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MICRO-CONTROLLER BASED DETERRENTS: ACOUSTIC DEVICES TO REDUCE HARBOUR PORPOISE (*Phocoena phocoena*) INCIDENTAL CATCH IN GILLNETS

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1. INTRODUCTION

In gill-net fisheries around the world, very large numbers of small cetacean are killed each year as bycatch Donavan [1]. If commercial fishing is to continue in areas where the incidental catch of cetaceans is significant then technical improvements to the method of fishing are required to mitigate the impact, Goodson [2]. Modifying fishing gear by the addition of acoustic *alarms* which signal the position of the net by the transmission of low level sounds was pioneered by Lien [3] in Newfoundland and this technique successfully reduced baleen whale interactions with set fishing nets and traps. These simple devices, which were constructed by the fishermen, were also tested in a bottom set gillnet fishery in the Bay of Fundy where harbour porpoise mortality is high. Encouraging results from that study resulted in an improved device being developed in the USA for use in a subsequent Gulf of Maine study, Kraus [4]. The low frequency signals developed as baleen whale deterrents were also tested on captive harbour porpoises Kastelein [5] where it was evident that the frequencies used were inappropriate. The technology used is electro-acoustically inefficient and the operating (battery) costs rather high. The apparent success of the Canadian work also encouraged a European Commission supported study of potential acoustic deterrent devices in the UK, Woodward [6]. As part of this work a wide variety of signal frequencies and waveforms were generated digitally and tested with a harbour porpoise contained within a large floating net cage enclosure, Kastelein [7]. A new generation of micro-controller based *beacon-mode alarms* developed, at Loughborough University, Newborough [8], is discussed here. These synthesise sounds known to be aversive to porpoises and implement new features intended to minimise habituation rates and maximise battery life. A preliminary field test with wild harbour porpoises in Scotland, Mayo [9] and Goodson [10], showed that these devices can induce a dramatic avoidance behaviour displacing the animals in this short test to a range greater that 640 m while the devices remained active. The design and engineering of this new technology device is discussed here in the context of preparing them for a forthcoming large-scale commercial fishery trial.

2. DESCRIPTION

2.1. The first generation of acoustic deterrents

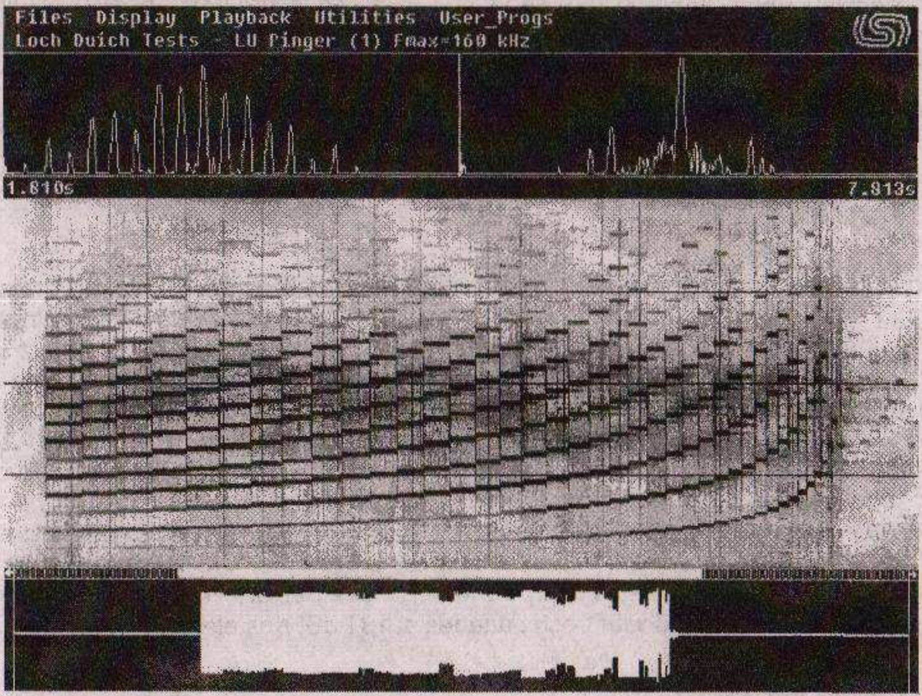
The first acoustic deterrents developed, at the Memorial University Newfoundland, were aimed at prevent gear-damaging interactions and the entanglement and entrapment of baleen whales in the local codtrap and ground gillnet fisheries. Operating at frequencies around 2-4kHz, a simple electronic design was developed used a commercial *beeper* (a vehicle reversing hazard beacon) enclosed in a waterproof case constructed from standard ABS plumbing fittings. This approach allowed fishermen to construct the devices themselves from easily obtainable components. The analogue design and the acoustic miss-match between the piezo (air) transducer and the water impaired the electro-acoustic efficiency and limited the operational life obtainable from four PP3 (9V) batteries. The variability in the sound spectrum produced by these devices may account for the limited success observed when re-deployed as deterrents for harbour porpoises. Source Levels (SL) appear relatively low, i.e. 115 dB and 119 dB re 1 μPa at 1m when two units were measured, Kastelein [2]. However, these SLs are very voltage dependent and one of these units was later re-measured with fresh batteries at 131 dB, Kastelein [7].

2.2. The second generation of acoustic deterrents

The 'Netmark 1000™' (Dukane Corp) is the first commercially available acoustic deterrent for use in gillnet fisheries. The device has a similar specification to the prototypes devised for use in the major gillnet trial carried out in the Gulf of Maine, Kraus [4]. These pingers nominally operate at around 10kHz (some samples measured have been between 11-13 kHz). The alarm emits a 300ms tonal pulse every 4 second at a minimum SL of 130 dB re 1 µPa at 1m. This device is housed in a robust, injection moulded, plastic case with an 'o' ring sealed screw on cap to allow the batteries to be changed. The devices are specified to operate to a depth of 100 fathoms (180 m). No water detection or external switch was present on the first production devices to allow the device to switch off when not immersed in water. Operating from four AA cell batteries the device is expected to last over 1 month in continuous use although its initial SL, which may exceed 145dB re 1µPa at 1 m with new batteries, falls steadily to below 130dB re 1µPa towards the end of the battery life. The device transmits in the audible range and can therefore be easily checked by fisherman without external equipment. The original sealed prototypes used in the NMFS supported fishing trial were seen to be very effective in that control nets fitted with dummy devices or no devices caught twenty porpoises [4], whereas the actively marked nets caught only two. Subsequent pinger trials in the USA, although generally encouraging, have raised questions as to the longer term effectiveness of these simple signals as small cetaceans are known to rapidly habituate to new phenomena, in addition the possibility that some of the porpoise's preferred prey, e.g. *herring,* might also be affected and be deterred needs further study. Such concerns and others were discussed in a workshop convened by the NMFS/MMC in March 1996, Reeves [11].

2.3. The next step - a programmable *beacon mode* digital deterrent.

This new generation of devices, designed at Loughborough University, attempts to improve the technology and overcome weaknesses perceived in the earlier devices. The signals to be transmitted were determined experimentally and are therefore known to be aversive to harbour porpoises [7] & [9].



The new devices exploit the latest generation of 8-bit micro-controller to synthesise required signals from software. This flexible approach to the signal generation, when combined with an efficient single cell battery inverter, offers the advantage of very compact low power hardware which maximises the electro-acoustic efficiency. A single alkaline 'D' cell battery contains enough energy to drive this device continuously for more than 6 months (or over one year in a normal commercial fishery). A variety of wide band signal waveforms, including frequency sweeps between 20kHz and 160 kHz (figure 1), can be synthesised with SL's peaking at 145-150 dB at mid-band. Capacitive environment sensing circuitry disables the device when it is out of the water and by placing the micro-controller circuitry into *sleep-mode* where the quiescent current consumption drops to <2% of its operating value allowing the device to be stored with very little energy loss. The *half-life* in dry storage is estimated to exceed 6 years after which its normal operating life in the fishery will be in the order of 6 months. This improved efficiency has encouraged the use of a *sealed-for-life* packaging with, it is hoped, the eventual option of trading in spend devices for re-working. The device has a low chip-count and these programmable hardware components permit different operational modes and signals to be implemented by simply changing the software during assembly. Two variants using this design have so far been *life-tested* in the laboratory. The first emulates a more conventional pinger as it operates with a 4-second inter-pulse interval and a 300 ms duration signal. It differs, however, in that it synthesises eight different waveforms and transmits these sequentially to minimise a small cetacean's rate of habituation to its regular output. The use of a fixed interval between pulses allows the device to *sleep* in a quiescent state between pulses in order to maximise the battery life (figure 4.) This device has now been running continuously for more that 260 days and although now emitting a modified signal which broadcasts the fact that has detected its low battery voltage condition, it is still continuing to transmit pulses at full power. This constant SL feature is ensured by using an inverter to regulate the supply voltage fed to the circuitry.

2.4 - Introducing pseudo-random interpulse timings

The second variant has been programmed to further minimise habituation effects by introducing a pseudo-random time delay between the pulses. Currently the inter-pulse timing limits have been set to ensure that the emissions occur after a delay varying between 4 and 30 seconds. This slower average repetition interval saves some power and the longest inter-pulse interval is calculated to be safe as, even at the harbour porpoise's maximum swimming speed, it cannot traverse the distance from the *aversive threshold* SPL contour around the device, Goodson [10], to reach the fishing net without being exposed to a significant number of transmissions. These power savings are negated by the need to continuously compute the inter-pulse timing intervals and the micro-controller does not enter its *sleep-mode* between pulses. This is borne out by the continuous life-test where the device under test failed first, lasting just over 6 months in continuous operation.

2.5 The future - an *interactive* approach.

Transmitting alarm signals only in response to the approach of an echolocating porpoise is the next objective. The idea being that *interactive* units will be placed around (in a pelagic trawl application) or along (gillnet) the fishing net at regular intervals as with the standard *beacon-mode* pingers. Upon deployment in the water these units *wake-up* from their quiescent inactive state (as with the beacon-mode devices) but make no acoustic sounds. These devices adapt their sensitivity to suit the background noise floor and listen for porpoise echolocation *clicks* above this. Upon detection of a porpoise-like *click* the device is programmed to transmit a aversive signal similar to those from a beacon-mode device and to continue to do this every two seconds until the echolocation stimulus is no longer detectable. If the devices are correctly spaced along the net, a *ripple-fire* effect is generated, outlining the extent of the fishing net hazard to the animal. The use of such synchronised outputs, instead of random emissions, are expected to supply more information to the animal and to allow it to determine a safe alternative route. The idea of supplying the animal with more information about the extent of the hazard is expected to provide a longer-term benefit, as the sound emissions only occur when the animal is echolocating within a pre-determined 'danger area'. A possible problem will arise with nets set near, or at, the surface as non-echolocating animals travelling or resting that may enter the 'danger area' will not activate the devices and could therefore reach the fishing net position without prior warning. To solve this problem the *interactive* devices are programmed to emit a *beacon-mode* signal every minute in order to 'awaken' silent swimming animals. This time duration has been calculated to ensure that even at the maximum swimming speed of the harbour porpoise, the animal could not reach the net without hearing at least one 'wakeup call'. The main advantage of this *interactive silent alarm* approach is its anticipated efficiency in the long term. A porpoise is less likely to habituate to this type of device over time, as the transponding action should stimulate a rapid learning process. The action of turning away or turning off the sonar signal will first slow the rate of emission from the device and then remove this stimulus. More experimental work is needed to explore this concept and to assess the reactions of different small cetaceans but it has been demonstrated to be technical feasible using prototype circuitry based on the programmable *Beacon Mode* device hardware.

2.6 Minimising environmental impact

The *interactive* approach allays criticisms that pinger modified fishing operations may increase underwater *noise pollution* and of concerns, already voiced, that pinger alarmed nets may have undesirable effects on other marine biota in the environment immediately surrounding the fishing gear.

2.7 Other fisheries with cetacean bycatch problems

Pelagic trawlers operating along the continental shelf edge may also find this interactive approach useful when trying to reduce the cetacean bycatch which can occur in that fishery. The conditions are very different from gillnets and such fatal interactions may be initiated by the dolphin's desire to predate on fish accumulating in the outer part of the trawl. The envelope of these trawl nets is far too large for a cetacean to image with its sonar and a distributed array of *interactive* pingers may be attached. These may be arranged to activate from a dolphin sonar stimulus or from a man-made impulse transmitted from the ship. Once triggered the ripple-fire effect should clearly indicate the net's geometry, whilst at the same time the aversive sounds should help to acoustically *push* the animal away in the only safe direction (towards the net mouth). This interactive device was initially conceived for this particular application as part of the EC funded CETASEL project [12].

3. MECHANICAL DESIGN

3.1 Construction methods

The mechanical construction of the *pinger* housing needs to be robust to survive the harsh stresses encountered in a commercial fishing environment however, to be economically viable in commercial production this assembly must be simple in design and inexpensive. The prototype devices were constructed inside a short section of 40mm diameter PVC tubing with a rolled 'lip' moulded at one end to retain the assembly (Figure 2.). The electrical components are placed centrally within this tube and 'potted' solid used an electronic grade of polyurethane encapsulation material. It proved rather difficult during this manual assembly operation to ensure that electronic components did not misalign and touch the tube wall. If this condition is allowed to remain uncorrected there is a possible risk of failure as, after heavy usage at sea the PVC material tends to separate from the urethane and seawater may then penetrate along this boundary. This mechanical construction was tested at sea using *dummy* pingers (i.e. a pinger with a battery, but without the associated electronic circuitry) on a commercial gillnet boat working out of Newlyn in Cornwall, UK. These *dummy* devices were attached to the headline and footrope of a 'tangle net' and fished for three months before being returned to Loughborough for evaluation. Only cosmetic damage was apparent externally and although the structure and the encapsulant remained intact, there was some evidence that the adhesion between the Urethane and the PVC tube had started to fail. Ten (full specification) units were also sent to Denmark for similar tests and again this PVC separation effect was reported after heavy usage. This information prompted a redesign in which the outer PVC casing was abandoned and the wall thickness of the urethane material increased to compensate. Precision metal multi-part moulds were then prepared which simplified the assembly process and made accurate component placement an easier task, (Figure 3.). The acoustic efficiency of this device was also improved slightly by the removal of the boundary between these plastic materials. The electronic components are assembled, complete with the battery, and then placed into the metal mould. The mould is then filled with the potting compound resulting in a solid unit with no joints and no external components or contacts. The number of attachment holes through the device was reduced to one after discussions with the Danish fishing gear technologists who were involved in arranging the first commercial fishing study.

3.2 Mass and buoyancy

The device produced for these tests is negatively buoyant, weighs 400 g in air, 35% of the weight is the energy store (battery), 60% is the potting compound (case) with the remaining 5% being the electronics. The actual dimensions are given in figure 3. Creating a neutrally buoyant device by introducing of an air filled cavity within the device has been considered but in order to do this the total volume of the device will first have to be increased. Negative buoyancy is not seen to cause a particular problem as the devices will normally be permanently attached to the fishing net headrope and additional floats can be placed on each side. These also provide the additional benefit of absorbing some of the mechanical shocks that occur when the net is shot.

4. ELECTRONIC DESIGN

The electronic circuit is designed using surface mount (SM) components to minimise the size and to permit high volume computer aided manufacture (CAM) thus reducing assembly time and costs (Figure 5.). The *beacon mode* deterrent employs a small 8-bit, low power, high speed CMOS micro-controller mounted on a small printed circuit 35 mm in diameter to match the battery cross-section. The micro-controller design allows software, to synthesis the acoustic signals, time intervals, output emissions and to control auxiliary hardware on the board. This software control permits the pinger's output transmissions and time delays to be changed without the expense of a circuit board redesign, making this pinger ideal for research applications. Using a 1.5V 'D' cell battery maximises the energy storage for size and cost. An 80-90% efficient DC-DC step-up converter generates the 3.3V or 5V required by the micro-controller and output circuitry. Inverter failure occurs at approximately 0.9V, with a pre-programmed signal output change to indicate a low battery voltage condition initiated at 1.25V. The DC-DC converter therefore extracts the full capacity of the battery and ensures the output source level, approximately 145dB re 1μPa at 1m, remains constant throughout the operating life. Once encapsulated these devices wake from *sleep-mode* at regular intervals too capacitively test for immersion in the sea. Two *beacon-mode* deterrents have now been operating continuously under laboratory test condition for seven months in order to evaluate their actual battery life. (Figure 4. shows the battery discharge plot for both devices). The *pseudo-random* pinger calculates its inter-pulse period between each output emission, this takes processing power and prevents full energy saving features of the device to be implemented as a result this unit eventually stopped transmitting after 210 days. The regular output device exploits the *sleep* feature that stops the external crystal clock and reduces current consumption to less than 2% of the active current between pings. An internal watchdog timer (WDT) is pre-scaled to *wake* the device from the *sleep* condition after the pre-programmed time has expired. The battery life plot for this device suggests that this design may be expected to fail after about 350 days continuous operation.

5. FIELD STUDY

The first successful field tests with wild harbour porpoises *(Phocoena phocoena)* took place in calm conditions in a quiet Scottish sea loch in September 1996, Mayo [9], Goodson [10]. After five days of observing the behaviour and general swim patterns within the loch, a small bay that was regularly attended by these animals was chosen for the pinger test. Figure 1 shows the spectrum of one of the two *beacon mode* sounds used in this study – a frequency modulated 'sweep' lasting approximately 300ms extending from 20kHz to 160kHz. Theodolite tracking data shows that upon activation of three pingers distributed across the mouth of the bay, the porpoises immediately turned back onto a reciprocal course and, after meeting the 10 m depth contour, they continued move away following the shoreline of the bay. Throughout the duration of this 30-minute duration test, the porpoises maintained a minimum displacement of 640m from these sound sources. At this range the Sound Pressure Level (SPL) has fallen significantly and the local sound level experienced by these animals were probably less than 88dB re 1μPa, Goodson [10]. As this SPL represents an *aversive threshold* to these specific signals, it is now possible to plan for a minimum distribution of devices along a fishing nets however the selected spacing must include sufficient overlap between devices to accommodate a single unit failure as otherwise such a situation would create an *acoustic hole* in the net which might function to attract a porpoise.

6. CONCLUSION

The new generations of digital acoustic deterrent devices were designed to overcome several problems recognised in earlier studies. These include the need to maximise battery life, achieve an optimum displacement effect on harbour porpoises and to minimise the habituation rate. The target species is the harbour porpoise and the intended application currently limited to commercial bottom-set gillnets. A large-scale field study in such a commercial fishery is currently in operation to evaluate the effectiveness of the *beacon mode pseudo-random* devices. Although too early to predict benefits in other cetacean bycatch situations, the digital micro-controller technology of this design allows considerable flexibility. In the future different signal characteristics may be needed to deter other species and it is anticipated that these can be synthesised by simply upgrading the software to be preloaded when the devices are assembled. Such modifications can be tested relatively easily without requiring costly changes to the hardware design. Alternative non-fishery applications can also be considered for both *interactive* and *beacon-mode* pingers, including acoustic alarms for attachment to hazardous deck cargo; acoustic marking of underwater objects etc.

7. ACKNOWLEDGEMENTS

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9. FIGURES

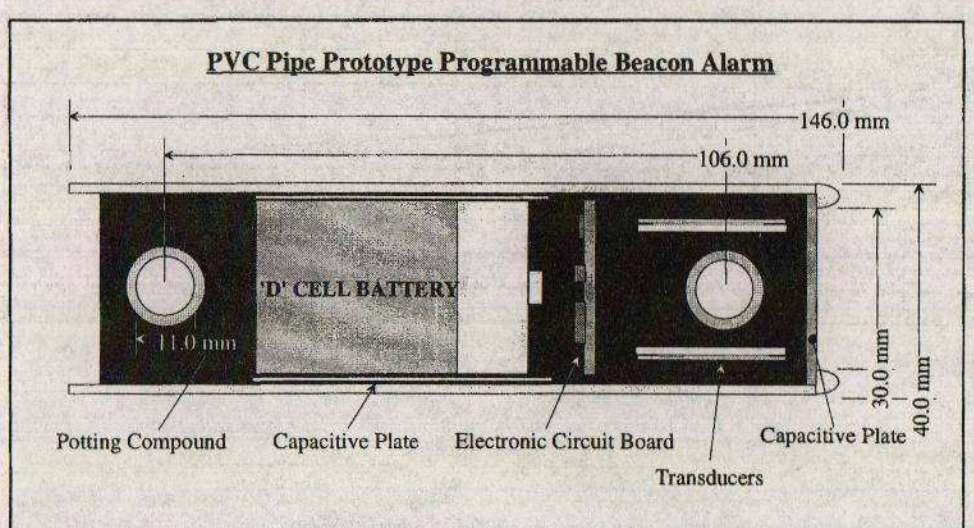

Figure 2. PVC pipe Beacon Alarm design

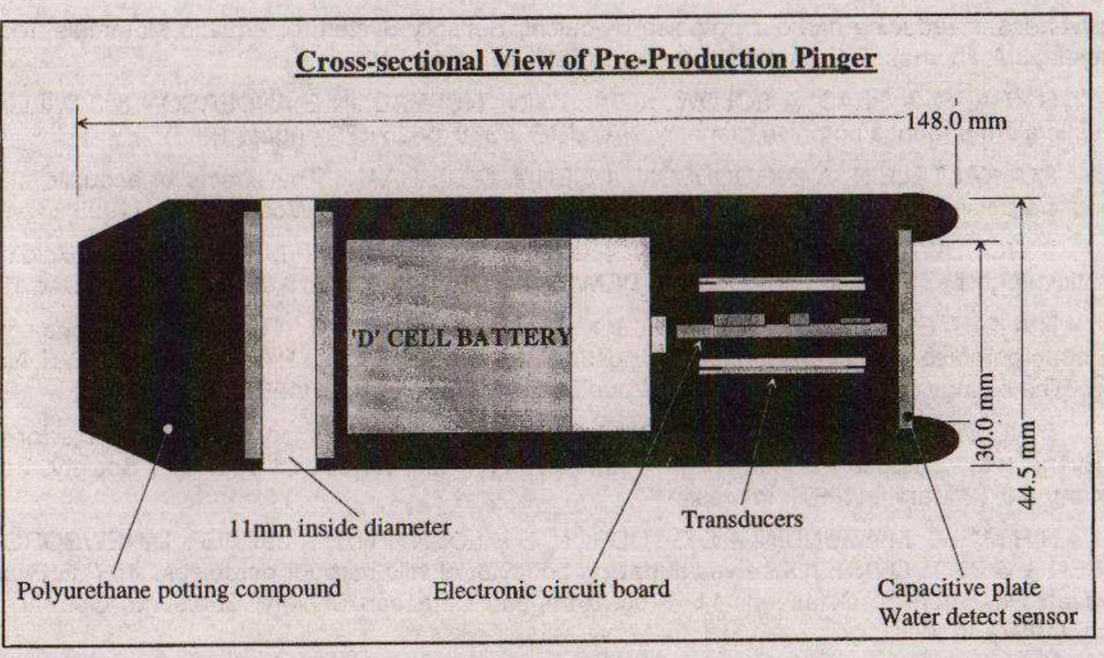

Figure 3. Pre-Production Beacon–Mode Alarm design

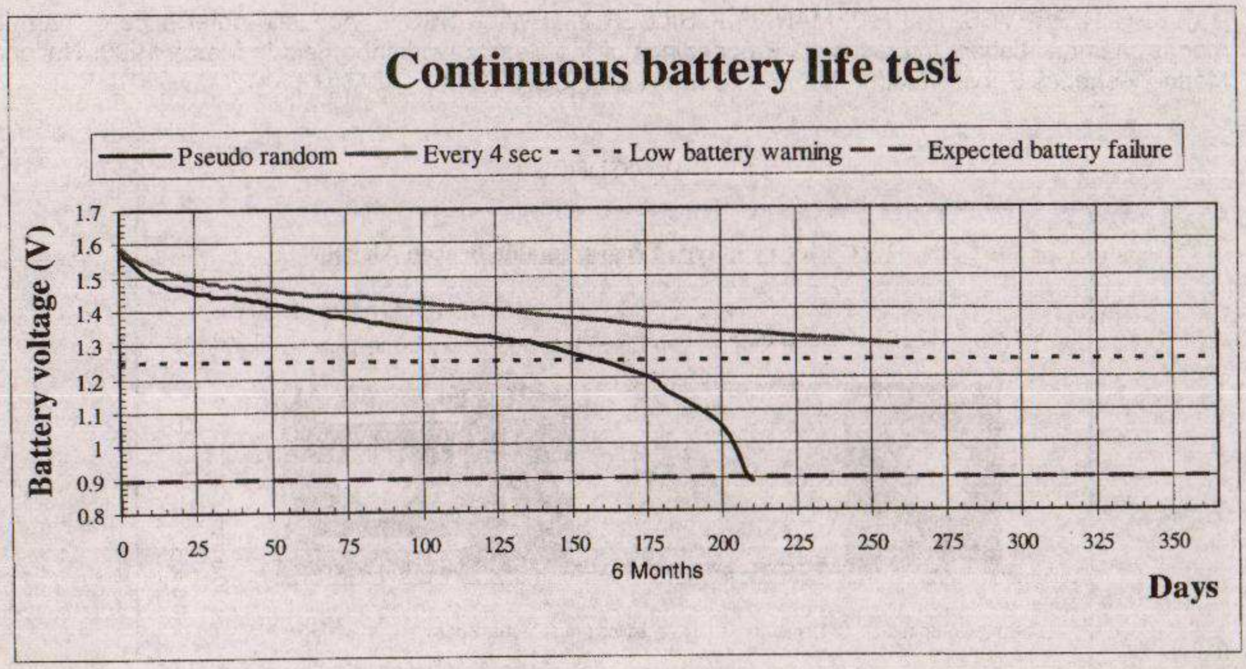

Figure 4. Battery discharge/life plots of the Loughborough University pingers

Figure 5. Computer Aided Manufacture (CAM) of the electronic circuit board