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An Ultraviolet Flashlight for Illuminating Fluorescent Charts

B. J. Wilson

Solid State Technology Branch
Electronics Division

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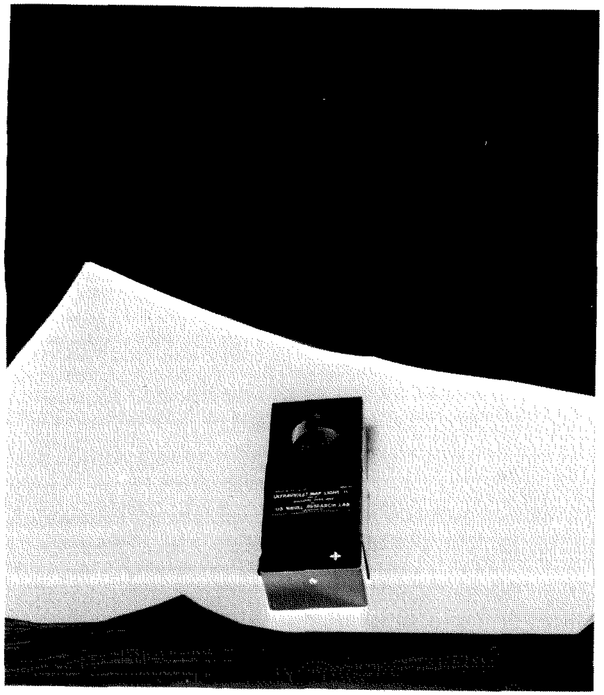
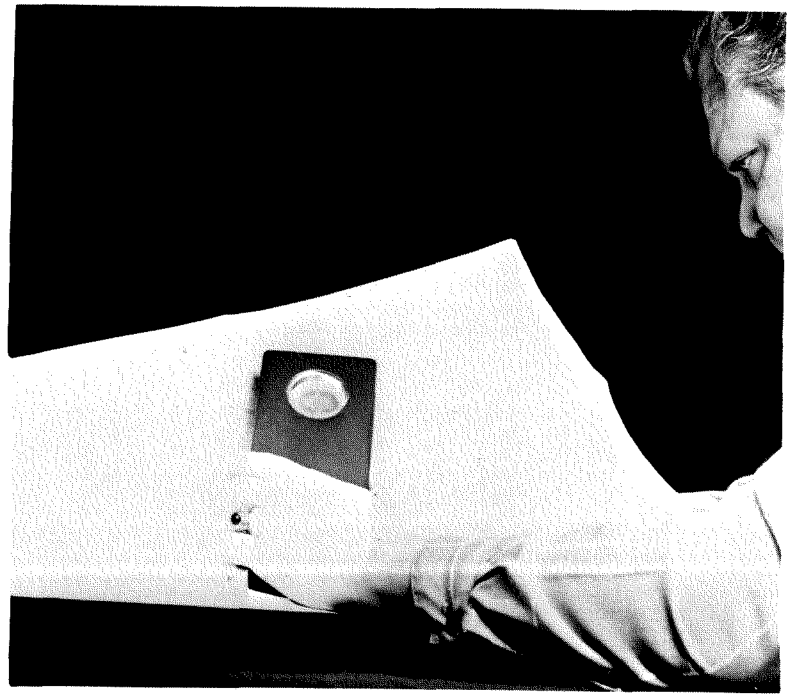


One of several NRL UV flashlight prototypes used in actual Vietnam combat operations.



Ultraviolet flashlight shown illuminating fluorescent map. Map is viewed through circular UV lamp concentric with magnifier.

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INTRODUCTION

The need for an ultraviolet (UV) source for nighttime chart or map interpretation arose as an outgrowth of developmental work on fluorescent charts extending from the 1930's to date. Both marine navigation and military purposes were involved. The primary purpose of the fluorescent map or chart was to preserve dark adaptation of the eyes, a process requiring some 30 min to achieve. The use of fluorescent inks on nonfluorescent chart paper was selected by NAVOCEANO in 1961 as the method which produced the least reradiated light, thus best preserving security.

In 1968, Marine and naval units in Vietnam expressed dissatisfaction with red illumination with respect to disclosure of the user's position. A combat-condition field evaluation was performed in 1969, and continued in 1970 under simulated combat conditions. The UV lights were cited for fragility, short life, and light leakage. The light developed at NRL in 1971 has overcome these shortcomings and has established a precedent with respect to the mode of operation of the UV lamp whereby size and operating life tradeoffs may be made routinely in connection with quantity production. Six of the NRL units were tested over a 6-month period in actual Vietnam combat situations and performed flawlessly, all being returned intact and operable.

SPECIFICATIONS

The design objectives for the UV flashlight were set by specifications for continuous on-time performance and equipment compactness and ruggedness. With the emphasis for this work being

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Circuit – Few guidelines are available that set forth criteria for converters to power nonlinear glow-discharge lamps. Some of the results from commercial scale studies (2) on using converters to power fluorescent lights is useful as a point of departure in connection with the small UV flashlights considered here.

The converter finally adopted is shown in Fig. 1. Actually, it evolved from the blocking oscillator (3) rather than the Royer (4) circuit as might be indicated from a superficial glance. The blocking oscillator (more recently being included under the classification of inductive-energy storage, along with switching regulators, flyback, and swinging-cloke converters) was initially chosen for its one-transistor/one-transformer simplicity, since transformer saturation could be avoided. When operating in this mode, however, the transformer suffers a basic disadvantage with respect to induction capability per unit size by operating with a unidirectional magnetization as it must. In the ac mode, reset is not automatic as it is in the dc-dc converter version. By coupling another blocking-oscillator converter to the original, synchronized to be on during the off-time of the original, flux reversal via reset results and yet only one transformer is needed. The bias system was kept most simple with a power consumption no more than 2 to 3% of the input power. This is a possible trade-off area, but starting dependability and additional complexity are involved.

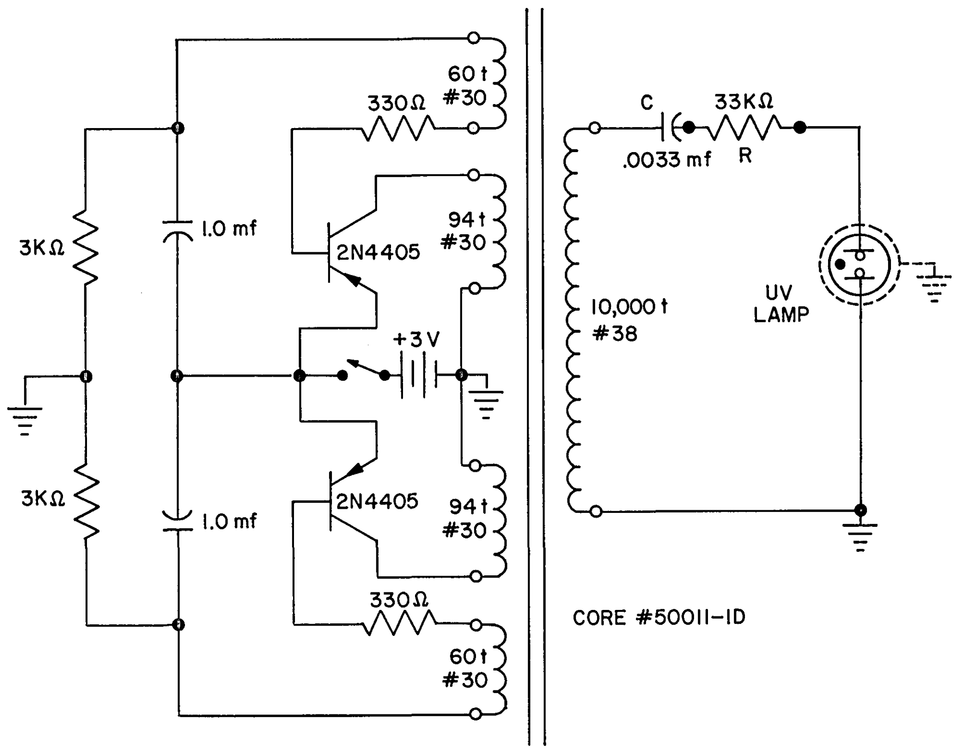

Fig. 1 – Schematic of UV flashlight power circuit

The resistance *R* in series with the UV lamp provides enough resistance to make the combined dynamic resistance positive to avoid load instability problems. The reactance of *C* served to balance somewhat the high leakage inductance of the transformer recondary winding. Incidentally, the reduction of the secondary winding's distributed capacitance is another trade-off area, since input no-load current is involved.

A common technique was used for reducing distributed capacitance and, coincidently, excessive voltages between turns, that of bunching turns as the winding process proceeds.

The circuit of Fig. 1 was reconnected as a Royer-type inverter, in which configuration it demonstrated a noticeably poorer performance with respect to output waveform and efficiency. This was due principally to dependence on the core saturation state to achieve switching, rather than on set point collector current.

BATTERIES

The batteries essentially determine the UV flashlight's performance with respect to useful life and susceptibility to environments. No latitude in battery choice was allowed. The specified performance was required utilizing batteries currently accessible at combat zones. Fortunately, from the standpoint of size, sufficient energy was available from two ordinary D-size leclanche incandescent flashlight batteries which were available in Marine issue. Energy requirements could be met with batteries of a roughly 7.5 w-hr/lb specific energy capability. The implications with respect to using more energetic batteries are obvious. They are commercially available and would probably triple the life expectancy of the flashlight per set of batteries. Of course, cost would be greater and supply handling more complicated because of their special nature, but this would be offset somewhat by virtue of the better shelf life of selected types of these more energetic batteries.

PERFORMANCE

One of the primary objectives was a continuous operating capability greater than 8 hr. It represents a rare and worst condition but sufficiently important to be stipulated. Results of these stringent continuous running tests will be reported below. It is only fair to point out that the normal operating mode is expected to be akin to that of an ordinary flashlight. As a consequence, available illumination, upon intermittent operation, will be far greater on the average than that characterized for continuous long-term operation. Since the results to be presented relate most closely to battery wearout, it is possible to predict to a rough approximation, from battery tables constructed for this purpose, the greater total life for intermittent operation total life at higher average illumination. Such tables are published by the battery manufacturers (5) for an arbitrarily standardized duty cycle. It should be pointed out, however, that no similar duty cycle has yet been prescribed by the Marine Corps office generating these requirements.

Light output as a function of time is shown in Figs. 2 and 3 with temperature as a parameter. At an upper limit of 90°F, a continuous operating life up to 30 hr is observed. At the other extreme, 0°F, as little as 0.4 hr is noted. An element of uncertainty is present here by virtue of the specification of a lower limit on acceptable light output. This lower limit was determined by a single trained observer. The extent of this subject's dark adaption was minimal. It is believed that with dark adaption over 1/2 hour, a lesser lower limit could be expected. The effect of this lowering would be most prominent at the lower temperatures, where operating times would be extended. At the upper temperature, however, the downward break in the characteristics suggests that battery end-of-life is imminent.

The implications are clear with regard to achieving maximum operating life. The maintenance of temperatures above roughly 60°F is highly desirable. Reduced operating life at lower temperatures is due both to the batteries and the UV lamp. An indication of this fact is observable

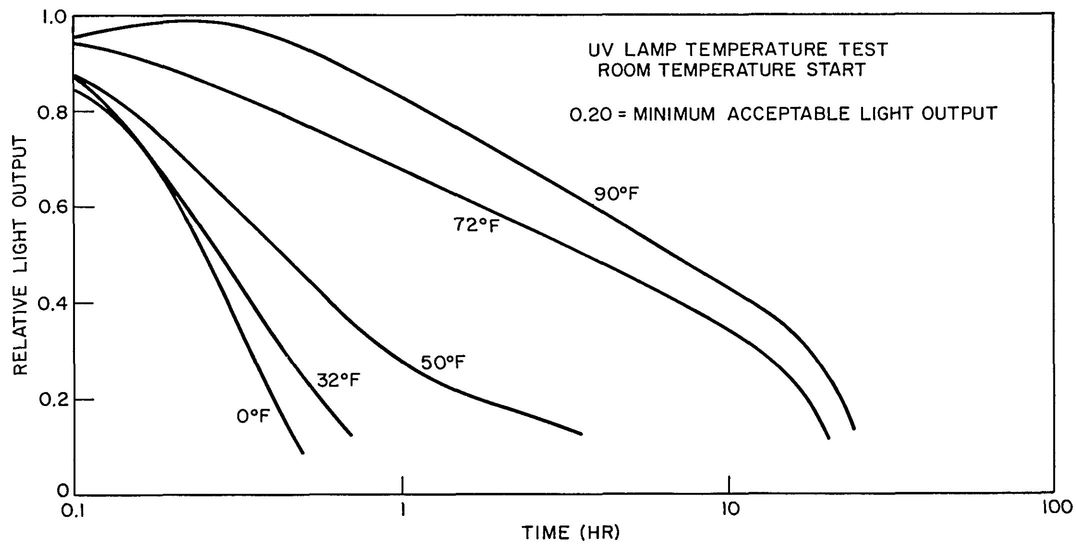

Fig. 2 — Continuous operating life of UV flashlight started at 72°F with ambient temperature as a parameter

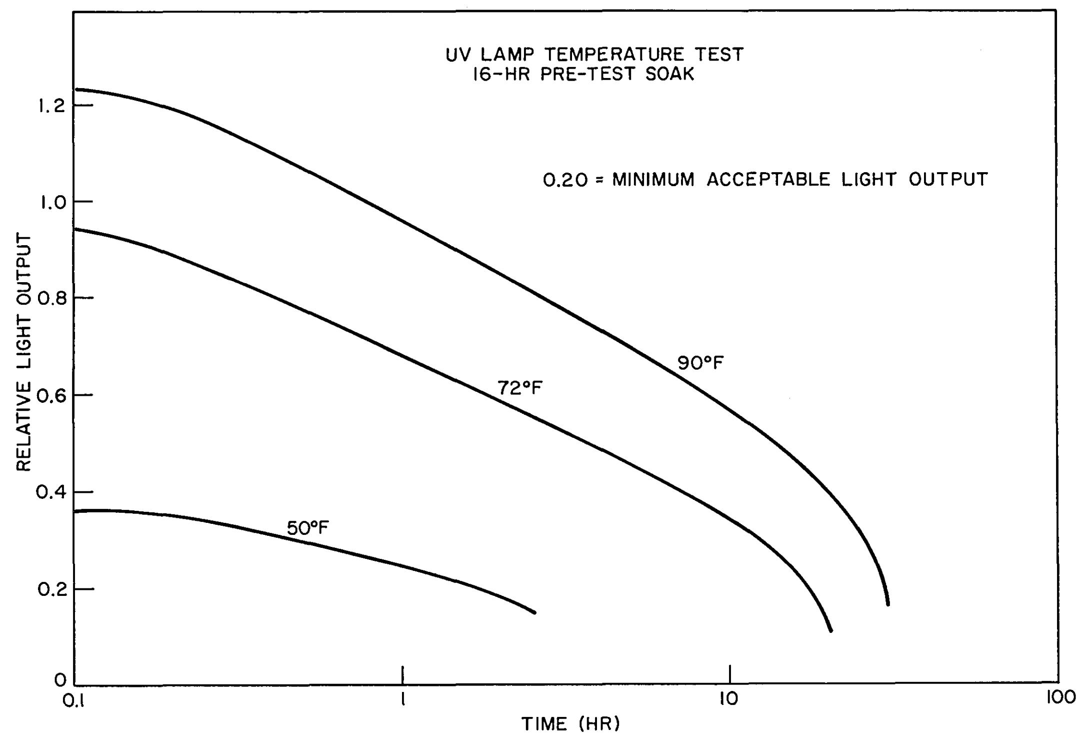

Fig. 3 — Continuous operating life of UV flashlight commencing from 16-hr pretest soaking at operating temperature

in Fig. 2 at the ordinate intercept where the lower thermal inertia of the UV lamp, in comparison to that of the batteries, clearly shows how the more quickly cooled lamp causes reduced output. A limiting condition for the lamp operation is shown in Fig. 4 where it is observed that, with the available voltage from the converter output, 40°F is the lowest temperature at which the

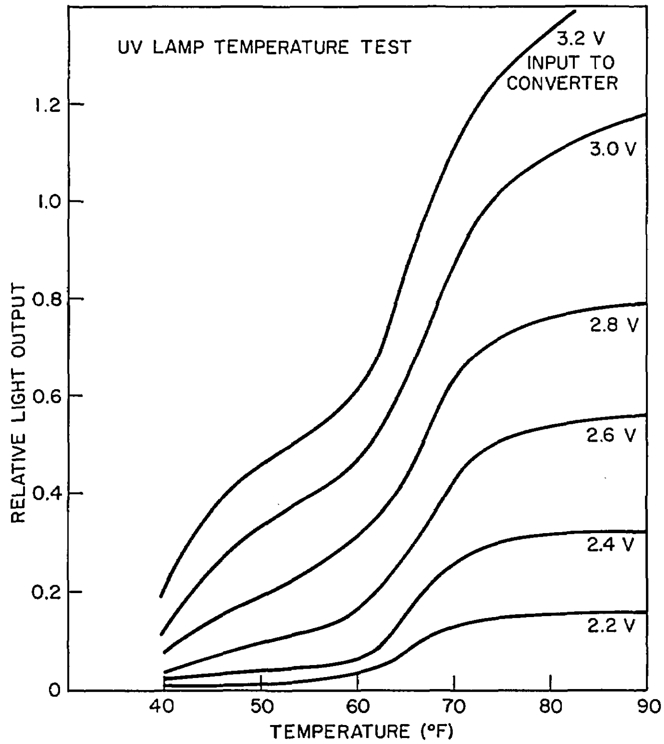

Fig. 4 — Relative light output as a function of temperature with battery voltage as a parameter

light output is at the minimum acceptable level. Another tradeoff at this point—greater voltage output from the converter may be produced by resorting to voltage control with the concomitant increased circuit complexity and lowered efficiency.

It is evident that designs for operation in cold climes should include insulation. With modern insulators, it is estimated that internal heating losses would provide the desired temperatures for 10-hr life. Body heat could be expected to provide the roughly 30 to 70°F starting temperatures.

The performance of the converter coupling the batteries and the UV lamp is shown in Figs. 5 and 6. The results apply at 72°F. The arbitrary lower limit of operation is indicated in Fig. 5 as a benchmark. This information would be routine were it not for the fact that the UV lamp load is significantly nonlinear on both large and small signal bases. This nonlinearity has immediate impact in complicating the efficiency evaluation. A lesser problem arises with respect to initiating glow discharge, the so-called starting condition. This problem was handled by providing steep wave fronts at as low a voltage as possible to the UV lamp, sufficiently high frequency to avoid glow quenching, and short discharge paths in the lamp. By these means it was possible to start the UV lamp at voltages significantly lower than the manufacturer's recommendations.

Efficiency calculation was complicated by the intractable nature of the lamp voltage and current waveforms. An approximate efficiency determination was made in lieu of more rigorous methods. Voltage and current measurements were made with a so-called true rms meter, and their product was formed to define load power. The voltage was roughly square with pronounced

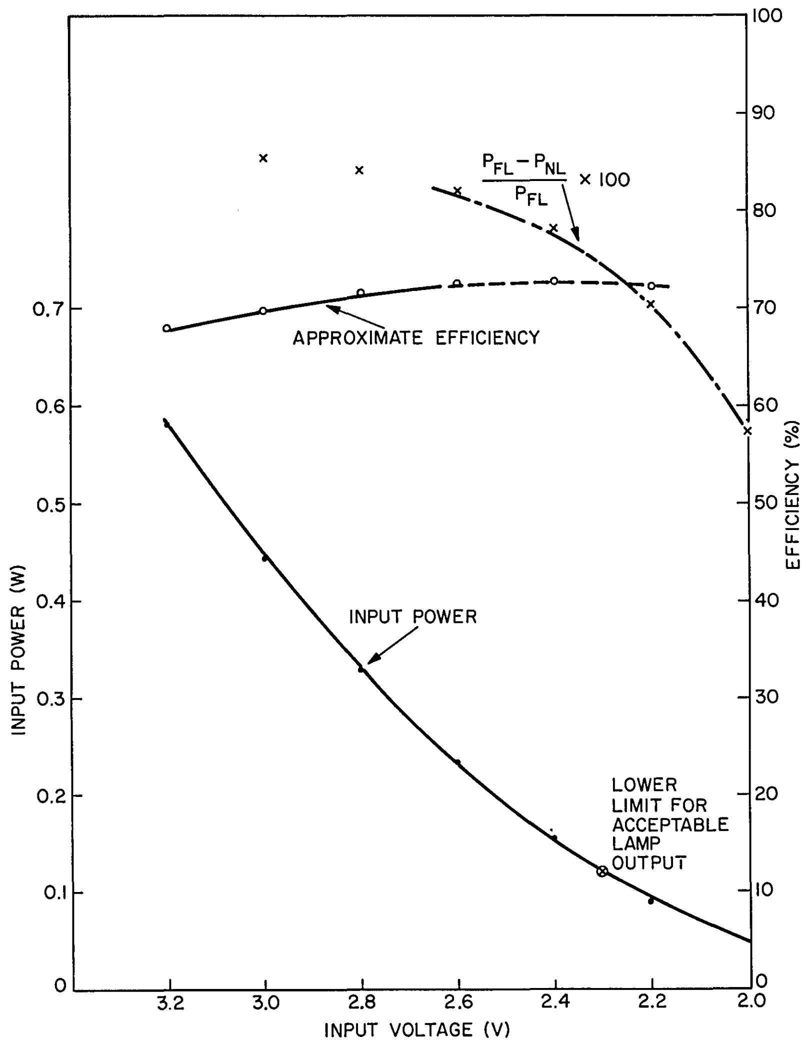

Fig. 5 — Input power and efficiency of converter section

rounded corners. The current waveform also tended to squareness, with the normally horizontal peaks and plateaus sloping to roughly 50% at the end of the half-cycle. An oscillatory switching transient was also present on the rise and fall traces. More exacting determination of power would call for the formation of instantaneous current and voltage products, averaged over the cycle, or Fourier resolutions of both voltage and current waves form. The approximate efficiency that is shown in Fig. 5, as determined by the product of rms values, exceeds 70% for the most part. The calculation defined by the difference between full-load and no-load input power divided by full-load input power was made for purposes of comparison at the low loads. This definition may be constructed as a quasi-efficiency for the converter at loads where copper loss is relatively low. The result is shown in Fig. 5.

The difference between no-load and full-load voltages in Fig. 6 reflects the extent of self-regulation imposed by the leakage impedance of the transformer, predominantly the secondary. Peak-to-peak information would ordinarily be vital to account for firing levels, but high quasi-static breakdown voltages were avoided here by use of fast rise times and shortened breakdown paths to a ground shield on the UV lamp.

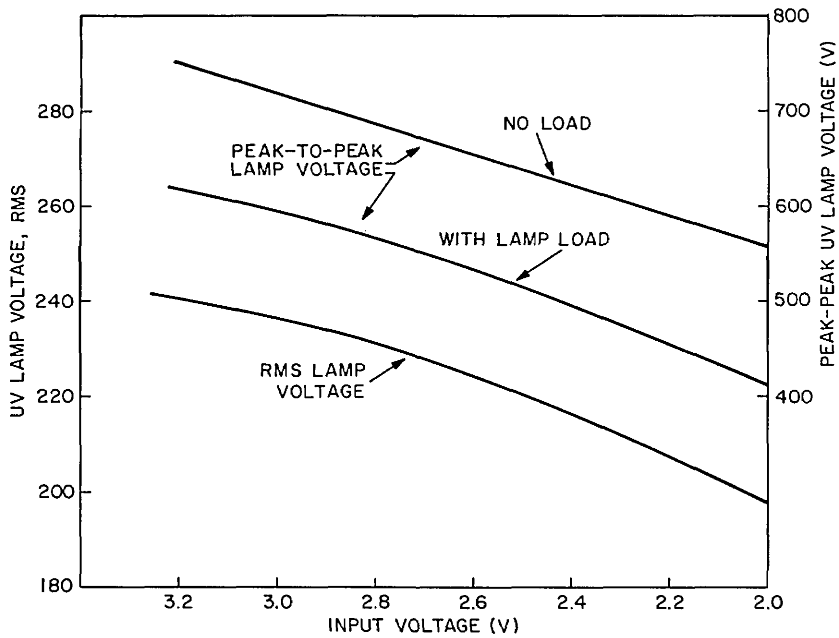

Fig. 6 — UV lamp operating voltages

CONCLUSIONS

The feasibility of providing a portable UV map reading light with an 8-hr continuously operating life has been demonstrated with an extremely simple battery/converter supply. It is possible to avoid the use of special starting circuitry by fast reversal of the ac waveform applied to the UV lamp and maintenance of short discharge paths in the lamp. In this case, up to 35 μs appears tolerable for reversal time which, although conservative from the standpoint of achievement, yet should not be taken for granted.

The end product of this dc-ac inverter design represents a compromise between efficiency and complexity. Efficiencies in the order of 70% are experienced in a simple unregulated circuit, where the UV lamp load is ballasted by a simple series resistance. An alternative to this is possible through a dynamic feedback control, whose action could conceivably save energy over that otherwise dissipated in the series resistance. Such feedback regulation would unquestionably result in a more complex system. However, in further effort on this problem area, it is expected that newly developed integrated-circuit switching regulators will be examined for possible benefits.

The energy capabilities are marginal in that the 8-hr requirement may be met only if a roughly 60 to 70°F temperature minimum is observed. A solution to this problem is indicated through the use of available insulators to the extent that low temperatures could be tolerated provided the starting temperature is kept above roughly 45°F.

A vast improvement in operating lifetime could be effected through use of commercially available batteries with greater specific energy. With such a greater energy source, the advisability for its use in heating may be considered. The need for voltage control would seem even less likely with these batteries, which tend to exhibit a flatter discharge characteristic than the leclanche battery.

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