Simple, Inexpensive Optical Beacon for Use on Small Satellites

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A Vivitar model 283 photography flash unit was modified and tested for use as an aid for acquiring a target in low-Earth orbit. External circuitry was added to control the flash rate and pulse duration; the relative visibility of the flash was then tested with respect to these parameters, using two types of low-light level television camera systems over a range of effective distances. A rate of 40 flashes/min and a pulse duration of 1.8 ms were found to be optimal within the power capabilities of the existing inverter circuit. Removing the color correcting lens in front of the flash tube was also found to improve the efficiency of the unit in this application.

Introduction

SEVERAL experiments over the last few years (e.g., the Christmas Comet and barium releases) have required terrestrial observers to acquire and track an orbiting satellite with optical instruments. In certain instances, the geometry, time of day, and altitude of the satellite can provide a reflected light signature bright enough for this purpose. It is more likely, however, that these experiments occur at night with the satellite in a low-Earth orbit, so that the reflected light is too faint to be observed. An obvious solution to this problem is to add an optical beacon that is bright enough to be detected by the observers' optical sensors but optimized for a spacecraft's limited size, weight, and power environment.

The work reported here was motivated by a requirement for an optical beacon on each of the small satellites to be used for the Chemical Release Observation[1] (CRO) experiments. These experiments are part of the Infrared Backgrounds and Signatures Survey (IBSS) mission, a Strategic Defense Initiative Organization (SDIO) program that is scheduled for a Shuttle launch in early 1991. In this application, the beacon must be acquired by the Shuttle crew with a low-light level television (L^3TV) system in order to more accurately point other infrared (IR), visible, and ultraviolet (UV) sensors at the satellite before and during a chemical release. Although acquisition of the satellite by the Shuttle crew is the primary purpose for the beacons on the CRO satellites, it is also desirable that they be detected by L^3TV camera systems used as part of sensor packages on aircraft and at ground sites that will also be observing the chemical releases. For these sensors, the beacons may not be the primary means for acquiring and tracking the satellite, but may provide an accurate reference point in the imagery data collected during these experiments.

The CRO satellites were designed to be low cost and to have short lifetimes. In addition to minimizing size, weight, and power consumption of the optical beacons to be used on these satellites, their cost also had to be low. A number of aircraft beacons and other commercial strobes were evaluated as candidates. The remainder of this paper describes the rationale for selecting the flash unit, the modifications that were made to it for this application, and the tests that were conducted to assess its visibility in a remote sensing mode with two different types of L^3TV cameras.

Flash Section

Flashing lights are commonly used in terrestrial and aircraft applications, but not on satellites. Thus, fabrication from scratch or modification of a beacon or flasher built for another application was necessary for the CRO application. Four types of off-the-shelf flashers were investigated for modification for CRO use: emergency vehicle strobes, aircraft anticollision strobes, emergency locator strobes for campers and boaters, and photography flash units. It should be noted that the first three of these types are designed to catch the attention of the unaided eye of a human observer, whereas photography flash units are designed simply to produce visible light as efficiently as possible. An intense short pulse is desirable for the photography application because it minimizes the time that a camera shutter must remain open, but for a human observer, the apparent brightness of a flash diminishes as the pulse duration is shortened even though the pulse energy remains constant.[2,3] For this reason, vehicle, aircraft, and emergency locator strobes are often designed to produce two short, low-energy pulses spaced close enough in time to appear as a single flash, instead of a single short, high-energy pulse to achieve the same effective brightness. In the CRO application, only the apparent brightness of the strobe as it appears to an L^3TV camera and monitor combination is important. In this respect, the photography flash is preferable because it will supply as many detectable photons as possible to the camera in a time less than a single TV frame. The question remains, however, of how bright such short pulses must be for a human observer to detect them on a TV monitor when captured by an L^3TV system under the conditions of interest.

Inspection of examples of all four types of off-the-shelf flashers confirmed that, due to component outgassing and lack of thermal sinking, none of the candidates would perform without modification. Even at modest light output energy and flash frequency, the aircraft and land vehicle models are quite large and heavy. Furthermore, they are all adapted to 12-V operation, whereas the satellite bus voltage, accommodating an electronics payload of digital electronics, was already established at 6 V. Space for the required dc-to-dc converter and the added power necessary to make up for the converter losses are both at a premium on the satellite. In contrast, the emergency locator strobes are designed to flash for hours or days while operating on the equivalent of only four standard AA dry cells. Thus, their light output per flash is quite low (10 to 15 mJ), making their visibility nil at the ranges required here.

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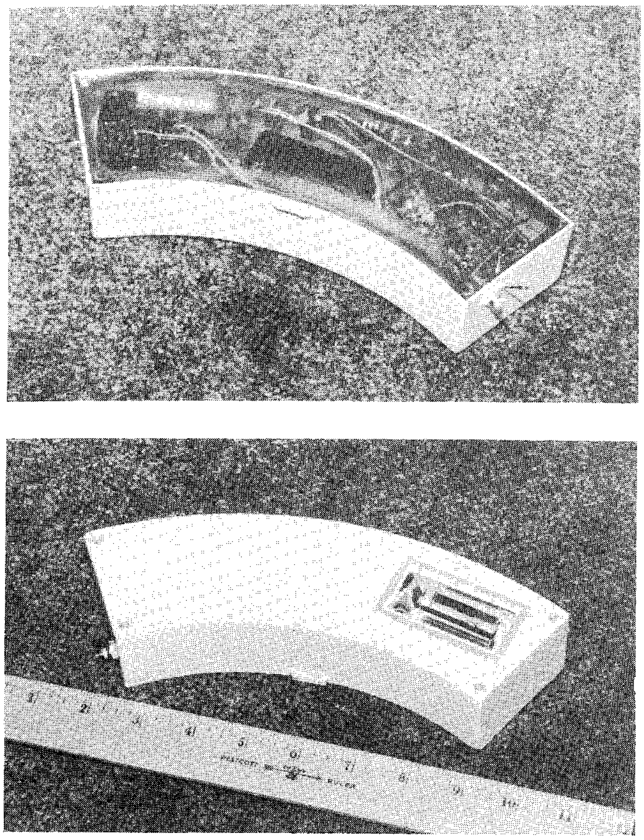

Fig. 1 The Vivitar model 283 photography flash unit, as modified for the CRO satellite showing the flash tube and reflector.

Because portability is a key element in amateur photography equipment, this group of products is much more compact and generally requires only 6 V (e.g., four AA cells) compared to the aircraft and land vehicle flashers. Furthermore, recent industry trends to supply larger flash energies have achieved compact units with single flash energies above 1 J. The Vivitar 283 was selected because it was among the most powerful (using flash guide numbers as the metric) of the compact designs that mount to the camera hot shoe above the prism/viewfinder. Table 1 shows that, in fact, about 10 J/flash is easily achieved with this model. Modifications to the Vivitar model 283 were required in order to operate it as a beacon and to make it flightworthy. To protect the unit for short-term use in space, the electronics were reconfigured and potted in epoxy. This prevents electrolytic devices from exposure to space vacuum, which may cause leakage, and provides mechanical support against launch vibration loads. Potting also provides adequate thermal sinking of components that normally rely on conductive and convective cooling from an ambient atmosphere. Beacon operation changes included circuitry for repetitive flashing and control of the pulse energy. Specific circuit changes are described in the next section.

Before potting, the flash electronics were separated onto three discrete boards. This allowed packaging into the conformal housing (Fig. 1), which best accommodated the available mounting space on the satellite. The feedback circuit controlling flash energy was replaced with a potentiometer, which was preset before potting. The flash power was adjusted to ensure that the flash frequency requirement was met and to keep power draw within the budgeted allowance. The first potted unit was used in the visibility tests described in this paper. All units were subjected to vibration testing and were run in a thermal vacuum chamber, where they were continuously operated in vacuum at 1 flash/s for 72 h and cycled between +60 and −60°C. Typical operation plans call for approximately 10 min of operation on orbit. No failures in the flash units have occurred in this type of testing to date. One unit failed during the camera tests, as described later, but the failure appears to have been caused by a flash tube lifetime problem rather than a failure due to the environment.

Flash Description

The flash trigger and quench of the Vivitar model 283 pictured in Fig. 1 are controlled with the external timing circuitry shown in Fig. 2. Components R2 and C1 control the frequency of one-half of the NE556 dual timer in a stable operation in the range from 200 Hz to 20 kHz. The CD4020B ripple counter divides this frequency by 2^{14} to produce flash trigger repetition rates that can be varied from about 60 flashes/min to less than 1 flash/min. In practice, it was not possible to reliably flash the unit faster than about 40 flashes/min, and although repetition rates as low as 6 flashes/min were used in the testing, rates below 10 flashes/min were too slow to be useful for the type of remote acquisition considered here. The observer had to wait too long between flashes and tended to move the sensor field of view too far and too fast searching for the next flash. It also took too long to set up with such long delays between flashes.

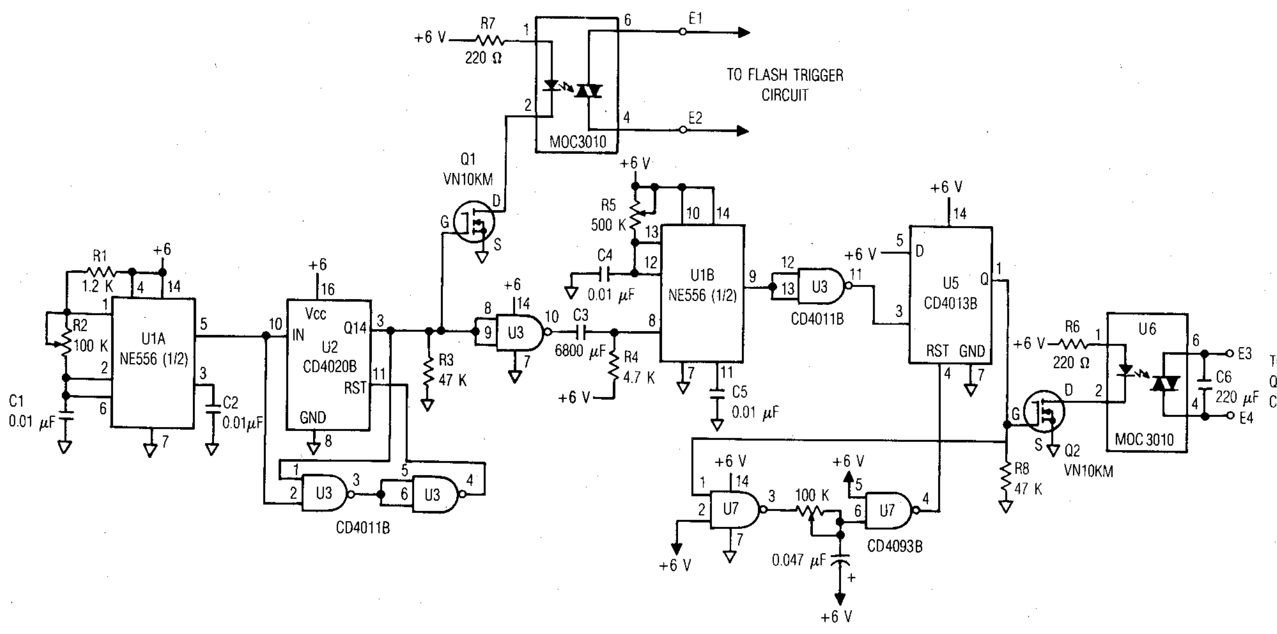

Fig. 2 Timing and control circuitry for the prototype CRO beacon.

In ordinary operation, the flash unit uses a phototransistor sensor with neutral density filters to trigger a quench circuit when the integral of the light reflected to the unit reaches a preset level.[4] In the modified flash, the phototransistor is replaced by an optoisolator switch, and the other half of the NE556 is used in monostable operation to close this switch after a delay time, which is controlled by R5 and C4, over the range from 0.05 to 6.0 ms. The energy of the flash is determined by the length of the pulse, although the relationship is definitely nonlinear. A side benefit derived from controlling the output of the flash with the quenching circuit is that the flash is extinguished without completely discharging the main storage capacitor. This allows a more efficient tradeoff between flash energy and repetition rate because less time is required to recharge after a short pulse and the unit can be cycled at a faster rate.

The characteristic shape of the visible light pulse from the flash unit is shown as the envelope of the superposition of pulses in Fig. 3. The pulse traces were recorded with a 1P28 photomultiplier tube and a digital oscilloscope. The initial 50-μs spike at the beginning of the pulse is typical for the output of a xenon flash tube in the green-yellow portion of the spectrum. The superposition of truncated pulses is annotated with the resistance value selected with R5 that produced the pulses.

The model 283 flash unit comes equipped with a plastic diffuser/Fresnel lens. The lens provides some focusing in the plane containing the cylindrical axis of the flashtube and also filters the light to more closely match the spectral characteristics of sunlight. With the lens removed, a 20% increase in the total energy of the flash output was observed by using a totally absorbing laser power meter looking straight into the flash. Measurements with an InAs detector and IR filter combination revealed that the lens attenuated the light from the flash by a factor of 50 beyond 1 μm. Since many TV camera tubes and CCD sensors have a significant response near 1 μm, additional measurements were made and testing was done to determine if removing the lens might increase the useful range of the flash as a beacon. A side effect of removing the lens is that the angular pattern of the flash spreads out in the plane containing the flashtube, this being the plane with wider coverage. It is interesting, however, that the half-power profile is approximately 80 × 160 deg in both cases.

In order to better characterize the flash intensity with respect to the pulse duration, approximate calibrations of the flash in both photometric and radiometric units were attempted with and without the lens removed. These data were intended to be used in predicting the relative response of L³TV systems to the modified flash in beacon operation. Photometric measurements were performed with a photographic flash meter, and radiometric measurements were made with the laser power meter. The power meter provides an estimate of the total flash energy that is insensitive to its spectral content. The results of these measurements are summarized in Table 1. These measurements were made on a single flash unit,

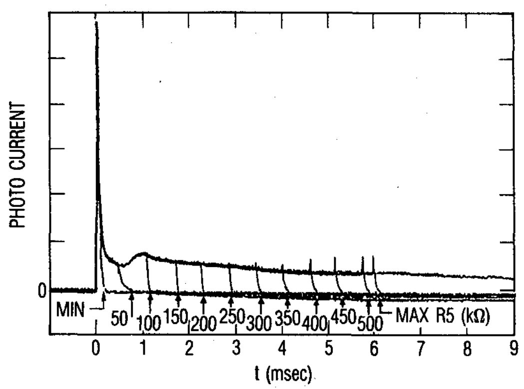

Fig. 3 Oscilloscope traces of the response of a photomultiplier tube to the light from the CRO beacon prototype.

Table 1 Photometric and radiometric calibration measurements

Index, R5 kΩ	Duration, msec	Brightness, cd-sec: With lens	Brightness, cd-sec: Without lens	Radiant energy, J: With lens	Radiant energy, J: Without lens
50	0.5	590	550	4.1 ± 0.1	4.5 ± 0.1
100	1.1	1050	980	6.4 ± 0.1	8.2 ± 0.2
150	1.8	1330	1210	7.9 ± 0.1	10.0 ± 0.3
200	2.4	1490	1390	8.6 ± 0.2	11.1 ± 0.3
250	2.9	1590	1490	9.2 ± 0.2	11.6 ± 0.3
300	3.5	1610	1500	9.9 ± 0.1	12.0 ± 0.2
350	4.0	1700	1590	10.3 ± 0.1	13.2 ± 0.3
400	4.7	1810	1590	10.6 ± 0.1	13.5 ± 0.3

although comparisons were made among a total of three beacon prototypes. It was found that, although the total flash energy varied by about 15% among the three units, the time behavior of the pulses from each one was identical.

The sensitivities of most TV cameras are given in photometric units, as these units are commonly used to specify the intensity of illumination for artificial lighting. However, L³TV cameras commonly are sensitive to wavelengths well outside the region of human eye response (about 0.38 to 0.78 μm), particularly in the long wavelength red and infrared regions. If the spectral content of the flash changes significantly with pulse duration, calibration of the flash output in photometric units might not provide an accurate indication of an L³TV response. For example, an effect of this type would occur if there were a large drop in the temperature of the plasma temperature inside the tube over the duration of the pulse.

The values in Table 1 show that the radiometric and photometric measurements are reasonably well correlated, at least for pulse durations of 3 ms or less. This suggests that relative spectral output from the flash is fairly constant for pulse lengths in this range. The maximum photometric brightness is consistent with the manufacturer's specification of 1280 to 2570 cd-s (candela-s; actually 138 to 277 lux-s at a distance of 10 ft).

It is interesting to note that removal of the lens results in an increase in the radiometric output but a decrease in the photometric output in the forward direction. Two factors contribute to this effect. Removing the lens spreads the pattern, which can dilute the amount of light seen directly in front of the unit. This explains the decrease in the observed photometric brightness. Removing the lens also permits more wavelengths to be transmitted, which explains the increase in the radiometric measurement. However, the additional light comes from outside the visible region and, as such, does not contribute to the photometric brightness. It was also noted that the lens fluoresces under ultraviolet light, which implies that it converts some of the ultraviolet output from the flashtube into visible light.

The laboratory measurements indicate that the apparent brightness of the flash as observed on the monitor of a L³TV system should increase with increasing pulse duration. It was not possible to predict if the flash would appear brighter with or without the lens removed from these measurements, and so this determination was made subjectively during the field tests. In conjunction with the field tests, however, many additional measurements were made in the laboratory of the flash-to-flash variations for several units. These measurements were done because of the large variability between flashes observed in the field for both of the camera systems used. The maximum flash variability observed in the laboratory for a single unit was never more than 5%, even while randomly blowing cooling air on the flashtube to simulate outdoor conditions. Other explanations are offered for the flash-to-flash variation in the field test in the description below.

Field Tests

Two different kinds of L³TV camera setups were used to test the utility of the Vivitar model 283 as an optical beacon: a

Cohu camera flown by NASA on the LearJet Observatory and Kuiper Airborne Observatory that has an intensified silicon intensified tube (ISIT), and a pair of Xybion ISS cameras that use intensified charge injection devices (ICID). The LearJet Observatory was one of several platforms considered for use in the CRO experiment, and its ISIT camera is similar to those used on other aircraft and at some ground-based optical sites. The two ICID cameras were modified by the Air Force Geophysics Laboratory (GL) for use in space on the Shuttle Pallet System that carries instruments for the IBSS mission. These cameras have each been fitted with a unique 1.4-in. diameter lens system, giving one camera a narrow (2.4 × 3.2 deg) and the other a wide (11 × 14.4 deg) field of view. During the IBSS mission, either may be used to acquire the optical beacon on the CRO satellite with fields of view chosen for the CRO experiment.

The ISIT has a demonstrated high sensitivity, being routinely used with a 3.5-in. diameter lens to acquire stars of magnitude 11 or fainter (13 was the limit observed with a new tube and fiber-optic bundle between the lens and camera). However, for a flashing source, if the flash occurs right after the scan has passed by the spot where the flash signal will appear, the signal can decay a significant amount before the scan returns to that spot. The ICID device is less susceptible to this problem, as it continuously collects photoelectrons arriving at each "pixel" detector until the total charge for the detector is read out. The ICID has less history in astronomical applications, and was therefore considered more of a risk to use for observing the beacon. The tests discussed here address this concern by producing observations of flash brightness that could be compared against observations of stars of known magnitude with both types of cameras, thus establishing the sensitivity requirements for an ICID camera to detect the CRO beacon in space.

Test Series 1

On the nights of March 8–9 and 9–10, 1988, two beacon prototypes were taken to a hairpin turn about 500 ft below Lick Observatory on Mt. Hamilton, California, that could be precisely located on a topological map. The NASA Ames LearJet Observatory guidescope system, which uses a 3.5-in. diameter Angénieux zoom lens as a light collector, was taken to a straight stretch of Quimby Road just below the ridge to the southwest of Mt. Hamilton peak. The line-of-sight distance was 4.34 miles, and USGS topographical maps were used to pinpoint both locations to a few yards. In addition to evaluating the Vivitar flash unit as a beacon to aid Shuttle astronauts in acquiring the CRO satellite and its usefulness as a beacon for airborne measurements at 500–600 miles, a third objective was to obtain videotape of both the flash and of stars with the whole system to use in training the NASA mission specialists or other sensor operations personnel. Subject to the limitations that the ISIT camera does not respond to the flash exactly like the ICID cameras selected for use on the IBSS mission, all of these objectives were met.

The first night, a series of tests with an automatically controlled flash was conducted at various pulse durations and repetition rates and with neutral density (ND) filters of 0.9, 2.0, and 4.2 (to simulate 12, 43, and 550 miles, respectively). This unit had a color compensating lens. The air was murky, making the use of a long baseline less reliable than ND filters in conjunction with the 4.34-mile baseline. The sites chosen had the advantages of very dark backgrounds, observatory lights nearby for quick acquisition of the flash site, and a totally unobstructed line of sight over which hand-held walkie-talkies could be used for clear, quick communication. The second night, a second prototype without the color correcting lens was operated with manual triggering to evaluate the effect of the lens on the apparent brightness of the beacon. In addition to the ND filter measurements, tests of the response of the camera to both units were made with each unit oriented at various angles with respect to the normal head-on aspect.

The ND filters were placed in front of the flash unit in order to compare the apparent brightness of the attenuated flash with stars of known magnitude for the same gain and focal length settings of the camera. Two types of ND filters (glass and Wratten gels) were used with comparable results, so that problems of spectral variation in the attenuation by the ND filters or saturation effects in these filters were not expected. After the nighttime experiments, follow-up tests of the ND filters were made and saturation effects at the levels used for the nighttime tests were found to be negligible. There was a variation in spectral attenuation, but not at a level sufficient to change the test conclusions.

Summary of Observations During Test Series 1

Many factors will affect the success of the use of the Vivitar flash as a beacon, and the factors peculiar to the LJO camera were quickly discovered. In general, ISIT cameras can be run at varying voltage levels (or gain levels), which lead to dramatically different sensitivities. The LJO system had an automatic gain setting (maximum gain on a dark scene) of 6.94 in arbitrary units related to the value of the high voltage used inside the tube. In addition to the tests made at the automatic gain setting, several tests on both stars and the beacon were made at lower gain values that were set by hand. In one case, at a gain setting of 4.6, only stars of about third magnitude could be seen, whereas at a gain of 6.94 stars down to about seventh magnitude, or about 40 times fainter, could be seen. Clearly, the test results presented here demonstrate that a given camera must be set up to be able to "see" stars of a particular magnitude or fainter to ensure the successful use of this type of beacon in a particular experiment scenario. If the camera is panning over a scene, the sensitivity will be decreased by a factor of about 5 (two units of magnitude) for typical slow manual scan rates, and more for faster scans. This margin must be included in the sensitivity requirements for the camera if it is to be used in a scanning mode.

The video scan rate of the TV is 30 frames/s, and the flash duration is only a few milliseconds. If the flash occurs at random times with respect to the start of the raster scan, there may be a delay of as much as 33 ms before the appropriate pixel detectors are interrogated, i.e., "between" frames. If the flash appears bright enough (as it did for a 6.94 camera gain setting, with a duration of 0.5 ms and an ND 2.0 filter corresponding to a range of 72 km), bloom and saturation, combined with the persistence of the ISIT phosphor, resulted in detecting all the flashes, although they did not appear equally bright. With an ND 4.2 filter (aircraft distance of roughly 910 km or 550 miles) and the same duration, flashes could still be seen, but the scintillations in the camera flickered on and off just as the beacon does. Without knowing where in the field to look, the flash would not have been identified under these conditions. Increasing the flash duration to 1.8 ms resulted in an easily discerned flash image, even with ND 4.2 filters. Thus, an aircraft (that could have a more sensitive system using, for example, a 10-in. diameter collector) should be able to acquire the beacon at a range of 500 to 600 miles.

The flash unit without the lens appeared appreciably brighter than the unit used the first night. Although the air was much clearer on the second night, the test was conducted over a relatively short distance, and it is believed that the removal of the lens caused the extra brightness. Removing the lens also results in more off-axis flux, further enhancing the chances of detection if the satellite axis is not aimed directly at the observer.

With the ISIT camera, repetition rates of 1 flash every 3 or 6 s were too slow; the observer needed to see more flashes, even if they were fainter, to be convinced that they were real. A rate of 40 flashes/min seemed a good compromise between rate and power.

For the Shuttle scenario, the 0.5-ms flash duration was more than adequate for the sensitivity of the LJO ISIT system. A duration of 1.8 ms was enough to meet the aircraft require-

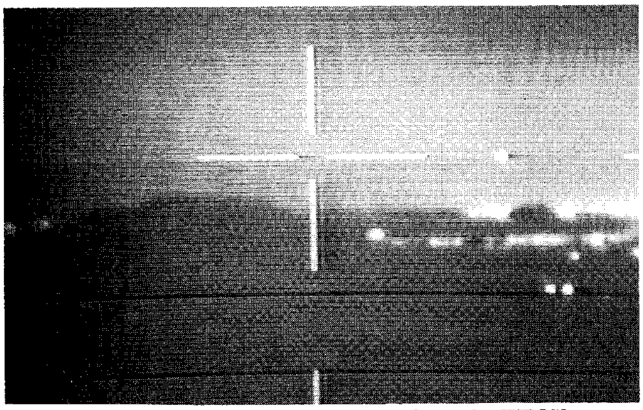

Fig. 4a The image recorded on videotape from the WFOV camera with no flash illumination.

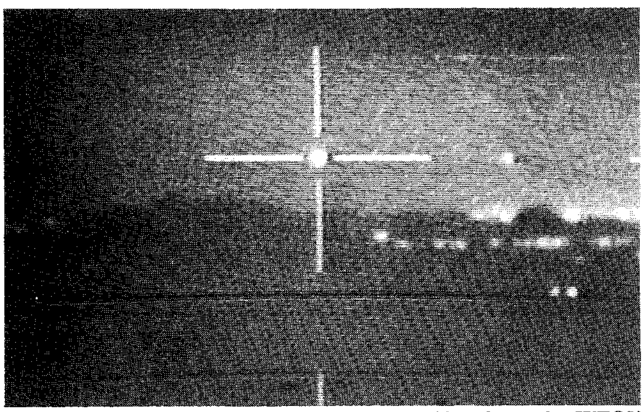

Fig. 4b Photo of a single frame from the video from the WFOV camera with the flash in the cross hair.

ments as well, although 0.5 ms might be sufficient if an ISIT camera were used with better sensitivity than the LJO system used here, and/or the camera had fewer scintillations (random, short-lived bright specks in the field when the camera is operated at high gain).

Measurements of camera response with respect to the line-of-sight angle to the flash showed that, within a range of ± 45 deg in azimuth and ± 30 deg in elevation, the flash did not appreciably degrade in brightness. If the line of sight of an observer to the flash is in the range of these angles, there is a good chance of detecting the beacon with a camera similar to one of the types used for these tests.

Test Series 2

The second series of tests used the Xybion ICID cameras as modified by GL. With the ICID, there is no dead time "between frames" and it was expected that, if these cameras were sensitive enough to detect the flash, there should be an improvement in the uniformity of the appearance of individual flashes. This should be a significant advantage over a system using an ISIT to find the flashing beacon. These cameras are also lighter and more compact than ISITs operated in the past, and are more rugged.

The two ICID cameras were tested at Kitt Peak National Observatory outside Tucson, Arizona, with the prototype CRO beacon set up on Mt. Lemmon, 92 km away. This afforded the nominal baseline for Shuttle operations without the need for neutral density filters. There was a distinct haze between the two mountain tops, and lights on Mt. Lemmon were seen to twinkle at a significant level, although the view toward the zenith was clear and reported to be of photometric quality by astronomers on the nearby telescope.

Summary of Observations During Test Series 2

Observations were also made with the ICID cameras (wide- and narrow-field of view) for various power levels and flash

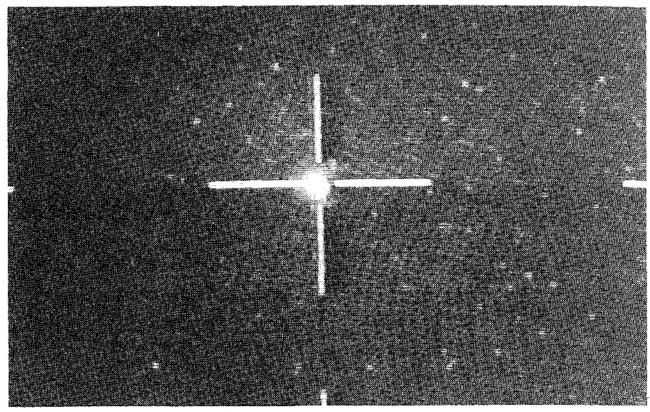

Fig. 5. Narrow field of view image with flash and camera scintillation speckles.

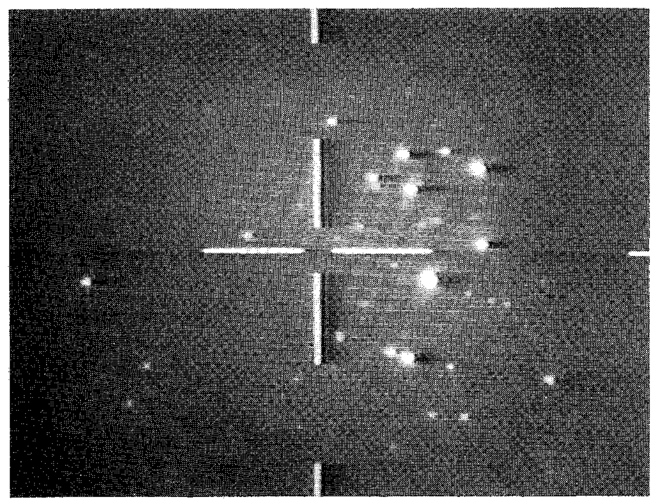

Fig. 6 The NFOV image of the Pleiades (Seven Sisters) star cluster.

repetition rates, much as was done with the ISIT camera. The variation in intensity of the individual flashes was much greater than expected. In contrast to the laboratory measurements, where individual flash intensities were repeatable to about 5%, more than a factor of 2 variation was observed at the test site. As noted above, nearby continuous sources also showed considerable variation due to atmospheric effects, as expected for a line-of-sight passing above a city such as Tucson. These observations are consistent with the correlation time for atmospheric transmission effects of 1-3 ms reported by Menyuk and Killinger.[5] On orbit this will not be a problem, and the flash may appear generally brighter as well, thus increasing the range at which the flash can be detected without increasing the power requirements.

In Fig. 4a, the wide field-of-view image without the flash has been reproduced from the videotape made during the test. In Fig. 4b, the same scene with a flash is shown in a photograph of a single frame in freeze-frame mode. Even though this image was recorded with a flash pulse duration of 1.8 ms, the image is very bright, if not saturated. Comparing the tape images of the flash with those of the Pleiades suggests the flash is brighter than a third magnitude star, and perhaps as bright as magnitude 0 to 1.

In Fig. 5, the narrow field-of-view image of another flash at the same power setting is shown. The additional scintillations (speckles) seen at this illumination level are associated with a narrower field of view. Note the extreme saturation and yet modest bloom of the flash image. None of the surrounding lights were within this narrow field of view, which explains the absence of other images. A faint shadow of a nearby hill can be seen on the original videotape.

In Fig. 6, a narrow field-of-view image of the constellation of the Pleiades can be seen. The magnitude limit is approximately 9, corresponding to a flux of about 8.1×10^{-17} W/cm^2 over a nominal 4800–6800 Å visual bandpass filter. (Note that the camera is actually responding to a wider bandpass in these tests, but this flux is referred to a standard V filter for reference purposes. See Allen[6] for more complete information on calibration.) This is a more than adequate verification of sufficient camera sensitivity to be able to detect the flash in the operational situation. The increased sensitivity provides the added benefit of detecting enough background stars to use them for pointing and tracking information.

In summary, test fields of the Pleiades, Orion, Cassiopea, and two planets (Jupiter and Mars) were obtained with the ICID. The camera, using a 1.4-in. diameter collector, was able to see to ninth magnitude, two magnitudes (a factor of 5) fainter than the requirement derived during the Series 1 tests for being able to detect the beacon on orbit. Again, the new observers and camera operator verified the choice of a relatively fast flash rate (≥ 0.5 Hz) at a reduced energy per flash over a slower rate with more energy per flash for the optimum visibility/detectability. The flash was again visible with both cameras at all durations of 0.5 ms or greater, but a duration in the 1- to 2-ms range is preferred if the corresponding power drain of the CRO satellite batteries can be tolerated. The resulting increased brightness would enhance the usefulness of the beacon at longer ranges, such as encountered in an airplane-based experiment, but the allowable power drain rate will depend on the total amount of time the beacon is required for the IBSS/CRO fine-pointing maneuvers, combined with the total power available on the satellite.

Conclusions and Recommendations

A relatively inexpensive, low-power consumption, high-reliability modified photographic flash unit has been developed and successfully tested for use as a beacon for remote acquisition situations. This unit is well suited for use on low-Earth orbit satellites or between two airborne platforms. Trade-offs of visibility and power consumption make this a versatile alternative to high-powered airplane strobes or searchlights. Tests with ISIT and ICID low-light-level TV systems show more variability than expected in displayed flash intensity. This is tentatively attributed to millisecond time-scale fluctuations in atmospheric transmission over the long horizontal lines of sight used for these tests. The ICID camera has some advantages over the ISIT camera because the ICID integrates continuously, whereas the short duration of the light pulse produced by the flash can occur between frames for the ISIT. Either type of camera can be used to find the beacon in the IBSS scenario, as long as it is sensitive enough to see seventh magnitude stars. This sensitivity can be achieved with either a low-noise camera at high gain, or a moderate sensitivity camera with a large telescope.

The performance of a prototype optical beacon was superior for this application without the plastic lens on the flash unit. Removing the lens resulted in a brighter signal and a larger range of angles over which the beacon could be observed with either type of camera tested. This will probably be true for any xenon flashtube camera strobe modified for use as an optical beacon. With the Vivitar 283 camera flash, a repetition rate of about 0.5 Hz and a pulse duration between 1.0 and 2.0 ms were adopted as the optimum trade-off between visibility and power consumption.

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