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THE BLUE-WHITE BOUNDARY
HORIZON SENSOR

by

H. H. Seward
September 1962

MIT INSTRUMENTATION
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THE BLUE-WHITE BOUNDARY HORIZON SENSOR

ABSTRACT

The blue-white boundary sensor is designed to minimize or eliminate measurement errors which are found in other horizon sensors and which are due to variations in horizon illumination caused by differences in cloud cover, earth surfaces (such as snow, water, and land), or aspect of the sun.

by H. H. Seward

September 1962

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THE BLUE-WHITE BOUNDARY HORIZON SENSOR

Introduction

The sensing of the angular position of the earth's horizon provides valuable navigational data. The blue-white boundary sensor is designed to minimize or eliminate measurement errors found in other systems, such as the infrared horizon sensor and the barely-visible boundary sensor. All three methods are shown schematically in Fig. 1.

Infrared Horizon Sensor

The most accepted method to date has been the infrared horizon-sensor which is shown operating on the night side of the earth in Fig. 1. This was developed for low-altitude earth satellites which spent about one-half of their orbit on the dark side of the earth, a condition which necessitated sensing the earth's black-body radiation. Although these horizon-sensors are satisfactory for attitude control, the accuracy limitations may not meet the requirements of other navigation systems.

The two foremost limitations of the accuracy of infrared horizon sensor are expected to be the unpredictable interference of the horizon view due to cloud cover or water vapor (Fig. 1) and secondly, the relative loss in optical resolution associated with the use of long-wavelength radiation.

Barely-Visible Boundary

Another method shown in Fig. 1 detects the "barely-visible" level of the atmospheric horizon. The barely-visible boundary

sensor makes use of the fact that for spacecraft other than low-altitude satellites, the vehicle will usually be within view of a sun-lit portion of the horizon. Thus, for many trajectories, ample opportunities are available to take navigation sightings using earthshine radiation.

It will be noted that in Fig. 1 the barely visible boundary is shown to vary in altitude with sun aspect. This effect is shown exaggerated for clarity. In areas where the sun rays enter normal to the earth's surface, the illumination of the upper atmosphere is relatively greater and the barely-visible boundary is at a correspondingly higher altitude. This altitude decreases gradually to zero as one observes the horizon about 90° away from the aforementioned region.

In addition, the barely-visible altitude will vary with the local reflections of light from the earth. This reflected light adds to the illuminance of the atmosphere and may range from a few percent for ocean regions to over 80 percent of the incident light for snow-covered regions. Certainly the most troublesome reflections result from variable cloud cover which, though not having quite as high an albedo as snow, produces unpredictable shifts in the barely-visible altitude.

Blue-White Boundary

The blue-white boundary sensor is also an earthshine sensor, but it senses the color of the horizon, e. g., the point on the horizon where an outer-space observer would see the blue atmosphere turn to white at the lower altitudes. The blue-white boundary, however, appears to be relatively insensitive to the effects which limit the reliability of the barely-visible boundary sensor. The altitude of this boundary might be selected to be about 40 to 60 thousand feet depending upon the spectral specifications one uses to define the boundary. Since this boundary is well above the altitudes of dense cloud cover, attenuation of the horizon signal due to clouds does not occur as with

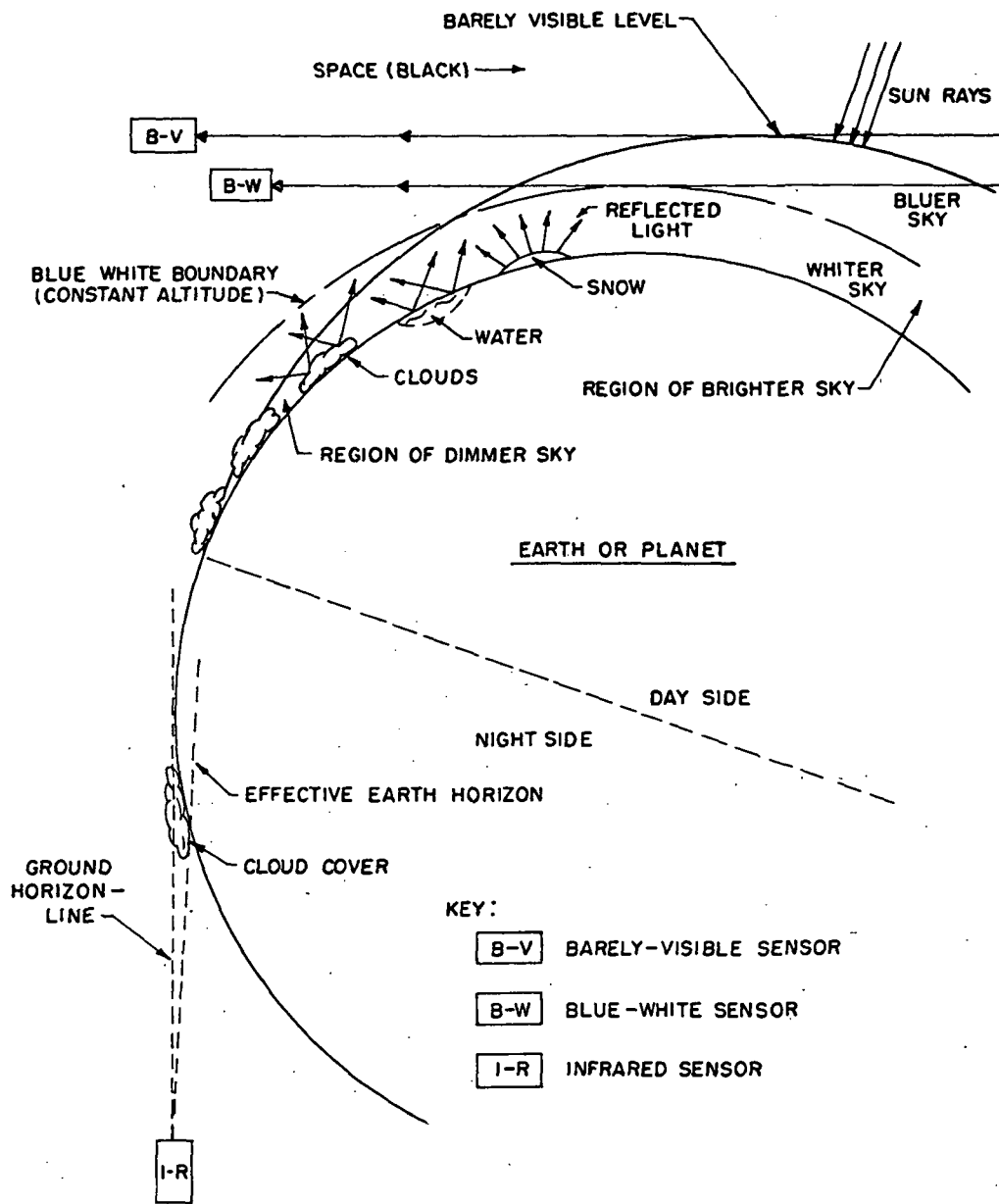


Fig. 1 Schematic comparison of three methods of horizon sensing.

the forementioned infrared horizon sensors. Also since the blue-white boundary is specified as a color rather than an intensity, the boundary does not shift significantly when the intensity of the incident sunlight or reflected sunlight changes with sun aspect or with cloud or ground cover.

Fortunately, clouds and snow fields are quite white and as such reflect sunlight back through the atmosphere without changing the color of the light. Although land and water are not as white, their total reflected light is so low as to be of small consequence as far as changing the color of the atmosphere. It should be noted, however, that very high altitude clouds do exist (noctiluscent clouds), and it is possible that these could appear to be the blue-white boundary at an erroneously higher altitude. However, these clouds are thin, and it might be expected that they would have no effect. On the other hand, from outer space they would be observed edgewise and could possibly be bright enough to prove troublesome. Observation of 70 mm films from a Mercury capsule show no obvious patches of such clouds above the blue-white boundary.

A more extensive study of such films may result in firmer convictions about horizon conditions as seen from space. In any event, should such clouds tend to raise the altitude of the blue-white boundary by an intolerable amount, a higher altitude transition occurring above these clouds could be used. For example, the blue-violet or blue-ultraviolet boundary occurring in the region between 75 to 120 thousand feet might be utilized.

It might also be noted that since an observation of the horizon color averages an extremely large volume of atmosphere, it is quite possible that the relatively insignificant volume of these clouds contributes at most a tolerable error. In addition, since several horizon observations may be made in succession or even continuously, any amount of averaging will decidedly reduce such errors due to such isolated phenomena.

Principles of a Prototype Horizon Sensor

A prototype horizon sensor was developed and breadboard-tested in August 1961 to detect the blue-white boundary. The schematic arrangement of this device is shown in Fig. 2.

The objective lens collects light emanating from the distant earth or planet and casts an image of this onto the aperture plate. This plate has a small hole which allows light from one section of the atmosphere to be transmitted to the color analyser shown behind the plate.

The aperture dimensions are such that during operation the section of atmosphere being analysed is about 10 to 20 thousand feet in altitude and at least that much in the dimension along the horizon. Based on previous experience, this should give a resolution of better than 1000 feet, possibly 200 feet.

The purpose of the color analyser is to detect when the light transmitted to it changes from blue to white, thereby locating the blue-white boundary of the atmosphere. To accomplish this, the light from the aperture is collected by a lens and directed through a direct-vision spectroscope which transmits red light without deviating it and deviates shorter wavelength, violet light up to about 15° . As the light leaves the spectroscope, it passes through a second cylindrical lens which focuses the image of the aperture hole in the plane of the sensors. This image thus appears as a spectral smear due to the varying refractions of the colors as caused by the spectroscope.

The two sensors are located so as to receive light with wavelengths near yellow, and near blue. The output of these sensors is electrically differenced and the condition of electrical null defines the blue-white boundary.

Horizon Sensor Operation

In operating the horizon sensor in conjunction with space

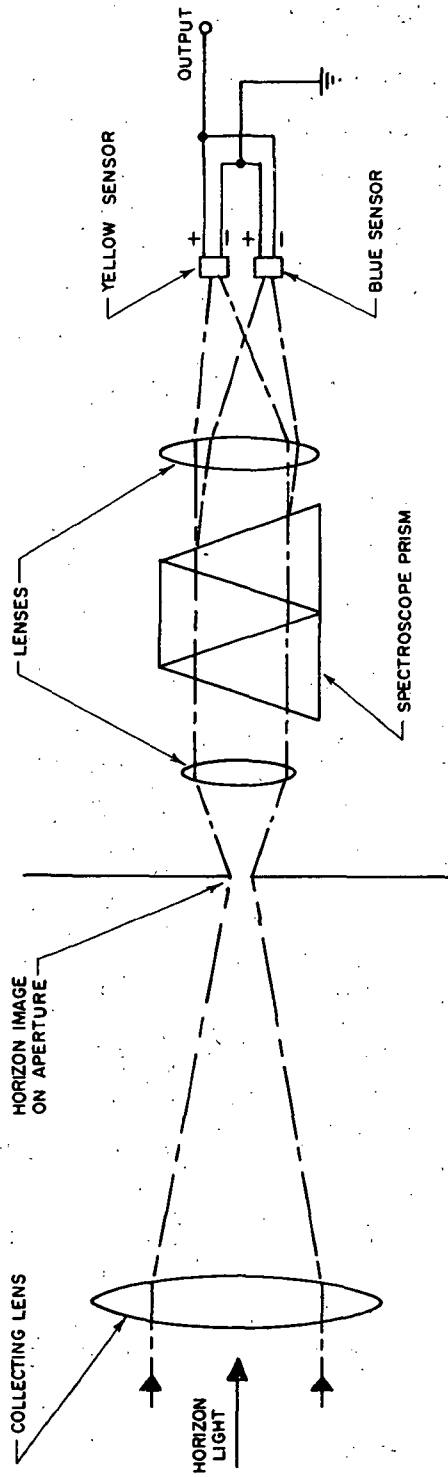


Fig. 2 Blue-white boundary sensor construction.

navigation measurements, the line of sight of the instrument is directed first toward the black space outside of the planet atmosphere. No signal will then appear from the instrument since neither sensor receives light. As the line of sight is brought into the atmosphere, the predominantly blue and violet light of the upper atmosphere, between altitudes of 50 and 100 thousand feet, excites the blue sensor generating a substantial positive signal at the output. This is shown in Fig. 3.

As the line of sight is directed lower into the atmosphere, the blue intensity approaches a saturated level while the longer wavelength energy continues increasing. The net effect of this is to cause a decrease of the positive output from the differential cell pair. Since the cells in the prototype horizon sensor are about twice as sensitive in the longer wavelengths, the output signal goes through zero and then to negative as the longer wavelength light builds up. The dotted curve illustrates how the zero-crossing occurs at a particular color of the horizon and is not affected by intensity change of the horizon.

Prototype Testing

Rudimentary laboratory tests of the horizon-sensor prototype using a simulated blue-white horizon indicate that the electrical null gives decidedly superior color resolution when compared to the human eye.

A more complete evaluation of the technique is necessary with a post-breadboard model. In these tests the horizon sensor would presumably view either an exact laboratory simulation of the horizon as seen from space, a particularly ideal sky from the ground, or a higher altitude sky from an aircraft, a balloon, or rocket.

The theoretical background for this approach to horizon detection is included in unpublished papers by E. M. Copps, Jr.

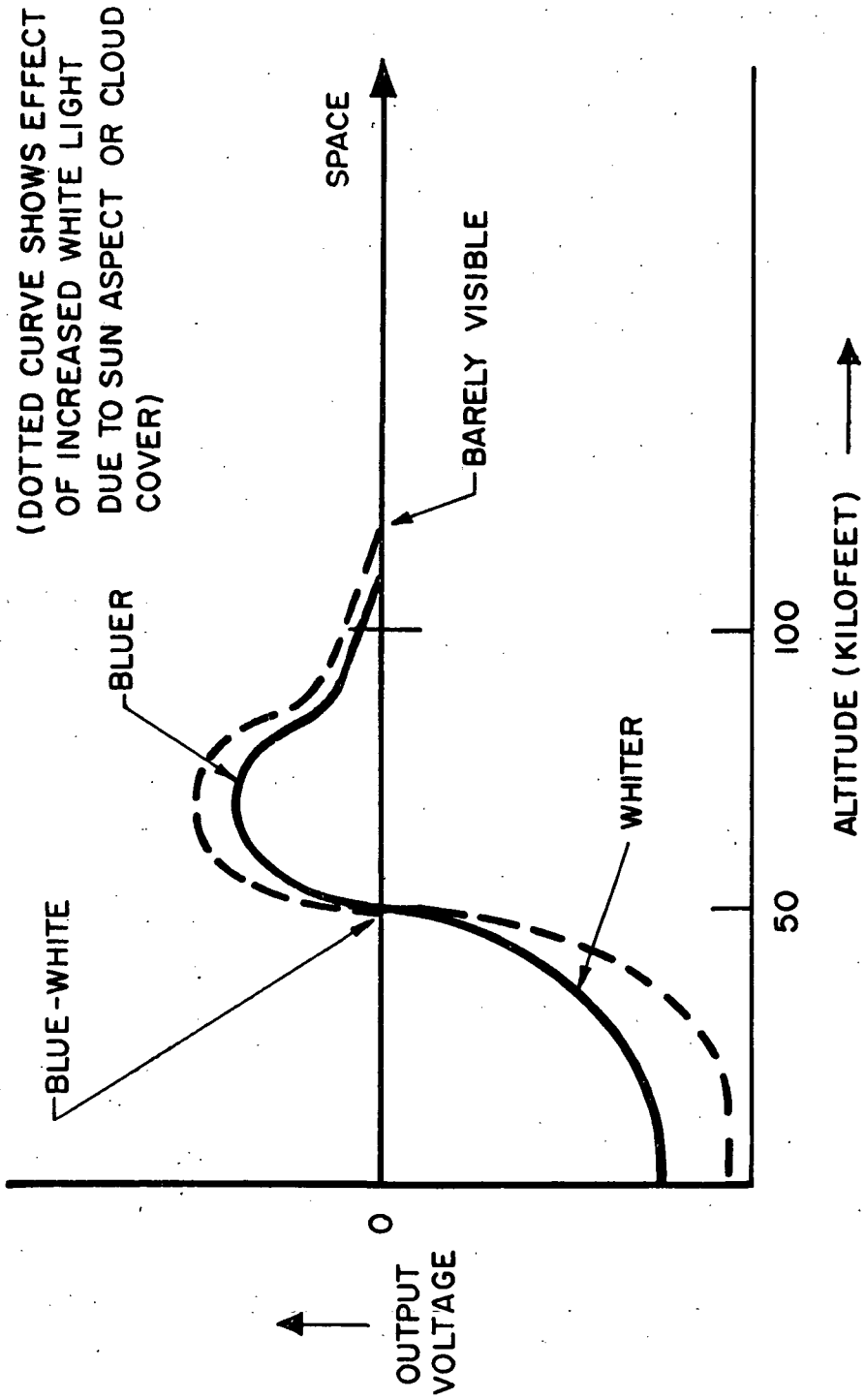


Fig. 3 Blue-white boundary sensor output.

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