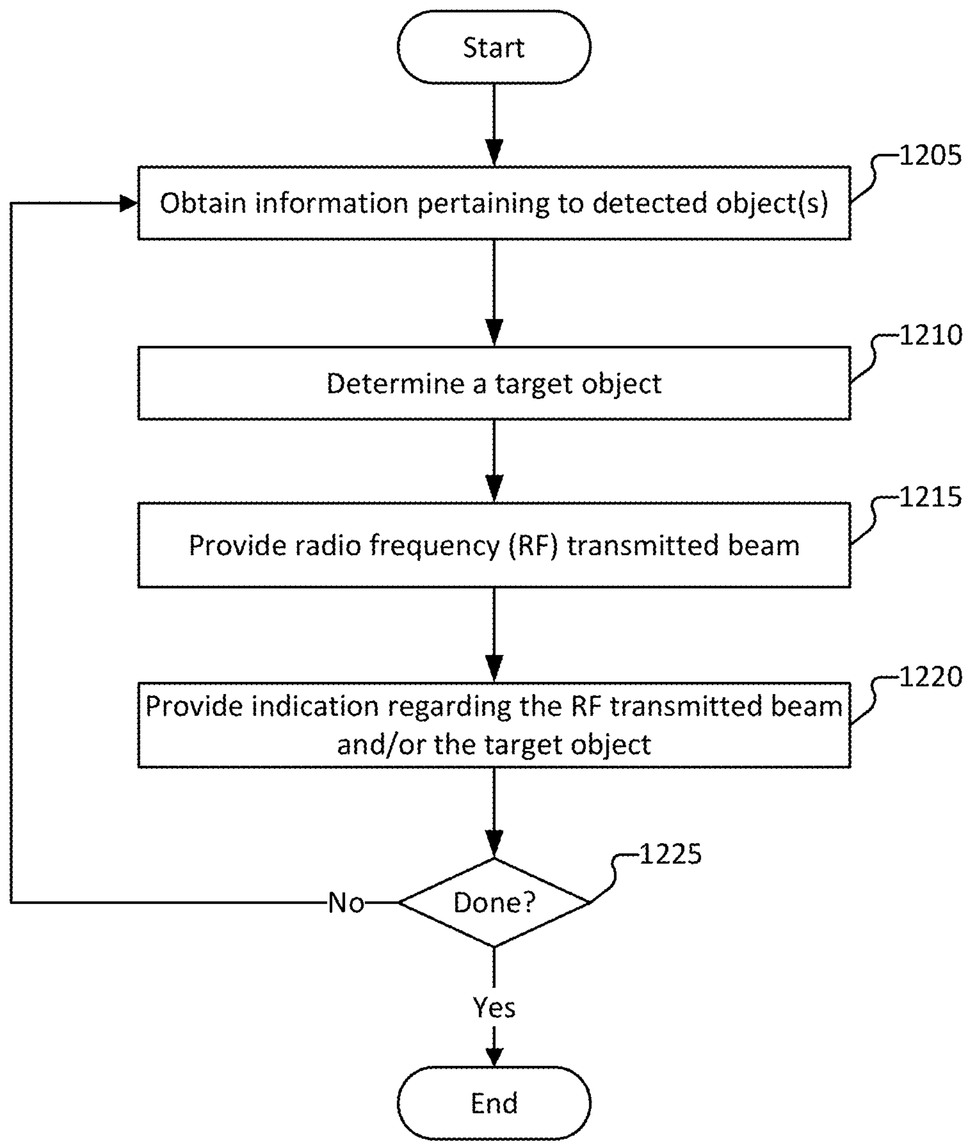

1000
1005
ADSP-BF707 EZ-KIT
DSP Data Capture Board
1010
EVAL-ADAR7251
EVAL-ADAR7251
EVAL-ADAR7251
EVAL-ADAR7251
Receive Path LNA, PGA, ADC
1015
EV-RADAR-MMIC2 (ADF5901, ADF5904)
EV-RADAR-MMIC2 (ADF5901, ADF5904)
EV-RADAR-MMIC2 (ADF5901, ADF5904)
EV-RADAR-MMIC2 (ADF5901, ADF5904)
Receiver Down Converter
1020
RX Antenna
1025
PC

FIG. 10


Start
Detect one or more objects
1105
Select an object
1110
1115
Obtain information pertaining to the object
1120
Store information pertaining to the object
1125
More detected objects?
Yes
No
Provide information pertaining to the detected object(s)
1130
Done?
1135
No
Yes
End

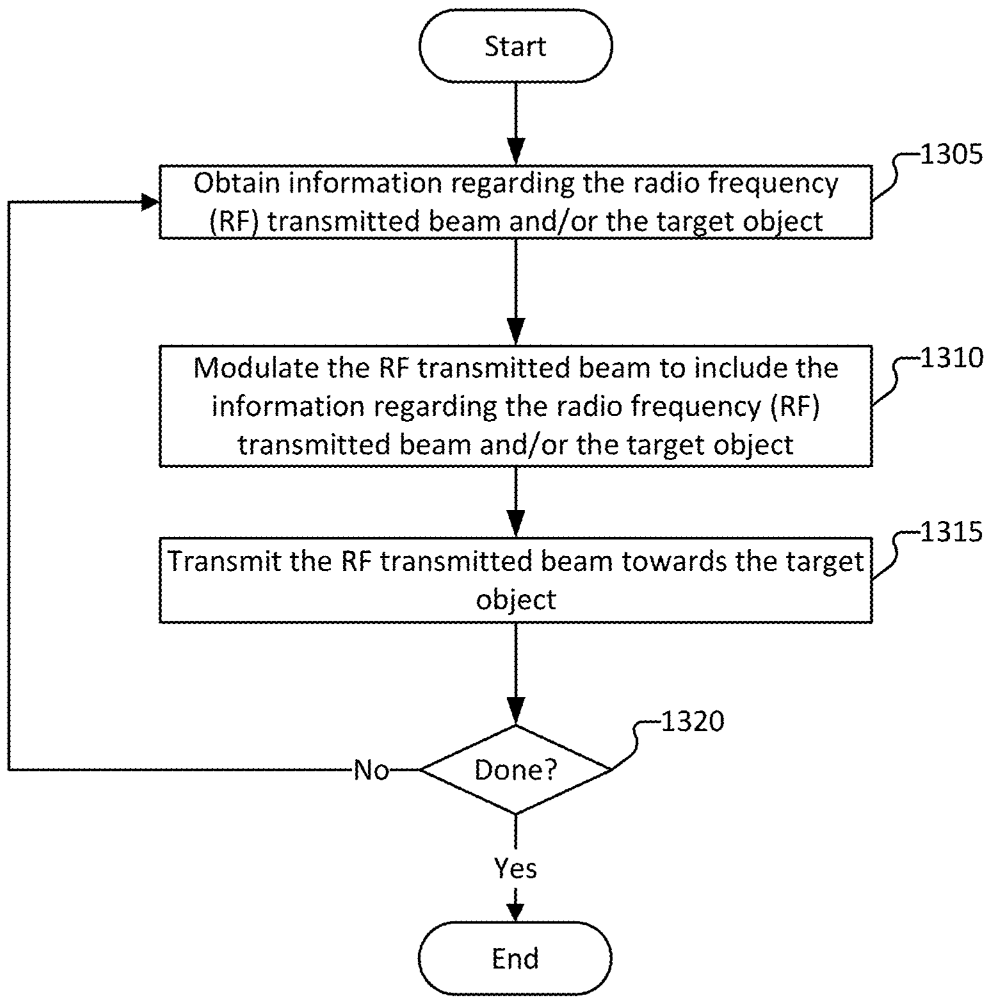
1100

FIG. 11


Start
Obtain information pertaining to detected object(s)
1205
Determine a target object
1210
Provide radio frequency (RF) transmitted beam
1215
Provide indication regarding the RF transmitted beam and/or the target object
1220
Done?
1225
No
Yes
End

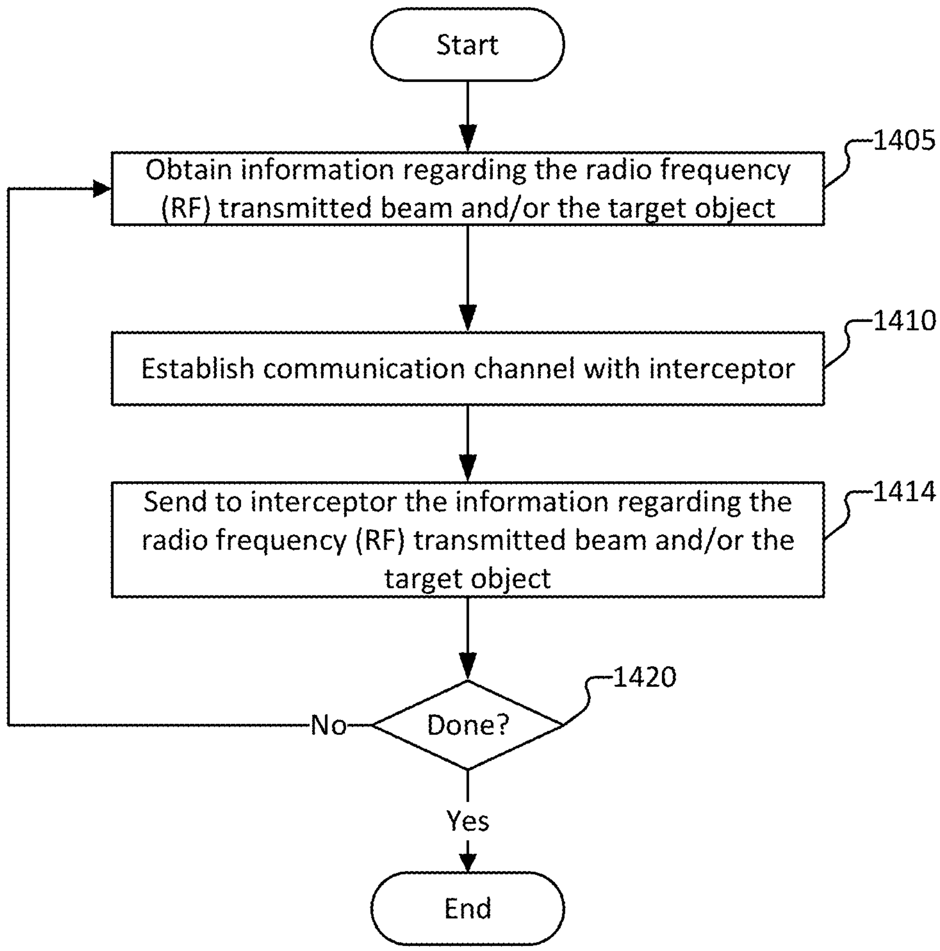
1200

FIG. 12



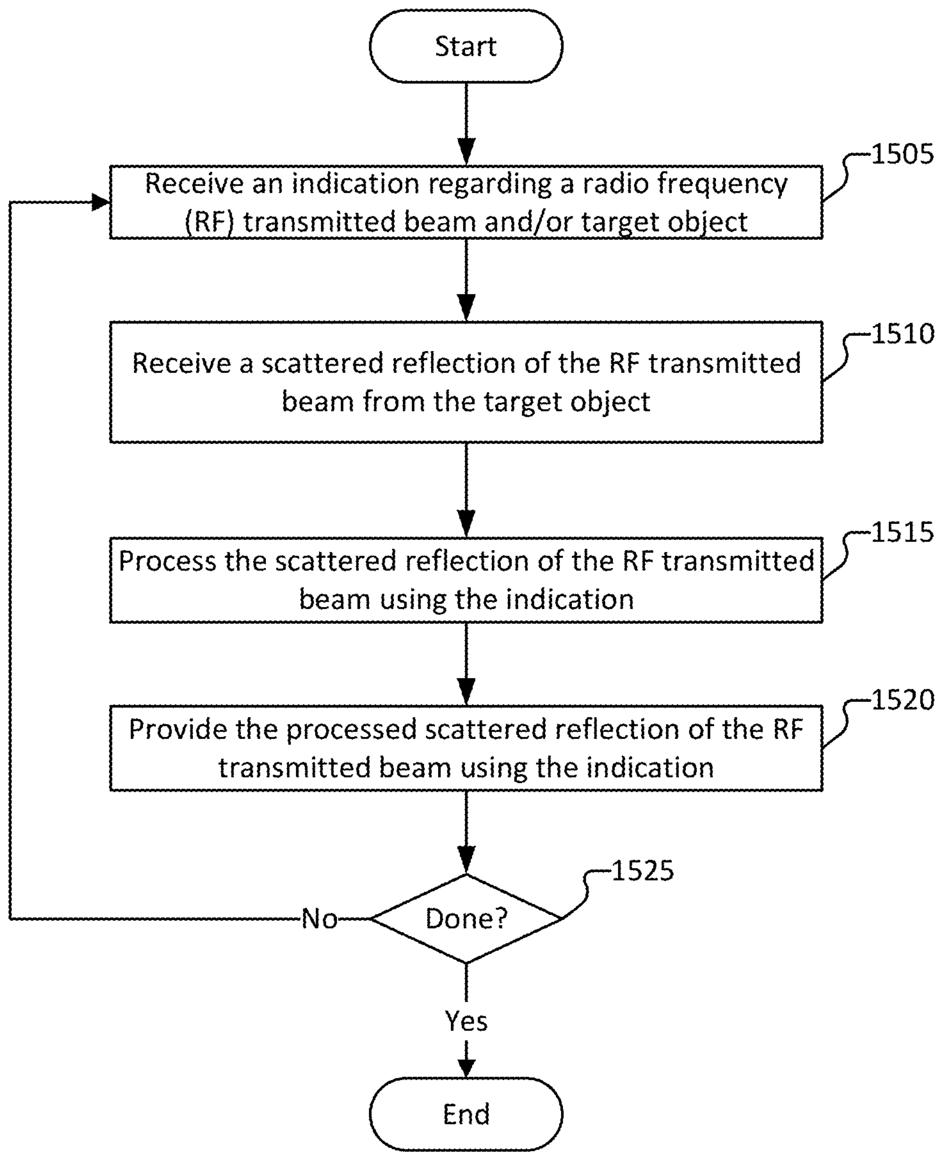
<u>**1300**</u>

FIG. 13


Start
Obtain information regarding the radio frequency (RF) transmitted beam and/or the target object
1405
Establish communication channel with interceptor
1410
Send to interceptor the information regarding the radio frequency (RF) transmitted beam and/or the target object
1414
Done?
1420
No
Yes
End

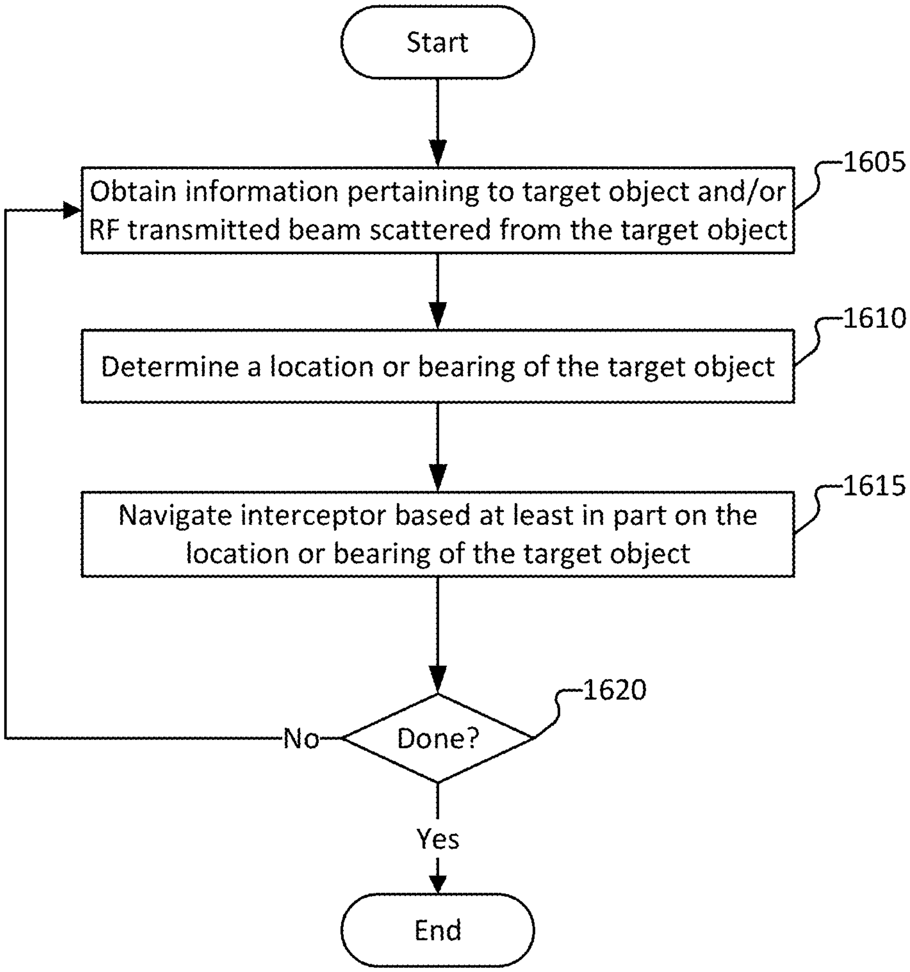
1400

FIG. 14


Start
Receive an indication regarding a radio frequency (RF) transmitted beam and/or target object
1505
Receive a scattered reflection of the RF transmitted beam from the target object
1510
Process the scattered reflection of the RF transmitted beam using the indication
1515
Provide the processed scattered reflection of the RF transmitted beam using the indication
1520
Done?
1525
No
Yes
End

1500

FIG. 15


Start
Obtain information pertaining to target object and/or RF transmitted beam scattered from the target object
1605
Determine a location or bearing of the target object
1610
Navigate interceptor based at least in part on the location or bearing of the target object
1615
Done?
1620
No
Yes
End

1600

FIG. 16

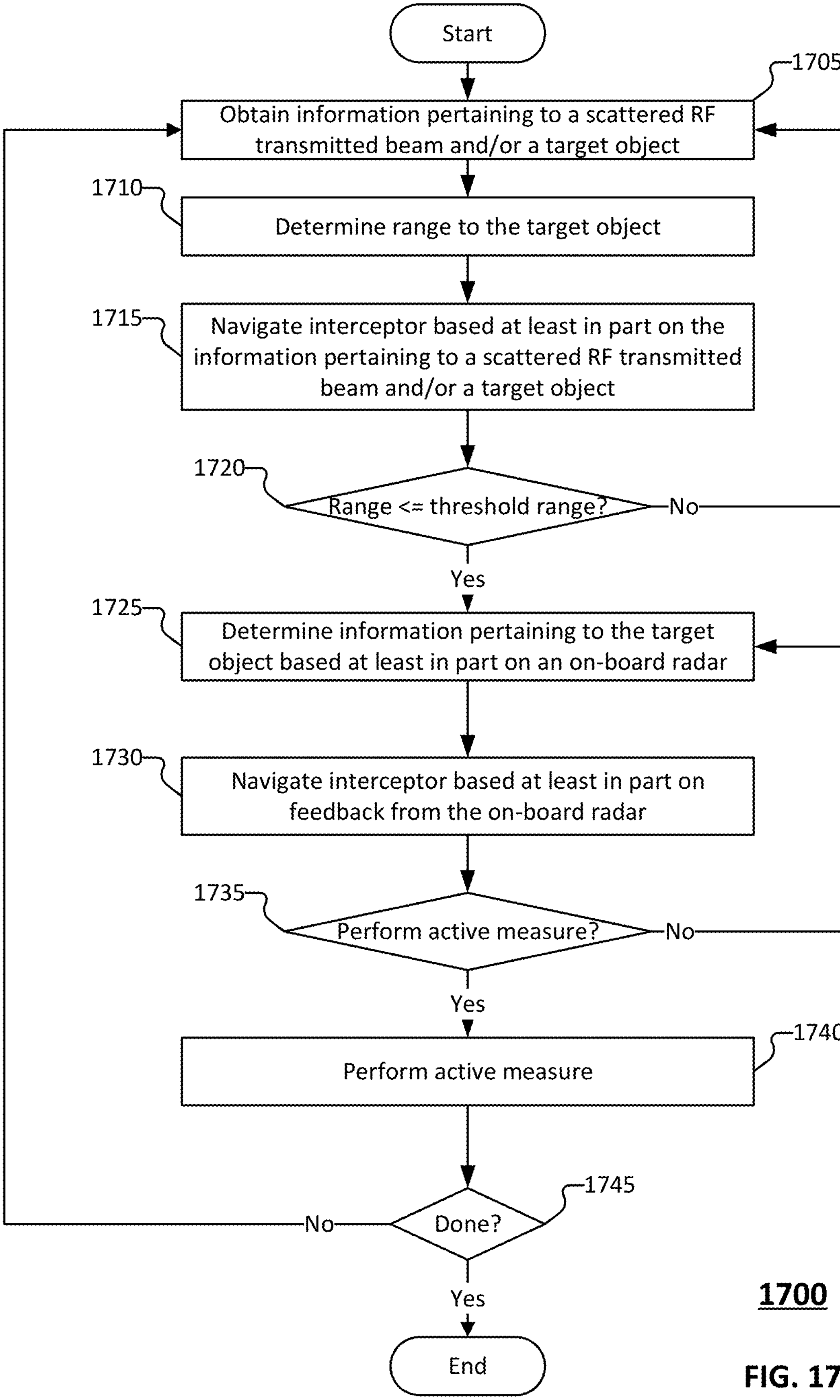

Start
1705
Obtain information pertaining to a scattered RF transmitted beam and/or a target object
1710
Determine range to the target object
1715
Navigate interceptor based at least in part on the information pertaining to a scattered RF transmitted beam and/or a target object
1720
Range <= threshold range?
No
Yes
1725
Determine information pertaining to the target object based at least in part on an on-board radar
1730
Navigate interceptor based at least in part on feedback from the on-board radar
1735
Perform active measure?
No
Yes
1740
Perform active measure
1745
Done?
No
Yes
End
1700

FIG. 17

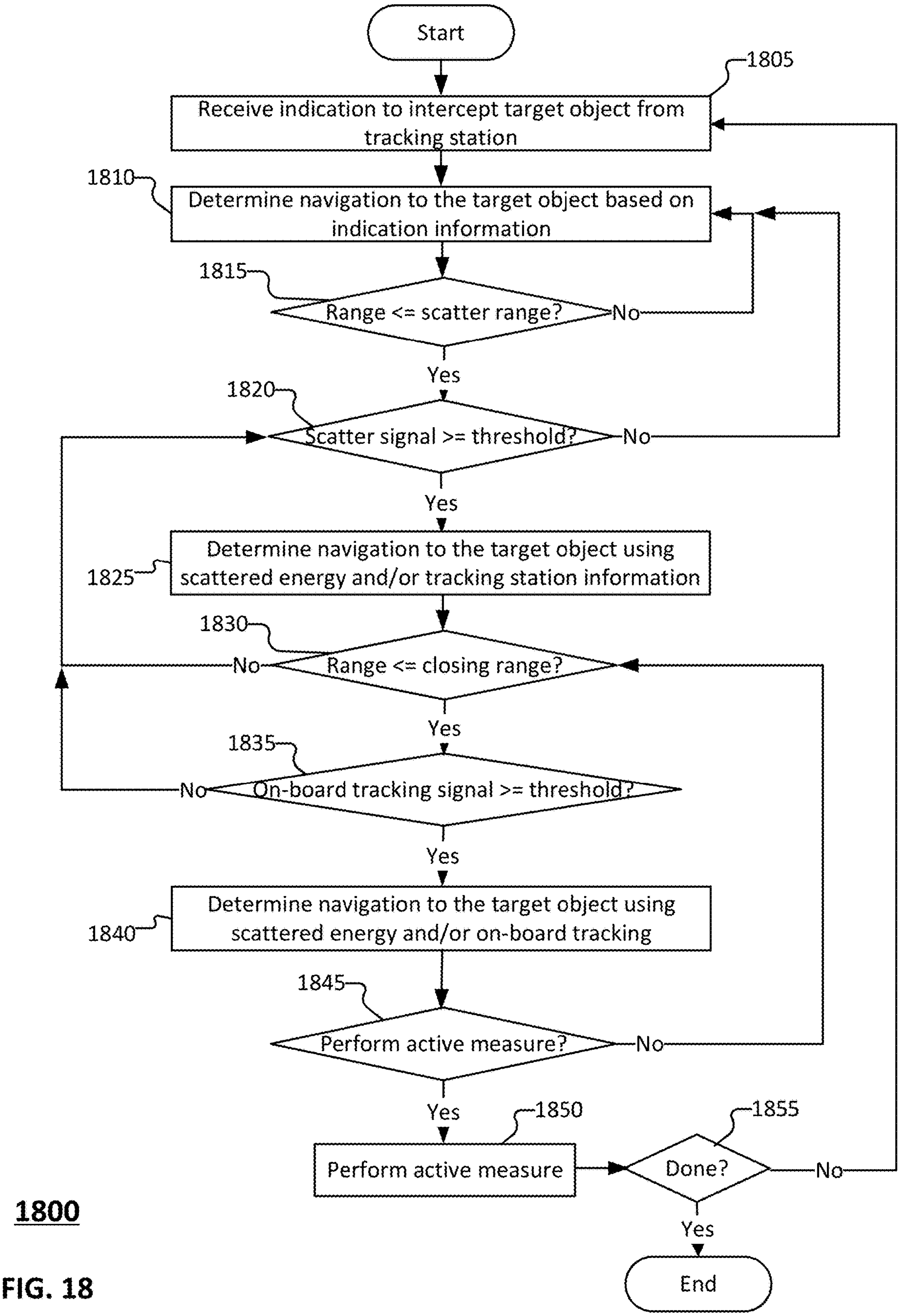

Start
1805
Receive indication to intercept target object from tracking station
1810
Determine navigation to the target object based on indication information
1815
Range <= scatter range?
No
Yes
1820
Scatter signal >= threshold?
No
Yes
Determine navigation to the target object using scattered energy and/or tracking station information
1825
1830
Range <= closing range?
No
Yes
1835
On-board tracking signal >= threshold?
No
Yes
Determine navigation to the target object using scattered energy and/or on-board tracking
1840
1845
Perform active measure?
No
Yes
1850
Perform active measure
1855
Done?
No
Yes
End
1800

FIG. 18

TARGETING SYSTEM FOR BISTATIC RADIO WAVE LOCALIZATION

CROSS REFERENCE TO OTHER APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 63/440,188 entitled BISTATIC RADAR filed Jan. 20, 2023 which is incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

[0002] Radio wave technology has been used for various applications including navigation, surveillance, and military applications. In particular, monostatic radars have been the most commonly used type of systems for such applications. Monostatic radars use a single antenna for both transmission and reception of electromagnetic waves. However, monostatic radars have certain limitations such as reduced detection range and susceptibility to interference from cluttering and jamming.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] Various embodiments of the invention are disclosed in the following detailed description and the accompanying drawings.

[0004] FIG. **1** is a block a diagram of a network system according to various embodiments of the present application.

[0005] FIG. **2** is a block diagram of a transmitter system according to various embodiments of the present application.

[0006] FIG. **3** is a block diagram of a receiver system according to various embodiments of the present application.

[0007] FIG. **4** is a diagram of a target tracking system according to various embodiments of the present application.

[0008] FIG. **5** is a diagram illustrating a bistatic radio wave localization transmitter according to various embodiments of the present application.

[0009] FIG. **6** is a diagram illustrating a local on-board radio detection system receiver according to various embodiments of the present application.

[0010] FIG. **7** is a diagram illustrating a bistatic radio wave localization transmitter according to various embodiments of the present application.

[0011] FIG. **8** is a diagram illustrating a bistatic radio wave localization transmitter antenna array according to various embodiments of the present application.

[0012] FIG. **9**A is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application.

[0013] FIG. **9**B is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application.

[0014] FIG. **9**C is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application.

[0015] FIG. **10** is a diagram illustrating a receiver according to various embodiments of the present application.

[0016] FIG. **11** is a flow diagram of a method for detecting objects according to various embodiments of the present application.

[0017] FIG. **12** is a flow diagram of a method for tracking a target object according to various embodiments of the present application.

[0018] FIG. **13** is a flow diagram of a method for providing an indication regarding a radio frequency (RF) transmitted beam and/or a target object according to various embodiments of the present application.

[0019] FIG. **14** is a flow diagram of a method for providing an indication regarding an RF transmitted beam and/or a target object according to various embodiments of the present application.

[0020] FIG. **15** is a flow diagram of a method for tracking an object based at least in part on an RF transmitted beam transmitted by a transmitter according to various embodiments of the present application.

[0021] FIG. **16** is a flow diagram of a method for controlling an interceptor based at least in part on an RF transmitted beam transmitted by a transmitter according to various embodiments of the present application.

[0022] FIG. **17** is a flow diagram of a method for performing an active measure with respect to a target object being tracked by a bistatic radio wave localization system according to various embodiments of the present application.

[0023] FIG. **18** is a flow diagram illustrating an embodiment of a process for determining guidance of an interceptor.

DETAILED DESCRIPTION

[0024] The invention can be implemented in numerous ways, including as a process; an apparatus; a system; a composition of matter; a computer program product embodied on a computer readable storage medium; and/or a processor, such as a processor configured to execute instructions stored on and/or provided by a memory coupled to the processor. In this specification, these implementations, or any other form that the invention may take, may be referred to as techniques. In general, the order of the steps of disclosed processes may be altered within the scope of the invention. Unless stated otherwise, a component such as a processor or a memory described as being configured to perform a task may be implemented as a general component that is temporarily configured to perform the task at a given time or a specific component that is manufactured to perform the task. As used herein, the term 'processor' refers to one or more devices, circuits, and/or processing cores configured to process data, such as computer program instructions.

[0025] A detailed description of one or more embodiments of the invention is provided below along with accompanying figures that illustrate the principles of the invention. The invention is described in connection with such embodiments, but the invention is not limited to any embodiment. The scope of the invention is limited only by the claims and the invention encompasses numerous alternatives, modifications and equivalents. Numerous specific details are set forth in the following description in order to provide a thorough understanding of the invention. These details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of these specific details. For the purpose of clarity, technical material that is known in the technical fields related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

[0026] Bistatic radio wave localization is an emerging technology that overcomes some of the limitations of monostatic radar systems. A bistatic radio wave localization system comprises two separate antennas for transmitting and receiving the electromagnetic waves (e.g., one for generating a radio frequency (RF) beam directed to an object and one for receiving the RF beam reflected from the object). The separation of antennas enables a bistatic radio wave localization system to detect and track objects that are beyond the range of a monostatic radar system. In addition, in some embodiments, the separation of the transmitting beam as situated in a ground-based station and a receiver as situated in a flying object enables implementation of the two devices with a higher cost high power transmitting beam in the ground-based station and a lower cost receiver in the flying object. Moreover, bistatic radio wave localization systems are less susceptible to interference from clutter and jamming.

[0027] One of the applications of bistatic radio wave localization systems is in tracking and intercepting objects such as missiles and other airborne threats. Bistatic radio wave localization systems can provide more accurate and reliable tracking information pertaining to the object(s) being tracked, which may be used for intercepting target objects.

[0028] Various embodiments include a method, system, and/or device for tracking a target object. The method includes (i) providing, by a transmitter, an RF transmitted beam toward a target object, and (ii) providing an indication regarding one or more of the RF transmitted beam and the target object.

[0029] Various embodiments include a method, system, and/or device for tracking a target object. The method includes (i) receiving, by a receiver, an indication regarding an RF transmitted beam, (ii) receiving a scattered reflection of the RF transmitted beam from a first target object, and (iii) processing the scattered reflection of the RF beam using the indication.

[0030] According to various embodiments, the system comprises at least one transmitter configured to track target objects and illuminate one or more of the target objects with an RF beam. For example, the at least one transmitter is configured to transmit the RF beam directed towards at least one of the one or more target objects. The system further comprises at least one receiver, such as a receiver comprised in an interceptor. The receiver is configured to detect the RF beam scattered/reflected by a target object. The transmitter provides information pertaining to the RF beam (e.g., the beam transmitted towards the target object) and/or the target object. As an example, the transmitter modulates information pertaining to the RF beam and/or one or more target objects. As another example, the transmitter sends the information pertaining to the RF beam and/or one or more target objects to the receiver over an established communication channel (e.g., a direct communication link or a network connection). The interceptor comprising the receiver can use the information pertaining to the RF beam and/or one or more target objects in connection with controlling navigation of the interceptor or determining whether to perform an active measure and causing the active measure to be performed if so determined.

[0031] Traditionally, seekers using radar systems to identify and seek out objects are very expensive. For example, such seekers rely on an expensive ground radar that communicates to the seeker (e.g., an airborne interceptor) where another airborne object is located. As another example, related art seekers need high power to capture reflective energy and for cooling. In some embodiments, the seeker (e.g., the interceptor configured with the receiver) uses passive detection of the RF beam scattered from a target object to track the target object. The use of the bistatic radio wave localization system as disclosed herein provides a more efficient (e.g., cost effective) system that has greater accuracy. For example, the bistatic radio wave localization system transitions target tracking to a high frequency RF band to transmit/receive signals that ping in a narrow beam form. Rather than using a camera to track an object, various embodiments use a radar with a tight beam form in order to attain a high fidelity tracking of the object. The narrow beam form allows the interceptor (e.g., an aircraft) to determine the location of the target object or the direction in which the object is moving. As the center of the beam form moves, the interceptor detects the movement of the beam form and tracks the object. Accordingly, the use of a transmitter to illuminate a target object using a tight beam form RF beam enables the interceptor to perform fast or immediate tracking of the target object.

[0032] According to various embodiments, the bistatic radio wave localization system is configured to have a separate detection system (e.g., a monostatic radar, a bistatic radar, a passive radar, an imaging system, etc.) that provides a track to an interceptor to head off toward. The track derived from the detection system is used to guide an interceptor to a target. In some embodiments, the detection system is able to detect the target at distances of at least between 10-25 km away. The detection system guides the interceptor to within a volume approximately 2 km away from the target. At that point the bistatic radio wave localization system is used to illuminate the target for a receiver on the interceptor. The transmitter antenna for the bistatic radio wave localization system is mounted on a tower and is dynamically (e.g., continuously) directed to the target object by a pan tilt unit (PTU) during object tracking. The receiver system (e.g., the receiver onboard the interceptor) has a finite range that depends on the target cross section (e.g., the finite range is designed to be approximately 2 km). For example, the receiver on the interceptor receives/acquires the transmitted signal reflected from the target object within the 2 km range. The receiver is configured to have a field of view of 50 degrees. The receiver has a form factor with an antenna size of about 12 cm×12 cm (e.g., 115.5 mm×116.3 mm). The bistatic radio wave localization system has an angular resolution of 5-10 degrees (e.g., 6.3 degrees) and an angular accuracy of less than 1 degree. An example of the radio wave localization system refresh rate is 15 Hz but may be configured based on processing gains and angular accuracy considerations.

[0033] FIG. **1** is a block diagram of a network system according to various embodiments of the present application. According to various embodiments, system **100** is implemented at least in part by system **200** of FIG. **2** and/or system **300** of FIG. **3**. In some embodiments, system **100** implements at least part of process **1200** of FIG. **12**, process **1300** of FIG. **13**, process **1400** of FIG. **14**, process **1500** of FIG. **15**, process **1600** of FIG. **16**, process **1700** of FIG. **17**, and/or process **1800** of FIG. **18**.

[0034] In the example illustrated in FIG. **1**, system **100** includes object tracking service **110**, data store **120**, and/or interceptor system **160**. System **100** may additionally include administrator system **130**, client system **140** and network **150** over which one or more of object tracking service **110**, data store **120**, administrator system **130**, and client system **140** are connected. Object tracking service **110** and interceptor system **160** may be connected via network **150** or via a direct connection link. In some embodiments, object tracking service **110** is implemented by a plurality of servers. In various embodiments, network **150** includes one or more of a wired network, and/or a wireless network such as a cellular network, a wireless local area network (WLAN), or any other appropriate network. System **100** may include various other systems or terminals.

[0035] System **100** may additionally include a detection system (e.g., a monostatic radar, a bistatic radar, a passive radar, an imaging system, etc.) (not shown). For example, object detection system **112** may comprise the detection system or may be configured to receive from the detection system information pertaining to the detection of objects. In some embodiments, a detection system (e.g., a monostatic radar, a bistatic radar, a passive radar, an imaging system, etc.) is separate and able to provide system **100** with data regarding objects.

[0036] In the example shown, object tracking service **110** comprises object detection system **112**, object tracking system **114**, and/or business application layer **116**. One or more of object detection system **112**, object tracking system **114**, and/or business application layer **116** may be implemented by a same device (e.g., computer/server) or by a plurality of devices (e.g., a plurality of servers or cluster of machines).

[0037] Object detection system **112** determines information pertaining to one or more detected objects, such as objects within a predetermined area. Object detection system **112** may comprise a radar system (e.g., a monostatic radar system, a bistatic radar system, a passive radar system, etc.) or an imaging system (e.g., a visual camera, an infrared imaging system, etc.) that detects the presence of objects within the predetermined area, or object detection system **112** obtains information pertaining to detected objects from an external detection system (e.g., a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system, etc.). In response to object tracking service **110** (e.g., object detection system **112**) determining that an object is detected, object tracking service **110** interrogates the one or more detected objects to determine whether the object is to be tracked or intercepted. For example, object tracking service **110** determines whether the object is a benign or friendly object, the object is malicious or an enemy object, or the object is to be surveilled such as in the case that the object is unknown (e.g., is not known to be benign or malicious) or otherwise does not match a predefined object template. Through the interrogating of the one or more detected objects, object tracking service **110** determines one or more target objects to be tracked. The one or more target objects may be a subset of the one or more detected objects. In some embodiments, object tracking service **110** uses a camera in connection with interrogating a detected object. For example, object tracking service **110** uses the camera to determine whether the object is a bird, a drone, etc.

[0038] In the case that the set of detected objects are interrogated and a plurality of target objects are identified, object tracking service **110** (e.g., object detection system **112** or object tracking system **114**) may determine to track one or more of the target objects. Object tracking service **110** determines respective priorities for the plurality of target objects. In some embodiments, object tracking service **110** applies one or more priority policies in connection with determining priorities for the plurality of target objects. A priority policy may be predefined, such as by an administrator of system **100**. The priority policy defines one or more parameters of functions for determining a priority. As an example, the priorities for the target objects may be determined based at least in part on one or more of: respective locations of the target objects, respective distances between the target objects and another location such as a location at which object tracking service **110** is deployed or a location of an interceptor (e.g., interceptor system **160**), an indication that a target object is malicious, a target object type (e.g., a surveillance aircraft, an attacking aircraft, etc.), a characteristic pertaining to a target object (e.g., size, speed, equipment), etc.

[0039] In response to determining the respective priorities for the target objects, object tracking service **110** determines, from the set of target objects, the one or more target objects to track (e.g., using object tracking system **114**). In response to determining the one or more target objects to track, object tracking system **114** configures an energy beam to be directed towards at least one of the target objects. The energy beam may be an RF beam, an infrared beam, a UV beam, etc. Various other types of energy may be directed toward the target object(s) to effectively paint or illuminate the target object(s) with such energy (e.g., which may be detected via detecting scattering reflected from the target object(s)).

[0040] In some embodiments, the energy beam is an RF beam. The RF beam has a frequency (e.g., a cycle frequency) between 2 GHz and 50 GHz. As an example, generally, the higher the frequency of the RF beam, the greater the energy required to transmit the RF beam. In some embodiments, the frequency of the RF beam directed towards a target object is 20-40 GHz. In some embodiments, the frequency of the RF beam directed towards a target object is 20-35 GHz. In some embodiments, the frequency of the RF beam is about 24 GHz. In some embodiments, the selection of the RF beam frequency is optimized for availability of commercially off the shelf (COTS) chipsets (automotive) and the right matching of medium loss characteristics and field of view (FOV) and angular resolution to get to the system's accuracy design goals.

[0041] In some embodiments, the energy beam (e.g., the RF beam) is generated/transmitted in a narrow beam form. Traditional beams used to track objects generally extend 10-15 degrees. Accordingly, traditional beams require relatively large amounts of energy to track the objects. In contrast, according to various embodiments, the energy beam extends less than 10 degrees. In some embodiments, the energy beam (e.g., the RF beam) extends a fraction of a degree. Thus, various embodiments are energy efficient and highly accurate mechanisms for tracking target objects.

[0042] As the target object being tracked moves, object tracking service **110** updates the direction of the energy beam. For example, object tracking service **110** (e.g., object detection system **112**) obtains an updated location for the target object and in response to determining that the target object has moved, object tracking service **110** (e.g., object tracking system **114**) updates the direction of the energy beam to ensure that the target object continues to be painted/

illuminated with the energy beam. In some embodiments, a mechanically steered pan and tilt unit (PTU) is used to point the transmitter and follow the target, and this steered to pointing direction information of the PTU is then used to provide information for updating the direction of the energy beam. In some embodiments, the system uses an active electronically scanned array (AESA) to track the target to provide information for updating the direction of the energy beam.

[0043] In some embodiments, the target object is tracked using a a detection system at first range (e.g., the first range is 10-25 km from a tracking station transmission system to an object—for example, a monostatic system, a bistatic radar system, a passive radar system, an imaging system, etc.), the target object is tracked using an energy beam reflected from the object and detected by an interceptor receiver at a second range between the object and the interceptor (e.g., the second range is 2 km or less between the interceptor and the object), and the target object is tracked using an interceptor-based tracking system (e.g., a greater than 24 GHz frequency—for example, 77 GHz interceptor based tracking system; In some embodiments, the selection of the interceptor-based tracking system frequency is optimized for availability of commercially off the shelf (COTS) chipsets and the right matching of medium loss characteristics and field of view (FOV) and angular resolution to get to the system's accuracy design goals) at a third range between the object and the interceptor (e.g., the third range is less than 300 m from the interceptor to the object).

[0044] In some embodiments, object tracking service **110** dynamically updates the locations of the target objects, adds new target objects based on updated detection information, removes target objects based on updated detection information (e.g., the determination that a particular target object has moved out of range or otherwise to a location/range that is not concerning to object tracking service **110**), etc. In some embodiments, object tracking service **110** uses a combination of a detection system (e.g., a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system etc.), an energy beam/interceptor detection system, and an interceptor-based tracking system to guide an interceptor to a target object. In some embodiments, the tracking of the object is guided first from the tracking station information (e.g., from the detection system) and then second from the interceptor (e.g., first using the detection of the energy beam and then as closer to the object the local tracking system). In response to the update to the target objects, object tracking service **110** dynamically re-prioritizes the target objects, such as according to one or more priority policies. Object tracking system **114** may configure the energy beam based at least in part on the updated re-prioritization of the target objects. For example, if object tracking system **114** determines to track a target object different from the target object(s) being tracked, object tracking system **114** re-configures (e.g., re-directs) the energy beam accordingly.

[0045] Object tracking service **110** can track a plurality of target objects simultaneously or serially. The simultaneous tracking of the plurality of target objects may include transmitting a plurality of RF beams respectively directed at different target objects. For example, object tracking system **114** comprises one or more detection systems and one or more energy beam transmitters which may be respectively configured to transmit different RF beams that are each directed to different target objects. As an example, object tracking system **114** may track a first set of two or more target objects using a first RF beam (e.g., transmitted by a first transmitter) and a second set of two or more target objects using a second RF beam (e.g., transmitted by a second transmitter). Additionally, or alternatively, the simultaneous tracking of the plurality of target objects may include tracking two or more target objects (e.g., in the event of a swarm of target objects) using a single RF beam that is modulated or duty cycled to direct at least part of the RF beam to the two or more target objects to be tracked using the single RF beam. The duty cycling may be performed at the order of seconds or tenths of seconds. For example, multiple target objects may be painted/illuminated with different modulations or patterns of the RF beam.

[0046] In some embodiments, the RF beam transmitted by a transmitter comprised in object tracking system **114** is modulated using one or more of a frequency modulation, a phase modulation, an amplitude modulation, a shift modulation, and/or a chirp modulation. As an example, a first modulation of the RF beam is directed to the first target object, and a second modulation of the RF beam is directed to a second target object.

[0047] In connection with tracking a target object(s) using an energy beam (e.g., an RF beam), object tracking service **110** provides information pertaining to the target object and/or energy signal/beam to a receiver such as interceptor system **160**. In some embodiments, the information pertaining to the target object comprises one or more of a position, a heading, an identifier, a type, a first detected location, a velocity, a speed, a speed toward or away from the transmitter, a speed perpendicular from the transmitter, etc. Interceptor system **160** uses the information pertaining to the target object and or energy signal/beam to track the applicable target object(s), such as to surveil, intercept, and/or engage the target object(s). In some embodiments, an indication of the information pertaining to the target object and/or RF beam is communicated via a communication channel established between the transmitter (e.g., object tracking system **114**) and the receiver (e.g., interceptor system **160**). The communication channel may be a network connection or a direct link between transmitter and receiver. Additionally, or alternatively, the indication of the information pertaining to the target object and/or RF beam is carried in the RF beam itself. For example, object tracking system **114** modulates the RF beam to comprise the indication of the information pertaining to the target object and/or RF beam (e.g., in a particular modulation of the modulated RF beam). The modulation of the RF beam to include the indication of the information pertaining to the target object and/or RF beam enables a robust/resilient tracking system. Network communication channels are susceptible to jamming or other interference. Thus, by modulating the RF beam to include the information pertaining to the target object or RF beam, object tracking service **110** is able to robustly communicate information to interceptor system **160** in the absence of a communication channel or in the event of a jamming of the communication channel. Accordingly, interceptor system **160** is able to robustly track the target object(s) by following the RF beam in the absence of a communication channel or in the event of a jamming of the communication channel.

[0048] Object tracking service **110** (e.g., object tracking system **114**) may be deployed on the ground, airborne (e.g., mounted on or comprised in an aircraft), or at sea (e.g., mounted on or comprised in a ship).

[0049] In some embodiments, system **100** comprises one or more receivers, such as interceptor system **160**. Interceptor system **160** may be airborne, such as a drone (e.g., an autonomous drone) or other aircraft. Although examples described herein include an interceptor (e.g., interceptor system **160**) that is airborne, the interceptor may be ground-based or sea-based. A receiver is configured to detect energy beams, such as an RF beam. For example, the receiver obtains scattering of the RF beam transmitted by a transmitter, such as parts of the RF beam that are reflected from the target object. In some embodiments, the receiver is configured to detect energy beams (e.g., RF beams) having a specific energy level, such as a particular frequency or range of frequencies.

[0050] In some embodiments, the receiver has a 30-60 degree view. The relatively large field of view enables interceptor system **160** to comprise the receiver without the receiver being mounted to a gimble. In contrast, related art systems have narrow fields of view and thus require expensive gimbles to enable the interceptor to effectively detect objects at a long range.

[0051] The sensor data (e.g., RF beam) detected by interceptor system **160** may be subject to noise/interference. For example, at high amplitudes, interceptor system **160** accumulates a significant amount of ground clutter. The ground clutter may be so significant that the clutter overwhelms the receiver.

[0052] The receiver (e.g., interceptor system **160**) is configured to process information pertaining to a detected energy beam (e.g., the RF beam). For example, the receiver processes the detected energy (e.g., the RF beam information) to remove (e.g., filter out) clutter reflected from the environment, such as the ground. In some embodiments, the received energy beam signal is analyzed using spectral analysis (e.g., a Fourier transform of the frequencies received). In some embodiments, the received energy beam signal scattered from the target object is analyzed using Doppler analysis (e.g., by performing a Fourier transform) and the signal from the target object is isolated by filtering out the signals from the background environment as they are distinct in Doppler space. In some embodiments, the signals from the target and from the background landscape are distinct in the spectral analysis space (e.g., frequency space) because they have different Doppler shifts and can be filtered to remove the background landscape contribution to the signal. In some embodiments, the receiver obtains Doppler information. The receiver uses the Doppler information to detect the target object. For example, the receiver views the Doppler space and obtains information pertaining to the target object (e.g., the object is moving at a different speed relative to the interceptor). Accordingly, the receiver detects the object moving relative to the ground/environment.

[0053] According to various embodiments, interceptor system **160** is controlled, or is navigated, based at least in part on the scattered energy (e.g., the scattered RF beam reflected from the target object(s)). Interceptor system **160** may be controlled, or is navigated, based on a detection system (e.g., a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system, etc.). Interceptor system **160** may be controlled based on the scattered energy to approach the target object, surveil, intercept, and/or eliminate the target object. Interceptor system **160** may be controlled based on a detection system to approach the target object, surveil, intercept, and/or eliminate the target object. Interceptor system **160** is navigated based on information from a detection system or scattered energy to intercept the target object, such as to approach the target object to move within a predefined range or distance of the target object from which the scattered energy (e.g., the RF beam or a local beam source) is reflected. For example, interceptor system **160** follows the scattered energy and moves towards the target object from which the energy beam is scattered. Interceptor system **160** may comprise a filter (e.g., a notch filter) to identify the energy beam and the receiver finds the hot spot in the environment (e.g., the hot spot in the sky corresponding to the target object painted/illuminated by the RF beam transmitted by the transmitter of object tracking system **114**).

[0054] Interceptor system **160** dynamically (e.g., continuously) monitors the energy detected by the receiver and adjusts course accordingly. Interceptor system **160** determines a distance to the target object. In response to determining that the target object is within a predefined range, interceptor system **160** may switch to a different local tracking system or sensor for tracking the target object. In some embodiments, the different local tracking system or other sensor is an interceptor-based tracking system (e.g., a local on-board radio detection system), such as a low power directional radar (e.g., a radar operating at 77 GHz). In some embodiments, the predefined range is 300 m. In some embodiments, the predefined range is 350 m. In some embodiments, the predefined range is less than 500 m.

[0055] According to various embodiments, interceptor system **160** navigates towards the target object based on information communicated by a pan tilt unit (PTU), such as at a ground station or object tracking service (e.g., target bearing and distance information conveyed over a communication link between the PTU, or object tracking service **110** and interceptor system **160**). For example, interceptor system **160** uses telemetry data received from the PTU to navigate towards the target object. When interceptor system **160** is within range of the target object, interceptor system **160** switches to navigation based on detected energy (e.g., an RF beam) scattered from the target object. As an example, interceptor system **160** relies on telemetry data provided by the PTU until interceptor system **160** is within about 2 km of the target object at which point interceptor system **160** uses the energy scattered from the target object to navigate to the target object. In various embodiments, the PTU includes a visual, a RF, a monostatic radar, a passive radar, a bistatic radar, an infrared, an imaging system, or any other appropriate detection system.

[0056] According to various embodiments, business application layer **116** provides an interface via which a user (e.g., using client system **140**) may interact with various applications such as a development application for developing a service, application, and/or code, an application to access raw data (e.g., data stored in data store **120**), an application to analyze data (e.g., sensor data), etc. Various other applications can be provided by business application layer **116**. As another example, an administrator uses an interface provided/configured by business application layer **116** to configure (e.g., define) one or more policies such as tracking policies, priority policies, or security policies including access permissions to information stored on a data store **120**, permission to access performance profiles, etc.

[0057] Administrator system **130** is a system by which an administrator uses or manages object tracking service **110**. For example, administrator system **130** comprises a system for communication, data access, computation, etc. An administrator uses administrator system **130** to maintain and/or configure object tracking service **110** and/or data store **120**. For example, an administrator uses administrator system **130** to start and/or stop services on object tracking service **110** (e.g., a detection service, a tracking service, etc.) and/or data store **120**, to reboot data store **120**, to install software on object tracking service **110** and/or data store **120**, to add, modify, and/or remove data on data store **120**, etc. Administrator system **130** communicates with object tracking service **110** and/or data store **120** via a web-interface. For example, administrator system **130** communicates with object tracking service **110** and/or data store **120** via a web-browser installed on administrator system **130**. As an example, administrator system **130** communicates with object tracking service **110** and/or data store **120** via an application running on administrator system **130**.

[0058] In some embodiments, business application layer **116** serves as a gateway via which the administrator may interface to manage, configure, etc. object detection system **112**, object tracking system **114**, and/or business application layer **116**.

[0059] Data store **120** stores one or more datasets. In various embodiments, the one or more datasets comprise detection data, tracking data, or target object data. Additionally, the one or more datasets may include datasets pertaining to active measures to be implemented in response to object detection/interception, or any other appropriate data. Data store **120** comprises a database system for storing data in a table-based data structure, an object-based data structure, etc.

[0060] According to various embodiments, a user uses system **100** (e.g., a client or terminal, such as client system **140**, that connects to system **100** via network **150**) to execute one or more tasks with respect to data (e.g., one or more datasets) stored on data store **120**. For example, a user inputs to a client terminal a query or request to execute an object tracking and/or an object detection, and object tracking service **110** receives the query or request to execute the object tracking or object detection from client system **140** via network **150**, etc. In response to receiving the query or request to execute the task, object tracking service **110** uses object detection system **112** to execute the object detection or object tracking system **114** to execute a tracking of a detected object and provides a result to the user (e.g., via the client terminal).

[0061] In some embodiments, in response to detecting an object, system **100** determines whether to perform an active measure based on such detection and object tracking. As an example, in response to interceptor system **160** intercepting the target object or travelling within a certain range of the target object, system **100** determines whether to perform an active measure. In response to determining to perform an active measure, system **100** implements the active measure or causes another system or service to implement the active measure (e.g., system **100** provides an indication that an active measure is to be performed, or interceptor system **160** determines the active measure and implements the active measure). Examples of active measures include providing an indication that an object is detected, surveilling the target object, eliminating the target object, intercepting the target object, jamming sensors comprised in the target object, etc. In some embodiments, system **100** determines the active measure to implement (if any) based on a mapping of objects (e.g., types of objects, object identifiers, etc.) to active measures.

[0062] FIG. **2** is a block diagram of a transmitter system according to various embodiments of the present application. In some embodiments, system **200** implements at least part of system **100** of FIG. **1**, such as object tracking service **110** or object tracking system **114**.

[0063] According to various embodiments, system **200** corresponds to, or comprises, a system for tracking an object, such as an object detected by a detection system (e.g., a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system, etc.). System **200** may be configured to paint/illuminate a target object using an energy beam (e.g., an RF beam, such as a high-powered RF beam having a frequency of 20-40 GHz). Additionally, system **200** may determine an active measure and/or cause an active measure to be implemented in response to determining that an object is detected in sensor data or otherwise intercepted by an interceptor (e.g., a receiver with which system **200** communicates).

[0064] In the example shown, system **200** implements one or more modules in connection with performing object detection and providing tracking information for tracking the target object, etc. System **200** comprises communication interface **205**, one or more processors **210**, storage **215**, and/or memory **220**. One or more processors **210** comprises one or more of communication module **225**, target object identifying module **227**, target object tracking module **229**, target object selection module **231**, transmitter module **233**, transmitter beam determination module **235**, transmitter beam control module **237**, and/or user interface module **239**.

[0065] In some embodiments, system **200** comprises communication module **225**. System **200** uses communication module **225** to communicate with various other systems, such as interceptors, aircraft, other associated vehicles (e.g., ground-based or sea-based vehicles), client terminals or an administrator system, or other modules of system **100** such as an object detection system **112**, object tracking system **114**, data store **120**, etc. Communication module **225** provides to communication interface **205** information that is to be communicated. As another example, communication interface **205** provides to communication module **225** information received by system **200**. Communication module **225** is configured to receive one or more queries or requests to execute tasks (e.g., requests for tracking an object, requests for implementing an active measure, setting an active measure policy, priority policy, tracking policy, etc.) such as from various client terminals or user systems (e.g., from administrator system **130** or client system **140** via business application layer **116**). The one or more queries or requests to execute tasks may be with respect to information stored in one or more datasets (e.g., data stored in data store **120**, such as datasets pertaining to tracked objects, detected objects, mission information for intercepting or performing active measures with respect to tracked objects, etc.). Communication module **225** is configured to provide to various client terminals, or other systems, an indication of the object that a receiver is configured to detect using scattered portions of the RF beam and/or a local detection system.

[0066] In some embodiments, system **200** comprises target object identifying module **227**. System **200** uses target object identifying module **227** to identify the one or more target objects in response to obtaining information pertaining to a detected object(s). For example, target object identifying module **227** receives an indication that a radar or camera system detected an object(s) within a range being monitored. Target object identifying module **227** receives an indication of which detected object(s) are to be tracked or target object identifying module **227** interrogates the set of detected objects to determine the one or more target objects (e.g., a subset of the detected objects). As an example, target object identifying module **227** determines whether to track an object (e.g., paint/illuminate with an RF beam and intercept using an interceptor) based on identifying the detected object(s) and/or identifying a type of object. Target object identifying module **227** may determine to track a detected object based at least in part on interrogating whether the detected object is benign (e.g., a bird, a civilian drone, a civilian plane), malicious (e.g., an enemy drone, an enemy plane), or unknown (e.g., system **200** is unable to determine an identifier or object type for the detected object). In various embodiments, the determination of whether to track a detected object is based on one or more of the following: a determination of a visual profile, a determination of a radio emission profile, a determination of a flight pattern characteristic, a determination of a size, a determination of a color, a determination of a speed, or any other appropriate determination. In response to identifying the one or more target objects, target object identifying module **227** provides an indication of the target object(s) to be tracked (e.g., to target object tracking module **229** or target object selection module **231**, etc.).

[0067] In some embodiments, system **200** comprises target object tracking module **229**. System **200** uses target object tracking module **229** to coordinate the tracking of one or more target objects. In response to determining the one or more target objects to be tracked (e.g., by target object identifying module **227**), target object tracking module **229** invokes targe object selection module **231**, transmitter module **233**, transmitter beam determination module **235**, and/or transmitter beam control module **237** to track at least one of the one or more target objects to be tracked. Target object tracking module **229** determines a target object(s) to be tracked, a priority of target objects to be tracked, a manner by which the target object(s) is to be tracked, etc. In various embodiments, a decision of which objects to track is based on one or more of the following: a local object risk assessment, a collaborative object risk assessment, a local ranking of object risks, a collaborative ranking of object risks, a user indication, or any other appropriate decision appropriate decision factor.

[0068] In some embodiments, in response to determining that a plurality of the detected objects correspond to target objects (e.g., objects that are to be subject to tracking by system **200** and/or one or more other such systems), target object tracking module **229** determines respective priorities for the plurality of target objects. The respective priorities may be determined based at least in part on one or more priority policies. Target object tracking module **229** then uses target object selection module **231** to select one or more of the target objects to be tracked with an energy beam transmitted by transmitter module **233**. In some embodiments, target objects that are tracked are assigned an interceptor (e.g., an interceptor is provided instructions to intercept or to move close to the target object). In response to selecting a target object(s) to track, target object tracking module **229** uses transmitter beam determination module **235** to determine a configuration of the energy beam, such as a frequency, a modulation, an intensity, etc. In some embodiments, the transmitter beam configuration (e.g., frequency, modulation, intensity, etc.) is provided to the interceptor via modulating the energy beam or via a separate radio communication link or channel. In response to determining the configuration of the energy beam, target object tracking module **229** uses transmitter beam control module **237** to control transmitter module **233** to transmit the energy beam.

[0069] In some embodiments, target object tracking module **229** dynamically updates the list of target object to be tracked and dynamically determines whether to track a different target object, such as based on one or more of (i) the movement of the target object being tracked, (ii) a new target object being identified (which has a higher priority than the current target object being tracked), (iii) a change in the priorities for target objects, (iv) the target object being intercepted, (v) the target object moving outside certain restricted geographical zone, etc. In some embodiments, the updated list of target object is used to update instructions to one or more interceptors to indicate a movement to a new location related to a different or same object target. In various embodiments, the list adds new target objects, the list deletes target objects, or the list keeps target objects the same. In some embodiments, the list is determined or updated based at least in part on a target object risk assessment, a ranking of risk of one or more target objects, or any other appropriate factor for determining or updating the list.

[0070] In some embodiments, system **200** comprises target object selection module **231**. System **200** uses target object selection module **231** to select one or more of the identified target objects. The selected target objects are to be tracked by system **200**, such as by one or more of (i) modulating a single energy beam such that different modulations are directed at different selected target objects, (ii) duty cycling a single energy beam across multiple target objects of the selected target objects, and (iii) transmitting multiple energy beams (e.g., using multiple transmitter modules) and respectively directing the multiple energy beams to different target objects of the selected target objects.

[0071] In some embodiments, system **200** comprises transmitter module **233**. System **200** uses transmitter module **233** to direct an energy beam towards one or more selected target objects. In some embodiments, the energy beam is an RF beam. The RF beam has a frequency (e.g., a cycle frequency) between 2 GHz and 50 GHz. In some embodiments, the frequency of the RF beam directed towards a target object is 20-40 GHz. In some embodiments, the frequency of the RF beam directed towards a target object is 20-35 GHz. In some embodiments, the frequency of the RF beam is about 24 GHz.

[0072] Transmitter module **233** configures and emits the energy beam based at least in part on a configuration provided by transmitter beam determination module **235** or transmitter beam control module **237**. The energy beam is directed to the selected target object(s) to paint/illuminate the target object for a receiver (e.g., an interceptor) to receive energy scattered from the target object.

[0073] In some embodiments, system **200** comprises transmitter beam determination module **235**. System **200**

uses transmitter beam determination module **235** to determine a configuration for the energy beam(s) (e.g., RF beams) to be directed towards the applicable target object. Transmitter beam determination module **235** determines whether to configure the energy beam to duty cycle between multiple target objects, whether to modulate the energy beam to include additional information, and/or whether to modulate the energy beam to include modulations that are respectively to be directed to different target objects. Transmitter beam determination module **235** may further determine a location at which to direct the energy beam, such as based on a location and/or bearing of the applicable target object. Transmitter beam determination module **235** may dynamically or continuously update the configuration of the energy beam, such as based on movement of the applicable target object and/or selection of a different target object. Transmitter beam determination module **235** may provide the configurations for the energy beam to transmitter beam control module **237**.

[0074] In some embodiments, system **200** comprises transmitter beam control module **237**. System **200** uses transmitter beam control module **237** to control transmitter module **233** to direct the energy beam towards the target object(s) for the target object(s) to be tracked (e.g., by a receiver on an interceptor that detects scattered energy corresponding to the energy beam reflected by the target object).

[0075] In some embodiments, system **200** comprises user interface module **239**. System **200** uses user interface module **239** in connection with configuring information (or the display thereof) to be provided to the user such as via administrator system **130** and/or client system **140** of system **100**. In some embodiments, user interface module **239** configures a user interface to be displayed at a client terminal used by the user or administrator, such as an interface that is provided in a web browser at the client terminal. In some embodiments, user interface module **239** configures the information to be provided to the user such as configuring one or more reports of information that is responsive to a query or task executed with respect to a target object or a tracking of the target object.

[0076] According to various embodiments, storage **215** comprises one or more of file system data **260**, transmission data **265**, and/or target object library **270**. Storage **215** comprises a shared storage (e.g., a network storage system) and/or database data, and/or target object activity data. In some embodiments, file system data **260** comprises a database such as one or more datasets (e.g., one or more datasets of sensor data, tracking data, etc.). In some embodiments, transmission data **265** comprises information pertaining to energy beams transmitted towards target objects, etc. In some embodiments, target object library **270** comprises information pertaining to one or more target objects or the tracking of target objects.

[0077] According to various embodiments, memory **220** comprises executing application data **275**. In some embodiments, the application data comprises data for one or more applications that perform one or more of receiving and/or executing a query or request for object detection or object tracking. The one or more applications may include applications for configuring energy beams, controlling target detection, generating a report and/or configuring information that is responsive to an object detection or classification, and/or providing to a user information that is responsive to a query or request pertaining to object detection. Various other applications may be comprised in and executed by system **200**.

[0078] FIG. **3** is a block diagram of a receiver system according to various embodiments of the present application. In some embodiments, system **300** implements at least part of system **100** of FIG. **1**, such as interceptor system **160**.

[0079] According to various embodiments, system **300** corresponds to, or comprises, a system for tracking an object, such as an object detected by a radar system. System **300** may be configured to detect a target object (e.g., based on scattered RF beams), approach a target object, intercept the target object, and/or perform an active measure with respect to the target object. Additionally, system **300** may determine an active measure and/or cause an active measure to be implemented in response to determining that an object is detected in sensor data or otherwise intercepted by an interceptor (e.g., an interceptor comprising system **300**).

[0080] In the example shown, system **300** implements one or more modules in connection with performing object detection and providing tracking information for tracking the target object, etc. System **300** comprises communication interface **305**, one or more processors **310**, storage **315**, and/or memory **320**. One or more processors **310** comprises one or more of communication module **325**, transmission beam detection module **327**, target object identifying module **329**, navigation module **331**, interceptor-based tracking system module **333**, active measure module **335**, sensor module **337**, intercepting module **339**, and/or user interface module **341**.

[0081] In some embodiments, system **300** comprises communication module **325**. System **300** uses communication module **325** to communicate with various other systems, such as a seeker (e.g., system **200**) or other system that paints/illuminates target objects using an energy beam. Communication module **325** may also communicate with client terminals or an administrator system. Communication module **325** provides to communication interface **305** information that is to be communicated. As another example, communication interface **305** provides to communication module **325** information received by system **300**.

[0082] In some embodiments, communication module **325** receives information pertaining to an energy beam directed towards a target object(s) and/or information pertaining to a target object, such as target object bearing, target object type, target object identifier, etc. The information pertaining to the energy beam and/or target object may be received via one or more communication channels/links, such as based on communication between system **300** and an object tracking service (e.g., object tracking service **110** of system **100**, system **200**, etc.).

[0083] Communication module **325** may be configured to receive guidance information from an operations control service (e.g., a ground radar station or PTU). The guidance information may provide system **300** with the location of a target object, a bearing of the target object, and/or a general area or direction to which the interceptor (e.g., system **300**) is to travel to obtain more specific location information or to be within range of a target object for system **300** to detect energy scatter reflected from the target object.

[0084] In some embodiments, system **300** comprises transmission beam detection module **327**. System **300** uses transmission beam detection module **327** as a receiver to receive energy beams/signals, such as RF beams scattered from a target object. Transmission beam detection module **327** comprises one or more sensors and/or antennas. When the interceptor is within range of a target object to which an energy beam is directed by a transmitter, such as a ground station, transmission beam detection module **327** may detect scattered energy that is reflected from the target object(s). The scattered energy may be within a predefined frequency range. In some embodiments, the interceptor determines whether to begin using the scattered energy in connection with navigation when the interceptor is within a predefined back scatter range (e.g., about 2 km) of the target object. For example, the interceptor uses the scattered energy rather than guidance information provided by the radar station (e.g., a ground station that detects objects using radar or cameras, etc.).

[0085] In some embodiments, system **300** comprises target object identifying module **329**. System **300** uses target object identifying module **329** to identify target objects or determine one or more characteristics pertaining to target objects. Examples of characteristics of target objects that are determined include: type, location, bearing, identifier, class, equipment, payload, etc. In some embodiments, target object identifying module **329** determines the target objects that the interceptor is to approach or intercept (e.g., the target objects selected to be tracked using system **200**). Target object identifying module **329** identifies the target objects based on one or more of (i) scattered energy beams (e.g., RF beams) that are reflected from a target object(s), (ii) a communication channel/link established with a transmission station (e.g., system **200** of FIG. **2**, or object tracking service **110** of FIG. **1**), and/or (iii) sensor data obtained by on-board sensors (e.g., sensor module **337**).

[0086] In some embodiments, system **300** comprises navigation module **331**. System **300** uses navigation module **331** to determine a strategy for moving towards a target object (s), including determining a path to travel, a speed, etc. Navigation module **331** may control the interceptor to move in accordance with the strategy for moving towards a target object(s). Before the interceptor is within a predefined first range (e.g., ~ 2 km), navigation module **331** controls the movement of the interceptor based on guidance provided by the object detection station (e.g., a ground station that uses object data detected by radar or camera, etc.). For example, navigation module **331** uses information that system **300** receives from the detection station to plan the strategy for approaching the target object. The information received from the detection station may include guidance information that specifies the location at which the interceptor is to travel to approach the target object. For example, the interceptor receives an indication to move to a designated target object. In some embodiments, the interceptor determines, based on the indication information (e.g., a target object's current position, speed, and heading), an initial heading and an initial speed for the interceptor to reach a volume of airspace surrounding the target object's current or projected location. In some embodiments, the interceptor receives periodic or as needed update indications to validate the or update the interceptor heading and speed to reach an appropriate volume of airspace surrounding the target object's updated current or updated projected location. In some embodiments, the interceptor (e.g., navigation module **331**) determines whether the target object is within a scatter range to begin monitoring for a back scattered signal from the RF beam illuminating the target. Once within a scatter range and having detected a signal, navigation module determines whether the back scatter signal is strong enough and/or consistent enough to switch navigation control to drop the guidance determination from the tracking station (e.g., a detection system-basedinformation stream as received by system **300**) and instead use the information from the back scattered signal. In some embodiments, the switch from one to the other guidance information is gradual—for example, system **300** uses guidance information from the tracking station, then a mix of information from the tracking station and the back scattered signal, then only from the back scattered signal. In some embodiments, in the event that the back scattered signal is lost, navigation module **331** of system **300** will transition back to using guidance information from the tracking station (e.g., camera detection system derived information—for example, a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system, etc.).

[0087] Upon the interceptor coming within the predefined first range (e.g., ~ 2 km, or such other distance that energy transmitted by a transmitter is scattered by a target object and detectable by system **300**), navigation module **331** determines a strategy for moving the interceptor based on using (i) information obtained by the scattered energy detected by system **300**, and/or (ii) information pertaining to the energy beam or target object received via a communication channel established between a transmission system (e.g., object tracking service **110**) and the interceptor (e.g., system **300**). For example, navigation module **331** detects, based at least in part on the scattered energy, a target object(s) painted/illuminated by a transmission system (e.g., object tracking system **114**). In response to detecting the target object, navigation module **331** determines or updates a strategy for approaching the target object. For example, navigation module **331** causes the interceptor to fly towards the target object. Navigation module **331** may update the strategy in real-time or otherwise contemporaneous with receiving the scattered energy beam via a receiver or information pertaining to the energy beam or target object via a separate communication channel.

[0088] In some embodiments, as the interceptor comes within a close range of the target object, the interceptor switches from using the scattered energy in connection with navigation to using a low-powered radar system (e.g., interceptor-based tracking system module **333**) on-board the interceptor. For example, in response to determining that the interceptor is within a predefined second range (e.g., ~ 300 m or such other range associated with interceptor-based tracking system module **333**), system **300** controls the interceptor to track the target object using the on-board low-power radar system and navigation module **331** uses information obtained by at least the on-board low-power radar system to determine/update the strategy for approaching the target object.

[0089] In some embodiments, system **300** comprises interceptor-based tracking system module **333**. System **300** uses interceptor-based tracking system module **333** to track the target object when the interceptor is within a predefined second range of the target object being tracked. In some embodiments, the predefined second range is about 300 m or such other range of interceptor-based tracking system module **333**.

[0090] In some embodiments, system **300** comprises active measure module **335**. System **300** uses active measure module **335** to determine an active measure, if any, to be performed with respect to the target object. Examples of active measures include surveilling, collecting information using one or more sensors (e.g., cameras, infrared, UV, etc.) such as via sensor module **337**, engaging the target object (e.g., with an interceptor payload), colliding with the target object, following the target object, etc. Active measure module **335** may determine an active measure based on instructions received from another system (e.g., object tracking service **110** or other administrator or control system) or based on a mapping of contexts to active measures. The mapping of contexts to active measures may be locally stored at the interceptor. Examples of mappings comprised in the mapping of contexts to active measures include an indication of an active measure to be performed based at least in part on a target object type, a target object identifier, a target object classification (e.g., friendly, civilian, enemy), a current path of the target object, a range of the target object to another predefined location or object, etc.

[0091] In some embodiments, active measure module **335** further determines when to perform the identified (e.g., selected) active measure and cause system **300** (or other system such as another interceptor or aircraft within range) to implement the active measure at such time or event. Active measure module **335** may dynamically update the plan for implementing the active measure (e.g., including selection of the applicable active measure) as the target object is tracked and contexts change.

[0092] In some embodiments, system **300** comprises sensor module **337**. System **300** uses sensor module **337** to collect information associated with the target object being tracked or the interceptor. Examples of sensors include a force sensor, an infrared (IR) sensor, an ultraviolet (UV) sensor, a light sensor, a radar sensor, etc. System **300** may use sensor module **337** to collect doppler information or other information pertaining to the environment, which system **300** (e.g., navigation module **331**) uses to remove/reduce ground clutter or other interference captured by system **300** such as via the collected scattered energy reflected off the target object. For example, system **300** (e.g., navigation module **331** or transmission beam detection module **327**) pre-processes the collected information comprising the scattered RF beam to remove/reduce interference in the signal for more accurate determination of the location, bearing, or other information for the target object.

[0093] In some embodiments, system **300** comprises intercepting module **339**. System **300** uses intercepting module **339** to intercept the target object. System **300** uses the strategy (e.g., path) for intercepting the target object, which is determined by navigation module **331**, to control the interceptor to move in accordance with the strategy. For example, system **300** controls intercepting module **339** to move the interceptor according to the strategy. In some embodiments, the intercepting module **339** includes a motor, an engine, a propeller, a payload to be released, etc.

[0094] In some embodiments, system **300** comprises user interface module **341**. System **300** uses user interface module **341** in connection with configuring information (or the display thereof) to be provided to the user such as via administrator system **130** and/or client system **140** of system **100**. In some embodiments, user interface module **341** configures a user interface to be displayed at a client terminal used by the user or administrator, such as an interface that is provided in a web browser at the client terminal. In some embodiments, user interface module **341** configures the information to be provided to the user such as configuring one or more reports of information such as data pertaining to a target object or a tracking of the target object. A user may use user interface module **341** in connection with configuring the interceptor, such as to configure payloads, mappings of contexts to active measures, navigation modules, etc.

[0095] According to various embodiments, storage **315** comprises one or more of file system data **360**, target object data **365**, and/or target object library **270**. Storage **315** comprises data used in connection with tracking a target object, such as a navigation module according to which navigation module **331** navigates the interceptor, settings/configurations of sensors, pre-processing algorithms or procedures to remove/reduce signal interference, etc. In some embodiments, file system data **360** comprises a database such as one or more datasets (e.g., one or more datasets of sensor data, tracking data, etc.). In some embodiments, target object data **365** comprises information pertaining to energy beams or other information received pertaining to a target object being tracked, etc. In some embodiments, target object library **370** comprises information pertaining to one or more target objects or the tracking of target objects.

[0096] According to various embodiments, memory **320** comprises executing application data **375**. In embodiments, the application data comprises data for one or more applications that perform one or more of receive and/or execute a request or instruction for object detection or object tracking. The one or more applications may include applications for configuring receivers to detect energy beams, controlling the interceptor, generating a report and/or configuring information that is responsive to an object detection or classification, and/or providing to a user information that is responsive to a query or request pertaining to object detection. Various other applications may be comprised in and executed by system **300**.

[0097] FIG. **4** is a diagram of a target tracking system according to various embodiments of the present application. In the example shown, system **400** comprises transmission system **405** and one or more interceptors, such as interceptor **410**. System **400** is a bistatic radio wave localization that is configured to detect and track objects, such as target object **415**.

[0098] System **400** uses a pan-tilt unit (PTU) (e.g., the PTU includes a radar system and/or a camera system) to detect an object and provide to interceptor **410** information pertaining to an object that system **400** determines to intercept/track. The PTU may be separate or integrated with transmission system **405** (e.g., a tracking station transmission system). In some embodiments, the PTU detects objects (e.g., within a predefined area) and interrogates the various detected objects to determine a set of target objects. The interrogating the detected objects may include determining whether a detected object is friendly, benign (e.g., a bird), civilian (e.g., a civilian drone, commercial aircraft), military, enemy, etc.

[0099] In response to determining the set of target objects, system **400** (e.g., transmission system **405**) designates a target object (e.g., selected from the set of target objects) to be targeted. Transmission system **405** may designate the target object based at least in part on respective priorities for the set of target objects. For example, transmission system **405** assigns priorities to the various objects in the set of target objects, and selects the target object based on the respective priorities (e.g., system **400** selects the target object(s) having the highest priority).

[0100] In the example shown, system **400** designates the target object to be target object **415**. In response to designating/selecting the target object, a PTU (e.g., tracking station comprising transmission system **405**) provides guidance information to interceptor **410**, which is selected to intercept/engage target object **415**. The PTU guides interceptor **410** towards target object **415** until interceptor **410** is within predefined first range **430** or another range within which a receiver on interceptor **410** detects scattered energy reflected from target object **415**. In some embodiments, predefined first range **430** is 2 km. However, various other predefined ranges may be implemented. The PTU may guide interceptor **410** via communication information pertaining to the target object (e.g., location, bearing, an identifier, etc.) to interceptor **410** via communication channel/link **425**.

[0101] In response to interceptor **410** moving to within the first predefined range of target object **415**, interceptor **410** uses an on-board receiver to detect energy being scattered by target object **415**. In some embodiments, system **400** uses transmission system **405** to provide energy beam **420** directed towards target object **415**. Transmission system **405** tracks target object **415** and updates energy beam **420** to continue to be directed at target object **415**. In some embodiments, transmission system **405** further communicates to interceptor **410** information pertaining to energy beam **420** and/or target object **415**. The information pertaining to energy beam **420** and/or target object **415** may be communicated via communication channel/link **425** and/or via modulation of energy beam **420**.

[0102] In some embodiments, the energy beam is an RF beam having a frequency (e.g., a cycle frequency) between 2 GHz and 50 GHz. As an example, the higher the frequency of the RF beam, the greater the energy required to transmit the RF beam. In some embodiments, the frequency of the RF beam directed towards a target object is 20-40 GHz. In some embodiments, the frequency of the RF beam directed towards a target object is 20-35 GHz. In some embodiments, the frequency of the RF beam is about 24 GHz.

[0103] In some embodiments, the energy beam is optionally modulated to include additional information or to identify (e.g., paint/illuminate) another object. For example, the energy beam is modulated to carry information pertaining to a target object(s) and/or the energy beam, such as characteristics of the energy beam. As another example, the energy beam is modulated to identify multiple target objects with a particular energy beam directed from transmission system **405**.

[0104] As interceptor **410** detects the scattered energy corresponding to energy beam **420** being scattered/reflected from target object **415**, interceptor **410** tracks target object **415** by following the scattered energy. For example, transmission system **405** paints/illuminates target object **415** with a particular type of energy (e.g., an RF beam having a certain frequency or range of frequencies). Interceptor **410** may determine the type of energy (e.g., the frequency or range of frequencies) to follow based on the communication from transmission system **405** of the information pertaining to the energy (e.g., RF beam). Additionally, or alternatively, interceptor **410** may seek scattered energy having a predefined energy profile.

[0105] In response to detecting the scattered energy beam **420**, interceptor **410** tracks target object **415** and approaches target object **415** or performs another active measure with respect to target object **415**.

[0106] Interceptor **410** uses the scattering of energy beam **420** to track target object **415** and optionally navigate towards target object **415**. When interceptor **410** moves within predefined second range **435** of target object **415**, interceptor **410** may use an on-board detection system (e.g., a low-powered radar system) to detect and track target object **415**. In some embodiments, predefined second range **435** is 300 m.

[0107] In some embodiments, the on-board detection system comprises an interior active array for low power integrated RF monolithic microwave integrated circuits (MMIC) to provide sufficient field of regard (FoR) at a short range (e.g., within 300 m) for final closing and tail chase of the target object. The on-board detection system is configured to have a 60 degree field of view. In some embodiments, the on-board detection system is configured to operate in the W band (e.g., 77 GHz). As an example, the range for the signal used by the on-board detection system is 350 m for −5 dBsm.

[0108] Interceptor **410** may be configured to perform an active measure with respect to target object **415**, such as to surveil or eliminate target object **415**. Interceptor **410** may autonomously determine whether to perform an active measure and cause the active measure to be implemented. For example, interceptor **410** stores a mapping of contexts to active measures and determines the particular active measure corresponding to the context of target object **415**. Additionally, or alternatively, interceptor **410** is controlled to implement an active measure based on receipt of an instruction or other control signal from another system such as transmission system **405**. For example, the instruction to implement the active measure may be communicated via communication channel/link **425**.

[0109] FIG. **5** is a diagram illustrating a bistatic radio wave localization transmitter according to various embodiments of the present application. In the example shown, bistatic radio wave localization transmitter **500** comprises signal transceiver **505**, a plurality of power amplifiers (e.g., power amplifier 1 **510**, power amplifier 2 **515**, power amplifier 3 **520**, power amplifier 4 **525**, power amplifier N **530**, etc.), timing generator **535**, and a plurality of antennas (e.g., antenna **545**, antenna **550**, antenna **555**, antenna **560**, etc.). Bistatic radio wave localization transmitter **500** may use omni-directional antenna **540** to transmit a timing reference signal generated by timing generator **535**.

[0110] In some embodiments, a transmission system (e.g., object tracking system **114**, system **200**, transmission system **405**, etc.) uses bistatic radio wave localization transmitter **500** to transmit an energy beam having a frequency (e.g., a cycle frequency) between 2 GHz and 50 GHz. For example, bistatic radio wave localization transmitter **500** is configured to transmit energy beams in the K band (e.g., a frequency between 18 GHz and 27 GHz), which enables transmission over longer ranges using relatively smaller antennas. Bistatic radio wave localization transmitter **500** may be operated with a transmission power of about 40 W (e.g., 46 dBm).

[0111] Bistatic radio wave localization transmitter **500** is configured to transmit an energy beam having a field of view of less than 10 degrees. In some embodiments, the energy beam has a field of view less than 5 degrees. In some embodiments, the energy beam has a field of view of about 3 degrees.

[0112] In some embodiments, bistatic radio wave localization transmitter **500** is controlled to transmit a radio wave signal using a narrow beam pointed at the target object, such as by a PTU. Bistatic radio wave localization transmitter **500** may be configured to modulate the signal being transmitted. For example, bistatic radio wave localization transmitter **500** may be a Frequency Modulated Continuous Wave signal (FMCW) that is configured to modulate the signal. In some embodiments, the transmitted energy beam (e.g., RF transmitted beam) is modulated using one or more of the following: a frequency modulation, a phase modulation, an amplitude modulation, a shift modulation, and/or a chirp modulation.

[0113] FIG. **6** is a diagram illustrating a local on-board radio detection system receiver according to various embodiments of the present application. In the example shown, on-board receiver **600** comprises antenna **605**, reference chirp generator **615**, reference timing signal rejection filter **620**, amplifier **625**, low noise amplifier (LNA) **630**, mixer **635**, and signal processing chain module **640**.

[0114] Antenna **605** may be an array of antennas used to detect/receive energy beams or scattered energy corresponding to an energy beam (e.g., an RF transmitted beam).

[0115] Onboard receiver **600** comprises a field of view of 60 degrees. On-board receiver **600** may have an angular resolution of 2 degrees azimuth by 3 degrees of elevation.

[0116] Reference chirp generator **615** is configured to receive a timing reference signal (e.g., transmitted by a ground station or object tracking service) via omni-directional antenna **610**.

[0117] On-board receiver **600** performs an angle of arrival estimation on signals (e.g., scattered energy) received from antenna **605**. The estimation of the angle of arrival does not require synchronization between the transmitter and receiver. Rather, the estimation of the angle of arrival uses the relative phase relationship among signals from antenna **605**. For example, only the relative phase relationship of received signals is required for a correct estimation of the direction.

[0118] In some embodiments, on-board receiver **600** performs azimuth and elevation measurements without a range or absolute doppler information. In some embodiments, on-board receiver **600** processes received signals for ground clutter elimination/reduction. For example, on-board receiver **600** implements relative doppler algorithms to process the received signals for ground clutter elimination/reduction.

[0119] FIG. **7** is a diagram illustrating a bistatic radio wave localization transmitter according to various embodiments of the present application. In the example shown, bistatic radio wave localization transmitter **700** comprises signal generator **705**, power divider **710**, drive amplifier **715** with power and bias control, power amplifier **720**, and antenna **725**. In some embodiments, drive amplifier **715** is configured to have a power and bias control. As illustrated, drive amplifier **715** comprises a plurality of amplifiers and power amplifier **720** comprises a plurality of power amplifiers. In the example shown, signal generator **705** provides signals to power divider **710** which splits the signal to the plurality of amplifiers of drive amplifier **715** (e.g., CMD291P4 with bias controls HMC970). The drive amplifier **715** provides signals to the plurality of power amplifiers of power amplifier **720**, which are provided to antenna **725**.

[0120] FIG. **8** is a diagram illustrating a bistatic radio wave localization transmitter antenna array according to various embodiments of the present application. In the example shown, transmitter **800** has a form factor of about 265 mm×270 mm. Transmitter **800** includes four groupings (e.g., group **802**, group **804**, group **806**, and group **808**) each with four arrays of conductor pads fed from the center of the grouping. The four groupings can be separately driven similar to an array of four dipole antennas. Each of the four arrays in turn have a set of four linear conducting pads (e.g., N pads in a line, where N is 16) on a top surface of a board. Transmitter **800** is configured to transmit signals within the K band, such as a band between 23.6 GHz to 24.25 GHz. In various embodiments, a transmitter antenna has different number of groupings, a different number of arrays, and a different number of linear conducting pads with a different number of pads in a line than what has been shown in FIG. **8** depending on the beam characteristics desired from the transmitter.

[0121] FIG. **9**A is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application. In the example shown, an antenna gain is depicted for a transmitter such as transmitter **800** of FIG. **8**.

[0122] FIG. **9**B is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application. In the example shown, a 3 dB beam width in the E plane or vertical direction is depicted. The depicted beam width is for a beam transmitted by a transmitter such as transmitter **800** of FIG. **8**.

[0123] FIG. **9**C is a diagram illustrating characteristics for a bistatic radio wave localization transmitter according to various embodiments of the present application. In the example shown, a 3 dB beam width in the H plane or horizontal direction is depicted. The depicted beam width is for a beam transmitted by a transmitter such as transmitter **800** of FIG. **8**.

[0124] FIG. **10** is a diagram illustrating a receiver according to various embodiments of the present application. In the example shown, onboard receiver **1000** comprises digital signal processing data capture board **1005**, receive path **1010**, receiver down converter **1015**, and antenna **1020**. In some embodiments, receive path **1010** is configured to have a low noise amplifier (LNA), a programmable gain amplifier (PGA), and analog-to-digital converter (ADC). As illustrated, receiver down converter **1015** comprises a plurality of monolithic microwave integrated circuits (MMICs). Antenna **1020** receives signals on the plurality of conductor pads along the edges of a circuit board. The signals are processed using received down converter **1015** (e.g., ADF5904), passed to receive path **1010** (e.g., ADAR7251), and digital signal processing data capture board **1105** (e.g., ADSP-BF707). Digital signal processing data capture board **1005** passes output to a computer (e.g., personal computer (PC) **1125**). In some embodiments, antenna **1020** is used for transmission as well using transmit MMICs (e.g., ADF5901).

[0125] FIG. **11** is a flow diagram of a method for detecting objects according to various embodiments of the present application. In some embodiments, process **1100** is implemented at least in part by system **100** of FIG. **1**.

[0126] At **1105**, one or more objects are detected. The system uses a radar or camera to detect objects within a predefined area. In various embodiments, the radar or camera are part of a tracking station that is ground based, the radar or camera are based on a vehicle, an airborne vehicle, a seaborne vehicle or platform, or any other appropriate platform or vehicle. At **1110**, an object is selected. In response to detecting one or more objects, the system selects an object such as for interrogation to classify the object (e.g., to determine whether the object is a target object to be tracked by the bistatic radio wave localization system). At **1115**, information pertaining to the object is obtained. For example, the system obtains information for the selected object. Obtaining the information for the selected object may include determining an identifier for the object, an object type, an indication of whether the object is benign, friendly, or unfriendly, etc. The system may further obtain an object bearing, speed, etc. At **1120**, information pertaining to the object is stored. At **1125**, the system determines whether another detected object is to be interrogated. In response to determining that another detected object is to be interrogated at **1125**, process **1100** returns to **1115** and iterates over **1115**-**1125** until no further detected objects are to be interrogated. In response to determining that no further detected objects are to be interrogated at **1125**, process **1100** proceeds to **1130**. At **1130**, information pertaining to the detected object(s) is provided. For example, the information is provided to an interceptor, which is instructed to intercept the detected object. At **1135**, a determination is made as to whether process **1100** is complete. In some embodiments, process **1100** is determined to be complete in response to a determination that the system has been provided to a transmitter of a bistatic radio wave localization system, no further objects are detected, a user has exited the system, an administrator indicates that process **1100** is to be paused or stopped, etc. In response to a determination that process **1100** is complete, process **1100** ends. In response to a determination that process **1100** is not complete, process **1100** returns to **1105**.

[0127] FIG. **12** is a flow diagram of a method for tracking a target object according to various embodiments of the present application. In some embodiments, process **1200** is implemented at least in part by system **100** of FIG. **1** and/or system **200** of FIG. **2**.

[0128] At **1205**, information pertaining to a detected object(s) is obtained. As an example, the transmission system (e.g., bistatic radio localization system transmitter) obtains object information for an object detected by a detection system, such as objects detected at **1105** of process **1100**. At **1210**, a target object is determined. The system determines whether a detected object is a target object based at least in part on the information pertaining to the detected object. For example, the system determines that the object is a target object in response to determining that the object is unfriendly. For example, the system determines that the object is a target object based at least in part on an object bearing, object location, object speed, etc. At **1215**, an RF transmitted beam is provided. In response to determining that an object is a target object, the system configures an energy beam to be directed towards the target object. The energy beam is a narrow beam that paints/illuminates the target object with a particular energy in order for a receiver in a bistatic radio localization system to detect the target object. At **1220**, an indication regarding the RF transmitted beam and/or the target object is provided. The system provides the information pertaining to the RF transmitted beam and/or the target object to the receiver, such as by communicating such information over a channel between the system and the receiver or by modulating such information into the energy beam directed at the target object. At **1225**, a determination is made as to whether process **1300** is complete. In some embodiments, process **1200** is determined to be complete in response to a determination that the interception of the detected objects is complete, no further objects are to be tracked, a user has exited the system, an administrator indicates that process **1200** is to be paused or stopped, etc. In response to a determination that process **1200** is complete, process **1200** ends. In response to a determination that process **1200** is not complete, process **1200** returns to **1205**.

[0129] FIG. **13** is a flow diagram of a method for providing an indication regarding a radio frequency (RF) transmitted beam and/or a target object according to various embodiments of the present application. In some embodiments, process **1300** is implemented at least in part by system **100** of FIG. **1** and/or system **200** of FIG. **2**. In some embodiments, process **1300** is invoked in connection with **1215** and **1220** of process **1200**.

[0130] At **1305**, information regarding the RF transmitted beam and/or the target object is obtained. At **1310**, the RF transmitted beam is modulated to include information regarding the RF transmitted beam and/or the target object. At **1315**, the RF transmitted beam is transmitted towards the target object. At **1320**, a determination is made as to whether process **1300** is complete. In some embodiments, process **1300** is determined to be complete in response to a determination that the target object has been intercepted, no further objects are to be tracked or intercepted, a user has exited the system, an administrator indicates that process **1300** is to be paused or stopped, etc. In response to a determination that process **1300** is complete, process **1300** ends. In response to a determination that process **1300** is not complete, process **1300** returns to **1305**.

[0131] FIG. **14** is a flow diagram of a method for providing an indication regarding an RF transmitted beam and/or a target object according to various embodiments of the present application. In some embodiments, process **1400** is implemented at least in part by system **100** of FIG. **1** and/or system **200** of FIG. **2**. In embodiments, process **1400** is invoked in connection with **1220** of process **1200**.

[0132] At **1405**, information regarding the RF transmitted beam and/or the target object is obtained. At **1410**, a communication channel is established with an interceptor. At **1415**, the system sends to the interceptor the information regarding the RF transmitted beam and/or the target object. At **1420**, a determination is made as to whether process **1400** is complete. In some embodiments, process **1400** is determined to be complete in response to a determination that the target object has been intercepted, no further objects are to be tracked or intercepted, a user has exited the system, an administrator indicates that process **1400** is to be paused or stopped, etc. In response to a determination that process **1400** is complete, process **1400** ends. In response to a determination that process **1400** is not complete, process **1400** returns to **1405**.

[0133] FIG. **15** is a flow diagram of a method for tracking an object based at least in part on an RF transmitted beam transmitted by a transmitter according to various embodiments of the present application. In some embodiments, process **1500** is implemented at least in part by system **100** of FIG. **1** and/or system **300** of FIG. **3**. Process **1500** may be implemented by a receiver in a bistatic radio wave localization system, such as an onboard receiver comprised in an interceptor.

[0134] At **1505**, an indication regarding an RF transmitted beam and/or a target object is received. In some embodiments, the system (e.g., the receiver) obtains the information pertaining to the RF transmitted beam or the target object via a channel, such as a channel between a transmitter of the bistatic radio wave localization system and the receiver of the bistatic radio wave localization system. In some embodiments, the system obtains the information pertaining to the RF transmitted beam or the target object from the RF transmitted beam, such as from a modulation in the RF transmitted beam. At **1510**, a scattered reflection of the RF transmitted beam is received from the target object. The system detects energy (e.g., parts of the RF transmitted beam) that is scattered from the target object. At **1515**, the scattered reflection of the RF transmitted beam using the indication is processed. In response to receiving the scattered reflection of the RF transmitted beam, the system processes the RF transmitted beam such as in connection with determining a location of the target object. In some embodiments, the system pre-processes the scattered reflection of the RF transmitted beam to eliminate or reduce interference or noise, such as clutter reflected from the ground, etc. At **1520**, the processed scattered reflection of the RF transmitted beam is provided using the indication. At **1525**, a determination is made as to whether process **1500** is complete. In some embodiments, process **1500** is determined to be complete in response to a determination that the target object has been intercepted, no further objects are to be tracked or intercepted, a user has exited the system, an administrator indicates that process **1500** is to be paused or stopped, etc. In response to a determination that process **1500** is complete, process **1500** ends. In response to a determination that process **1500** is not complete, process **1500** returns to **1505**.

[0135] FIG. **16** is a flow diagram of a method for controlling an interceptor based at least in part on an RF transmitted beam transmitted by a transmitter according to various embodiments of the present application. In some embodiments, process **1600** is implemented at least in part by system **100** of FIG. **1** and/or system **300** of FIG. **3**.

[0136] At **1605**, the system obtains information pertaining to the target object and/or the RF transmitted beam scattered from the target object. As an example, the system obtains such information from **1220** of process **1200**. At **1610**, a location or bearing of the target object is determined. The system determines the location or bearing of the target object based at least in part on the information pertaining to the target object and/or the RF transmitted beam scattered from the target object. At **1615**, an interceptor is navigated based at least in part on the location or bearing of the target object. The system controls the interceptor to move in a direction or manner in order to intercept the target object or to perform an active measure with respect to the target object. At **1620**, a determination is made as to whether process **1600** is complete. In some embodiments, process **1600** is determined to be complete in response to a determination that the target object has been intercepted, the interceptor is instructed to no longer track or intercept the target object, no further objects are to be tracked or intercepted, a user has exited the system, an administrator indicates that process **1600** is to be paused or stopped, etc. In response to a determination that process **1600** is complete, process **1600** ends. In response to a determination that process **1600** is not complete, process **1600** returns to **1605**.

[0137] FIG. **17** is a flow diagram of a method for performing an active measure with respect to a target object being tracked by a bistatic radio wave localization system according to various embodiments of the present application. In some embodiments, process **1700** is implemented at least in part by system **100** of FIG. **1** and/or system **300** of FIG. **3**.

[0138] At **1705**, the system obtains information pertaining to a scattered RF transmitted beam and/or a target object.

[0139] At **1710**, a range to the target object is determined. The system determines the range or location of the target object based at least in part on the scattered RF transmitted beam or the information pertaining to a scattered RF transmitted beam and/or a target object.

[0140] At **1715**, an interceptor is navigated based at least in part on information pertaining to a scattered RF transmitted beam and/or a target object.

[0141] At **1720**, the system determines whether the range to the target object is less than or equal to a threshold range. In response to determining that the range is not less than or equal to the threshold range at **1720**, process **1700** returns to **1705** and iterates over **1705-1720** until the range to the target object is less than or equal to the threshold range. In response to determining that the range to the target object is less than or equal to the threshold range at **1720**, process **1700** proceeds to **1725**.

[0142] At **1725**, information pertaining to the target object is determined based at least in part on an on-board radar. For example, the system uses a low power radar (e.g., having a smaller range, such as less than 500 m) to determine the location of the target object, the target object bearing, etc.

[0143] At **1730**, an interceptor is navigated based at least in part on feedback from the on-board radar. The system detects feedback (e.g., reflected energy beams) from the target object, and the system determines the location of the target object, the target object bearing, etc. The system navigates the interceptor based at least in part on the location of the target object or other information determined from the feedback from the target object.

[0144] At **1735**, the system determines whether to perform an active measure. In response to determining that an active measure is not to be performed at **1735**, process **1700** returns to **1725** and iterates over **1725-1735** until the system determines that an active measure is to be performed. In response to determining that an active measure is to be performed at **1735**, process **1700** proceeds to **1740**.

[0145] At **1740**, an active measure is performed. The system may implement the active measure or cause the active measure to be performed.

[0146] At **1745**, a determination is made as to whether process **1700** is complete. In some embodiments, process **1700** is determined to be complete in response to a determination that the target object has been intercepted or eliminated, the interceptor is instructed to no longer track or intercept the target object, no further objects are to be tracked or intercepted, a user has exited the system, an administrator indicates that process **1700** is to be paused or stopped, etc. In response to a determination that process

1700 is complete, process **1700** ends. In response to a determination that process **1700** is not complete, process **1700** returns to **1705**.

[0147] FIG. **18** is a flow diagram illustrating an embodiment of a process for determining guidance of an interceptor. In some embodiments, the process **1800** is implemented at least in part by system **100** of FIG. **1** and/or system **300** of FIG. **3**. In the example shown, in **1805**, an indication is received to intercept a target object from a tracking station. For example, a detection system comprising one or more of a monostatic radar system, a bistatic radar system, a passive radar system, an imaging system, a visual camera, a lidar system, an infrared detection system is/are used to determine a target object and the system determines whether the target object is to be tracked. In **1810**, navigation to the target is determined based on the indication information. For example, the location and/or heading information from the detection system is used to determine an intercept navigation course. In **1815**, it is determined whether the range to the target object is less than or equal to a scatter range. In response to the range to the target object being not less than or equal to the scatter range, control passes to **1810**. In response to the range to the target object being less than or equal to the scatter range, control passes to **1820**. In some embodiments, **1815** is omitted and the process flows directly from **1810** to **1820**. In **1820**, it is determined whether the scatter signal is greater than or equal to a threshold. In response to the scatter signal not being greater than or equal to a threshold, control passes to **1810**. In response to the scatter signal being greater than or equal to a threshold, control passes to **1825**. In **1825**, navigation to the target object is determined using scattered energy and/or tracking station information. In some embodiments, in response to the scatter energy being greater than or equal to the scatter threshold, determine the navigation to the target object based at least in part on 1) the scatter energy or 2) the scatter energy and the indication from the tracking station. In **1830**, it is determined whether the range to the target object is less than or equal to a closing range. In response to the range to the target object being not less than or equal to the closing range, control passes to **1820**. In response to the range to the target object being less than or equal to the closing range, control passes to **1835**. In some embodiments, **1830** is not performed and the process flows directly from **1825** to **1835** or the process flows directly from **1845** to **1835**. In **1835**, it is determined whether the on-board tracking signal is greater than or equal to a threshold. In response to the on-board tracking signal not being greater than or equal to a threshold, control passes to **1820**. In response to the scatter signal being greater than or equal to a threshold, control passes to **1840**. In **1840**, navigation to the target object is determined using scattered energy and/or on-board tracking. In some embodiments, navigation to the target is based at least in part on 1) the on-board tracking signal or 2) the on-board tracking signal and the scatter energy. In **1845** it is determined whether to perform an active measure. For example, it is determined whether the indication to intercept target included instruction for an active measure and the type of active measure to be performed. In response to not determining to perform an active measure, control passes to **1830**. In response to determining to perform an active measure, control passes to **1850**. In **1850**, and active measure is performed. In various embodiments, the active measure comprises one or more of the following: providing an indication that an object is detected, surveilling the target object, eliminating the target object, intercepting the target object, jamming sensors comprised in the target object, or any other appropriate active measure. In **1855**, it is determined whether interception with a target object is done. In response to determining that interception with a target object is not done, control passes to **1805**. In response to determining that interception with a target object is done, the process ends.

[0148] In some embodiments, in the event that an on-board tracking signal goes away, the system falls back to the scattered energy signal for tracking. In some embodiments, in the event that the scattered energy signal for tracking goes away, the system falls back to the indication from the tracking station (e.g., monostatic radar, bistatic radar, passive radar, imaging system, etc.).

[0149] Various examples of embodiments described herein are described in connection with flow diagrams. Although the examples may include certain steps performed in a particular order, according to various embodiments, various steps may be performed in various orders.

[0150] Although the foregoing embodiments have been described in some detail for purposes of clarity of understanding, the invention is not limited to the details provided. There are many alternative ways of implementing the invention. The disclosed embodiments are illustrative and not restrictive.

What is claimed is:

1. A system, comprising:

a receiver, wherein the receiver is configured to:

receive an indication regarding a radio frequency (RF) transmitted beam;

receive a scattered reflection of the RF transmitted beam from a first target object; and

process the scattered reflection of the RF transmitted beam using the indication.

2. The system of claim **1**, wherein the receiver is comprised in an interceptor.

3. The system of claim **2**, wherein the interceptor is airborne.

4. The system of claim **2**, wherein the interceptor is configured to navigate based at least in part on the scattered reflection of the RF transmitted beam.

5. The system of claim **4**, wherein the interceptor navigates based on following or tracking the scattered reflection of the RF transmitted beam.

6. The system of claim **4**, wherein the interceptor navigates to intercept or move within a is predefined range of the first target object.

7. The system of claim **4**, wherein the interceptor switches to navigation based on an onboard directional radar in response to determining that the interceptor is within a predefined distance of the first target object.

8. The system of claim **1**, wherein the RF transmitted beam comprises an energy beam.

9. The system of claim **8**, wherein the energy beam comprises a beam with a carrier frequency of 2-50 GHz.

10. The system of claim **8**, wherein the RF transmitted beam is modulated.

11. The system of claim **10**, wherein the RF transmitted beam is modulated using one or more of the following: a frequency modulation, a phase modulation, an amplitude modulation, a shift modulation, a chirp modulation.

12. The system of claim **10**, wherein a first modulation of the RF transmitted beam is directed to the first target object, and a second modulation of the RF transmitted beam is directed to a second target object.

13. The system of claim **10**, wherein the RF transmitted beam is modulated to comprise information regarding the RF transmitted beam or the first target object.

14. The system of claim **1**, wherein the indication includes one or more of: RF transmitted beam modulation information, a target bearing, and a target distance.

15. The system of claim **1**, wherein processing the scattered reflection of the RF transmitted beam comprises determining one or more of a relative target bearing and a relative target distance.

16. The system of claim **1**, wherein processing the scattered reflection of the RF transmitted beam comprises filtering based at least in part on Doppler analysis to isolate a signal from the first target object.

17. The system of claim **1**, wherein the receiver has a field of view between 30 degrees and 60 degrees.

18. The system of claim **1**, wherein the receiver is configured to receive, via a communication channel established with a transmitter associated with transmission of the RF transmitted beam, an indication of information regarding the RF transmitted beam or the first target object.

19. A method, comprising:

receiving, by a receiver, an indication regarding a radio frequency (RF) transmitted beam;

receiving a scattered reflection of the RF transmitted beam from a first target object; and

processing the scattered reflection of the RF transmitted beam using the indication.

20. A computer program product embodied in a non-transitory computer readable medium and comprising computer instructions for:

receiving, by a receiver, an indication regarding a radio frequency (RF) transmitted beam;

receiving a scattered reflection of the RF transmitted beam from a first target object; and

processing the scattered reflection of the RF transmitted beam using the indication.

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