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Radio-controlled xenon flashers for atmospheric monitoring at the HiRes cosmic ray observatory

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Abstract

Stable, robust ultraviolet light sources for atmospheric monitoring and calibration pose a challenge for experiments that measure air fluorescence from cosmic ray air showers. One type of light source in use at the High Resolution Fly's Eye (HiRes) cosmic ray observatory features a xenon flashbulb at the focal point of a spherical mirror to produce a 1 μs pulse of collimated light that includes a strong UV component. A computer-controlled touch tone radio system provides remote operation of bulb triggering and window heating. These devices, dubbed "flashers", feature stand-alone operation, ± 5% shot-to-shot stability, weather proof construction and are well suited for long-term field use. This paper describes the flashers, the radio control system, and a 12-unit array in operation at the HiRes cosmic ray observatory © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The study of the highest energy cosmic rays ($E > 10^{19}$ eV) by means of measuring air fluorescence requires monitoring changes in the aerosol component of the atmosphere. These changes can affect significantly the fraction of light that propagates from the air shower to the detector. This in turn affects both the calculation of the detector aperture and the calculation of shower energy.

It is desirable to monitor as much of the actual volume of atmosphere as possible in which the cosmic rays are measured. This requires a light source that can be observed over a distance scale of 10–30 km and can be located where power and telephone lines are not available. The entire system must have the capability to operate in a stable manner over the many year lifetime of an experiment and must survive large changes in ambient temperature and weather conditions. The source spectrum must include the three main nitrogen fluorescent wavelengths in air: 337, 357, and 391 nm [1,2].

Because long-term use of airborne sources to measure light propagation directly is logistically impractical, the High Resolution Fly's Eye (HiRes [3]) uses collimated sources placed on the ground. The atmosphere scatters light out of the beam produced by the source. The same detector used to measure light from cosmic ray showers is used to measure this scattered light (Fig. 1).

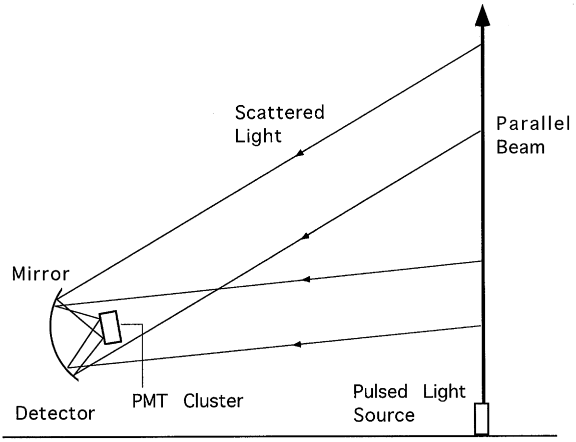

Fig. 1. Diagram (not to scale) showing the path of light from a collimated source on the ground to the cosmic ray detector. The detector measures this scattered light to probe the atmosphere where the cosmic rays are detected.

2. Xenon flashers

A flasher produces a pulsed beam of light. Parameters are listed in Table 1. Flashers were built initially as a diagnostic tool and monitor for the Fly's Eye detector [4].

2.1. Optics and alignment

The optics of a flasher are similar to those of a reflecting telescope but with the light path in the opposite direction. A xenon flashbulb is located with the midpoint of its two discharge electrodes at the focal point of a 20.3 cm/*f*2.0 spherical mirror. The flashbulb has a cathode and anode separated by 1.5 mm and is filled with xenon to a pressure of 2 atm. The light reflected by the mirror travels upward through a Pyrex window at the end of a cylindrical steel housing. The position of the flashbulb assembly can be adjusted in three dimensions relative to the mirror to minimize beam divergence and to align the beam so that it is perpendicular to two bubble levels mounted near the mirror.

A method to align flashers to within 0.05° of vertical was developed for field use. The basis of the technique is to establish a temporary vertical laser

Table 1
Summary of flasher parameters

Flash bulb	EG&G FX-279
Firing voltage	1800 V (typical)
Discharge capacitor	0.5 μF
Discharge energy	0.8 J at 1800 V
Shot to shot variation	$1\sigma = 5\%$
Pulse width	1 μS
Output variation vs. HV	$< 3\%$ over 2000 to 2500 V
Temperature coefficient	$+ 0.25\%/°\text{C}$
Beam divergence	0.1° (typical)
Alignment accuracy	$\pm 0.05°$
Mirror diameter	20.3 cm
Mirror radius of curvature	81.2 cm
Mirror *f*-stop	2.0

beam and then to align the flasher using this beam as a reference. A rotating table centered over a flasher holds two levels and a small HeNe (pen) laser pointing vertically. The laser beam reflects off a 45° mirror mounted temporarily above the flasher and onto a target approximately 30 m away. The locations of the laser beam spot at the target are recorded while the table is rotated and leveled. The center of the laser beam spot images corresponds to the vertical direction and is marked on the target. After the rotating assembly is removed, the flasher is fired and mounting bolts that hold the entire flasher assembly are adjusted center the image of the flash at the target the mark.

2.2. Window heater and mechanical construction

A heater element beneath the window can be turned on to melt frost or snow or to evaporate dew. The element is made of 10 ohm/m (0.38 mm) nickel–chromium wire and dissipates 40 W at 12 V. Under continuous operation it can melt approximately 10 cm of snow per hour from the window. Cycling the heaters with a 30% on time suffices to keep the flasher window free of frost and dew under most conditions when the cosmic ray observatory is collecting data.

The flashbulb assembly, mirror, and heater are located inside a sealed cylindrical steel housing. Perforated tubes filled with desiccant are also mounted inside the housing. The housing is connected to a mylar balloon (located in a separate control box) that inflates or deflates to reduce pressure differences between the inside the flasher housing and the outside caused by changes in environmental conditions. Electrical connections are routed through a 14 pin mil-spec. connector.

2.3. Trigger circuit

The heart of the flasher is the assembly containing the xenon flashbulb, discharge capacitor and trigger circuit (Fig. 2). The design uses only passive components. There are two electrical connections: ground and positive high voltage. If the supply voltage is below the fixed trigger threshold voltage, typically 1800 V, the bulb does not fire. When the voltage exceeds the threshold, the bulb will fire at a rate between 1 and 2 Hz. The light output is nearly independent of input high voltage. For operation in the field, this is especially important because this high voltage is proportional to the voltage of a battery driving a 1:200 DC/DC converter. The battery voltage, and consequently the high voltage, can vary because the system drains charge during the night. A solar panel charges the battery during the day.

The firing circuit works as follows. A positive voltage applied to the system starts charging a high-voltage 0.5 μF capacitor (Plastic Capacitors Inc. P/N OF0-504) connected across the cathode and anode electrodes of the xenon bulb. At the same time a lower voltage, determined by the R1, R2 voltage divider, develops across the three Sidacs (Sylvania part number EGC 64119). When this voltage reaches a critical value, typically 360 V, the resistance of the Sidacs drops nearly to zero on the time scale of a few hundred nanoseconds.

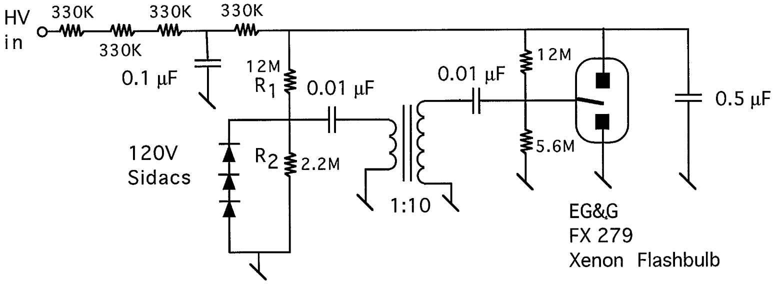

Fig. 2. Flasher trigger circuit. The design features a single voltage connection. The bulb output is nearly independent of the input high voltage.

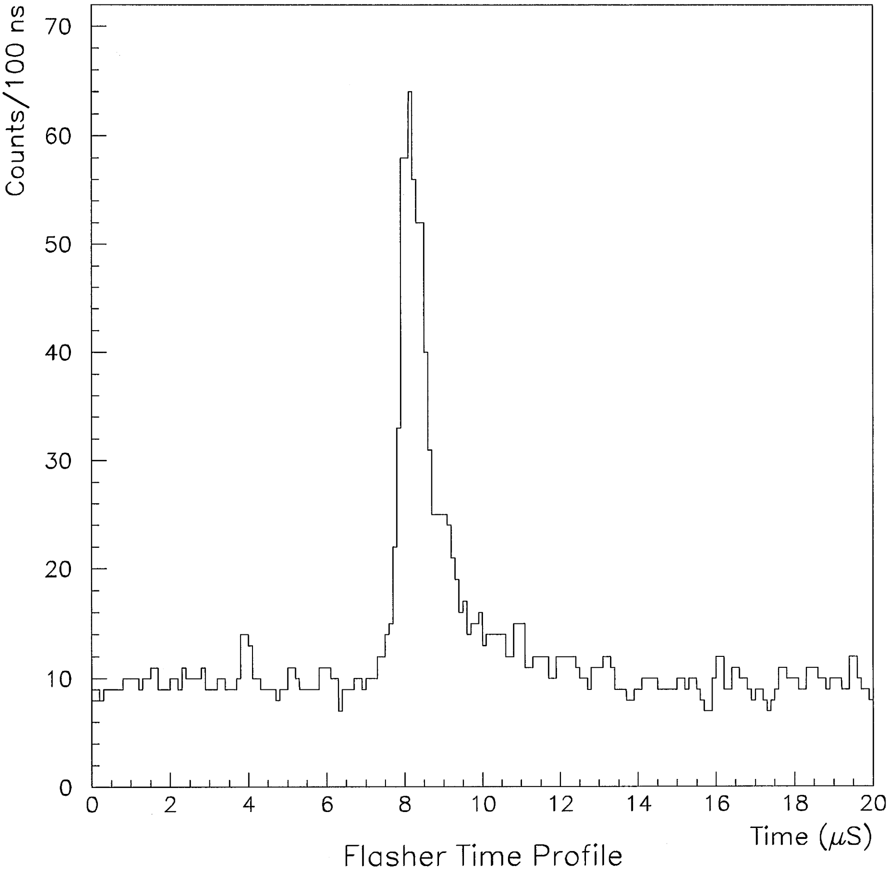

Fig. 3. Time profile of flasher signal. This measurement was made by one PMT in the cosmic ray observatory of scattered light from a vertical flasher 3.3 km distant.

The capacitor between the Sidacs and the transformer discharges through the Sidacs and sends a negative pulse to a 1:10 transformer. The transformer increases the pulse voltage, providing the trigger pulse which initiates the discharge of the flash lamp. A time profile of the light output is shown in Fig. 3.

The voltage at which the bulb fires, and consequently the light output, can be changed by changing the value of R2. In practice, R2 is tuned so that the bulb fires when the discharge capacitor voltage reaches 1800 V. As the supply voltage is increased, the flasher firing rate increases because the capacitor charges faster. A flasher may be operated in two modes. In burst mode, the HV is turned on for specific amount of time, typically 10 s, and the flasher fires continuously until the HV is turned off. In single-shot mode, the output of a photo transistor inside the housing provides a feedback to an external circuit that turns off the HV after one flash.

2.4. Spectrum and energy

Fig. 4 shows the typical spectrum of a xenon flashbulb and the transmission curves for the optical filter glass used in the HiRes, the quantum efficiency of the photomutiplier tubes used in HiRes, and product of the three curves. Superimposed are the relative intensities of the three main air fluorescence lines for 1.4 MeV electrons at 600 mmHg [5]. Note the overlap between the

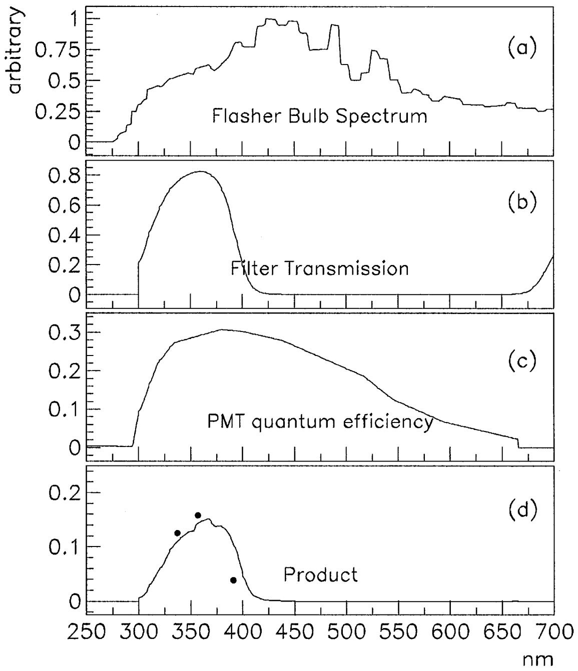

Fig. 4. Xenon flashbulb spectrum (a), the transmission of the filter glass placed in front the PMTs (b), the quantum efficiency of a PMT (c), and the product of all three terms (d). The three dots in (d) correspond to the relative intensities of the three main air fluorescent lines at 337, 357, and 391 nm after multiplication by the curves in (b) and (c).

spectral response of the cosmic ray detector to flasher light and to the air fluorescence light.

The amount of energy between 300 and 400 nm in the collimated beam was found to be 10^{-4} J by comparing HiRes detector measurements of a flasher and nitrogen laser of known energy. For this test both beams were aimed vertically from a point on the ground 4 km from the detector. This measurement can be compared with a calculation. The discharge energy of the flasher is 0.81 J ($1/2CV^2$ where $V = 1800$ V, $C = 0.5$ μF). According to the manufacturer [6], the fraction of discharge energy that produces light is about 50% multiplied by an operating efficiency, typically 50%: 10% of the light falls between 300 and 400 nm. The F2 mirror subtends 1/64th of the total solid angle. Finally, the transmission through the bulb envelope and flasher window, the reflectivity of the mirror, and the obscuration caused by the flashbulb assembly reduce the amount of light in the beam by an estimated 40%. Multiplication of 0.81 J by these factors yields a predicted beam pulse energy of 2×10^{-4} J.

2.5. Temperature variation and flashbulb lifetime

A solar panel (Arco Solar, Genesis Series Thin-film Solar Electric, Model G100) configuration was developed to make field and laboratory measurements of the relative flasher output. A piece of UV pass filter glass of the type used in the HiRes detector and a piece of 1.5 mm Teflon for attenuation are placed between the solar panel and the flasher window. The solar panel covers the entire flasher window. The output of the solar panel drives a zero input impedance circuit (OPA-128 op-amp, 300 Ω feedback resistor). A portable oscilloscope (Fluke series II, model 99) records and integrates the signal across the feedback resistor. The measurement resolution of the system is about 1%. Linearity of this system was verified by measuring a smaller flashbulb device that could be attenuated by calibrated neutral density filters, and by comparison with detector measurements of a flasher in the field as different fractions of the window were masked.

The temperature coefficient of a flasher was measured using the solar panel device. An entire flasher was placed in an environmental chamber. After several hours at the desired temperature, the flasher was removed and its output quickly measured. The process was repeated for temperatures between −10°C and +20°C. The majority of the measurements were taken near 0°C, the average ambient air temperature when the Fly's Eye detector is operated. Results (Fig. 5) show a temperature coefficient of 0.25% per degrees°C.

The flashbulb lifetime was also measured. A new bulb was installed in a flasher and fired continuously at 1.5 Hz for 240 h for a total of 1.3×10^6 pulses. Periodically, 25 pulses were measured and averaged. Fig. 6 shows these averages as a function of the total number of pulses since the beginning of the test. After one million pulses, the relative output decreased by 50%. A significant fraction of this decrease is caused by darkening of the inside of the glass envelope, probably from electrode material.

A typical pattern of yearly use in the field is 1200 h of operation at a rate of 10 pulses every

10 min, for a total of 7.2×10^4 flashes. At this rate, one million pulses represents 13.8 years of operation. If the bulbs are replaced after 3.6×10^5 pulses, or 5 years of operation, the variation in output is less than 10% about the mean for this period.

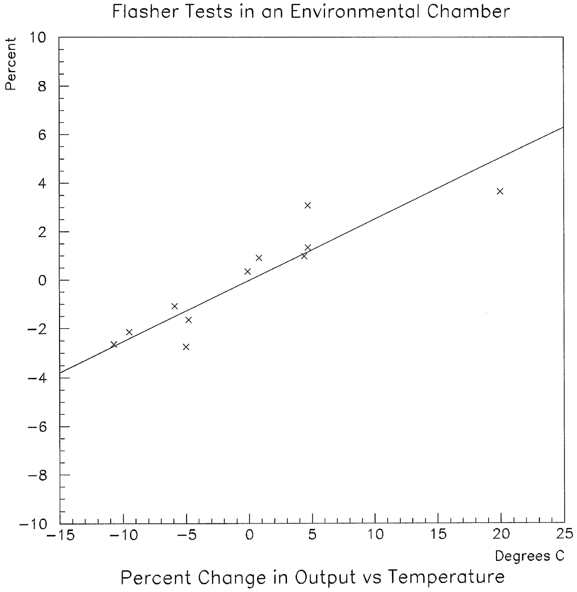

Fig. 5. Laboratory measurement of the change in flasher output verses temperature. The average ambient temperature when the HiRes observatory collects data is 0°C.

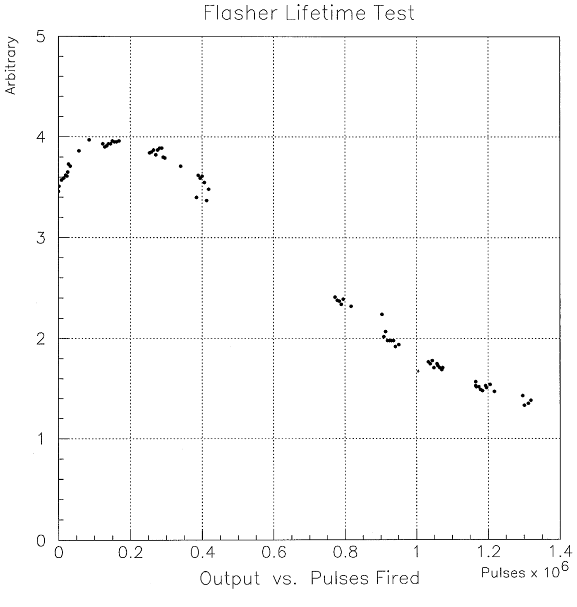

Fig. 6. Laboratory measurement of the relative output of a flasher as a function of the number of shots fired. In this laboratory test the flasher was fired at 1.5 Hz.

3. Radio control system

A system was developed to operate flashers remotely. This system is more flexible and efficient than one with light sensors and timers that control flashers autonomously. A remote control system also requires smaller batteries and solar panels because the window heater can be used as necessary. Also, the flashers can be fired when the cosmic ray observatory is operating and not at other times to extend time between bulb replacement.

A radio link was chosen for reliability and ease of installation and service and to avoid the cost of running cables. The link is one way. The base station broadcasts commands to the flashers as pairs of dual-tone multi-frequency (DTMF) tones, often referred to as telephone touch tones. DTMF tones are the superposition of two audio frequencies and provide a total of 16 digits. A pair of tones allows 256 commands.

A block diagram of the system including one flasher station is shown in Fig. 7. To minimize the number of components in the field an identical simple control circuit is located at each flasher. Command timing and sequencing are controlled in software by a personal computer (PC) interfaced to a DTMF tone generator that drives the radio transmitter that broadcast commands. At the flasher the radio receiver sends the tones to the flasher control board that decodes them and executes functions. All flasher stations operate on the same frequency and receive and decode all tones broadcast.

System operation in case of a communication disruption was considered in the design. In case of hardware failure or human error, a default sequence of flashes, typically one every 15 min, provides limited atmospheric monitoring. This feature can be enabled and temporarily disabled through the radio link. The heater is turned off

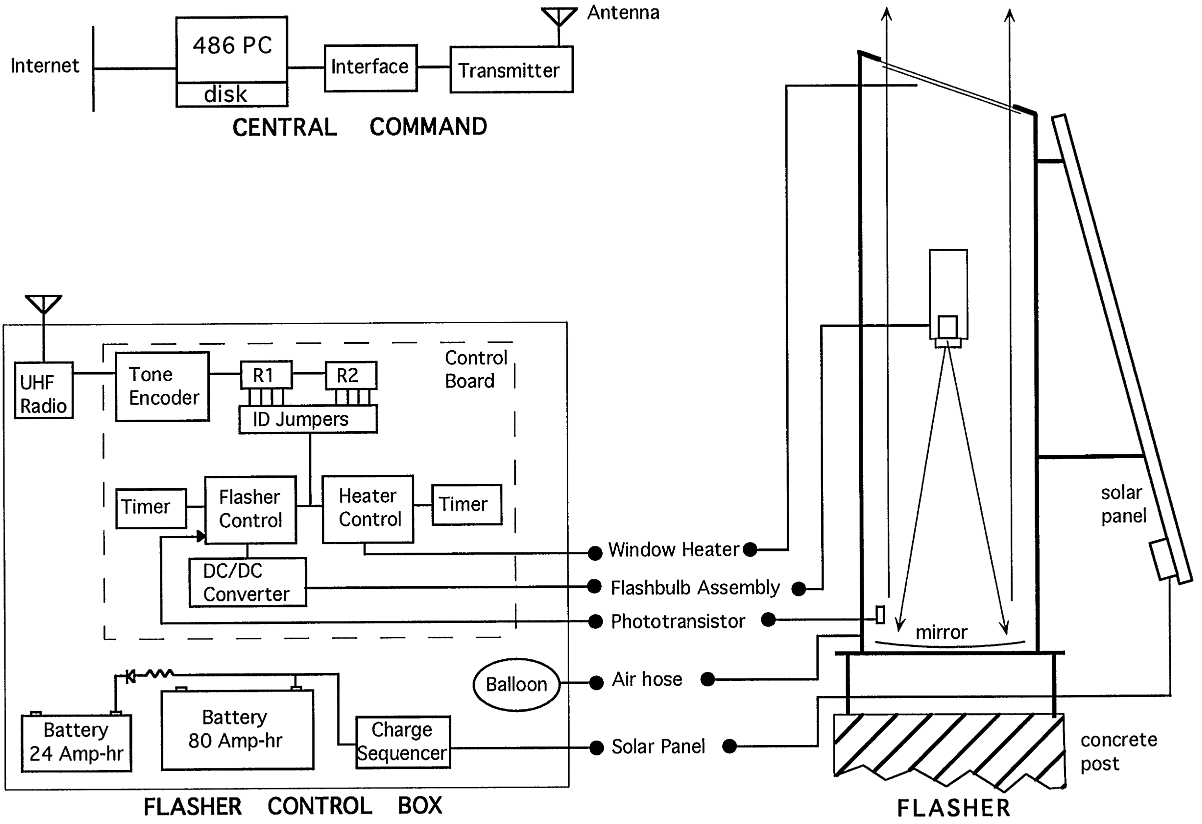

Fig. 7. Block diagram of the radio-controlled flasher system. Commands to operate the flashers in the desert are broadcast by radio from a central command.

automatically after a few hours to prevent battery drain in case communication fails.

3.1. Radios

The radios provide line of site communications over distances of at least 40 km. They are 5 W 461.325 MHz transceivers (Maxon Model dm 0530 sc) although only the receiver part is used at the flashers and only the transmitter part is used at the base station. These transcievers are convienently packaged and high gain antennas for 450 MHz are relatively small. A hand-held transceiver (RELM Model whs450) with a touch tone keypad is used for lab and field testing. Antennas tested include a commercial 5 element YAGI directional antenna (9 dB gain), a commercial whip antenna (3 dB gain), and a simple dipole of RG-58 coax and plastic pipe. In 10 km tests with the RELM transceiver broadcasting, the control board recognized all tones for all three receiver antennas. With directional antennas at the 5 W transmitter and at the receiver, the link worked for a line of site separation of 40 km.

3.2. Central computer

The central computer is a 486 PC running the Linux operating system. This configuration is inexpensive and simple to access and program remotely. Operation of the flasher array is changed by editing a simple text file containing the sequence of commands to broadcast. A small program (written in C) reads this file to an array and loops through it at a specified rate writing 7 words to the parallel port for each command: transmitter on, broadcast tone 1, broadcast no tone, broadcast tone 2, broadcast no tone, broadcast "C", and transmitter off. A command requires 700 ms to execute. Each command is time stamped, written to a local file, and sent via UDP socket to data acquisition system at the observatory where it is merged with the detector data in real time.

3.3. Flasher control board

The control board consists of a tone decoder circuit and circuits that control the flash operation, the high voltage operation, and the heater operation. Schematics diagrams and other details are available upon request [7].

The audio output of the receiving radio is sent to the DTMF decoder. For each valid tone received, the decoder outputs a 4-bit word. A "Data Valid" line acts as a clock for two registers into which the 4 bit words are shifted and inhibits a pair of 4–16 line decoders until shifting is complete. For a pair of tones, 1 of 16 outputs on each of 2 line decoders goes high and drives an AND gate connected by jumper wires that map tone pairs to commands. Group commands are configured by using the same jumpers on all flashers. Commands and codes for a 30 flasher system are listed in Table 2. The "C" tone is reserved to separate tone pairs so that adjacent tones from two commands are not interpreted as a third command.

Four commands control the flash sequence. The Flash command sets a flip-flop to enable the high voltage that fires the bulb. The high voltage to stop the flashing can be turned off in two ways. A photo transistor inside the flasher housing becomes conducting when the flasher fires and resets the flip flop to turn of the high voltage and ensure that exactly one flash is produced. A timer turns off the high voltage after a preset time, typically 6 s, to provide a backup in case the photo transistor fails.

The Heater On Confirm command checks the status the heater control logic. When the command is received and the heater logic control is on, one flash is produced.

The Default State Off and Default State On commands control automatic flashing. The timer on the control board automatically triggers the flasher at regular intervals. The default state off command turns this feature off. When the time (set by a jumper wire) is reached, typically 14 h, the default state is re-enabled. When the observatory is not operating, the central control broadcasts a "default disable" command several times a day to turn off automatic flashing. The "Default State On" command will cause automatic flashing to resume immediately. Radio-controlled flashes can be produced in either state.

The high voltage to fire the flashbulb is provided through a DC–DC converter (Spellman P/N MM2.4P2.5/12). 12 V across the input produce approximately 2400 V at the output. When the negative input is connected to ground, either through the FET controlled by the flash command logic, or through a test button, high voltage is provided to the flashbulb circuit. Typically the high voltage must be on for one second to charge the capacitor across the bulb electrodes and fire the flasher.

Three commands control heater operation. The Heater On command sets a flip-flop to control a FET that turns on the heater element. For this command to be executed on the control board the battery voltage must be at least 8 V as measured by a voltage sensor.

Either the Heater Off of the All Heaters Off. commands turn the heater off. A group command turns off all flasher heaters, or an individual command turns off a specific unit. The heater off commands resets the heater control Flip-Flip causing the heater FET to become non conducting and interrupting current flow to the heater element. A timer will also turn off the heater after a preset time, typically 2 h. The timer is reset when it reaches the preset time, or if a heater on command is received.

The control board also provides on-off control for an additional device through the Alt On and Alt Off commands.

3.4. Mechanical construction and solar power system

The flasher control board, the radio, the charge control module, fuses and terminal blocks housed in a US Army surplus waterproof box (Fig. 8). A plate divides the box. The two batteries and the balloon are located in the lower compartment.

Table 2
Command codes for a 30 flasher system. In this scheme, each flasher is assigned a unique "fire" command. Group commands are: ## All Heater On, ** All Heater Off, DD All Disable

Flasher	Flash	Heater Conf.	Default Enable	Heater Off	Alt On	Alt Off
1	01	31	61	A1	1*	*1
2	02	32	62	A2	2*	*2
3	03	33	63	A3	3*	*3
4	04	34	64	A4	4*	*4
5	05	35	65	A5	5*	*5
6	06	36	66	A6	6*	*6
7	07	37	67	A7	7*	*7
8	08	38	68	A8	8*	*8
9	09	39	69	A9	9*	*9
10	10	40	70	A0	0*	*0
11	11	41	71	B1	1#	#1
12	12	42	72	B2	2#	#2
13	13	43	73	B3	3#	#3
14	14	44	74	B4	4#	#4
15	15	45	75	B5	5#	#5
16	16	46	76	B6	6#	#6
17	17	47	77	B7	7#	#7
18	18	48	78	B8	8#	#8
19	19	49	79	B9	9#	#9
20	20	50	80	B0	0#	#0
21	21	51	81	D1	A#	#A
22	22	52	82	D2	B#	#B
23	23	53	83	D3	D#	#D
24	24	54	84	D4	AB	BA
25	25	55	85	D5	AD	DA
26	26	56	86	D6	BD	DB
27	27	57	87	D7	91	95
28	28	58	88	D8	92	96
29	29	59	89	D9	93	97
30	30	60	90	D0	93	98

A second insulated cover box reduces temperature variations and provides additional protection.

A 75 W solar panel (Siemens Model 4 JF-M75S) charge an 80 A-h sealed battery through a sequence module (Speciality Concepts Model ASC 12/8). The solar panel is tilted at 63° in elevation to maximize exposure to the winter sun at Dugway. This battery powers the heater and radio and charges a 24 A-h battery that powers the control board. A diode and current limiting resistor prevent the small battery from charging the large battery. The control board draws 20 mA (200 mA when flashing), the radio draws less than 20 mA and the heater 4 A.

The charge budget provides for year-round operation. HiRes and the flashers are run when there is atleast 3 h of dark moonless sky. Winter dark periods meet this requirement for as many as 18 consecutive nights. The batteries start the 18 day period fully charged (104 A-h). During the 18 days, the solar panel generates 5–10 A-h per day. Thus 200–280 A-h are available. The heater consumes 120 A-h over the 18 nights, assuming 120 h at a 30% duty cycle. Everything else uses 30 A-h. Thus in the worst case, the capacity of 200 A-h exceeds the demand of 150 A-h. In practice, the cloudy skies that reduce the power generated also reduce the power consumed because

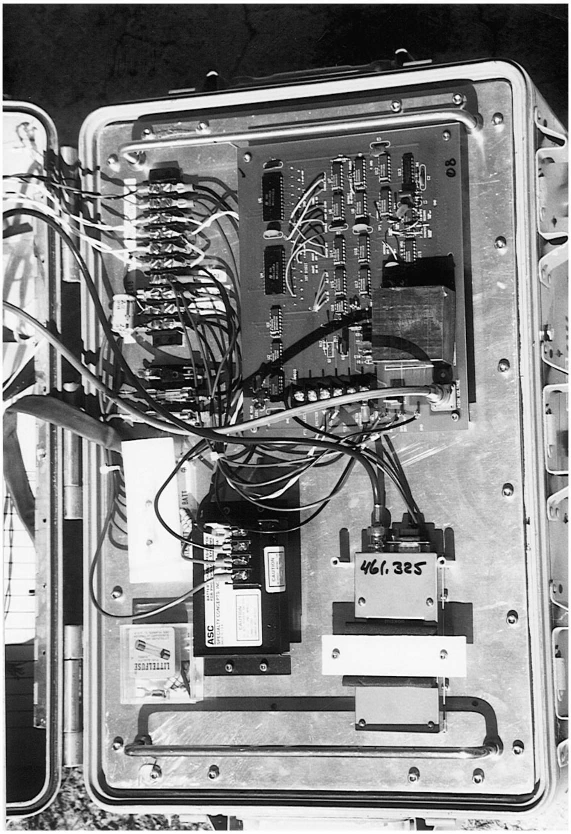

Fig. 8. Photograph of control box showing the control circuit board (right), the solar panel charge module, and the radio (lower left). The batteries are beneath.

the detector and flashers are not operated during bad weather.

4. HiRes detector stations

The detector stations that view the flashers are described briefly. Light from the night sky is reflected by a spherical mirror (2.75 m^2 effective area) through a UV pass filter onto a cluster of 256 hexagonal photo multiplier tubes (PMTs). Each PMT views about $1 \times 1^\circ$ of night sky. As a flasher light pulse crosses upward through the field of view of a mirror, the light collected by the mirror is focused on a spot that crosses downwards through the cluster triggering PMTs along its path.

Calibration of relative PMT gain is performed nightly using UV light delivered by fiber optics from a monitored xenon flashbulb system. The bulb is the same model as that used in the flashers. Tube to tube gain differences are less than 20%. The nominal PMT gain is 10^5 electrons per photoelectron. The nominal quantum efficiency is 25%.

The detector readout system uses sample and hold electronics. Signal digitization and data formatting are performed by local electronics at the mirror level. PMT outputs are AC coupled and processed by two independent channels. The channel A trigger uses a low pass single pole filter with a 100 ns time constant. The channel B trigger uses a three pole bessel filter with a 375 ns time constant. Charge integration gates are 1.5 and 4.5 ms wide. In analysis of data from flashers, only the channel B measurements are used. TDCs measure times between tube triggers and the mirror triggers by integrating a gated constant current source. The A and B thresholds are adjusted at a software-specified interval of 4 s to maintain a software-specified count rate. Channel A and B single pixel trigger rates are 50 and 300 Hz. The trigger requirement for a signal digitization is a sixfold coincidence. Within a 16 PMT subcluster, the signals of at least three PMTs are required to be above threshold within a 25 ms interval. The digitization trigger requires two subcluster triggers within 25 ms. Typical, trigger rates are 5–10 Hz per mirror. System deadtime is less than 2%.

5. Flasher array at Dugway

An array of 12 vertically pointing radio-controlled flashers has been installed at Dugway Utah (Figs. 9 and 10). They are 1, 2, 4, 8, and 10 km from the detector to provide sampling along a typical horizontal extinction length and arranged in two rows. Each row is centered in azimuth in the field of view of a HiRes mirror. Each flasher is viewed between 3.5 and 30.5° of elevation angle. The positions relative to the mirrors are known within 2 m radially and 0.2 m in the perpendicular direction.

This geometry has several advantages. For a given row, the flasher beams are centered on the same set of PMTs to simplify calibration. Flasher

Fig. 9. A flasher station at Dugway Utah. The flasher assembly is inside the white cylinder and is mounted on a concrete post. A steel frame attached to the flasher holds the solar panel. The antenna, control box, and insulated cover box are also shown.

light reaching a given PMT has scattered out of the beam by the same angle. The scattering angles are between 93 and 120°, a region where the molecular and aerosol phase functions are relatively constant. The two flasher rows and the independent detector stations that view them form duplicate experiments that can be cross checked.

The array has been in operation since December 1996. On each night of detector operation the HiRes operator logs on to the PC remotely and starts the control program. The command sequence fires each flasher and cycles the power to the window heaters. The two 1 km flashers are fired on alternative seconds for a total of ten times each followed by a 20 s pause while the window heaters are turned on for 10 s, then the 2 km flashers are fired and so on. The cycle completes in 200 s and is repeated every 600 s. Between cycles, the window heaters are turned on for 120 s.

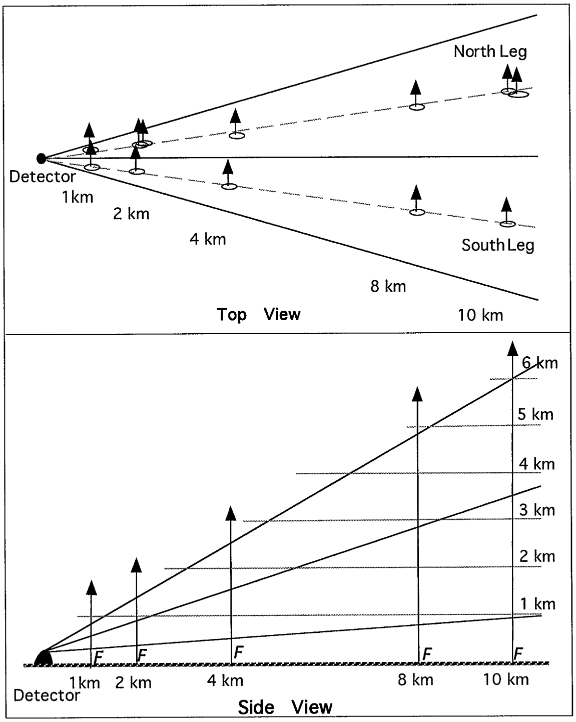

Fig. 10. Geometry of the radio-controlled flasher array. The solid lines in the top panel denote the field of view in azimuth of two HiRes mirrors.

Between December 5 and March 18, 1997, the detector and flashers system were operated on 50 nights. One failure was detected (a failed IC was replaced). The system ran reliably. No significant changes in flasher stability were observed during this period, which included nights of −10°C temperatures. Several snowstorms passed through the area. The heaters melted the snow from the windows. On Dec. 5, Dec. 30, Feb. 11, and March 18 flashers and control boxes were inspected and tested and found to be operating normally. There was no evidence of water leakage. The relative output of each flasher was measured by the solar panel device described previously. For each data the average of 50 measured shots was calculated and normalized to the mean of the entire array for that date.

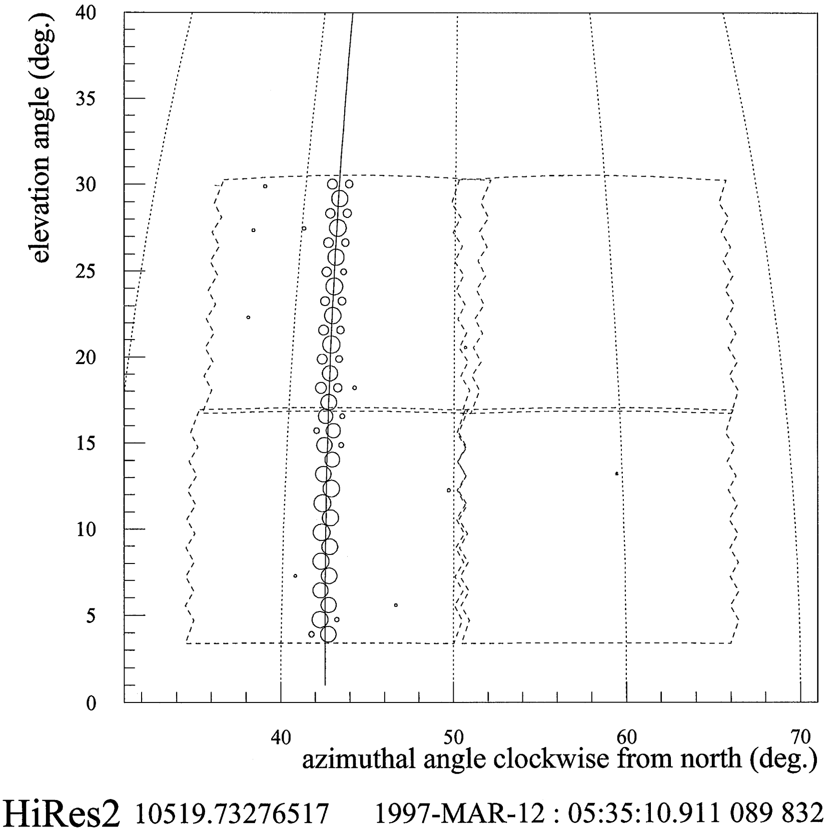

Fig. 11. A track measured by the HiRes detector of a vertical flasher 4 km distant. Each circle represents a triggered photomutiplier tube. This track passes through the field of view of two mirrors.

The variation of flasher outputs about their mean value was 3.5% standard deviation, consistent with the shot-to-shot variation.

Flasher tracks were identified from the HiRes detector data by requiring they trigger a minimum number of specific tubes and be associated with a specific recorded command sequence. Fig. 11 shows a typical event for a flasher 4 km from the detector. For each 10 shot group for each flasher, the total number of photons was calculated for eight elevation bins containing four horizontal rows of PMTs.

The detector response for the 3–8° elevation bin is shown in Fig. 12 for a series of 4 nights. Somewhat hazy conditions are recorded in the operations log. These data are normalized to the detector response for a relatively haze-free night. As shown, the amount of light measured from the near flashers increased as the amount of light measured from the farther flashers decreased. This trend increased over these nights and can be explained by an increasing atmospheric aerosol component. For the flashers nearest the detector and viewed at a lower elevation where aerosol concentration is typically greater, more aerosols scatter more light out of the beam. Because the distance to the detector is small compared to a typical extinction length of 10 km, the increase in scattering dominates and the 1 and 2 km flashers appear to brighten. The 8 and 10 km flashers, approximately one extinction length distant dim because effects of atmospheric extinction

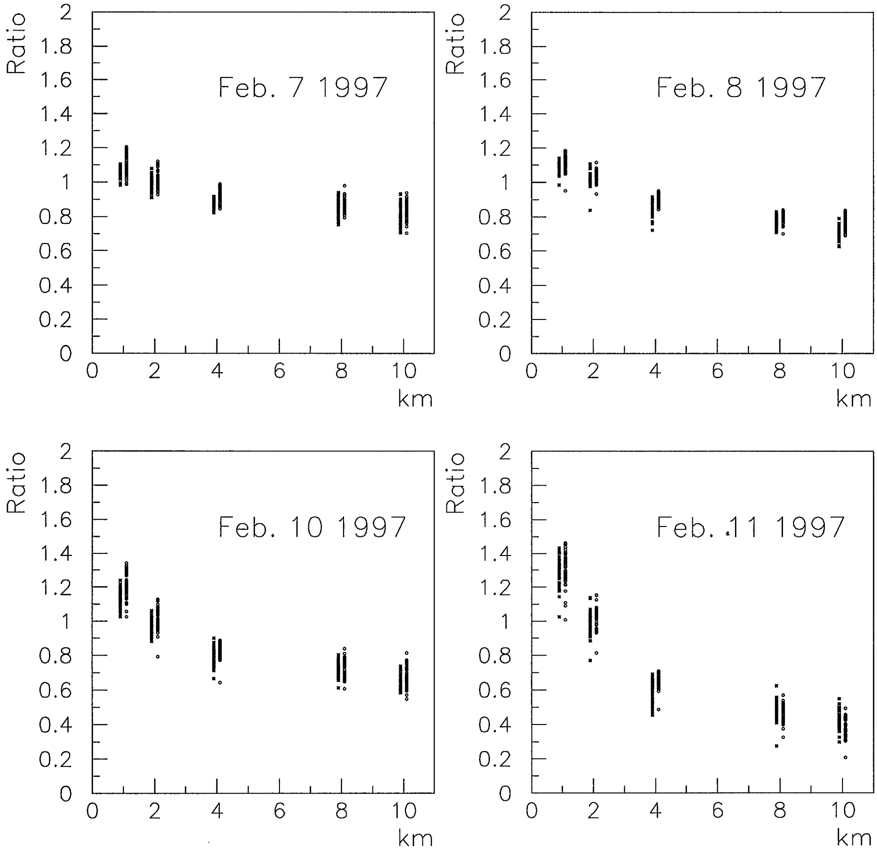

Fig. 12. HiRes detector measurements of 10 vertical flashers vs horizontal distance. These measurements are normalized to those for a relatively haze-free night. Adjacent bands of points correspond to two flashers at the same distance from the detector but separated by 16° in azimuth.

dominate over effects of scattering. Most of the nights were similar to the nominal clear night used for normalization.

The simultaneous increase in light from the near flashers and decrease in light from the distant flashers is predicted by Monte Carlo simulation. In this simulation, the aerosol component is increased by a decreasing a ground level horizontal extinction length parameter. The aerosol scale height in the model is 1.2 km. The steeper curves in Fig. 13 correspond to shorter horizontal extinction lengths. The simulation includes the flasher spectrum, the detector optics including the mirror, the UV filter, and the PMT quantum efficiency and geometry.

The measurements of the two legs of flashers track each other. This is evidence of horizontal atmospheric uniformity over the 0.1–3 km range of separation between flashers that are equidistant from the detector.

6. Expanding the system

The radio flasher system is simple and flexible. The system can be maintained and reconfigured by relatively inexperienced personnel. The radio link, the light-source and the array geometry are several aspects that could be upgraded.

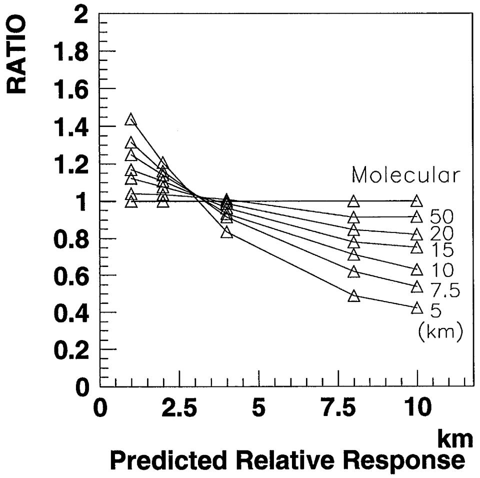

Fig. 13. Monte Carlo simulations of the HiRes detector response to vertical flashers as a function of the distance to the flasher. The flat curve corresponds to a purely molecular atmosphere for which the extinction length at ground level is 18 km. The other curves correspond to simulations that include an aerosol component. The horizontal extinction length for the aerosol component only is listed next to each curve.

The two-way capability of the radio transceivers could be used to read back information from each flasher station such as a relative measurement of each flash. Sampling the light via fiber optics would reduce noise pickup. One could also broadcast data from other devices such as low cost infrared detectors used to monitor clouds [8] back to the central control. Spread-Spectrum communication could provide a considerably higher speed data link.

A brighter light source located farther from the cosmic ray detectors would increase the volume of atmosphere monitored and increase the sensitivity to changes in the horizontal extinction length. A flasher yielding twice the signal at 20 km as the existing flashers do at 10 km would have to be about ten times brighter. While some increase is possible by increasing the discharge capacitor or raising the trigger voltage, the increase in pulse width and decrease in bulb life limit this approach. Replacing the mirror with an F1 UV transmitting Fresnel lens would collect more light for the beam. One could also trigger multiple bulbs with a time jitter small compared to the width of the light pulses. A factor of ten could be reached by a five bulb system and Fresnel optics that doubled the light collection efficiency. Increased stability and lifetime might be obtained with a bulbs of more recent design such a EG and G 1100 series [9].

Other geometries could provide additional atmospheric information. Flashers can be deployed anywhere line of site communication is possible. Flashers pointed towards the detector and viewed over a wide range in scattering angles provide a very sensitive probe of changes in aerosol concentrations near the detector [10]. One could make a flasher that pointed in different directions under remote control, to rotate about one axis in fixed steps. Finally, systematic effects can be reduced by simultaneously measuring flashers from two separated detector stations.

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