Electrical Engineering and Nontechnical Design Variables of Multiple Inductive Loop Systems for Auditoriums

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This research analyzed both engineering and nontechnical issues involved in the use of Induction Loop Amplification (ILA) devices in auditoriums or large gathering places for hard-of-hearing individuals. A variety of parameters need to be taken into account to determine an optimal shape/configuration for the ILA device. In many cases, an optimal configuration is different from those proposed for classroom use (Ross, 1969; Hodgson, 1986; Clevenger, 1992). Experimental results were obtained for a double-loop configuration in such a setting (a university gymnasium/auditorium in this case). The results demonstrate that a double-loop configuration is a viable possibility for auditorium use. Several variables using this configuration were examined, and experimentation was done. Various implications, including consequent nontechnical issues specific to this application, are discussed as well. Technical and nontechnical aspects of the ILA configuration need to be examined together when designing an optimal system.

Induction Loop Amplification (ILA) devices, also known as electromagnetic loop systems, have been used since the 1950s (Pascoe, 1986). The basis for this technology is the same as that used for communication onboard World War II warships (Bellefleur & McMenamic, 1965). In both cases, a speaker talks into a microphone. The signal is sent into a long loop of wire whereby its current induces a magnetic field around the wire. This magnetic field in turn induces a current in the teleloop receiver. The resulting current can be used to generate a signal to the earpiece so that communication between speaker and listener can occur. In the case of a World War II warship, the communication was between captain and crew. For hard-of-hearing people, this principle has been used to amplify a central speaker's voice so that hard-of-hearing individuals can listen through their hearing aids.

One benefit of ILA devices involves the earpieces needed for picking up the signal. Unlike with other methods, a regular hearing aid (with a telephone coil) can be used to pick up magnetic signals generated by ILA devices. It is this facet of ILA devices that makes them well suited for classroom use and eliminates the cost of a signal receiver. Another benefit is mobility. No wires are needed to connect the audience's hearing aids to the speaker's microphones. This has proven very useful in school and preschool classrooms where mobility is imperative for classroom activities, especially in the case of younger children (Matkin, 1973). Another advantage is that ILA systems have fewer parts than a comparable system in which wires are used to connect the listener to speaker. Thus, there is a smaller chance of failure somewhere in the system.

ILA devices have been explored in a number of applications including school classrooms and preschool classes. The problems associated with ILA devices for these applications, and the optimal configuration to minimize these problems, have been discussed

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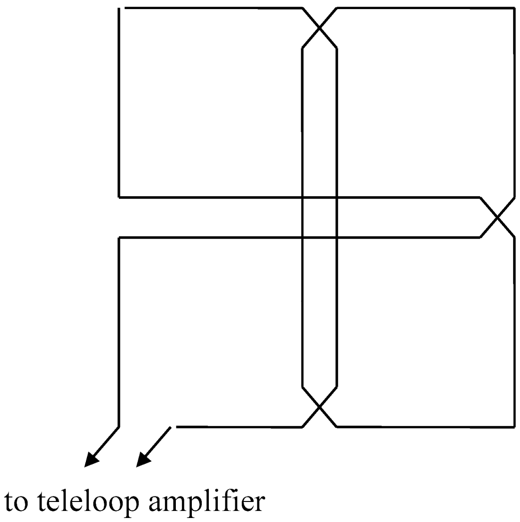


Figure 1 The cloverleaf loop design (Matkin & Olsen, 1973) illustrated in this figure was proposed for a classroom setting.

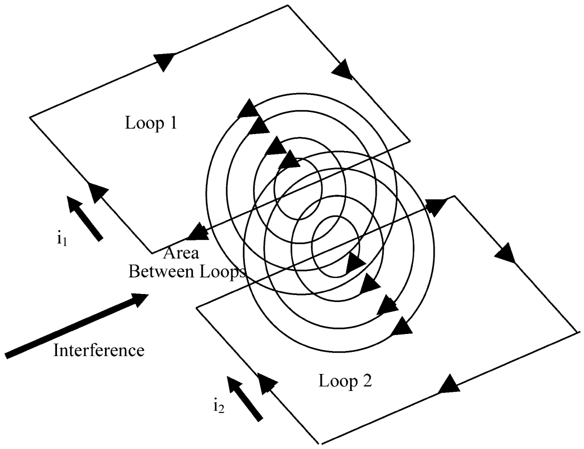


Figure 2 Magnetic fields are generated in the two loops. The opposing magnetic fields virtually cancel each other out when current is applied in the same direction in both loops. Constructive interference occurs when current is applied in the opposite direction in the loops.

previously (Clevenger, 1992). A variety of relevant nontechnical issues relating to hard-of-hearing and hearing populations in education were explored by Power and Hyde (2002). Holden-Pitt and Diaz (1998) showed 62% of deaf and hard-of-hearing people integrated in some way into mainstream classrooms. The numbers are higher for hard-of-hearing students alone. These statistics have been rising in the last few decades (Schildroth & Hotto, 1996). Broad use of ILA systems in auditorium/conference hall settings would allow hard-of-hearing individuals to continue to stay in mainstream post-secondary education environments in a manner that allows discreteness for those who desire it.

Given only a cursory glance, the classroom and auditorium settings appear quite similar. This observation would lead one to consider using the same configuration of the loop for an auditorium setting as in a classroom setting (see Figure 1). However, this is not the case, as the two situations are inherently different. In a classroom design, spill-over (of the signal to other classes) needs to be minimized. Yet this is not a vital consideration when designing a configuration for use in an auditorium since it is unlikely that there is another meeting room in the building being used for the same purpose simultaneously. Another difference is that, when used for meeting places, the device configuration must be easy to set up since meetings are quite often in different rooms. Thus, the design needs to be simple so that the wire can be attached to the floor quickly before the meeting. Also, since the meeting rooms are often used for many purposes, the ILA configuration must be easy to remove and mobile so that it can be carried from one location to another once the meeting is over. In the classroom designs discussed, such designs require an arduous setup process as a result of their shape. In addition, they would be hard to place in an auditorium with seats in close proximity.

The double-loop shape proposed in this paper eliminates these problems. Being a simple loop in shape, each individual loop is easy to set up. Also, their simple shape allows them to be placed so that the two loops can be separated by an aisle. Thus, it does not have to be threaded between the rows, as the previously mentioned classroom loop designs would have needed. In addition, interference between the two loops would only affect the area in between the two loops (see Figure 2) as a result of the clashing magnetic fields. However, because this space will be in the aisle, it will not affect the audience. In the Cloverleaf design (Figure 1), the cancellation of the magnetic fields is a cross-shaped area. It can be noted that the Cloverleaf design and others were originally conceived, in part, to control spill-over. Since the auditorium application is not as concerned with spill-over, this provision is

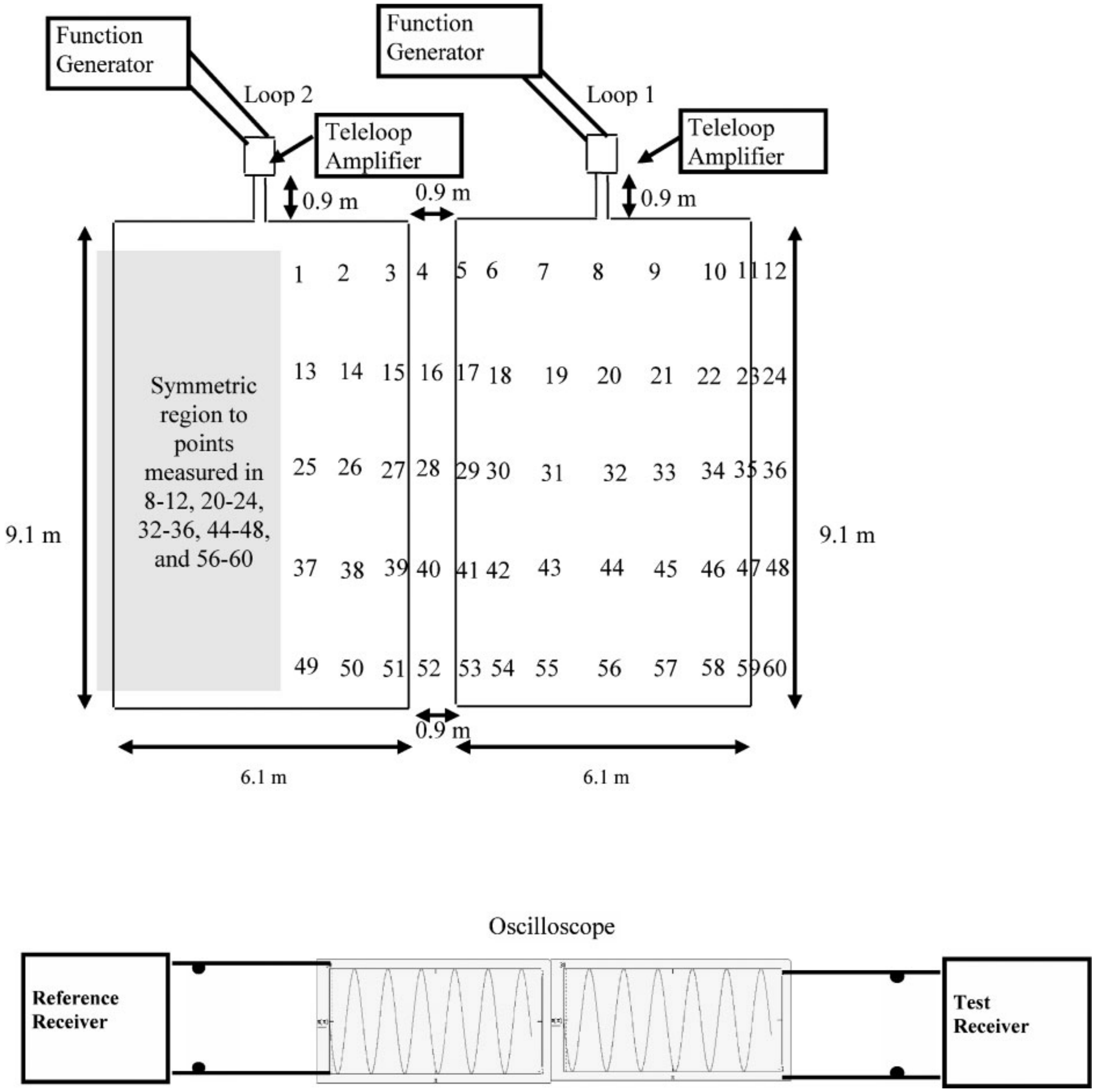


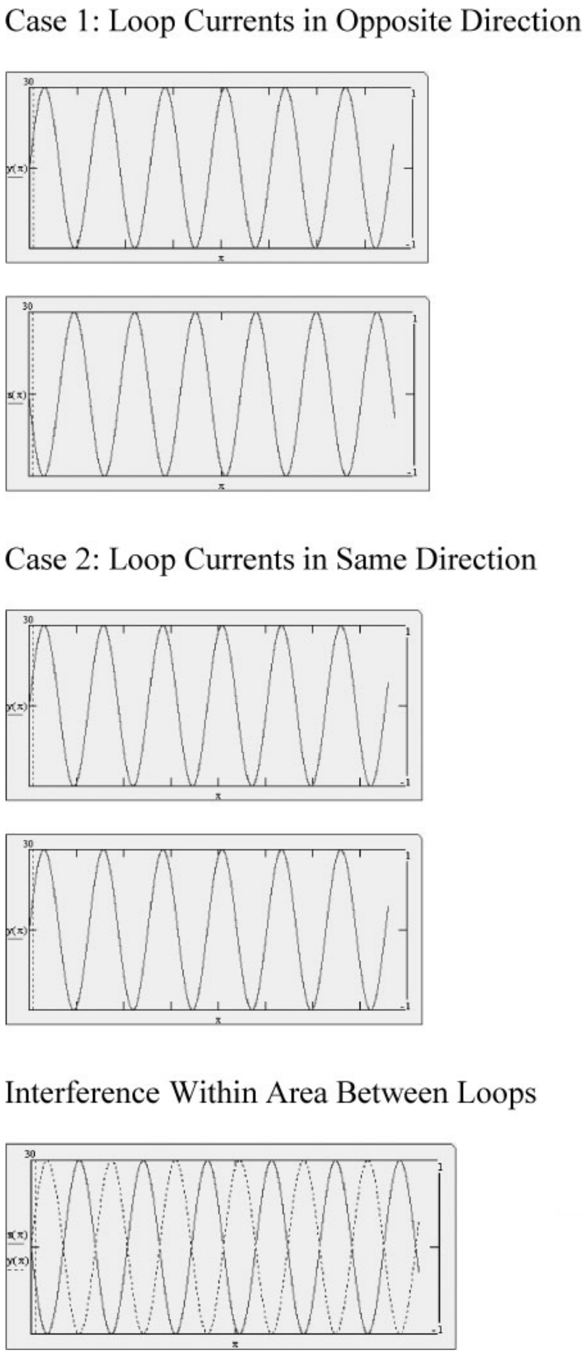
Figure 3 Figure shows map of the two loop experiment. The position numbers were locations at which experimental data points were recorded.

unnecessary. Yet, a double-loop configuration meets the necessary specifications as outlined above.

Methods

In this project, two loops approximately 30.5 m in length each as well as two teleloop amplifiers were used. The wires were taped down on a gym floor in the configuration shown in Figure 3. The width of each side was 6.1 m while the length was 9.1 m. They were placed 0.9 m apart from each other (approximately the width of an aisle).

Since the earpiece's electrical terminals were inaccessible for measurement, the equivalent resistance of the T-coil and hearing aid internal resistance was used for estimating the voltage across it. This paper uses voltage root-mean-square (V_{RMS}) across an equivalent resistance (500 Ohms) of the earphone piece as its measure of the input signal to the ear. In order to test the device at specific frequencies, a function generator was



Case 1: Loop Currents in Opposite Direction

Case 2: Loop Currents in Same Direction

Interference Within Area Between Loops

Figure 4 The various cases of voltage on the earpiece are outlined here.

used. This device's output was connected to the input of an Oticon amplifier system. An oscilloscope was then used to measure V_{RMS} across this equivalent resistance by connecting the probes to the two ends of the resistor (see Figure 3). The volume setting of the teleloop receiver was held constant throughout. Also, the height of the receiver with respect to the ground (0.9 m) and its orientation were held constant.

The experiment was conducted in three phases. First, an individual loop was powered and tested. Second, the loops were tested when they were both powered on to examine the interference and the effects of the overlapping magnetic fields. Reception was recorded for frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz. These frequencies are representative of certain vocal sounds: 500 Hz ("i," "o," and other sounds), 1000 Hz ("p" and other sounds), 2000 Hz ("g," "sh," and other sounds), and 3000 Hz ("k" and other sounds). The position numbers at which data points were recorded can be located on the two loops (see Figure 3). Positions were approximately 0.9 m apart (horizontally) inside the loops. The column of positions 3, 15, 27, 39, and 51 were measurement points located directly on the edge of loop 2. Positions 5, 17, 29, 41, and 52 were measured right over the left edge of loop 1, while positions 11, 23, 35, 47, and 59 represent the points on the right edge of the first loop.

In the second phase, the loops were powered in two different directions. First, data was collected when the two loop currents were directed in the opposite direction, while in the second case data was obtained when the loop currents were in same direction (see Figure 4). After the data was collected, analysis was done using a computer workstation.

Results

The results of experimentation done on the single loop show that audibility is essentially constant throughout the loop as desired (see positions 6–10, which are within the loop in Figure 5). Once the receiver was positioned near the edge or outside of the loop, however, the signal that it picked up decreased quickly (positions 5, 11–12 in Figure 5 and positions 11, 12 in Figure 6). Thus, it was confirmed that using the single loop worked well in covering approximately 9.1 m × 6.1 m or 55.5 m^2.

One of the variables explored was the response of the hearing aid receiver at various frequencies. It can be seen in Figure 7 that, of the four frequencies analyzed (500 Hz, 1000 Hz, 2000 Hz, and 3000 Hz), the signal received appeared to be strongest for the 2000 Hz signal (independent of measurement position), followed by the 3000 Hz and 1000 Hz signals, and weakest for the 500 Hz signal on the average. In addition, no

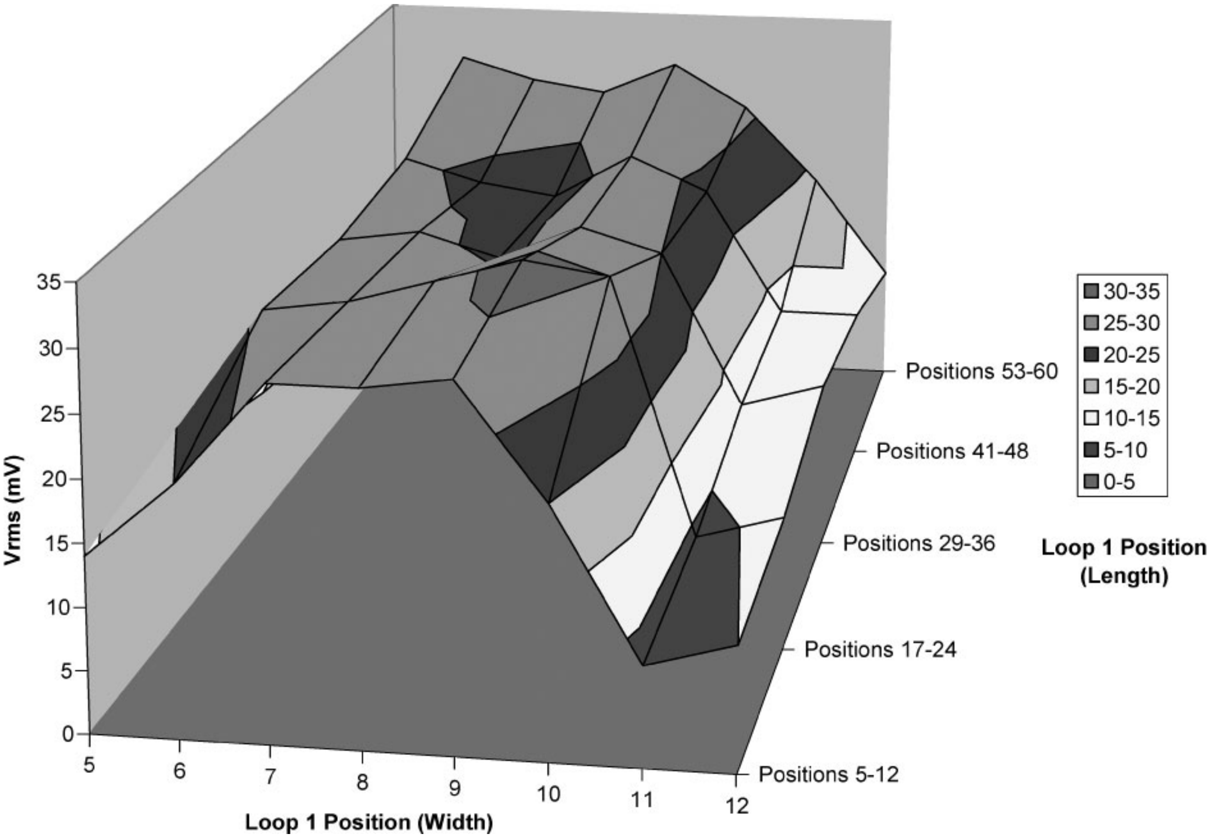


Figure 5 The position-dependent voltages in loop #1 are shown for a frequency of 500 Hz. The x-axis is analogous to the width of loop #1 (6.1 m) while the z-axis (depth) is analogous to the length of the loop (9.1 m).

phase shift was observed in the signal as the frequency was varied from 500 Hz to 3000 Hz.

When both loops were turned on simultaneously, the section between the two loops was analyzed. The graphical results can be seen in Figures 8 and 9. Figure 8 shows that when the loop currents were directed in the opposite direction, the clashing magnetic fields in the area between the two loops virtually cancel themselves out so that reception is very weak. In contrast, when the two loop currents are in the same direction, the magnetic fields complement each other, resulting in a stronger field between them (positions 27–29 in Figure 9). However, it was observed that the sections inside loop 1 and loop 2 that were near the edges (position 25–27, 29–31 in Figure 9) showed a decrease in reception as a result of interference caused by the magnetic fields. The signals of the two loops were in phase in the first case and out of phase in the second.

From the data it appears that applying the loop currents in the opposite direction (Figure 8) is most appropriate for the applications outlined here. Using this method, the reception is strong throughout the loop and weakest in the aisle (where none of the audience is seated). In an optimal configuration, the loops would be placed as close to one another as possible so that the area with poor reception (between the loops) is minimized.

Discussion

This project explored using a double (or multiple) loop configuration in a large environment such as an auditorium or meeting place. In terms of design, issues ranging from ease of setup to mobility were taken into account. There are several advantages to using such a configuration. In addition to those mentioned, there is another reason for using multiple smaller loops instead of one large loop (no matter what the loop configuration is). Using multiple loops allows more

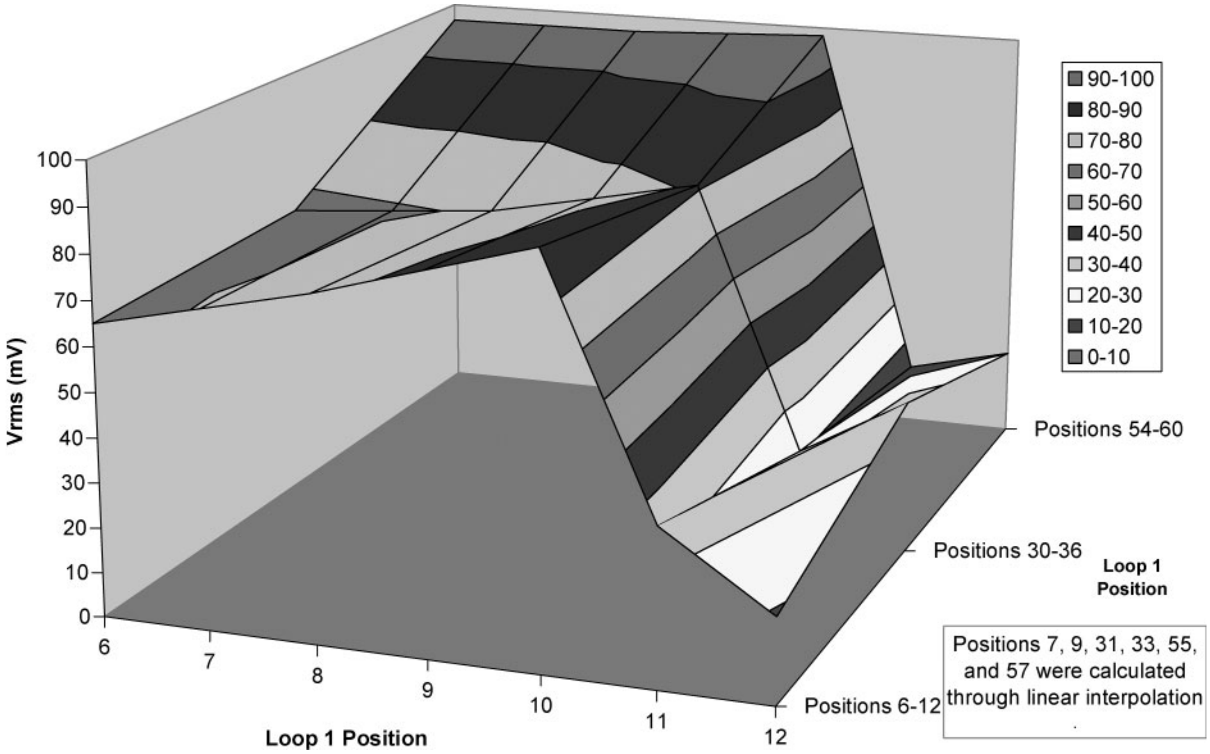


Figure 6 Decreased reception (V_{RMS}) is seen near the edge of a loop (using a frequency of 1000 Hz). The reception decreases dramatically outside the loop.

versatility. If meeting rooms are small enough and separated, the two loops can be used in different locations simultaneously. Also, it is easier to fit a large auditorium with several smaller loops than with one large one. This is because with multiple loops, small loops can be added to fit the area of an auditorium optimally, especially if it is irregular in shape. If one has only one loop, then that loop needs to be long enough to encompass the largest room in which it is ever used. Other advantages of using multiple loops as outlined in this paper are cost and mobility. The longer the individual loop, the higher the cost, weight, and bulkiness of the amplifier that drives the loop. Thus, using smaller loops makes it easier to pack in small boxes and thereby increases mobility.

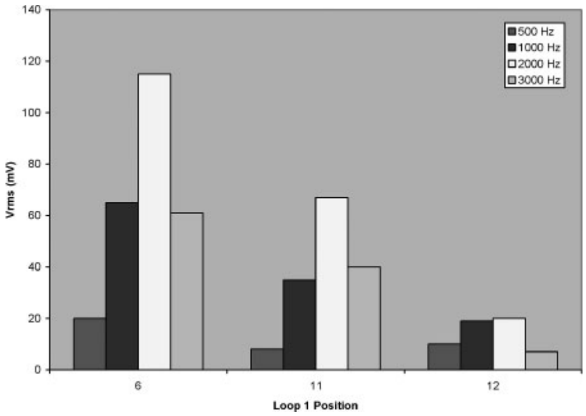


Figure 7 The reception was influenced by the frequencies used. The best reception was achieved near 2000 Hz relative to the other frequencies irrespective of where the measurement was taken.

Although this project only tested a double-loop configuration, multiple loops could easily be used to fit other types of rooms. For example, many auditoriums have a configuration that contains three sections separated by two aisles on the sides of the main section. For this application, a three loop system would be convenient with the loop edges near each other in the two aisles. Using this type of loop configuration lends itself to other similar applications. A movie theater and a playhouse often have similar seating arrangements so such a configuration is useful in these cases as well.

There are certain problems with using a multiple-

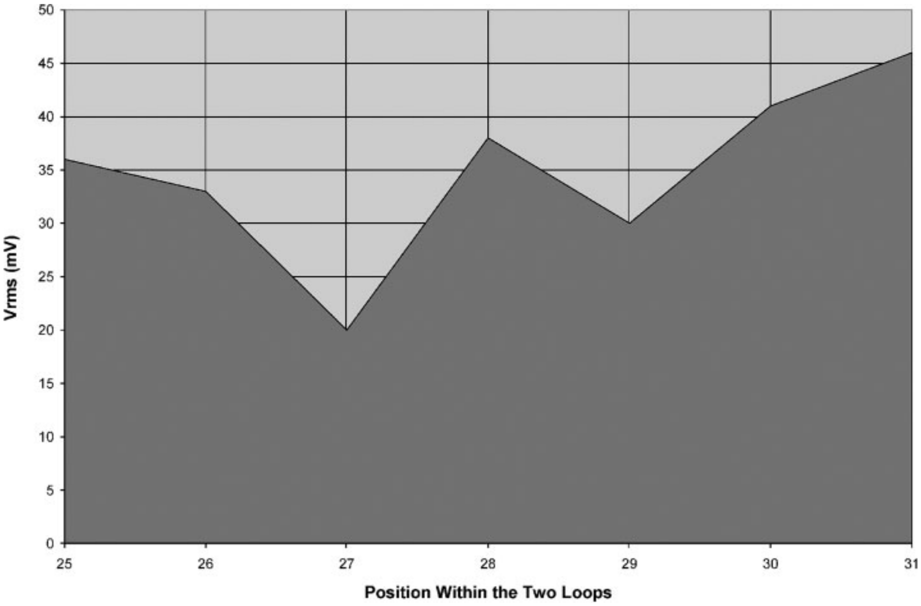


Figure 8 Reception is shown in the region between the two loops. Here, the currents are applied in the opposite directions resulting in a detrimental effect near the edges of both loops (points 1–3, 5–7 on the x-axis)

loop ILA system. First, it has been noted by Bellefleur and McMenamic (1965) that hearing aids "will amplify and transmit the noise generated by fluorescent lights." Thus, the ILA method may not be the optimal choice for all types of rooms. However, this interference usually does not adversely affect the reception to such an extent that the understanding of the speech is severely impaired. Therefore, it would be appropriate

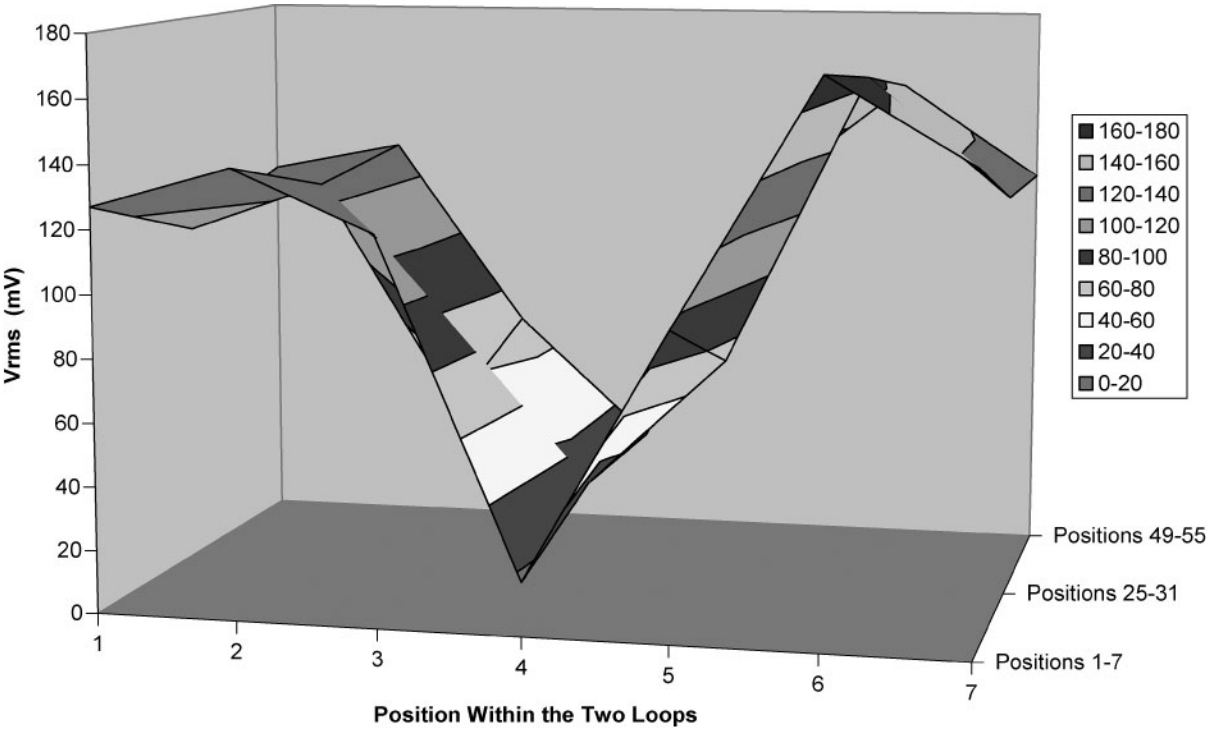


Figure 9 The result of two clashing magnetic fields (see Figure 2) is quantified here. The area between the loops (points 2–6 on the x-axis) is adversely affected as currents are applied in the same direction.

to test a room with a loop system prior to scheduling a meeting in order to check interference.

Another problem with this method is that the signals picked up by the hearing aids (using the T-coils) can be dramatically affected by the orientation of the hearing aid receiver. In most cases this is unimportant since the individuals are usually seated while in a meeting room or auditorium setting so the hearing aid is in the same orientation throughout. This problem can be important in classroom applications where students are involved in activities and move around often.

Other nontechnical issues need to be considered as well. ILA can allow for special broadcasts to hard-of-hearing individuals that are different in content from that given to the hearing population. In large international meetings or conferences, ILA loops can be used to communicate in different languages to select members of the audience. For example, one loop can broadcast the speech in English and other can include Spanish so that the listener can choose the language based on seating. Alternatively, the use of ILA in this setting could be utilized to broadcast tone and prosody information that is hard to convey via signing without affecting the hearing population in the audience. Lastly, ILA can reduce the need for someone signing near the stage, which would allow greater freedom of seating for hard-of-hearing listeners in a large auditorium. The listener also does not then have to be in the line-of-sight of the signer. Thus, both technical and nontechnical engineering issues are important in the design of an optimal ILA system layout and need to be based on both the auditorium specifications and listener preferences.

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