ARS 42-38
January 1960

UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Service

A TRANSISTORIZED POWER SUPPLY AND AUTOMATIC-CONTROL UNIT FOR BATTERY OPERATION OF SURVEY-TYPE ELECTRIC INSECT TRAPS 1/

By Joe P. Hollingsworth and C. P. Briggs, Agricultural Engineers
Agricultural Engineering Research Division, ARS 2/

Electrically operated survey-type insect traps are being used rather extensively at the present time for determining the presence, abundance, and time of occurrence of many species of economic insects (8).3/ Such traps are used primarily by research and regulatory entomologists of State and Federal agencies and by commercially employed entomologists. The need often arises for operation of traps at locations remote from central-station electric service; this requires a dependable, portable source of 115-volt, 60-cycle alternating current to operate the attracting blacklight. Even in areas where central-station electric service is available, need has been demonstrated for such a power source in order to reach certain suspect fields. In addition, it may be impractical to obtain conventional electric service in carrying on research, because of the expense of line extensions.

This report describes the design, construction, and operation of an efficient and dependable automatically controlled power unit for insect traps to be used in survey investigations.

DESIGN REQUIREMENTS

Consideration of the problem of designing a power supply unit capable of meeting the requirements of electric-trap survey operations indicated the need for a unit with the following features:

1/ The material in this paper reports results of cooperative research between the Agricultural Engineering Research Division, Agricultural Research Service, USDA, and the Agricultural Engineering Department, Texas Agricultural Experiment Station.
2/ Located at the Agricultural Engineering Department, Texas A&M College, College Station, Tex.
3/ Numbers in parentheses refer to Literature Cited, p. 12.

This publication was prepared by the Agricultural Engineering Research Division, ARS, USDA.

1. Portability. The unit should be of such size and weight that it could be handled conveniently by one person.

2. High-capacity, lightweight, source of basic power. Automotive-type batteries are readily available with high volt-ampere capacities. These are of such size and weight that they can be readily handled by one person.

3. Environmental protection. Since the traps are operated out of doors, adequate protection against common environmental hazards should be provided for components.

4. Automatic on-off control. Since survey traps of this type are operated only during the night, some self-operating means should be provided for turning the power supply off during the daylight hours to prevent unnecessary operation of the unit.

5. High conversion efficiency. An inverter with highest possible efficiency of conversion of direct current to alternating current should be utilized in order to extend the useful life of the battery.

6. 115-volt, 60-cycle a.c. voltage output. The inverter should provide 115-volt, 60-cycle a.c. voltage, because the commonly used survey traps are designed for operation on 115 volts at this frequency.

7. Dependability. The unit should be relatively trouble free and maintenance free, and should be capable of performing satisfactorily throughout a wide range of ambient temperatures.

8. Simplicity. The unit should be as simple as possible, not only to keep costs low but also to insure easy and proper operation when it is used by inexperienced personnel.

With these design requirements as the main considerations, investigations were made of several possible methods of constructing a suitable power unit.

THE INVERTER

For many years the conventional method of transforming low-voltage direct current to high-voltage alternating current has been by use of mechanical, vibrator-type inverters or rotary inverters. Typical vibrator-type inverters have efficiencies in the order of 40 to 75 percent with power ratings of 15 to 400 watts. However, with this type of inverter broken vibrator reeds and fused contacts eventually develop. Thus units with vibrator-type inverters are limited to an operating life of 1,000 hours or less. Rotary inverters have efficiencies ranging from 50 to 70 percent and power output ratings from 10 to 500 watts. The utility of these units is limited by the fact that they require periodic maintenance, and brushes and bearings eventually wear out (3).

Recent developments in the power-transistor field have made possible the design of practical semiconductor circuits which are efficient and rugged converters of low-voltage direct current to high-voltage alternating current. These transistor power supplies have no moving parts and are very simply and compactly arranged. Efficiencies of 70 to 90 percent can be achieved with well-designed circuits. Such supplies are instantaneous in starting, are completely silent in their operation, and are easily filtered for prevention of electrical interference from other electronic equipment. Input voltages may range from 1-1/2 to 50 volts d.c. with power outputs from a few milliwatts to several hundred watts (6). Because of the elimination of all moving parts, life expectancies are greatly extended, limited only by the life of the components (9, 10).

These inherent advantages of transistor inverters over other types of power conversion units appeared to justify the use of the transistor type in the construction of the insect trap power supply.

Transistor power supplies are currently being used extensively in aircraft and missile work. As a result, transistorized inverters for such applications are produced by a number of manufacturers. Two of the main considerations in power supplies for missiles or aircraft are weight and size. These units are commonly designed for operating frequencies of 400 c.p.s. and higher owing to weight and component-size reductions made possible through the use of high operating frequencies.

Specifications were obtained from several manufacturers on current production models of transistor inverters. Most of these were found to be impractical for insect-trap operation because of frequency of operation, power-output rating, or high cost. Of several units considered, the Model PC-1 inverter as furnished in kit form by the Heath Company,[4/] Benton Harbor, Mich., was selected for use in the insect-trap power supply. This selection was made on the basis of published specifications and relatively low cost.

The Heath Model PC-1 inverter is designed for popular use with radios, lamps, electric shavers, high-fidelity amplifiers, and similar equipment. Specifications furnished by the manufacturer are as follows:

4/ Mention of trade names of specific equipment in this publication is made for purpose of identification and does not imply endorsement by the U. S. Department of Agriculture over similar equipment not mentioned.

Power output	115 v.(a.c.), nominally 60 c.p.s. at 125 watts, continuous duty. (Up to 200 w., intermittent service.)
Power input	12 v.(d.c.) nominal from storage battery. Current will be between 1-1/2 and 15 a., depending on load. (Continuous duty.)
Efficiency	75% average at any load between 70 and 125 w.
External load	Power factor of load should be between 0.8 and 1.0 for greatest efficiency.
Controls	ON-OFF switch
Overload protection . .	15 a. fuse on front apron.
Transistors	2 - 2N442 power transistors.
Overall size	10 in. long by 4-1/4 in. wide by 4-3/4 in. high.
Net weight	5 lb.

A unit of this type was constructed. Operational checks showed that the 60-cycle square-wave output was satisfactory for starting and operating either the 15-watt fluorescent blacklight lamp (General Electric F15T8/BL) equipped with the commonly used low power factor ballast or the three 2-watt argon glow lamps (General Electric AR-1) as used with special pink bollworm survey traps. However, the conversion efficiency with the argon lamp load of 6 watts was found to be extremely low, in the order of 30 to 35 percent. With this type of trap the conversion efficiency appeared too low for practical use, and various methods of improving the efficiency without completely modifying the unit were investigated. It was found when furnishing power to this 6-watt load that by increasing the value of biasing resistor R_5 (see Fig. 1) from 3.0 to 50 ohms the conversion efficiency was raised to approximately 60 percent. A frequency change from 60 cycles to approximately 80 cycles occurred as a result of this modification, but the difference represented is well within the practical operational frequency for lamps of this type. Thus, by making a minor modification in a readily available commercial unit, an immediate need was filled for an inverter capable of providing a dependable source of power for operation of the two types of survey traps. The need remains, however, for units designed specifically for these loads in order to achieve maximum conversion efficiency.

THE CONTROL UNIT

In order to achieve maximum utilization of energy from the storage battery, some means should be provided for deenergizing the inverter during the daylight hours when the lamps on the traps do not need to be operated. The original thought on this control was for use of a spring-wind time switch which would give on-off operation of the unit at preselected time intervals. Major clock and timer manufacturers were contacted, but it was learned that inexpensive spring-wind time clocks are not now readily available.

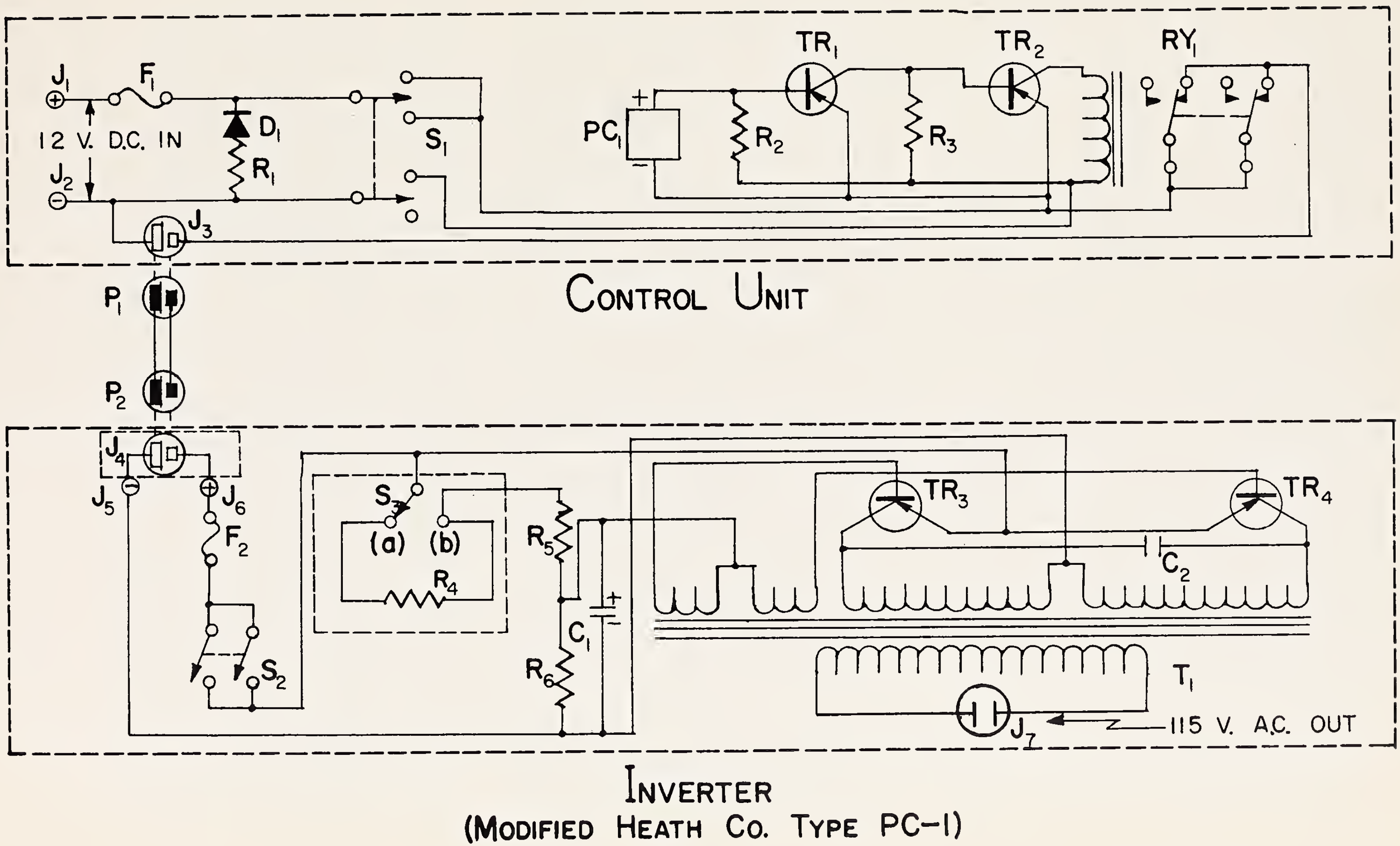


Figure 1.--Circuit diagram of power-supply control unit and modified invertor. Inverter modifications are shown in dashed enclosures.

It was then decided to investigate circuitry involving the use of a light-actuated relay for controlling the on-off operation of the inverter. The design of such a control unit appeared to be rather simple and straightforward when first considered (1, 4, 7). Sensitive relays capable of operating from photovoltaic cells are readily available. The use of such a system seemed very desirable because of the fact that no signal amplification or auxiliary batteries would be required. A unit of this type was constructed but was found to be unsatisfactory because of arcing and resultant sticking of relay contacts. This arcing resulted from the highly inductive load presented by the primary winding of the inverter power-supply transformer. Several recommended techniques for arc suppression were tried without success (2). Work with this control system indicated that a heavier duty relay would be required since there appeared to be no simple technique for completely eliminating arcing and consequent sticking of the relay points when using the extremely sensitive-type relay.

Several other types of relays were tested for possible use in providing automatic on-off operation. A Potter & Brumfield type MR11D double-pole, double-throw relay was found to switch the load satisfactorily, with no trouble due to corroded and sticking points indicated after hundreds of cycles of operation. The coil on this relay has a resistance of approximately 95 ohms and is designed for operation on a nominal voltage of 12 volts d.c. Contacts are rated at 8.0 amperes for noninductive loads. This relay consumes approximately 1 watt of power as compared to the 5 to 20 milliwatts consumed by the more sensitive relays, previously considered. Double-pole contacts were selected so that the contacts could be connected in parallel. This arrangement insures that one set of the points will remain clean and provide a low resistance path for current, since it is the inherent nature of such relays to consistently close one set of points earlier than the other.

The use of this higher wattage relay meant that signal amplification would be required and that transistor amplification was therefore indicated. Since low cost, simplicity, and dependability were the main considerations in circuitry for controlling this relay, an inexpensive photovoltaic cell was selected for use with a conventional two-stage, direct-coupled transistor amplifier. Direct-coupled amplifiers have a number of advantages. Component parts are reduced to a minimum, transistor temperature stability is improved, and operation from low-voltage power supplies is possible (7). Resistance values selected for this amplifier were intended for use with 12 volts as the supply voltage. Since 12 volts is available from the storage battery used to furnish power to the inverter, there was thus eliminated the need for auxiliary batteries.

Because these units will necessarily be operated in exposed localities at ambient temperatures as high as 125° F., checks were made of operating characteristics at elevated temperatures. It was found that resistance values had to be changed in order to compensate for characteristic changes in transistors with increasing temperature. The final values selected were those values which gave satisfactory operation of the relay at temperatures up to 150°. The values selected will also permit operation at 55° and lower. This compensation for high-temperature operation resulted in some sacrifice of sensitivity to light. The unit as finally developed will operate in the vicinity of 100 to 150 foot-candles. Since this light intensity occurs near sunrise and sundown, it was considered unnecessary to attempt a further improvement in sensitivity.

REVERSE-POLARITY PROTECTION

Another factor which must be considered when working with transistors is the need of observing the correct polarity of potentials applied to the transistors. In this particular unit, if suitable protective circuitry is not provided, accidental reverse-polarity connection to the battery could damage both the amplifier and the inverter. Use of semiconductor diodes for providing this protection seemed to be the best solution to the problem. Such diodes in capacity ratings which will handle the entire current flow from the battery are available, but these are quite expensive (5). Small, inexpensive diodes are available, however, which will carry momentary overloads of up to 30 or 40 times their rated values. The SD500 International Rectifier Corp. diode is of this type and was employed in the construction of the power supply. This particular diode is rated to carry 150 milliamperes continuously and 5,000 milliamperes for 1 second. Investigations showed that a five amp fast-acting instrument type fuse provided sufficient capacity to carry the supply current to the control unit and the inverter when used with either type of survey trap. However, tests with the small diode showed that this fuse would not fail quickly enough to prevent damage to the diode on a direct short across a 12-volt source of direct current. A 1.0-ohm resistor in series with the diode limits the surge of current just enough to protect the diode while the 5.0-ampere fuse is failing.

As shown in the wiring schematic (Fig. 1), the fuse (F_1) and diode (D_1) are incorporated ahead of the on-off control switch (S_1) in such a manner that accidental reverse-polarity connection will cause the fuse to blow immediately, thus providing protection to all transistors and other components.

ASSEMBLY AND CONSTRUCTION

Control Unit.--The relay, transistor amplifier, photovoltaic cell, and diode protection circuit are incorporated into a small metal utility cabinet with appropriate input and output terminals and switches. Color-coded terminal posts accommodate the power input leads from the battery. A polarized 2-pole female receptacle is provided for the controlled power output to the inverter. The fuse receptacle and DPDT toggle switch are mounted on the front of the unit and are accessible for operation through the chassis cover. The small photovoltaic cell is mounted on top of the unit. No. 16 AWG stranded wire is used for all connections that carry full-inverter-load current; No. 22 AWG stranded wire is used for other connections. The unit and the arrangement of the components are shown in figures 2 and 3.

Inverter.--Figure 4 shows the arrangement and location of components in the modified inverter. A SPDT switch is mounted on the front (at pencil point, figure 5) to switch in the additional 47 ohms of resistance in the oscillator circuit required for efficient operation of the argon lamp load. A two-pole polarized receptacle is mounted on top of the inverter chassis to accommodate the polarized controlled power input lead from the control unit.

Chassis and Battery Case.--As shown in figure 5 and the assembly pictorial of figure 6, the inverter is mounted on a small chassis which is in turn mounted on top of the lid for the battery case. The control unit is mounted within the chassis cover which has sides deep enough to enclose it. Flexible lead wires connect it with the inverter. Battery leads are brought to the control unit through grommetted holes in the chassis and battery case lid. The two switches on the inverter, the "on-off" and the "125-watt max load - 6-watt max load," are accessible only when the chassis cover is removed, as shown in figure 5. This assembly attaches to the battery-case carrying handles by means of wingnuts and carriage bolts.

The chassis cover, chassis, and battery case (including cover) are constructed of 16-gage metal to insure ruggedness. All metal surfaces are primed and the exterior surfaces are finished with white lacquer or enamel in order to keep heat absorption low. The interior of the battery case and lid is protected from acid corrosion by a coating of plastic resin of the type commonly used with glass cloth.

The complete power-supply assembly is shown in figures 7 and 8. As shown in figure 7, vent holes are provided in the upper part of the chassis cover underneath the cover overhang. A ring of a jar lid is soldered into the opening directly above the photovoltaic cell on the control unit. A jar is mounted in this ring to permit light to reach the cell. The 5.0-ampere fast-acting fuse and the DPDT, center-off switch of the control unit are accessible from the front side of the

Figure 2.--Control unit for power supply.

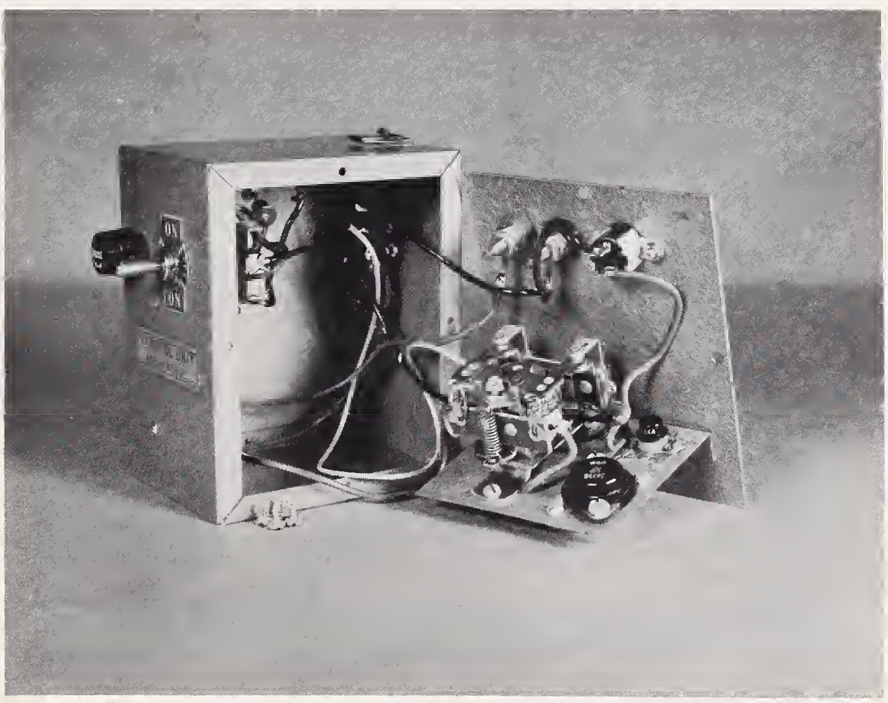


Figure 3.--Interior view of power-supply
control unit.

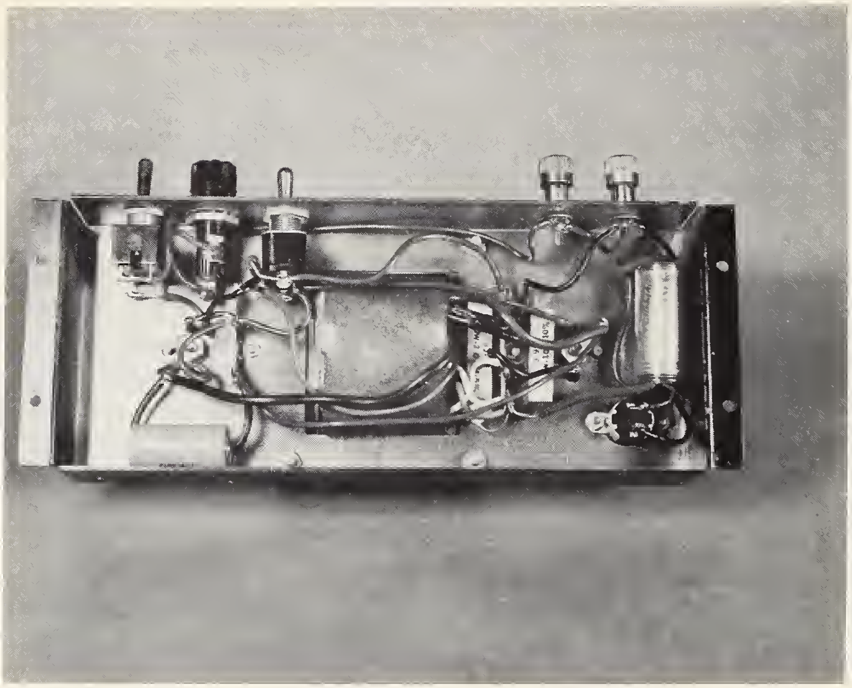


Figure 4.--Interior view of inverter showing switch, resistor, and polarized receptacle added for modification.

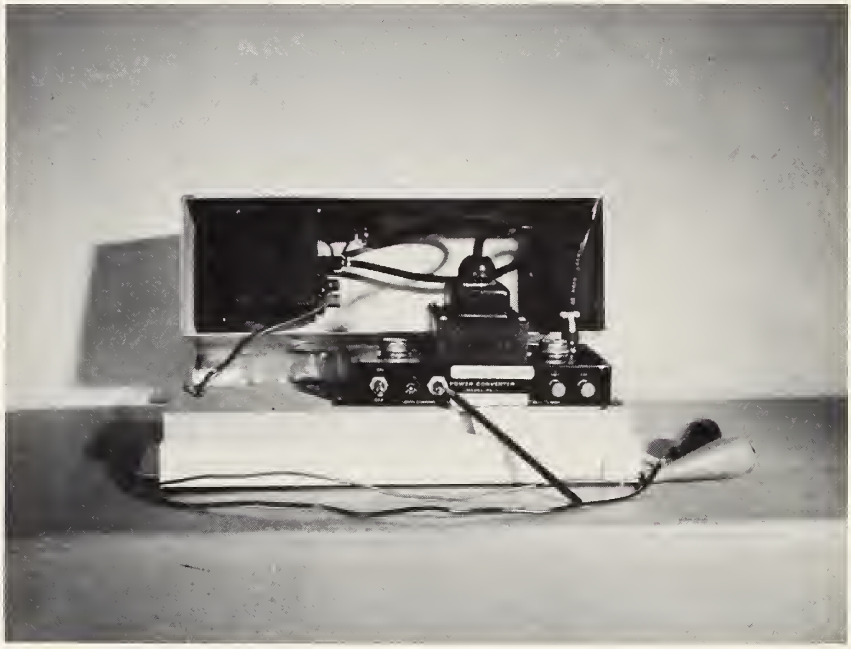
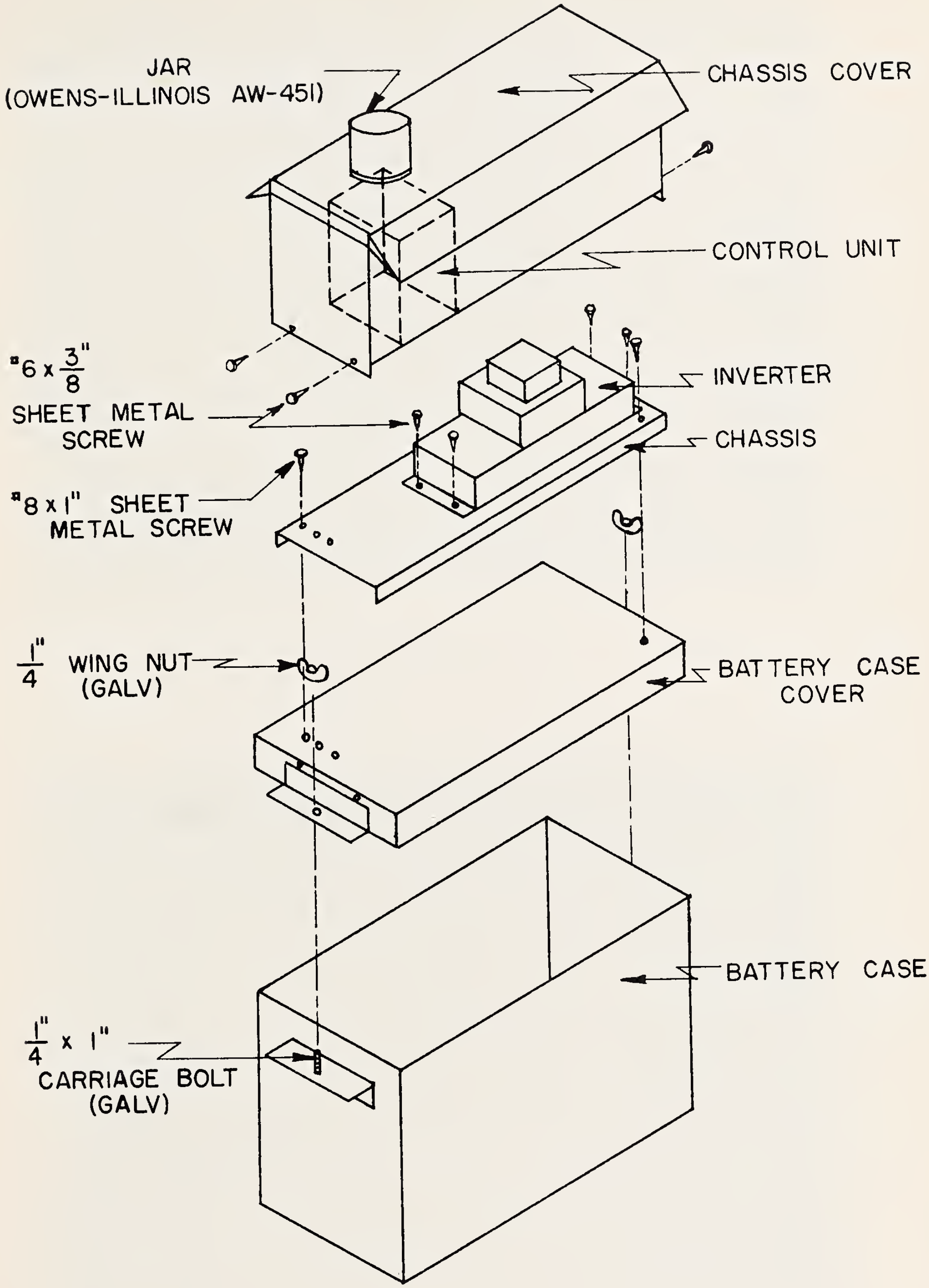


Figure 5.--Control unit and inverter mounting arrangement on housing and chassis.



ASSEMBLY PICTORIAL

Figure 6.--Arrangement and assembly of components for complete power supply.

Figure 7.--Complete power supply with cover removed from battery case.

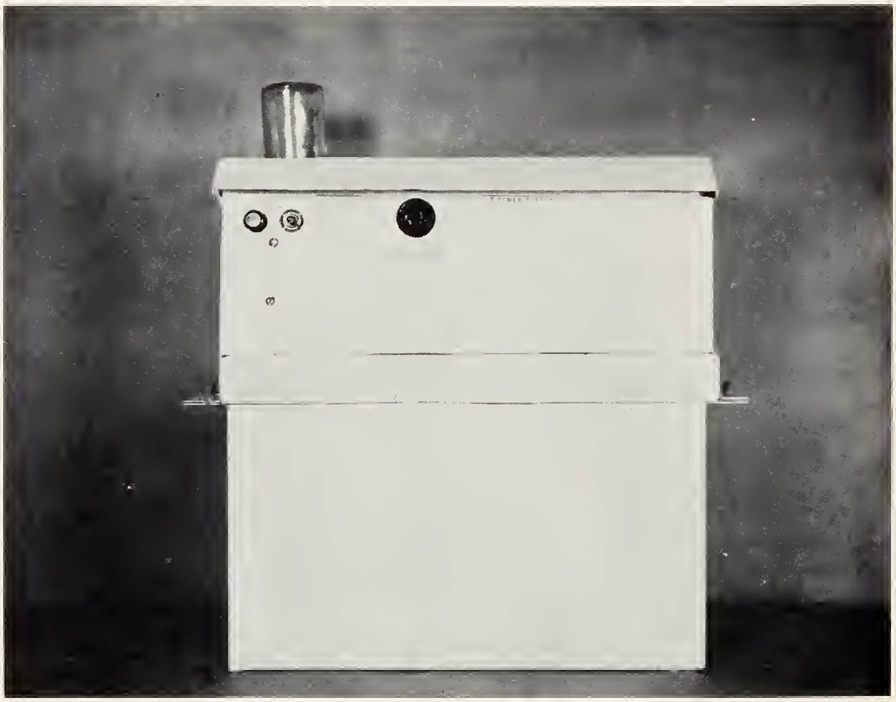


Figure 8.--Front view of power supply.

chassis cover. This control switch provides for either manual or automatic operation. Alternating current output to the traps is provided by an a.c. outlet mounted on the front of the chassis cover. Spring clips with color-coded insulators are provided for connecting to the battery terminal posts.

The entire assembly weighs 30 pounds without battery and 78 pounds with a 12-volt, 72-ampere-hour, type 60K automotive battery installed in the case.

PARTS LISTS

Table I lists the component parts for the control unit and inverter. Table II lists additional parts and materials required for the complete assembly. Parts and materials for the complete unit cost approximately $65.00 (based on prices as of September 1959).

Table I. -- Parts List For Control Unit and Inverter 1/

C_1 - 100-mf., 50-v. electrolytic capacitor (Heath Part #25-28)
C_2 - 5-mf., 100-v. nonpolarized capacitor (Heath Part #27-75)
D_1 - Diode (Int. Rect. Corp. SD-500)
F_1 - 5-a. fuse (Littelfuse 8 AG or Buss AGX)
F_2 - 15-a. fuse (Heath Part #421-7)
J_1 - Binding post (Superior DF 30 RC)
J_2 - Binding post (Superior DF 30 BC)
J_3, J_4 - 2-pole polarized socket (Cinch-Jones S-302-AB)
J_5, J_6 - Binding post (Heath Part #426-2)
J_7 - 115-v. (a.c.) female receptacle (on power transformer)
P_1, P_2 - 2-pole polarized plug (Cinch-Jones P-302-CCT)
PC_1 - Self-generating selenium photocell (Int. Rect. Corp. B2M)
R_1 - 1.0-ohm, 10-w. resistor (Ohmite "Brown Devil")
R_2 - 62,000-ohm ($\pm$ 1%), $\frac{1}{2}$-w. resistor (Aerovox CP$\frac{1}{2}$)
R_3 - 3,300-ohm ($\pm$ 1%), $\frac{1}{2}$-w. resistor (Aerovox CP$\frac{1}{2}$)
R_4 - 47-ohm ($\pm$ 1%), 1-w. resistor (Aerovox CP 1)
R_5 - 3-ohm, 10-w. resistor (Heath Part #3J-17)
R_6 - 100-ohm, 7-w. resistor (Heath Part #3-9G)
RY_1 - DPDT relay, 12.0-v. (d.c.) coil (Potter & Brumfield MR11D)
S_1 - DPDT, center-off, toggle switch (Cal-Rad TS16)
S_2 - DPST, toggle switch (Heath Part #61-3)
S_3 - SPDT, toggle switch (Cutler-Hammer 7505-K4)
  Position (a) - 6-watt maximum load
  Position (b) - 125-watt maximum load
T_1 - Power oscillator transformer (Heath Part #54-74)
TR_1 - 2N188A transistor (G.E.)
TR_2 - 2N256 transistor (CBS)
TR_3, TR_4 - 2N442 transistor (Delco)

1/ See text footnote 4.

Table II.-- Additional Parts and Materials Required For Complete Power Supply Assembly 1/

1 battery case and lid, chassis and chassis cover
2 - $\frac{1}{4}$" x 1" galvanized carriage bolts with wingnuts
1 utility cabinet (Bud C-1795)
1 transistor socket (Elco 3301)
1 power transistor socket (Motorola MK-15)
1 fuseholder (Buss HJM)
2 battery clips (Mueller 24A)
1 pkg. battery clip insulators (Mueller 26)
1 jar and metal lid (Owens-Illinois AW-451)
1 a.c. female receptacle (Amphenol 61-F)
10 ft. - #16 AWG stranded wire, red (Alpha MW-C 16(26)U)
10 ft. - #16 AWG stranded wire, black (Alpha MW-C 16(26)U)
miscellaneous - rubber grommets, lockwashers, machine screws, sheet-metal screws, soldering lugs, tiepoints, flexible hookup wire, plastic resin, metal primer, and paint.

1/ See text footnote 4.

PERFORMANCE CHARACTERISTICS

Operational tests with the power-supply unit show that the commonly used 15-watt blacklight trap can be operated for approximately 21 hours from a fully charged 72-ampere-hour automotive-type battery. The special pink bollworm survey trap equipped with three 2-watt argon glow lamps can be operated for approximately 48 hours from the same type of battery. Thus, operating the 15-watt blacklight trap will require a freshly charged battery every other day, and operating the argon trap (with modified inverter) will require a new battery every fourth day of operation.

Output voltage changes in both magnitude and frequency during the battery-discharge period, with resultant changes in ultraviolet output from the lamps. In the use of three argon lamps as a load with 13.0 volts d.c. input, peak square-wave output voltage is approximately 135 volts at a frequency of 90 c.p.s. With 9.0 volts d.c. input, peak voltage is approximately 90 volts at a frequency of 65 c.p.s. Ultraviolet output (365 mμ) from the lamps varies from approximately 140 percent to 70 percent of normal between these two extremes, based on ultraviolet output of lamps operated from 115 volts a.c., 60-cycle sine wave. Conversion efficiency is approximately 60 percent at the nominal input of 12.0 volts d.c. when operating this 6-watt load.

In the use of a 15-watt BL lamp as a load with 13.0 volts d.c. input voltage, peak square-wave voltage is approximately 135 volts at a frequency of 72 c.p.s. With 9.0 volts d.c. input, peak voltage is approximately 94 volts at a frequency of 52 c.p.s. Ultraviolet output (365 mμ) from the lamp varies from 85 percent to 58 percent of normal between these two extremes. Conversion efficiency is approximately 45 percent with this load at the nominal 12.0 volts d.c. input.

Detailed construction plans for this unit are available on request from the Farm Electrification Research Branch, Agricultural Engineering Research Division, Agricultural Research Service, Beltsville, Md.

SUMMARY

Information is presented on the design, construction, and performance characteristics of a transistorized power supply and automatic-control unit for operation of survey-type electric insect traps. The unit described utilizes a 12.0-volt automotive-type battery as the basic power source and provides 115 volts a.c. for operation of the argon insect survey trap (three 2-watt argon lamps) or the blacklight insect survey trap (one 15-watt BL lamp). Electronic components include a transistor inverter and a light-actuated control unit. The battery and other components are contained in a metal case and comprise a single unit which is readily portable.

LITERATURE CITED

1. Army, Department of the, Headquarters.
Basic Theory and Application of Transistors. U. S. Dept. of the Army, TM11-690. March 1959.

2. Henny, Keith, and Walsh, Craig.
Electronic Components Handbook, Volume 1.
New York, New York, 1957.

3. ____________, and Walsh, Craig.
Electronic Components Handbook, Volume 2.
New York, New York, 1957.

4. International Rectifier Corporation.
Selenium Photovoltaic Cells. International Rectifier Corporation Bul. PC-649A. El Segundo, Calif.,

5. International Rectifier Corporation.
Engineering Handbook, Ed. 1. International Rectifier Corporation publication. El Segundo, Calif., 1949.

6. Pye, T. R.
Design of Transistor Power Converters. Electronics. Vol. 32, No. 36. September 1959.

7. Sasuga, John.
The Use of Selenium Photocells and Sun Batteries. International Rectifier Corporation. El Segundo, Calif., 1956.

8. Taylor, Hollingsworth, Stanley.
Electric Insect Traps for Survey Purposes. U.S. Dept. Agr., Agr. Res. Serv., ARS 42-3. 1956.

9. Tomer, Bud.
Transistor Power Supplies. CBS-Hytron Bul. E-281. Danvers, Mass., October 1957.

10. __________.
Transistors Replace Wall Outlet. Popular Electronics. July 1958.