Induction Loops

Do you know what it's like not to be able to hear what's going on at a concert or a meeting? Vivian Capel describes a British system that will enable many hearing-aid users to find out what they've been missing.

PERSONS WITH normal hearing rarely appreciate the problems associated with the condition of those who are not so blessed. Hearing aids don't restore normal hearing. Owing to the inverse square law which governs sound propagation, microphones are much more sensitive to nearby sounds than distant ones. The human ear seems able to do a certain amount of filtering out of unwanted sounds that hearing aids are not capable of. The result is that a hearing-aid user is very suceptible to unwanted, distracting sounds.

Another effect experienced by hearing-aid users is that sound from a public address system sounds hollow, and it is difficult to distinguish the syllables. This is due to the reflections and reverberations set up in the auditorium. Here two ears come to the rescue of those with normal hearing because the reflected sound is of random phase, while the direct arrives in-phase. So our ears ignore much of the reverberation and concentrate on the direct sound.

Faced with these problems, hearing-aid users often try turning up the gain to make the sound more intelligible. Of course it doesn't work, in fact it makes matters worse, as the rustles, coughs and other sundry noises now become deafening. In despair, many turn off their aids altogether and try to hear with what limited natural hearing they have.

Plugged-in Audience?

Ideally, anyone hard of hearing should be plugged in directly to the PA system so that they receive only the sound from the stage microphones minus auditorium reverberation and without the audience noises. In the past some attempt has been made to do this in certain halls where a section would be reserved for deaf people, with a number of audio outlets for headphones.

Such arrangements were fraught with problems. One was that the users might have to be segregated from their friends, which made them self-conscious. Another was the constant damage done to the headphones and wiring; it was common for users to forget they were wearing headphones and stand up and move away while still connected! Yet another problem was the regular disappearance of loaned headsets.

All these drawbacks can be overcome by the installation of a magnetic loop around the periphery of the whole auditorium which is fed from the PA system. The PA output can then be received by anyone with a suitable hearing-aid within the area. So there is no segregation, the users can sit where they like; there is no wiring or connections to worry about so no maintenance problems; and the users can still hear if they move from their seats.

Hearing-Aids

What then about the receivers? Special headphone sets with built-in amplifiers and induction pick-up coils have been made by firms such as Beyer, Eagle and others for some time. However, for this application these are not necessary. Since 1974, all National Health Service and many North American hearing-aids have a selector switch which has two positions marked M and T. In the M position, the internal microphone is switched on for normal usage. The T position is for telephone use and it disconnects the microphone and switches in an induction coil. This responds to the magnetic field of some telephone earpieces and thus enables the user to hear the telephone without double transduction, that is sound generated by the earpiece being converted back to an electrical signal by the hearing-aid microphone. This greatly improves the quality and intelligibility of the sound heard.

When switched to the T position, the normal hearing-aid becomes an ideal receiver for a magnetic induction-loop sound system. The coil is mounted vertically, which is in the same plane as a loop wired around a hall, and so achieves maximum signal pickup.

From the management's point of view, this means no separate hearing devices to be supplied, with their repair liability and disappearances.

From the user's standpoint, there is no fuss over having to obtain and return an aid. The aid can be switched from normal to T at the start of the performance and back again at the end, in an instant. All extraneous noises are cut out, in fact in some cases users can hear better than those with normal hearing! A further big advantage is that the volume can be individually adjusted to suit the particular user, as he or she would do when using the aid normally.

Though many privately-sold hearing-aids incorporate a telephone switch, not all do. Those worn inside the ear lack the facility, as there is simply no extra room for a coil and switch. Some others have an induction coil but no switch so that both microphone and coil output are heard at the same time. This is less satisfactory than being able to switch the microphone out, but providing the signal from the loop is high, it is not too great a drawback.

Looping the Loop

Designing a loop is reasonably straightforward, being a matter of taking the area to be covered and the length of the longest side, then calculating the cable resistance, number of turns, and amplifier power to produce the required field strength.

The ideal strength is that which presents a signal to the hearing-aid which is comparable to the output of the internal microphone. Too weak a signal is not desirable as this would mean users having to turn the gain well up, which would make the noise of the internal amplifier noticeable. There is a British Standard (BS 6083 Part 4: 1981) which specifies the optimum strength as 100 mA in a single-turn loop of 1 metre diameter.

This highlights a basic factor, that it is the current and the number of turns that influence the resulting field in any given size of loop. Because the hearing aids will require negligible power from the magnetic field, the voltage required is only that needed to drive the required current through the resistance of the loop. If the resistance can be made very low, the necessary current can be achieved with only a small voltage, hence with minimum power. However, as the field strength is proportional to the product of the current

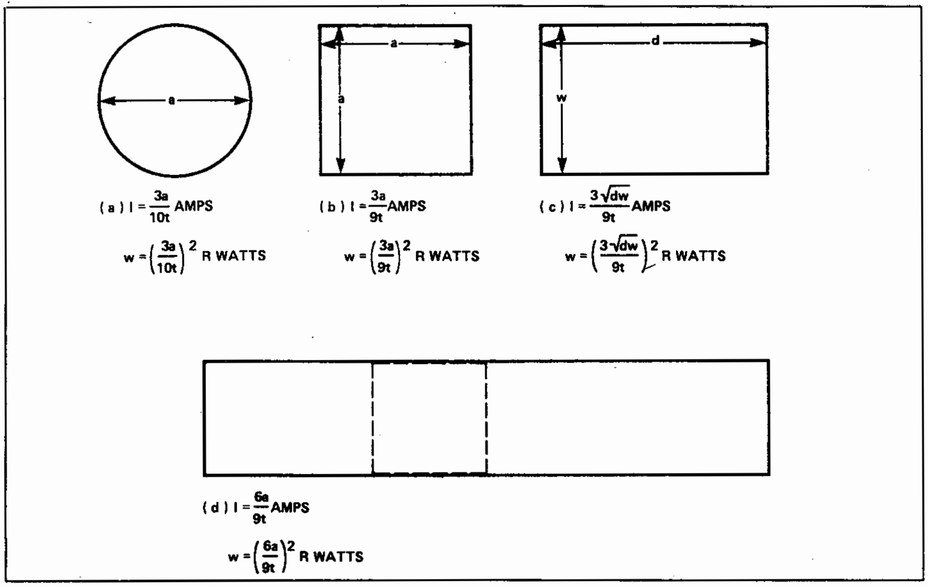

Fig. 1. Formulae for current and power requirement for loops of various shapes.

and the number of turns, it can be an advantage to increase the turns even though this also increases the resistance.

The specified current of 100 mA/metre is for the average signal, but peaks will exceed this, especially with music. The British Standard recommends allowing for peaks of 12 dB above average, which increases the current requirement by four times. If dynamic range compression is used in the feed amplifier, this could be reduced. However, if the system is to be used mainly for speech, then only much lower peaks need be accommodated. In practice, allowance for 6 dB peaks, or twice the average, has been found to be adequate. However, to ensure a good safety margin, the following calculations assume peaks of 10 dB, or three times average.

If the average current in amps is a/10 (where a is the diameter of the loop in metres), the peak is 3a/10. With the exception of the Albert Hall, few halls are circular. A square loop needs slightly more current to provide the same field, about 112 mA for a square of side 1 metre, so the formula becomes I = 3a/9 amps.

However, most halls are rectangular. Doing the calculation properly would be complicated, but for practical purposes we can work out a close figure for halls with a length of no more than 1½ times the width. This can be done by multiplying length and width to give the area, then finding the square root to give the side of a square of equal area. So our formula becomes $I = 3\sqrt{dw}/9$, where d is the length and w the width.

In the case of long narrow areas, things are rather different. With a square loop, each side contributes equally to the field. But if we take a square section, somewhere near the middle of a long narrow loop, the sides are too far way to have much effect. So only two of the four sides of the square are generating any field. Hence the field is approximately half what it would be with a square loop of the same width in the central portions, rising to around three-quarters in the parts adjacent to the sides.

Choosing The Cable

The above calculations apply for a single-turn loop, but there is no reason why several turns cannot be used to advantage. As you would expect, the current required is divided by the number of turns, so the formula becomes 3a/9t for a square loop (where t is the number of turns).

A convenient method of wiring multi-turn loops is to use multi-conductor cable and connect the conductors in series using a junction box or terminal strip. Thus a single loop of standard three-conductor cable gives a three-turn circuit without actually running three separate turns around the area.

Now we must match the loop resistance to the output of the amplifier. If a separate amplifier having a four-ohm output is used, the loop should equal this or be a little higher, say five ohms. This is about the lowest resistance that can normally be matched to a standard power amplifier.

Table 1 gives the resistance per 100 metres of a single wire of various gauge cables. One of the most commonly used is 20 AWG, three-conductor which has a resistance of 3R3 per conductor or 10R total. The heavier gauge 18 can also be used if the run is long and resistance high as a result. This comes out at 2R1 per conductor or 6R3 for three conductors.

The first step, then, is to measure the total length of the run. This must include detours around door or window frames, and recesses. For a medium-sized hall, a run of around 80 metres is a common average. This gives about 8 ohms for 3x20 AWG which matches nicely with an 8R output amplifier. Any value below this needs a 4R output, even though it may be closer to 8R, because the load should never go below the rated impedance of the amplifier. It is a matter of juggling the gauge and number of turns to produce the desired resistance for the measured length. Never add a series resistor to make up a value, as this not only wastes power, but also has an adverse effect on the loop performance.

Amplifier Power

Although the production of the magnetic field is not a function of power out of current alone, a certain voltage is required to produce the necessary current, hence power is expended. So, what power will be needed from the amplifier?

The formula for calculating power is $W = I^2R$, where the symbols used have the usual meanings.

Combining this with the earlier formula we get:

$$W = (3a \div 9t)^2 R$$

If we remember that R depends on the number of turns, and write R = rt, where r is the resistance per turn, then we can re-write the formula for the power as:

$$W = (3a \div 9)^2 \times r \div t$$

which shows that the more turns we use, the less power is necessary to drive the loop.

Let us look at an example to illustrate. Supposing a hall having 18m as the root of its area and needing 80m of cable to enclose, is wired with 20 gauge. The resistance for a two-turn loop would be from the table, 5.33 ohms, and for a three-turn loop, 7.99 ohms.

For the two-turn loop we have:

$$W = ((3 \times 18) \div (9 \times 2))^2 \times 5.33 = 48 \text{ watts}$$

In the case of the three-turn loop:

$$W = ((3 \times 18) \div (9 \times 3))^2 \times 7.99 = 32 \text{ watts}$$

Table 1

AWG (Copper)	Resistance per 100m
12	0R52
14	0R83
16	1R32
18	2R09
20	3R33
22	5R30
24	8R42

With 18 gauge cable, the resistance for two-turns is 3R34. The three-turn cable has a resistance of 5.02 ohms. So using the above formula we have:

$$W = ((3 \times 18) \div (9 \times 2))^2 \times 3.34 = 30 \text{ watts}$$

two-turns, and for three-turns:

$$W = ((3 \times 18) \div (9 \times 3))^2 \times 5.02 = 20 \text{ watts}$$

Amplifiers

A separate amplifier fed from the 'line out' socket of the existing PA amplifier is the most flexible and satisfactory means of supplying a loop. The power rating can be chosen from the formula already described. However, in some cases, it is possible to take a feed from the output of the PA amplifier already installed.

If it is a proper PA amplifier, it will have a 100 V output tap, and this should be used with a suitable matching transformer. The main requirement is that the amplifier has sufficient power to supply both the loop and the speakers. With many PA systems there is an ample reserve; it is not uncommon to find 80-100 watt amplifiers feeding speakers tapped at 25-40 watts.

100 V Outputs

A word of explanation regarding 100 V operation and transformer power tappings would not be amiss here. A 100 V output is a much more convenient method of connecting mixed loads than working out their impedances, when connected in parallel, and ensuring that they do not fall below that of the amplifier tap being used. Each load has its own matching transformer which enables each one to be individually adjusted.

The 100 V is the output voltage obtained when the amplifier is delivering its full rated power. From the formula:

$$Z = E^2/W$$

it can be seen that the actual impedance of this tap depends on the wattage rating of the amplifier, for a 50-watt amplifier it is 200 ohms, for a 100-watt, 100 ohms, and so on.

The transformers used for matching PA speakers to the 100 V output have a secondary rated in ohms: 4, 8, 16, or often all of these via tappings. These are connected to a speaker of the appropriate impedance. The primary has tappings rated in watts so that when a particular tapping is selected, the specified wattages will be taken from the 100 V output and fed to the speaker.

So you can have a mixed bag of speakers all set to different powers to suit different locations in the PA system, and the only calculation necessary is to add up all the tappings and make sure that the total does not exceed the power rating of the amplifier. Much easier than calculating parallel impedances!

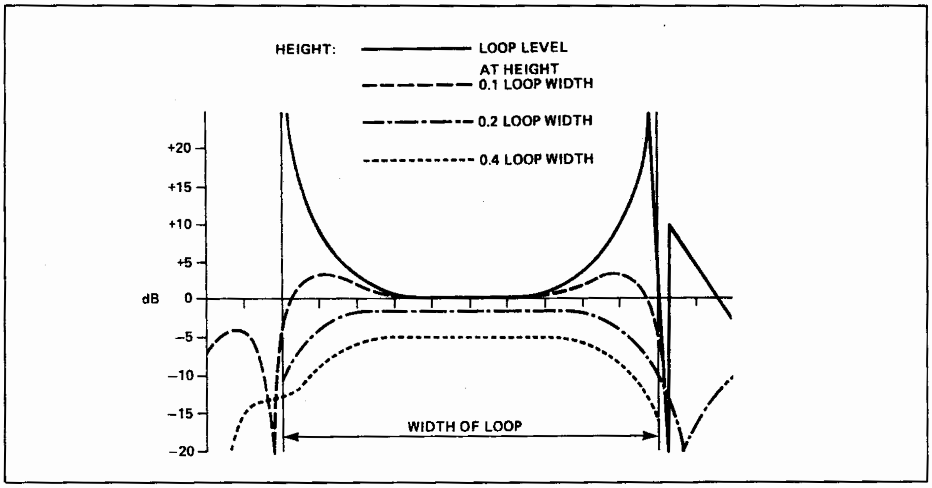

Fig. 2. Vertical field distributions for different heights above (or below) the loop level.

The 100 V Loop

The loop is taken to the appropriate secondary tapping on the 100 V transformer, and the primary tapped to give the required wattage.

Some installations in small halls may not have a PA amplifier with 100 V output, and the speaker system may be operating at low impedance from an ordinary amplifier. In this case there is less room for manoeuvering, but if there is plenty of amplifier power to spare, it may be possible if the impedances work out right.

Field Distribution

So much for the electrical features; now we will consider the magnetic field and its distribution. If the loop is level with the receiving devices, and we start at the middle of the loop, the vertical component of the field rises gradually as we move toward the walls supporting the loop. At about halfway between the centre and the walls, it shoots up dramatically to +22 dB or thereabouts, at a point close to the loop. Then it drops to a null point actually just over the loop at the boundary wall. Beyond this, outside the loop, it rises again to about +10 dB, then falls linearly. This is shown by the solid line in Fig. 2.

Obviously this is not entirely satisfactory, as there are wide differences in field strength across the loop which would call for different gain levels in the user's hearing-aids according to their positions. If instead, the loop is displaced vertically so that it is above or below the level of the hearing-aid coils, the distribution curve can be made more even. Figure 2 also shows vertical components of field distributions for displacements of one-tenths, two-tenths and four-tenths of the loop width.

Of all these curves, the one obtained from the one-tenth displacement is the most satisfactory, and usually it is the most convenient. For a hall 10 metres wide, which is a fair average for a medium-sized hall, the required displacement will be one metre. For seated users, this would put the loop near the floor, which is a practical place to mount it. It could be at floor level, especially if the hall is wider, as the positioning is by no means critical.

The loop could just as well be run above the hearing-aid level, and in some cases this may prove to be more practical. This could be rather conspicuous, however, and may detract from the decor. In both cases, running the loop over door frames or around other relatively small objects will make little difference to the field level in the body of the hall, though it may cause local anomalies.

Vertical displacement of the loop from the level of the receivers causes a lower signal which should be compensated for by an increase in the loop current, hence power supplied by the amplifier. Table 2 gives the ratios of displacement in units of loop-width with the multiplying factors for current and power. For the one-tenth displacement, the power is only 1.2 times and can be ignored. For larger displacements though, the power requirements increase drastically. So this is a further reason for keeping the loop to the one-tenth level.

Table 2

Ratio h/a	Multiply current by	Multiply power by
.1	1.1	1.2
.2	1.25	1.6
.3	1.5	2.25
.4	2.0	4.0
.5	2.5	6.25
.6	3.25	10.6
.7	4.25	18.0
.8	5.5	30.2
.9	7.0	49.0
1.0	8.5	72.2

Null and Overspill

It may be wondered why there is a null point as the receiver passes over the loop, or at greater height, just beyond the loop. It is not that the total field disappears, just the vertical component. If the receiver coil is placed horizontally instead of vertically, then there will be maximum pickup over the loop wire, and minimum within the loop, the opposite of normal. One user was heard to complain that the sound faded out to zero when he bent down to pick up something from the floor. This was, of course, because the hearing-aid coil was tilted through 90° to the horizontal.

Overspill (the magnetic field outside the loop) is unaffected by normal building materials, but falls off linearly with distance. Beyond about a quarter of the loop width, it drops to too low a level for practical use. Even this, though, can be useful. In one case a delighted user related how he could still hear what was going on during a visit to the washroom in the foyer!

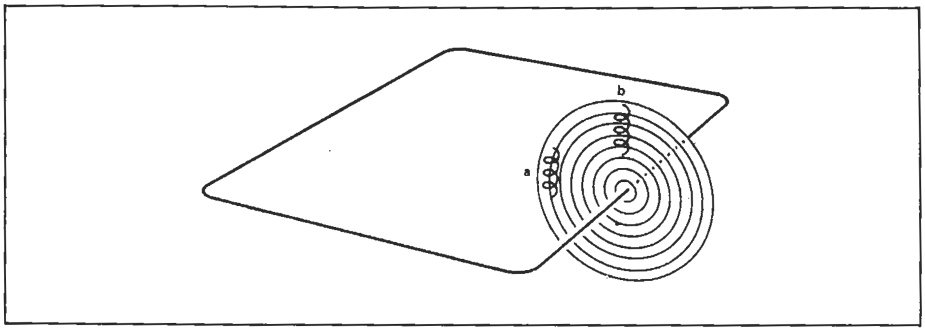

Fig. 3. Field null: at point a, the field is entirely vertical; at point b, the field is entirely horizontal.

In The Home

There is no reason why the same technique should not be used in the home of a person with hearing difficulties, to enable them to listen to records, for example. The major problem will be getting a loop with a sufficiently high resistance to be fed by a domestic amplifier; however, this difficulty can be overcome by using several turns of fairly thin wire.

Listening to the television this way poses the added difficulty of coupling the output from the TV to the amplifier. Unless your TV has a special output socket, as a few of the more enlightened manufacturers have taken to including, the best solution is to use a TV sound tuner.

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