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SOME BRITISH SONAR TRANSDUCERS OF THE 1950'S

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INTRODUCTION

During the early part of the 1950's, sonar transducer technology in the UK underwent a rapid change, when the first ferroelectric ceramic, barium titanate, became available from commercial suppliers in production quantities. For a few years, four distinct types of active material were in use, each with their own technology; these were quartz, water soluble crystals (ADP, Lithium Sulphase etc.) magnetostrictives and barium titanate. By the middle of the decade, quartz and ADP were obsolescent and most British transducers used barium titanate or magnetostrictives.

From the earliest days of sonar until the 1960's, the development and manufacture of transducers for the Royal Navy was carried out in Admiralty research laboratories and factories, with very little participation from Industry and therefore the transducers described in this Paper are of Admiralty origin.

QUARTZ TRANSDUCERS

The quartz transducer was the main type used in Royal Navy sonars from about 1920, following the pioneering work of Langevin in France during the First World War. After steady development, the multi-layer quartz-steel sandwich was evolved, first as two-ply and by the mid 1930's as a four-ply device. This had reproducible characteristics even in relatively large scale manufacture under wartime conditions and it was used for active sonars through the Second World War and on into the early 1950's. Two main types of quartz-steel transducer were made, the long strip type for fan-shaped beams and the circular type for searchlight beams; the latter will be described.

From the very beginning the dimensions of the circular quartz transducer were standardised, the radiating face diameter was fixed at 15 inches (38 cm) for most sonars and all the transducers were mounted in identical watertight cases. Resonant frequencies were arranged in 1 kHz steps from 10 to 26 kHz to avoid mutual interferance. The construction of these transducers is shown in Figure 1.

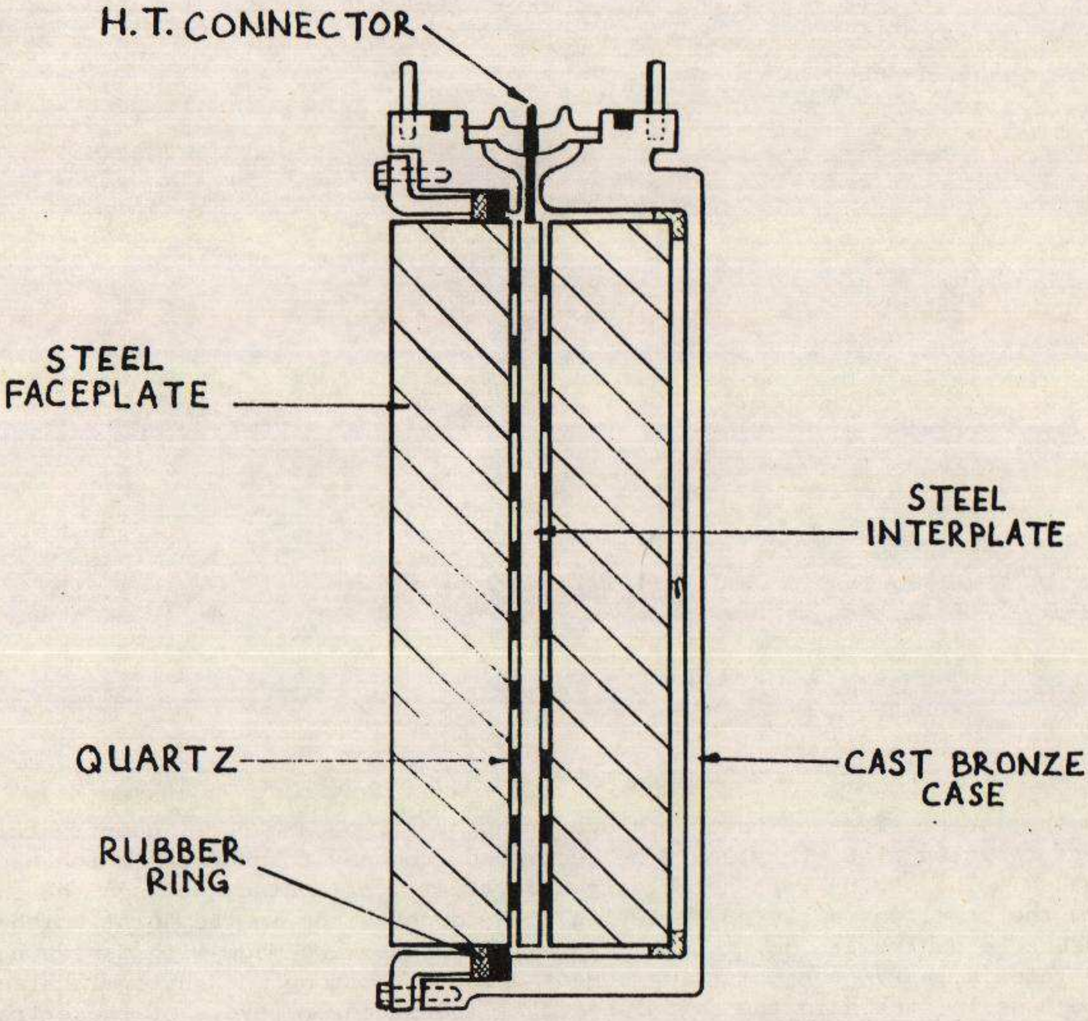

Figure 1 Quartz Steel Transducer

Two layers of quartz were sandwiched between heavy steel plates, the desired resonant frequency was obtained by varying the thickness of the plates. Each layer of quartz consisted of 10 strips 1/2 in (12 mm) wide, 1/8 in (3.2 mm) thick. The strips were cut from natural quartz crystals and as can be seen in Figure 2, the diamond saw blades then available were so wide that a lot of quartz was wasted and it was also a very slow process. The cut slice shown exhibits an effect known as "twinning", with domains of opposite polarity, and some with zero piezoelectric activity. This limited the amount of useful material obtained from the crystals.

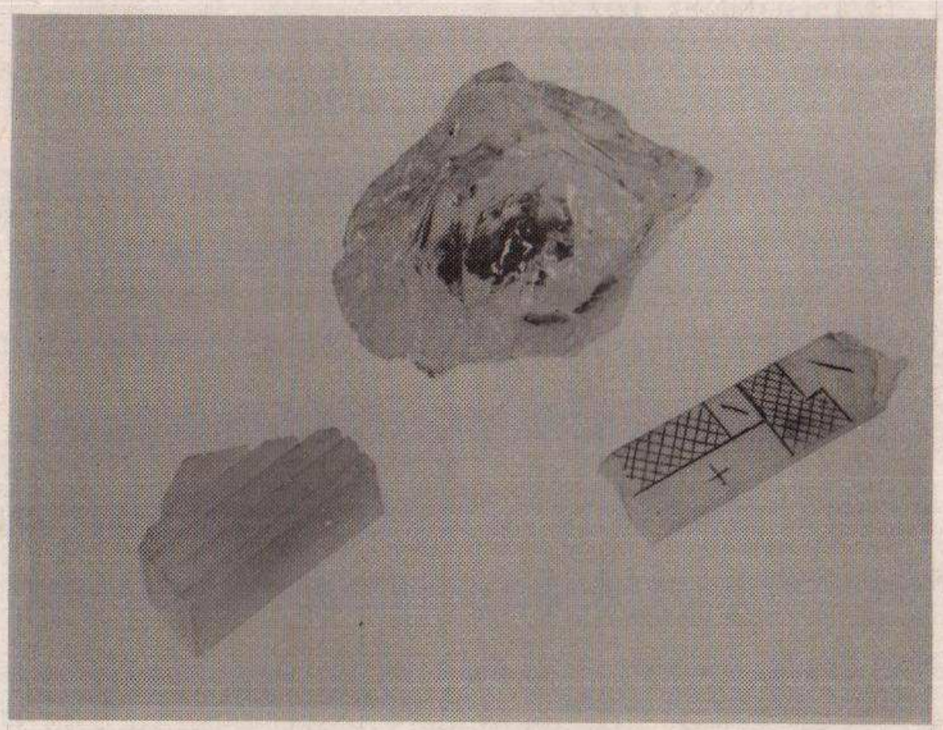

Figure 2 Quartz Crystals

As the larger sizes of naturally occurring quartz became rare, quartz strips were recycled since they could be recovered from any transducers which had leaked. The strips were not electroded, electrical contact between the quartz and the steel was achieved by laying thin copper wires in the joint which also ensured a controlled joint thickness. The joints were made with Canada balsam or later with PVA thermosetting cement which was strong enough to withstand the tensile stress in the sandwich at the modest power levels of these transducers. A robust gunmetal casting housed the element assembly with a square section rubber seal ring under compression between the steel faceplate and the body, see Figure 1. The performance of a 15 kHz unit is shown below, notable is the "Q" of 25, high by todays standards.

Table 1. Quartz transducer characteristics

Resonant frequency	15.0 kilohertz
Qm	25
Admittance at Fr	5.3 + j138 micromho
LF capacitance	1500 picofarad
Proj sensitivity	141 dB re 1 micropascal/volt @ resonance
Efficiency	50% @ resonance
Max input power	25 watt
Active area	1134 sq centimetre
Weight in air	150 kilogram

Transmit levels of 2000 volts RMS were used at resonance, which required a special high quality coaxial cable and the maintenance of good insulation resistance in the transducer. Well damped pulse trains were ensured by driving from an amplifier with a low (about 50 + J1600 ohm) source impedance. The low frequency capacitance of the transducer was about 1500 pF. The electroacoustic efficiency of the transducer was about 50% at 10 kHz, though this fell to nearer 35% for the high frequency versions.

ADP TRANSDUCERS

The limited supply of large naturally occurring quartz crystals led to the search for alternatives and by the end of World War 2, Ammonium Dihydrogen Phosphate (ADP) crystals were being grown in the UK in small quantities and a new generation of transducers was under development. This work was much more advanced in the USA than in this country and no major sonars were fully developed here using ADP technology because Barium Titanate soon became available. However some ADP transducers made at that time are still used today as acoustic calibration standards and one of these will be described.

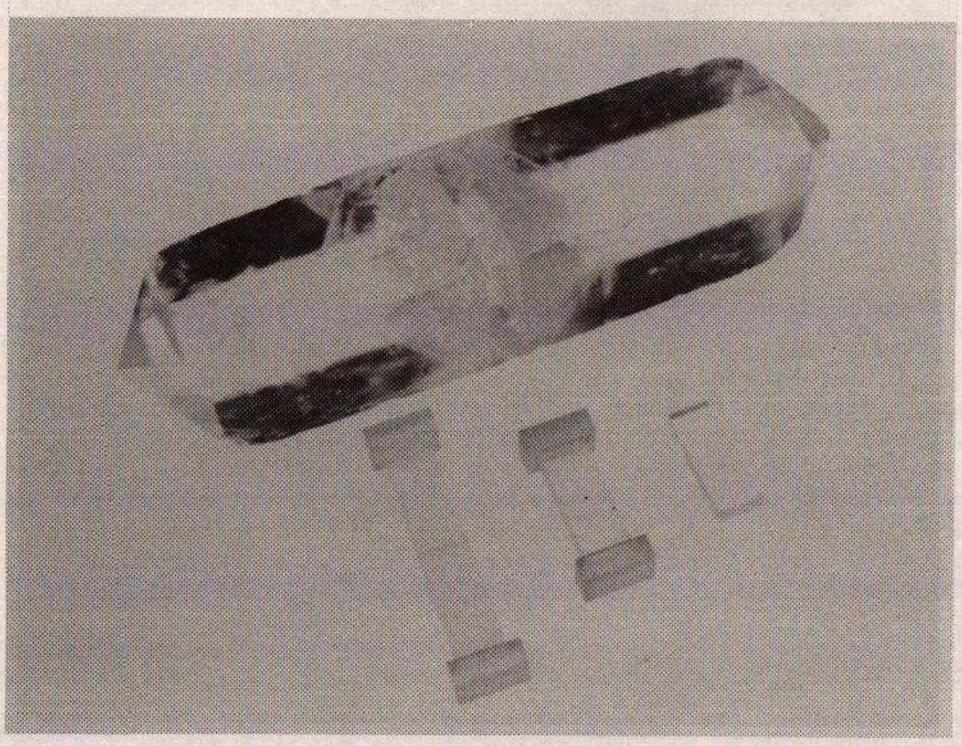

Figure 3 ADP Crystals

Shown above is a single ADP crystal and the sort of blocks which could be cut from it. Nickel electrodes were applied to the blocks which were then assembled into an array of the desired size. The length mode resonance of these crystals was 50 kHz and also shown are some other crystal configurations developed for lower frequencies. The single block with glass heads resonates at 22 kHz and the double block assembly at 16 kHz. Closed cell sponge rubber was inserted between and behind the crystals to separate them and reduce unwanted radiation. Figure 4 shows the completely assembled array of blocks for a 50 kHz transducer.

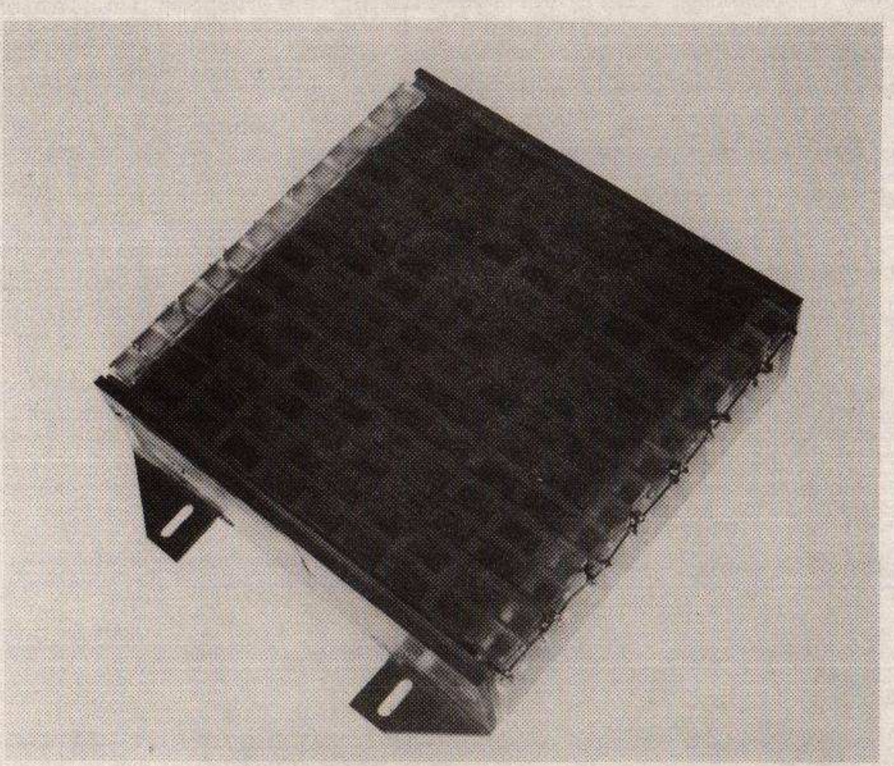

Figure 4 ADP Transducer Element

Because ADP crystals are water soluble, the whole assembly was enclosed in a castor oil filled bronze body with a rho-c rubber window. As with quartz, high voltage drive was required, up to 1500 volts away from resonance. The acoustic performance of a 50 kHz standard is shown in Table 2 below. This type of transducer has proved to be very reliable and shows stable characteristics over a long time, hence the use as a calibration standard; some of the elements assembled in the 1950's are still extant, having had a number of oil and rubber window replacements, but still using the same crystals. ADP has applications other than in sonar transducers and is still available commercially.

Table 2. ADP transducer characteristics

Resonant frequency	50 kilohertz
Qm	13
Admittance at Fr	213 + j931 micromho
LF capacitance	2700 picofarad
Projector sensitivity	153 dB re 1 micropascal/volt @ resonance
Efficiency	35%
Max input power	5 watts
Active area	169 sq centimetre
Weight in air	30 kilogram

MAGNETOSTRICTIVE TRANSDUCERS

The development of magnetostrictive transducers as an alternative to quartz was being actively pursued in the 1930's in the UK and some designs for echo-sounders became operational. However this work was almost stopped during World War 2 because the well-proven 15 inch quartz transducers were adequate for the searchlight beam sonars then in use and only limited effort was available for new developments. A new generation of high power, lower frequency sonars were being developed in the 1950's; this renewed interest in magnetostrictives and several successful magnetostrictive arrays reached production in the UK and saw service in the Fleet.

Figure 5 shows an array developed in 1951; it is approximately 1.2m square, weighed 2 tons and operated at 6,7.5 or 9 kHz. The array was assembled from 30 separate transducers in a 5 high by 6 wide arrangement, mounted in a large bronze casting. Each transducer had four nickel stacks with permanent magnets for bias and with a signal winding for each pair of stacks, so that the array could be configured as 12 vertical strips for beam forming.

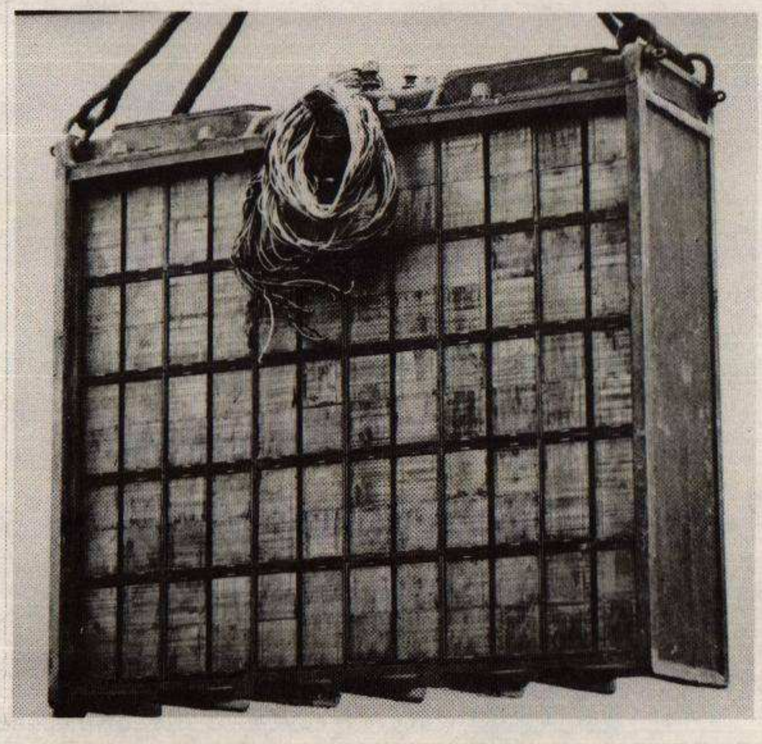

Figure 5 Magnetostrictive Transducer Array

Each assembly of four stacks was separately housed in a SRBF (Synthetic resin bonded fabric) reinforced plastic box. The nickel laminations were stamped from sheet metal and annealed in a nitrogen atmosphere before being consolidated in a jig using epoxy resin. A consolidated stack is shown below. Pressure release rubber pads (not shown below) were glued behind the stack heads to reduce back radiation and reduction of the source level. This type of transducer was easy to manufacture and the transducers were reliable and fairly rugged. The electroacoustic performance is shown in Table 3, for a single transducer. The low efficiency and the escalating cost of nickel eventually made these transducers uncompetitive in comparison with ceramic types.

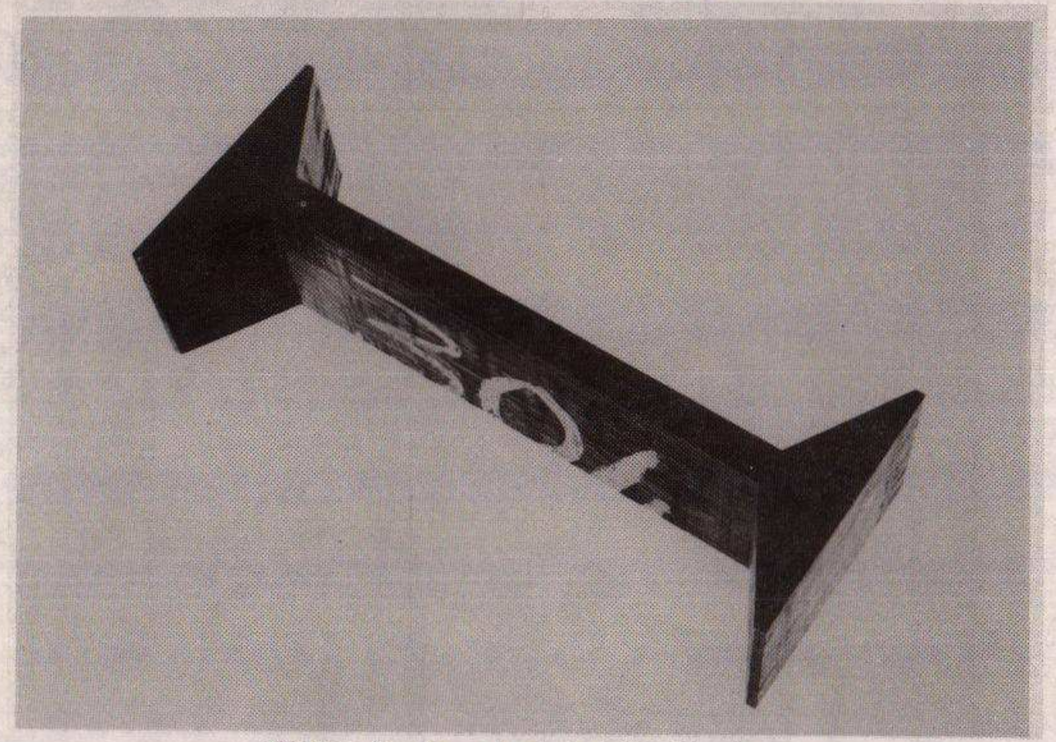

Figure 6 Magnetostrictive Stack

Table 3. M/S transducer characteristics

Resonant frequency	7.5 kilohertz
Impedance at res.	5 + j20 ohm
Proj sensitivity	190 dB re 1 micropascal/amp @ res.
Efficiency	30%
Max input power	1000 watt
Active area	339 sq centimetre
Weight in air	23 kilogram

CERAMIC TRANSDUCERS

At first, relatively small discs of barium titanate were available and this limited the possible types of transducer construction. There was also a tendency at first to use barium titanate merely as a direct replacement for quartz and so some ceramic-steel sandwich constructions were devised. It was soon realised that the new material offered much more scope than this and the designs began to depart noticeably from previous practice. One type of construction became dominant because of the ease of assembly and its predictable performance. The transducer to be described is an early version of the 'tonpilz' or mass-spring element, dating from 1952. Shown in Figure 7 is a barium titanate ceramic-aluminium sandwich with tapered head and tail masses with its watertight case.

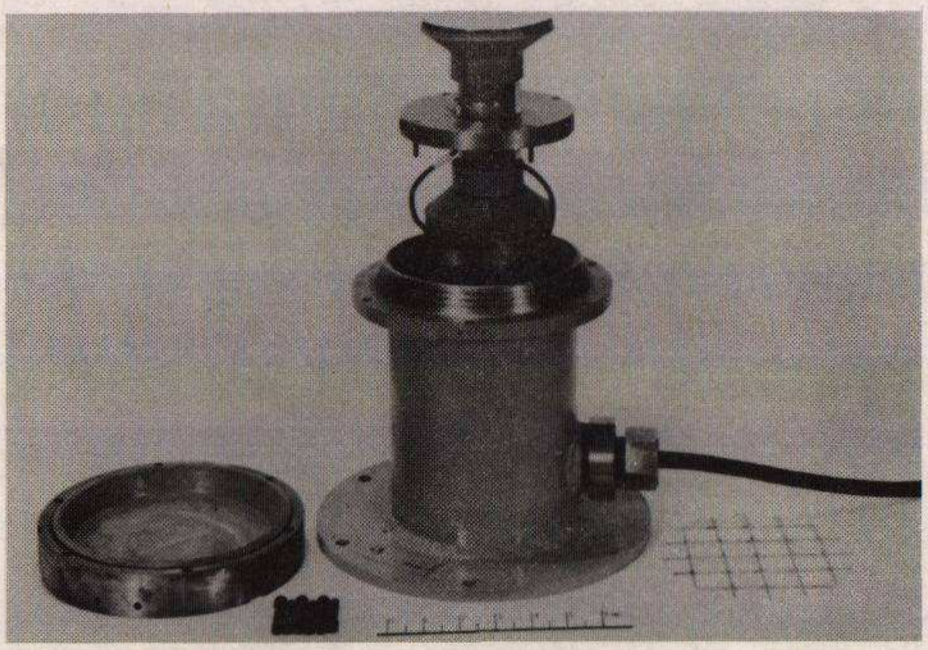

Figure 7 Ceramic Stack Transducer

The sandwich elements were cemented together with Araldite D adhesive and a layer of expanded copper was included in each joint to control its thickness. Because there was no stress rod, joint failures were a recurrent problem. The undesirable radiation from the back of the head and from the tail was suppressed by the closed cell rubber pads and so the transducer was depth limited. The design shows an early type of nodal plate mounting which reduced the coupling to the case. The transducer case was oil filled and the rubber window in front of the head was sealed by clamping it against a ribbed tapered part of the case. The transducer characteristics are shown in Table 4. The aluminium interplates in this experimental design were soon discarded and transducer stacks assumed a style recognisably similar to present day designs, with a stress bolt and an air-filled case.

Table 4. Ceramic transducer characteristics

Res frequency	9.5 kilohertz
Qm	3
Admittance at res.	51.6 + j410 micromho
LF capacitance	4000 pF
Projector sensitivity	135 dB re 1 micropascal/volt @ res.
Efficiency	60%
Max input power	40 watts
Active area	182 sq centimetre
Weight in air	27 kilogram

CONCLUSION

In the early 1950's the transducer designer could choose between several active materials, with significantly different properties resulting in a variety of technologies being developed. The intervening years since then have been dominated by the piezoelectric ceramics in the 'Tonpilz' construction. Once again several technologies are available, for example, PVDF, Fibre-optical sensors, Rare-earth magnetostrictives and Ceramic-elastomer composites. The material selected will depend upon the increasingly demanding requirements of the sonar system, for example, totally different technologies may be used in the same sonar for the transmit and receive arrays. It is probable that ceramics will eventually lose their position as the most used material for sonar transducers, though much remains to be done in the practical application of the newer materials before this happens.