250-203.R 56

Aug. 31, 1965 E. M. WORMSER ETAL 3,204,100

INFRARED RADIOMETER WITH BACKGROUND ELIMINATION

Filed Oct. 5, 1961

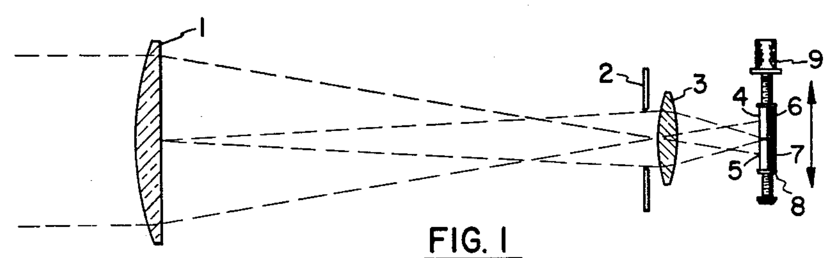

FIG. 1

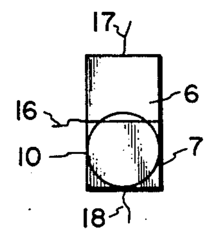

FIG. 2

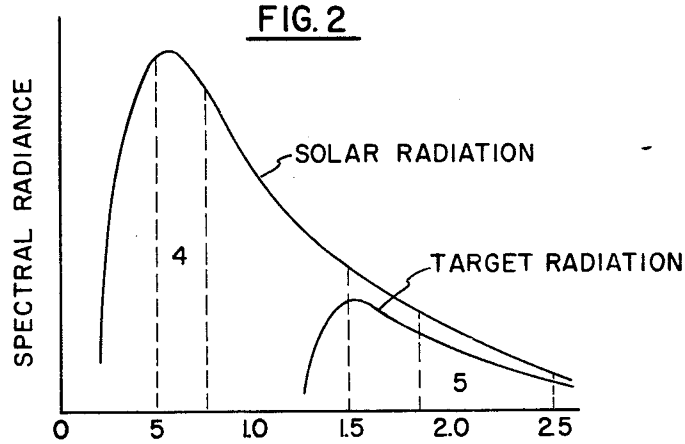

FIG. 3

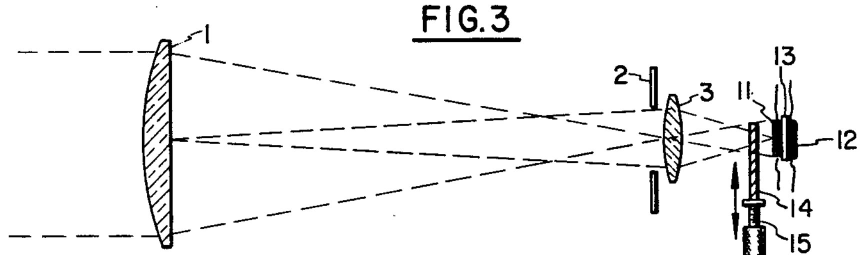

FIG. 4

INVENTOR.
ERIC M. WORMSER
ABE L. POGODA
ROBERT W. ASTHEIMER

BY Robert Ames Norton
ATTORNEY

United States Patent Office

3,204,100

Patented Aug. 31, 1965

3,204,100

INFRARED RADIOMETER WITH BACKGROUND ELIMINATION

Eric M. Wormser, Stamford, Conn., Abe L. Pogoda, Paramus, N.J., and Robert W. Astheimer, Westport, Conn., assignors to Barnes Engineering Company, Stamford, Conn., a corporation of Delaware

Filed Oct. 5, 1961, Ser. No. 143,219
10 Claims. (Cl. 250—83.3)

This invention relates to instruments for detecting radiations from small targets which radiate primarily in a particular spectral region in the presence of large backgrounds illuminated or radiating intensely in a different spectral region. More especially the present invention deals with the detection of targets radiating in the infrared in the presence of sunlit backgrounds.

Infrared instruments often are used with relatively small targets of only moderate intensities. A very serious problem has arisen when such instruments are to be used in the daytime as the sky or sunlit background will normally subtend a larger angle at the detector than that of a small target radiating in the infrared. The total radiation intensity from the brightly lit background or sky may be many hundreds of times as great as the infrared radiation received from a small target.

A number of elaborate devices such as are described and claimed in the copending application of Monty M. Merlen, Serial No. 78,772 filed December 27, 1960, now Patent No. 3,169,164, and used, for example, in infrared trackers as described in U.S. Patent 2,961,545. These systems involve spatial filtering, the chopping of the infrared or other radiation with a reticle combined with a mask in which the edges across which the reticle pattern moves are provided with segments inclined to the pattern and covering a whole number of pattern cycles. The devices operate by reason of the fact that a uniform background is not chopped at all, whereas radiation from a small target is. By using A.C. electronic processing circuits for the output signal from the detector, the unchopped background produces no A.C. signal and so is completely rejected whereas the radiation from a small target is chopped and is fully amplified. An extraordinary degree of uniform background rejection is possible, in excess of 100,000 times target radiation.

The devices relying on spatial filtering are most useful with backgrounds which are uniform or relatively uniform and fail in the case of backgrounds which vary nonuniformly, have nonuniform illumination or in which the radiations from the background change rapidly in time.

In the present invention background interference is eliminated spectrally and this can be effected without significant loss of target energy and it is possible to compensate at frequent intervals for a changing background condition.

The present invention operates optically and if it is not necessary to employ chopping reticle position encoding techniques, such as for example azimuth and altitude error signals in trackers, there can be practically a 100 percent energy utilization. If it is necessary to obtain information which is only practical with chopped radiation even the present invention cannot eliminate the energy losses entailed by chopping but even in such cases maximum energy utilization is possible and the great advantage of discriminating against nonuniform and slowly changing backgrounds is achieved.

The present invention operates by using a differential detector system or two detector systems in conjunction with spectral filters, one filter passes radiation in an intense part of the spectrum of background illumination, for example

in the visible spectrum in the case of a sunlit background. If desired this filter may be made quite narrow spectrally. The other detector system transmits wavelengths in which there is extensive target radiations. In the case of a sunlit background the target may emit primarily in the ultraviolet but the most common situation is where the target emits primarily in the infrared. In the remainder of this specification this particular modification of the invention will be described. The instrument also is provided with a field stop and particularly with a field lens or similar optical element which images the entrance pupil of the collecting optics onto the plane of the detectors. Means are provided for varying the energy striking the two detectors. These means always provide for a major fraction of the beam coming through the entrance aperture striking the target detector and there is, therefore, no large loss in energy whereas formerly half or less of the energy incident at the aperture was so used.

The instrument may be adjusted by moving the beam varying means either manually or automatically to provide minimum signal against actual backgrounds when a target is not present in the field of view.

In order to achieve the above results several types of optical variation of beam cross-section may be used. Two of them are particularly useful and constitute the two preferred modifications of the present invention although they are not the only optical means which can be used. One method, which has the advantage of simplicity but sets some limits on total energy, is to move the differential or double detector in the image plane of the field lens. Greater or less detector area falls in the two spectrally operated beams. Theoretically one might assume that if the short wave radiation of the background were less intense than the target radiation a balance could be achieved with less than 50% of the radiation being in the infrared. Actually this never occurs in practice because the background to be eliminated receives solar radiation which is normally very much more intense than infrared radiation in the range which covers target radiation. As a result most of the radiation beam entering through the aperture strikes the infrared detector and typically this will be from 80% to almost a 100% as opposed to the much smaller amount of the shorter radiation. The present invention should not be confused with the system in which the radiation is equally split and only the short wave half is attenuated. Such a system, of course, can never transmit more than 50% of the infrared radiation.

Another method, slightly less simple but capable of greater utilization of radiation, is to provide two detectors in series such as a photodetector which responds to short wave radiation, for example, in the visible spectrum, but is substantially transparent to infrared radiation and behind in another photodetector which responds efficiently in the infrared band. A filter such as a germanium or silicon plate can then gradually be moved across the stationary detector sandwich obscuring more and more of the short wave radition while passing the infrared radiation with negligible loss. This requires another element but permits somewhat greater sensitivity. In both cases an extremely rugged device is possible because the movements either of the split detector or of the filter can be by a micrometer screw which is an extremely simple and rugged device which can withstand harsh enviroment in portable use.

When the first modification is used in which there are side by side detectors with two filters it is preferable to have the filters closely adjacent to the detectors. The best construction is to have them mounted directly on the detectors. This forms a very simple and rugged structure and is preferred. It should be understood, of course, that the filters can be just back of the extrance aperture or otherwise disposed in the beam so that one detector receives radiation through one filter and the other through the other. Such instruments are included in broader aspects of the invention but are less desirable than the filters that are directly mounted on the detectors.

The present invention may be said to be operating as a two-color system, using color in its broader sense as different wavelength ranges. Theoretically there should be no limit on the particular wavelength ranges used so long as one receives most of the energy from the background and the other primarily the energy from the target. In practical instruments the background to be eliminated is almost always irradiated by sunlight, either a sky or a daylit background and most targets radiate effectively in the moderately near infrared. A typical situation would utilize filters one of which passed visible light and stopped between 0.4 and 0.6 micron and the other involved infrared radiations from 1.8 microns on to the limit of effective detector response. The invention will be described in conjunction with practical instruments where this choice of radiation bandwidths is employed it being understood that this is only an example, although a practically very important example, of the two colors used in the invention.

The present invention is essentially an optical invention. It is true that detectors are used which transform radiations onto electrical signals but the electronic processing circuits are conventional and do not necessarily differ from those used with other sensors. They will, therefore, be described only generally in connection with their function as their specific circuit configuration forms no part of the present invention.

The invention will be described in greater detail in conjunction with the drawings in which:

FIG. 1 is a semidiagrammatic section through the optics and detector of the present invention;

FIG. 2 is a plan view of the differential detector of FIG. 1;

FIG. 3 is a graph of the radiation spectrum of the sun and a typical target radiating primarily in the infrared, and

FIG. 4 is a semidiagrammatic cross-section of a system using a sandwich type detector.

In the modification shown in FIGS. 1 and 2 the radiation entering the system passes through an objective **1** which also defines the entrance pupil. A field stop **2** defines the field of view and then a field lens **3** images the entrance pupil on the plane of two detectors **6** and **7**. Each detector is provided with a filter **4** and **5** in front of it and the detector assembly is mounted in a frame **8** which can be moved by the micrometer screw **9**. A shown the detector, which is a diffrential detector, as can be seen best in FIG. 2, has a central lead **16** and two end leads **17** and **18**. The signals are in opposition and are handled by conventional differential circuits which are, therefore, not shown.

The field lens **3** images the entrance pupil at **10** on the differential detector which can best be seen in FIG. 2. The filters are shown removed.

In operation the instrument is first nulled by pointing at the sky or a sunlit background. The screw **9** is then turned until there is no net signal from the differential detector. This is ordinarily indicated by a conventional meter (not shown), in the differential output circuits. The upper filter **4** is designed to pass a band in the visible spectrum. This is shown on FIG. 3 the band carrying the same reference numeral as the filter. Filter **5** on the other hand has a cutoff at about 1.8μ and the band which it passes also appears in FIG. 3. For the values given the filter **5** may be of germanium which has a short wave cutoff at about 1.8μ. From FIG. 3, which shows the spectrum of the sun and also of a typical target having a temperature from 1,000° to 2,000° K., it will be apparent that the energy from the sky or sunlit background is very much more intense and as a result when the screw **9** has been turned until there is a zero signal from the sunlit background only a small portion of the entrance pupil is imaged on filter **4** and most of it is on filter **5**. This is shown in FIG. 2 which represents the position after nulling. With a typical background some 10 to 15% of the incoming energy strikes the filter **4** and the remainder goes through the germanium filter **5**. The detectors which are photoconductors are illustrated as lead sulfide detectors which accounts for the long wave cutoff in the band of radiation passing through filter **5** as illustrated in FIG. 3. The germanium filter, of course, passes infrared radiation much longer than that shown but the detector used is not sensitive thereto and as a result the effective band is as shown in FIG. 3.

After nulling the instrument is then used for locating a target which may be any small target such as the exhaust of a vehicle, the flare of a short range rocket or the like. The radiation from the target is practically all in the region beyond the long wave cutoff of filter **4** and as a result it will contribute to the signal produced by detector **7** but will add a completely negligible amount to the output signal of detector **6**. The differential output circuits will, therefore, indicate the radiation and will definitely distinguish the target from the much more intense sky or sunlit background.

The present invention is directed to a radiation sensor. Once the output signals have been produced by the differential detector or the two detectors the invention is not concerned with the use to which these signals are put. They may be utilized either to detect a target, to control the target or to track it. These various functions are well known and the conventional electric circuits used to effect such purposes are not changed in any way by the present invention. It is an advantage of the invention that the signal produced is suitable for almost any ordinary purposes. While the invention is not to be considered as limited to any particular use it may be pointed out that the light weight and ruggedness of the instrument lends itself to the control of antitank rockets in the field. In such a case the instrument is aimed at the tank or other target after nulling and as soon as the rocket flare is picked up by the instrument the angular error signal can be used to bring the rocket into the line of sight against the tank or other object as seen from the observation control station. This method of short range rocket control by error signals is known and is not changed in any way by the present invention which, however, presents many practical advantages for this use.

The filters have been shown in FIG. 1 as applied directly to the two halves of the differential detector. This is preferable and makes for the best mechanical construction. However, it is possible to place the filters at other positions, for example, directly behind the objective **1** and, therefore, in its broadest aspects the invention is not limited to a particular filter location. However, there are so many practical structural advantages in incorporating the filters directly with the detectors that this constitutes a preferred modification.

FIG. 4 is a modified form which, for certain purposes, is advantageous. The portions of the optical system of FIG. 1 which are the same will carry the same reference numerals. Instead of having two detectors or two halves of one detector arranged side by side with the filters in front of them the detectors are arranged back to back in the form of a sandwich. In front is a detector **11** which may be made of silicon, gallium arsenide or other suitable photodetector or material which responds to short wave radiations and transmits the long wave radiation. This detector is mounted on a suitable substrate **13** which may be fused silica or other material which is transparent to the near or intermediate infrared spectrum. On the back of the mount is a detector **12** which responds to the near or intermediate infrared, for example, lead sulfide or indium antimonide. The two detectors are connected to produce a differential output as in the case of the detectors of FIGS. 1 and 2. However, control is effected in a different manner by moving a germanium filter plate **14** by means of a micrometer screw **15**. As this plate is moved across the composite detectors it cuts off completely radiation in the visible and lets through only infrared radiation beyond 1.8μ.

The modification using a sandwich detector has an important advantage. In the case of the instrument of FIGS. 1 and 2 the field lens has to be of high quality and image the entrance pupil point by point. This requires not only a relatively expensive quality of field lens but it is not practical unless the image of the entrance pupil is fairly large. This in turn means a fairly large detector or detectors. In FIG. 4 a cheap field lens can be used. As high resolution is not necessary, it is possible to produce a very much smaller image. This in turn makes a smaller detector possible with increased sensitivity. The modification of FIG. 4, therefore, effects both economy in the optics and, which is much more important, a very substantial increase in sensitivity.

Nulling against a uniform sky or sunlit background is effected by moving the plate **14** until only a very small portion of the image of the entrance pupil as seen by the short wavelength detector is transmitted. The nulling effect is the same as in FIGS. 1 and 2 where the whole detector system is moved and in each case the vital feature of the present invention is retained, namely that at balance or null a very large and major fraction of the incoming radiation activates the detector which responds to the infrared and a very small fraction activates the detector which responds to visible light. Since the whole cross-section of the image of the entrance pupil strikes the infrared detector at all times the response in this region approaches 100% being limited only by the small absorption of the thin germanium plate **14** and the short wavelength detector. It is thus possible to approach closer to 100% utilization of the aperture for target energy than is possible with the modification of FIGS. 1 and 2 where the initial nulling required that a portion of the image of the entrance pupil did not fall on the infrared detector. FIG. 4 has some disadvantage in that the detectors and filters are not separate and under certain circumstances the selectivity is not quite as sharp. The best system to use will depend on a consideration of all the factors involved.

In connection with the above detailed description of two typical modifications of the invention it is desirable to give some analytical thought to what the detectors and filters really are doing. They constitute a differential and selective detecting system and calibrating or nulling is effected by varying the relative area of the incoming radiation beam which activates each detector. In every case, however, at null or balance by far the largest proportion of the radiation strikes the infrared detector. The precise mechanism by which the cross-section is varied is a little different in the two modifications but the result accomplished is substantially the same regardless of whether the whole selective detector system is physically moved in the beam or only a single filter element as in FIG. 4. In each case precise nulling is effected with maximum utilization of the infrared radiation and the instrument can be nulled both quickly and accurately. This is important when it is used in the field as the radiation from a sunlit background can change. Recalibration or renulling can be effected from time to time rapidly and the instrument can be maintained continuously in a properly calibrated state. This is one of the practical advantages of the invention.

We claim:

1. An instrument for detecting radiation from a target in the presence of intense radiation from a background in a different spectral region which comprises in combination and in optical alignment,

(a) means for collecting radiation, said means including an entrance pupil,

(b) a composite selective differential detector system including two detector elements one of which responds to the target radiation and the other to a portion of the background radiation,

(c) means for imaging the entrance pupil of the radiation collecting means into the plane of the differential detector system, and

(d) means for balancing detector outputs from the background only by varying the relative cross-section of the incoming radiation beam encountering each detector element, said means causing at balance a very large portion of the incoming beam to encounter the detector system element responding to target radiation and a relatively very small and minor part of the beam to encounter the detector element responding to background radiation.

2. An instrument according to claim **1** for use against backgrounds illuminated by solar radiation one detector element responding to short wave radiation including substantial response to radiation in the visible and the other detector element responding to relatively long range radiation having a short wave cutoff in the near infrared.

3. An instrument acording to claim **2** in which the detector elements are photodetectors.

4. An instrument according to claim **3** in which the differential detecting system comprises two photo-conductor areas side by side and filter means splitting the beam into two parts, one passing through one filter and the other part through the other filter and means for translating the detector elements in the plane of the image of the entrance pupil whereby the relative proportions of said image striking the two detector elements is varied.

5. An instrument according to claim **4** in which one filter passes visible radiation and the other filter has a short wave cutoff in the near infrared the detector elements being photodetectors of the same type.

6. An instrument according to claim **5** in which the detector elements are lead sulfide and the short wave cutoff filter is germanium.

7. An instrument according to claim **2** in which the detector elements are a composite sandwich, the front surface responding to short wave radiation and the back surface responding to long wave radiation and means are provided for moving a filter element across the image of the entrance pupil on the detector eelments, said filter element having a short wave cutoff in the near infrared.

8. An instrument acording to claim **7** in which the movable filter element is germanium, the short wave responsive photodetector is gallium arsenide and the long wave photodetector is lead sulfide.

9. An instrument according to claim **7** in which the movable filter element is germanium, the short wave responsive photodetector is silicon and the long wave photodetector is lead sulfide.

10. An instrument according to claim **7** in which the movable filter element is germanium, the short wave responsive photodetector is silicon and the long wave photodetector is indium antimonide.

References Cited by the Examiner

UNITED STATES PATENTS

2,694,956	11/54	Rebikoff	88—22.5
2,931,911	4/60	Nicholas	250—83.3
2,961,545	11/60	Astheimer	250—203
2,972,282	2/61	Forsterling	88—22.5

RALPH G. NILSON, *Primary Examiner*.