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National Marine Fisheries Service

A Freshwater Fish Electro-Motivator (FFEM)-Its Characteristics and Operation

JAMES E. ELLIS and CHARLES C. HOOPES

SEATTLE, WA
November 1972

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ABSTRACT

A prototype Freshwater Fish Electro-Motivator (FFEM) system was developed as a research tool to test the application of electricity for use with active and passive fishing gear for increasing the gear's catching efficiency. The system's basic characteristics and operating modes are explained. The prototype system is extremely sophisticated, and its versatility permits single or multiple time-sequenced electrode loading and various pulse patterns, and allows duty cycles over a wide dynamic electrode load range. A summary of the field testing is discussed.

INTRODUCTION

In 1966, investigations into the application of electricity in conjunction with fishing gear were undertaken by the National Marine Fisheries Service at Ann Arbor, Mich. The specific aim of these investigations was to develop an electrical apparatus for researching the application of electricity for commercial fishing of all freshwater fish stocks in the Great Lakes. In essence, this gear was to be designed for any freshwater species found in the contiguous 48 States.

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Work by other investigators had demonstrated that bottom trawls lost up to 60% of their catch due to fish escapement back through the trawl's mouth area (Kreutzer, 1964). McRae and French (1965) and Shentaykov (1965) demonstrated that the overall catch rate of an electrified bottom trawl was increased by as much as 2.0 to 2.5 times. Ellis (1972) showed that electricity increased an electrical trawl's catch rate up to 1.86 times that of a standard control trawl. Seidel (1969) showed that a commercially feasible shrimp fishery in daylight hours was practical if electricity was used in conjunction with a trawl.

Our review of prior work indicated that available fish shockers were not fully utilizing electrical currents for obtaining maximum power outputs at optimum pulse characteristics. In addition, this review pointed out the advantages of designing a circuit using SCR (silicon-controlled rectifier) static switching in conjunction with capacitor-discharge pulses. This design would allow us to produce fast rise flat-topped rectangular pulses with exponential trailing edges of durations of 1 msec or more. Pulses having this shape are considered to give the optimum neurophysiological effect for fish taxis (Vibert, 1970).

As a result of our literature survey, we concluded that a versatile research tool could be devised to study ways of increasing the catching efficiency of freshwater fishing gear using electricity. Consequently, developmental work was started on the Freshwater Fish Electro-Motivator (FFEM) system. Four basic modes of operation were considered in the initial design. These operating modes were: 1) *phased array* — use of electrical stimuli to herd or direct fish into active or passive fishing gear; 2) *increasing net aperture* — use of stimuli to increase the effective aperture of a net by confining the fish to a region wherein they will be caught by the mechanical fishing gear; 3) *confinement* — use of electrofishing techniques to prevent fish from escaping once they are trapped by the fishing gear; and 4) *concentric spheres* — use of electrical stimulus in conjunction with a fish pump-light for removing fishes that are positively phototactic.

To achieve this goal, we contracted with the University of Michigan to work with us on the development of an FFEM. Two main studies were conducted: the development of a prototype FFEM and its field testing. In this paper we will cover the design characteristics and operation of the FFEM and give a summary of the field test. Another report covers the field test in detail (Ellis and Pickering, in press).

CHARACTERISTICS AND OPERATION OF THE FRESHWATER FISH ELECTRO-MOTIVATOR

The FFEM system as shown in Figure 1 is divided into a pulser and a power supply. The physical and electrical parameters of each system are as follows.

Pulser

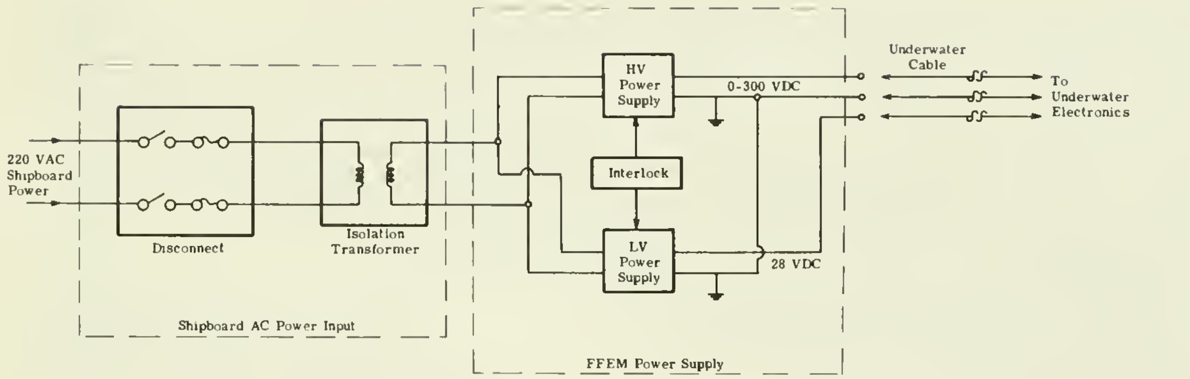
The FFEM pulser is by far the most complex portion of the system (Figure 2). Its physical characteristics are shown in Figure 3. The pulser housing is an aluminum tube, 165.1 cm in length, 20.3 cm nominal diameter with 1.3 cm walls, and weighs 116.1 kg including electronic components. It consists of three bulkhead plates, P1, P4, and P8 along with two tubes, T1 and T2, as shown in Figure 3. The bulkheads and tubes are held in compression by two sets of four aluminum connection rods, R1 and R2.

The right bulkhead end plate has an air check valve which permits the pulser to be pressurized with air to about 13.6 kg/cm^2. This pressurization tests the O-ring seals for leaks before submerging the unit. A cap is placed over the check valve to prevent water from entering the housing since external water pressure will at times exceed the internal air pressure. The left bulkhead end plate has six bulkhead electrical connectors and mating plugs. One connector is for supplying external electrical power to the pulser while the other five connectors are for supplying power to the electrode arrays in sequential or single mode firing orders.

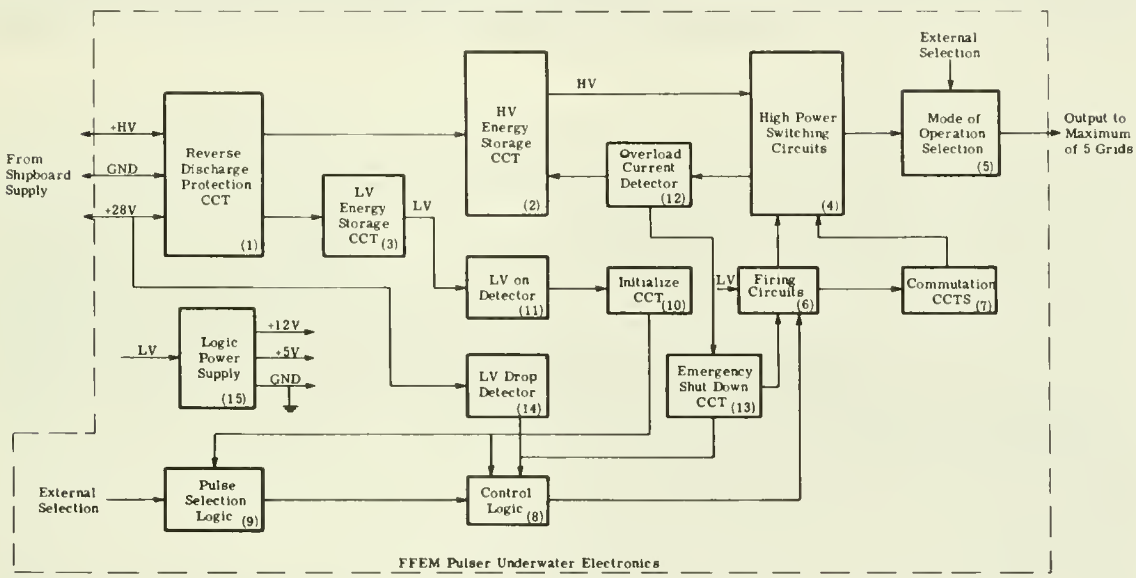
The firing circuits and power silicon-controlled rectifiers (SCR) of the FFEM pulser contained within the aluminum housing are shown schematically in Figure 4. The pulser has a maximum voltage of 300 volts[3] peak output with the capability of any intermediate voltage level. A minimum load resistance presented by the electrodes to the pulses should be 1.5 to 2.0 ohms. For an "effective duty cycle" of 100% (equivalent to an on-time of 1 msec and an off-time of 7 msec) at full voltage, the pulser is capable of an average output of 7,500 watts with a peak pulse power output of 60,000 watts.

Pulse control logic.— The pulse control logic (Figure 1, items 8 and 9) generates the gate input pulses to the firing circuits (Figure 1, item 6) which controls the firing of the SCR for the desired output pulse parameter. To achieve the basic 8-msec timing cycle, a 1-KH_z clock is used with a three-stage binary counter which divides

[3] This maximum was dictated by the size and availability of electrolytic capacitors.



(a) FFEM Primary Power Supply



(b) FFEM Pulser

Figure 1. — Basic electrical system block diagram.

the clock rate by eight. Decoding logic is used to generate the required timing waveforms.

Pulse selection logic.— The pulser has logic for 1-msec output pulses at selectable duty cycles, selectable periods, and distribution to one (two electrode arrays) to four (five electrode arrays) loads in a selectable sequential order. To select a desired pulse pattern the left bulkhead end plate is removed exposing three female plugs; one for selecting *pulse pattern*, one for selecting the desired *load distribution*, and one for *bench testing*. Prewired male mating plugs are inserted to produce the desired performance.

The pulse parameters available are as follows: The number of on-pulses N_{on} is 2 (S_{on}) where S_{on} is selectable in seven steps from 1 to 7. The number of off-pulses N_{off} is (S_{on}) times (S_{off}) where S_{off} is selectable in eight steps from 0 to 7 and S_{on} is the same as above. The combination of N_{on} pulses followed by N_{off} missing pulses is referred to as a "pulse set." The number of pulse sets distributed to a

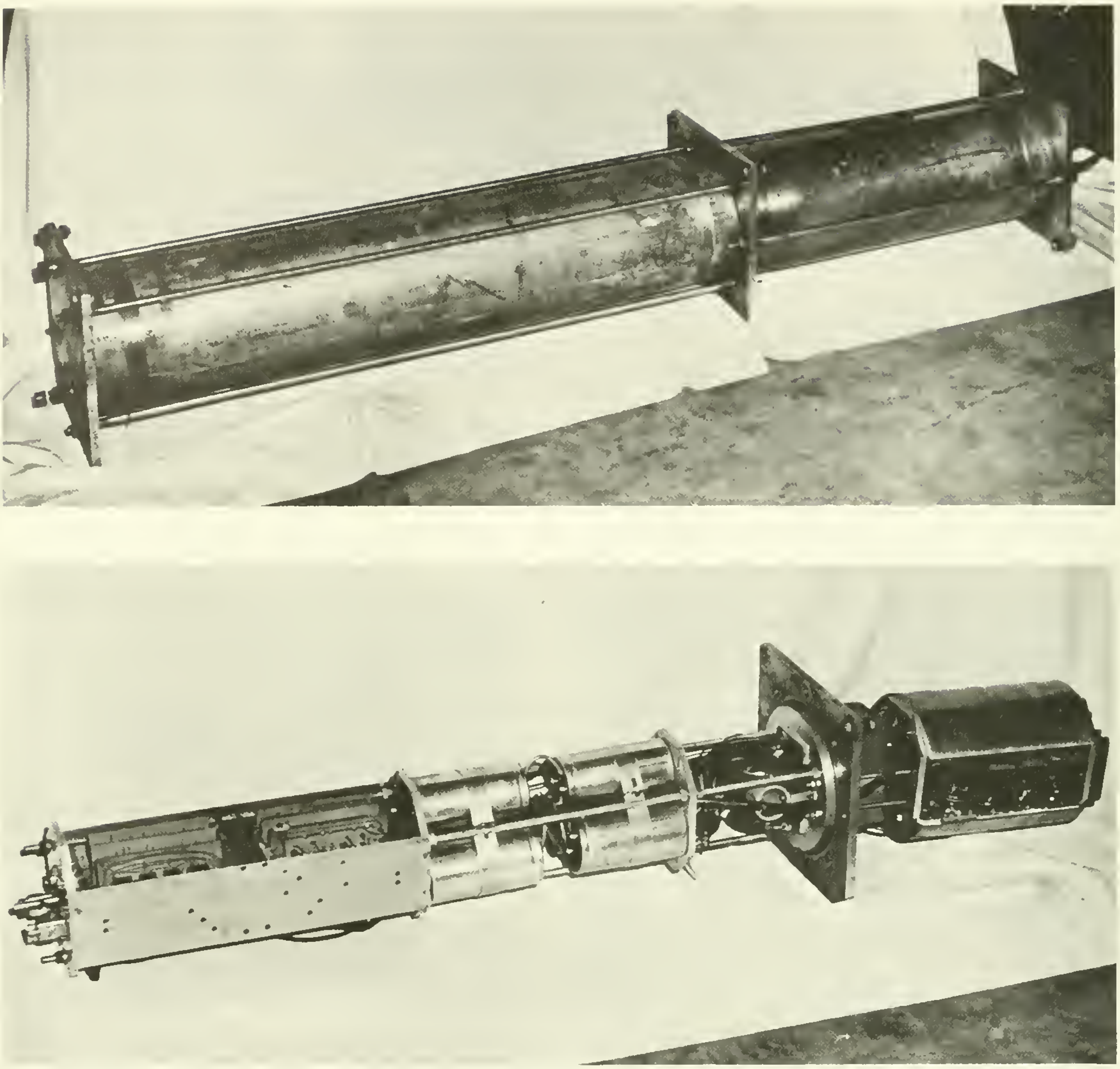
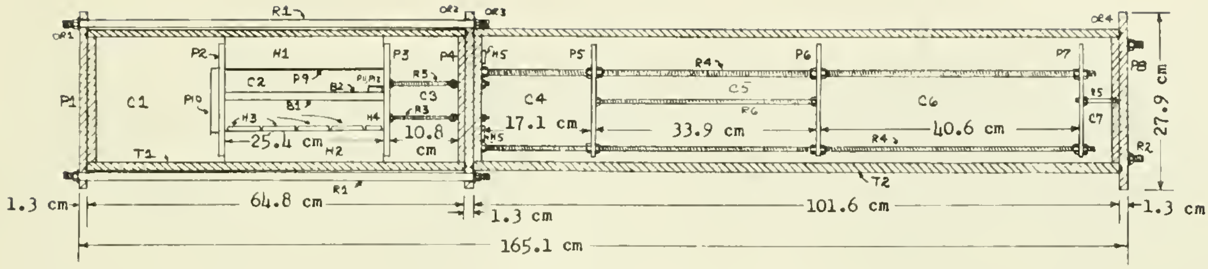


Figure 2. — Freshwater Fish Electro-Motivator (FFEM) pulser with and without protective aluminum housing.

given electrode load N_{dist} before switching to another load is selectable in 15 steps from 1 to 15. Also, the order of pulsing electrode pairs is selectable after N_{dist} sets of pulses to a given load. The above pulse parameters are all based on the 1-msec on, 7-msec off basic pattern.

As examples of pulse parameters possible, we will give situations where a single load (2 electrode arrays) and two loads (3 electrode arrays) are fired (Figure 5). For a single load, suppose $S_{on} = 2$, $S_{off} = 3$, and $N_{dist} = 1$. The output to this load would appear as shown in Figure 5a. In this example, the pulse set N_{on} and N_{off} equals 10 and produces a total pulse period of 80 msec and an effective duty cycle of 40%. In all situations the number of basic pulse groups (N_{on} N_{off}) can be varied with $N_{on} = 2X$ and $N_{off} = YX$ where X can be selected 1 through 7, and Y can be selected 0 through 7. For the basic pulse pattern in Figure 5 with t_p (total pulse or pulse



NOTE:

P1, P4, P8	bulkhead plates	R1, R2	outside tie rods
P2, P3, P5, P6, P7	divider plates	R3, R4, R6	inside support rods
P10	insulated connection plate	C1, C7	chambers
P9	insulated cover plate	R5	centering rod
T1, T2	outside cover tubes	OR1, OR2, OR3, OR4	bulkhead plate "O" rings
H1	resistor heat sink	B1, B2	firing CCT support bars
H2	SCR heat sink	P11	tie point plate
H3, H4, H5	semiconductor ins. & heat sinks	P12	current transformer plate

Figure 3. — Mechanical layout sectional drawing of Freshwater Fish Electro-Motivator (FFEM) pulser.

set) = 8 msec, the pulse parameter has an effective on-time of $t_{on} = N_{on}$ times t_p = 32 msec and an off-time of $t_{off} = N_{off}$ times t_p = 48 msec. Thus the effective duty cycle while being pulsed for the pulse parameter shown (Figure 5) is expressed as follows:

Percent effective duty cycle:

$$= \frac{T_{on}\ 100}{T_{on} + T_{off}}$$

$$= \frac{N_{on}\ t_p\ 100}{N_{on}\ t_p + N_{off}\ t_p}$$

$$= \frac{N_{on}\ 100}{N_{on} + N_{off}} = \frac{2X\ 100}{2X + XY} = \frac{200}{2 + Y}$$

From the above equation the percent effective duty cycle[3] is:

100% for Y = 0
67% for Y = 1
50% for Y = 2
40% for Y = 3
33% for Y = 4
29% for Y = 5
25% for Y = 6
22% for Y = 7

For two loads which are to be pulsed alternately, suppose $S_{on} = 2$, $S_{off} = 3$, and $N_{dist} = 2$. The output to these loads would appear as shown in Figure 5b. In this example, the pulse set $N_{on} = 4$ and $N_{off} = 6$ will give a total pulse period of 80 msec for each set ($S_{on} = 2$ and $S_{off} = 3$) and in this example there are two sets per load; thus, the duty cycle is 40% per load Number 1 and 40% per load Number 2 when being pulsed or an overall duty cycle of 20% because of the sharing between the two loads.

Switching circuits.— The high power switching circuitry in Figure 1 is composed of three sets of SCR: 1) routing, 2) timing, and 3) commutation. There are eight routing SCR, one timing SCR, and three commutation SCR. A simplified diagram of the routing and timing circuits is given in Figure 6. For discussion purposes, we represent the SCR with single-pole, single-throw switches. As noted, the switches (SCR) are grouped into: 1) routing switches and 2) a timing switch. (The commutation SCR are not shown.)

Three modes of operation are shown. Referring to Figure 6a, if only one electrode pair is used, one is connected to point 9 and the other is connected to point 10, then when the switch is closed, the voltage E will appear across the two electrodes and current will flow from

[3] Actual duty cycle is only one-eighth of the effective duty cycle.

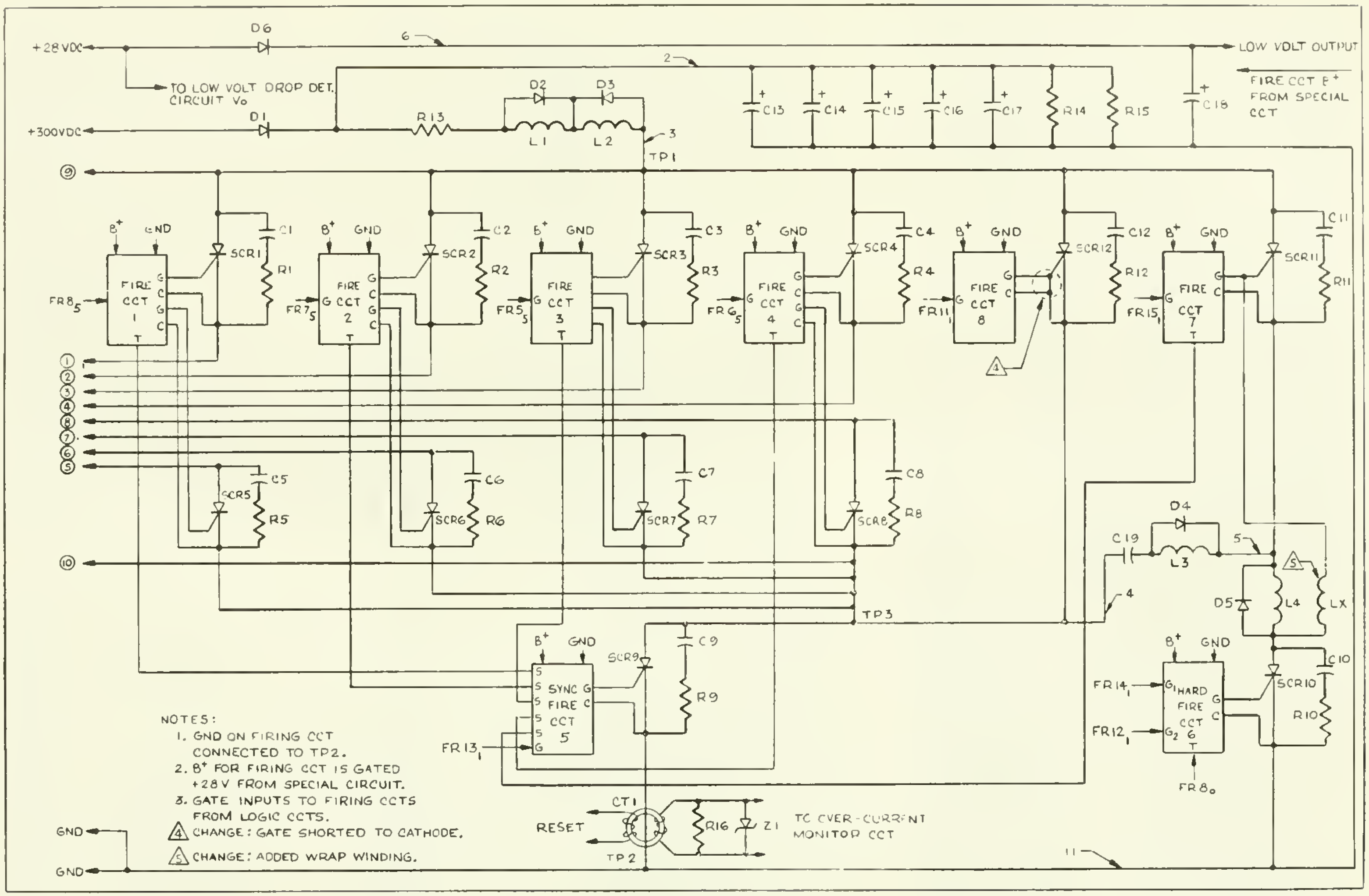
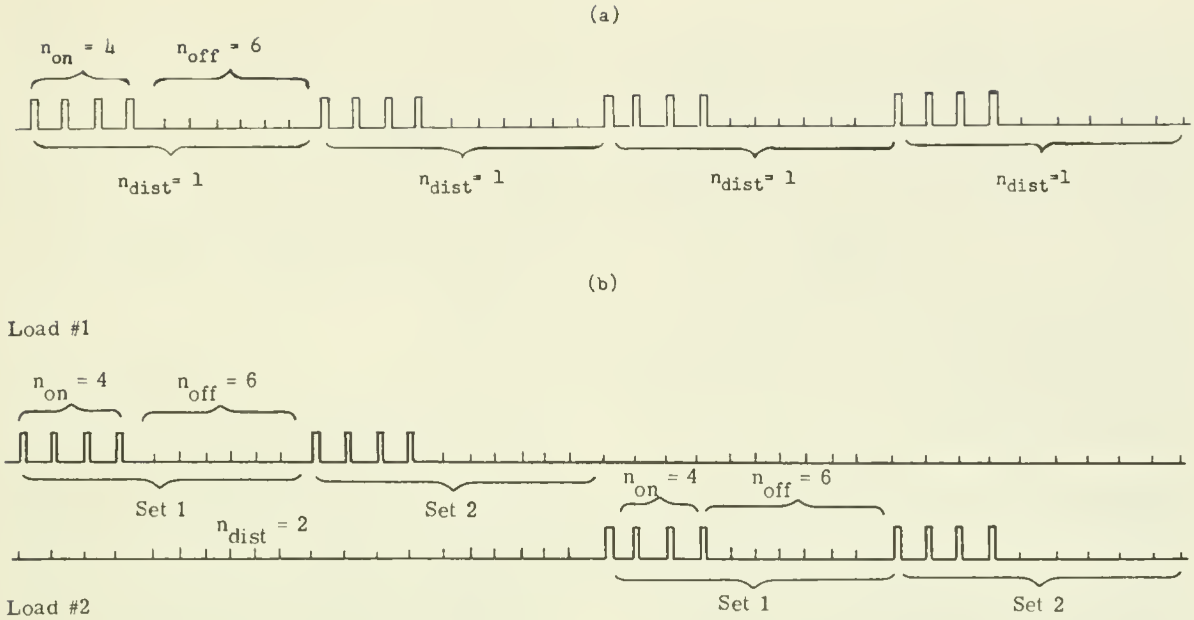


Figure 4. — Electrical schematic of Freshwater Fish Electro-Motivator (FFEM) pulser.



Note: Each division corresponds to the 8 msec basic control cycle.

Figure 5. — Examples of Freshwater Fish Electro-Motivator (FFEM) pulse patterns: (a) one load, $S_{on} = 2$, $S_{off} = 3$, $N_{dist} = 1$ and (b) two loads, $S_{on} = 2$, $S_{off} = 3$, $N_{dist} = 2$.

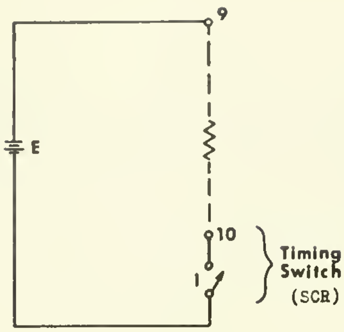
point 9 (anode) to point 10 (cathode) via the water path surrounding the two electrodes.

For multiple loads having a common anode, the switching arrangement is shown in Figure 6b. If we use point 9 as the anode and points 4, 5, 6, and 7 as the cathodes, then current will flow in the electrode load whenever any of the switches e, f, g, or h is closed and switch i is closed. Current can only flow when the timing switch is closed.

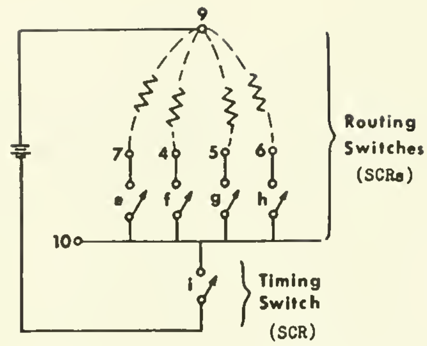
For multiple loads, where a given electrode may be used as an anode and at a different time be used as a cathode, such as in the phased array, the switching arrangements are shown in Figure 6c. If electrodes are attached to points 7, 1, 2, 3, and 8 with points 1 and 4, 2 and 5, and 3 and 6 jumpered, then when a single pair of switches (a-e loading i; b-f loading i), current will flow between a pair of electrodes. For example, if only routing switches b and f are closed, then current will flow between the anode electrode (point 2) and the cathode electrode (point 1 or 4) when switch i is closed. Now if routing switch c and g are closed, then current flows between the anode electrode, point 3 and the cathode electrode (point 2 or 5) when the switching SCR is closed. In the first case, the electrode at point 2 served as the anode, and in the second case, it became a cathode. To achieve the greatest versatility, the arrangement shown in Figure 6c is used, and a subset of the switches are used for the other alternatives.

In reality SCR are used in place of the switches. An SCR is basically an on-off switch which can be turned on by momentary application of current to the gate which causes current to flow from anode to cathode only. Once turned on, the gate cannot be used to turn off the SCR. Thus, for turning off the SCR in the load distribution and switching logic, a reverse voltage is applied across the anode and cathode of the SCR. To accomplish the turn-off we use a self-commutation circuit.

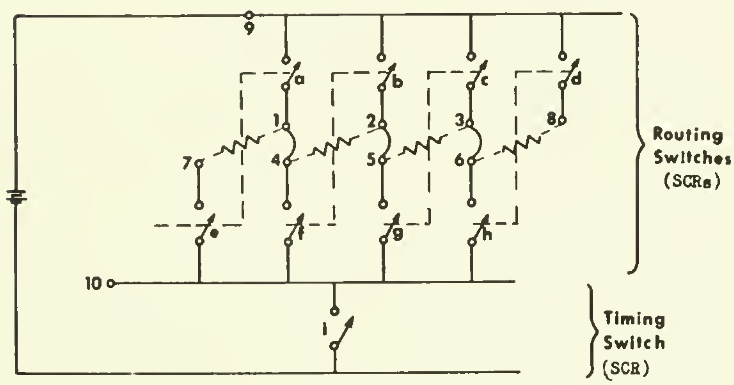
The commutation circuit consists of three SCR, a capacitor (C_2), and inductor (L_2) (Figure 7). The commutation is performed as follows: assume that there is no current flowing in the circuit and that C_2 is discharged. Now, if



(a) Single Load



(b) Multiple Loads (common anode)



(c) Multiple Loads (phased array)

Figure 6. — Switch representation of high power switching circuit.

SCR k and SCR i are turned on, the current flows from voltage source E through path L_1, R_1, SCR k, L_2, C_2, and SCR i. The series connected inductors L_1 and L_2 limit the rate of change of current, and the resistance R_1 limits the maximum current. As current flows, C_2 is charged to the source voltage E. At this time, the voltage across SCR k and SCR i is near zero, and the current is near zero; thus these two SCR turn off, and C_2 has a voltage E with the right hand plate of C_2 positive. Next, assume routing SCR a and SCR e are turned on. At this time current flows from E through the path L_1, R_1, SCR a, water load, SCR e, and SCR i. Again the inductance L_1 limits the rate of current change, and R_1 in series with the water load limits the maximum current through the electrodes. At the end of 1 msec (the pulse-on time), SCR j is turned on. This places charged capacitor C_2 in parallel with SCR i. Discharge current flows from C_2 through the path L_2, SCR j, SCR i, and back to C_2. This negative current through SCR i cancels the original electrode load current in SCR i, and SCR i turns off. Current continues to flow through L_1, R_1, SCR a, electrode load, SCR e, C_2, L_2, and SCR j even though SCR i is off. However, this current charges the capacitor C_2 in the opposite direction to a voltage near E at which time the current through SCR a, SCR e, and SCR j drop below the holding current and these SCR self-commutate. The charge left on C_2 makes the left plate of C_2 positive which is the wrong polarity for the next commutation; thus, the cycle begins again with SCR i and SCR k turned on. This allows C_2 to discharge and recharge with the correct polarity (right plate positive). Again SCR i and SCR k self-commutate. SCR l is used to insure self-commutation of SCR a, SCR e, and SCR j independent of the water load. It is turned on shortly after

SCR j is fired and forces self-commutation within the correct time limit.

The various safety checks and circuits designed into the FFEM system which will automatically shut the system down are: 1) high or low current overload, 2) reverse discharge of capacitor banks, and 3) loss of high or low voltage. In addition, all systems are electrically isolated from the primary electrical source.

Power Supply

The FFEM power supply consists of the following: 1) a variable high voltage supply capable of 0 through 300 v DC at 25 amp DC and 2) a fixed low voltage power supply producing 28 v DC at 7 amp DC (Figure 8). These power supplies share a common ground; thus a three-conductor number 10-wire power cable is required to interconnect the FFEM power supply with the FFEM pulser.

High voltage.— The high voltage supply is basically a slave full-wave rectified L-C (L-inductor, C-capacitor) filter power supply. The input is 230 v AC single phase power applied at the main input. This output is connected to a 0-300 v AC variac. The high voltage power supply output is floating relative to shipboard ground.

Low voltage.— The low voltage power supply consists of a 28 v DC 7 amp, regulated power supply and a step-down transformer. An interlock exists between the high voltage and low voltage supplies. This interlock prevents the low voltage from being applied to the pulser SCR before the high voltage is properly adjusted to approximately 25 v. Also, the interlock removes the low voltage if there is a failure in the high voltage supply.

The FFEM power supply uses a 0-300 v panel volt meter and a double set point 0-30 amp meter for monitoring output parameters. The

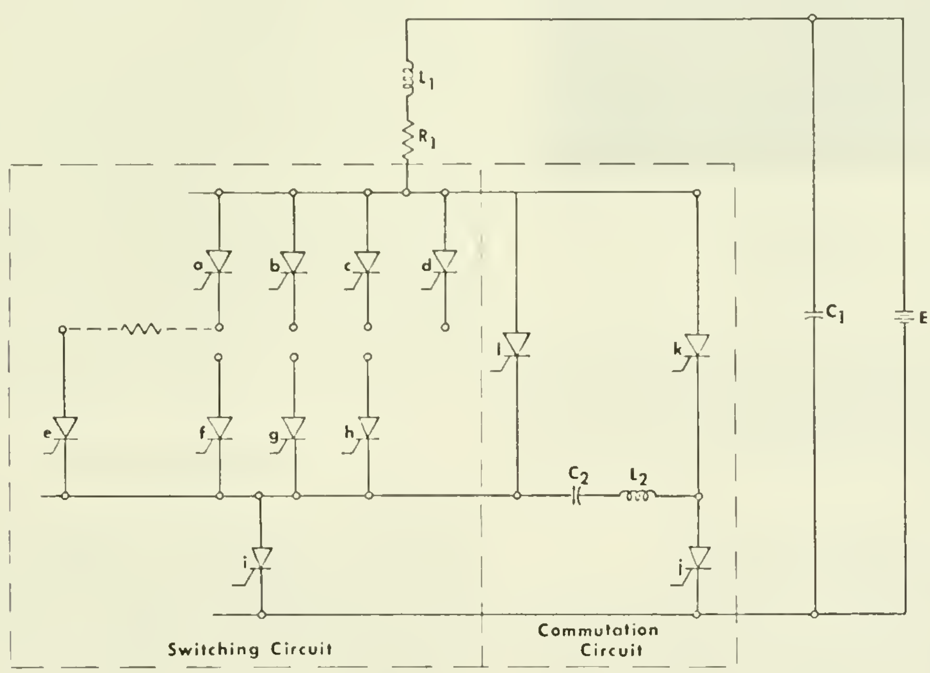


Figure 7. — High power switching and commutation circuit.

Figure 8. — Freshwater Fish Electro-Motivator (FFEM) power supply.

double set point meter will detect current which is either above or below normal limits and trip an alarm of either red or amber lamps respectively. Other pilot lamps indicate when the main power is on and when the low voltage is on.

Summary of Field Testing

The FFEM system was tested for reliability in 21 10-min fishing drags and 22 15-min voltage plotting drags aboard the RV *Kaho* in the Saginaw Bay area of Lake Huron. Ellis and Pickering (in press) give a complete discussion of an experiment involving the use of this gear and allied

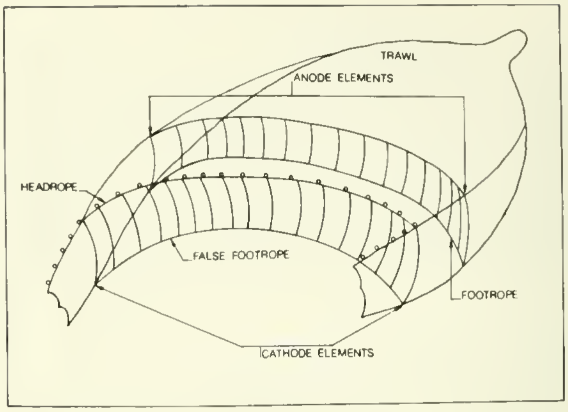


Figure 9. — Diagram of electrical trawl showing arrangement of electrode arrays in mouth of net.

equipment. During the field testing, the maximum power output was limited to 90 v DC due to an anomalous electronic signal in the pulse generator which shut the power supply down when this limit was exceeded. However, this signal presented no problem in our test.

A 21.3-m (headrope) wing trawl, rigged with an electrode array as shown in Figure 9, was used. The spacing between arrays was 1.5 m and between electrode array elements was 0.3 m.

We experienced no problems with the FFEM during the voltage plotting. We had a heterogeneous electrical field which ranged from 21.1 v within 38.1 cm of the cathode array to 1.0 v midway and then rose to 16.9 v within 38.1 cm of anode array. The FFEM did shut down at the end of the 21st fishing drag probably due to the electronic anomaly which we knew was present. The catch rate in kilograms of the trawl with power on was 1.65 times or 65.6% more than the catch rate in kilograms with power off.

DISCUSSION

The prototype FFEM system fully utilizes electrical currents for obtaining maximum power outputs at optimum pulse characteristics. The system permits multiple time-sequenced loads (from 1 to 4), varying pulse patterns and duty cycles, varying load distribution patterns, and variable output voltages and operates over a wide dynamic load range. Its versatility as a research tool is almost endless; however, it must be pointed out that its pulse width is fixed at 1 msec and its pulse shape is also fixed. These were designed into the system after we made a study of capacitator-discharge pulse generators. If time and funds were available, these two fixed characteristics could be redesigned for flexibility.

In designing a follow-up FFEM, a considerable savings can be realized through the use of polyvinal chloride pipe in place of the high impact aluminum tube. In addition, for a commercial application the system could be designed without the sophistication and versatility of our prototype thus realizing a considerable savings. The catch rate of the electrical trawl possibly could have been increased with a more homogeneous electrical field and/or more power to the array system during our field tests.

ACKNOWLEDGMENT

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