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(54) Title: PROXIMITY SENSOR

(57) Abstract: A forward-looking proximity sensor comprises one or more antenna elements mounted on a carrier platform in a lateral direction of said carrier platform, said antenna elements being configured to transmit a modulated signal in a direction of travel of said carrier platform, said antenna elements receiving a reflected portion of said modulated signal from said target; and a processing unit configured to generate said modulated signal based on a baseband signal and a carrier signal, said processing unit further determining characteristics of said target based on said reflected portion of said modulated signal, said characteristics of said target indicating a range of said target and at least one feature of said target.

PROXIMITY SENSOR

DESCRIPTION

Related Application(s)

[001] This application claims the benefit of priority to U.S. Provisional Application No. 61/709,397, filed October 4, 2012, which is incorporated by reference herein in its entirety.

Field of the Invention

[002] This disclosure relates to radar systems in general and proximity sensor based on radar sensing in particular.

Background of the Invention

[003] Radar sensors uses radio signals to detect targets. By analyzing the radio signals reflected from the targets, radar sensors may extract information about the targets, such as their shapes, sizes, velocities, etc. Radar sensors may serve as proximity sensors to determine a distance or proximity of a target based on the reflected signals. Conventional proximity sensors determine the proximity of a target based on a transmission delay of the radio signals reflected from the target or based on a Doppler frequency of the reflected signals.

[004] For example, missile systems may use proximity sensors to trigger a warhead when the missile platform is in a position to have the warhead become lethal to the target. Conventional proximity sensors for missile systems have a narrow field of view that is typically directed to a side of the carrier platform. The conventional side-looking proximity sensor only allows sensing of the time the carrier platform crosses the target based on a point of closest approach. The conventional side-looking sensor may be realized by using Doppler beam sharpening that uses the Doppler frequency associated with the target to determine when the carrier platform passes the point of closest approach or when the slope of the Doppler curve changes. These conventional proximity sensors, however, do not allow for robust discrimination of target characteristics such as length, shape, orientation, etc. Conventional proximity sensors also perform poorly in a stressing environment, which may

include, for example, multiple objects, high-speed objects, adverse weather conditions, interferences from other radiation sources, etc.

SUMMARY OF THE INVENTION

[005] In accordance with an embodiment, a forward-looking proximity sensor comprises one or more antenna elements mounted on a carrier platform in a lateral direction of said carrier platform, said antenna elements being configured to transmit a modulated signal in a direction of travel of said carrier platform, said antenna elements receiving a reflected portion of said modulated signal from said target; and a processing unit configured to generate said modulated signal based on a baseband signal and a carrier signal, said processing unit further determining characteristics of said target based on said reflected portion of said modulated signal, said characteristics of said target indicating a range of said target and at least one feature of said target.

[006] In accordance with an embodiment, the characteristics of the target include an angle of arrival of the target with respect to the direction of travel of the platform.

[007] In accordance with another embodiment, a method of detecting proximity of a target comprises: forming a modulated signal based on a baseband signal and a carrier signal; transmitting said modulated signal through one or more antenna elements towards a target in a direction of travel of a carrier platform, said one or more antenna elements being mounted on said carrier platform in a lateral direction of said carrier platform; receiving a reflected portion of said modulated signal from said target; and determining characteristics of said target based on said portion of said reflected portion of said modulated signal, said characteristics of said target indicating a distance to said target and at least one feature of said target.

[008] In accordance with another embodiment, a system for detecting a target comprises: a carrier platform traveling in a direction and a forward-looking proximity sensor disposed on said carrier platform. Said forward looking proximity sensor comprises: one or more antenna elements mounted on said carrier platform in a lateral direction of said carrier platform and configured to transmit a modulated signal in said direction of traveling of said carrier platform, said antennas receiving a reflected portion of said modulated signal from said target; and a processing unit configured to generate said modulated signal based on a baseband signal and a carrier signal, said processing unit further determining characteristics

of said target based on said reflected portion of said modulated signal, said characteristics of said target indicating a distance of said target and at least one feature of said target.

[009] Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

[010] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

[011] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the disclosure and together with the description, serve to explain the principles of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[012] Fig. 1 illustrates a diagram of a proximity sensor, according to an embodiment;

[013] Fig. 2 illustrates a diagram of a baseband waveform for forming a modulated signal, according to an embodiment;

[014] Fig. 3 illustrates an exemplary range-Doppler image formed by the proximity sensor of Fig. 1, according to an embodiment;

[015] Fig. 4 illustrates a range signal generated by the proximity sensor of Fig. 1, according to an embodiment;

[016] Fig. 5 illustrates a diagram of a proximity sensor, according to another embodiment;

[017] Fig. 6 illustrates a range signal generated by the proximity sensor of Fig. 5, according to an embodiment;

[018] Fig. 7 illustrates a diagram of a proximity sensor, according to still another embodiment;

[019] Fig. 8 illustrates a process of generating a range-Doppler image by a proximity sensor, according to an embodiment;

[020] Fig. 9 illustrates an exemplary engagement process of a missile system carrying a proximity sensor, according to an embodiment;

[021] Fig. 10 illustrates a conformal antenna array for the proximity sensor, according to an embodiment;

[022] Fig. 11 illustrates a two-way beam pattern of the conformal antenna array of Fig. 10, according to an embodiment;

[023] Fig. 12 illustrates a frequency response of the conformal antenna array of Fig. 10, according to an embodiment;

[024] Fig. 13A illustrates a top view of an antenna array configured to measure an angle of arrival of a target, according to an embodiment;

[025] Fig. 13B illustrates an end view of an antenna array configured to measure an angle of arrival of a target, according to an embodiment;

[026] Fig. 14 illustrates a carrier platform having a proximity sensor disposed therein, according to an embodiment;

[027] Fig. 15 illustrates range-Doppler images for various fall angles generated by a proximity sensor operating as a height-of-burst (HOB) sensor, according to an embodiment;

[028] Fig. 16 illustrates set points determined by a conventional HOB sensor and an HOB sensor according to an embodiment of the disclosure; and

[029] Fig. 17 illustrates a missile system equipped with an HOB sensor operating in a single set point mode, according to an embodiment.

DESCRIPTION OF THE EMBODIMENTS

[030] Reference will now be made in detail to the present embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[031] Fig. 1 illustrates a schematic diagram of an exemplary proximity sensor **100** according to an embodiment. Proximity sensor **100** includes one or more antennas **102A** and **102B**, an analog module **104**, and a processing module **106**. Antennas **102A** and **102B** may each be configured to transmit as well as receive signals, such as radio frequency (RF) signals, optical signals, laser signals, infrared signals, etc. Alternatively, one of antennas **102A** or **102B** may operate as a transmitting antenna configured to transmit the signals and another one of antennas **102A** or **102B** may operate as a receiving antenna configured to receive the signals. According to an embodiment, the signals transmitted by antennas **102A**

and **102B** may be continuous wave (CW) signals. Alternatively, the signals transmitted by antennas **102A** and **102B** may be pulse signals.

[032] According to a further embodiment, antennas **102A** and **102B** may be formed into desired shapes that are suitable for integration with a carrier platform, such as a vehicle, an aircraft, or a vessel. Antennas **102A** and **102B** may each include one or more metal sheets that may be conformed to the shape of the carrier platform or a portion thereof. Although Fig. 1 illustrates two antennas, one of ordinary skill in the art will appreciate that any number of antennas may be used in sensor **100**.

[033] Analog module **104** may include analog components configured to generate the signals that are suitable for transmission through antennas **102A** and **102B** and receive reflected signals through antennas **102A** and **102B**. More specifically, analog module **104** may receive baseband signals from processing module **106** and up convert the baseband signals to a higher frequency band that is suitable for transmission through antennas **102A** and **102B**. Analog module **104** may also be configured to down convert the reflected signals received through antennas **102A** and **102B** to baseband signals and provide the baseband signals to processing module **106** for further processing. Analog module **104** may perform the up conversion and the down conversion by way of direct conversion between the baseband frequency and the radio frequency. Alternatively, analog module **104** may perform the up conversion and the down conversion through an intermediate frequency (IF).

[034] Alternatively, signals transmitted by antennas **102A** and **102B** may be modulated signals. Analog module **104** may generate modulated signals by modulating baseband signals to a carrier signal at a carrier frequency band according to frequency modulation. Analog module **104** may also demodulate reflected signals received through antennas **102A** or **102B** to recover baseband signals. According to an embodiment, analog module **104** may use frequency modulation and demodulation for conversion between baseband signals and modulated signals. In an embodiment, baseband signals may include a sawtooth waveform as shown in Fig. 2. As a result, analog module **104** may carry out frequency modulation by linearly varying or sweeping the frequency of the carrier signal within a frequency band B. In alternative embodiments, baseband signals may include other linear or nonlinear waveforms known in the art. Thus, analog module **104** may carry out frequency modulation according to the linear or nonlinear waveforms.

[035] According to a further embodiment, analog module **104** may include one or more beam formers configured to control the timing and phases of the signals transmitted through antennas **102A** and **102B**. The one or more beam formers may control the signals to

form beam in a desired direction towards a target. The one or more beam formers may change the direction of beam so as to allow signals to track target. According to a further embodiment, beam former may cause antennas **102A** and **102B** to transmit the signals in substantially the direction of travel of carrier platform. Thus, system **100** may have a forward-looking field-of-view.

[036] According to an additional embodiment, analog module **104** may further include filtering components for removing or suppressing undesired signal components. For example, analog module **104** may include one or more low-pass filter(s), high-pass filter(s), or band-pass filter(s) configured to retain only signals at a desired frequency band. Analog module **104** may further include power amplifier(s) for increasing the signals components to a level that is suitable for transmission through antennas **102A** and **102B** or for subsequent processing by processing module **106**. Analog module **104** may further include other circuit components, such as a voltage-controlled oscillator (VCO), suitable for generating carrier frequency signals.

[037] Processing module **106** may be configured to generate baseband signals with desired characteristics, such as frequencies, amplitudes, and phases and transmit the baseband signals to analog module **104** for further conversion to the signals suitable for transmission. According to an embodiment, processing module **106** may include digital signal processor **110** and memory **112**. Memory **112** may be configured to store instructions and data relevant to the processing and generation of the digital signals. Processor **110** may be configured to execute instructions to process and generate digital signals. Memory **112** may include ROM, RAM, flash memory, or other computer-readable media known in the art. Processor **110** may include general-purpose processor, such as an INTEL processor, or proprietary signal processor designed to generate and processing the digital signals. Alternatively, processor **110** may include programmable logic device, such as a field programmable gate array (FPGA) or application-specific integrated circuit (ASIC), that may be specifically configured to provide the functions described herein in connection with the processing of the digital signals.

[038] According to a further embodiment, processing module **106** may include digital-to-analog convertor (DAC) for converting digital signals generated by processor **110** to the baseband signals for further processing by analog module **104**. Additionally, processing module **106** may include analog-to-digital convertor (ADC) configured to convert the baseband signals received from analog module **104** to the digital signals for processing processor **110**.

[039] According to a further embodiment, processing module **106** may determine characteristics of target based on a portion of the transmitted signals that is reflected from target and received by receiving antenna. For example, processing module **106** may determine distance or range, velocity, shape, surface property, or other characteristics of the target based on reflected signals from target. According to an embodiment, processing module **106** may determine characteristics of target based on a time difference between the transmission of output signals and reception of reflected signals. Processing module **106** may then calculate range of the target based on time difference and speed of the signals. According to another embodiment, processing module **106** may determine characteristics of the target based on Doppler processing of the received signals. The Doppler processing will be further described hereinafter.

[040] Processing module **106** may further track the target based on characteristics of target. For example, processing module **106** may update characteristics of target periodically based on the received signals to estimate location, distance, range, velocity, size, or orientation of target or features thereof. As another example, processing module **106** may also calculate angle of arrival or "look angle" of target with respect to a direction of travel of carrier platform. Processing module **106** may perform the estimation based on known techniques, such as Kalman filtering.

[041] According to a further embodiment, processing module **106** may have decision module **114** configured to determine triggering events for carrier platform based on characteristics of target determined by processing module **106**. For example, decision module **114** may estimate time of impact between platform and target. Decision module **114** may also determine course or trajectory for carrier platform to aim platform at target or cause platform to avoid target. Decision module **114** may also determine optimal detonation time or fire time to fuze the platform to maximize damage to target.

[042] Sensor **100** may further include interface(s) for communication with other systems onboard carrier platform. For example, sensor **100** may receive electric power through power interface from battery or electrical source onboard carrier platform. Sensor **100** may communicate with global positioning system (GPS) of carrier platform though system interface to receive data indicating location of carrier platform. Interface module **108** may also communicate with actuation system of carrier platform through actuation interface to adjust operation of carrier platform according to determination results of decision module **114**. Sensor **100** may communication with, for example, fuze/firing system, rocket booster, braking system, engine, steering system, motor, robotic arm, etc. Through the interfaces,

sensor **100** may cause actuation system of carrier platform to perform certain actions or operations based on characteristics of target. For example, sensor **100** may cause warhead of carrier platform to detonate at calculated time or distance from target. System **100** may also cause carrier platform to accelerate or decelerate by varying power generated by rocket booster, engine, motor, or braking system of carrier platform. System **100** may also cause carrier platform to change course or direction by controlling lateral thruster or steering system of carrier platform.

[043] According to a still further embodiment, sensor **100** may communicate through interface(s) with command system external to carrier platform. For example, sensor **100** may communicate with command system located on the ground or onboard another vehicle, aircraft, or vessel. Sensor **100** may receive communication signals from external command system or transmit the characteristics of target determined by processing module **106** to external command system. Thus, sensor **100** may allow external command system to control carrier platform. For instance, sensor **100** may receive communication signals from external command system, which causes carrier platform to operate according to communication signals. Sensor **100** may also receive communication signals to update instructions and data stored in memory **112**.

[044] According to a further embodiment, forward-looking proximity sensor **100** may be integrated with missile system to provide the benefit of "watching" the target as missile comes in for the kill. Newer targets such as unmanned aerial vehicles (UAVs) and artillery with smaller cross sections and hardened warheads require increased accuracy with regard to aim points. Unlike conventional proximity sensors, forward looking proximity sensor **100** provides more accurate measurements during the homing phase of missile's trajectory. Proximity sensor may accurately predict the optimal detonation point, which may increase the lethality for target.

[045] According to a further embodiment, sensor **100** may be configured to generate two-dimensional range-Doppler image of target. Fig. 3 illustrates an exemplary range-Doppler image **300** that may be generated by sensor **100** according to an embodiment. Range-Doppler image **300** includes pixel array defined by first dimension **302** representing the speed of target and second dimension **304** representing range of target. Each pixel includes a value indicating signal energy returned from a corresponding target point within sensor's field of view. The location of each pixel within pixel array corresponds to speed and range of target point that returns signal energy. When target enters sensor's field of view, range-Doppler image **300** may show target image **306** of target. Target image **306** may

include one or more pixels that indicate shape and structure of target. By analyzing range-Doppler image **300**, sensor **100** may determine various characteristics of target, such as speed, range, shape, size, etc. Sensor **100** may further identify different features, structures, or portions of the target based on analysis of target image **306**.

[046] According to another embodiment, sensor **100** may be low bandwidth sensor. Low bandwidth sensor is configured to detect presence of target and determine distance between carrier platform and a point of target that is closest to carrier platform.

[047] According to another embodiment, analog module **104** and processing module **106** may be integrated into processing unit including both analog and digital components. Processing unit may include circuit boards having circuit components affixed thereon. Processing unit may further include standard or proprietary interface components for providing actuation interface, system interface, and power interface described above.

[048] Fig. 4 illustrates an exemplary range signal **404** generated by low bandwidth sensor in response to target **402**. Range signal **404** is defined with respect to range axis **408** that indicates distances between carrier platform and various portions of target **402**. As further shown in Fig. 4, range signal **404** may include a variation in signal strength **406**, such as a rising edge or a falling edge, which corresponds to a portion of target **402** that is closest to carrier platform. Thus, by detecting signal variation **406** in range signal **404**, sensor **100** may identify target **402** and determine distance to target **402**. Sensor **100** may generate range signal **404** as part of range-Doppler image shown in Fig. 3. For example, sensor **100** may extract range signal **404** from range-Doppler image at a particular speed.

[049] Fig. 5 illustrates another exemplary proximity sensor **500** based on high range-resolution homodyne system, according to an embodiment. Proximity sensor **500** includes one or more antennas **502A-502D**, analog module **504**, and processing module **506**. Antennas **502A-502D** are separated into transmitting array formed by antennas **502A** and **502B** and receiving array formed by antennas **502C** and **502D**.

[050] According to another embodiment, antennas **502A-502D** may be highly diversified in order to provide reliable signal transmission and reception. For example, antennas **502A-502D** may be disposed on different portions of the carrier platform and directed to different directions. Sensor **500** may monitor operation of each antenna and select antenna with, for example, the greatest signal-to-noise ratio (SNR). Sensor **500** may include switch **514** for selecting antennas **502A** or **502B** for transmitting signals and switch **516** for selecting antennas **502C** or **502D** for receiving reflected signals.

[051] According to a further embodiment, sensor **500** may use a Linear Frequency Modulated (LFM) waveform with a wide frequency band. Accordingly, analog module **504** of sensor **500** may have a much wider frequency range than analog module **404** of sensor **400**. Separate analog-to-digital and digital-to-analog converters may accommodate the bandwidth of the received and transmitted signals along with a processor **510** to provide computational power for signal processor and tracking algorithms. Processor **510** may be FPGA, ASIC, or other processor known in the art. Sensor **500** may further include memory **512** for storing instructions that may be executed by processor **510**.

[052] According to another embodiment, sensor **500** may include signal feedback for automatic calibration. More particularly, analog module **504** may include voltage-controlled oscillator (VCO) **520** for generating a waveform signal to be transmitted through antenna **502A** or **502B** or to be converted to a modulated signal described above. Analog module **504** may further include signal divider **518** for returning a portion of the waveform signal. The portion of the waveform signal returned by signal divider **518** may be processed by a frequency control unit **526**. Processor **510** may analyze signals from frequency control unit **526** to determine whether the waveform signal has desired characteristics, such as predetermined frequency or phase. This may be performed by any frequency detecting circuit, such as a frequency counter, as known in the art. Frequency control unit **526** may be implemented as part of processor **510** and integrated therein. When determining that characteristics of the waveform signal deviate from desired values, processor **510** may control VCO **520** to recalibrate the waveform signal. Processor **510** may control VCO **520** through sweep generation unit **522**. Processor **510** may further adjust the frequency of the waveform signal generated by VCO **520** in set frequency range so as to allow sensor **500** to operate in relatively wide bandwidth. In general, wider bandwidth allows sensor **500** to generate finer-resolution signal and to identify greater details of target. Thus, signal divider **518** and frequency control unit **526** provide signal feedback from VCO **520** to processor **510**, which allows sensor **500** to operate in a wide temperature range and in different aging conditions.

[053] According to another embodiment, sensor **500** may include actuation unit **528** that may communicate with actuation interface for generating actuation signal for controlling operation of carrier platform. Sensor **500** may further communicate with other systems of carrier platform through system interface and receive electrical power through power interface as described above in connection with Fig. 1.

[054] According to an embodiment, sensor **500** may be high bandwidth sensor that is capable of not only detecting the presence and the distance of target, but also identifying individual features, structures, portions, or other characteristics of target. For example, when sensor **500** is coupled to missile system, sensor **500** may track the target during an engagement as well as guide missile system to aim at a particular portion of target so as to maximize lethality.

[055] Sensor **500** may identify a track point based, for example, on one portion of signals returned from target and identify an aim point based on another portion of signals returned from target. High bandwidth of sensor **500** allows processing unit **504** to identify specific surface features based on returned signals. For example, sensor **500** may identify variation of cross-sectional dimension of target, reflectivity of surface of target, structural variation of surface of target, etc.

[056] High-bandwidth sensors, such as sensor **500**, are employed when a specific part of target must be identified. As shown in Fig. 6, sensor **500** may generate high-resolution range signal **600** that includes details corresponding to different portions or structures of target **606**. Based on range signal **600**, sensor **500** may identify separate points on target **606**, such as track point **604** and aim point **602**. Sensor **500** may then track target **606** during the engagement based on track point **604**, while creating a firing solution for carrier platform base on aim point **602** so that it may impact a desired portion of target **606**.

[057] According to another embodiment, sensor **500** may also determine velocity (including speed and direction of travel) of target, size of target, shape of target, and angle of arrival of target with respect to a line of sight between carrier platform and target. In another embodiment, sensor **500** may also determine surface properties of target, such as reflectivity.

[058] According to a further embodiment, low-bandwidth sensor and high-bandwidth sensor described above may be selected for particular carrier platform depending on target characteristics. For targets that may be tracked and aimed using the same point, low-bandwidth sensor may be used. For targets that are tracked and aimed using different points, high-bandwidth sensor may be used.

[059] Fig. 7 shows another exemplary forward-looking proximity sensor **700** according to an embodiment. Proximity sensor **700** includes antenna network **702**, analog module **704**, and processing module **706**. Antenna network **702** may include one or more antennas suitable for transmitting and receiving signals. The signals may include Linear FMCW (LFMCW) or other modulated or un-modulated signals.

[060] According to a further embodiment, processing module **706** may include image processor **714** configured to generate the range-Doppler image similar to that shown in Fig. 3. Image processor **714** may include dedicated circuits for performing Fast Fourier Transform (FFT). According to a further embodiment, image processor **714** may generate range-Doppler image with pixel array of desired size including a plurality of rows and a plurality of columns. Accordingly, image processor **714** includes first FFT module **716** configured to perform a multi-point FFT for rows of pixel array and a second FFT module **718** configured to perform a multi-point FFT for columns of pixel array. Image processor **714** may communicate with processor bus **720** to receive parameters, such as range weights and Doppler weights, for calculating the range-Doppler image. Image processor **714** may receive parameters from digital signal processor **710** or storage medium **722** or **724**. Image processor **714** may further include one or more storage media **726**, **728**, and **730** for storing parameters and data generated during calculation of range-Doppler image. Range-Doppler image may be stored in RDI buffer **732** for later retrieval by other system components such as digital signal processor **710**.

[061] Fig. 8 shows a process **800** for generating range-Doppler image **300** according to an embodiment. Process **800** may be implemented on any one of the proximity sensors described above. According to process **800**, at step **802**, the proximity sensor generates modulated signal, such as linear chirp-mixed signal with sweeping frequency **810** having frequency band B. Sweeping frequency **810** may vary within frequency band B repeatedly and periodically at set Pulse Repetition Interval (PRI) as sensor transmits signal.

[062] Proximity sensor further receives reflected signal in response to chirp-mixed signal. Due to the relative velocity between target and carrier platform, reflected signal may include frequency **812** having Doppler frequency shift f_d. Doppler frequency shift f_d may vary at different temporal portion of reflected signal because of changes in relative velocity. Thus, Doppler frequency shift f_d indicates relative velocity between target and carrier platform. In addition, reflected signal may also include time delay t_d due to the round-trip transmission time between target and carrier platform. Thus, time delay t_d indicates the range to target.

[063] At step **804**, the proximity sensor may acquire time-domain samples of reflected signal and arrange samples in storage medium, such as buffer. The samples may be arranged in a two-dimensional matrix that has a first dimension representing the time domain and a second dimensional representing the Pulse Repetition Interval.

[064] At step **806**, the proximity sensor may perform range FFT on time domain samples within each RPI resulting in complex range/PRI samples, which form Range-Time Image (RTI). At step **808**, proximity sensor performs Doppler FFT across PRI domain for each range bin resulting in final range-Doppler image.

[065] According to an embodiment, proximity sensors described above in connection with Figs. 1-8 may operate as a forward-looking proximity sensor for guiding the carrier platform, such as missile or other projectile, towards target. The forward-looking proximity sensor may provide optimal detonation decision to maximize damage to target. Fig. 9 depicts an exemplary embodiment of a missile system **900** equipped with forward-looking proximity sensor similar to that described above. Fig. 9 illustrates missile system **900** on course to engage with target **902**.

[066] Conventional proximity sensor would trigger detonation of missile at Doppler threshold or trip wire as missile flies by target. The proximity sensor described herein, however, provides forward-looking field of view that allows the sensor to "watch" target as missile comes in for the kill. By integrating measurements during the homing phase of missile's trajectory, proximity sensor can accurately predict optimal detonation point which creates the greatest lethality for warhead.

[067] The basic timeline and actions provided by proximity are further shown in Fig. 9. More specifically, at stage A, proximity sensor may transmit outbound signals, such as FMCW signals, in direction of travel of a carrier platform, such as missile system **900**. Proximity sensor monitors reflected portion of outbound signals from target **902** to determine characteristics of target **902**, such as range and speed of target **902**. At stage B, the proximity sensor may detect that range of target **902** is less than threshold value, such as 10 meters, at which track quality is sufficient to allow proximity sensor to track target **902**. At stage C, proximity sensor may start tracking target **902** and project position of target **902** using tracker, such as α-β tracker or Kalman filter as known in the art. At stage D, proximity sensor may determine an operation for the carrier platform, such as calculating a fire solution, based on tracking data. Proximity sensor may initiate calculation when tracking data fidelity is optimal at about 2.5 to 1.0 meter from target **902**, depending on closing velocity between missile **900** and target **902**.

[068] At stage E, the proximity sensor may cause the carrier platform to execute the operation according to the determination at stage D. For example, the proximity sensor may issue detonation signal to trigger detonation of missile **900**. The proximity sensor may issue detonation signal when the carrier platform reaches the RF centroid or when an impact

between missile **900** and target **902** is detected. Alternatively, the proximity sensor may issue the detonation signal when the carrier platform is at a specific distance to target **902** before or after crossing the RF centroid. Still alternatively, the proximity sensor may identify a particular feature or structure of target **902** when operating in a high-resolution mode. Accordingly, the proximity sensor may measure a distance between the carrier platform and the identified feature or structure of target **902** and issue the detonation signal according to the distance to the identified feature or structure of target **902**.

[069] The proximity sensor described above may be used to not only enable low-cost forward-looking proximity fuzing or high-range-resolution (HRR) aim point resolved fuzing, but also can reuse processing resources during different phases of flight to enable communication, radar cross section (RCS) enhancement, and seeker functions. Since proximity sensor is configured to track target for a substantial amount of time prior to fuzing, fuze can take advantage of information about target supplied by other guidance system, such as onboard seeker, ground radar, etc., to refine fuzing solution based on engagement geometry, target orientation, or target type.

[070] Since many missile systems utilize seeker to provide guidance information to maneuver platform into position to intercept target, front ends of the missile systems are often occupied with antennas, optics, and other electronics utilized by seeker systems. Therefore, antennas, data links, telemetry, and other system components of proximity sensors described herein may be disposed behind existing seeker and further away from the front end of the missile system.

[071] According to a further embodiment, proximity sensors described herein may include conformal antenna array **1000** as depicted in Fig. 10. Conformal antenna array **1000** may include one or more flat metal sheet radio antenna elements configured to conform or follow prescribed shape. For example, flat metal sheet antenna elements may be curved to conform to the shape of cylindrical body of missile and mounted on the side in a lateral direction of cylindrical body of carrier platform or wrapped around a portion of cylindrical body.

[072] According to an embodiment, conformal antenna array **1000** is configured to provide a forward-looking beam pattern that is directed in the direction of travel of carrier platform, rather than a lateral direction as in a conventional proximity sensor. The forward-looking beam pattern may enable proximity sensor to have enhanced field of view to make accurate range and velocity measurements of target. Typically this pattern matches the field-of-view of onboard seeker, so that both proximity sensor and seeker can view target at the

same time. Seeker may guide missile system to target, while proximity sensor may determine an optimal firing solution for warhead carried thereon.

[073] According to a further embodiment, conformal antenna array **1000** may include transmitting element **1002** and receiving element **1004**. Transmitting element **1002** and receiving element **1004** may be disposed 180 degrees apart on missile body and provide two-way forward-looking beam pattern as depicted in Fig. 11. The overall gain of antenna **1000** is given by the two-way pattern between transmitting and receiving elements **1002** and **1004**. As further shown in Fig. 11, two-way forward-looking beam pattern is relatively uniform in a forward cone and may be tailored to suit particular systems.

[074] According to a further embodiment, additional antenna elements may be added to allow polarization diversity and to mitigate shadowing effects on relatively large carrier platforms. In addition, the placement of transmitting and receiving antennas **1002** and **1004** at a 180 degree offset increases antenna isolation by placing one element in the nulls of another element, thereby providing improved performance. According to a further embodiment, multiple pairs of antenna elements as shown in Fig. 10 may are used in a sequential fashion to improve overall system performance without the problem of nulls in the beam pattern that is typically associated with conventional antenna arrays.

[075] Furthermore, bandwidth of conformal antenna array **1000** is determined by a number of parameters such as material thickness, aperture, or geometry of each antenna element. A plot of exemplary frequency response of conformal antenna array **1000** is shown in Fig. 12. The material used for conformal antenna array **1000** may enhance cost-effectiveness and may be readily available at printed board fabrication houses combined with standard flat panel manufacturing techniques. Thus, combination of these two aspects provides a low cost and reliable antenna array. Once the elements of antenna array **1000** are fabricated, they are conformed to a shape of carrier platform, such as missile body. For example, antenna array **1000** may be formed into cylindrical shape that conforms to a section of missile body. Beam pattern formed by antenna array **1000** may be steered along axial direction of cylindrical shape. According to a further embodiment, each element of antenna array **1000** may include multiple layers that are developed utilizing the same technique for accommodating feed structures. Standard conductive and nonconductive adhesives may be used to assemble the multiple layers.

[076] According to a further embodiment, proximity sensor described herein may provide an additional detonation mode to missile system in addition to primary detonation mode. For a hit-to-kill missile, proximity sensor may detect a miss and detonate missile

when the miss has occurred. In this manner, lethality may be enhanced for targets while preserving the primary mission of missile. Proximity sensor operates in conjunction with existing seeker systems to provide more integration time on target. Proximity sensor continues to estimate range and velocity of target as missile approaches target and allows for greater detonation accuracy.

[077] According to another embodiment, proximity sensor described herein may use linear engagement geometry to estimate range and speed of target prior to reaching non-linear region of engagement. Linear engagement geometry simplifies firing solution calculations and increases lethality over conventional side-looking proximity sensors that must operate in non-linear engagement regions. Thus, proximity sensor described herein provide simpler and more accurate estimate of target aimpoint.

[078] According to another embodiment, proximity sensor may collect and process information about target during the endgame (i.e., the final portion of engagement between missile and target). Based on the information, proximity sensor forms a better estimate of the time of crossing between missile warhead and target aim point than conventional side-looking proximity sensors. Two-way beam pattern between transmitting and receiving antennas allows conformal antenna to focus energy in the direction of target. The field-of-view of proximity sensor may be set by existing seeker and guidance parameters.

[079] According to a further embodiment, to prevent shadowing and handle polarization effects, conformal antenna array of proximity sensor may include a plurality of sets of transmitting/receiving antenna pairs with different polarities, locations, and parameters. During the endgame, transmitting/receiving antenna pairs may be alternated every Coherent Processing Interval (CPI) by an RF switch that is synced to firmware of proximity sensor. In this embodiment, the proximity sensor may provide a forward-looking field of view with an estimation of an angle of arrival of the target.

[080] Fig. 13A illustrates a lateral view (A view) of an antenna system **1300** for forward-looking proximity sensor disposed on a section of a carrier platform **1304**, according to an embodiment. Fig. 13B illustrates an end view (B view) of antenna system **1300**, according to another embodiment. As shown in Figs. 13A and 13B, antenna system **1300** includes a receiving array and a transmitting array. Receiving array may include a plurality of receiving antenna elements **1302A** and **1302B**. Transmitting array may include one or more transmitting antenna elements **1306**. Receiving antenna elements **1302A** and **1302B** and transmitting antenna element **1306** may be disposed on one or more side surfaces of carrier platform **1304**. Antenna elements **1302A**, **1302B**, and **1306** may each include a metal

sheet that is curved to conform to a shape of the side surfaces of carrier platform **1304**. The metal sheet of each antenna element may be oriented to face a first direction **1314** that is substantially perpendicular to the direction of travel **1312** of carrier platform **1304**. In one embodiment, carrier platform **1304** may have a cylindrical body. Antenna elements **1302A**, **1302B**, and **1306** may each form an arch structure that follows a curvature of the cylindrical body of carrier platform **1304**. Antenna elements **1302A**, **1302B**, and **1306** may also be formed into other shapes as desired to fit a particular application.

[081] According to an embodiment, as shown in Fig. 13A, receiving antenna elements **1302A** and **1302B** may be arranged on carrier platform **1304** along a second direction **1316** that is substantially perpendicular to the direction of travel **1312** of carrier platform **1304**. Receiving antenna elements **1302A** and **1302B** may be separated from each other by a distance of d (measured from center to center) along second direction **1316**. The transmitting array and the receiving array and may be disposed on opposite side surfaces of carrier platform **1304** so that they are 180 degrees apart. The transmitting array and the receiving array of antenna system **1300** may form a forward-looking two-way beam pattern in the direction of travel **1312** of carrier platform **1304**.

[082] According to an embodiment, antenna system **1300** may include more than one pair of transmitting array and receiving array as shown in Fig. 13B, each corresponding to a channel. For example, antenna system **1300** may include two pairs of transmitting array and receiving array. The first of the two pairs of arrays including receiving elements **1302A** and **1302B** and transmitting element **1306** may be disposed on top and bottom side surfaces of carrier platform **1304**, respectively. The second of the two pairs of arrays including receiving elements **1308A** and **1308B** and transmitting element **1310** may be disposed substantially 90 degrees apart from the first pair and on left and right side surfaces of carrier platform **1304**, respectively. Antenna system **1300** may include more than two pairs of transmitting array and receiving array that are disposed on the side surfaces of carrier platform **1304** at substantially equal angular intervals. The proximity sensor may include one or more switching elements for selecting one of the pairs of arrays at a time. The switching elements may switch among the channels based on a coherent processing interval (CPI) of the proximity sensor. In a further embodiment, for each channel, additional antenna elements may be added to allow polarization diversity and to mitigate shadowing effects on relatively large carrier platforms.

[083] According to an embodiment, antenna system **1300** may allow the proximity sensor described herein to determine an angle of arrival of a target with respect to the

direction of travel **1312**. For example, the first pair of transmitting array and receiving array disposed on the top and bottom surfaces of carrier platform **1304** may generate signals indicating an angle of arrival of the target in a horizontal plane. The second pair of transmitting array and receiving array disposed on the left and right surfaces of carrier platform **1304** may generate signals indicating an angle of arrival of the target in a vertical plane. When antenna system **1300** includes more than two pairs of transmitting array and receiving array, each pair may be configured to generate signals indicating a corresponding angle of arrival.

[084] According to a further embodiment, each transmitting antenna element (e.g., **1306**, **1310**) may be configured to generate RF signals with a forward-looking beam pattern. When the RF signals are returned from the target, receiving antenna elements (e.g., **1302A**, **1302B**, **1308A**, **1308B**) each receives a portion of the returned signals and provide the returned signals to the processing unit of the proximity sensor to determine the corresponding angle of arrival of the target. The processing unit may analyze the returned signals from the receiving antenna elements and determine the angle of arrival based on, for example, a propagation time difference or a phase difference between the returned signals received at different receiving antenna elements.

[085] In one embodiment, the angle of arrival θ corresponding to a particular pair of transmitting array and receiving array may be determined by solving the following equation:

$$\Delta\varphi = \frac{2\pi}{\lambda} d \sin(\theta),$$

where $\Delta\varphi$ is the phase difference between returned signals received by different receiving elements and λ is the wavelength of the carrier waveform. Each channel of antenna system **1300** may have a field of view (FOV) determined according to the following equation:

$$\theta_{FOV} = \sin^{-1}\left(\frac{\lambda}{2d}\right).$$

Parameter λ and d may be chosen to provide a desired field of view for a particular application. A target located outside the field of view may be wrapped into the first ambiguity region of the antenna system **1300**. For target outside of the field of view, a cue for the angle of arrival of target may be provided to the proximity senor to make correct determination.

[086] In an embodiment, the variance of the angel of arrival determined based on antenna system **1300** may be determined based on the following equation:

$$\sigma_\theta^2 = \left(\frac{\lambda}{2\pi d}\right)^2 \frac{1}{SNR},$$

where SNR represents the signal-to-noise ratio at the receiving elements. Thus, λ and d may be adjusted to provide a desired measurement accuracy for the angle of arrival

[087] Fig. 14 depicts another exemplary embodiment of proximity sensor **1402**. Proximity sensor **1402** may be disposed anywhere volume is available within carrier platform **1400**. Antenna elements for proximity sensor **1402**, similar to those shown in Fig. 10, may be co-located with electronics package or routed to other portions of carrier platform **1400** based on design requirements. The antenna elements may be placed on carrier platform **1400** in such a way as not to interfere with normal function(s) of carrier structure **1400** or other components. In addition, antenna elements may be tangential to surface of carrier platform **1400** and formed to curvature of body of carrier platform **1400**. Antenna element(s) may include rolled copper plate with etched circuitry.

[088] According to a still further embodiment, proximity sensor described herein may operate as height-of-burst (HOB) sensor for carrier platform. Projectiles or missiles designed to be aimed at targets, such as those on the ground, often require an HOB sensor, i.e., a target detection device (TDD), to fire or fuze warhead of missile at a height of a few meters from target to increase lethality. Proximity sensor disclosed herein may provide accurate measurement of height as missile approaches the targeted surface and generate accurate warhead fire signal when missile reaches a predetermined height above targeted surface. Proximity sensor may allow firing solution to be robust in terms of abilities to withstand very high-g accelerations, storage life, and performance in the presence of countermeasures, while being low cost and small size. Proximity sensor may also be configured to differentiate targets in complex scenes, handle diverse fall angles of the missile, and provide increased accuracy for aim points and reduced susceptibility to environmental effects.

[089] Fig. 15 shows three different fall angles of a carrier platform **1500** equipped with HOB sensor **1502**, which may be implemented by proximity sensors described above, according to an embodiment. HOB sensor **1502** may generate range-Doppler image corresponding to given height and fall angle. Fig. 15 illustrates three range-Doppler images **1504**, **1506**, and **1508** for the three different fall angels at -15°, -90°, and -110°, respectively, when carrier platform is at height H above ground surface.

[090] Each of range-Doppler images includes an image pattern (e.g., image pattern **1510**) representing the ground surface within the field-of-view of sensor **1502**. The height H of carrier platform is indicated by range of closest signal return (e.g., point **1512** in range-Doppler image **1508**). Ground signal return may be distributed over range **1514**, also known as ground spreading, because ground surface within field-of-view of sensor **1502** falls within range **1514**.

[091] Image pattern corresponding to ground surface may be a function of fall angle. For example, when fall angle of missile **1500** is near incident (e.g., -90°), ground spreading in range-Doppler image is minimum. When missile **1500** has a flatter trajectory with, for example, a fall angel of -15°, ground spreading is maximum. Thus, by analyzing image feature of range-Doppler image, HOB sensor **1502** may determine height and fall angle of missile body with respect to ground surface. Upon determining that carrier platform **1500** reaches predetermined height above ground surface, HOB sensor **1502** may generate signal to adjust operation of carrier platform **1500**. For example, HOB sensor **1502** may generate detonation signal to fuze warhead onboard carrier platform **1500**, thereby maximizing lethality for target on ground surface.

[092] According to a further embodiment, HOB sensor **1502** may use tracking filter to estimate characteristics, such as range or range rate, of image feature **1510**. Tracking filter may minimize or eliminate effects of amplitude variation on track and reduce the effects of noise and interference by discounting tracks that cannot be valid due to the physics of the engagement. Fig. 16 illustrates exemplary track points **1608** for tracking based on range-Doppler image generated by HOB sensor **1502**.

[093] Fig. 16 further illustrates height of burst **1602** determined by HOB sensor **1502** compared with height of burst **1604** determined by conventional HOB sensor using single bin filter **1606**. Due to noise and variation, conventional HOB sensor tends to produce an imprecise result, while HOB sensor **1502** generates an HOB set point that is substantially equal or closer to the true value **1610** of the desired height.

[094] Fig. 17 illustrates a tracking of the height H by HOB sensor **1502** when carrier platform **1500** approaches the ground surface. Exemplary range-Doppler images **1702-1708** are shown corresponding to heights at 45 meters, 35 meters, 25 meters, and 15 meters, respectively. As carrier platform **1500** approaches ground surface, image feature corresponding to ground surface moves to closer range bins. At the same time, the strength of the reflected signal becomes greater because of reduced distance between carrier platform **1500** and the ground surface. In addition, HOB sensor **1502** may implement feature

identification and suppression in analyzing range-Doppler images to suppress effects of any countermeasures or undesired environments such as foliage and adverse weather.

[095] According to a further embodiment, HOB sensor **1502** is configured to operate in single–set-point mode as further shown in Fig. 17. In single-set-point mode, preset HOB set point, such as 15 meters, may be set in HOB sensor **1502**. HOB sensor **1502** may continue to measure and track the height of carrier platform **1500** above the ground surface as the closest point on the ground to the antenna array disposed on the carrier platform. HOB sensor **1502** operating in single-set-point mode uses preset HOB set point as a single threshold to determine whether fuze commend should be generated to adjust the operation of carrier platform, such as detonating warhead carried by carrier platform **1500**. The HOB set point may be defined within the two-dimensional range-Doppler map. For example, the HOB set point may be a user-selected point on the range axis that corresponds to a Doppler velocity of zero. Alternatively, the HOB set point may correspond to a non-zero range and a non-zero Doppler velocity. HOB sensor **1502** may monitor the image of the ground surface in the range-Doppler map and determine whether the image of the ground surface matches the HOB set point.

[096] In an embodiment, antenna array may be located near warhead carried by carrier platform **1500** such that the distance between the front end of carrier platform **1500** and antenna array may be negligible. In another embodiment, antenna array may be disposed at remote location from warhead. In this embodiment, HOB sensor **1502** may first estimate a fall angle by, for example, analyzing image feature in range-Doppler image sequence. HOB sensor **1502** may then determine height of front end of carrier platform **1500** based on range provided by range-Doppler image and distance between antenna array and warhead.

[097] In addition to single-set-point mode, HOB sensor **1502** may also be configured to operate in multiple-set-point mode. In multiple-set-point mode, HOB sensor **1502** may provide an accurate HOB measurement in a stressing environment including uneven ground features such as trees, hills, buildings, etc. In this embodiment, HOB sensor **1502** may differentiate undesired ground features from true ground target and issue a fuze command at the correct HOB. In particular, HOB sensor **1502** may define a plurality of set points in the range-Doppler map and determine whether the image of the ground surface in the range-Doppler map matches the plurality of set points. The plurality of set points may be designed to ensure accurate identification of the ground surface in stressing environments.

[098] According to some embodiments, proximity sensor disclosed herein may be used on any type of vehicle including automobiles, vessels, or aircrafts to detect other

vehicles or pedestrians. For example, proximity sensor may be adopted and installed on a vehicle for: detecting a potential collision; and/or triggering an alarm signal to warn an operator. Signals provided by proximity sensor may be further used to control or guide vehicle, vessel, or aircraft to a destination or target or to avoid the potential collision with objects or hazards. For example, proximity sensor may provide signals to computer system, which determines, based on signals, whether vehicle comes within predetermined distance from other objects such as another vehicle, a pedestrian, a building, etc. Proximity sensor may further identify different portions of an object within predetermined detection distance, thereby causing on-board computer system to control vehicle in response to signals provided by sensor.

[099] As another example, the proximity sensor may be used to guide a manned or unmanned vehicle, vessel, or aircraft to a particular location or along a particular route. For example, the proximity sensor may identify a particular location and provides signals to on-board computer system, reflecting an estimation of distance between the vehicle and the particular location, object, or hazard. The on-board computer system may then issue commands to control the vehicle based on signals provided by proximity sensor. Alternatively, proximity sensor may identify predetermined route or characteristics thereof, and provide signals to on-board computer system to guide vehicle along predetermined route.

[0100] According to another embodiment, proximity senor described herein may be integrated with package processing system for detecting and identifying packages or a manufacturing system for handling products during a manufacturing process. For example, package processing system may include automatic transportation unit, such as conveyer belt, for transporting packages through the system. Package processing system may further include a number of processing units, such as robotic arms, labeling machines, etc., for handling packages. One or more proximity sensors similar to those described herein may be installed in the system for detecting whether a package is transported to a predetermined processing unit. A proximity sensor at processing unit may determine distance and speed of package with respect to processing unit and estimate amount of time required for package to reach processing unit. Processing unit may then prepare to handle package according to the estimations.

[0101] Additionally, proximity sensor may determine characteristics of package, such as size, shape, materials, etc., and instruct processing unit to handle packages according to characteristics of package(s). For example, processing unit may separate packages into different categories according to size, shape, etc. Processing unit may also apply different

labels to packages depending on size, shape, materials, etc. Because proximity sensor may distinguish different portions of the package, it may further instruct processing unit to handle a particular portion of package.

[0102] According to an embodiment, proximity sensor described herein may perform a Power-Up Built-In-Test (PBIT) including verification of communication interfaces, VCO calibration, and receiver noise checks. Proximity sensor may also perform additional Transmit/Receive Built-In-Test (TRBIT) mode, which requires less than 2 ms to complete verification of transmitter and receiver status with a delay line test.

[0103] When proximity sensor operates as HOB sensor, it may be configured to track the fall rate of carrier platform and maintain a real-time height of carrier platform over the ground surface. Fuze trigger latencies due to finite driver rise time can be removed and the fuze trigger may be much less than one microsecond from HOB detection.

[0104] Other embodiments of the disclosure will be apparent to those skilled in the art from consideration of the specification and practice of the disclosure. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

WHAT IS CLAIMED IS:

1. A forward-looking proximity sensor, comprising:

one or more antenna elements mounted on a carrier platform in a lateral direction of said carrier platform, said antenna elements being configured to transmit a modulated signal in said direction of travel of said carrier platform, said antenna elements receiving a reflected portion of said modulated signal from a target; and

a processing unit configured to generate said modulated signal based on a baseband signal and a carrier signal, said processing unit further determining characteristics of said target based on said reflected portion of said modulated signal, said characteristics of said target indicating a range of said target and at least one feature of said target.

2. The forward-looking proximity sensor of claim 1, wherein the processing unit is further configured to form an image including a representation of the target based on the reflected portion of the modulated signal, the image including a first dimension representing ranges of objects within a field of view and a second dimension representing speeds of objects within the field of view.

3. The forward-looking proximity sensor of claim 2, wherein the processing unit is configured to determine the distance and the feature of the object based on the image.

4. The forward-looking proximity sensor of claim 2, wherein the processing unit is configured to select a first point of the image corresponding to a first feature of the target for tracking the target.

5. The forward-looking proximity sensor of claim 4, wherein the processing unit is configured to select a second point of the image corresponding to a second feature of the target for aiming a weapon at the target.

6. The forward-looking proximity sensor of claim 2, wherein the processing unit is configured to compare the distance of the target with a threshold distance and generate a command for adjusting an operation of the carrier platform when the distance of the target is less than the threshold distance.

7. The forward-looking proximity sensor of claim 2, wherein the processing unit is configured to identify, based on the image, the target among the objects within the field of view.

8. The forward-looking proximity sensor of claim 7, wherein the processing unit is configured to identify the target based on a plurality of set points defined in the image.

9. The forward-looking proximity sensor of claim 8, wherein the processing unit is configured to identify the target when the representation of the target matches the plurality of set points.

10. The forward-looking proximity sensor of claim 7, wherein at least one of the set points corresponds to a preset range and a speed of zero.

11. The forward-looking proximity sensor of claim 10, wherein the set region corresponds to a preset non-zero range and a preset non-zero speed.

12. The forward-looking proximity sensor of claim 1, wherein the antenna elements include a plurality of metal sheets conformed to a shape of the carrier platform and configured to form a two-way forward-looking beam pattern in the direction of traveling of the carrier platform.

13. The forward-looking proximity sensor of claim 1, wherein the target includes a ground surface and the range of the target indicates a height of the carrier platform above the ground surface.

14. The forward-looking proximity sensor of claim 1, wherein the target includes at least one of an airborne object, an automobile, a vessel, a pedestrian, or an object carried by a conveyer.

15. The forward-looking proximity sensor of claim 1, further comprising:

a voltage-controlled oscillator configured to generate the carrier signal having a frequency; and

a signal divider configured to separate a portion of the carrier signal,

wherein the processor is further configured to control the voltage-controlled oscillator according to the separated portion of the carrier signal and the voltage-controlled oscillator varies the frequency of the carrier signal within a set frequency range.

16. The forward looking proximity sensor of claim 1, wherein the characteristics of the target include an angle of arrival of the target with respect to the direction of travel of the carrier platform.

17. A method of detecting proximity of a target, comprising:

forming a modulated signal based on a baseband signal and a carrier signal;

transmitting the modulated signal through one or more antenna elements towards a target in a direction of travel of a carrier platform, said one or more antenna elements being mounted on said carrier platform in a lateral direction of said carrier platform;

receiving a reflected portion of said modulated signal from said target; and

determining characteristics of said target based on said portion of said reflected portion of said modulated signal, said characteristics of said target indicating a distance to said target and at least one feature of said target.

18. The method of claim 17, further comprising forming an image including a representation of the target, the image including a first dimension representing ranges of objects within a field of view and a second dimension representing speeds of the objects within the field of view.

19. The method of claim 18, further comprising:

defining a plurality of set points in the image;

determining that the representation of the target matches the set points; and

generating a command for adjusting operation of the carrier platform.

20. The method of claim 17, wherein the characteristics of the target include an angle of arrival of the target with respect to the direction of travel of the platform.

21. A system for detecting a target, comprising:

a carrier platform traveling in a direction; and

a forward-looking proximity sensor disposed on said carrier platform, said forward looking proximity sensor comprising:

one or more antenna elements mounted on said carrier platform in a lateral direction of said carrier platform and configured to transmit a modulated signal in said direction of travel of said carrier platform, said antennas elements receiving a reflected portion of said modulated signal from said target; and

a processing unit configured to generate said modulated signal based on a baseband signal and a carrier signal, the processing unit further determining characteristics of said target based on said reflected portion of said modulated signal, said characteristics of said target indicating a distance of said target and at least one feature of said target.

22. The system of claim 21, wherein the carrier platform is a projectile having a cylindrical body and the antenna elements include a plurality of metal sheets conformed to the cylindrical body of the carrier platform.

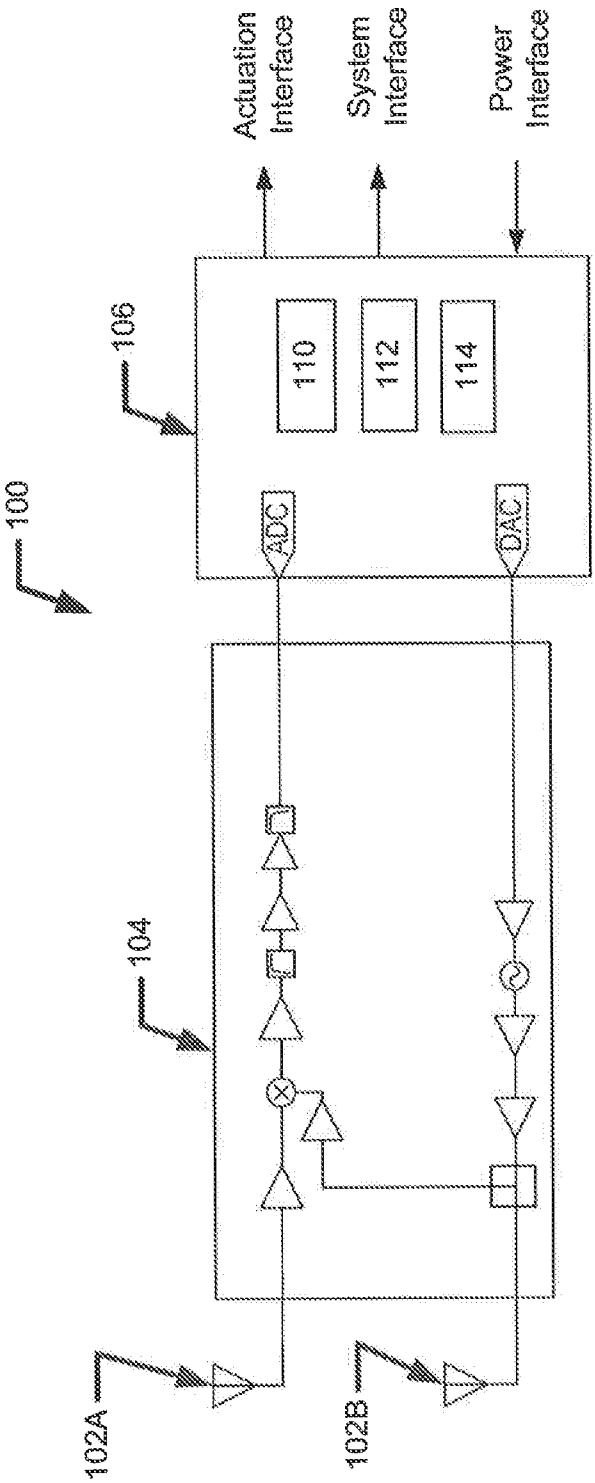

Actuation Interface
System Interface
Power Interface
106
110
112
114
100
ADC
DAC
104
102A
102B

FIG. 1

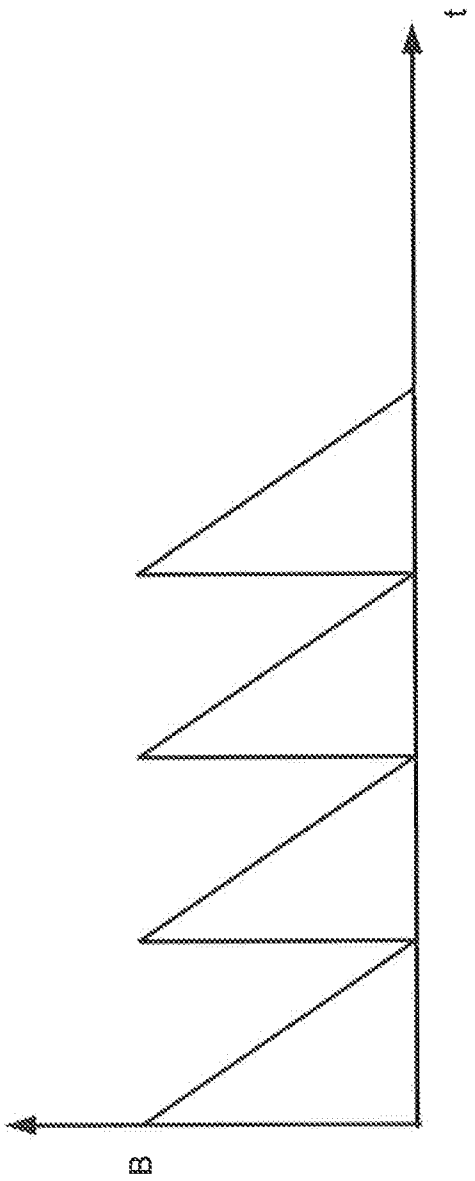


FIG. 2

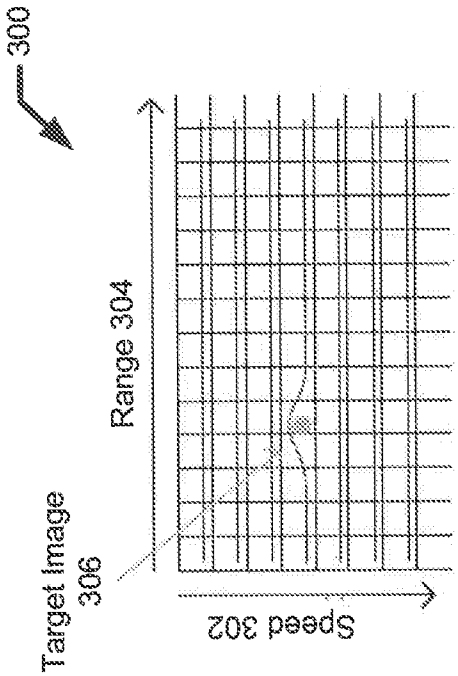


FIG. 3

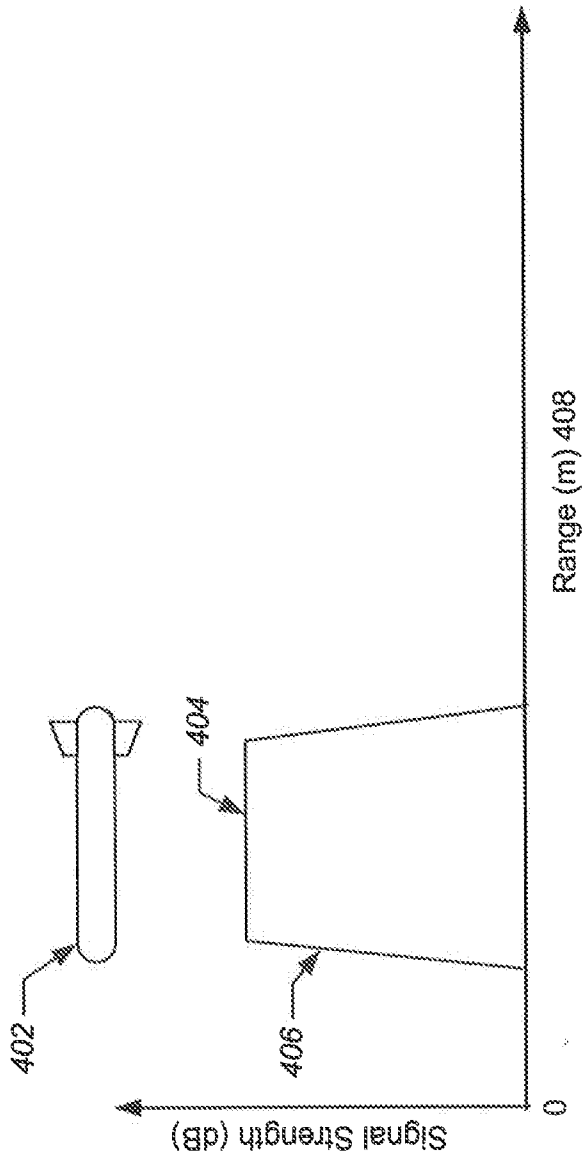


FIG. 4

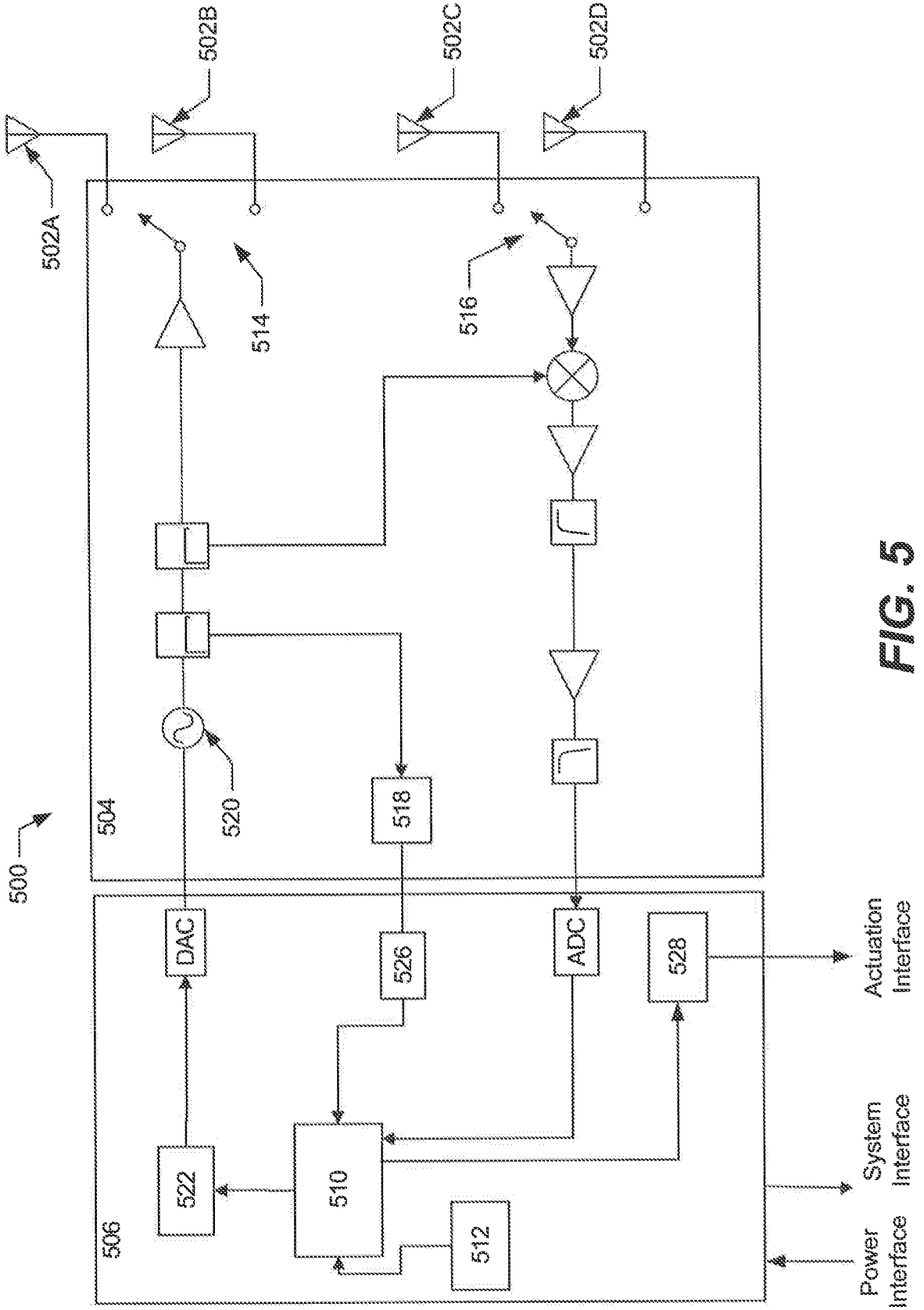

502A
502B
502C
502D
514
516
520
518
504
500
DAC
526
ADC
528
522
510
512
506
Actuation Interface
System Interface
Power Interface

FIG. 5

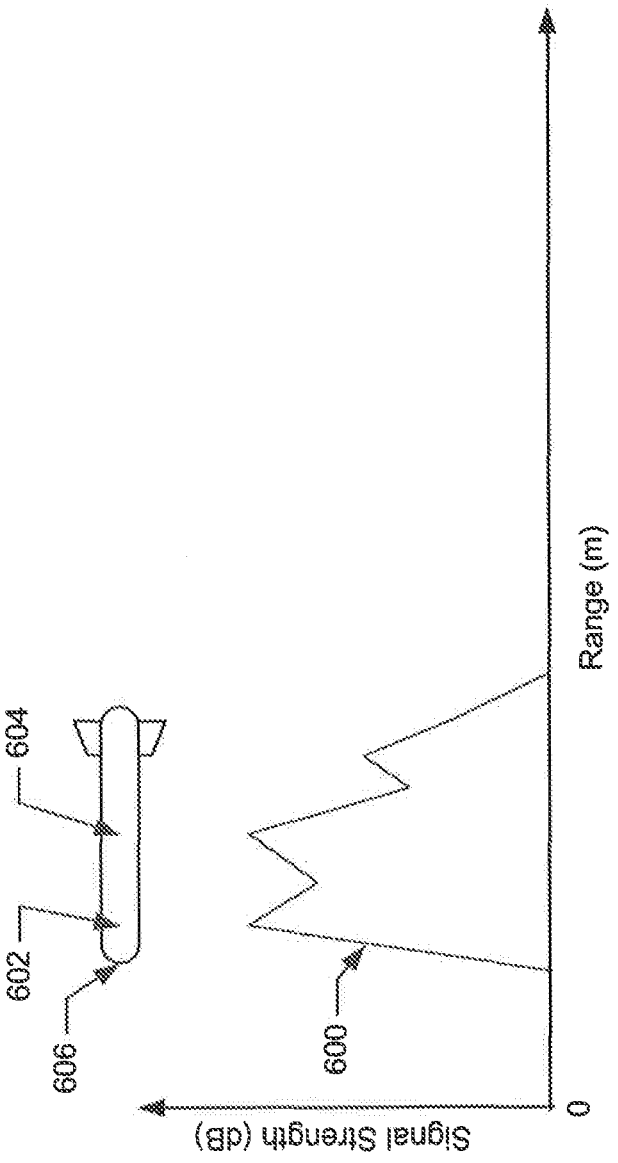


FIG. 6

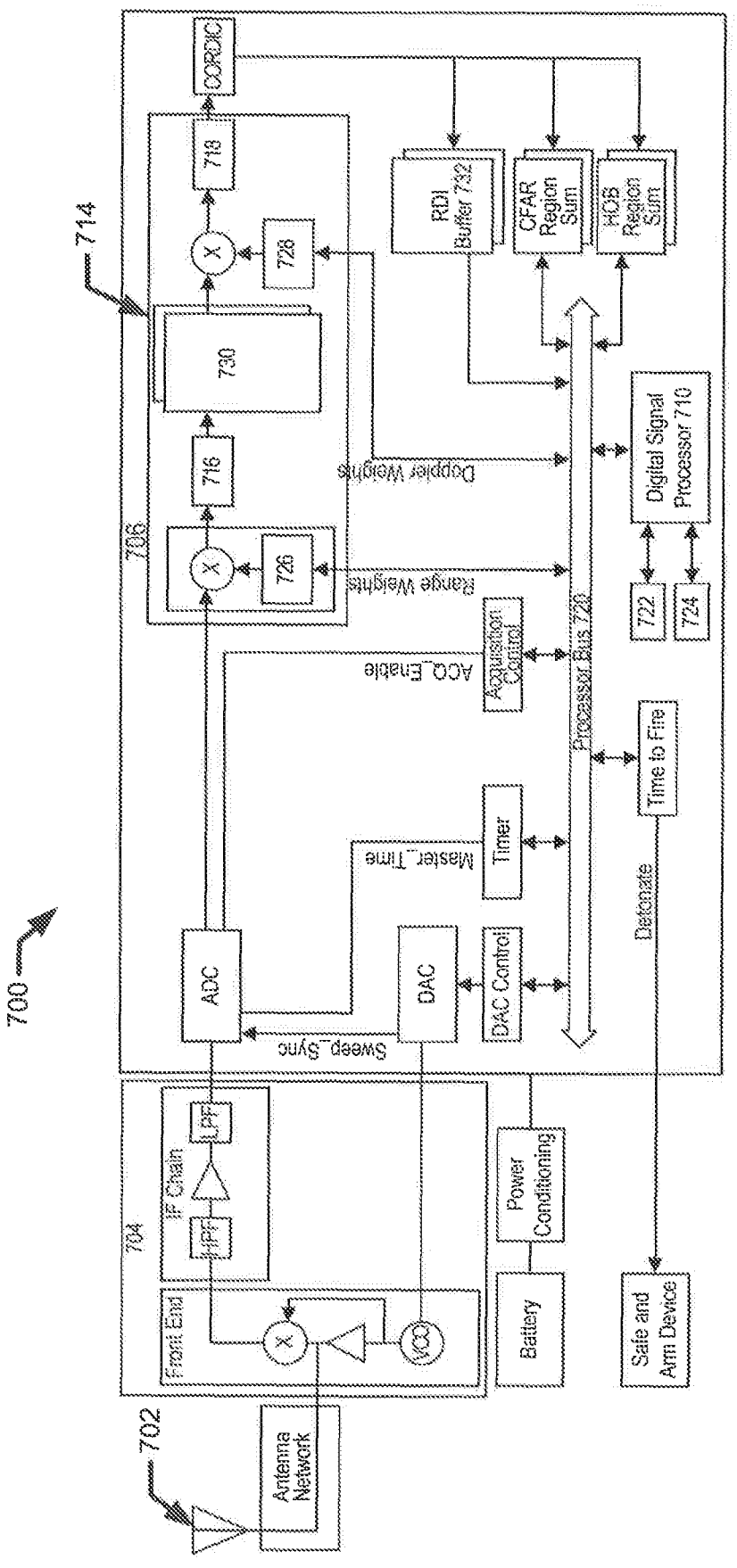

700
702
Antenna Network
704
Front End
IF Chain
PF
LPF
VCO
ADC
DAC
DAC Control
Timer
Master_Time
Sweep_Sync
Power Conditioning
Battery
Safe and Arm Device
Detonate
706
714
CORDIC
718
728
730
716
726
Doppler Weights
Range Weights
RDI Buffer 732
CFAR Region Sum
HOB Region Sum
Digital Signal Processor 710
722
724
Processor Bus 720
Acquisition Control
ACQ_Enable
Time to Fire

FIG. 7

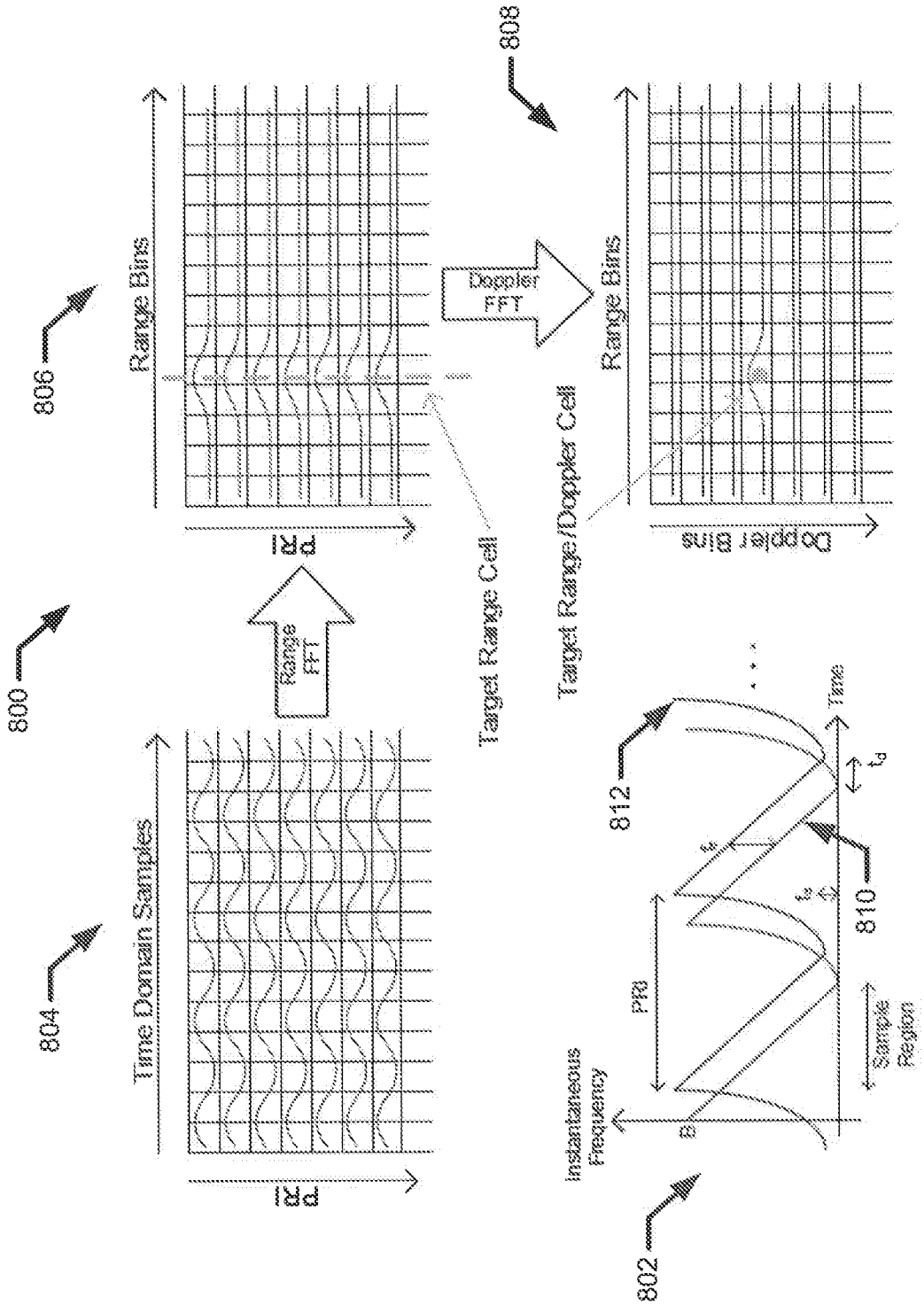

800
802
804
806
808
810
812
Time Domain Samples
PRI
Range FFT
Range Bins
Doppler FFT
Target Range Cell
Target Range/Doppler Cell
Doppler Bins
Instantaneous Frequency
PRI
Time
Sample Region

FIG. 8

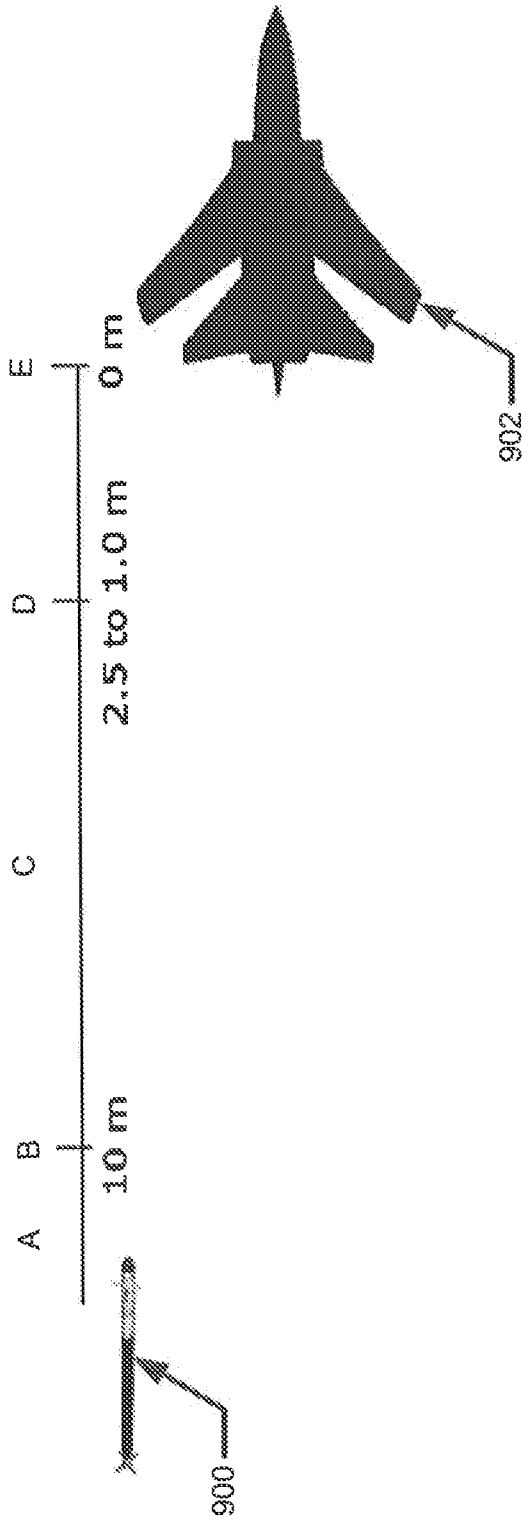


FIG. 9

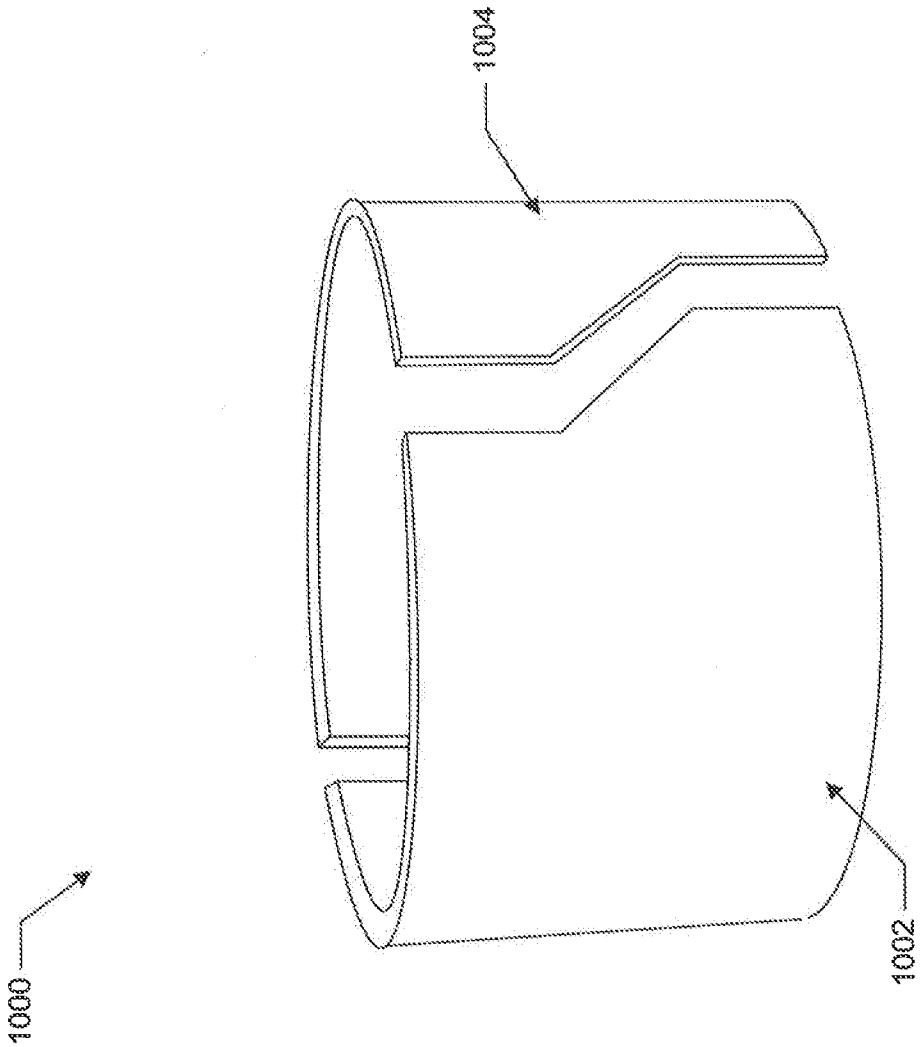


FIG. 10

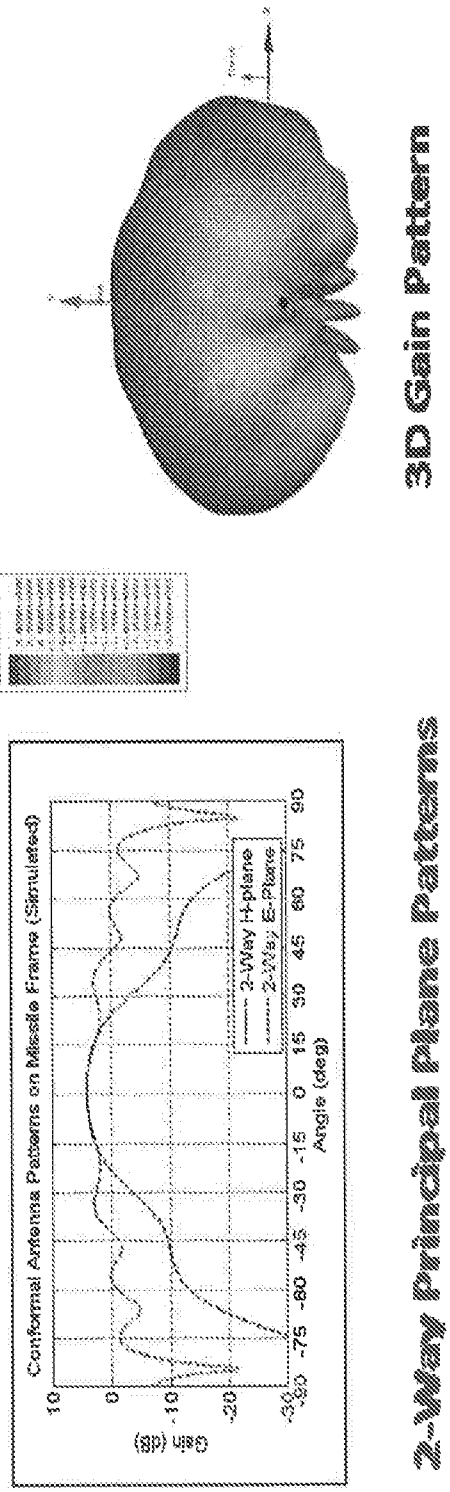

Conformal Antenna Patterns on Missile Frame (Simulated)
Gain (dB)
10
0
-10
-20
-30
-90 -75 -60 -45 -30 -15 0 15 30 45 60 75 90
Angle (deg)
2-Way H-Plane
2-Way E-Plane
2-Way Principal Plane Patterns
3D Gain Pattern

FIG. 11

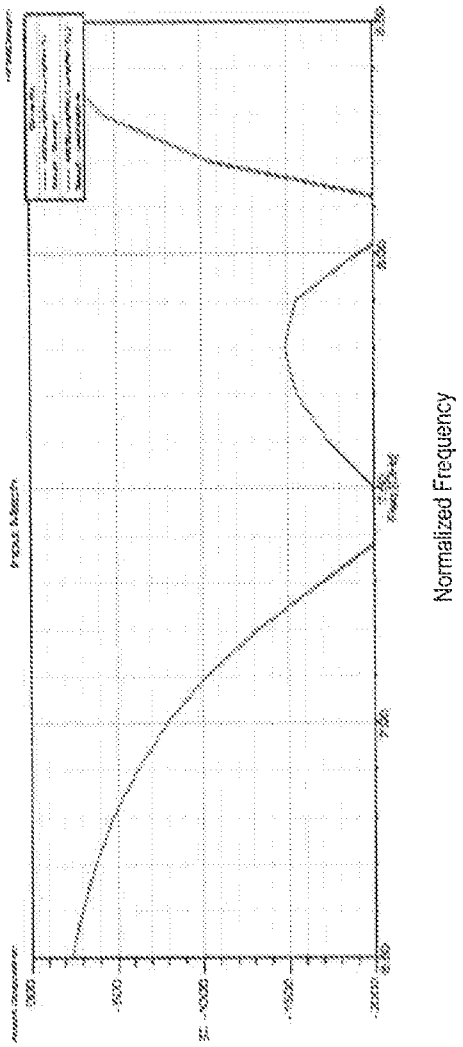


FIG. 12

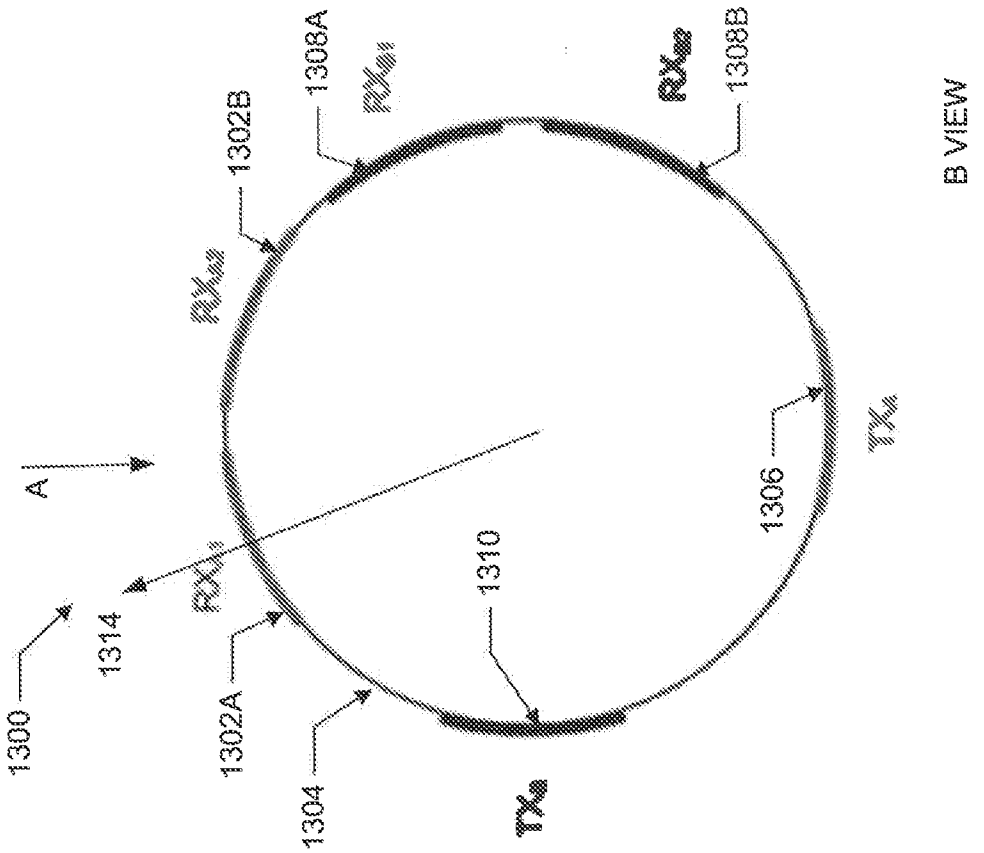


FIG. 13B

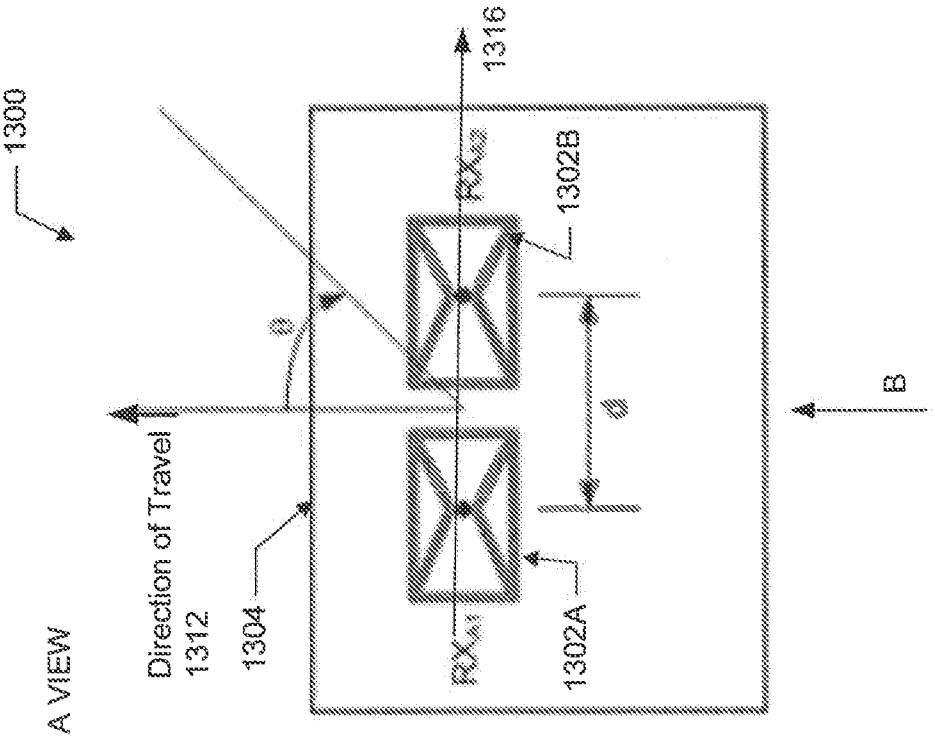


FIG. 13A

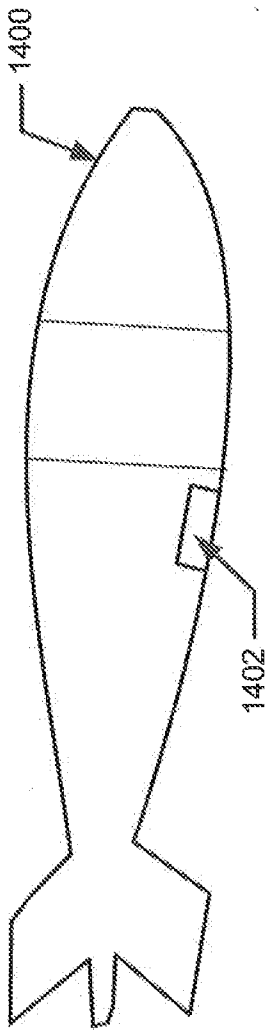


FIG. 14

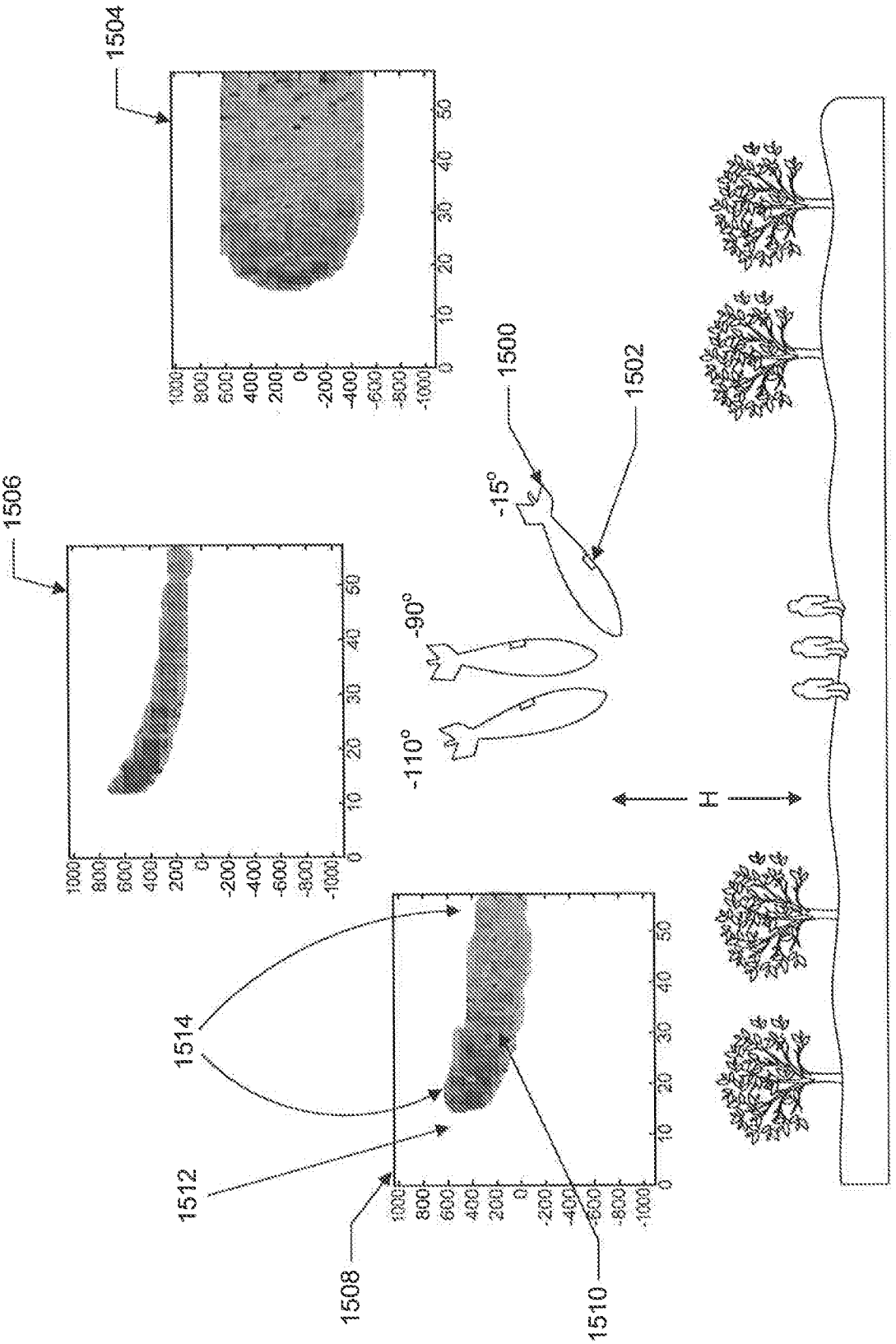


FIG. 15

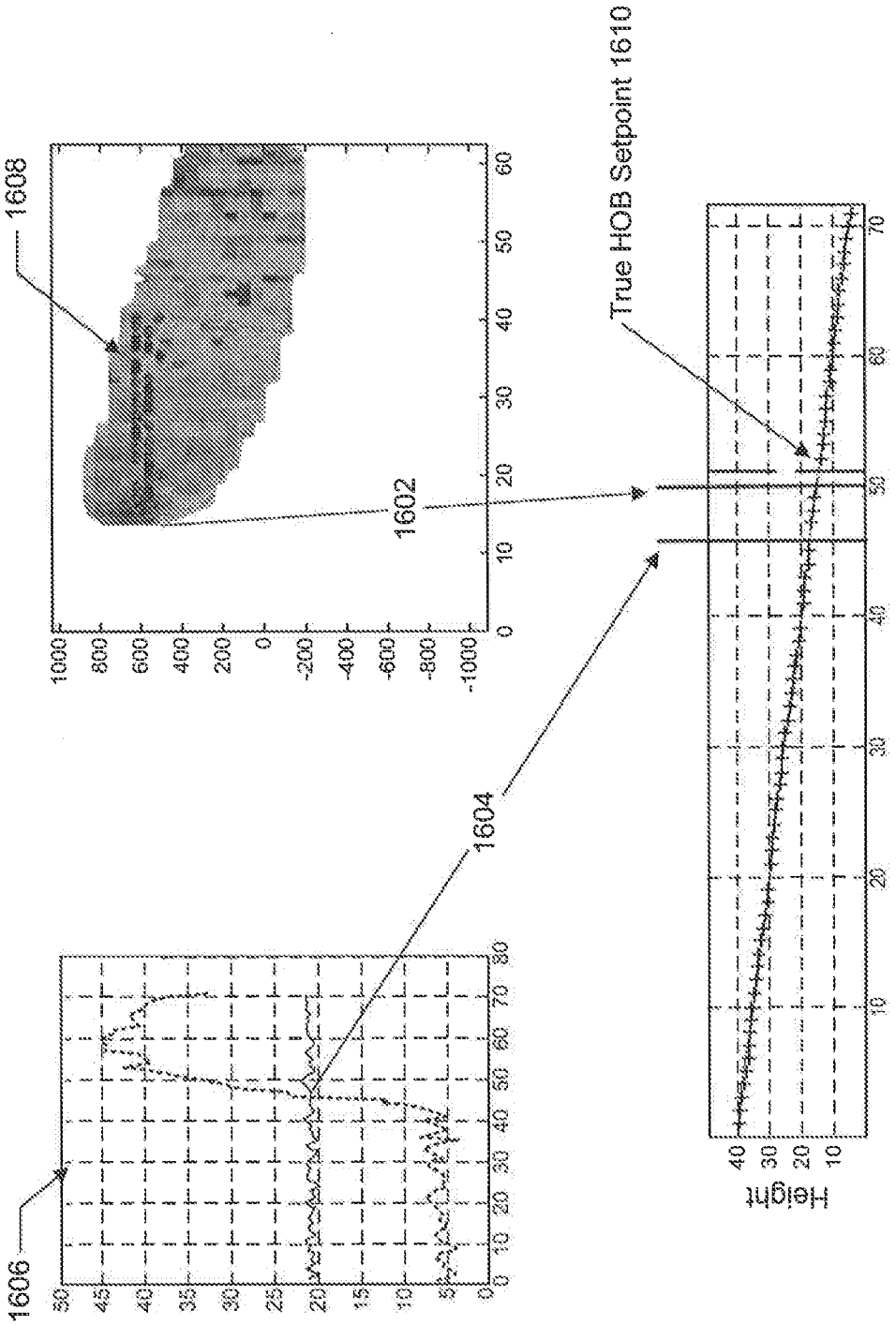


FIG. 16

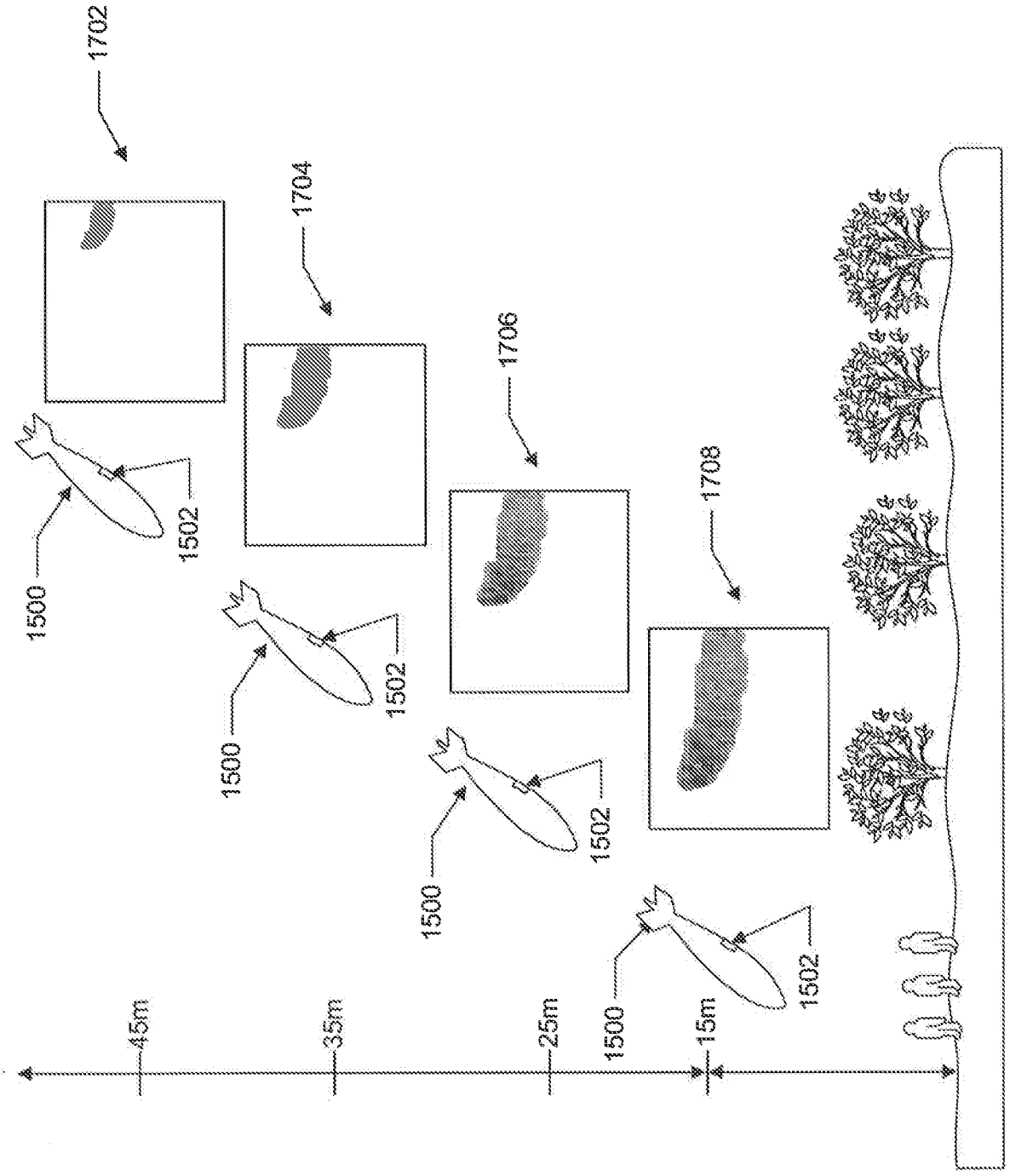


FIG. 17