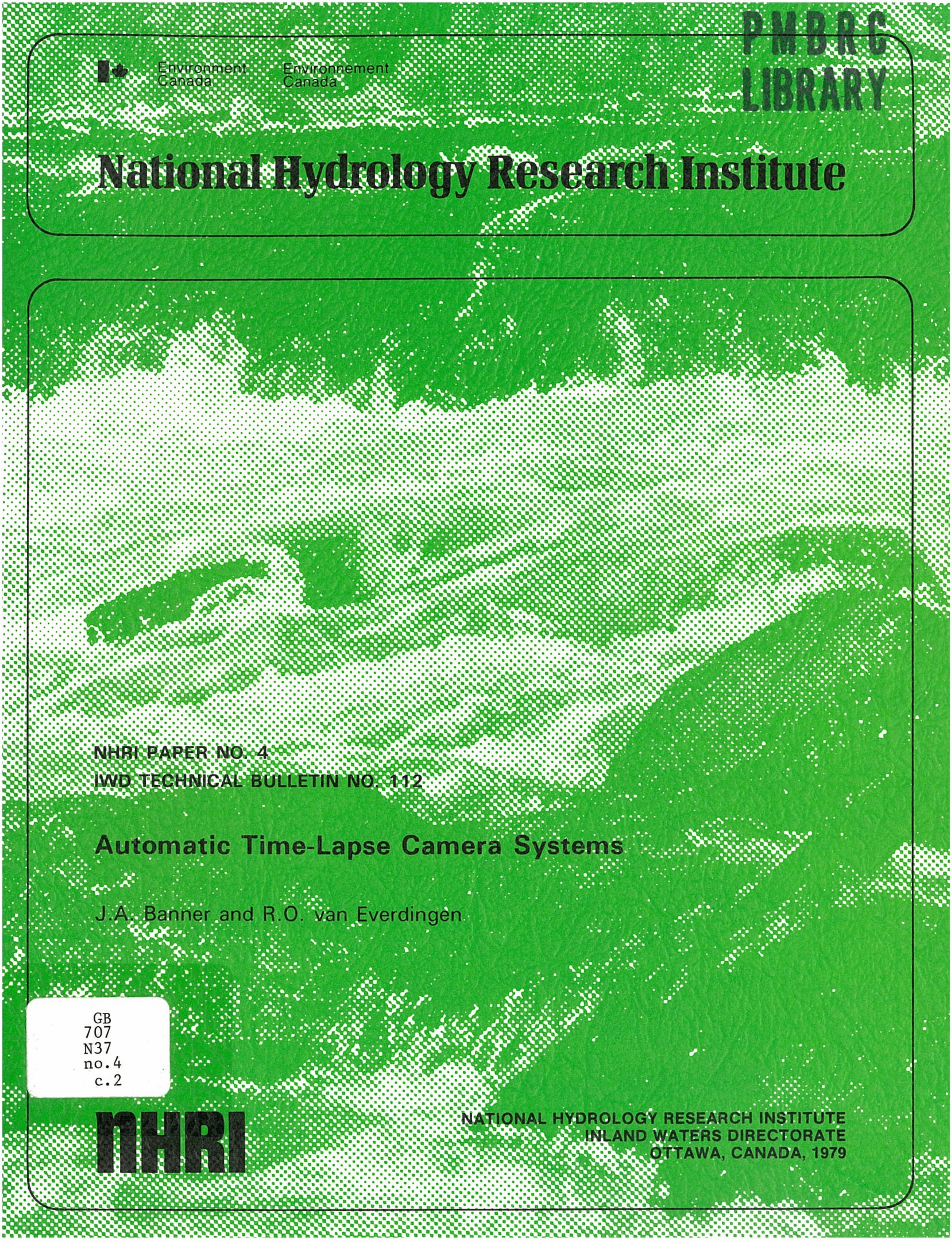

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Automatic Time-Lapse Camera Systems

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Abstract

This report provides construction and operation details for the automatic time-lapse camera system that was developed and used to monitor natural phenomena in northern Canada. Modified Eastman Kodak KB9A 16-mm strike-recording motion picture cameras were used in this system. Some of the results obtained with the system are presented and discussed. Suggestions for the adaptation of other cameras for time-lapse photography are also given.

Résumé

Le rapport renferme les détails de construction et d'opération d'un système automatique pour photographie accélérée quotidienne, développé et employé pour enregistrer des phénomènes naturels au nord du Canada. Ce projet a utilisé des appareils de film à 16 mm «enregistreur-de-coup», du type Eastman Kodak KB9A, spécialement modifiés. Certains des résultats obtenus à partir du système sont présentés et discutés. En outre, quelques suggestions sont fournies pour adapter d'autres appareils de photographie pour la photographie accélérée automatique.

Automatic Time-Lapse Camera Systems

J.A. Banner and R.O. van Everdingen

INTRODUCTION

This report is intended to enable the reader to duplicate the automatic time-lapse camera system developed by the authors or to construct a similar system. It is also intended to serve as a guide to the installation of automatic time-lapse camera systems in the field and to illustrate the results that can be obtained with them. The results of various cold-room and field tests of the system are described, including a method for calculating battery requirements.

Although the authors' system was designed around the Eastman Kodak KB9A camera, it could also be used with other cameras. A circuit designed specifically for adaptation of common movie cameras and motor-drive still cameras for automatic time-lapse photography is described in the Appendix, together with suggestions for its use.

Background

Frost blisters that form every winter at the Bear Rock spring site near Fort Norman, N.W.T., have been studied by the Hydrology Research Division, Inland Waters Directorate, Environment Canada, since 1975 (van Everdingen, 1978). Prior to 1977, intermittent observations in the periods between early March and late September documented the progressive destruction of each new generation of frost blisters. Little was known, however, about the timing and rate of their growth.

Installation of recording heave gauges would have required either advance knowledge of the location of any new frost blisters or the installation of a relatively dense pattern of instrumentation. As an alternative, the decision was made to use time-lapse photography by means of cameras mounted on trees along the edge of the natural clearing at the spring site. Development of a battery-powered automatic time-lapse camera system was started in early 1977.

The first cameras were installed in March 1977, at Bear Rock and at two karst depressions subject to seasonal flooding. Cameras were changed several times during the summer, and minor modifications were made to improve operation. The growth period of the frost blisters at Bear Rock was successfully recorded by cameras installed on September 26, 1977, and retrieved on May 3, 1978; the degradation period was recorded from May 6 to September 13, 1978 (van Everdingen and Banner, 1979).

AUTHORS' SYSTEM

The system used by the authors at Bear Rock and at other northern locations was based on the KB9A 16-mm strike-recording motion picture camera, manufactured by the Eastman Kodak Company (military surplus). The specialized circuits developed for use with the KB9A, however, are usable with similar cameras, and the general approach to modification of the camera and to housing of the system is similar.

This automatic time-lapse camera system consists of five components: a camera to hold, transport and expose the film; a motor control to regulate the speed of the camera motor and to stop it after the exposure of a burst of a preselected number of frames; a quartz clock to control precisely when the bursts of exposures occur; a housing to protect the camera and the control circuits and to facilitate mounting of the system; and a battery pack. Construction, modification and internal operation of the first four components are covered in this section of the report. Battery requirements, which depend on operating conditions, are discussed in the section on "Field Installation and Operation."

Camera

The KB9A camera is easily interchangeable and comes complete with heaters to permit operation at temperatures from -53.5°C to 71°C. It has a capacity of 10.7 m of film, giving in excess of 1300 usable frames. It is fitted with an f/3.5, 35-mm (mild telephoto) lens, fixed focused at infinity, with aperture adjustable by means of a holed disk. While the aperture does not automatically correct exposure, good results can still be obtained by the selection of an average setting (see "Field Installation and Operation"). The camera must be loaded and unloaded in complete darkness. This presents few problems, however; a spare camera, loaded with unexposed film in the laboratory, is substituted for the camera with exposed film in the field and the latter returned to the laboratory for unloading, cleaning and inspection.

The one major problem with this particular type of camera was its lack of single-frame capabilities. Because it is normally a relatively high-speed camera (32 frames per second), it could not simply be shut off after one frame. The camera would coast for several more frames and stop with its rotating disk shutter in a random position. If the shutter were open, a large number of frames would be lost by fogging. The solution to this problem was the development of an electronic speed governor, capable of operating the camera slowly enough that it would not coast excessively, and a detection circuit that would determine when an exposure had been completed. Very little extra was required to include a counter, permitting the exposure not only of single frames but also of a controlled number of frames (up to nine) each time the camera is activated. This multi-frame capability turned out to be much more useful than at first realized. Under certain field conditions, a film frame remaining in the gate for long periods of time may fog slightly. If each burst of frames includes at least two frames, however, then at least one will not be fogged; even at three frames per burst the film will last about 440 days when activated once a day.

Completion of an exposure is detected by a piano wire contact (S_1 on Figure 1) which is momentarily grounded by the Geneva drive pin. With this arrangement and a camera speed of seven frames per second, the gear carrying the Geneva drive pin does not coast more than one-half revolution after completion of an exposure, even with an empty camera. To install the contact, it was first necessary to remove (and discard) a mechanical three-second timer consisting of a solenoid, Microswitch, gear train and associated levers and springs, leaving (or removing and reinstalling) the Geneva, motor, motor capacitor, take-up spindle complete with gear and clutch, body heater and heater thermostat. A length of 0.92-mm piano wire and a length of 20-gauge hook-up wire were soldered to the ungrounded lug of a 2-lug terminal strip (GC Electronics 1782); after a corner of the mounting lug was trimmed to clear the motor, the terminal strip was installed. It was held in place with a 2-56 flat head machine screw passed from the film side of the camera through the solenoid mounting hole nearest the motor, through a 4-40 nut acting as a spacer, through the mounting lug and into a nut. The terminal strip was then glued with 5-min epoxy to the camera body and to the heater to prevent turning. After the glue had set, the piano wire was bent to clear the motor shaft and gears and to just touch the Geneva drive pin when the latter was farthest from the eight-tooth Geneva wheel (Fig. 1). This contact constitutes switch S_1 shown in Figure 2. The camera was then wired as shown in Figure 2, using the longer, grounded tie point and the shorter, insulated tie point as required.

For correct exposure timing, the shutter was also modified. The shutter was removed from the camera with a 0.9-mm (0.035-in.) Allan wrench; the shutter disk was removed from the hub by first drilling out only the expanded

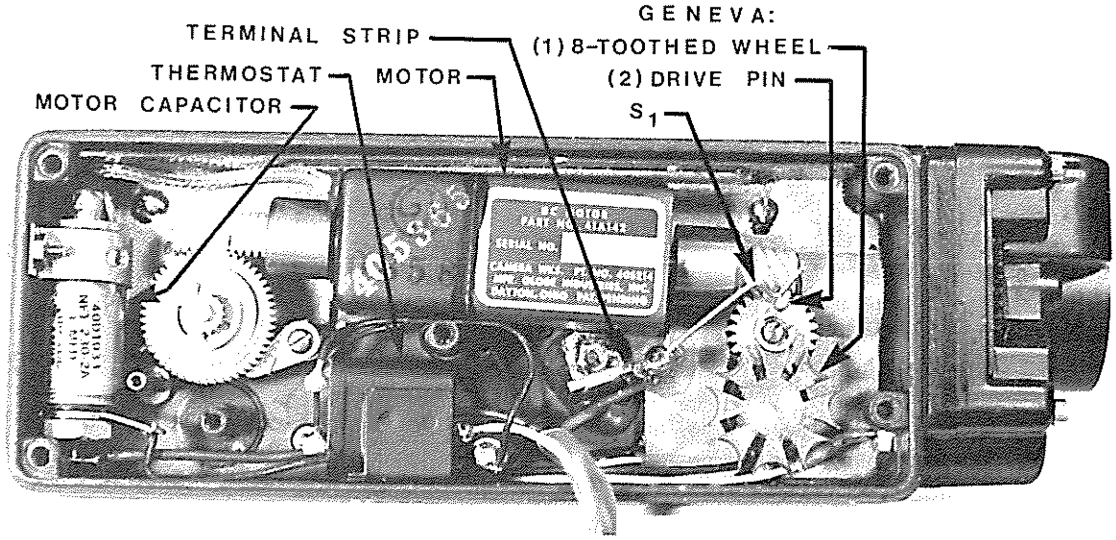


Figure 1. Modified KB9A camera viewed from mechanism side.

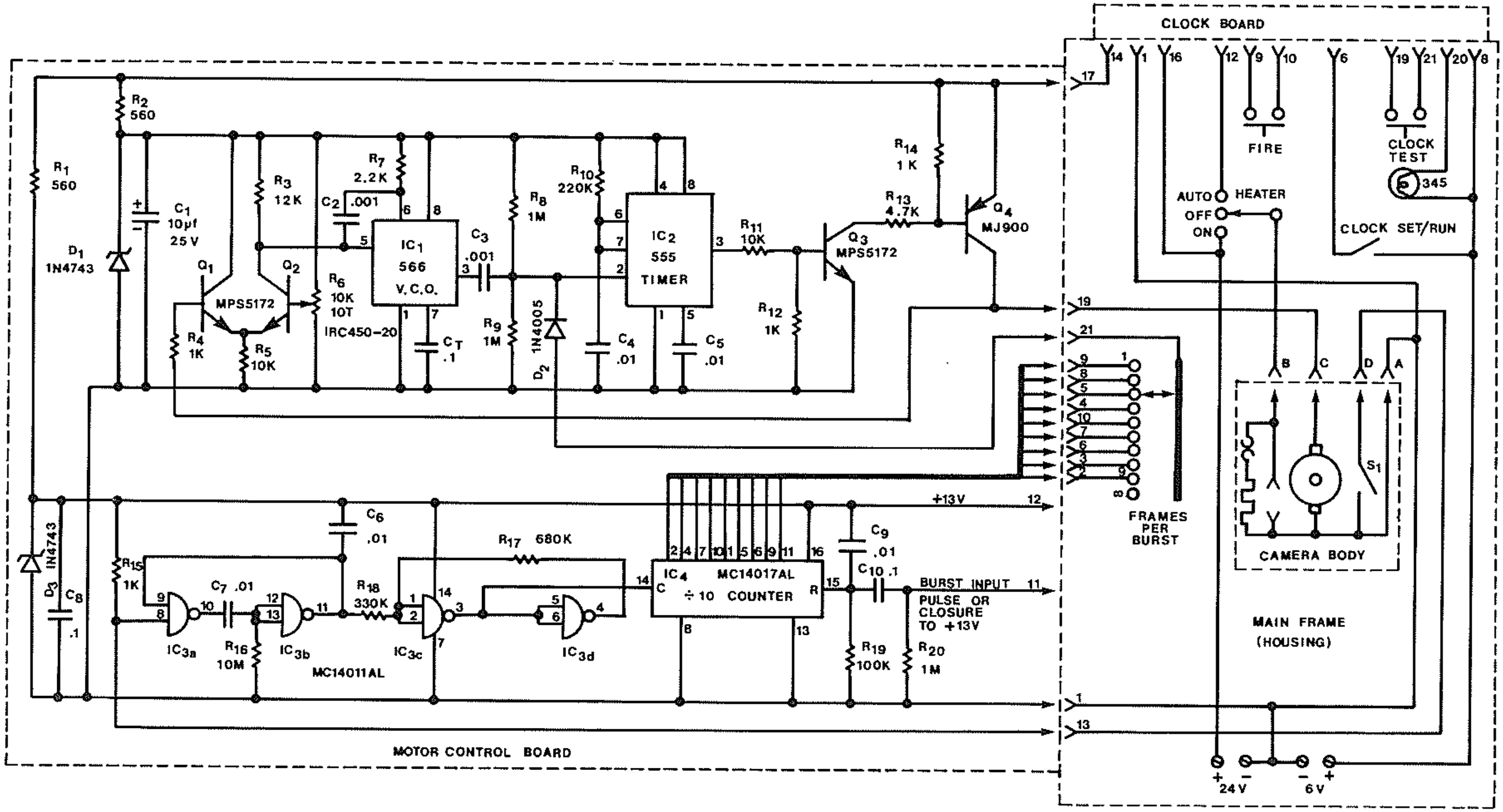


Figure 2. Circuit diagram of motor control (including main-frame and camera wiring).

ends of the three rivets with a No. 50 drill, then driving the bodies of the rivets out with a 1/16-in. or 1-mm pin punch and finally reaming the holes with the No. 50 drill. A new disk was made from 0.32-mm (30-gauge) tin plate using the old disk as a template but reducing the opening to 25°. The three mounting holes in the hub were tapped 2-56 and the new disk was mounted with 2-56 round head machine screws. After tightening, the three screws were cut off flush at the back and the heads ground down to about 0.5 mm. The disk and hub were then cleaned, etched with concentrated hydrochloric acid, primed and painted flat back. Good results were obtained with Krylon primer and paint; another brand cracked and flaked at low temperature. The shutter was installed and timed such that the shutter just opened as the Geneva drive pin was just leaving the eight-tooth Geneva wheel. (Note that the gear on which the pin is mounted turns *counterclockwise* when viewed from the mechanism side of the camera; timing the shutter while turning this gear clockwise will guarantee completely blurred pictures. The gear can easily be turned by rotating the motor shaft with a finger.) The shutter should be closed by the time the Geneva drive pin just touches the contact wire; if not, the contact must be repositioned. The modified shutter gives an exposure time of 1/100 s, and the timing scheme permits over 300° of coasting of the shutter after completion of an exposure.

To facilitate loading and to prevent jamming with cold, stiff film, the guide pin immediately following the sprocket wheel in the film path was removed and discarded.

The modifications discussed concern the KB9A camera specifically. The general approach, however, should be similar for other electric motor driven cameras that lack single-frame capability. In general, they will require some method to prevent excessive coasting, a shutter timed to allow for any coasting that may occur, and a method of determining when exposure of a frame has been completed. A different approach, using cameras that have built-in single-frame capabilities, is discussed in the Appendix.

Motor Control

The motor control circuit has two major functions: governing the speed of the camera motor to prevent excessive coasting, and controlling the number of frames exposed each time the camera is activated.

The electronic speed governor (Fig. 3) consists of a comparator, a voltage-controlled oscillator, a one-shot multivibrator and a driver, with feedback from the camera motor. Referring to Figure 2, the motor is fed 24-V pulses 2 ms wide from the one-shot, IC_2, via the driver, Q_3 and Q_4. The one-shot, timed by R_{10} and C_4, is triggered by the voltage-controlled oscillator, IC_1. The frequency of the oscillator, within the range set by R_7 and C_T, is governed by the comparator, Q_1 and Q_2, which compares the back EMF of the motor between pulses with a voltage provided by R_6. If the motor speed drops below the speed set by R_6, the frequency of IC_1 is increased, augmenting the motor power by increasing the repetition rate of the fixed width, fixed amplitude pulses fed to it. Similarly, if the motor speed becomes too high, the pulse repetition rate drops to reduce power. Thus the camera operates at a constant speed independent of load changes caused by temperature or other factors.

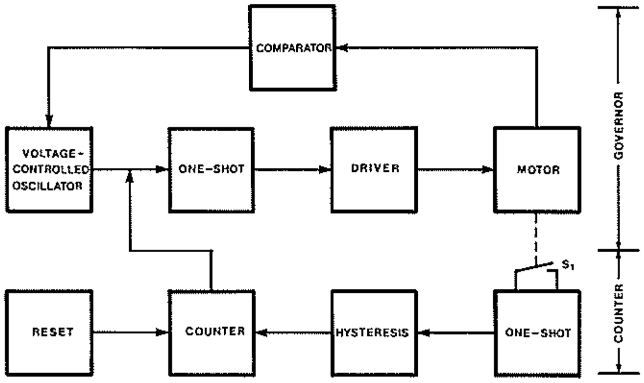


Figure 3. Block diagram of motor control.

The frame counter (Fig. 3) consists of a switch, a one-shot, a hysteresis circuit, a counter and a reset circuit. The switch, S_1 in Figures 1 and 2, closes once per revolution of the Geneva driver, that is, once per frame. The normally erratic switch closure signal is stretched by a one-shot consisting of IC_{3a} and IC_{3b}, and inverted and shaped by a hysteresis circuit IC_{3c} and IC_{3d} (Fig. 2). The leading edge of this stretched and shaped pulse clocks the counter IC_4 once per frame until the output selected by the "Frames per Burst" switch goes high and inhibits the one-shot in the speed governor via D_2. If ∞ frames per burst is selected by the "Frames per Burst" switch, the one-shot can never be inhibited and the camera will continue to run until the switch is reset or power is removed.

The frame counter can be reset to zero and a new burst initiated in three ways. Manual control can be achieved by closing a switch connected between the "Burst Input" and +13 V to reset the counter. Automatic control of burst speed (or frame speed if one frame per burst is selected) can be achieved by connecting a source of positive-going 12-V pulses to the "Burst Input." A new burst (or frame) is initiated each time a pulse resets the counter. By altering the repetition rate of the pulses, the time between bursts (or frames) can be varied from 1/7 s to as long as desired. These two methods are appropriate in the laboratory where power consumed between bursts is unimportant. For field use, the third method, in which power is applied momentarily by a clock, is the most satisfactory. Because C_9 resets the counter and C_6 resets the one-shot when power is first applied, a burst is initiated by simply turning on the power.

The motor control board requires only a single adjustment: setting the motor speed control R_6. An oscilloscope is connected across S_1 and the camera run continuously by selecting ∞frames per burst. Then R_6 is adjusted for seven pulses per second, corresponding to a camera speed of seven frames per second. It should be noted that in the field cameras (Fig. 8), the "Frames per Burst" switch was replaced by a jumper and the "Burst Input" was not used.

Although the motor control board was developed specifically for the KB9A camera, it would likely work with little or no modification with similar electric-drive cameras. Most likely to require modification for a different camera type would be the width of the pulses fed to the motor. These pulses should be wide enough that a single pulse can turn the motor a fraction of a revolution but not so wide that the motor coasts more than a fraction of a revolution after a single pulse. Suitability of pulse width can be checked with the circuit itself by disconnecting the left end of C_3 from IC_1 and connecting a jumper to the free end of C_3. Then every time the jumper is touched first to pin 8 then to pin 1 of IC_2, one pulse will be produced. Because pulse width is directly proportional to the resistance of R_{10}, it is easily changed as required. The frequency range of the oscillator can then be changed to compensate for the new pulse width by changing R_7 by the same ratio as R_{10} was changed, provided that if R_7 were to become less than 2000 ohms, a value ten times higher should be selected and C_T should be decreased by a factor of 10 to keep the value of R_7 between 2000 and 20 000 ohms.

To simplify duplication of the motor control board used in this project, the printed circuit layout is shown in Figure 4a. A full-size high contrast negative can be made from this figure (corrected to full size by reference to the millimetre scale shown in the figure) and used to produce a printed circuit board from photosensitized copper-clad

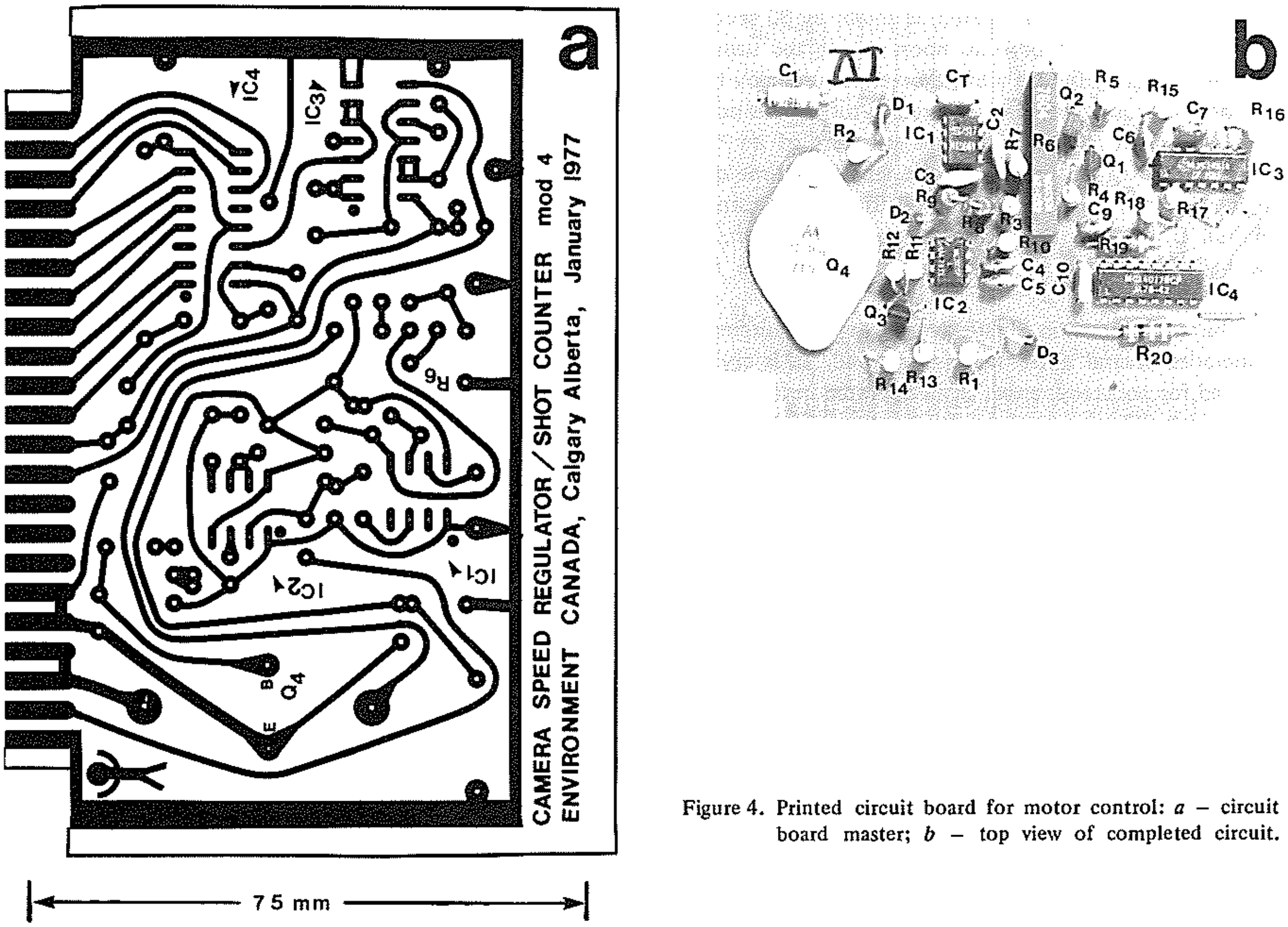


Figure 4. Printed circuit board for motor control: *a* – circuit board master; *b* – top view of completed circuit.

printed circuit board material. Most of the originals were made on 1/16-in. (1.59-mm) epoxy-glass boards with gold-on-nickel plated connector terminals. They are designed to mate with card edge connectors having 22 pins on 0.156-in. (3.96-mm) centres. Figure 4b indicates component placement on a finished board.

In assembling the circuit, care must be taken to insert the integrated circuits, transistors, diodes and electrolytic capacitors correctly and to protect the integrated circuits from static. Pin 1 of each integrated circuit is indicated by a dot on the foil side of the circuit board; correct polarity of transistors, diodes and electrolytic capacitors can be determined from the schematic. Because of the wide range of temperatures to which these boards are likely to be subjected, extra care should be taken to avoid any possibility of cold solder joints. It is recommended that assembly of these boards be attempted only by, or under the guidance of, a qualified electronics technologist unless the user is thoroughly experienced in electronic assembly.

Clock

The clock required for this project had to be capable of keeping accurate time for long periods at widely varying temperatures. If the clock drifted as much as 30 seconds per day a camera set for solar noon during the summer would be operating before sunrise or after sunset by mid-December. The clock was also required to turn on the power to the heaters in the camera three quarters of an hour before the camera was operated, the length of time cold-room testing had shown was required to heat the cameras from -55°C to operating temperature. In addition, the clock had to operate on a battery of reasonable size.

The clock shown in Figure 5 meets these requirements and includes several extra features as well. It is crystal-controlled for accuracy; a test clock operated in the laboratory lost only 77 s in one year. It operated equally well in a cold room at -55°C and, except for some melting, in an oven at 100°C (the test clock and some of the clocks used in the field used commercial grade plastic packages rated at -40° to +85°C instead of the military grade ceramic packages rated at -55° to +125°C specified in Figure 5).

The clock is controlled by a crystal oscillator operating at 1 553 446 Hz. The oscillator frequency was initially set to 1 553 446 Hz, using a counter (Fluke 1900A) connected to test point TP in Figures 5 and 7. The clock was then tested for 24 h against WWV with the counter disconnected. The oscillator frequency was reset proportional to the measured error. This procedure automatically corrected for counter time-base error and for oscillator-frequency shift caused by connecting the counter.

The output of the oscillator is divided by 2^{20} by IC_1. The output of IC_1, at approximately 1.48 Hz, is fed via inverter IC_{7a}, the "Clock Test" push button and transistor Q_5 to the "Clock Test" lamp. It is also divided by 10 three times by IC_2, IC_3 and IC_4 to give 128 cycles per day. This in turn is divided in IC_5 by 2^2 to give 32 cycles per day and divided by 2 five more times to give 16, 8, 4, 2 and 1 cycle per day. These signals (32 through 1 cycles per day) can be fed via jumpers to AND/NAND gate IC_6. With all the jumpers connected as in Figure 5, the NAND output goes low once every 24 h and goes high again 45 min (one half of one-sixteenth day) later. When the NAND output goes low, inverter IC_{7e} turns Q_2 and, in turn, Q_4 on to pass current to the camera heaters. If the camera heater switch is in the "Auto" position and if the camera-heater thermostats are calling for heat, the heaters turn on. When the NAND output goes low, a one-shot consisting of inverters IC_{7b} and IC_{7d} is triggered, turning on Q_1 and Q_3 via inverter IC_{7c}, to provide power for the camera motor. The one-shot can also be triggered by momentarily forcing the AND output of IC_6 (which is connected within IC_6 to an inverter that provides the NAND output) high via capacitor C_6 and the "Fire" push button. To set the clock, the "Clock Set/Run" switch is closed, resetting all the counters. At the appropriate time, the switch is opened and a timing cycle begins.

Because jumpers are used on the printed circuit board, other timing schemes can be achieved relatively easily. The timing diagram for the last six stages of division in the clock is shown in Figure 6. At the left of each line are the number of cycles per day from IC_5 and the input pins to IC_6. The time along the bottom is relative to the "Clock Set/Run" switch being opened. When all the inputs to IC_6 are high, the heaters are on. At the moment one or more go low, the heaters are turned off and the camera is activated. In Figure 5, pin 1 of IC_6 is shown jumpered to +6 V and is therefore always high. Therefore, at 23:15, all inputs to IC_6 are high and the heaters are turned on at this time. Forty-five minutes later, at 24:00, some of the inputs go low, turning off the heaters and activating the camera. If the 32-per-day jumper were disconnected from +6 V and reconnected to pin 11 of IC_5, it would not be until 23:37:30 that all inputs in IC_6 would be high and the heaters turned on. After 22.5 min the heaters would be turned off and the camera activated. Similarly, if the one-per-day jumper were disconnected from pin 3 of IC_5 and reconnected to +6 V, all inputs to IC_6 would go high twice a day, at 11:15 and 23:15, resulting in two 45-min heating cycles followed by camera activations each day. In general, as each high-numbered jumper in turn is disconnected from IC_5 and connected to +6 V the heating period is doubled, and as each low-numbered jumper in turn is disconnected from IC_5 and connected to +6 V the number

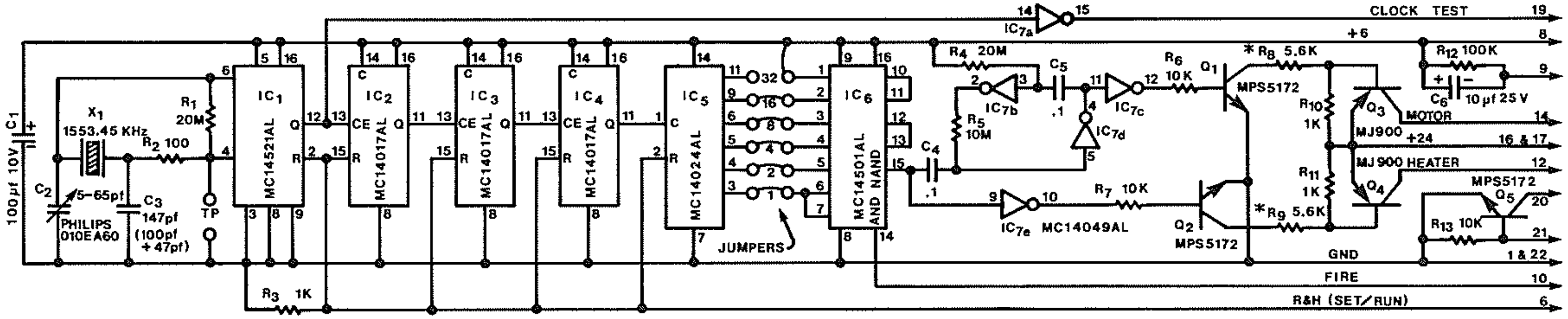


Figure 5. Circuit diagram of crystal-controlled clock. Resistance values are given for 24 V at pins 16 and 17 of card. For R_8 and R_9 (indicated by asterisks) use 5%resistor closest to 250 (V - 1.2) ohms, where V is the voltage at pins 16 and 17.

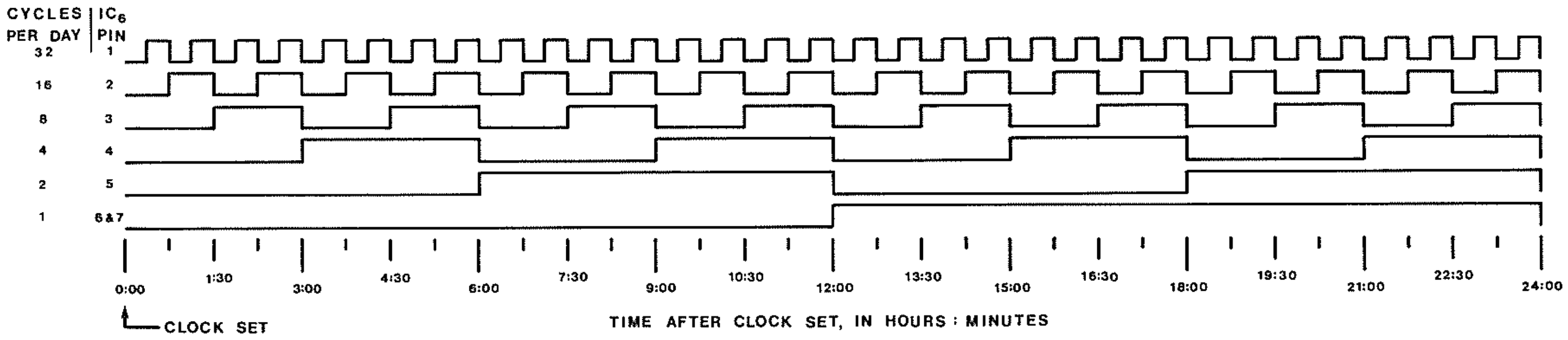


Figure 6. Clock timing diagram.

of shots per day is doubled. In Table 1, some of the possible timing schemes achievable with the authors' system are suggested. To attain a given timing scheme, the clock jumpers (Figs. 5 and 7b) are connected either from IC$_6$ to IC$_5$ or from IC$_6$ to +6 V, as indicated. Note that jumpers must *never* connect IC$_5$ to +6 V and that *all* inputs to IC$_6$ must be connected. The times in column 2 are arbitrary. By advancing or retarding these times, all the times in column 1 are equally advanced or retarded. Heating time is 45 min except where noted.

It is also possible to activate the camera 10, 100 or 1000 times per day by removing one or more of IC$_2$, IC$_3$ or IC$_4$ and installing a jumper, in place of each IC removed, between pins 11 and 13. By moving the jumpers between IC$_5$ and IC$_6$ as explained previously, the number of activations per day can be increased still further by factors up to 32. As heating time would be divided by 10, 100 or 1000, in most cases heater cycling would not be practical but, because of the speed with which the film supply would be exhausted, the camera could be heated continuously if required.

The "motor" output of the clock need not operate the motor at all, either directly or, as in this system, via a motor-control circuit. By adding a resistor (about 1 K) from the "motor" output to ground, the clock can be used to trigger other circuits, for example the intervalometer detailed in the Appendix. In this case, the heater voltage need not be 24 V, but can be any dc voltage up to 60 V (minimum 4 V if used with the intervalometer), provided the current does not exceed about 1 A.

Figure 7a shows the printed circuit board layout for the clock. It can be used to duplicate the clock board in the same way that Figure 4a can be used to duplicate the motor control board. The photograph of the completed

Table 1. Wiring for Selected Timing Schemes

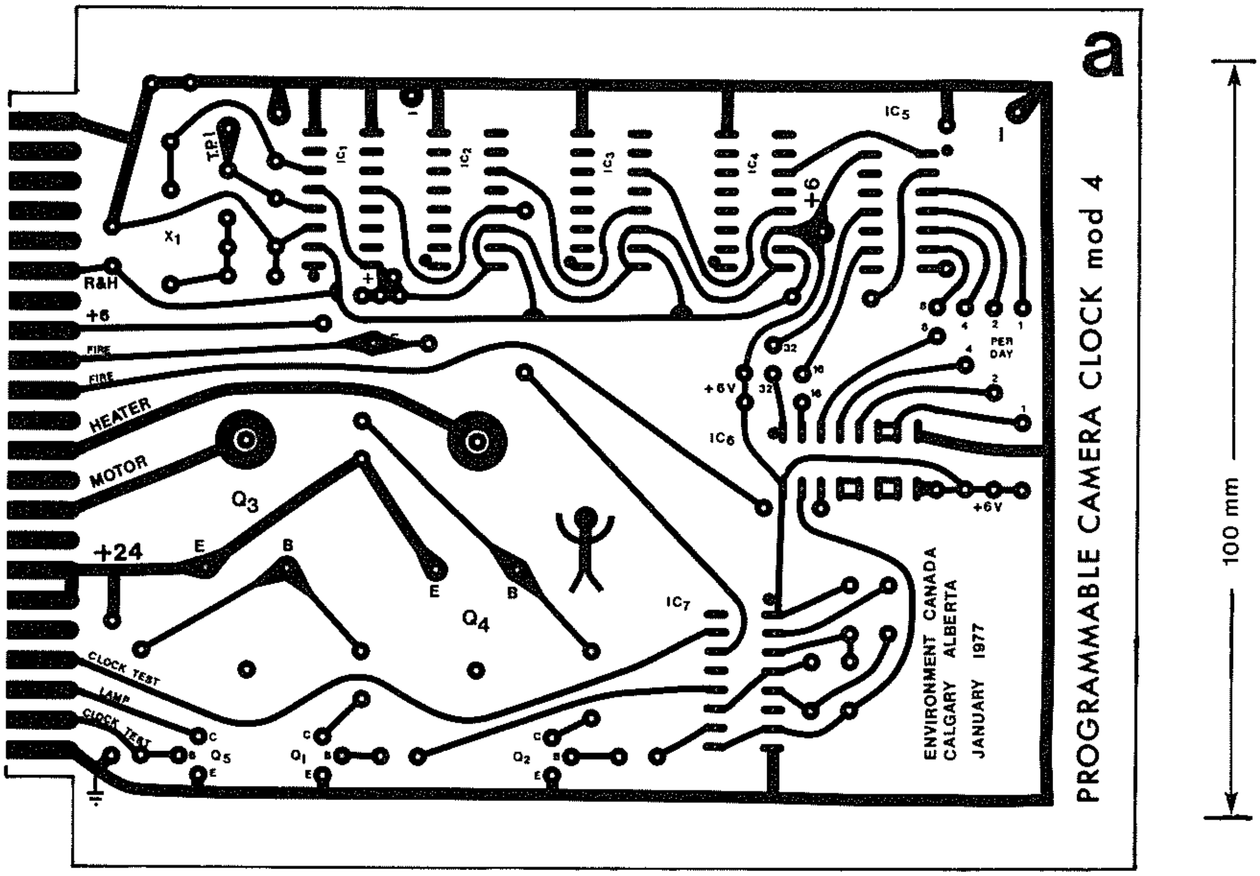
Time at which camera activated	Time at which clock set	Jumper number					
		1	2	4	8	16	32
12:00	12:00	IC$_5$	IC$_5$	IC$_5$	IC$_5$	IC$_5$	+6 V
00:00, 12:00	00:00 or 12:00	+6 V	IC$_5$	IC$_5$	IC$_5$	IC$_5$	+6 V
00:00, 06:00, 12:00, 18:00	Any of these times	+6 V	+6 V	IC$_5$	IC$_5$	IC$_5$	+6 V
00:00, 03:00, 06:00, 09:00 12:00, 15:00, 18:00, 21:00	Any of these times	+6 V	+6 V	+6 V	IC$_5$	IC$_5$	+6 V
Every 1.5 h	Any of these times	+6 V	+6 V	+6 V	+6 V	IC$_5$	+6 V
Every 45 min*	Any of these times	+6 V	+6 V	+6 V	+6 V	+6 V	IC$_5$
09:00, 15:00	15:00	IC$_5$	+6 V	IC$_5$	IC$_5$	IC$_5$	+6 V
07:30, 10:30, 13:30, 16:30	16:30	IC$_5$	+6 V	+6 V	IC$_5$	IC$_5$	+6 V
07:00, 08:30, 10:00, 11:30 13:00, 14:30, 16:00, 17:30	17:30	IC$_5$	+6 V	+6 V	+6 V	IC$_5$	+6 V
10:30, 13:30	13:30	IC$_5$	IC$_5$	+6 V	IC$_5$	IC$_5$	+6 V
10:00, 11:30, 13:00, 14:30	14:30	IC$_5$	IC$_5$	+6 V	+6 V	IC$_5$	+6 V
11:15, 12:45	12:45	IC$_5$	IC$_5$	IC$_5$	+6 V	IC$_5$	+6 V
11:00, 11:45, 12:30, 13:15	13:15	IC$_5$	IC$_5$	IC$_5$	+6 V	+6 V	+6 V
04:30, 07:30, 16:30, 19:30	07:30 or 19:30	+6 V	IC$_5$	+6 V	IC$_5$	IC$_5$	+6 V
03:45, 05:15, 06:45, 08:15 15:45, 17:15, 18:45, 20:15	08:15 or 20:15	+6 V	IC$_5$	+6 V	+6 V	IC$_5$	+6 V

*Heating time 22.5 min.

board, Figure 7b, also shows wires which were connected from the ground and +6-V lines directly to the battery terminal block, bypassing the card edge connector.

Camera Housings

The original cameras were mounted in housings, 13.5 in. long by 10.5 in. high by 9 in. wide (34.3 cm by 26.7 cm by 22.9 cm), made of 0.75-in. (19-mm) plywood, fitted with mitered plug doors (Fig. 8). Wood was chosen because it was easy to handle both in the manufacture of the housings and later in mounting them in the field. Other types of housings, for example those designed for outdoor mounting of closed circuit T.V. cameras, would likely serve as well or better. These closed circuit T.V. camera housings can be equipped with optional heaters (useful where power



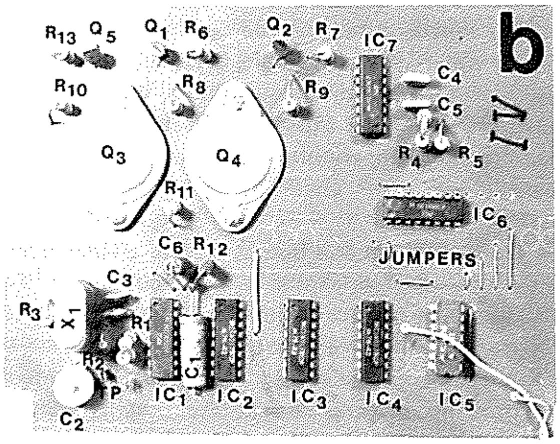


Figure 7. Printed circuit board for crystal-controlled clock: *a* – circuit board master; *b* – top view of completed circuit.

is available), windshield wipers, and a choice of mounting hardware.

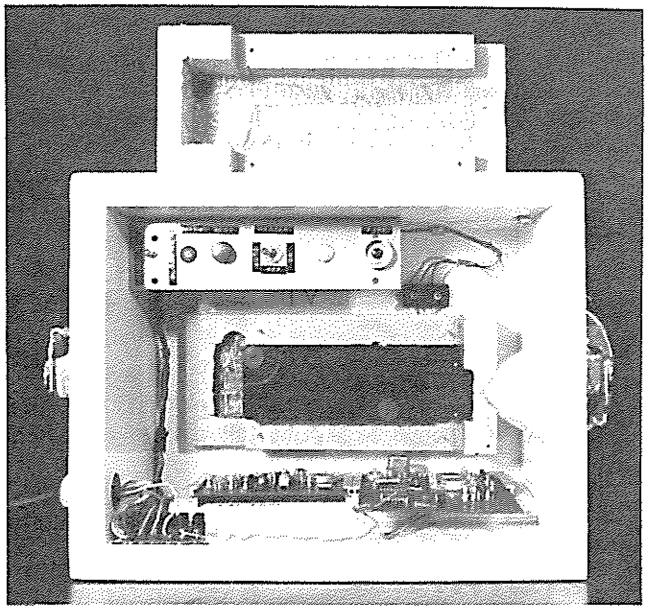


Figure 8. Camera in camera housing; front half of insulator, removed to show camera, is on top of housing.

To prevent excessive heat loss, the KB9A camera was installed in the housing in a Styrofoam insulator (Fig. 9) carved with a hot-wire cutter out of 3-in. (7.6-cm) sheet Styrofoam. Wood screws, passing through the camera mounting plate, through the Styrofoam and into the plywood back of the housing, held both the mounting plate and the back half of the insulator in place. The front half of the insulator was aligned with the back half by round wooden toothpicks and held in contact with the back half by a piece of foam rubber glued to the inside of the door. Cold-room tests indicated that with this scheme, only 10% of the total energy required to heat the camera from -55°C to operating temperature was lost through the insulation; the remaining 90% was used to raise the temperature of the thermal mass of the system.

The camera faced outside via a hole cut in one end of the insulator and a larger (6.8-cm diameter) coaxial hole (lens port) cut in one end of the housing. To prevent accidental blocking of the view, a short cone cut from a polyethylene funnel was inserted coaxially between the camera lens and the inside of the housing and glued to the back half of the insulator and to the housing with Dow Corning Silastic (bathtub sealer). A glass cover, glued and sealed with Silastic, was later placed over the outside of the lens port.

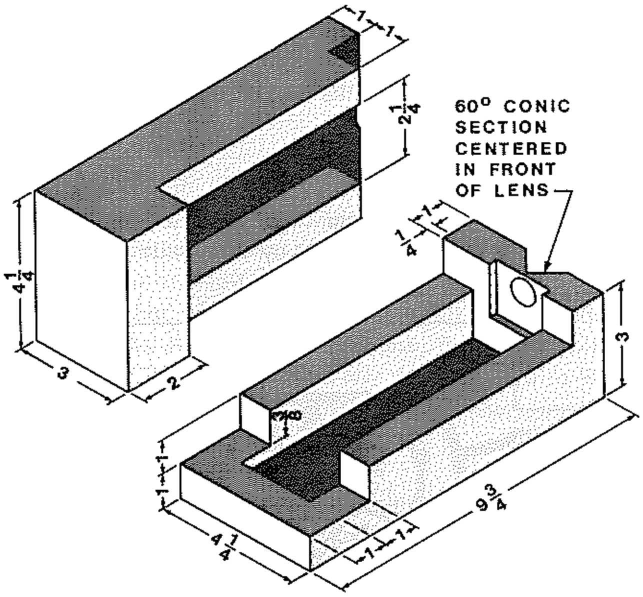


Figure 9. Styrofoam camera insulator.

The housing was also fitted with a metal bracket for mounting switches and the clock test lamp, two card edge connectors for the circuit boards and a carrying handle. A Thomas and Betts 2521 strain-relief connector was used to hold and seal the battery cable.

The door, held in place by a pair of sash locks (Amerock BP-7020-26), had a foam weather stripping dust seal. This was later supplemented with nonhardening glazing putty when initial field tests, confirmed by cold-room testing, indicated a moisture problem. It was found that when the film was exposed to low but above-freezing temperatures at high relative humidity for several days, the emulsion became sticky and the cameras jammed. By adding the glass cover to the lens port, installing two or more cloth bags, each containing about 200 g of silica gel, in the housings, and sealing the doors, camera jamming was avoided. Although this scheme works, the sealing on each of three cameras tested for 133 days leaked an average of 112 g of water which was held by the silica gel. It seems likely that other film-camera-housing combinations will also require sealing and a drying agent if they are to be used at near-freezing temperatures accompanied by high relative humidity.

The KB9A cameras do not feature a viewfinder, and bore-sighting adapters appear to be unobtainable. To aim the cameras, one camera was modified by replacing the film transport mechanism with a front-surface mirror set at 45° to the lens axis and adding a series of lenses to focus on the virtual image generated at the original film plane. This modified camera is substituted for the film camera while the housing is being mounted and aimed. The small inverted image, however, is difficult to work with. A better solution, provided the camera is not intended for close-up applications, would be to fit a wire-frame viewfinder which could consist of a wire with a small loop (peep hole) at the rear of the housing and a large rectangular loop, outlining the scene viewed by the camera, at the front of the housing. Provision could be made to fold the viewfinder against the housing or slide it into the housing when not required. By first mounting the housing with the camera installed and photographing a distant scene and then, without moving the housing, having the film processed and printed, it should be possible to fabricate a wire-frame viewfinder which would outline the scene as depicted in the print.

FIELD INSTALLATION AND OPERATION

Time-lapse cameras are equally useful in the laboratory and in the field; however, only their installation in the field is considered here. Although the battery requirements, installation, operation and film handling procedures described relate particularly to the authors' system, the general approach and many specific suggestions apply equally to other systems.

Battery Requirements

The camera system was designed to operate on two batteries, one a 6-V dry-cell lantern battery to provide 1.5 mA continuously to the clock and the other a 24-V lead-acid wet-cell battery consisting of two 12-V automobile batteries in series to provide 1.0 A intermittently to the camera motor and heaters. Based on ampere-hour capacity, a single Eveready 731 or Mallory M918 battery should operate the clock for more than a year. Considering shelf life and safety factors, it would be better to use two of the above zinc-carbon batteries in parallel or an alkaline lantern battery such as a Mallory MN9180. The only camera failure to date was caused by a pair of M918's that expired after 265 days. Their demise was likely hastened by discharge through snowmelt water from the drifted snow that had been observed in that particular battery box.

The life of the 24-V battery depends almost exclusively on heating requirements; only a small fraction of an ampere-hour is needed to operate the motor for a full load of film (for operation above freezing, a 24-V battery consisting of four 6-V lantern batteries in series can operate the camera for many rolls of film; calculations indicate more than 250 rolls).

Extensive cold-room testing of one camera installed in the type of Styrofoam insulator used in the field indicated the energy required per heating cycle was 0.10 (2.8 - T) + 0.088 Ah at 24 V for $T \leqslant 2.8^\circ C$, where T is the temperature of the camera at the start of the heating cycle. Above 2.8°C, the thermostats in the camera were open and no power was required for heating.

In practice, a somewhat larger battery was found necessary. Cameras installed near Fort Norman, N.W.T., between September 26, 1977, and May 3, 1978, required a heating cycle every day for 220 days, for a total of 5800 heating degree-days [based on heating to 2.8°C and on the minimum daily temperatures for the period at Norman Wells lowered by 3.2°C, the amount by which long-term mean daily minimum temperatures for these months are colder in Fort Norman than in Norman Wells (Burns, 1973)]. The cold room derived formula would suggest an energy consumption of 77.5 Ah at 24 V; in practice, the 90-Ah Globelite 24C90 batteries used, while still able to operate the cameras, were exhausted according to hydrometer tests. The "loss" of 12.5 Ah was likely due to self discharge over the relatively long period of time and reduced efficiency at low temperature (minimum temperature during the period was -41.3°C).

From these results, it would appear that the rated capacity of the 24-V battery should be about 20 Ah per thousand heating degree-days based on heating from the mean minimum daily temperatures to 2.8°C once per day, with a safety factor of 30%.

If a power line were available at the camera site, the motor and heaters could be operated from it, through a suitable power supply, or the housing could be continuously heated and the motor run from lantern batteries. Because the clock circuit resets randomly after even a momentary interruption of power, battery power would still be required for the clock.

Installation and Operation

All of the field installations so far have been made by attaching the camera housing to the side of a tree (Fig. 10). An axe was used to shave a vertical flat area at about shoulder height on the side of a selected tree, such that the plane of the flat area was approximately aligned with the desired direction of view. A sub base, 6 in. by 12 in. (15 cm by 30 cm), made of two glue-laminated pieces of 0.75-in. (19-mm) plywood and provided with three counter-bored holes at each end, was attached to the flat area with at least two lag bolts, 5/16 in. by 3 in. (7.9 mm by 7.6 cm). A shelf, 8 in. by 12 in. (20 cm by 30 cm), provided with a back, 6 in. by 8 in. (15 cm by 20 cm), braced with gussets, was then attached to the tree, shelf uppermost, by passing a lag bolt, 5/16 in. by 6 in. (7.9 mm by 15.2 cm), through a hole in the centre of the back, through a hole in the centre line of the sub base about 3 in. (7.6 cm) from its top, and into the tree. Next, the camera housing was set in place and aimed with the aid of the viewfinder by turning the housing on the shelf and the shelf on the lag bolt. When the camera was properly aimed, the lag bolt was fully tightened and the shelf locked in place by running two or more wood screws, No. 8 by 1.5 in. (3.4 mm by 3.8 cm), through corner holes in the shelf back. The camera housing was attached to the shelf with similar wood screws passed upward through corner and centre holes in the shelf. If the tree was small and only two lag bolts had been used to attach the sub base, two braces, drilled and counter-bored across their width at one end and drilled through their thickness at the other, were attached with wood screws under the ends of the shelf and with lag bolts to the tree to prevent yaw. A roof or sunshade, 16 in. by 24 in. (40 cm by 60 cm), was attached at an angle over the camera housing by means of wood screws into the housing and a lag bolt into the tree.

Figure 10. Camera housing installed: *1*–sub base; *2*–shelf; *3*–housing; *4*–roof; *5*–braces.

Connections between the camera and batteries can be made with Belden 8407 or similar cable. Although electrostatic shielding is not required, use of a cable with braided shield is recommended because it affords protection against squirrels and other small chewing animals without having to resort to flexible conduit (BX). It can easily be stapled to trees with little chance of damage by using staples sold by electrical suppliers for installing nonmetallic sheathed cable in wooden buildings.

Batteries have been installed in two ways. The simpler way was placing the batteries in a heavy-duty plastic garbage bag and taping the bag closed around the wire. The bag and batteries were placed on level ground, the snow being cleared where present, and the neck of the bag was positioned such that rainfall or snowmelt could not enter the bag. The second method involved using plywood boxes (also usable as shipping crates) to house the batteries. While this method reduces the chances of batteries tipping over in spring when the ground below them thaws, the one camera failure so far encountered apparently occurred when snow drifted in through vent holes cut in the battery box, prematurely draining a pair of clock batteries by short circuit when it melted. The best method probably would be to wrap the batteries in a plastic bag and then install them in a wooden box.

After the camera housing and batteries were installed, the clock was tested by depressing the "Clock Test" button and observing the flashing light. The "Clock Set/Run" switch was then turned to "Set." A camera, previously loaded with film in the laboratory and transported in moisture-proof wrapping, was unwrapped, the lens protector removed, the aperture set, and then the camera was installed. The front half of the camera insulator was then installed. After heating the camera, if necessary, by switching the "Heater" switch to "Manual" for the required time, the heater was switched to "Auto" or "Off" and several test bursts were fired, followed by a burst of blank frames (made by covering the lens port and pushing the "Fire" button). At the time of day that the cameras were to be activated (generally solar noon), the "Clock Set/Run" switch was turned to "Run" and the "Heater" switch was checked to be sure it was set to "Auto" if heating was going to be needed or to "Off" if it was not. The door was prepared for installation by running a bead of nonhardening window glazing putty around its edges. Just before the door was installed, two or more cloth bags, each containing about 200 g of silica gel, oven-dried in the laboratory and transported in sealed cans, were removed from their cans and placed in the camera housing. The glass cover was checked for cleanliness and at the same time a check was made to ensure that the lens protector (red screw-in filter supplied with the camera) had in fact been removed.

Several other steps were taken to keep the cameras operating. Cloth bags of moth balls were nailed close to the cameras and batteries to discourage squirrels and other small pests. (Before moth balls were used, three layers of plywood had been eaten off the top of one camera housing; since moth balls have been used, no additional damage has occurred.)

Brush and deadfall were cleared from an area around the installation and piled on top of the batteries. This made it unattractive for large game to walk over the batteries (which were generally placed directly below the cameras) and more attractive to walk around them.

For setting the camera aperture a light meter is of little help. Instead, a photographer's old rule of thumb of setting the shutter speed at one over the ASA film speed and the aperture to f/16 on a sunny day can be revised and used to generate a table of f numbers for the fixed shutter speed of 1/100 s:

Conditions	f Number
Sunny, sand or snow	0.22 x ASA
Sunny, average subject	0.16 x ASA
Cloudy, average subject	0.11 x ASA
Dull, average subject	0.08 x ASA
Subject in shade	0.056 x ASA

If a film with ASA 50 were chosen and anticipated conditions ranged from bright sun on snow to dull skies and dark subject, a median aperture of 0.11 ASA could be chosen; the f number would be 0.11 X 50 = 5.5 and the camera would be set to the closest aperture, f/5.6. Colour or black and white negatives can withstand two stops overexposure or underexposure, possibly with some colour shift in the colour material.

To increase reliability, cameras can be set up in pairs, each with its own batteries. If the scene is the same for both cameras but the cameras view the scene from slightly different angles, the images form stereo pairs. Some of the cameras tested were set up about 10 ft (3 m) apart, and the stereo effect, while very obvious, is hard to look at because the required image separation is different for foreground and background. Better stereo pairs would likely have resulted if the cameras had been mounted on opposite sides of the same tree. In this case, one camera would have operated upside down, but for making paper prints this would not matter.

Film Handling

The exposed film was removed from the cameras in a darkroom and sent to commercial establishments for processing. Kodak 7247 colour negative film was processed and three film prints, one normal, one push-two-stops and one pull-two-stops, were made through Cine Audio Ltd., Calgary. Kodak 7231 black and white negative film was processed and a single light film print made by Alpha Cine Services Ltd., Vancouver, B.C. The negatives and prints were installed in microfilm cartridges (3M No. 78-8000-2596-3) to facilitate handling and to enable viewing in a microfilm reader (3M Filmac 400).

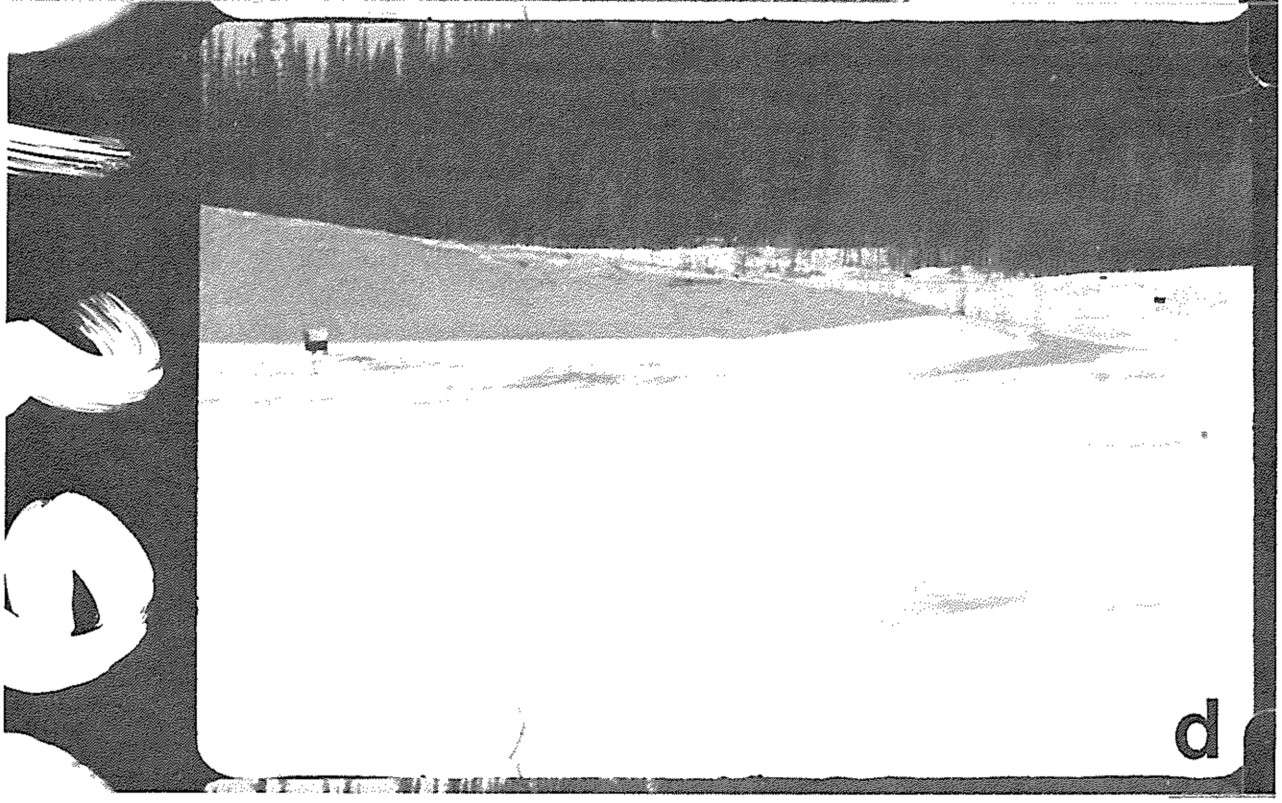
Time-lapse movies were made by rephotographing one frame from each burst taken by the system. The selected frames were rephotographed twelve or more times each, using a 16-mm motion picture camera (Canon Scoopic 16 MS), to show at least one-half second per original burst when projected. Where the original film was black and white, paper prints corrected for underexposure or overexposure of the negative were rephotographed on Kodak 7240 colour-reversal film. Colour originals were rephotographed on Kodak 7250 colour-reversal film off the screen of the microfilm viewer, with exposure being corrected by camera adjustment and colour temperature by adjustment of viewer-lamp voltage. Black and white time-lapse movies could also have been made using the microfilm viewer, by rephotographing the selected negatives on negative film to produce a positive, with exposure corrected through adjustment of either the camera or the viewer-lamp voltage. The paper prints, however, were required for photogrammetry anyway and rephotographing the paper prints permitted easy correction for movement of the time-lapse cameras.

A film print from an original negative or an original positive can be projected directly as a time-lapse movie; however, the smaller number of frames for each burst, the lack of exposure correction, and the reduced density of the last frame in each burst make this method less satisfactory. In addition, the camera must be installed right side up in the field to make this possible. The camera is right side up and the resulting film is compatible with a standard movie projector if the lens points to the left when the camera is viewed from the film side.

Frames to be printed on paper were first numbered on the blank edge of the film negative with a fine-tipped felt pen. This number and an image, 11 cm by 15 cm, were projection-printed onto paper, 5 in. by 8 in. (12.7 cm by 20.3 cm), using an enlarger (Omega Prolab B66) fitted with a 110 film size negative carrier modified to hold two microfilm cartridges. With this method, the film could be

Figure 11. Selected prints from Bear Rock films: *a* - North-facing camera, September 28, 1977; *b* - North-facing camera, October 23, 1977; *c* - North-facing camera, February 10, 1978; *d* - West-facing camera, February 10, 1978.


c


d

transported from cartridge to cartridge through the enlarger without being touched and the prints automatically received a number which could not be accidently removed.

RESULTS

Three frames from a north-facing camera and one from the west-facing camera operated at Bear Rock near Fort Norman from September 26, 1977, to September 13, 1978, are shown in Figure 11. Figure 11a, taken two days after installation, shows a number of targets. These targets, 12 in. (30.5 cm) square and painted half black and half white, were installed and surveyed to serve as reference points. Even though later obscured by snow, the size and location of objects (in this case, frost blisters) could still be deduced by comparing the photographs under a stereoscope or by means of a plot of the targets.

Figure 11b shows the effect of wind-blown snow partially obscuring the lens-port glass cover. A total of 16 frames were completely obscured by snow and 25 more were partially obscured in the film from this north-facing camera. Film from the west-facing camera at the same site shows no frames completely obscured and only 12 frames partially obscured, indicating that mounting the camera to look across prevailing winds, or at least across winds that accompany snow, is a better choice. An extra cone installed over the glass cover or a trap door arrangement that opens just before the picture is taken and closes just after, may help, provided that the first does not become packed with snow or the second freeze closed.

Comparison of Figures 11a and 11c indicates that during the intervening 135 days, the camera was tilted upwards 18% of frame height and turned to the left 18% of frame width. The tilting may have resulted from ground heave and the turning from twist in the tree trunk induced by freezing. A plot of tilt and turn with time is shown for this camera in Figure 12. Although not all the cameras moved this much, it would seem unwise to position anything of interest too close to the edge of view when aiming a tree-mounted camera.

Figure 11c shows two fine white lines running across the top of the picture. Close inspection of the negative revealed that these are cracks in the emulsion, extending from the end of the sprocket hole to which the sprocket applies pressure when transporting the film. Some pictures also show short cracks extending from the nonpressure end of the sprocket hole. These cracks appear to be a result of bending dry film around the relatively small-diameter guide roller in the camera. While many pictures exhibit these cracks, not one film has been broken either in cold-room testing or in field testing and operation (some of the cameras that jammed in field testing, before silica gel was used, tore out sprocket holes, but even then they did not break the film).

Comparison of Figure 11c with Figure 11d, taken on the same day at approximately the same time but looking west, indicates that side lighting (looking at right angles to the direction of the sun) and a lower camera angle can help to accentuate features that otherwise would tend to blend with the background. This is particularly true on sunny days.

Many of the pictures are of inferior quality compared with the examples shown, due to poor lighting and other conditions beyond the control of the authors. Some of the

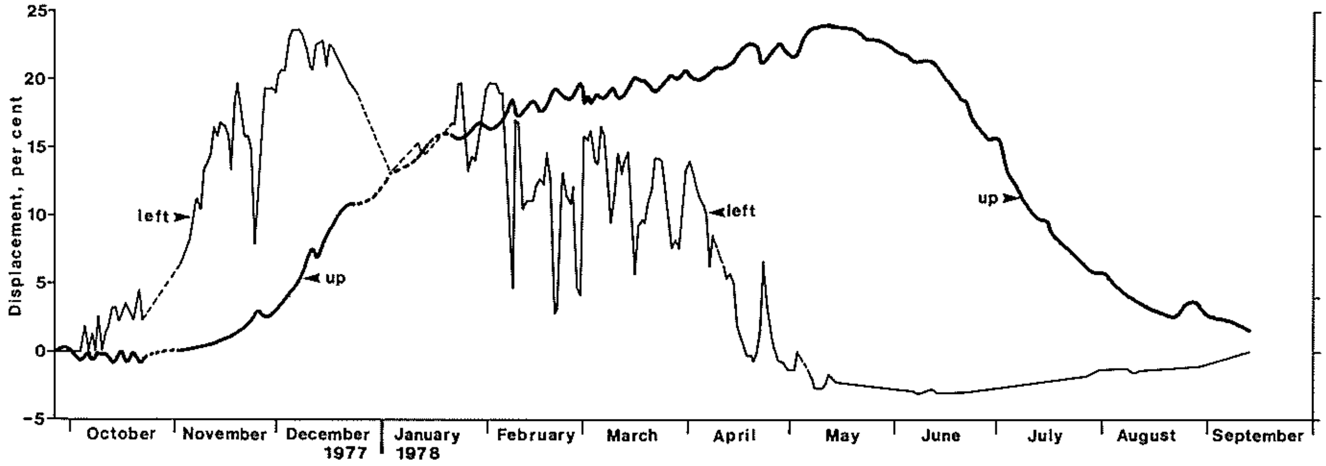


Figure 12. Displacement of north-facing camera at Bear Rock, with time; upward displacement in percentage of frame height, leftward displacement in percentage of frame width.

poorer pictures, seen by themselves, appeared to convey nothing useful. When they were viewed as part of a series containing much better pictures, it became relatively easy to pick out the features of interest. Measurements to determine the rate of growth of the frost blisters could be made even on the poorer pictures, including many that were partially obscured by snow on the glass cover.

SUMMARY AND CONCLUSIONS

The authors' time-lapse camera system has been used successfully through an entire year at several locations in northern Canada. The system consists of a specially modified Eastman Kodak KB9A 16-mm strike recording motion picture camera; a motor control circuit to regulate the speed of the camera motor as well as the number of frames exposed during each burst; a quartz clock to control when each burst is taken; a housing to protect the camera and associated circuits, and to facilitate mounting of the system; and a battery pack.

Detailed instructions provided in this report for the modification of the camera and for the assembly of the control circuits and the housing apply specifically to the KB9A camera. The general approach, however, will be similar if other cameras lacking single-frame capabilities are used. A circuit designed for adaptation of common movie cameras and motor-drive still cameras for automatic time-lapse photography is described in the Appendix.

The provision of adequate battery capacity, although important for any field installation, becomes crucial when the time-lapse system is to be operated during the winter. Power requirements are determined on the basis of the system's power consumption, measured during cold-room tests, and the temperature records for the area of operation. Comparison with battery manufacturer's data on rated capacities will then permit selection of an appropriate power pack. The use of this approach enabled the authors' system to operate uninterruptedly for 220 days, from September 26, 1977, to May 3, 1978, at a site near Fort Norman, N.W.T. It should be stressed that the clock has to be powered by a battery, even where mains power is available.

Between September 26, 1977, and October 20, 1978, a total of six time-lapse camera systems were in operation for various periods of time at four separate locations, for a total of 1464 camera days. A shorted battery in one system resulted in the loss of 49 days of record, giving a data recovery of 96.7%.

Both black and white and colour negative film have been used in the authors' system. While both produce good results, the colour film produces a higher resolution.

Automatic time-lapse photography can be useful in many situations in which natural discontinuous processes produce visible changes in the landscape that are difficult, prohibitively expensive or impossible to record with available instrumentation. It is especially attractive in cases where access is difficult and/or expensive. Examples include the study of glacier surges, icefall dynamics, iceberg calving, avalanches, growth and decay of icings, spring breakup in streams, seasonal flooding, riverbank and lakeshore erosion, landslides, etc. A wide choice of time-lapse intervals permits monitoring of both fast and slow processes.

A number of improvements in the design and operation of the authors' automatic time-lapse system may be possible and some potential applications may require modification of the system. For instance, provision for automatic triggering of the system by the phenomenon of interest (e.g., an avalanche) would permit relatively short-interval photography over long periods of time, without undesirable waste of either film or battery power. Suggestions and enquiries from future users and potential users will therefore be very much appreciated.

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Appendix

The use of cameras similar to the KB9A was mentioned in the section describing the authors' system. Another class of cameras suitable for automatic time-lapse photography consists of cameras with built-in single-frame capabilities. These include 35-mm still cameras with motor drives (and possibly extended magazines) and most Super-8 and 16-mm movie cameras. Suitable 35- and 16-mm cameras are quite expensive, but Super-8 cameras, because of the larger market, are relatively cheap. The large 35-mm film format has the best resolution of the three, but the small Super-8 frames can give a surprising amount of detail, especially if slow-speed colour films are used.

Motor drive and movie cameras are typically battery operated and can be activated by an intervalometer. In addition, through-the-lens viewing, zoom lenses and automatic exposure control make these cameras easy to aim, noncritical to locate relative to the scene to be photographed, and able to expose every frame properly.

The major shortcoming of these cameras is their inability to operate at low temperatures. This could be overcome by heating the camera. A heated enclosure could be provided by first making a Styrofoam insulator (as was done for the KB9A) and then installing strings of carbon resistors to act as heaters. For example, a string of 24 two-ohm one-half-watt resistors in series could be installed in one half of the insulator and a similar string in the other half. Wired in parallel and connected to 24 V, the two strings together would provide 24 W of heat. A thermostat, set to open at a temperature slightly above freezing, would prevent unnecessary heating.

Although these cameras are designed to operate with an intervalometer, commercial intervalometers have neither a long enough period between shots nor a stable enough timer. An intervalometer, shown in Figure A-1, was therefore designed to serve this and other purposes. It provides two contact closures to the camera, one to turn the camera on and the other to operate the shutter.

Many Super-8 cameras have no provision for external power or for externally turning the internal power on and off. It is possible, however, to interrupt the battery circuit by inserting two thin metal disks, separated by a thin insulator, between one of the batteries and the contact it normally touches. Two wires, connected from these disks to the "Camera Power" contacts in the intervalometer, will then permit the intervalometer to complete the camera's power circuit (if the camera's "Off/On" switch is left "On" at all times). Cameras with provision for external power can be run by a battery pack wired in series with the "Camera Power" contacts in the intervalometer.

After completing the power circuit, the intervalometer provides an adjustable delay, during which the photocell in the camera can adjust the exposure setting. At the end of the delay, the "Shutter Release" contacts in the intervalometer close, operating the camera shutter via the camera's remote electric shutter-release connection. The intervalometer operates cyclically, with cycle times adjustable in eleven steps from 0.3 s to 60 s. During each cycle, the "Shutter Release" contacts close once and stay closed for the percentage of the cycle time that is set by the "Duty Cycle" control, adjustable from 0 to 100%. If the camera is set for normal operation, it will take a burst and each burst will last for the percentage of the cycle time selected by the "Duty Cycle" control. If the camera is set for single-frame operation, it will take a single frame for each cycle, provided the "Duty Cycle" control is set to less than 100% (normally, it would be set to 50% for single-frame operation). The number of cycles that occur before the intervalometer shuts itself off is adjustable by means of a switch from 1 to 9 and infinity. The intervalometer can be triggered and cycling initiated by the crystal-controlled clock described earlier or by other suitable sources.

Figure A-1 also includes circuitry for operating photofloods which would be turned on and off along with the camera power. Photofloods could be considered if power to operate them were available. The intervalometer circuit has been assembled and tested in the laboratory and found satisfactory. Because it has been neither tested in the field nor built in quantity, it is not yet considered a "proven" circuit. To assist in its further development, its operation is detailed below.

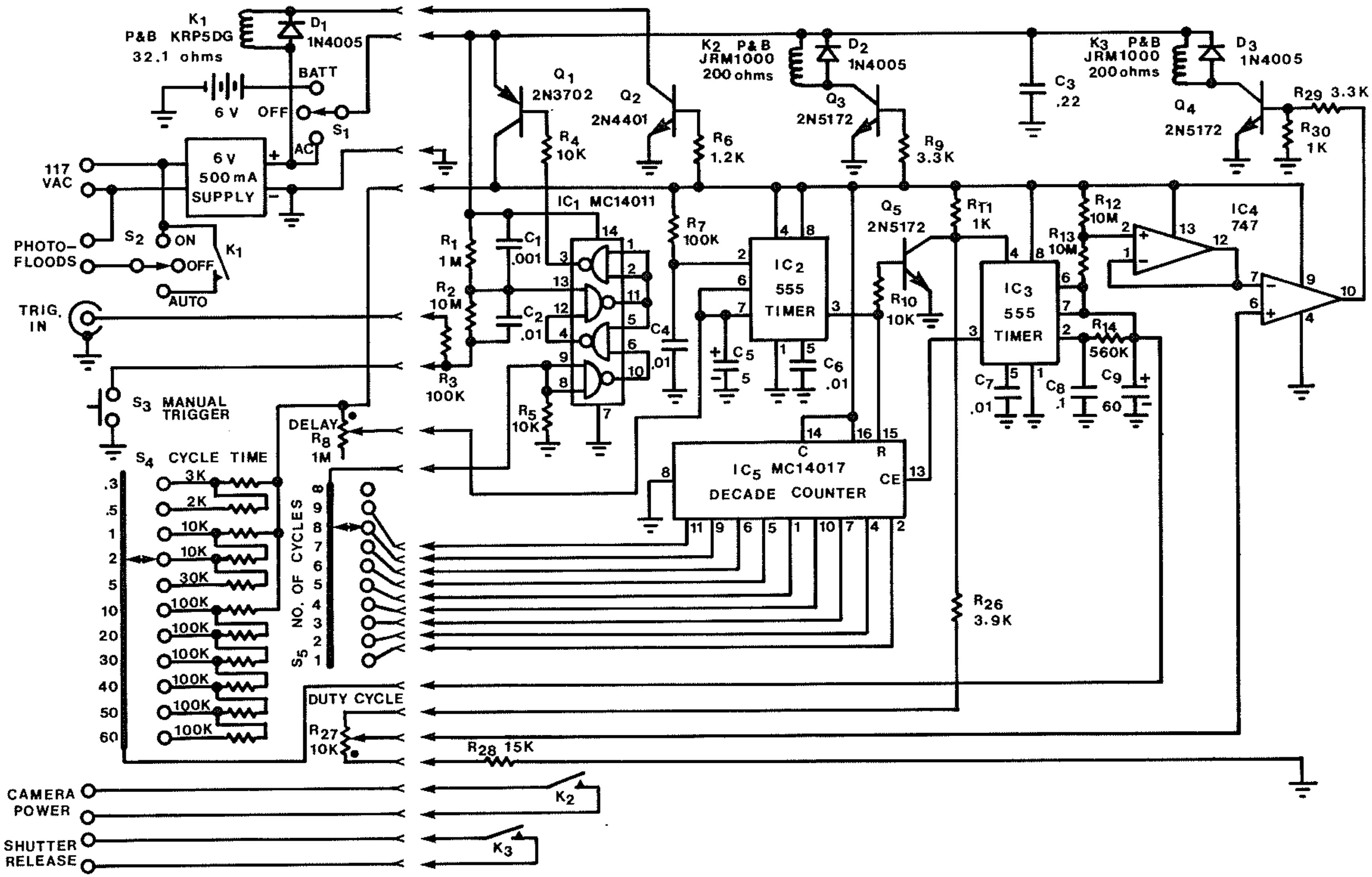

Figure A-1. Circuit diagram of multipurpose intervalometer.

The circuit is turned on and off by a quad 2 input CMOS NAND gate, IC_1. In the off state, the circuit consumes little current (<1 nA). When a contact closure or negative-going voltage momentarily sets pin 13 of IC_1 low via C_2, pins 11 and 5 go high. With pins 8 and 9 low, and therefore 10 and 6 high, pin 4 goes low, keeping pin 11 high. With pins 1 and 2 high, pin 3 goes low, turning on Q_1 via R_4. With Q_1 on, Q_2 and Q_3 are turned on via R_6 and R_9, pulling in K_1 (if used) and K_2, which in turn completes the power circuit for the camera.

When Q_1 is first turned on, the delay timer IC_2 is triggered by a momentary low across C_4. Its output at pin 3 then goes high until the voltage across C_5, charging at a rate determined by the setting of "Delay" control R_8, exceeds two thirds of the voltage at pin 8. While pin 3 of IC_2 is high, the counter IC_5 is reset and Q_5 is turned on via R_{10}, keeping the voltage at pin 4 of IC_3 low and holding IC_3 reset. Furthermore, the voltage at pin 6 of IC_4, which is derived via the "Duty Cycle" control R_{27} from the collector of Q_5, is also low during the delay period, keeping pin 10 of IC_4 low and Q_4, K_3 and the shutter release contacts turned off.

After the delay period expires, pin 3 of IC_2 goes low, Q_5 is turned off, the voltage at pin 6 of IC_4 exceeds that at pin 7, pin 10 goes high, turning on Q_4 via R_{29}, relay K_3 pulls in and the camera shutter is operated via the contacts of K_3. Meanwhile, with Q_5 off, the reset voltage at pin 4 of IC_3 rises, permitting IC_3 to cycle. The voltage across C_9 begins to rise at a rate determined by the amount of resistance inserted by "Cycle Time" control S_4. One half of the voltage across C_9 and one half of the supply voltage are added together by R_{12}, R_{13} and the left-hand half of IC_4; the sum, at pin 7, is compared with the duty-cycle-control voltage at pin 6. When the voltage at pin 7 exceeds that at pin 6, the output of the right-hand half of IC_4 drops, turning off Q_4, K_3 and the camera shutter release. The voltage across C_9 continues to rise until pin 6 of IC_3 senses a voltage equal to two thirds of the voltage at pin 8, then pin 3 goes high, incrementing counter IC_5 one count and pin 7 shorts C_9 to ground.

Shortly after C_9 is discharged, C_8, discharging via R_{14} and pin 7 of IC_3, reaches a voltage equal to one third of the voltage at pin 8, triggering pin 2 and initiating a new cycle. Cycling continues until the output of IC_5 that is selected by the "No. of Cycles" control S_5 is reached. When this output goes high, pins 8 and 9 of IC_1 go high via S_5, setting pins 10 and 6 low. With pin 6 low, pins 4 and 12 go high, setting pins 11 and 5 low to keep pin 4 high, and setting pins 1 and 2 high to set pin 3 low and turn Q_1 off. The circuit is then in the off state awaiting a new trigger signal. Diodes are used across the relay coils to suppress transients and C_3 is included to bypass transients across the battery. C_1 is used to assure reset to the off state when the power is applied via S_1. If desired, C_1 can be connected between pin 13 of IC_1 and ground, with the result that a new cycle will be initiated whenever power is applied.

Triggering requirements are broad. Contact closures across the trigger input will initiate cycles, with manual triggering available when the contacts are open. A variety of pulses, including square waves, can also be used, provided they include a sharp falling edge of at least two thirds of the supply voltage. Positive pulses must be relatively wide to permit charging of C_2 via R_1, as wide as 50 ms for pulses two thirds of the supply voltage. Tests to determine maximum limitation on pulse height were unsuccessful. Pulses applied by a 130-V dc supply and by connecting the trigger input directly to the 117-V ac power line did not damage the circuit. Manual triggering is available with pulse triggering connected, provided that the instantaneous voltage, of either polarity, at the pulse input has a magnitude of at least two thirds of the supply voltage.