8 Making and performing simple electroacoustic instruments

HUGH DAVIES

Historically almost by accident, the principal development of electronic music so far has been inextricably linked with the storage of sounds on magnetic tape. If the pressure of wartime scientific research in Germany had not hastened the final stages of improvement of magnetic tape and tape recorders in the early 1940s, it is possible that the experimentation in early electronic music and *musique concrète* which was under way in several countries less than ten years later might have led to methods of producing these sounds directly in concert performance.

Breakthrough to commercial viability is not, however, necessarily the final technological leap forward. For example, it is expected that digital tape recorders will be widely available at compatible prices by the mid-1980s, with very considerable improvements in recording quality compared with present standards. Yet it is interesting to note that, until the development of the telephone and the phonograph in consecutive years during the 1870s, audio and optical communications devices were *primarily* digital (such as those that used the Morse code) up to and including the misfunctioning prototype *Harmonic Telegraph* (Bell) and the speeded-up replay of the *Telegraph Repeater* (Edison) that stimulated these two inventors into their breakthroughs which ushered in a century of *analogue* devices.

If we look at the musical precursors of electronic music as we have come to know it, two of the four main areas of experimentation were concerned with recording (manipulated or retrograde gramophone records and hand-drawn or retrograde film soundtracks) and two with live performance (electric musical instruments and mechanical or electromechanical noise machines). The most significant compositions in this period up to 1948 that primarily feature such equipment (apart from the use of electric instruments, such as the ondes Martenot, as one element in works for large conventional forces, by Varèse and Messiaen for example) are a series of *Imaginary Landscapes* composed by John Cage between 1939 and 1942. These three pieces formed one aspect of Cage's current explorations of unusual percussion instruments (including the prepared piano of 1938) and use, among other things, a contact microphone, a gramophone cartridge to amplify a coil of wire, oscillators and oscillator tones recorded on discs which are manipulated by hand; the whole designed to be recorded live in a radio studio, but easily performable live in a concert once such equipment, together with reasonably portable amplifiers and loudspeakers, became generally accessible during the 1950s.

Without wishing to deny the value of tape in electronic music, I should like to suggest (and have done so for several years) that it is likely that live performance with electronic music apparatus will become the principal method of presentation, with tape reserved for certain more complex operations that cannot be carried out in real time. The relationship has existed throughout musical history in the West, the Middle East and the Far East: nearly all music has been performed live, with a few pieces specially composed for musical clocks, musical automata, mechanical (mainly keyboard) instruments and other antecedents of the musical box (for which Hassler, W. F. Bach, C. P. E. Bach, Handel, Haydn, Mozart, Beethoven, Stravinsky, Hindemith and Stockhausen - among many others - have composed works). The tensions that come into play during performance in front of an audience are an important part of the final musical result, and many performers find it hard to recreate the same feelings artificially for themselves when in a recording studio. Today the composer-performer is once again on the increase, after a decline during the last one and a half centuries, and thus 'live electronic music' is a quite natural development; many composers who were dedicated to working with tape during the 1950s - including such opposite poles as Cage and Stockhausen - became equally involved in live electronic music during the 1960s.

From the several areas of live electronic music, which include the use of devices such as filters and ring modulators to modify the sounds of voices or conventional instruments and performance on synthesisers, I shall limit myself here to electroacoustic instruments.

The processes of choosing the sound qualities that a composer wants are considerably restricted by the instruments or apparatus available. Often a composer is forced to limit these to the narrow range imposed by the instrumentation that he or she has selected or which has been externally defined by the terms of a commission; on other occasions the composer may hear music in his or her head and will search to find the most suitable instrumentation for it. If the latter is not possible with traditional instruments recourse may have to be made to the electronic music studio. In a small studio the equipment required may be its complete installations; in a very large studio it will be only a small proportion of it. A notable example of the latter is Stockhausen's 35-minute-long *Kontakte*, which only employed thirteen devices (plus five tape recorders), but with great technical ingenuity and expertise, to produce an enormous range of sounds.

Thus the basic way in which a composer works until he or she is as familiar with the possibilities of a particular electronic music studio as with those of an orchestra (a knowledge that is largely assimilated unconsciously in the course of day-to-day experience of music over many years, starting in childhood) is very much trial and error, exploring sounds and sound combinations that he or she likes. Exactly the same process applies to inventing new musical instruments, acoustic as well as electroacoustic. The inventor accumulates experience in assessing the suitability of cetain materials and the unsuitability of others, in knowing which type of microphone will be the most appropriate, and even why one microphone is much better

in the instrument in question than one which is apparently very similar. I have sometimes found that a microphone or sound object that I have bought in the hope that it will be particularly effective initially turns out not to be so, but at a later date proves to be ideal for something else; thus the instrument that has the most extensive range of sound possibilities of all those that I have made was built in a single day as a result of 'giving another chance' to a type of microphone that I had bought as second-best because the shop in question was out of stock of the type I was really looking for.

All this is rationalisation after the event. My own development has been briefly as follows. After limited experience both of small tape studios and of live transformation of instrumental sounds, I started to assemble my own private studio with limited funds, and expanded my very small range of sound materials by amplifying everyday items (such as combs, small springs, broken light bulbs etc.) with contact microphones. A year later, in the summer of 1968, I produced what I soon recognised as my first self-contained amplified instrument. With this clarification of my activity (paralleled by concert performances involving amplified objects and electronic transformation of sounds played by live performers) I was able to progress as an instrument inventor, trying out a wider range of materials and microphones, and expanding my range of creations to include 'sound sculptures' for exhibitions and - unamplified - sound toys. An additional strong influence in this expansion, and in increasing my self-confidence in the visual aspects, has been my collaboration from time to time since 1969 with the artist John Furnival. Everything that follows is based on my own experience or on direct observation of the experiences of friends and colleagues. Although mine has been an exploratory, unplanned development, over the years most of the gaps have been filled in.

As an inventor of electroacoustic instruments I have been told on a number of occasions by electronic composers that they had worked for several hours in an electronic music studio to produce a particular sound that was very similar to one that I had just played on one of my instruments. (A simple example: slowly pulling one's finger over the bristles of an amplified toothbrush, or pulling a toothbrush in a similar way across an instrument amplified by a contact microphone, can resemble filtered white noise!) Such instruments need not only be used in concert performance, of course; several electronic composers have used a selection of 'my' sounds in tape compositions, and on a couple of occasions when I myself have worked with tape I have done the same.

This chapter will consist of a discussion of the various types of microphones that can be used, notes on some of the materials that are effective in instrument building and a more detailed description of four of the instruments that I have made.

Microphones

When I first set out to write this chapter, it only gradually dawned on me that no

single microphone that I have ever used in any of my electroacoustic instruments is now commercially available in Britain. Models have been discontinued, manufacturers have gone out of business, and shops selling old-fashioned electrical bits and pieces have been replaced by shops specialising in microcomputers and pocket digital calculators or in disco equipment. In only ten years everything in the electronics world has changed.

In my original chapter, half finished, I took most of the space to describe the various microphones that had been so easy to obtain in London when I first began constructing instruments. This became far too complicated for a book of this nature. I have therefore considerably reduced the section devoted to microphones, in the expectation that anyone who wishes actually to build their own microphones will either already know more or less how to go about doing so, or realise the necessity of collaborating with someone who has the necessary technical background. I have given some hints on how to start, but few precise details. Each person experimenting with amplified sounds will have different aims and ideas, will try out different materials and would assemble a range of microphones different from my own even if all those that I have been able to choose from were still available. There are still a few relatively cheap microphones on the market under such names as 'lapel microphone' which, in the right hands, could probably produce excellent results, although the choice is considerably smaller than it was at the end of the 1960s. Anyone coming across any of the older types shouldn't hesitate to buy them on the off-chance that they might turn out to be ideal!

An electroacoustic instrument is one which relates, not necessarily in any immediately obvious manner, to one or more traditional instruments with the addition of a special microphone. In the context of this chapter it is further defined as an instrument that is virtually inaudible, at least in a concert, without the use of this microphone and an associated amplification system. The best known electroacoustic instrument is the electric guitar, invented in the middle 1930s, shortly after the less successful electroacoustic violins, cellos and pianos were built. Typically, the microphone is installed as a permanent part of the instrument in a position where the most faithful equivalent of the instrument's acoustic ancestor is achieved. The use of similar special microphones as alternatives to the normal 'air' microphones, merely to amplify a traditional instrument, concerns us here only insofar as such microphones serve for comparisons.

When inventing completely new electroacoustic instruments, fidelity to a known sound is less relevant. One must make one's own decision, relying on musical judgement, as to what the ideal sound of each instrument is to be. I usually either build the microphone permanently into the instrument, or provide a single position where the microphone is always fixed. Occasionally - mostly with magnetic microphones - I find that I wish to have a freer relationship between the microphone and the vibrating, sound-producing object. Sometimes an additional factor is the need to be able to pack the instrument away for transportation, which with fragile materials and certain kinds of contact microphones is best done by dismantling at least part

of the instrument (ten of the instruments that I use most frequently in concerts pack away in a single cardboard box which measures only 27 x 27 x 14 cm). Since an electroacoustic instrument has no 'real' sound apart from what is heard over the loudspeaker (and this is likely to vary with different amplification systems and rooms even more than is the case with conventional instruments), the inventor may choose to exploit what would normally be considered as distortion or an uneven frequency response in order to focus on more unusual sound qualities.

Two main kinds of microphone are used: contact microphones and magnetic pick-ups. The former include a variety of commercial and home-made devices, such as 'normal' contact microphones, record cartridges, strain gauges, accelerometers, stethoscope microphones, throat microphones and microphone or hearing aid inserts; the latter are found on electric guitars, in certain old telephones, some military and industrial microphones and headphones and a few brands of cheaper hi-fi headphones.

Contact microphones

These function by being in direct physical contact with the object which is to be amplified, and are not sensitive to air vibrations unless these are so strong as to cause the microphone's container to vibrate, such as by speaking or blowing with one's mouth only a couple of centimetres away. Most types of contact microphone are rather fragile, and so particular care should be taken not to drop them or even to submit them to direct vibrations of too strong a nature, such as those of percussion instruments. The most useful contact microphones for our purposes are usually based on a piezoelectric ceramic crystal (these are the fragile types); a few use magnetic or other principles.

Until 1975 a cheap Japanese contact microphone, known variously as 'guitar' or 'harmonica' microphone, was widely available, but its importer at the time, Tandy Corporation (Radio Shack), withdrew it from their 1976 catalogue. It is possible that it will reappear again one day, since in the past it was unavailable for a long period on a couple of occasions, although never for such a long period as the current one. Another type of contact microphone that I have in the past found in Germany, Merula, may still be available, though it is several years since I have tried to buy one there; it costs about the same as the Japanese one but is of a higher quality, excellent for amplifying traditional stringed instruments, for which the Japanese microphones are inadequate. However, I have only used a Merula microphone for one of my invented instruments, which resembles an amplified fretted cello. Another potential source of contact microphones is in pop music stores, although their prices tend to be excessive.

The kinds of contact microphone that are comparatively easy to obtain are much more expensive - those made by firms such as FRAP and Barcus-Berry. These are specifically designed for individual instruments: guitars, other strings, woodwind, brass, piano and percussion. Perhaps the advent of these much higher-quality contact microphones was the cause of the demise of the cheap Japanese model, since

they are ideal for a performer who is likely to buy just one such microphone during his or her working life.

Record cartridges were first used for electroacoustic sounds in *March* (*Imaginary Landscape No. 2*) by John Cage in 1942, and were later largely featured by him in *Cartridge Music* (1960), one of the earliest live-electronic compositions. In this latter work small items such as lengths of wire, matchsticks, hairpins and pipe-cleaners were inserted into the hole intended for the needle (so big in those days that one can hardly call it a stylus). Modern cartridges, designed for increasingly smaller styli, cannot be used in this way; the older the better, with the early 1960s being the time when cartridges ceased to be suitable for our purposes (mono only!). To use a cartridge as a permanent microphone in an electroacoustic instrument, one feature is of prime importance: a fixing screw set at 90°, or a slightly smaller angle, to the shaft of the needle and designed to hold it tightly in place. This is essential if a string is to be inserted into the cartridge, as on several of my instruments.

As can be expected, record cartridges have an excellent frequency response. I have used them mostly with metal strings (such as those on sale for electric guitars), one end of which is fixed into the cartridge with the fixing screw. Most other contact microphones must be fastened on to the vibrating object, or on to the surface to which this vibrating object is also fixed a short distance away. This is particularly important where the vibrations are very strong and sharp, which will tend to cause distortion of the sound when the microphone directly touches the object, and percussion instruments such as gongs, tam-tams and cymbals could even damage a crystal contact microphone unless some damping material is inserted between them, or the microphone is attached to part of the instrument's stand. If the microphone has some sort of clip, this can often be used; otherwise there is a wide choice of methods that include bolts, screws, wing-nuts, insulating or masking tape, rubber bands, springs and beeswax (this latter is often used for accelerometers and the single-instrument special contact microphones). It is always unwise to use glue: it may hinder the microphone from vibrating freely, and it makes any repair or adjustment of position difficult without damaging the microphone or the instrument.

The frequency responses of other contact microphones vary considerably. Excellent are accelerometers (obtainable from scientific instrument suppliers) and the single-instrument microphones as well as the more expensive general-purpose contact microphones such as the Merula; less good are the Japanese ones, microphones and hearing aid inserts and throat microphones, while stethoscope microphones have an especially strong low bass response. There is, however, a second factor that must be considered in conjunction with frequency response, and that is sensitivity. When dealing with smaller and more delicate vibrations than is the case when amplifiying traditional instruments, many of the best quality contact microphones turn out to be ineffective, because the volume level is too low. Here the Japanese microphones have considerable advantages, in addition to their low cost. I have used well over one hundred of them in twelve years, which apart from anything

else would have been impossibly expensive with better quality microphones. Their frequency response is adequate, particularly when there is no known original with which to compare the loudspeaker sound. I have always made my electroacoustic instruments in terms of the sound given by the microphones, using the microphones right from the start of the experimentation which is to result in an instrument rather than adding them at the last minute. When, out of interest, I have subsequently tried a Merula contact microphone on an instrument incorporating a Japanese one, the qualities for which I made the instrument have largely vanished - exactly the reverse of the procedure that would take place when comparing these two microphones' effect when used with, say, a violin.

In certain contexts one may want to amplify a large resonant object. Apart from the need, already discussed, to damp the vibrations when using a sensitive crystal contact microphone (which would not be the case, for example, with a Barcus-Berry or FRAP percussion microphone), excellent results can be achieved by using two or more different contact microphones of medium or poor frequency response. Each will give a very different version of the spectrum of the sound, and these can be selected individually or variously combined by employing a mixer channel for each microphone. Similarly, two identical microphones can be placed at different points on an instrument, or fixed or damped differently.

I have never used a throat microphone myself in any way apart from amplifying throat sounds, but I have heard them used effectively as contact microphones on a couple of occasions. It is usually necessary to replace the military or Post Office cable with screened audio cable. Of the other kinds of contact microphones mentioned above, a few comments can be added on each. Accelerometers are extremely expensive precision transducers used in laboratories for testing stresses in materials; I have seen one that had been made up much more cheaply in a university physics department, which worked well as a contact microphone. Strain gauges are used in a similar manner; they are inexpensive and make good general-purpose contact microphones.

The function of stethoscope microphones is self-explanatory; unfortunately the firm which manufactured the ones I have used no longer exists. Doubtless one could discover other brands through catalogues of medical equipment suppliers. Presumably the hearing aid inserts that I bought several years ago are now also unobtainable or obsolete; their size was 12 x 18 mm (some a bit smaller), mostly with very tiny bumps of solder to which a cable had to be wired. Around these inserts I wrapped foam rubber, like a sandwich, with the inside faces covered in glue (in this one instance, if repairs are needed, it is likely to be the foam rubber that gets damaged in dismantling the assembly, and this is easily and cheaply replaced). This reduced their functioning as air microphones and made them into fairly sensitive contact microphones with a frequency response largely restricted to a medium pitch range. I have found them useful in a few contexts. Conventional microphone inserts could also be tried out.

The next problem with contact microphones is their preamplification. Those

based on piezoelectric crystals are extremely high in impedance (from about 1 megohm upwards), but do not function satisfactorily with most high impedance microphone preamplifiers in mixers and tape recorders, as the output signal is too weak. The only easy solution is to use a low impedance microphone input (about the only instance where a high impedance source connected to a low impedance input will not cause any damage), which gives a normal signal strength, comparable to that of air and magnetic microphones; nevertheless this mismatch will cause considerable clipping of the resulting sound spectrum. In the case of invented instruments this is, once again, of less importance. But when I first tried out instruments of mine, whose sound had been chosen in terms of what the Japanese microphone connected to a low impedance preamplifier gave, with a specially designed high impedance microphone preamplifier (as has recently been built for me, in the form of a mixer), an unexpected range of sound was added; more so with some instruments than with others. Once again, the firms that make the high-quality single instrument contact microphones usually also manufacture, at a price, suitable preamplifiers. Accelerometers are also likely to need special preamplifiers, and should *not* be mismatched into normal low or high impedance microphone preamplifiers.

The high-impedance microphone preamplifier was designed as part of a research project devoted to contact microphones that I undertook in Amsterdam at the end of 1977. I wished to be able to construct my own contact microphones, which would be less fragile than most commercial types, and whose qualities would lie between those of the Japanese ones (extremely sensitive but with poor frequency response) and the much more expensive ones for individual instruments (extremely good frequency response but not very sensitive). Clearly a gain in one aspect is likely to be at the expense of the other. The basis for these contact microphones is the piezoelectric ceramic crystal (PXE), which is quite cheap. Many different models of PXE are manufactured for a variety of purposes, including microphones, headphones and gramophone cartridges. Here are a few general points which may be helpful to anyone who intends to experiment with PXE. The microphone's container should be fairly sturdy, which is not as straightforward as it may sound because one does not have access to mass-production facilities or, usually, to metal casting or shaping equipment. The microscopically flexible nature of the crystal, and the direction or plane in which it bends, should be assisted by the way in which it is mounted, and it should be damped as little as possible by whatever is used to hold it in place. Deliberate distortion of the frequency response could be arrived at by changing the shape of the PXE crystals, which are circular, square or rectangular. Because excessive heat can destroy the nature of the crystal, the PXE should not be cut or sawn, but snapped or drilled ultrasonically. Similarly, if the output cable is to be soldered directly to the PXE, a low temperature soldering iron should be used.

Magnetic pick-ups

The variety of magnetic microphones is considerably less than that of contact

microphones. A magnetic pick-up basically consists of a bar magnet around which enamelled (insulated) copper wire has been tightly coiled a considerable number of turns. This is much easier to construct and experiment with in a school science laboratory than a PXE-based contact microphone. Two points only need to be mentioned here: in order to solder an audio lead to the two ends of the copper wire, the enamelling must be scraped or filed off the last centimetre of each end; and there appears to be no simple formula for calculating the number of turns the wire should be coiled around the magnet - first wind a small number of turns, such as 50, and measure the impedance, and then calculate the number of turns required for a specific impedance in a similar ratio. More information can be found in any book which describes in detail the construction of an electric guitar.

Just as different kinds of contact microphones are suitable for different types of vibrating object, so magnetic pick-ups also have a specific area in which they are most effective. Only metallic objects with sufficient iron content will affect the magnetic field and produce a sound; as with the electric guitar, it is not necessary for the object actually to touch the magnet - in some of my instruments they touch and in others they don't.

The most expensive kind of magnetic microphone, but still comparable to medium-priced contact microphones, is the type used in electric guitars. They are the easiest to obtain and can be found in most shops catering for pop music instruments. I have not found them very suitable for my own needs, preferring ones with a single larger, stronger magnet. (But Mauricio Kagel has used an expensive model very effectively for a giant 'harp' in his composition *Unter Strom.*) One may find such magnetic units serving either as microphones *or* as loudspeakers (since each exactly reverses the functioning of the other, there is a point - in telephone systems and related apparatus - where the two are interchangeable). The first magnetic pick-ups that I used came from ex-RAF microphones, which much later I discovered had been used in Spitfires during the Second World War! Subsequently, once the supply of these dried up, I turned to telephone handset *ear*pieces (I have used nearly 100 microphones from each source, plus around 50 from other sources such as the earpieces of headphones used by the military or by telephone operators). It should be stressed that magnetic earpieces were only used in certain models of the older black Bakelite telephones in Britain, and in none of the present-day models. All magnetic microphones and earpieces (with the exception of those made for electric guitars) can be identified by the thin metal 'diaphragm' disc that is placed above the magnet, visible once the protective cover has been unscrewed or otherwise removed. This diaphragm operates when air from the speaker's mouth causes it to vibrate. In an electroacoustic instrument it is replaced by whatever ferrous metal object is to produce the sound (a diaphragm can also be used to alter the sound of an instrument by inserting it between the magnet and this object, and displacing it with regard to the magnet). When the diaphragm is in place it is sufficiently sensitive for the microphone to function not only as an air microphone but also as a contact microphone - such as in throat microphones, which are basically magnetic pick-ups with diaphragms.

An interesting effect that can be obtained by displacing the diaphragm will be described later one.

Some of the magnetic microphones that I use are telephone earpieces that have been removed by undoing two or four bolts and then screwed on to a small piece of wood through the bolt-holes; others are completely dismantled until just the magnet and coils are isolated, and can then be screwed on to the wooden base of an instrument from underneath, facing upwards, set into a small hole that has been specially cut. Nearly all of these magnets are U-shaped, and it is economical and effective to use *each* of the ends of the U to pick the vibration of a single string, spring or similar item (seen in cross-section: Ü).

Even with the range of similar-seeming telephone earpieces there can be considerable differences in impedance: I regularly use ones that have the extremes of 8.2 ohms and 2 kilohms. For most purposes one should try to use magnetic pick-ups which have an impedance of around 100-600 ohms. Some preamplifier inputs designed for low-impedance microphones will not even 'see' an input that is less than about 5 ohms, and treat it like a short circuit. Above 600 ohms, because magnetic microphones produce a stronger voltage than most crystal microphones, they should be connected to a high-impedance microphone input. When more than two parallel strings or springs are used, more than a single pick-up will be necessary, which does not happen with a contact microphone (apart from special filtering effects). It is usually preferable to connect them in series rather than in parallel, which increases rather than reduces the impedance, unless a large number of pick-ups are involved.

When the magnet and coil are left in the original Bakelite holder, some units will be solid, with two small slits in the plastic where the tops of the magnet ends come through, while others will contain an empty space between the magnet and the rim of the holder. Both kinds are useful, although I usually dismantle the former. Many unusual effects can be obtained with the latter, as, for example, with a spring stretched across the holder, which will only be damped by the two opposite edges of the rim and by the magnet itself; in a fraction of a second it is possible to alternate between any of these three plus a combination of the magnet with either edge of the rim.

The different characteristics of fairly similar pick-ups (impedance and voltage) mean that a particular object may sound much better with one pick-up than with another (see p.154), so that a selection of these can be valuable for trying out the object one wishes to amplify. As with my earlier comment on combining different contact microphones for a single large instrument, so it is possible to combine several different magnetic microphones. One of my instruments uses five different models, covering a wide range of impedance; these are combined by means of a mixer and not simply wired in series or parallel.

Although I have been careful to try out different microphones before deciding on the most suitable one for each instrument, it is often possible to obtain interesting sound variants by using totally different microphones. In a recent collective improvisation I decided after one minute that I would only use a 'wrong' micro-

phone with each instrument from then until the end of the concert, and I was very surprised and pleased by the result.

Building electroacoustic instruments

Unlike other musical cultures, the tendency in Western music has been for instruments to become more neutral in sound. For example, the harpsichord was replaced by the piano, and the viol family by the violin family. These later instruments have to be able to cover a much wider range of musical styles and expression; a pianist can get away with playing music written for the harpsichord, but one cannot play genuine piano music from after the end of the eighteenth century on the harpsichord. Conversely because classical composers were, naturally, unable to compose for the new instruments that have come and continue to come into existence during the twentieth century, one can question the need to be able to play on them the kind of music written before they were invented. Should a new instrument be tuned to the tempered scale, or indeed to any predetermined scale? Few electronic tape compositions adhere rigidly to any scale, even if this is so far removed from the tempered system as to include no octave relationships. Today's new electroacoustic instruments should be used primarily for contemporary music, whether specially composed for those instruments, composed for unspecified instruments, or improvised. Because one is thus freed from the need to cater for a large chunk of musical history, it is possible once again in our music to obtain more unusual, rich and resonant sounds and to let future musicians make their own decisions as to whether or not they will use our new instruments; complex overtones can be stressed in a way that is much harder with traditional instruments, forms of impure note production (such as 'wolf notes') can be explored for their own inherent interest; sounds demanded by today's composers which previously were only available by treating traditional instruments in a way often contrary to their nature and possibly harmful (such as playing inside the piano or using the 'wrong' mouthpiece in the case of a wind instrument) turn out to be quite natural to electroacoustic instruments.

The advantage of using amplification with electroacoustic instruments is that one largely avoids the need for special resonators. The difference between the electric guitar and its acoustic predecessor clearly illustrates this: a solid block of wood, whose shape can vary quite substantially and is thus not crucial, replaces the carefully made hollow framework with which even slight changes can affect the sound detrimentally. A number of my own instruments are mounted on blockboard, a composite wood (somewhat similar to plywood) that is easily available and not too expensive. Little research needs to be done in trying out different woods, shapes or sizes or thicknesses for the resonator, taking into account its own resonant frequency and so on, because these are comparatively unimportant. Instead one needs to know a certain amount about the properties of this composite wood (which is made like a sandwich, with the grain of the two outer covers at right angles to the grain of the interior), about the vibrating objects which will make the sounds and about the

most suitable kinds of microphones. Another great advantage is the comparatively little extra work that is needed in order to obtain really low notes, compared with the substantial expense and sheer hard work that, for example, Harry Partch put into his bass instruments. With long springs it is quite easy to stretch them or tune them down so far that the fundamental disappears and one only hears the overtones, as also happens with the lowest pedal notes of a large organ or the additional major third added below the lowest A in the bass of a Bösendorfer grand piano; these, however, only go down to about 16 and 22 Hz respectively, whereas my lowest spring goes down to about 5 Hz.

On several occasions, without initially realising it, I have built into an electroacoustic instrument the equivalent of a piece of electronic music transformation equipment such as a filter, reverberation unit or certain kinds of modulation. Filtering by using different microphones on the same object or instrument (or identical ones at differently resonating positions) has already been described; a similar effect can also be produced by using various damping materials, such as foam rubber, to isolate the vibrating object from one of two or more microphones. In addition, when a magnetic pick-up is mounted in the basic board, a diaphragm can be inserted between the sound source and the pick-up.

It must be assumed that a certain amount of equipment will be available at any school which wishes to build electroacoustic instruments. Apart from amplifiers and loudspeakers (the more the merrier, since it can be confusing to share a loudspeaker), the most essential item is some device which has a microphone input. This is unlikely to be the amplifier, unless pop group equipment is used. Ideal would be a mixer with microphone inputs; a tape recorder with microphone inputs can also be used (though not every tape recorder permits you to hear a sound on external loudspeakers before it has been recorded). Without a mixer, it will only be possible to hear as many instruments simultaneously as there are loudspeakers. If the microphone inputs give a choice of 'low' or 'high' (impedance), it is wise to try 'high' first, and if the sound is very quiet with the volume control(s) turned up quite high, then try 'low'.

In building electroacoustic instruments simple carpentry and soldering will be needed. It is wise to get a group of children to use two or three different instruments as models, not only because of the lack of contrast when they are played together, but also so that queues do not form for a crucial tool that just happens to be in short supply that week. Find out the correct name for the plugs required for the microphone inputs: on many occasions I have been told 'I think it's a jack' because it is the only term for a plug that many people have heard of, or because jacks are used for almost every connection with pop music equipment.

Electrical safety precautions must be taken, primarily with magnetic microphones. Though the microphones are not in themselves at all dangerous, an inadequately maintained amplification system or lack of proper mains earthing in the building can, as has happened with electric guitarists, prove fatal. For acoustic reasons, to avoid hum, it sometimes turns out to be necessary to earth the actual magnet of

the pick-up in addition to the end of the coil that you choose to be earthed. Then, as already stated, the ferrous-metal object may touch the actual magnet and not hover above it. One of my instruments requires this, and I have added two complementary devices which I gather should be safe. The ideal one, however, is a small transformer, but a famous shop which specialises in transformers was unable to supply what a friend told me to get. There exists a device for electric guitarists, which probably includes a transformer, and it would be wise to invest in one of these per instrument if there are any doubts about the safety of any part of the electrical system.

Before describing four of my instruments in detail, I will write a bit more fully about my activity in this area. My first few instruments all use contact microphones. The first self-contained instrument, Shozyg I, contains a selection of small items, including two fretsaw blades, a small spring and a ball-bearing-mounted furniture castor (played by fingers, finger nails, a screwdriver, needle file, toothbrush, small electric motor etc.) which are amplified by two contact microphones for stereo and built inside the covers of an encyclopaedia volume, SHO-ZYG. Hence the title, which I have subsequently adopted to describe all the (mostly amplified) instruments I have built inside everyday containers: a matching second encyclopaedia volume, a larger book, two television sets, a radio set, breadbin, electric toaster, electric heater, accordion file, imitation mixing console (operated by zips instead of faders) and so on. One day I will probably have an exhibition of a shozyg kitchen and living room!

Towards the end of 1969 I began to use magnetic pick-ups for the first time. Initially I used one to amplify a spring that was 14 cm long and 3 mm in diameter, held above a complete pick-up in its original holder mounted on a small square of chipboard, with a key-ring fitted to each end of the spring, enabling it to be stretched to at least 40 cm. A word of warning here: there is a point beyond which all except the least flexible extension springs will no longer return to their original length. I use two versions of this particular spring, one of which is now nearly twice its original length. From this spring I developed the first in my family of Springboards (see Project 1), of which the first five all use identical springs, stretched up to 45 cm in length. With the same magnetic pick-up I also use an egg slicer (see Project 3).

Since magnetic pick-ups are used in about one third of my electroacoustic instruments, quite a large proportion of my sound materials are metal. With cartridges I also use metal strings or wire, and only with contact microphones do I sometimes use other materials: plastic (as in a plastic breadbin containing a 'keyboard' of six plastic spoons and stirrers mounted on inverted plastic cups and mugs, a plastic knife with serrated edge and 'to finish off with' a toothbrush), wood (usually for mounting other objects on, thus more a means of modifying the transmission of vibrations to the microphone) and nylon strings (fishing nylon; also useful for acoustic instruments, as for example with my *Lady Bracknell*, in which a length of fishing nylon attached to an empty coffee tin - like half a child's telephone - is

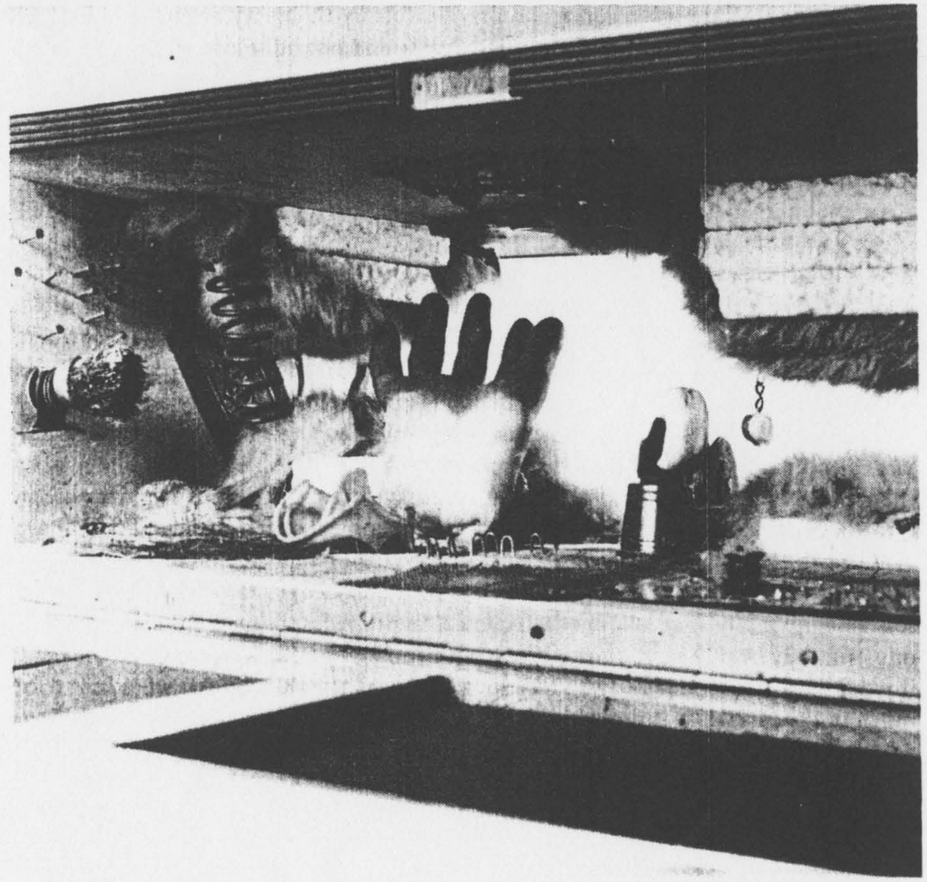

Plate 10 Hugh Davies and John Furnival – The Jack and Jill Box (Feelie Box)

rubbed with wetted fingers). In the several amplified Feelie Boxes that I have made with John Furnival there is a variety of small, primarily tactile surfaces which mostly produce very little sound even when amplified, such as: sandpaper, fur, carpeting, corduroy, metal foil, polystyrene, unusual shapes of plastic to be guessed at, gloves made of rubber, wool and string (stuffed with foam rubber, fir cones, plaster of Paris, soya beans, crinkly cellophane wrapping paper, electric light fittings and a bedspring), steel wool juxtaposed with cotton wool (one of our many built-in jokes), a nylon dish scourer, metal mesh, a Perspex triangle and corrugated cardboard (Plate 10).

The item I have used most of all is the spirally coiled spring. This comes in a great variety of shapes and sizes. There are basically three types of spring: (Ex)-tension, Torsion (rather similar to Extension) and Compression. I mainly use

the first type: compression springs are less flexible by their very nature, and I normally perform on them in their original state and not built into an instrument, although the most flexible ones of this type can be manually compressed and even slightly expanded. Some compression springs are cone-shaped helices. Extension springs can be stretched manually as described above, either with both hands or, by fixing the other end to part of the instrument, with only one hand; or they can be fixed in place at both ends, as is the case with my Springboards. Not all springs are suitable: those made for the heating elements of electric fires do not have sufficient tension and never return to their original length, even if only stretched a small amount. A few others, mainly compression springs, are not made of primarily steel wire, but of a largely non-ferrous alloy, and thus have too little effect on the magnetic field of the microphone. Compression springs, especially those of thicker gauges, tend to have their ends filed flat so that they will stand upright on a magnetic pick-up rather than leaning at an angle like the tower of Pisa, with a continual risk of falling off the microphone. Extension springs often have their ends twisted into loops, which makes it easy to attach them to key-rings or screwhooks fixed to an instrument, or for screws to be inserted through the loops. A type of extension spring that is well known to children is the Slinky. This is somewhat limited in its range of sound, due to its very large diameter and because it is actually a very long length of wire and thus produces so low a fundamental that one primarily hears its overtones. If one were to mount a Slinky on a piece of wood it would need to be at least five yards long, and even then the Slinky would sag too much in the middle. It is probably at its best with one end resting on a table, amplified by a contact microphone. At the other extreme of extension springs are the easily obtainable 'typewriter springs', which are also somewhat limited, this time because they are rather too short to produce much variety of pitches.

When building a new instrument, it is often helpful to make a series of careful scale drawings in order to decide on the ideal layout, size and relative proportions. Occasionally this is insufficient, and a prototype must be made first. After constructing a few instruments one begins to see signs of a logical development and of one's own particular preferences, and elements of previous instruments are incorporated into new ones; sometimes one object that is only a small part of an instrument becomes the prototype for the whole of a completely new one. In many of my instruments the microphones are built into the constructions so that they remain fixed in the place that I have decided produces the best sound. With magnetic pick-ups this is not always so clearly defined, and in some cases the microphone is moved by hand into different positions around the instrument, or the instrument is similarly moved across the microphone. In the latter case the instrument is frequently a found object. A single spring held at each end by a key-ring virtually qualifies as such; but I am thinking more of the collection of found objects used in my composition *Salad*, in which four different egg slicers (different brands have the 'strings' tuned to different pitch ranges, though unfortunately 'they don't make them like they used to', and brands currently available use what I can only assume to be less ferrous alloys

for their strings, resulting in a considerably weaker amplified sound), two 'identical' tomato slicers (with small saw-blades) and a cheese slicer (with a wire cutting edge) are amplified by five magnetic pick-ups, four of which are mounted together on a piece of chipboard (at the top of an old microphone stand) as a tightly fitting square.

When I have completed a new instrument I try to discover the most suitable context in which to use it, rather than imposing preconceived ideas onto it. Thus it might be played sitting down, sitting at a table, standing up, walking around (not so good with amplified instruments), crouching, kneeling or sitting on the floor. It might be suitable for a solo performance in a concert, for a more auxiliary role as part of a collection of instruments used by one player in a group improvisation, for an exhibition or as a toy – or a combination of these. I find improvisation helps me to learn more about my instruments' potentialities. In a classroom there is obviously a need to suggest some more coherent musical relationships. I find that a good way to start is with a small group, with instructions to hold a conversation or discussion using sounds instead of words. There will be occasional solos and duos, sometimes everyone plays at once causing a confused chaos, some statements consist of only a single sound or short phrase, others are very elaborate; some statements echo what another player has just played and expand it, others are contradictory. Just as happens with words. Another possibility is rhythmic pieces handled in the same way as with a group of percussion instruments. I should add that I have tried out such things, but only on a couple of occasions with children playing instruments made by me. The reason for this is simply that when coming from outside to work with a class of children for three hours or two days or a whole week I want the children to be able to play their instruments after I have gone home, which is unlikely to be possible when these are electroacoustic. Therefore when working with children I avoid amplification, and usually use bamboo as the main material since it is easy to work and sounds good. But I greatly welcome the present opportunity to pass on ideas about making electroacoustic instruments, even if it is at one remove.

With electroacoustic instruments it is difficult to hear your own sound in the loudspeaker clearly without being too loud in relation to other people who are playing traditional instruments, even if these are also amplified. The problem is considerably reduced when all the instruments are electoacoustic. Because there is little or no acoustic sound and the physical vibrations transmitted through the player's body are much smaller, monitoring one's sound in the loudspeaker becomes very important. It will be helpful for the players to have the opportunity of getting to know their instruments individually, to practise them alone just as with any conventional instrument, before starting to play together. One awkward thing that can happen with electroacoustic or amplified acoustic instruments when the microphone is fixed directly on the instrument, is that sometimes one is faced with the problem of taking one's hand or finger off the instrument or moving to a different finger position during a silence, since the microphones are often so sensitive that this movement will be audible over the loudspeaker. One solution is for each player

to have a foot-operated volume pedal like an electric guitarist (I once made some boxes that could be attached to one's belt, for a similar purpose); however, familiarity with such quirks through practice can help to avoid such things or at least to cover them up. Similarly, when using contact microphones with an instrument that is to be played while sitting at a table, the table effectively becomes part of the instrument. Any unintentional bang or object dropped on to the table will be audible over the loudspeaker, unless the table is so heavy and solid that it has little resonance. A solution is to place a layer of foam rubber underneath the instrument, which would be particularly relevant when more than one instrument using any kind of microphone is played at the same table.

Project 1: Springboards

The background to this family has already been described. The first five Springboards all use the spring referred to, 14 cm long and 3 mm in diameter. Three models use four springs, one uses two, and one the grand total of fourteen. Each spring is amplified by means of half of a U-shaped magnetic pick-up. The layout of the springs in most models is parallel, making its kinship with the electric guitar clearer. Proportions: all Springboards are mounted on blockboard ½ in thick, and the three Springboards with four springs each measure, on average, 50 x 16 cm; the two-spring model is only 6 cm wide. The springs vary in length from 20 to 45 cm, arranged symmetrically like the cross-section of a pyramid: parallel lines whose centre points would makes a straight line at a right angle to them. The microphone is usually placed only slightly off-centre and not close to one end (typically it is about 4 cm from the centre point), so that the instrument does not have a right way round, but can be reversed. This produces slightly different timbres for those pitches that are available from both directions. The springs are fixed down by looping their ends over screwhooks (the smallest size that can be found at a well-stocked ironmongery) which are screwed into the top surface of the blockboard.

On the underside are mounted the pick-ups, screwed into place facing upwards, in holes approximately 1½ x 2 cm. These holes require care in cutting if the result is not to look messy: I normally drill several small-diameter holes around the perimeter (for which I have made a template on transparent paper, which is slightly smaller than the final hole size) and cut through the barriers between them with a Stanley knife, leaving a rough hole that is still somewhat smaller than needed. This is then expanded to the right shape and size with a small flat or half-round file. It is possible to mount the pick-up in such a way that the top ends of the magnet would be nearer to the springs by cutting away the outer sandwich layer on the underside of the blockboard around the microphone hole. While on the subject of the composition of the blockboard, I usually cut it so that – primarily for the visual appearance – the grain of the outer layer goes lengthwise; exceptions are the very narrow Springboards (3½ cm and 6 cm) with which I was afraid that the wood would be more prone to snapping due to the fact that the interior rectangular

blocks would be cut into many short pieces placed side by side. As it is, these two instruments have one or two interior blocks that run lengthwise.

Apart from other comments made earlier in the section on magnetic pick-ups, there are two further items concerning microphones. The wires that come out at each end of the double coil (a coil around each arm of the U-shaped magnet) are very thin and fragile. I solder a short length of covered connecting wire to each pick-up wire, and fit their other ends into a two-way plastic terminal block that is screwed on to the underside of the blockboard; to the other side of the terminal block is connected the screened audio cable which has on its other end a plug appropriate to the microphone input. It does not matter which of the wires from the coil is treated as the earth and which as the signal. In some cases, as already mentioned, it may also be necessary to earth the actual magnet. If there are any audio problems – such as the microphone picking up radio or even television sound – a small ceramic disc capacitor of about 0.01 μF can be connected across the two wires from the pick-up by inserting it in one side of the terminal block (a higher value would start to clip the sound, acting as a filter). Concerning the choice of wiring more than one pick-up in series or parallel, see p.161.

I usually fit four medium-sized rubber feet on the corners of the underside of a Springboard, so that it will lie flat on a table rather than rocking around on the pick-up(s) and terminal block that protrude underneath. The final stage in the construction concerns the decoration of the top surface, with the springs temporarily removed. I prefer to use clear varnish (three layers) which brings out the grain of the wood; some kind of varnish is advisable to protect the wood from stains and grubby fingermarks. Children would probably enjoy painting, burning or carving a design, which could later be covered with clear varnish.

All springs, even the very shortest, produce medium to low pitches when played as 'open springs'. This is due to the lengths that would result if they were pulled out into straight wires. It is possible to tune a spring to a lower pitch, but not to a higher one; and indeed stretching a spring hardly changes its pitch, since the same amount of wire is still vibrating loosely, which is not the case with strings. Tuning is changed by selectively stretching alternate short lengths of a spring, each about 1 cm long, fairly vigorously so that these alternatively wider coils do not return to their original density. Performance technique is like that of the guitar, with the exception that the pick-up is the only point from which the vibrations will reach the listener: stopping a spring and then plucking it on the side away from the pick-up will give virtually no sound at all. To produce very high sounds, two fingers of one hand stop the spring, one on each side of the pick-up; so short a length of spring gives little resonance to the sound and in such a situation I tend to flick the spring with my fingernail rather than pluck it. Tremolos are effective at any pitch for producing sustained sounds. Needle files, screwdrivers and so on can be used in addition to fingers for playing and stopping the springs. Fingernails scraped rapidly along a spring will bring out the overtones of its fundamental, the faster the action, the higher the overtone. A separate, loose pick-up can also be used above the springs,

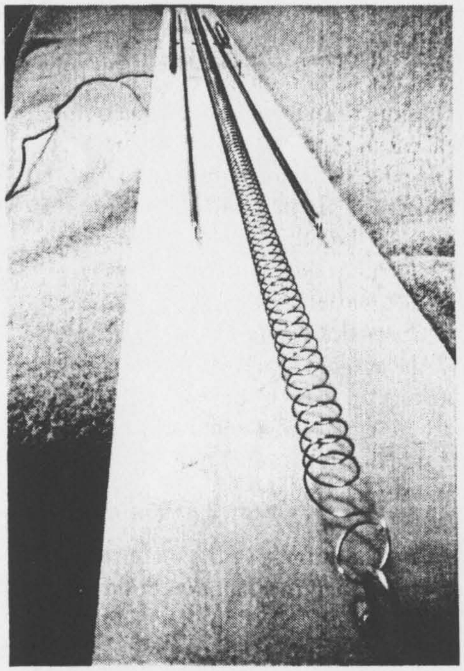

Plate 11 Hugh Davies – Springboard Mk VI (133 cm long)

partly to give a different version of the sound when operating with a stereophonic set-up and partly to play or stop the springs. An ensemble of different Springboards can also be very effective.

The later Springboards, whose family consists of a dozen at the time of writing, develop the same basic principles but uses a considerable variety of other extension springs (see Plate 11). Three of them develop a new principle first tried out in the early Springboard with fourteen springs. Pursuing the idea of springs radiating out from a key-ring with seven pick-ups mounted in a semicircle close to the key-ring (see Plate 12), I then made several springs of different qualities meet above a single pick-up at a small split-ring (like a key-ring) about 1 cm in diameter. These springs are sufficiently flexible for the ring to be shifted off-centre in different directions by one finger. A further development of this consists of a spider's web arrangement of about five short springs radiating out from this central ring to a larger concentric ring (which can itself consist of about ten short springs), from which in turn about five longer springs radiate outwards. Vibrations from these outer springs must pass through the inner web to reach the microphone, and it is possible to damp some of the inner springs selectively with one's fingers in order to change the route and the distance the vibration has to travel, affecting the timbre and pitch often quite substantially. The inner springs can, of course, also be played. When several springs

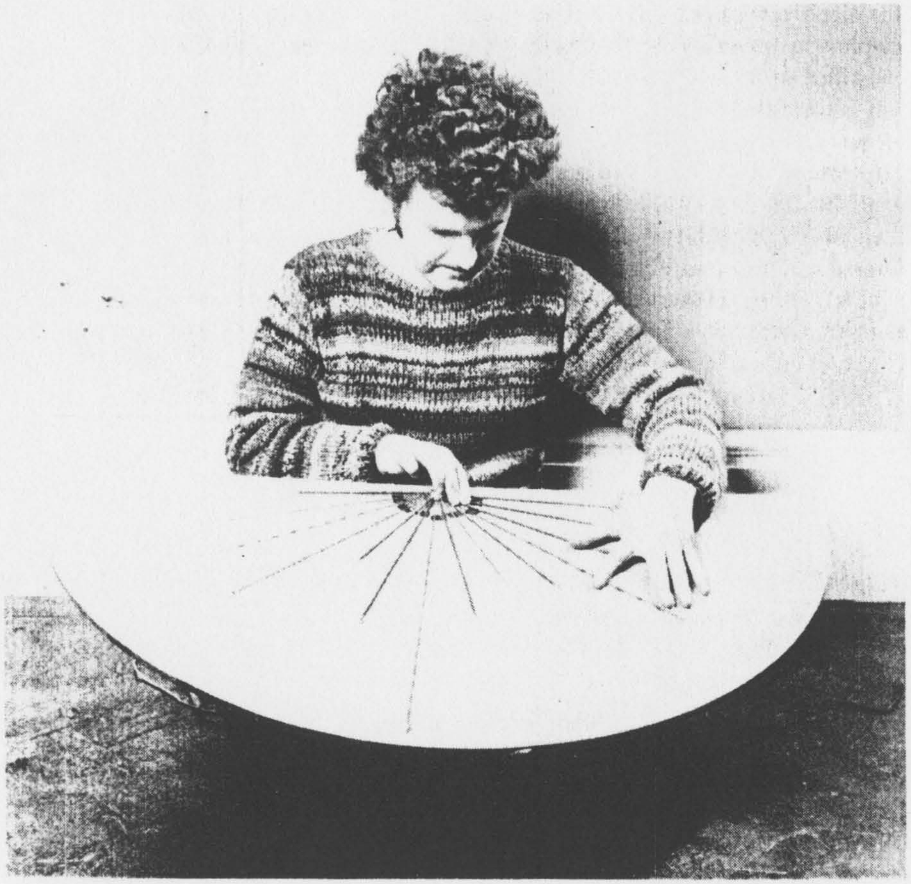

Plate 12 Hugh Davies playing his Springboard Mk III

converge at a single point such as a split-ring one often needs to damp some of the springs because they all tend to resonate from the vibrations produced by just one of them. When used deliberately, the player can control the reverberation imparted to the sound in a way that is similar to operating an electronic reverberation unit. Examples of four Springboards can be heard on the accompanying cassette. (*Cassette examples 8.1–8.4*).

Project 2: Bowed Diaphragms

I explained earlier (p.160) how the diaphragm of a magnetic pick-up functions. Two possible uses of the diaphragm are combined in my composition *Music for Bowed Diaphragms* (*Cassette example 8.5*). If the pick-up is retained in its original state as found in a telephone handset or other device, when the cover has been removed

the diaphragm can be shifted off-centre, so that the pick-up's rim will damp the diaphragm disc in a variety of ways. This alters its frequency response, and has the effect of filtering the sound. The most interesting applications I have found for this are with the human voice (as I devised for *Group Composition VI* by the group *Gentle Fire,* of which I was a member; in this piece four old-style telephone earpieces were transferred to the mouthpiece of the handset so that the voices could be modified by the displacement of the diaphragms, and these sounds were then passed through two of the terminals of the telephone dials, enabling the filtered and distorted voices to be chopped up with interspersed silences) and with a 'bow'. The bow is actually a single strand of horsehair from a violin bow; this can also be used on a Springboard, where the hairs of a complete bow are inclined to get caught in the coils of the springs.

Music for Bowed Diaphragms is for five magnetic pick-ups with their original diaphragms. Each pick-up is different, and between them a wide range of impedance is covered. They are connected to the five channels of the stereo mixer that I always use in performances. Two of the pick-ups have solid top surfaces in which the magnet is embedded, the other three have gaps between the rim and the magnet. I use five bow-hairs, which can be pulled across the diaphragms (in various off-centre positions) either above the discs or between them and the pick-ups. A single bow-hair can be pulled across the edge of the disc, along its diameter, or moved around the protruding part of its circumference. All five bow-hairs can be pulled towards the player if they are between the diaphragms and the microphones. Since the bow-hairs are held fairly tightly between one's two hands they can also be plucked by a spare finger while held against a diaphragm edge, which leads to an unusual paradox. While the bow-hair travels across the edge of the diaphragm, it is a bow moving across an 'instrument' that is 'built into' the microphone; but if one then plucks the hair while it is still moving, it also becomes a string that is amplified by a microphone. The diaphragms are all mounted fairly closely together on a piece of blockboard so that any two can be played, e.g. in stereo, by a single bow-hair.

I have experimented with two further possibilities using diaphragms. The first involves slightly filing down the Bakelite rim of a pick-up so that it provides a convex surface for the diaphragm (or a vibrating egg slicer) to rest on. The second consists of using the diaphragm as an instrument in its own right that can be moved across the microphone to create different sounds, and can be tapped, rubbed and scraped. To do this I sawed off one side of the disc to reduce its size somewhat, bolted a small handle on to the opposite side and inserted the handle through a slit that I had made in the side of the microphone's original screw-on Bakelite cover. As will no doubt be clear by now, in such a miniature and microscopic world as mine, tiny changes in construction and performance can produce great changes in the resulting sounds.

Project 3: From Egg Slicer to Aeolian Harp

When I first began to make instruments a couple of friends used to play egg slicers

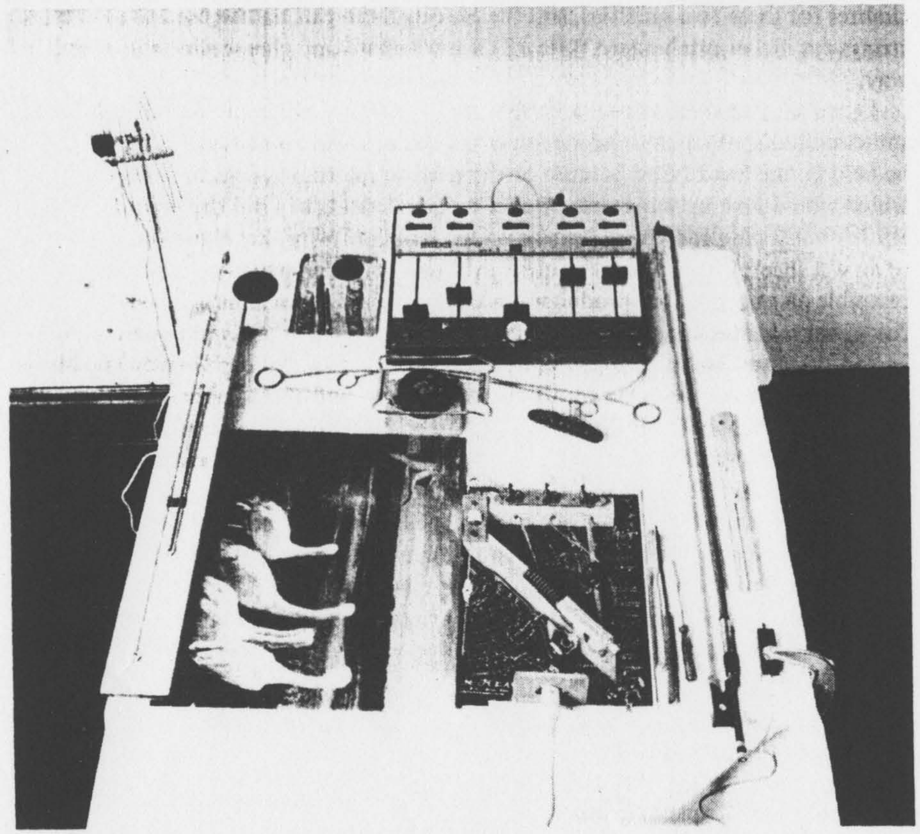

Plate 13 Hugh Davies – solo performance table
- *Centre left:* *Springboard with two springs*
- *Rear left:* *Aeolian harp, two diaphragms and springs in tin*
- *Rear centre:* *stereo mixer*
- *Centre:* *egg slicer on magnetic pick-up, behind it two springs with key-rings, to the right two springs vertical on a guitar pick-up*
- *Front centre:* *Shozyg II*
- *Front right:* *guitar string in cartridge clamped to the table*

amplified by contact microphones. The strings of any egg slicer have quite a range of pitches, even though they are identical in gauge and length. By gently squeezing the longer sides together it is possible to alter the tension of the strings and therefore their pitch. I discovered that with the amplification level turned up higher it was possible to blow on the strings in addition to being able to pluck them. Furthermore, placing an egg slicer on or above a magnetic pick-up produces different

timbres for these two qualities, and the pick-up's rim can also be used to stop the strings for higher pitches (see Plate 13). I use tomato and cheese slicers in a similar way.

I then wanted to construct a more varied egg slicer, either circular or shaped something like a harp. Several attempts at making a fairly small device that could be held in one hand failed because of the need to use tuning pegs of some kind which would take up more space than I wished, lacking as I did the factory machinery for tensioning and fixing the single long length of wire that is used for the strings of an egg slicer. I finally found a quite different solution, which does not really resemble an egg slicer but produces the kind of sound I was aiming at. Nine very fine fretsaw blades are mounted in a holder consisting of a sandwich of aluminium bars in three sections held together by bolts on either side of each blade. The blades protrude above and below in roughly equal proportions, giving eighteen different lengths and pitches. The holder fastens on to an old collapsible aerial fitted to a heavy base that stands on the floor, and there is a wingnut which enables the contact microphone to be attached to it. This instrument can also be both plucked and blown. Because of the ethereal qualities of the latter I have called the instrument, slightly inaccurately, Aeolian harp (plate 13), and indeed a strong wind will cause it to sound. This instrument seems to be the favourite out of all my instruments with the majority of people with whom I have talked at performances of mine, because of the delicate, floating sounds produced when one blows on it (*Cassette example 8.6*).

Project 4: Metal Rod 'Xylophone'

This instrument requires mainly soldering skills, and at the time of writing I have not developed it beyond a small prototype. I deliberately collected other people's rubbish for it, consisting of the ends of wires (between 1 and 4 cm long) that had been cut off electrical resistors and capacitors by friends who were fitting components on to electrical circuit boards. One could also purchase a similar type of tinned copper or steel wire, gauges between 18 and 24 swg. These wires are arranged by length and soldered to a piece of circuit board with holes so that the solder connections are underneath and the wires stick up vertically through the board. The underside ends of the wires should be wrapped together or around additional wires for strength, and longer lengths of wire could serve as two rods by bending them into a long thin U-shape. A contact microphone is fitted by placing a bolt with a wingnut on top through the circuit board to one side of the rods. Gently plucking the tips of the rods produces high clear sounds, which when recorded and played back at half-speed on a tape recorder sound like a xylophone or marimba; hence the contradiction in my title (*Cassette example 8.7*).

Appendix 1 Glossary

amplifier — A device which increases the amplitude or strength of an electrical signal.

amplitude — of an oscillating wave-form; strength of the signal measured about its mean point or average value, corresponding to the loudness of the sound.

analogue — A representation of the variables of one medium in terms of another. The rise and fall of a voltage can be analogous to the rise and fall in the dynamics of a sound, for example. The term is often used in contradistinction to *digital*, where the difference to be stressed is that analogue signals are continuously variable, whereas digital signals are transmitted in previously defined units, however small.

attack — The initial portion of a sound's or signal's envelope as it rises to its maximum amplitude.

balanced lines — Twin-conductor screened cables used in professional audio applications, as opposed to the single-core screened cable where the screen is used as the return wire of the circuit and known as an 'unbalanced line'.

bulk eraser — A powerful electromagnet designed to erase a full reel of tape in only a few seconds.

capstan — Drive spindle of tape recorder.

cut-off point — The setting on a filter which divides the passed from the rejected frequencies.

decay — The final portion of a sound's or a signal's envelope as it declines to silence or, in some envelope shapers, to a predetermined *sustain* level.

decibel — (Abbreviated dB). The ratio of two signal levels, which can refer to electrical signals or to sound intensities. Since the same ratio can apply to two signal levels of low intensity or to two signals of high intensity, it is often necessary to specify a fixed reference. Electrically the reference usually adopted is 1 milliwatt power in a 600 ohm line as the standard for 0 dB, expressed, as a fixed reference point, as dBm. The zero dBm rating also represents a level of 0.7746 volts. The table below gives the rating in watts and volts for different dBm levels.

dBm	wattage	voltage
+60	1000 W	774.6
+50	100 W	244.9
+40	10 W	77.46
+30	1 W	24.49
+20	100 mW	7.746
+10	10 mW	2.449
0	1 mW	0.7746
-10	0.1 mW	0.2449
-20	0.01 mW	0.07746
-30	0.001 mW	0.02449

Appendix III Select bibliography

The full bibliography of electronic music is now vast. In order to keep this select bibliography as useful and practicable as possible, the works listed are those recommended for further study or to provide information not available in the present book. Those works shown with an asterisk(*) contain extensive bibliographies; those shown with a dagger (†) contain valuable discographies.

Acoustics and technical books

Backus, J., *The Acoustic Foundations of Music* (Norton, 1969)
Borwick, J. (ed.), *Sound Recording Practice* (Oxford University Press, 1976)
Taylor, C., *The Physics of Musical Sounds* (English Universities Press, 1965)
Winckel, F., *Music, Sound and Sensation – A Modern Exposition** (Dover, 1967)

General works on electronic music – mainly for the listener

Ernst, D., *The Evolution of Electronic Music*† (Schirmer/Macmillan, 1977)
Griffiths, P., *A Guide to Electronic Music* (Thames and Hudson, 1979)
Schwartz, E., *Electronic Music – A Listener's Guide** (Secker and Warburg, 1973)

Electronic music in education

Drake, R., Hender, R. and Modugno, A.D., *How to Make Electronic Music* (Harmony/Educational Audio Visual, 1975)
Dwyer, T., *Making Electronic Music* (Oxford University Press, 1975)
Miliaret, G. (ed.), *The Psychology of the Use of Audio Visual Aids in Primary Education* (Harrap/Unesco, 1966)

Works giving information for the advanced practice of electronic music

Appleton, J.H. and Perera, R.C. (eds.), *The Development and Practice of Electronic Music* (Prentice-Hall, 1975)
Howe, H.S., Jr, *Electronic Music Synthesis* (Dent, 1975)
Keane, D., *Tape Music Composition** (Oxford University Press, 1980)
Strange, A., *Electronic Music – Systems, Techniques, Controls** (Wm C. Brown/Kalmus, 1972)

Instrument making, acoustic and electronic

Brosnoe, D., *Guitar Electronics: A Workbook* (dB Music Co., 1980)
Sawyer, D., *Vibrations – Making Unorthodox Musical Instruments* (Cambridge University Press, 1977)
Toop, D. (ed.), *New/Rediscovered Musical Instruments* (Quartz/Mirliton, 1974)

Reference works

Cross, L.M., *A Bibliography of Electronic Music* (University of Toronto Press/Oxford University Press, 1967)
Davies H., *International Electronic Music Catalog*† (Massachusetts Institute of Technology Press, 1968)

Appendix V Manufacturers and suppliers

Synthesisers

ARP Instruments Inc., 45 Hartwell Ave., Lexington, Mass. 02173, USA
Buchla & Associates, Box 5051, Berkeley, Cal. 94705, USA
Dataton AB, Box 257, S-581 02 Linköping, SWEDEN (*System 3000*)
ElectroComp, Electronic Music Laboratories Inc., PO Box H, Vernon, Conn. 06066, USA
Electronic Dream Plant, Red Gables, Stonesfield Rd., Combe, Oxford OX7 2ER (*Wasp Synthesiser*)
Electronic Music Laboratory, I.W. Turner Inc., 31 Slocum Ave., Port Washington, NY 11050, USA
EMS Synthesisers, 277 Putney Bridge Road, London SW15
Moog Music Inc., Academy Street, Williamsville, NY 14221, USA
Rod Argent's Keyboards, 20 Denmark Street, London WC2H 8NA

Synthesiser kits and modules

Chadacre Electronics Ltd, 43 Chadacre Avenue, Clayhall, Ilford, Essex
DEW Ltd, 254 Ringwood Road, Ferndon, Dorset BH22 9AR
Eμ Systems, 417 Broadway, Santa Cruz, Cal. 95060, USA
Phonosonics, 22 High Street, Sidcup, Kent DA14 6EH
Powertran Electronics, Portway Industrial Estate, Andover, Hants SP10 3NM
Selidor Electronics, 6 Shirley Road, Southampton SO1 3EU
Serge Modular Music Systems, 572 Haight St., San Francisco, Cal. 94117, USA
Taylor Electronic Music Devices, PO Box 42, Greyfriars House, Chester CH1 2PW

Contact microphones

FRAP. UK distributor: Stateside Electronics, Unit 8, New Road, Ridgewood, Uckfield, Sussex TN22 5SX
Barcus-Berry. UK distributor: Guild Guitars (UK), 151 Portland Road, Hove, East Sussex
Merula. No model number or manufacturer's details available (West Germany)
C-ducer (a range of microphones for stringed instruments, including piano, and drums): C-Tape Developments, 7 Riverdale Road, East Twickenham, LONDON TW1 2BT

Strain gauges

Techni Measure, Eastern Dene, Hazlemere, High Wycombe, Bucks HP15 7BT (Many types, incl. PL-3)
RS Components, 13-17 Epworth Street, London EC2P 2HA (Single type, 2 versions, stock numbers 308-102 and 308-118) Also branches in Birmingham and Stockport.

PXE piezoelectric ceramic crystals

Edmundson Electronic Components Ltd., 30/50 Ossory Road, London SE1 5AN (distributors of Mullard = Philips)

Gulton Europe, The Hyde, Brighton, Sussex BN2 4JU (Glennite piezoceramics, incl. strain gauges)

Component suppliers

Maplin Electronic Supplies, PO Box 3, Rayleigh, Essex SS6 8LR (Components, tape heads and small microphone mixers)
Marshall Electronics, 40 - 42 Cricklewood Broadway, London NW2 3ET (Components)
Bi-Pak, PO Box 6, Ware, Herts. (Bargain packs of potentiometers, plugs, sockets, and audio leads)
Other addresses may be found in the popular electronics magazines.

Vibrator-transducer

Ling Dynamic Systems Ltd, Baldock Road, Royston, Herts. (100 Series Vibrators)