NATIONAL INSTITUTE OF OCEANOGRAPHY

WORMLEY, GODALMING, SURREY

The N.I.O. Acoustic Transponder

by

M. J. TUCKER

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Introduction

An underwater acoustic transponder is a device which, when it hears the correct interrogating pulse, emits another pulse itself. The simplest transponder in concept is one which emits a pulse similar in character to the interrogating pulse and with negligible delay: it can therefore be used with an ordinary pulsed sonar and looks like a strong target at its true range. The transponder described in this report is of this type.

The main fundamental problem in the design of a transponder is to make sure that it triggers only on the correct signal and not on noise or on its own echoes and reverberation. Various solutions to this problem have been used (see bibliography), including, for example, devices which discriminate against noise by looking at the ratio of the energy in various parts of the acoustic spectrum, and devices which reply on a frequency different to the interrogating frequency so that they do not trigger on their own reverberation. The device described below emits a reply pulse on the same frequency as the interrogating pulse when the signal in the listening pass-band rises to a preset level relative to the average background noise. This level is set so that with gaussian noise, a false trigger happens less than once per hour (see the appendix for the theory of this). Following transmission, the device is de-sensitised for 1·9s and echoes received after this time from its own pulse (which is relatively weak) are unlikely to be strong enough to re-trigger it.

It is designed to work mainly with a precision echo-sounder transmitting once every 2s on 10kHz. For faster transmission rates it will miss some pulses, but regular "echoes" will still be obtained and this can, in fact, be used to distinguish it from other types of echo if necessary. Identification can also be obtained by coding the transponder pulse: for example, by using a pair of pulses separated by a fixed delay, or it can be used as an interrogatable telemeter by making the delay of the second pulse depend on depth or temperature or any other parameter which can be converted to a pulse delay.

Some obvious applications of transponders spring readily to mind, such as navigation marks and beacons to mark equipment, but they have also shown themselves to be useful in less obvious ways. For example, figure 1 shows a record of the signals from a transponder attached to a grapnel during an attempt to recover some equipment on the sea bed in a depth of approximately 2,000m. The equipment had a free-running acoustic "pinger" attached to it which was triggering the transponder, and the direct signal from the pinger together with that via the transponder were recorded using an echo-sounder type of recorder whose sweep repetition rate was the same as the pinger pulse repetition rate. From this record it can be deduced that the grapnel passed within 38m of the pinger.

The advantages of a transponder beacon relative to a free-running beacon are firstly that the power consumption of the listening amplifier can be made very low so that the life can be long, and secondly, it gives range. Thus, a local navigation system can be set up depending on range determination only, which is much simpler instrumentally aboard ship than the bearing systems required with free-running beacons.

It may also be worth noting that the received intensity from a transponder obeys an inverse-square law with range (in a homogeneous medium) compared with an inverse fourth-power law from a passive target. At close range the received intensity can therefore sometimes look rather unimpressive.

General description

The electronics and battery are housed in a standard N.I.O. cylindrical aluminium-alloy pressure case 3 inches (7·6cm) internal diameter and 3 feet 6 inches (107cm) long (figure 2). A handle and cable clamp are normally fitted, but other fixing arrangements are available if required. The acoustic transducer used is a nickel scroll which, though rather inefficient, has the advantages of being cheap, robust, requiring no pressure release, and being a standard item at N.I.O. The same scroll is used for both transmission and reception.

The quiescent power consumption is approximately 3mA from 6V, so that there is no difficulty in providing batteries to last 3 months, and a year's supply could be provided at the expense of lengthening the housing by a few inches. When transponding, the transmitter consumes approximately 10mA from 30V, so that a standard battery will last for at least 200 hours of continuous interrogation.

The output pulse has an acoustic power of only about 5W (approximately omnidirectional). This can be detected adequately with the standard ship's precision echo sounder when the transponder is approximately below the ship in depths of up to at least 6,000m. Using towed hydrophones, detection ranges of up to 8 miles have been achieved in exceptionally good conditions, but 5 miles is a more usual range. It is hoped to increase this power by at least 6db using better scrolls and more efficient driving circuits.

Circuit description

A block diagram of the circuit is shown in figure 3 and the detailed circuit diagram in figure 4. These are largely self-explanatory, but some points of interest are as follows.

The listening amplifier has enough gain to start the A.G.C. operating on self-noise, which should be exceeded by sea noise except in the very quietest conditions. With typical noise levels it is controlled hard by the A.G.C. voltage which is then at a ratio relative to the battery voltage approximately equal to the ratio of the 330KΩ and 1MΩ bias resistors on the first two stages.

The threshold device is a "zener" diode. The stabilisation mechanism of these undergoes a transition from the true Zener effect at low voltage to an avalanche effect above about 6V, the latter having a much sharper knee and therefore being more suitable for the present application. Thus, a 7·4V (nominal) zener diode is used, and this in fact fits in quite well with convenient A.G.C. voltage levels.

Low power consumption was one of the most important requirements and raised problems particularly with the rectifier stage. This had to be both sufficiently linear to allow moderately accurate setting of the signal/noise decision threshold, and capable of giving the comparatively high voltage and current required to operate the zener diode threshold device. A class B amplifier was therefore used, but even so this stage is the major consumer of power in the quiescent state.

Because of the sensitive listening amplifier, it was thought inadvisable to use the usual gated continuously-running oscillator system for generating the output pulse. A keyed oscillator was therefore used, but the design was complicated by the necessity to use little or no power in the quiescent state, which precluded most of the more conventional circuits. Though the design adopted works adequately, it is probably the least satisfactory part of the whole circuit.

The inductance of the scroll is tuned by C22, and the mean collector current during the pulse (approximately 10 Amps) aids the remanence of the scroll to provide the correct magnetic bias.

A/

APPENDIX

Theory of the signal/noise decision level

We wish to choose a level of rectified signal relative to mean rectified background noise such that in the absence of signal this level will be exceeded less than once an hour by random chance. Any voltage which exceeds this level will then be assumed to be due to an interrogating pulse and the circuit will transpond.

It will be assumed that the filtered background noise is Gaussian, so that, since we are dealing with a narrow band, the probability distribution of its envelope follows the Rayleigh law.

$$P(v) = (2v/C^2)\exp(-v^2/C^2) \qquad (1)$$

where C is a constant.

The rectifier output is smoothed with a time constant short enough to follow the envelope so that we shall take v as being the output voltage of the rectifier. Thus, the noise output averaged over a long period of time is

$$\bar{v} = \int_0^\infty v\,P(v)dv$$

$$= (C\sqrt{\pi})/2$$

$$= 0{\cdot}88\ C \qquad (2)$$

The probability of v exceeding a certain value V is

$$P(v > V) = \int_V^\infty P(v)dv$$

$$= \exp(-V^2/C^2) \qquad (3)$$

We now have to decide how many effectively independent samples of the input voltage there are in an hour. A precise calculation of this is very difficult, depending on the exact shape of the filter passband. However, the value is not critical, and for the present purpose we can take it as $2\Delta f$ per second, when Δf is the nominal pass band, which is 500Hz in our case. This gives $3{\cdot}6 \times 10^6$ samples per hour, and therefore our criterion for one false firing per hour is

$$P(v > V) = \frac{1}{3{\cdot}6 \times 10^6}$$

or $$V^2/C^2 = \log_e 3{\cdot}6 \times 10^6$$

$$= 15{\cdot}1$$

or $$V = 3{\cdot}88\ C$$

$$= \underline{\underline{4{\cdot}41\ \bar{v}}} \qquad (4)$$

Of course, the relative threshold cannot be set-up in the present circuit to high precision. For one thing, the actual threshold voltage V is constant, whereas the high signal-level A.G.C. voltage $\bar{v}$ is roughly proportional to the battery voltage. Thus a factor of safety is required, and the design value of $V/\bar{v}$ used is actually 5.

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This is not meant to be an exhaustive list, but contains some of the more relevant papers on transponders which have come to the author's attention.

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FIGURE CAPTIONS

(1) (N.I.O. photograph 2566/1). A record taken while attempting to recover some equipment on the sea bed in a depth of approximately 2000m using a grapnel with an acoustic transponder attached 50m ahead of it on the warp. The equipment had a free-running pulse generator ("pinger") on it and the direct pulses from this together with the pulses repeated by the transponder were received on the ship and recorded. The sweep repetition rate of the recorder stylus is set to be identical to the P.R.F. of the pulse generator (approximately 1/sec) so that successive pulses fall under one another on the record to form the lines seen.

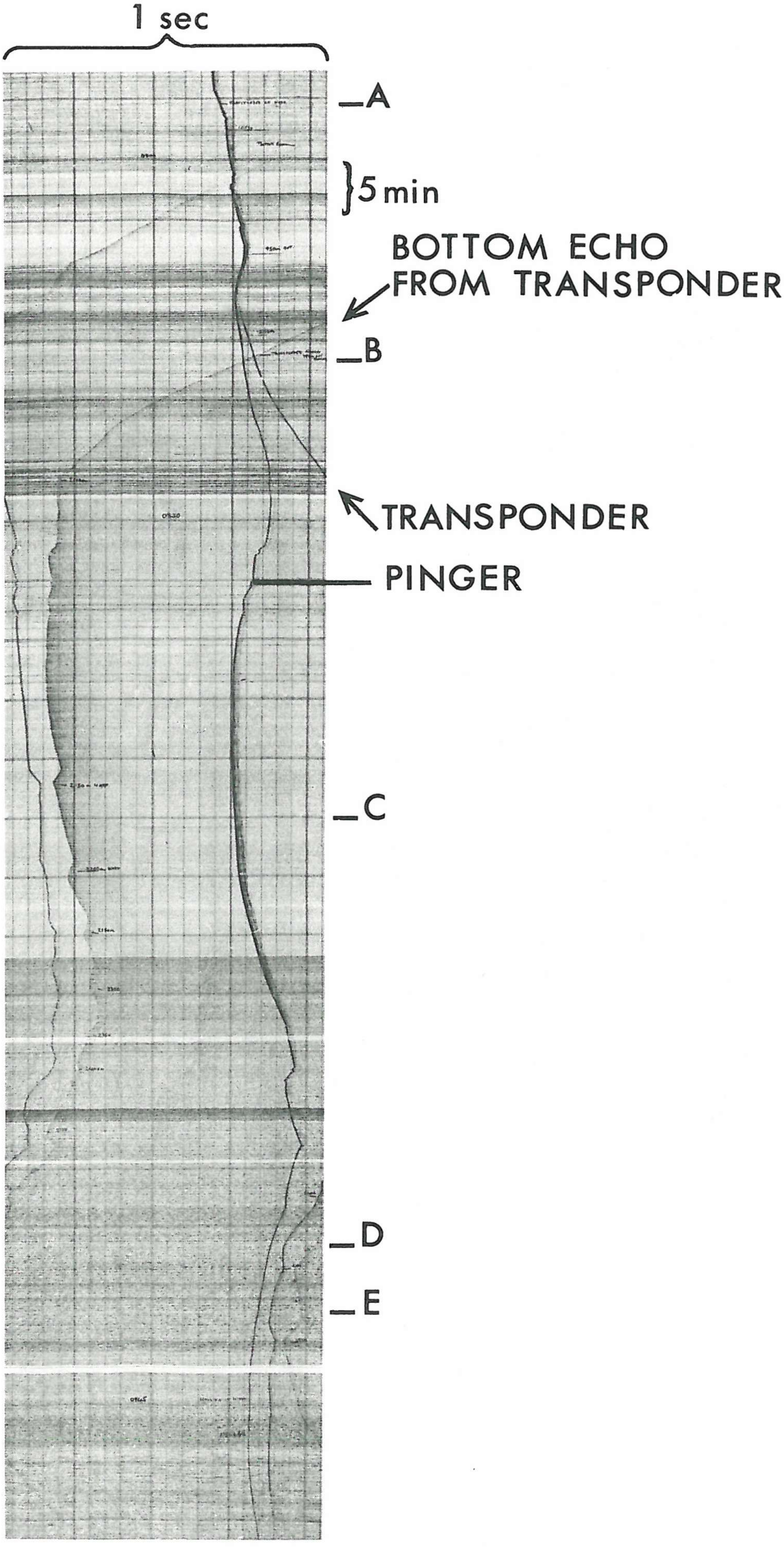
The transponder entered the water at the point marked A and immediately started transponding from the pinger. The difference in the paths pinger-to-ship and pinger-transponder-ship was small at first and increased only slowly as the warp was paid out because the two paths continued to make a very acute triangle. However, at the time B when the transponder was approximately 750m from the sea bed the triangle started opening out and the path difference started increasing, reaching a maximum of 280m at time C. At this time the bottom echo shows that the transponder was rather more than 50m off the sea bed. The transponder then approached the pinger until at some time between D and E it achieved its closest approach. During this interval the two sound paths must at some time have formed an isosceles triangle, so that the closest approach is represented by a travel time of about 50ms, or 38m.

(2) The electronics, battery pack and housing of the transponder.

(3) Block diagram of the transponder.

(4) Circuit diagram of the transponder.

FIGURE 1



1 sec
A
5 min
BOTTOM ECHO FROM TRANSPONDER
B
TRANSPONDER
PINGER
C
D
E

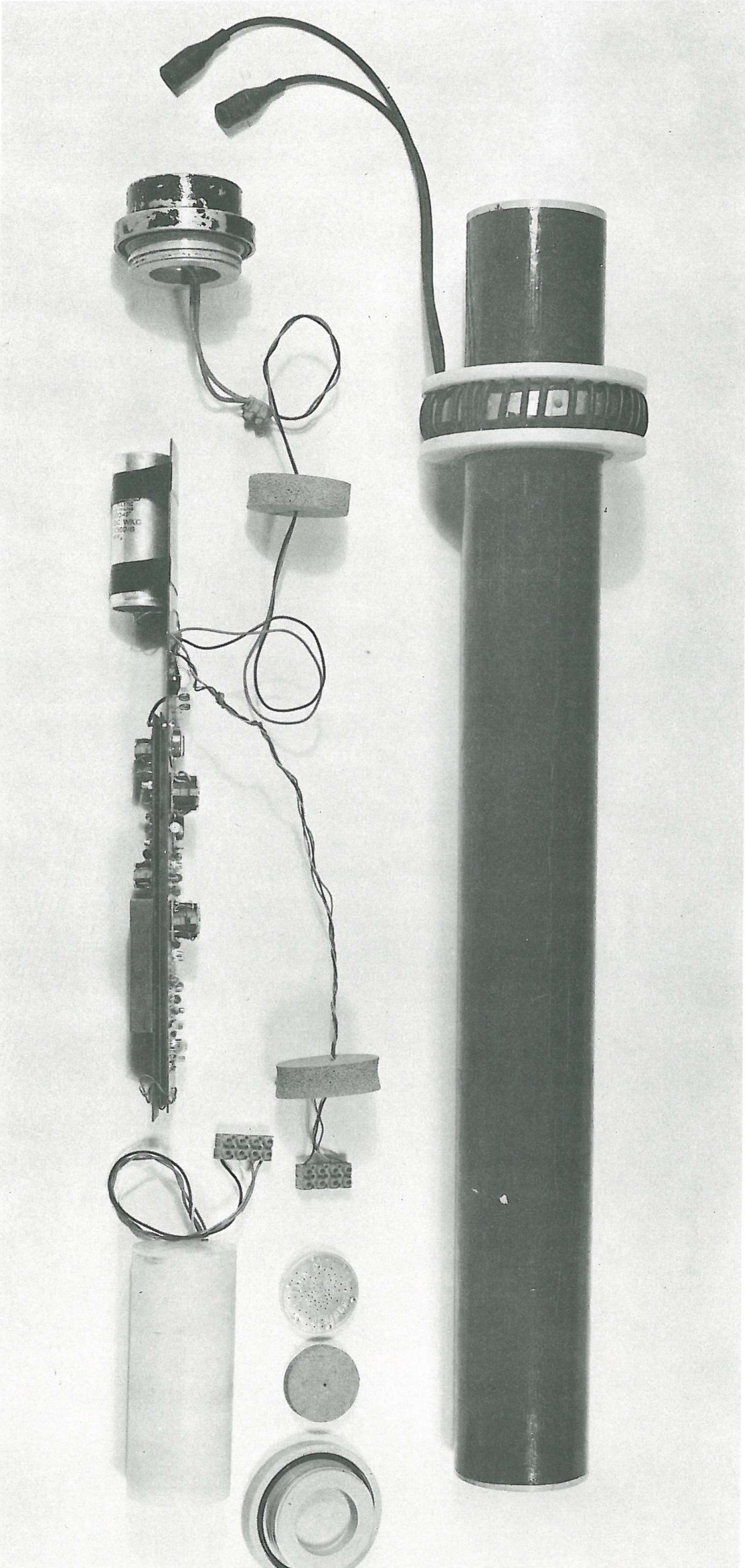
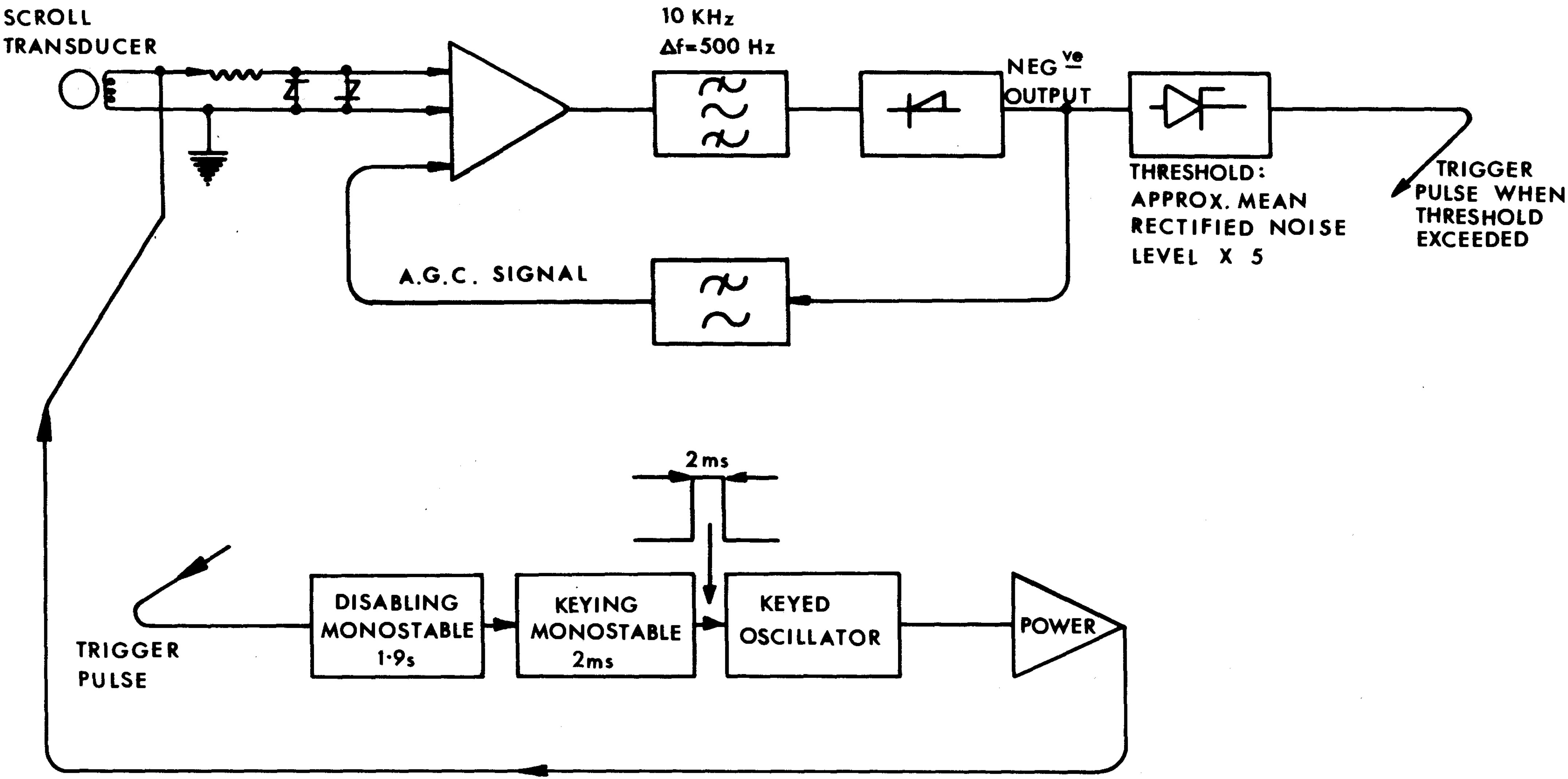
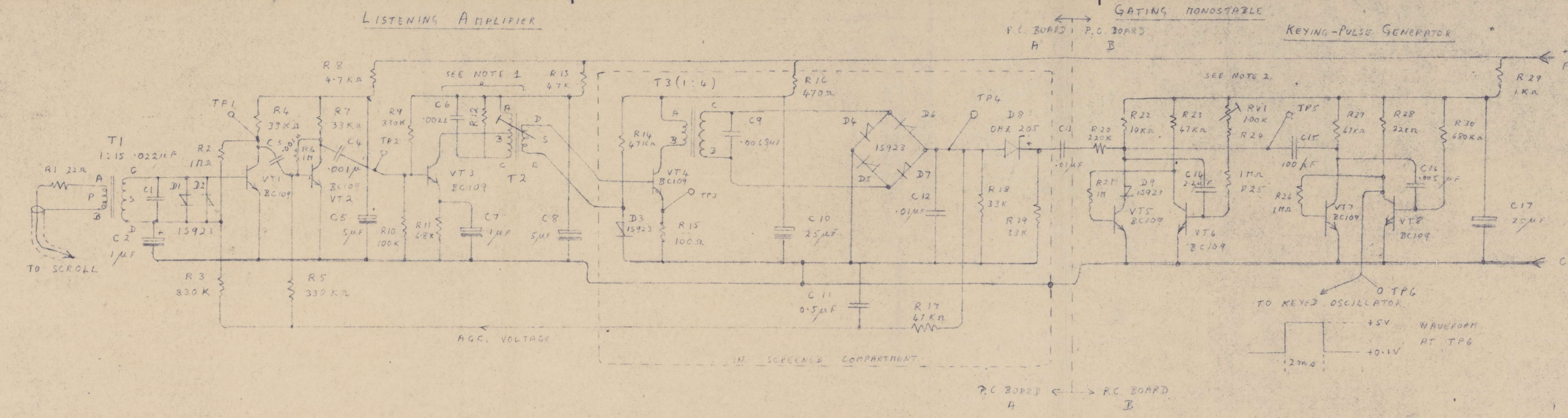
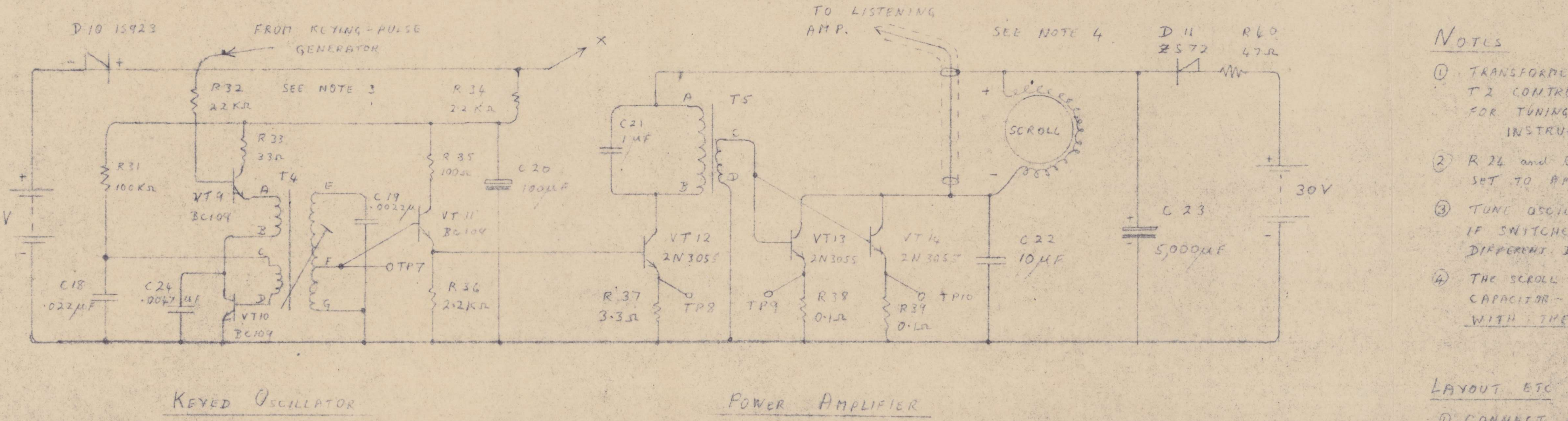


FIGURE 3 N.I.O. TRANSPONDER : BLOCK DIAGRAM







NOTES

1. TRANSFORMERS T1, T3 & T5 ARE WIDE BAND ($\Delta F \simeq 2$ kHz). T2 CONTROLS THE BANDWIDTH OF THE LISTENING AMP. FOR TUNING & ADJUSTMENT OF BANDWIDTH SEE SETTING-UP INSTRUCTIONS
2. R24 and RV1 CONTROL THE DEAD TIME FOLLOWING A TRANSMISSION SET TO APPROX. 1.8S.
3. TUNE OSCILLATOR TO 10 kHz USING PULSE OPERATION. NOTE THAT IF SWITCHED ON CONTINUOUSLY, FREQUENCY IS NOTICEABLY DIFFERENT DUE TO VOLTAGE DROP ACROSS R34
4. THE SCROLL SHOULD BE POLARISED BY CONNECTING IT TO A CAPACITOR-DISCHARGE TYPE PINGER FOR A FEW PULSES WITH THE SAME POLARITY

LAYOUT ETC

1. CONNECT ALL VINKOR FRAMES TO COMMON
2. 6V BATTERY LEADS TO CONNECT TO OUTPUT END OF P.C. BOARD A.

FIG 4. CIRCUIT DIAGRAM OF TRANSPONDER.