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(54) **CLOSED-LOOP INFRARED COUNTERMEASURE SYSTEM USING HIGH FRAME RATE INFRARED RECEIVER**

(75) Inventors: **Danny E. Brown**, Mogadore; **Allen T. Hicks**, Uniontown; **Daniel E. Laird**, Peninsula; **Timothy E. Macklin**, Newton Falls, all of OH (US)

(73) Assignee: **Lockheed Martin Corporation**, Akron, OH (US)

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(52) **U.S. Cl.** .............................. **356/139.04**; 250/203.6; 250/526; 244/3.16; 348/169; 359/111

(58) **Field of Search** ....................... 356/139.01–139.08; 348/169–172; 250/203.6, 526; 249/3.16; 359/111

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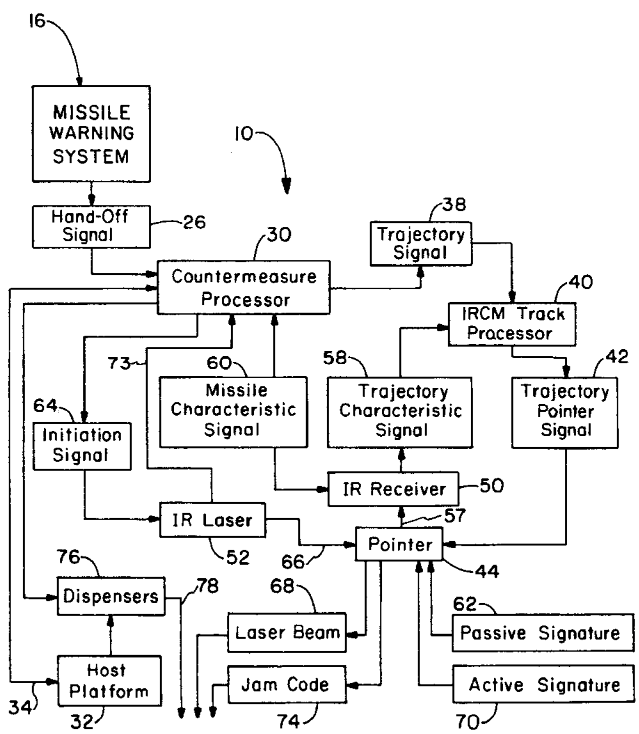
*Primary Examiner*—Stephen C. Buczinski
(74) *Attorney, Agent, or Firm*—Renner, Kenner, Greive, Bobak, Taylor & Weber

(57) **ABSTRACT**

A missile tracking and deflection system for protecting a platform includes a missile warning system for detecting the presence of a missile and generating a warning signal. A countermeasure processor receives the warning signal and analyzes characteristics of the missile to prioritize a trajectory signal. A track processor receives the trajectory signal and generates a pointer signal. The system also includes a receiver, which is positioned by a pointer that receives the pointer signal, for receiving a passive and/or active signature of the missile to confirm the presence thereof. The countermeasure processor then directs a laser beam at the missile to determine its operational parameters and receives an active signature from the missile. The receiver delivers the passive and/or active signatures to the countermeasure processor and the track processor, wherein the track processor updates the pointer signal and the countermeasure processor generates a jam code delivered by the laser beam to divert the trajectory of the missile away from the platform.

**15 Claims, 3 Drawing Sheets**



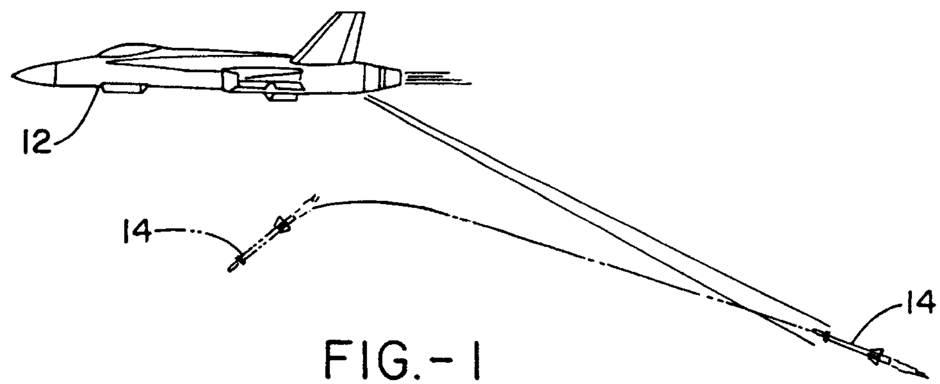

12
14
14

FIG.-1

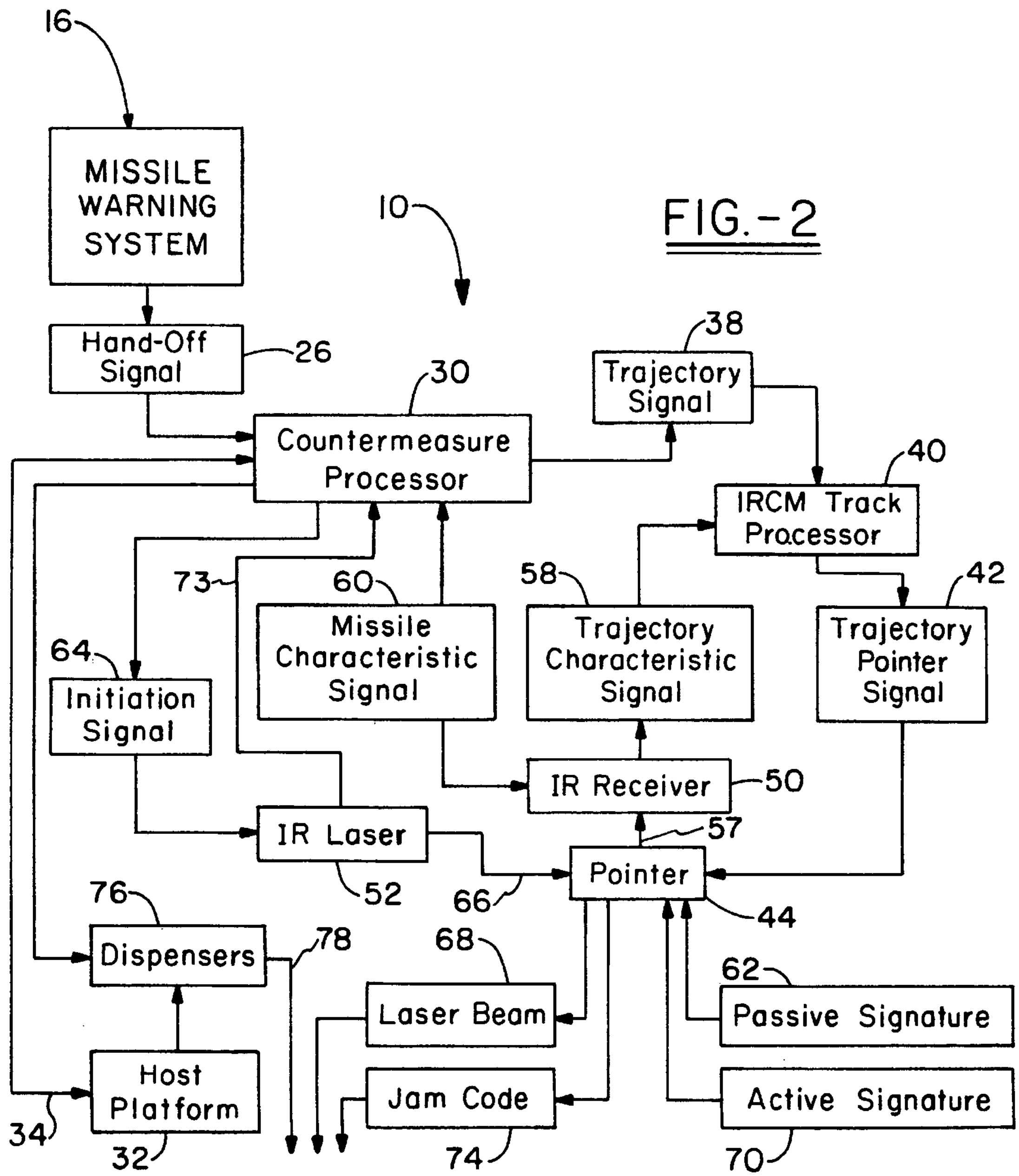

16
MISSILE WARNING SYSTEM
10
Hand-Off Signal
26
30
Countermeasure Processor
38
Trajectory Signal
40
IRCM Track Processor
73
60
Missile Characteristic Signal
58
Trajectory Characteristic Signal
42
Trajectory Pointer Signal
64
Initiation Signal
IR Receiver
50
57
IR Laser
52
66
Pointer
44
76
Dispensers
78
68
Laser Beam
62
Passive Signature
Host Platform
34
32
Jam Code
74
Active Signature
70

FIG.-2

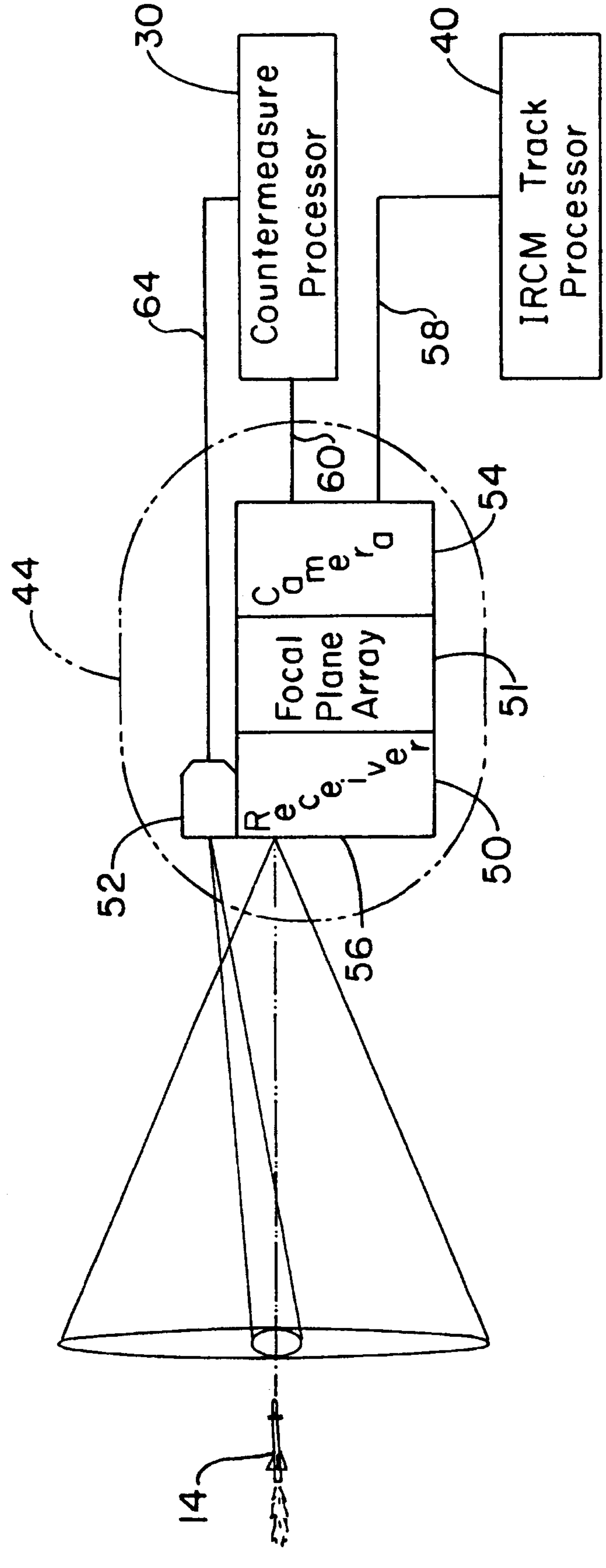

30
Countermeasure Processor
40
IRCM Track Processor
64
58
60
54
44
Camera
Focal Plane Array
Receiver
51
52
50
56
14

FIG.-3

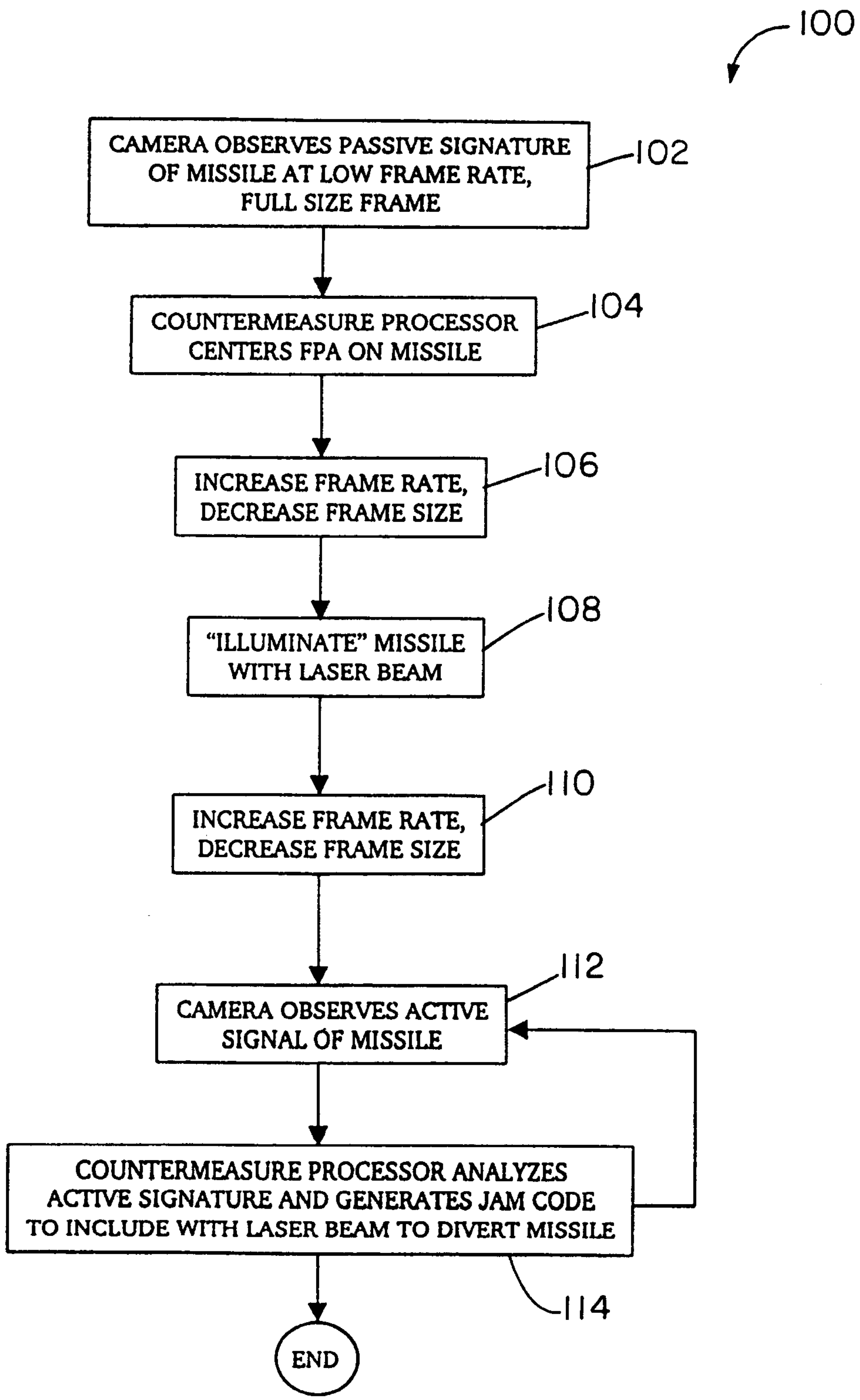

100
CAMERA OBSERVES PASSIVE SIGNATURE OF MISSILE AT LOW FRAME RATE, FULL SIZE FRAME
102
COUNTERMEASURE PROCESSOR CENTERS FPA ON MISSILE
104
INCREASE FRAME RATE, DECREASE FRAME SIZE
106
"ILLUMINATE" MISSILE WITH LASER BEAM
108
INCREASE FRAME RATE, DECREASE FRAME SIZE
110
CAMERA OBSERVES ACTIVE SIGNAL OF MISSILE
112
COUNTERMEASURE PROCESSOR ANALYZES ACTIVE SIGNATURE AND GENERATES JAM CODE TO INCLUDE WITH LASER BEAM TO DIVERT MISSILE
114
END

FIG.-4

# CLOSED-LOOP INFRARED COUNTERMEASURE SYSTEM USING HIGH FRAME RATE INFRARED RECEIVER

## TECHNICAL FIELD

The present invention herein resides in the art of defense systems for diverting the trajectory of incoming missiles. More particularly, the present invention relates to a system which provides simultaneous tracking and identification/classification functions with an infrared receiver having a focal plane array. Specifically, the present invention relates to a system which provides variable imaging rates to detect, jam and divert an incoming infrared missile.

## BACKGROUND ART

To protect and defend military platforms, such as ships, aircraft, and ground-based installations, it is known to provide countermeasure systems that detect incoming threats such as enemy aircraft or missiles. Known systems detect incoming threats, such as infrared missiles, and then deploy defensive countermeasures in an attempt to destroy or divert the threat. These systems are referred to as open-loop systems since no immediate determination as to the type of threat or effectiveness of the countermeasure is readily available. Due to the inefficiency of the open-loop systems, closed-loop systems have been developed.

There are known performance benefits to using a directional, laser-based, closed-loop infrared countermeasure system to defeat infrared missiles. In a closed-loop system, the incoming missile is identified and the countermeasure system generates or tunes a jam code according to the specific incoming missile. The optimized jam code is directed at the missile which executes a maximum turn-away from its intended target. An additional feature of closed-loop techniques is the ability to monitor the classification and identification process during the jamming sequence. This provides a direct observation of the countermeasure effectiveness as well as an indication of the necessary corrective action required for the jam code. It will be appreciated that the benefits of the closed-loop performance system must be balanced against the cost of upgrading existing infrared directional countermeasure systems with a closed-loop capability, or against the cost of developing an entirely new closed-loop system.

One possible configuration for introducing a closed-loop receiver into a directional countermeasure system is to use a high resolution tracking sensor side-by-side with an infrared detector assembly. Accordingly, an independent receive channel, which is a separate optical path, must be added to the detection system with a separate expensive cooled detector. The cost and size impact of such a configuration to the countermeasure system is prohibitive.

Another approach is to incorporate an infrared detector assembly into the countermeasure system and split a portion of the received optical path for the high resolution tracking sensor. Unfortunately, this approach causes at least a 50% receive loss for both the track sensor and the receiver, plus the cost for adding another cryogenically cooled detector. Another problem with this approach is that the apertures of the sensor and the receiver may not match which would require a larger overall assembly to accommodate both.

Based upon the foregoing, it is apparent that there is a need in the art for a single imaging infrared receiver having a focal plane array capable of sufficient frame rates to provide sensor data for three primary closed-loop countermeasure functions. The receiver must have a passive high resolution tracking capability, it must be able to receive and process laser signals, and finally, the receiver must be able to perform countermeasure effectiveness measurements.



## DISCLOSURE OF INVENTION

In light of the foregoing, it is a first aspect of the present invention to provide a closed-loop infrared countermeasure system using a high frame rate infrared receiver.

Another aspect of the present invention is to provide a countermeasure system with a missile warning system that detects the presence of an object that may be considered a threat to a platform upon which the system is associated.

Yet another aspect of the present invention, as set forth above, is to provide a countermeasure processor, in communication with the warning system, which coordinates all of the functions and processing of the closed-loop system.

Yet another aspect of the present invention, as set forth above, is to provide a track processor which receives a trajectory signal representative of the missile path from the countermeasure processor based upon the communication received from the warning system to generate a trajectory pointer signal.

Yet a further aspect of the present invention, as set forth above, is to provide a pointer which positions itself based upon signals received from the countermeasure processor and the track processor.

Still a further aspect of the present invention, as set forth above, is to provide an infrared receiver positioned by the pointer, wherein the infrared receiver has an infrared focal plane array that functions simultaneously as a laser receiver and a high resolution track sensor or camera.

Still a further aspect of the present invention, as set forth above, is to provide a laser carried by the pointer, which is bore-sighted with the infrared receiver, which receives instructional signals and commands from the countermeasure processor, wherein a laser beam generated by the laser is initially directed toward the incoming missile threat and obtains operational characteristics therefrom which are received by the infrared receiver, which in turn are transmitted to the countermeasure processor which generates a jam code that is included with the laser beam impinging upon the incoming missile.

Still an additional aspect of the present invention, as set forth above, is to instruct the focal plane array to initiate variable imaging rates, in particular, a first imaging rate is employed to initially acquire and track the incoming threat, a faster second imaging rate is employed to provide a high resolution tracking of the incoming threat and an even faster third imaging rate is employed to obtain operational characteristics of the incoming missile.

The foregoing and other aspects of the present invention, which shall become apparent as the detailed description proceeds, are achieved by a missile tracking and deflection system for protecting a platform, comprising a missile warning system for detecting the presence of a missile and generating a warning signal, a countermeasure processor for receiving the warning signal and generating a warning report, a track processor for receiving the warning report and generating a pointer trajectory signal, a pointer for receiving the pointer trajectory signal to position the pointer toward the missile, a receiver carried by the pointer to receive a passive signature of the missile and generate a trajectory characteristic signal received by the track processor for updating the pointer trajectory signal, and a laser carried by the pointer which directs a laser beam at the missile to generate an active signature received by the receiver which generates a missile characteristic signal received by the countermeasure processor to identify the missile and generate a jam code carried by the laser beam to divert the trajectory of the missile away from the platform, the receiver observing the passive and active signatures, and generating the trajectory characteristic signal and the missile characteristic signal simultaneously.

Other aspects of the present invention are attained by a method for diverting the trajectory of a missile, comprising the steps of detecting the presence of a missile and generating a warning signal, analyzing characteristics of the warning signal with a countermeasure processor which generates a trajectory signal, processing the trajectory signal to generate a trajectory pointer signal, receiving the pointer signal in a receiver which has a single focal plane array that tracks the trajectory of the missile and detects operational characteristics of the missile, the receiver delivering a signal to the countermeasure processor which generates a jam code employed to divert the trajectory of the missile.

Still other aspects of the present invention are attained by an object tracking system comprising a receiver for observing the object, the receiver having a focal plane array for obtaining information about the object, and a processor in communication with the receiver, the processor imaging the focal plane array over at least two frame rates, wherein a first frame rate images a large portion of the focal plane array to observe the object, and a second frame rate, faster than the first frame rate, images a smaller portion of the focal plane array to track the object.

## BRIEF DESCRIPTION OF THE DRAWINGS

For a complete understanding of the objects, techniques, and structure of the invention, reference should be made to the following detailed description and accompanying drawings, wherein:

FIG. **1** is a schematic representation of a platform and an incoming missile threat;

FIG. **2** is a schematic diagram of a closed-loop infrared countermeasure system according to the present invention;

FIG. **3** is a schematic representation of an infrared receiver tracking and delivering a jam code to an incoming missile; and

FIG. **4** is a flow chart showing operation of the infrared countermeasure system.

## BEST MODE FOR CARRYING OUT THE INVENTION

Referring now to the drawings, and in particular, to FIGS. **1** and **2**, it can be seen that a closed-loop infrared countermeasure system, according to the present invention, is designated generally by the numeral **10**. It will be appreciated that the system **10** is incorporated into a platform **12** such as a plane, ship, or ground-based installation. The system **10** is employed to detect the presence of an in-bound infrared missile **14**, determine the operating characteristics of the missile, and then divert the trajectory of the missile so that it turns away from the platform **12**. The system **10** may also be employed to track any moving object by observing any time varying frequency components thereof. Although an infrared-based system is disclosed, it will be appreciated that the aspects of the present invention are applicable to other frequency-observable phenomena.

As seen in FIG. **2**, the system **10** includes a missile warning system **16** which may be carried by the platform **12**. The missile warning system **16** detects the presence of an object, which could be an incoming threat, by either an infrared camera, an ultraviolet camera, by sight, by radar, or any other device which can generate information about the possible location and trajectory of the object. The missile warning system **16** acquires passive information about the object and determines if the object is in fact a missile. Accordingly, the missile warning system **16** generates a hand-off signal **26** which is received by the system **10**. It will be appreciated that the missile warning system **16** is a low resolution system that looks at high spatial coverage areas for the primary purpose of detecting the presence of any type of threat, such as a missile or enemy aircraft. The hand-off signal **26** includes information such as amplitude, how long the threat has been tracked, speed, intensity, and angle range from the platform **12**.

A countermeasure processor **30**, which provides the necessary software, hardware, and memory for controlling and coordinating the various aspects of the system **10**, receives the hand-off signal **26**. The countermeasure processor **30** prioritizes the threat according to the information acquired and predetermined criteria. The countermeasure processor **30** is in communication with a host platform **32** via host signal **34** for the purpose of communicating with the command structure controlling operation of the platform **12**. Initially, the countermeasure processor **30** generates a trajectory signal **38** received by an infrared countermeasure track processor **40**. Accordingly, the track processor **40** initiates a tracking sequence for the potential in-bound missile **14** indicated by the hand-off signal **26**. In particular, the track processor **40** generates a trajectory pointer signal **42** which provides mechanical control functions to position selected components of the system **10** in the appropriate direction.

A pointer **44**, as seen in FIGS. **2** and **3**, receives the pointer signal **42** and slews the components thereof to observe the angle and position of the in-bound missile **14**. The pointer **44** positions an infrared receiver **50** and an infrared laser **52** which are bore sighted.

The infrared receiver **50** is a high frame rate, infrared focal plane array which integrally and simultaneously combines the functions of a high resolution track sensor or a camera **54** and a laser receiver **56**. In the preferred embodiment, the receiver **50** has an aperture of about 35–50 mm, although other aperture sizes could be used. The pointer **44** provides an optical path **57** for the infrared receiver **50**. The infrared receiver **50** generates a trajectory characteristic signal **58** that is received by the track processor **40** for updating the trajectory pointer signal **42**.

The infrared receiver **50** provides a single focal plane array generally designated by the numeral **51** as best seen in FIG. **3** to function both as a passive viewing device and an active viewing device. The receiver **50** has a relatively large field of view, wherein the focal plane array **51** provides a full frame, 512×512 pixel display that generates an optical image that is converted into an electrical signal. Of course, other size focal plane arrays may be used. The receiver **50** functions as the tracking camera **54** by employing the focal plane array **51** to passively observe the trajectory of the missile. Since the receiver **50** employs a single focal plane array, the function of the camera **54** is inherently boresighted with the function of the laser receiver **56**. Accordingly, both the receiver **56** and the camera **54** functionally observe substantially the same scene. As will be discussed hereinbelow, the laser receiver **56** functions to employ relatively smaller portions of the focal plane array to actively observe the trajectory of the missile. The infrared receiver **50** communicates with the countermeasure processor **30** via a missile characteristic signal **60**.

Referring now to FIG. **4**, an operational flow of the countermeasure processor system is designated generally by the numeral **100**. After the pointer **44** slews itself toward the missile **14**, the tracking camera **54**, at step **102**, observes a passive signature **62**, typically thermal emissions generated by the missile. Other possible passive signatures that may be viewed with a similar camera are light frequencies in the visible or near visible spectrum including ultraviolet light, or acoustic signals. At step **102**, a relatively low frame rate, up to about 120 frames per second and preferably about 60 frames per second, is used by the track camera **54** to communicate information obtained from the passive signature **62** to the track processor **40** via the trajectory characteristic signal line **58**. Accordingly, at step **104**, the countermeasure processor **30** instructs the track processor **40** to position the pointer **44** so that the missile **14** is centered in the focal plane array **51** of the receiver **50**. At step **106**, the countermeasure processor **30** instructs the track processor **40** to increase the imaging rate to a frame rate of the focal plane array of the receiver **50** to between about 120 to about 1000 frames per second and preferably about 400 frames per second. When this is done, the observation area of the focal plane array is reduced to a mid-size frame smaller than full frame or preferably to about 32×32 pixels centered about the missile **14** as it appears on the focal plane array **51**.

At step **108**, the countermeasure processor **30** generates an initiation signal **64** which instructs the infrared laser **52** to "illuminate" the missile **14**. Upon receipt of the initiation signal **64**, a laser beam **68** is generated by the laser **52** and directed at the missile **14**. Accordingly, as the laser beam **68** impinges upon the missile **14**, an active signature **70** is reflected and received by the laser receiver **56** aspect of the receiver **50**. The countermeasure processor **30** then instructs the receiver **50**, at step **110**, to employ a frame rate of up to 50,000 frames per second and preferably about 32,000 frames per second over an even smaller sub-array frame size **90** of about 16×16 pixels. In other words, the ultra-fast imaging rate may be applied to a pixel array of 1×1 up to an array size employed for the prior imaging rate. It will be appreciated that these imaging rates are only limited by the operational characteristics of the receiver **50**. The image of the active signature **70** is processed at step **112**, in the manner described above to maintain the high resolution track on the missile **14**. Those skilled in the art will appreciate that the laser receiver **56** employs pixel detectors, such as photo diodes, which are digitally sampled and processed by the countermeasure processor **30** via the optical path **57** and the missile characteristic signal **60**. The processor **30** in turn performs a Fourier analysis of the amplitude modulation or time varying characteristics of the incoming signals **62**, **70** via the optical path **57** and/or the signal **60** to determine operational characteristics of the missile **14**. The processor **30** monitors the performance of the laser **52** via a signal line **73**.

Once the active signature **70** is returned from the missile **14**, the infrared receiver **50** simultaneously generates corresponding updated signals for the trajectory characteristic signal **58**, which in turn updates the pointer trajectory signal **42**, and the missile characteristic signal line **60**. At this time, the countermeasure processor **30** analyzes the components of the active signature **70** and generates a jam code **74**, at step **114**, for inclusion with the laser beam **68**. Accordingly, the missile **14** is diverted from the actual platform and eventually self-destructs, as the jam code **74** is included with the laser beam **68**. A countermeasure effectiveness measurement is performed by the countermeasure processor **30** by simultaneously examining dynamic track and classification and identification information provided by the trajectory characteristic signal **58** and the signature **70**. As such, if the jam code **74** is found to be ineffective, the countermeasure processor **30** can immediately make adjustments thereto.

If desired, the system **10** may also provide dispensers **76** which eject infrared expendable devices **78** that may also be used to divert the trajectory and/or path of the incoming missile **14**. The dispensers **76** are in communication with the host platform **32** so that it may be monitored thereby.

Based upon the foregoing structure and method of the use presented above, the system **10** effectively analyzes a trajectory of an incoming missile and its operational characteristics and generates a jam code to divert the trajectory of the missile away from the platform. Previous approaches to closed-loop laser infrared countermeasure required the use of a separate laser receiver to collect interrogation signals from an infrared missile and a separate infrared focal plane array camera for high resolution tracking of the threat. The separate laser interrogation receiver has significant negative system impacts on the cost, size, weight, power efficiency, performance, reliability, and maintainability. By employing the present invention, wherein the laser receiver function and the high resolution tracking function are incorporated into a single, infrared focal plane array, these system impacts are eliminated or greatly reduced. Still yet another advantage of the present invention is that current open-loop systems may be converted to closed-loop systems with substantially improved performance in defending from missile attacks. Moreover, the present invention avoids adding additional operating equipment which would require the splitting of signals and reducing the strength thereof to the detriment of the host platform **32**. Another advantage of the present invention is that the same signal may be processed with a relatively smaller aperture than may be otherwise provided.

Thus, it can be seen that the objects of the invention have been satisfied by the structure and use of the invention as presented above. While in accordance with the patent statutes, only the best mode and preferred embodiment of the invention has been presented and described in detail, it is to be understood that the invention is not limited thereto or thereby. Accordingly, for an appreciation of the true scope and breadth of the invention, reference should be made to the following claims.

What is claimed is:

1. A missile tracking and deflection system for protecting a platform, comprising:

a missile warning system for detecting the presence of a missile and generating a warning hand-off signal;

a countermeasure processor for receiving said warning hand-off signal and generating a trajectory signal;

a track processor for receiving said trajectory signal and generating a pointer trajectory signal;

a pointer for receiving said pointer trajectory signal to position said pointer toward the missile;

a laser positioned by said pointer, said laser emitting a laser beam at the missile to generate an active signature; and

an infrared receiver comprising an infrared focal plane array that integrally and simultaneously combines a tracking camera and a laser receiver, said infrared receiver positioned by said pointer, said camera receiving a passive signature of the missile and generating a trajectory characteristic signal received by said track processor for updating said pointer trajectory signal, said laser receiver receiving said active signature and generating a missile characteristic signal received by said countermeasure processor to identify the missile and generate a jam code carried by said laser beam to divert the trajectory of the missile away from the platform.

2. The system according to claim 1, wherein said focal plane array operates at least at a first and a second frame rate, said tracking camera operating at a first frame rate for tracking the missile over a large portion of said focal plane array to generate said trajectory characteristic signal which is received by said track processor for updating said trajectory pointer signal, said laser receiver operating at a second frame rate for observing the missile over a smaller portion of said focal plane array to receive said active signature.

3. The system according to claim 2, wherein said infrared receiver is bore-sighted with said laser, said laser receiving an initiation signal from said countermeasure processor to generate said laser beam, the missile returning said active signature to said laser receiver which receives said active signature and monitors the trajectory of the missile.

4. The system according to claim 3, wherein said focal plane array operates at a third frame rate over a mid-sized portion thereof, between said large portion and said small portion, said third frame rate establishing a high resolution tracking of the missile via said trajectory characteristic signal, wherein said countermeasure processor simultaneously monitors said trajectory characteristic signal and said active signature, and if needed, updates said jam code.

5. The system according to claim 4, wherein said first frame rate is about no greater than 120 frames per second.

6. The system according to claim 4, wherein said third frame rate is between about 120 to about 1000 frames per second and said mid-sized portion of said focal plane array is sized to be about 32×32 pixels.

7. The system according to claim 4, wherein said second frame rate is greater than about 1000 frames per second and said small portion of said focal plane array is sized to be about 16×16 pixels.

8. A method for diverting the trajectory of a missile, comprising the steps of:

detecting the presence of a missile and generating a warning hand-off signal;

analyzing characteristics of said warning handoff signal with a countermeasure processor which generates a trajectory signal;

processing said trajectory signal to generate a trajectory pointer signal;

receiving said pointer signal in a pointer that follows the missile trajectory, said pointer positioning a laser and an infrared receiver which has a single focal plane array that integrally and simultaneously combines the functions of a tracking camera and a laser receiver;

directing said laser to generate a laser beam toward the missile so as to generate an active signature;

observing said active signature with said laser receiver and observing a passive signature of the missile with said tracking camera to track the trajectory of the missile, said laser receiver observing said active signature to detect the operational characteristics of the missile, said infrared receiver delivering a signal to said countermeasure processor which generates a jam code employed to divert the trajectory of the missile.



9. The method according to claim 8, further comprising the steps of:

generating a missile characteristic signal by said laser receiver based upon said active signature; and

receiving said missile characteristic signal in said countermeasure processor which in turn generates said jam code for inclusion with said laser beam.

10. The method according to claim 8, further comprising the steps of:

generating a trajectory characteristic signal by said infrared receiver based upon said active signature or said passive signature; and

receiving said trajectory characteristic signal in a track processor which updates said trajectory signal.

11. The method according to claim 8, further comprising the step of: imaging said focal plane array at a rate of about no greater than 120 frames per second when initially receiving said pointer signal.

12. The method according to claim 8, further comprising the step of:

imaging said focal plane array at a rate between about 120 to about 1000 frames per second to establish a high resolution track on the missile.

13. The method according to claim 8, further comprising the step of:

imaging said focal plane array at a rate greater than about 1000 frames per second when said laser beam illuminates the missile and whereupon said jam code is included with said laser beam.

14. The method according to claim 8, further comprising the step of:

dispensing expendable countermeasure devices at the missile as instructed by said countermeasure processor.

15. An object tracking system comprising:

an infrared receiver for observing the object, said infrared receiver having a focal plane array for obtaining information about the object, said focal plane array integrally and simultaneously combining a tracking camera and a laser receiver;

a processor in communication with said infrared receiver, said processor controlling said focal plane array over at least two frame rates, wherein said tracking camera images a large portion of said focal plane array to passively observe the object at a first frame rate, and wherein said tracking camera images a smaller portion of said focal plane array to track the object at a second frame rate, faster than said first frame rate; and

a laser bore sighted with said infrared receiver and in communication with said processor, said processor activating said laser to direct a laser beam toward the object, whereupon said processor initiates a third frame rate, faster than said second frame rate, and said laser receiver monitors a returned laser beam signal from the object, wherein said processor receives said returned laser beam signal and images an even smaller portion of said focal plane array at an even faster third frame rate to observe the effect of said laser beam on the object.

* * * * *