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Scientific Note

Design and construction of an Electric Fish Finder

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We provide notes on the design and construction of an Electric Fish Finder - a portable differential amplifier for detecting the electrostatic fields of gymnotiform knifefishes. The device can be adapted to locate electric fishes in any kind of aquatic environment. It is rugged, water resistant, and powered by alkaline batteries. This contribution is part of a series of technical papers designed to encourage students of neotropical ichthyology to explore the ecology, systematics, and electric signaling of gymnotiform fishes.

Nós fornecemos o esquema e as instruções para a construção de um Detector de Peixes Elétricos - um amplificador portátil de banda larga utilizado para detectar os campos elétricos de peixes gymnotiformes. Este aparelho pode ser adaptado para encontrar peixes elétricos em diversos ambientes aquáticos. É resistente, à prova d'água e energizado por baterias alcalinas. Esta contribuição faz parte de uma série de artigos técnicos que pretende encorajar estudantes de ictiologia neotropical a explorar a ecologia, sistemática e comunicação elétrica de peixes gymnotiformes.

Key words: Electric Organ Discharge, Gymnotiformes, Knifefishes, Method.

Introduction

Wells & Crampton (2006) provide a detailed description of the design, construction and calibration of a bio-amplifier for research on electric fishes. This device was designed primarily for laboratory investigations of the repetition rate and waveform structure of gymnotiform electric organ discharges (EODs). Here we provide notes on the design and construction of a simpler and more rugged device intended to function as an 'Electric Fish Finder' (EFF) in the field. The EFF amplifies electric fish signals from a submerged dipole electrode and converts them into sound via an integrated loud speaker. The EFF is an indispensable tool for the rapid localization and targeted capture of electric fishes, especially in habitats where they are relatively uncommon.

Specifications. The EFF described here is a differential amplifier designed to accept signals from a submerged, grounded dipole electrode via a differential input. Amplification is controlled by a three position switch: off; low-gain (x 100); and high-gain (x 500). For either low or high-gain, the signal is further amplified (x 20) and converted into sound via an integrated loud speaker.

Power is provided by two 9V alkaline (or Ni-Mh rechargeable) batteries, allowing the unit to operate continuously for up to 24 hours at the low-gain setting, and 14 hours at high-gain. The unit weighs 0.55 kg (0.63 kg with batteries). The circuit board and battery bay are contained within a watertight aluminum enclosure, and the loud speaker, dipole connection, and switch are all also sealed so that the unit is resistant to dust, splashes, and short periods of total immersion in water. The unit can also survive a drop of up to 1 m onto a hard surface with no damage to the components. Swivels allow the attachment of a carrying strap so that the unit can be hung around the neck.

Field tests demonstrated that the EFF picks up clear signals from gymnotiform fishes with all known signal types (see review in Crampton & Albert, 2006). These included those with EODs containing low frequencies, near the frequency sensitivity of small loudspeakers (*e.g. Electrophorus electricus* and *Sternopygus macrurus*, and also those with EODs containing high frequencies, such as *Hypopygus lepturus* and *Sternarchella schotti*. The EFF will also clearly amplify and broadcast the weak EODs of small post-larval gymnotiform fishes (*e.g*. ca. 20 mm *Gymnotus carapo* where the peak-to-peak amplitude is < 10 mVcm^{-1}@10 cm).

Circuit Design. The circuit plan is illustrated in Fig. 1, with stages A - E annotated (see below). A list of components is provided in Table 1. The signal enters the amplifier via the grounded dipole electrode input. A 3-pin Lemo input is pre-

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ferred for its extremely rugged construction and water resistance, although a 3-pin microphone connector would suffice. In stage A the signal is differentially amplified 100 times and converted to a single ended output. Stage B provides an optional 5 x gain (x 500 total) only when the switch is set to high-gain. Stage C provides a further 20 x gain to drive the magnetic loud-speaker. Section D provides the ground for the circuit by dividing the voltage difference of V+ and V- between two equal value resistors. The node between the resistors can thus be considered a reference or 0V. It is important to select two 12K resistors whose resistance lies within 2% of each other (the value need not be precisely 12K). This will ensure that the reference will be precisely centered between V+ and V-. The 22uF capacitor between V+ and V- eliminates large fluctuations in the supply voltage. If there is a sudden demand for current and the battery cannot supply this fast enough, stored charge in the capacitor will provide the deficit, thus preventing a precipitous voltage drop. Section E illustrates the 3-way toggle-switch schematic. No calibration or maintenance of the circuit is required. A standard electronic textbook (*e.g.* Sinclair, 2005) is all that is needed to follow the circuit plan.

Construction. The EFF is built in an aluminum box (152 x 83 x 50 mm) with an external black polymer coating and hermetically sealed removable lid (Fig. 2). Holes are drilled at opposite ends of the box for the dipole connector and toggle-switch. All components are soldered to the main circuit board and connected with circuit wire. An alternative approach is to have the circuit board professionally etched and each component soldered in place. This allows several boards to be made automatically, and reduces assembly effort, but does not result in improved performance. The finished circuit board is glued to the base of the box at each corner with large beads of clear silicone sealing rubber. These rubberized attachments protect the circuit board and its components from physical shock if the unit is dropped. Should the board need to be repaired, these attachments can be pulled off and remade.

Holes drilled in a pattern on the lid allow sound from the loudspeaker to exit the box. The speaker is glued using silicone sealant to the lid. The Mylar polymer cone of the loudspeaker and the silicone sealant prevent water entering the box via the holes. The leads to the loudspeaker should be long enough to allow the lid to be taken off and placed aside the box during battery changes. The battery bay is lined with a layer of packing foam to provide a tight fit for the 9V batteries. The dipole socket and toggle switch are water resistant. The Jig-latch bolts for the swivels are each secured in position with a hex nut, locking washer and a bonded steel/rubber sealing washer to provide a watertight seal.

Tests demonstrated that no water will enter the unit during heavy rain or splashing, or during complete submersion for ten seconds. For normal field use (avoiding any more than momentary accidental submersion) a small sachet of silica gel kept inside the box will keep the components completely dry. This sachet can be recharged at the end of each day in the field. Should the unit be submerged for longer it should be opened and if necessary dried in strong sunlight and then left for 6 hours in a desiccating chamber.

Operation and probe types. For most field applications, the fish finder is connected via a grounded dipole connector to a 2 – 2.5 m microphone cable (Figs. 3, 4). The two channels corresponding to the differential inputs in Stage A are stripped from the main body of the end of the cable to the desired length and left in their plastic shields, exposing only the terminal 2-3 mm of metal as contacts with the water. The grounded shield (which wraps around the channels) is exposed, cut, and twisted to form a small stub near the main cable where the two channels depart (Fig. 3). The combination of the two exposed contacts and the ground is hereafter called the 'dipole'.

For locating electric fishes in marginal roots and vegetation, or leaf litter banks of small streams, the separated channels of the dipole can be firmly attached with

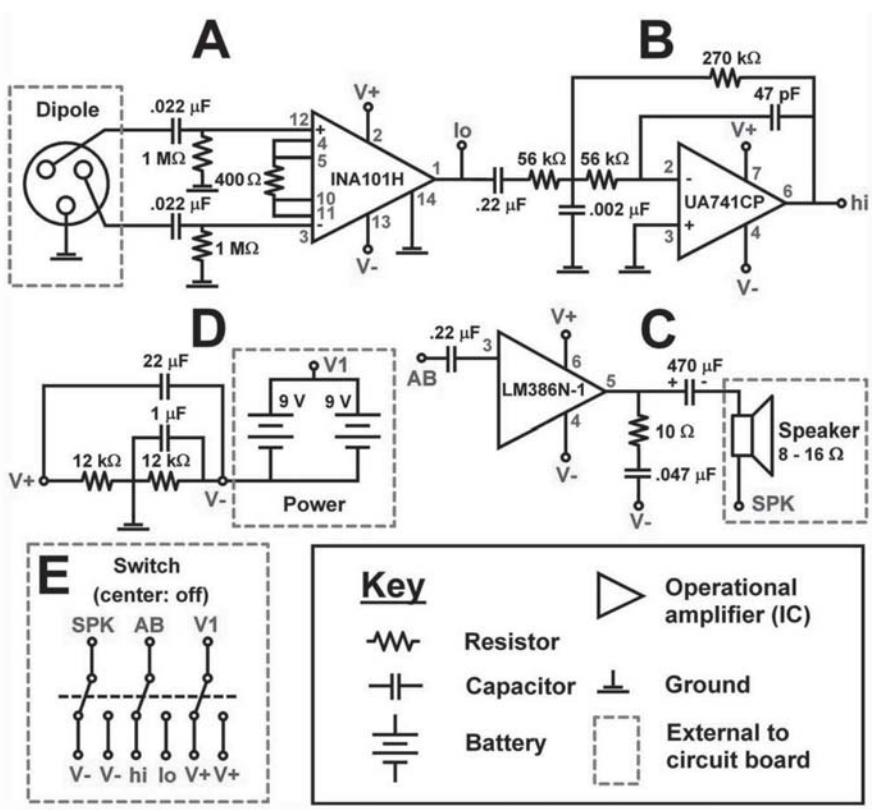

Fig. 1. Circuit plan for Electric Fish Finder. See text for description of stages A - E. Boxes with dashed lines refer to components external to circuit board. IC = integrated circuit.

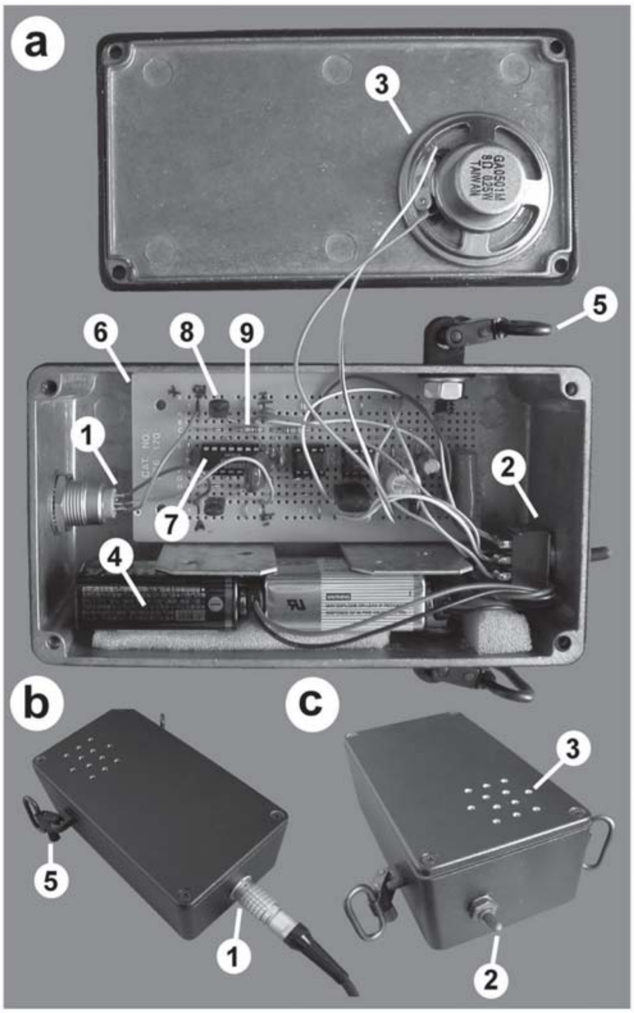

Fig. 2. Internal (a) and external (b, c) views of the Electric Fish Finder. a: 1, dipole input; 2, toggle switch; 3. magnetic speaker; 4, batteries and terminals in foam-lined bay; 5, swivels for strap attachment; 6, circuit board; 7, operational amplifier (INA101HP); 8, capacitor (polymer-film); 9, resistor.

duct tape to the end of a straight pole or cut branch (Fig. 4). The terminals should be separated by approximately 10 – 15 cm, with the ground in any position that will be submerged at the same time as the exposed wires (somewhere in the middle is preferable). The position of a gymnotiform can be determined in the field by sweeping movements of the dipole, with the EFF switched to the high-gain setting. On locating a fish, the EFF should then be switched to the low-gain setting to allow a determination of its exact position by more confined movements of the dipole. In low-conductivity water (5 – 20 μScm^{-1}) a 15 cm pulse-type gymnotiform (*e.g.* a *Gymnotus*) is typically detectable at a range of up to 3 m with the high-gain setting, and 1 m with the low-gain setting. In higher conductivity water these ranges are reduced. Following detection and localization, gymnotiforms can be captured using a dip net (Fig. 4). Typically the net brings up sand, mud and organic material. The net can be lifted from the water and briefly touched with the dipole to determine if the fish is in the net or

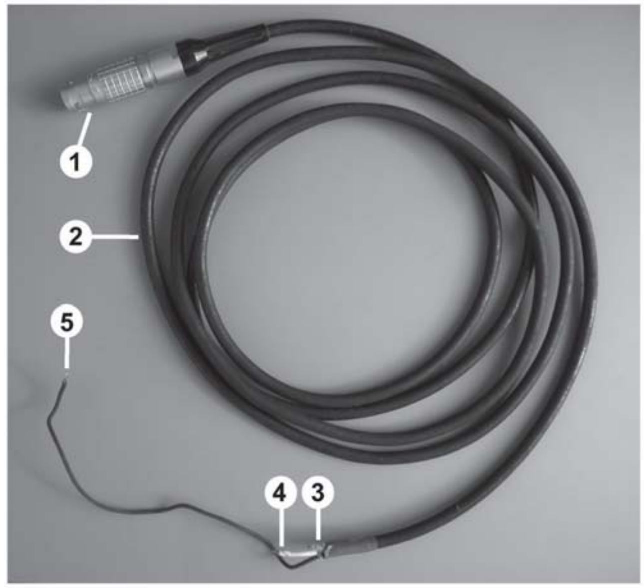

Fig. 3. Dipole construction for Electric Fish Finder. 1, dipole connector; 2, microphone cable; 3, exposed ground stub; 4, channel-1 unraveled from within cable, cut short, and copper wire exposed only at end; 5, channel-2 with longer length exposed. The dipole is mounted on a pole with duct tape in the field (Fig. 4).

Fig. 4. Electric Fish Finder/dipole and dip net used in combination to catch a juvenile *Hypopomus artedi* from a leaf litter bank in a rainforest stream, northern Suriname.

Table 1. List of components for the construction of an Electric Fish Finder and dipole probe. Qt. = quantity. IC = integrated circuit. F = Farad. Ù = Ohm. * See text for discussion of useful cable lengths.

Component	Qt.	Part Number	Manufacturer/Supplier
Circuit board			
PC board (cut to 110 x 50 mm)	1	276-170	Radio Shack
Operational amplifier: 14-pin IC	1	INA101HP	Texas Instruments
IC socket: 14-pin retention contact	1	276-1999	Radio Shack
Operational amplifier: 8-pin IC	1	UA741CP	Texas Instruments
Operational amplifier: 8-pin IC	1	LM386N-1	National Semiconductor
IC socket: 8-pin retention contact	2	276-1995	Radio Shack
Resistor: 1 MΩ	2	271-1356	Radio Shack
Resistor: 270 kΩ	1	271-312	Radio Shack
Resistor: 56 kΩ	2	271-312	Radio Shack
Resistor: 12 kΩ	2	271-312	Radio Shack
Resistor: 10 Ω	1	271-312	Radio Shack
Resistor: 400 Ω	1	271-312	Radio Shack
Capacitor (ceramic disk) 47 pF	1	272-130	Radio Shack
Capacitor (polyester film) 0.002 µF	1	140-PF2A202F	Mouser
Capacitor (polyester film) 0.022 µF	2	272-1066	Radio Shack
Capacitor (polyester film) 0.047 µF	1	272-1068	Radio Shack
Capacitor (polyester film) 0.22 µF	2	272-1070	Radio Shack
Capacitor (metal film) 1.0 µF	1	272-1055	Radio Shack
Capacitor (electrolytic) 22 µF	1	272-1026	Radio Shack
Capacitor (electrolytic) 470 µF	1	272-1030	Radio Shack
External to board			
3-pin socket (dipole input)	1	EGG.2B.303.CLL	Lemo
Magnetic speaker (50 mm, Mylar)	1	GA0501M	CUI
3 PDT toggle switch	1	MTE306E	Tyco Switch Electronics
Toggle switch cap	1	B2210	Tyco Switch Electronics
9V battery connector	2	271-0312	Radio Shack
Casing			
Aluminum box	1	1590WP1BK	Mouser
¼″ Jig-latch bolt for swivels (optional)	2	832850	Valtra
¼″ Hex Nut	2	08421	Crown Bolt (Home Depot)
¼″ Lock washer	2	20401	Crown Bolt (Home Depot)
¼″ Bonded Sealing Washer	2	601	Crown Bolt (Home Depot)
Quick-detach swivels (optional)	2	286964 (1 pair)	Uncle Mike's
Probe			
3-pin plug (dipole input)	1	FGG.2B.303.CLAD527	Lemo USA
Cable strain relief for plug	1	GMA.2B.050.DN	Lemo USA
Shielded microphone cable	*	-	Any audio cable retailer

not. A machete is often required to cut away dense vegetation or root mats in order to dislodge gymnotiforms.

In very shallow water (< 10 cm) the dipole terminals are best mounted at the ends of the prongs of a forked stick. The ground should be positioned near the end of one of the prongs to ensure that it is also submerged. For locating electric fishes in dense rafts of floating macrophytes, the best results are achieved by attaching the two channels to the ends of two parallel prongs mounted on the end of a pole. Such a fork can be constructed from narrow PVC tubing. The fish finder can also be used to detect gymnotiform fishes in deep water by utilizing a long shielded microphone cable, with the electrode contacts attached to a weighted cable. To avoid damage by stretching or abrasion, the microphone cable should be attached to the weighted cable with duct tape or cable ties at 1 m intervals. Tests in the Amazon River in Peru confirmed that the fish finder described here can readily detect the signals of gymnotiforms at depths of 50 m, or more, permitting surveys of even the deepest sections of large rivers.

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Literature Cited

Crampton, W. G. R. & J. S. Albert. 2006. Evolution of electric signal diversity in gymnotiform fishes. I. Phylogenetic systematics, ecology and biogeography. Pp. 647-696, 718-731. In: Ladich, F., S. P. Collin, P. Moller & B. G Kapoor (Eds.). Communication in Fishes. Enfield, N.H. Science Publishers Inc.

Sinclair, I. R. 2005. Practical Electronics Handbook. Oxford, Newnes Press.

Wells, K. & W. G. R. Crampton. 2006. A portable bio-amplifier for electric fish research: design and construction. Neotropical Ichthyology 4(2): 295-299.

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