

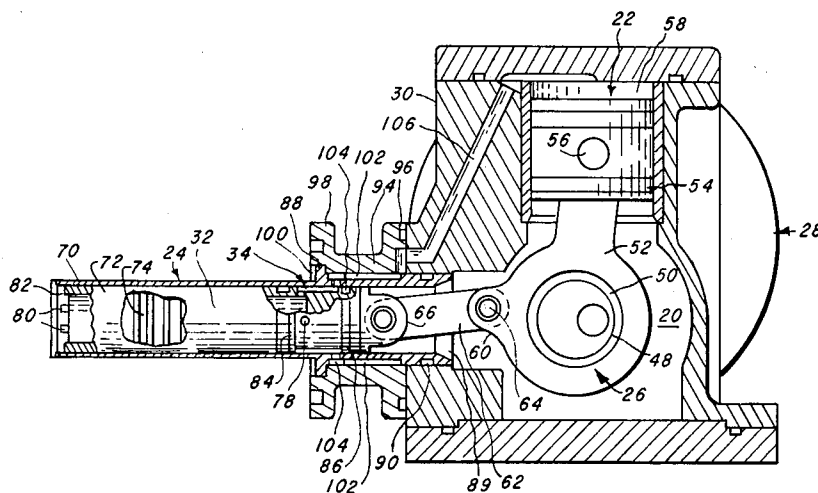
[54] **CRYOGENIC COOLER OFF-AXIS DRIVE
MECHANISM FOR AN INFRARED
RECEIVER**[75] Inventors: **Stephen L. Whicker**, Dallas; **Carol O. Taylor**, Anna, both of Tex.[73] Assignee: **Texas Instruments Incorporated**,
Dallas, Tex.[22] Filed: **June 25, 1973**[21] Appl. No.: **373,355**[52] U.S. Cl. **250/352**[51] Int. Cl. **G01t 1/16**[58] Field of Search 250/330, 332, 334, 352;
62/6[56] **References Cited****UNITED STATES PATENTS**3,435,137 3/1969 Altshuler et al. 250/352 X
3,638,441 2/1972 Rietoijk 62/6*Primary Examiner*—James W. Lawrence*Assistant Examiner*—Davis L. Willis*Attorney, Agent, or Firm*—Harold Levine; Rene' E.

Grossman; Alva H. Bandy

[57]

ABSTRACT

A thermal energy receiver having an infrared detector array mounted in a detector-vacuum module and a refrigerator for cooling the detector to an operating temperature is disclosed. The detector-vacuum module includes a dewar having a cold finger supporting a detector array mount and an infrared detector array attached to the mount. The refrigerator includes a cold finger having at one end a heat transfer mechanism, a regenerator-displacer having an annulus structure, and an off-axis drive mechanism interconnecting the regenerator-displacer and a compressor piston to a driver motor. The heat transfer mechanism provides a greater efficiency in cooling the detector array, the annulus provides a cryogen passage from the compressor to the regenerator-displacer throughout reciprocation thereof to eliminate "dead-space" when the displacer is mounted in a closed cylinder, and the off-axis drive mechanism structure provides a large bearing structure which resists axial movement due to shock vibration.

5 Claims, 7 Drawing Figures

SHEET

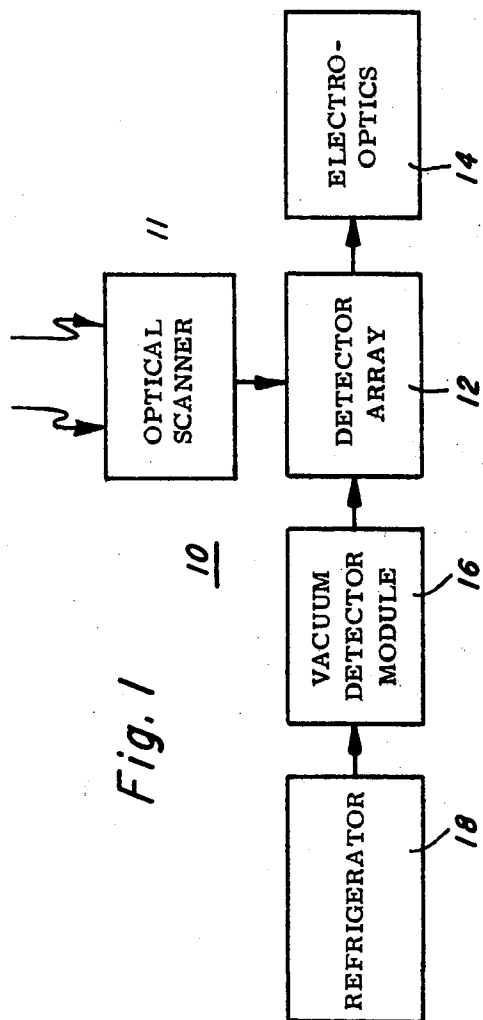
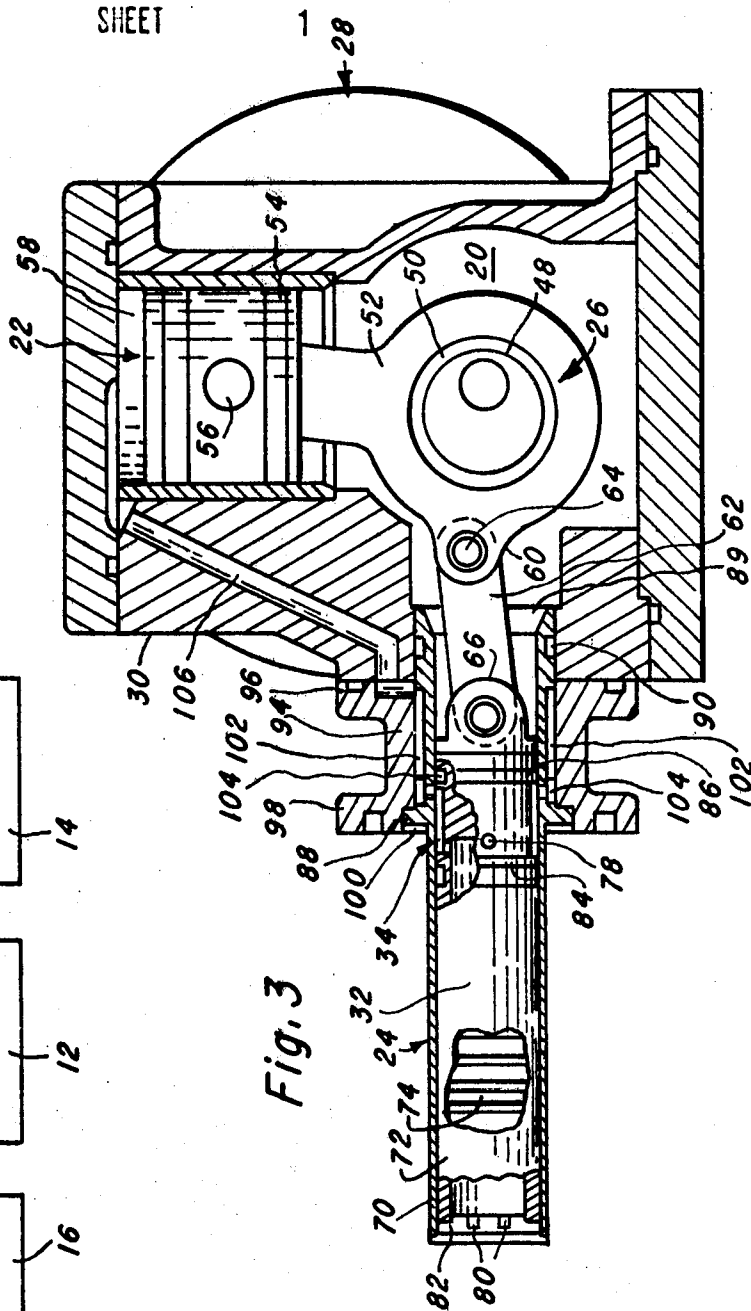
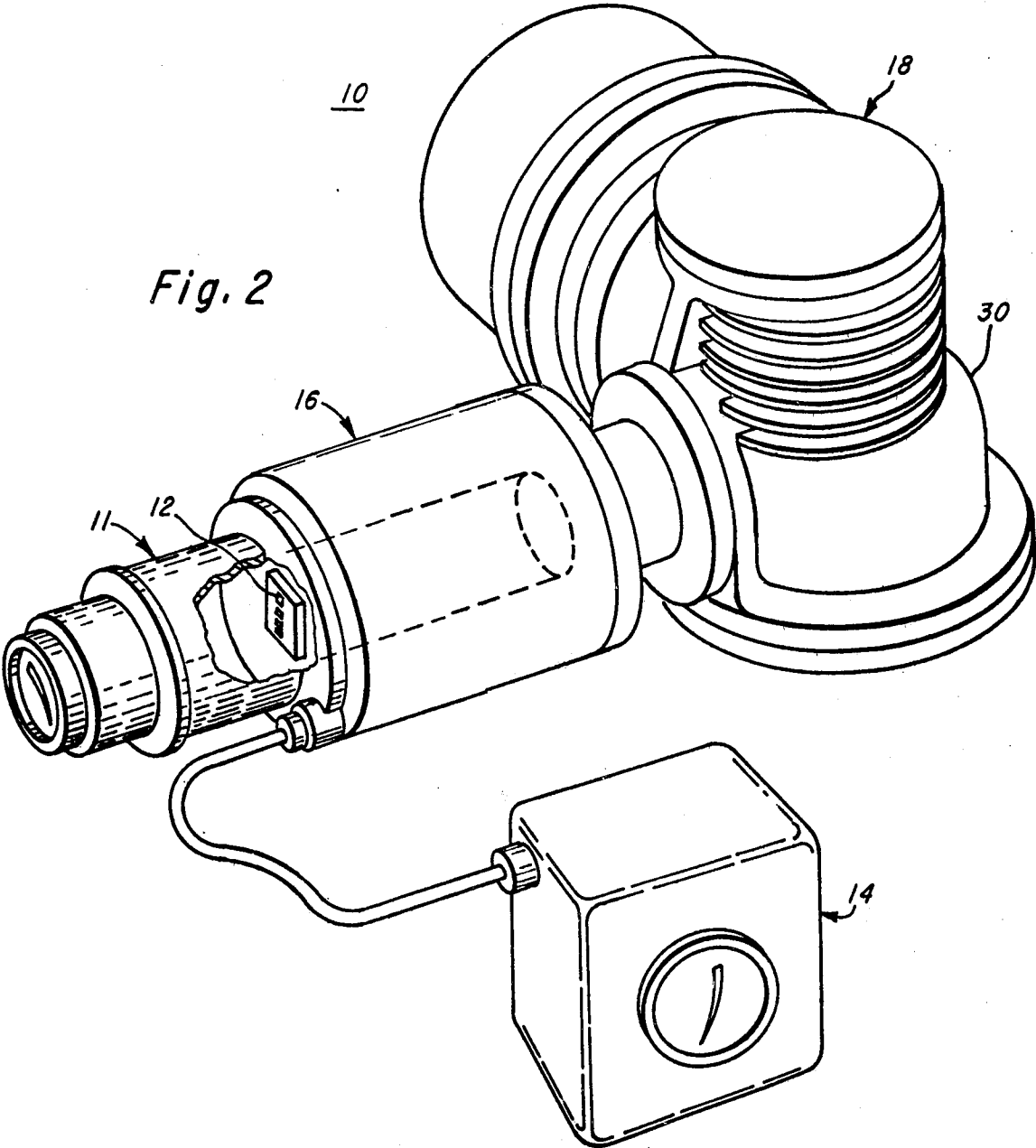
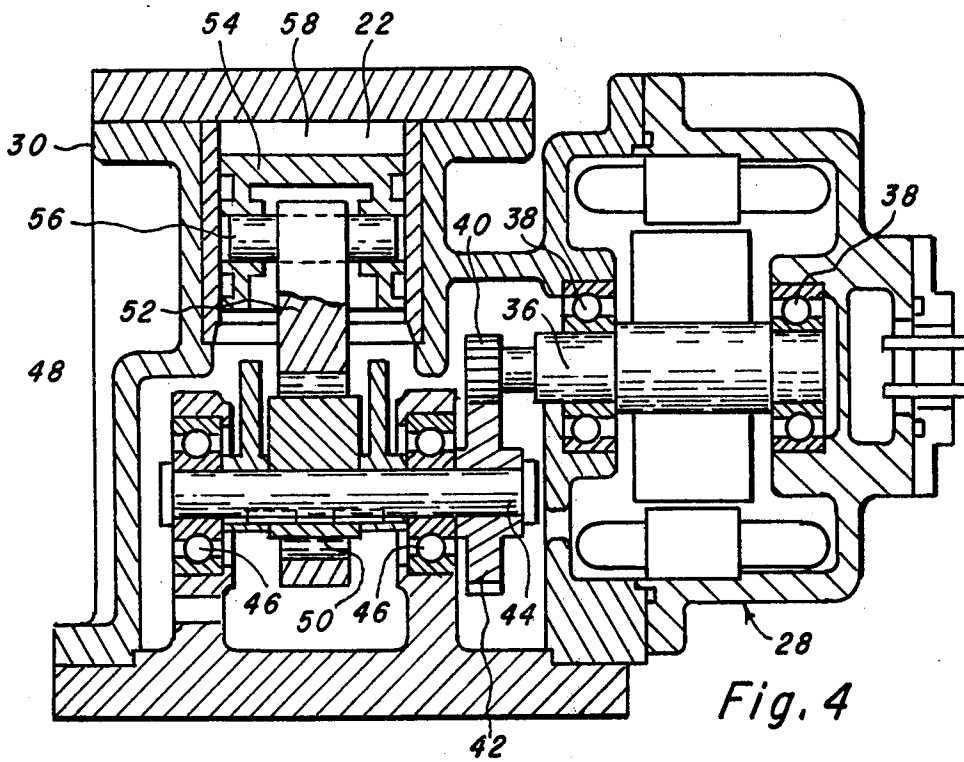
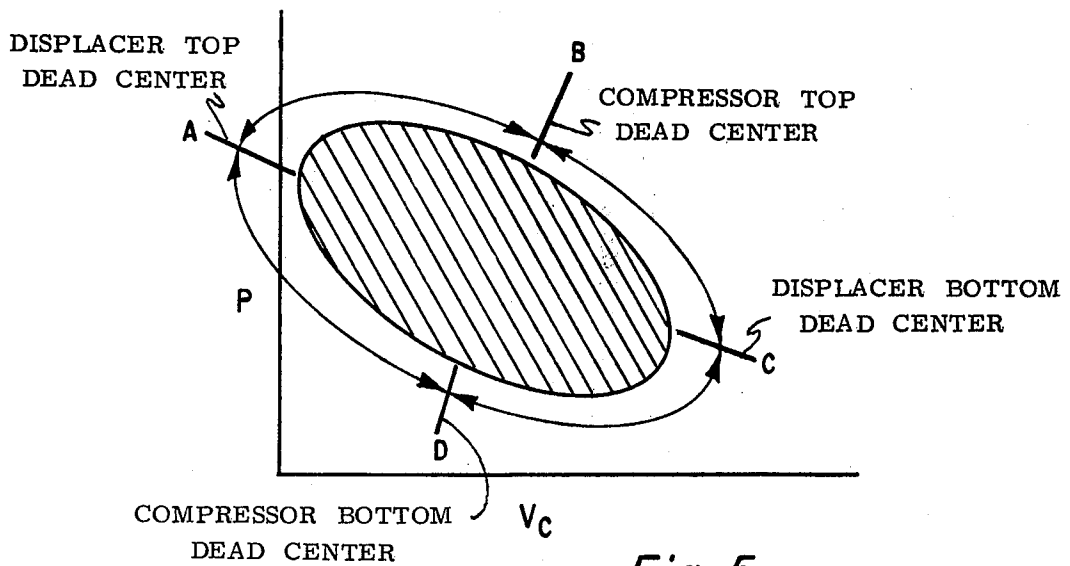
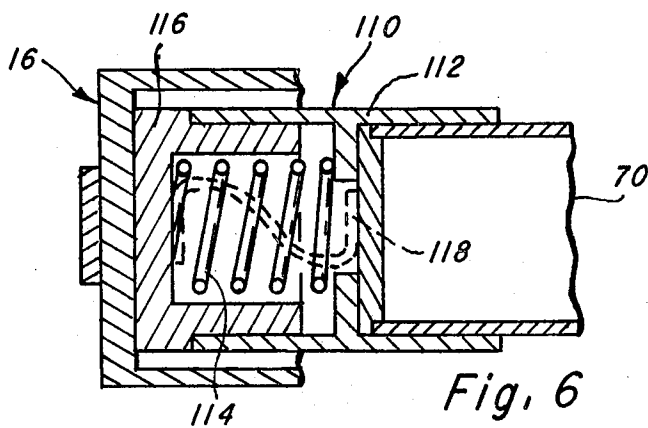


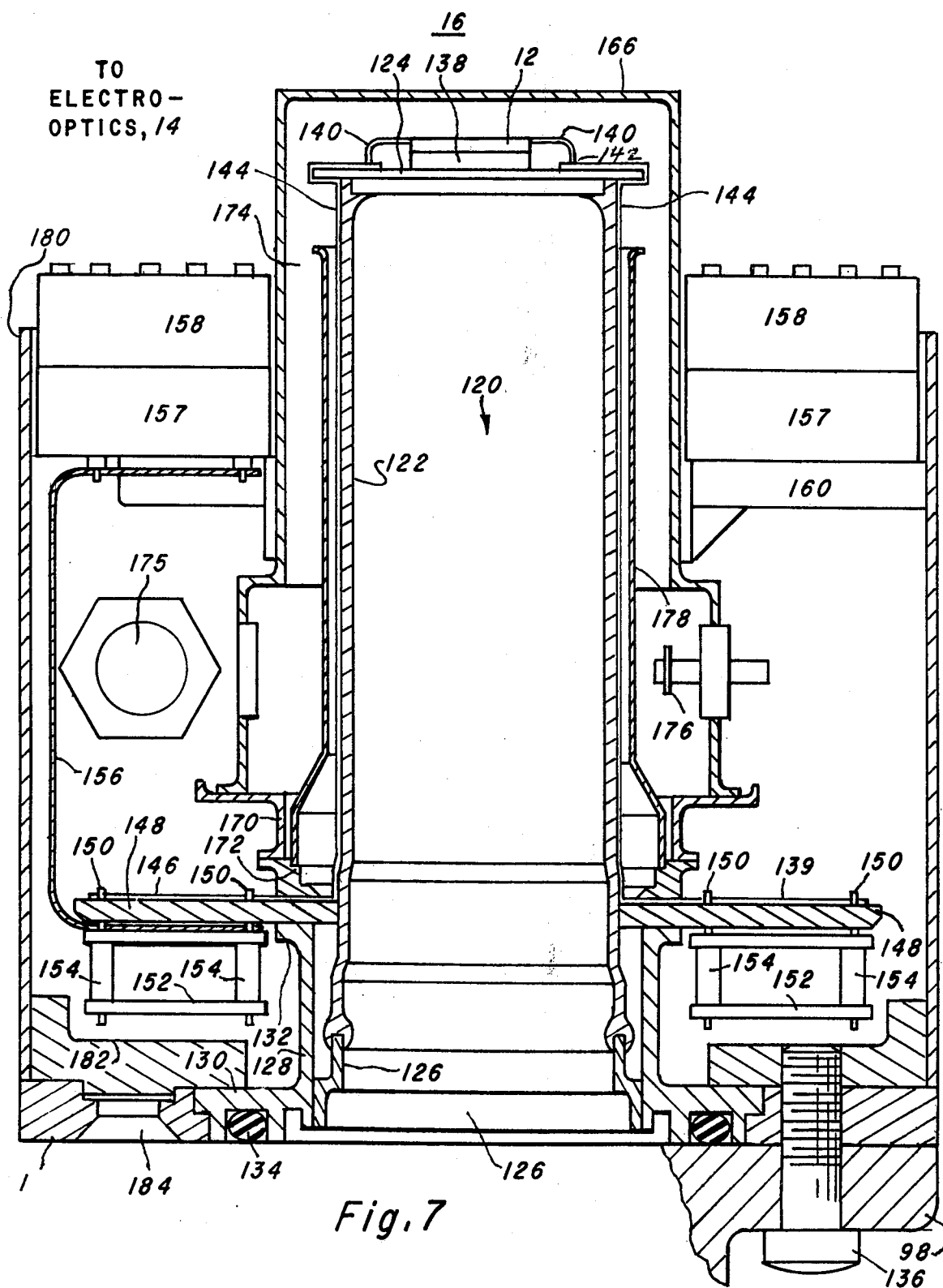
Fig. 3











CRYOGENIC COOLER OFF-AXIS DRIVE MECHANISM FOR AN INFRARED RECEIVER

This invention relates to a thermal energy detector and more particularly to an infrared receiver having a refrigerator with a novel drive mechanism interconnecting the motor drive shaft to the compressor piston and regenerator-displacer.

In the past infrared receivers have had the detector array permanently mounted upon the cold finger of the refrigerator, and the refrigerator has been either an open cycle or closed cycle refrigerator system. The refrigerator included one of several kinds of drive mechanisms interconnecting the motor drive shaft to the compression piston and regenerator-displacer, any one of which produces a force couple about the crank axis and creates high bearing loads thereon.

Many problems have resulted from use of the above-mentioned structures in infrared receivers. These problems stem from the reliability, maintainability, power, heat dissipation, and weight of such prior art systems. For example, the reliability of the prior art systems have been dependent upon the mean time before failure of the refrigerators rather than the detectors; thus, an improved refrigerator would increase the life time of the receiver. The use of an off-axis drive system that produces substantially no force couple about the drive shaft and low rod bearing loss increases substantially the reliability of the refrigerator.

Accordingly, it is an object of this invention to provide an improved, highly reliable thermal energy receiver which is economical to manufacture.

Another object of the invention is to provide a modular thermal energy receiver which is easy and economical to maintain and repair.

Still another object of the invention is to provide an efficient refrigerator system for a detector-vacuum module of the thermal energy receiver.

Yet another object of the invention is to provide a drive mechanism for interconnecting the motor to a compressor cylinder and regenerator-displacer in an infrared receiver to provide a highly reliable infrared receiver.

The above and other objects of this invention are accomplished by providing a modular type thermal energy receiver which comprises four separate or independent modules; namely, a cryogenic cooler or refrigerator, an optical scanner, a detector-vacuum module, and an electro-optics module. The cryogenic cooler may be, for example, either a Joule-Thomson cooler or cryostat, or a closed cycle refrigerator such as that disclosed in U.S. Pat. No. 3,334,491 issued Aug. 8, 1967. The refrigerator disclosed in the patent has been modified to incorporate a modified off-axis drive mechanism to improve the cooling efficiency and reliability of the refrigerator.

Other objects and features of this invention will become more readily apparent from the following detailed description when read in conjunction with the accompanying drawings in which:

FIG. 1 is a block diagram of the thermal energy receiver incorporating the subject matter of this invention;

FIG. 2 is an isometric view of the infrared receiver utilizing the off-axis drive mechanism embodiment of the invention;

FIG. 3 is a view, partly in section, disclosing in the refrigerator the off-axis drive mechanism embodiment of the invention;

FIG. 4 is a view, partly in section, disclosing the motor drive mechanism for the off-axis drive mechanism of the refrigerator;

FIG. 5 is a plot of the operating cycle of the refrigerator;

FIG. 6 is a partial view of the infrared receiver showing the details and relationship of the heat transfer mechanism to the refrigerator cold finger and the cold finger of the detector-vacuum module;

FIG. 7 is a view partly in section showing the relationship of the parts of the detector-vacuum module to the cold finger of the refrigerator.

Referring now to the drawings, the thermal radiation receiver 10 is shown in FIG. 1 as a block diagram to illustrate the operational relationship of the major components. The thermal radiation receiver 10 (FIGS. 1 and 2) comprises an optical scanner 11, detector array 12, electro-optics 14, vacuum module 16, and refrigerator 18. The detector array 12 is in the path of incoming thermal energy scanned by optical scanner 11 to which it is responsive to produce electrical signals representative of the thermal energy image impinging thereon. The electrical signals of the detector array 12 are processed for display in a selected one of many electro-optical systems 14. An example of a suitable electro-optics display system is the system of previously referred to U.S. Pat. No. 3,742,238 issued June 6, 1973. The detector array 12 is mounted for cooling in a detector-vacuum module 16. The detector or detector array 12 of the detector-vacuum module 16 is cooled by a suitable cooler such as, for example, a refrigerator 18 or cryostat 18 (FIG. 8). The refrigerator 18 (FIGS. 1 and 2) must have a sufficient cooling capacity to cool the detector array to its operating temperature. The system hereinafter described is particularly suitable for cooling an infrared detector array such as, for example, a mercury, cadmium telluride detector array to a temperature of about 77°K or below.

In the preferred embodiment of the invention the thermal energy detector 10 is cooled by a closed cycle refrigerator such as a Stirling Cycle Cooler 20 (FIG. 3). The refrigerator system is comprised of two major components; namely, a compressor 22 and a cooling head 24. The major components are interconnected by a common drive mechanism 26 driven by a motor 28. Except for the cooling head which is attached to housing 30, all of the components are mounted in the housing 30. The working fluid or cryogen, which may be for example, helium, flows freely between the compressor and cooling head as will be hereinafter described; that is, no valves are included in the cryogen system for controlling the flow of the cryogen. The compressor 22 is preferably an air cooled, dry lubricated unit of single piston design. The cooling head 24 (FIG. 3) consists of a regenerator-displacer 32, and an annulus 34 which, as shown, is formed as an integral part of the regenerator-displacer 32.

The motor 28 (FIG. 4) may be, for example, an electrical motor of about one-twentieth horsepower powered by either, a d.c. or a.c. source of power to rotate a drive shaft 36 mounted in ball bearings 38. Drive shaft 36 is connected to a geared speed reducer consisting of spur gears 40 and 42. Spur gear 40 is a driving pinion gear 40 and the other spur gear 42 is a driven

gear. The driven gear 42 is mounted on output shaft 44 journaled in ball bearings 46. The output shaft 44, which is driven at about 1,500 rpm, has an eccentric cam 48 (FIG. 3) mounted thereon engaging bearing surface 50 of master piston connecting rod 52. The master piston rod 52 (FIG. 3) is connected to compressor-piston 54 by pin 56 passing through the piston's skirt. The compressor piston 54, which has a diameter of about 1 inch, is mounted in compression cylinder 58, formed in housing 30. A boss 60 is formed on the eye, which has a diameter of about 1 inch, of the master rod 52 at right angles to the rod portion thereof. An auxiliary or slave rod 62 has one end pivotally connected to the boss 60 by pin 64 and at its other end pivotally connected to ears 66 of the regenerator-displacer 32, which has a diameter of about one-half inch, mounted in a cylinder or cold finger 70. This off-axis drive mechanism, when driving the piston and regenerator-displacer of the above-mentioned sizes, produces no force couple about the crank axis, and the master rod provides a wide bearing seat on the crank that resists rod rotation while maintaining low bearing loads. It has been found that this arrangement increases substantially the reliability of the refrigerator.

The regenerator-displacer 32 includes a displacer cylinder 72 enclosing a heat exchanger 74 such as, for example, a plurality (about 850) of fine (about 325-400) mesh metal (stainless steel) screens. The displacer cylinder 72 is about one-half inch in diameter and is made of plastic such as, for example, Lexan or fiberglass. An annulus 34 is formed in the periphery of the cylinder 72 adjacent the ear bearing end. As the annulus 34 is formed as part of the reciprocating regenerator-displacer, it is referred to as a floating annulus. A plurality of ports 78 are provided in the bottom of the annulus 34 which provide passages to the heat exchanger 74. The cylinder 72 has a plurality of ports 80 in the end opposite the annulus 34; these ports provide passages into a cold chamber 82 defined by the space between the cylinder 72 and the interior of cold finger 70. The annulus 34 of the cylinder 72 is sealed off from the cold chamber 82 and the off-axis drive mechanism chamber by a pair of seals 84 and 86 such as those sold under the trademark Bal Seals (a spring loaded Teflon) which are in sealing engagement with the interior of the cold finger 70 above and below the annulus 34. These seals 84 and 86 also provide axial motion guides for the regenerator-displacer. The floating annulus substantially eliminates the "dead space" of systems utilizing a stationary cylinder with a reciprocating heat exchanger mounted therein. The only dead space being that of the annulus 34. The minimum annulus volume is determined by the allowable pressure drop therein.

The cold finger 70 has a lower portion defined by an outwardly extending flange 88 and an open end 89. The open end 89 is seated in a bore provided therefore in the housing 30. A sealing ring 90 seals the space between the cold finger 70 and the housing 30 to prevent the escape of cryogen from that part of the housing 30 enclosing the off-axis drive mechanism 26. A retaining member 94 has a lower flange 96 attached to housing 30 and an upper flange 98 which has an annular recess 100 in which the flange 88 of the cold finger is seated.

The cold finger 70 has a manifold 102 having a plurality of ports 104 in communication with the annulus 34 of the regenerator-displacer 32. The manifold 102

is also in communication with an air cooled passage 106 of housing 30 opening into the compression cylinder 58.

The volumes of the compression cylinder 58, housing passage 106, cold finger manifold 102, regenerator-displacer annulus 34, cylinder 72, and cold chamber 82 form the cryogen line which is filled with a suitable cryogen such as, for example, helium.

In operation, the regenerator-displacer 32 and the compression piston 54 being connected to the off-axis drive mechanism 26, operate along intersecting axes and 90° out of phase with one another. Thus, as the regenerator-displacer 32 reciprocates, the volume of the cold chamber 82 decreases and increases in accordance with the following description of one operating cooling cycle.

The refrigeration cycle may best be understood by referring to FIG. 5 wherein the letters A, B, C, and D represent the positions of the regenerator-displacer 32 and the compression piston 54 as follows: positions A and B represent respectively the top dead center positions of the regenerator-displacer and the compressor piston, and positions C and D represent respectively the bottom dead center positions of the regenerator-displacer 32 and the compressor piston. It is known that in the Stirling Cycle the cryogen flowing through the regenerator-displacer absorbs heat from the regenerator mass during its flow from the colder end of the regenerator to the hotter end and gives up heat to the regenerator mass during its flow from the hotter end to the cooler end. It is also known that the cryogen is cooled and densified in passing through the regenerator-displacer and during its expansion in the cold chamber. Thus, at position A the regenerator-displacer 32 has reached top dead center and the compressor piston 54 has reached the mid-point of its compression stroke in cylinder 58. At this point the cryogen pressure is approaching its maximum value and the volume of the cold chamber is increasing from a minimum. The regenerator mass is absorbing heat from the cryogen. At position B the regenerator-displacer 32 has been withdrawn through the cryogen flowing into the cold chamber and the volume of the cold chamber has increased to one-half its maximum; the compressor piston 54 has arrived at top dead center to complete its upward stroke. The cryogen has passed its maximum pressure point and the pressure has returned to an intermediate value. At point C the regenerator-displacer 32 is at bottom dead center and the compression piston 54 has proceeded downwardly to the midpoint of compression cylinder 58. The cryogen pressure has further decreased and the cold chamber is at its maximum volume. The cryogen at this point is approaching the completion of its expansion and its flow is back through the regenerator mass collecting heat on its way to the compression cylinder 58. At point D, the regenerator-displacer has moved upwardly to reduce in half the volume of the cold chamber 82 and the compressor piston has reached bottom dead center. At this point the cryogen has passed its lowest pressure point and the pressure is on the rise; the volume of the cold chamber has passed its maximum volume and its volume has reduced to about one-half its maximum volume. The cryogen is now being compressed and is flowing out of the compression cylinder 58. The cycle is completed when the regenerator-displacer returns to its position at point A. It will be understood that the heat of compres-

sion of the cryogen is dissipated through the housing 30 and the cryogen enters the regenerator at the ambient temperature on its way to the cold chamber 82 where it reaches its cooling temperature, and upon its return through the regenerator mass it collects heat and leaves the regenerator at the ambient temperature and reenters the compression cylinder for another cycle.

The cold finger 70, as previously mentioned, is cooled by the extraction of heat therefrom by the refrigerator and in the past, the the detector array was mounted directly on the exterior wall of the cold finger 70 and the dewar was formed therewith. However, to improve maintenance capability a detector-vacuum module 16 (FIG. 7) which is removable from the cold finger 70 is used in the embodiment of the present invention. To alleviate the loss of cooling capacity the cold finger 70 is provided with a heat transfer mechanism 110 (FIG. 6). The heat transfer mechanism includes a coupling member 112 having an "H" cross-section. The lower portion of the coupling member 112 is configured after the configuration of the cold finger 70 upon which it is mounted and secured by brazing, for example. The upper portion of the coupling member is opened and seats a coil spring 114 together with a depending portion of flanged member 116. The spring 114 biases the flanged member 116 into engagement with the detector-vacuum module 16. The heat transfer mechanism may be coated with a material having a high heat transfer coefficient such as a silver filled silicone grease, or the flanged member 116 may include a flexible heat transfer strip 118 of a heat conducting metal as shown in dotted lines in FIG. 6. The heat conducting metal flex strip 118 has one end portion attached to the flanged member 116 and the other end attached to the cross member of the coupling member 112, or if the crossmember is cut out as shown in FIG. 6, to the end of the cold finger 70. Another arrangement for the heat transfer mechanism 110 eliminates the coupling member 112 by making the flanged member 116 a coupling member which fits slidably over the cold finger with the spring 114 therebetween.

The detector-vacuum module (FIG. 7) includes a cylinder or second cold-finger 120. The cylinder 120 has walls 122 formed of a suitable insulating material such as a hard glass sold as Corning Glass No. 7052, an open end and a closed end 124 of a suitable metal or glass. The metal end 124 is constructed of a metal alloy having a glass matching coefficient of expansion such as the metal alloy sold under the trademark Kovar. The combination of Corning Glass No. 7052 and Kovar is preferred as the temperature coefficients of expansion are compatible. The open end of the cylinder is formed by a metal ring 126 also constructed, for example, of the Kovar metal alloy. The metal ring 126 is attached to an adapter 128 having a lower flange 130 and an upper support flange 132. The lower flange 130 receives O-ring 134 and fasteners such as screws or bolts 136 for attachment to the upper flange 98 of the cold finger retaining member 94.

The detector array 12 is attached by a suitable bonding material such as an epoxy to a mount 138 attached to the metal or glass end 124 of cylinder 120. A plurality of leads 140 (220 for a 180 element detector array) are provided which connect the detectors of the detector array 12 to a plurality of lead terminals 142 of leads 144. The lead terminals 142 are formed on insulating material attached to the metal end 124, and the leads

140 are attached by any suitable technique such as ball bonding. The leads 144 are preferably metalized on the glass walls 122 of cylinder 120, and are connected to ends of a lead pattern 146 formed on a flat annular disk 148. The disk 148 is formed from an insulating material which, for example, may be of a ceramic material. The annular ring 148 circumscribes the cylinder 120 and is supported by the upper support flange 132. The lead pattern 146 may be formed by metalizing a lead pattern on the ceramic ring 148.

The lead pattern 146 includes at ends opposite those connected to leads 144 a plurality of terminals connected to conductor posts 150 mounted in holes in the ceramic ring 148. The posts 150 extend above and below the ceramic ring 148. A plurality of resistor biasing packs 152 are attached beneath the ceramic ring 148. For example, four biasing packs 152 are provided — each carrying forty-five resistors 154 connected to the lower ends of conductor posts 150. The lower ends of posts 150 are also attached to a corresponding number of leads which may be formed on an "H" film 156 having their other ends attached to receptacle 157 for the electrical input terminals of the detector-vacuum module 16. The receptacle 157 is supported by bracket and gusset 160. The electrical input terminals 158, which are connected to the output terminals 157 of the infrared receiver, are attached to the electro-optics package 14, and supply a bias for the detector circuits from a bias power source and receive the biased output of the detector array 12.

The detector array 12 is enclosed by a cylinder 166 having an open end secured to a flange of adapter 170. The other end of the adapter is attached to a support member 172 sealing the adapter 170 to the ceramic ring 148 to form a vacuum chamber 174 between the cylinders 120 and 166. A pinch tube 175 is used to provide the vacuum in vacuum chamber 174.

The vacuum chamber is equipped with a getter 176 mounted in cylinder 166. The active getter 176 is connected to a source of power (not shown) and fired on an as required basis to maintain the vacuum in the vacuum chamber 174. The getter 176, which may be, for example, SAES non-evaporable active getter material, extends substantially the life of the detector-vacuum module 16. A shield 178 surrounds a substantial portion of the walls of cylinder 120 to protect the cold finger and cylinder 122 from the action of the getter 176 and to reduce dewar thermal heat leak; it is mounted in the support member 172.

A housing 180 encloses the components of the detector-vacuum module 16. The housing 180 has an inwardly extending flange 182 to which a retaining member 183 is attached by screws 184 to support flange 130 for rotation. The rotation of flange 130 permits positional adjustment of the detector array to the optical scanner 11 to effect proper scanning action for the field of view.

The biased outputs of the detectors of the detector array 12 are fed to the electro-optical system 14. Although the electro-optical system 14 is determined by the type of display desired, many systems are known to those skilled in the art. A suitable electro-optical system is shown in the above-mentioned U.S. Pat. No. 3,742,238 issued June 26, 1973.

In operation of the infrared receiver 10, the refrigerator 18 is activated to cool the detector array 12 to its operating temperature. The infrared receiver 10 is then

directed to a desired field of view; infrared energy emanating from the subject of the field of view impinges upon the detectors of the detector array 12. The detectors produce electrical signals representative of the intensity of the infrared energy. These electrical signals are biased by a standard bias to provide signals of a strength suitable for processing by the electro-optical system 14. Processing includes amplification of the signals and applying them to light emitting diodes for producing visible light signals which may be televised, displayed upon a screen, or viewed directly as desired.

Although several embodiments of this invention have been described herein, it will be apparent to a person skilled in the art that various modifications to the details of construction shown and described may be made without departing from the scope of this invention.

what is claimed is:

1. In an infrared receiver including an infrared detector in a scanning path for infrared energy emanating from a source thereof for producing electrical signals representative of impinging infrared energy; an electro-optical system coupled to the detector for processing video signals from the electrical signals produced by the detector; and a refrigerator for cooling the detector to an operating temperature, the refrigerator having a cooling member including a cylinder, a regenerator-displacer reciprocally mounted in the cylinder, and a cold chamber formed between an end of the cylinder and the regenerator-displacer, a housing enclosing a cylinder-piston type compressor motor and drive mechanism and a passage means interconnecting the compressor cylinder, regenerator-displacer, and cold chamber of the cooling member, said compressor cylinder, passage, regenerator-displacer, and cold chamber forming the working volume for a cryogen, the improvement comprising an off-axis drive means mounted in the housing exteriorly of the cold member and compressor cylinder to allow the compressor cylinder

der and piston to be matched in size with the regenerator-displacer for increased refrigerator efficiency, said off-axis drive mechanism interconnecting the regenerator-displacer of the cold member and the compressor piston to the motor, whereby the motor actuates the off-axis drive mechanism to sequentially reciprocate the regenerator-displacer and the compressor piston for circulating the cryogen throughout the working volume.

2. An infrared receiver according to claim 1 wherein said off-axis drive means includes a master rod having an end pivotally connected to the compressor piston and an eye end having a boss formed thereon, said eye of the eye end connected to an eccentric drive means coupled to the crank shaft of the motor exteriorly of the compressor piston and cylinder, and having a diameter not less than about that of the compressor piston to provide a wide bearing seat on the crank shaft to resist rod rotation while maintaining low bearing loads, and a slave rod having ends pivotally connected to the regenerator displacer and the boss of the master rod whereby the off-axis drive means in operation produces substantially no force couple about the crank shaft.

3. An infrared receiver according to claim 1 wherein the axis of the master rod and the axis of the slave rod of the off-axis drive mechanism intersect to form an angle of about 90° between them.

4. An infrared receiver according to claim 1, wherein the eccentric drive means of the off-axis drive mechanism includes a cam mounted upon the drive shaft of said motor.

5. An infrared receiver according to claim 1 wherein the eccentric drive means of the off-axis drive mechanism includes a cam mounted upon a drive shaft, and a speed reducer coupling the drive shaft to the drive shaft of the motor.

* * * * *

40

45

50

55

60

65