Audiology and Communications Technology *A Symbiotic Relationship*

by Harry Levitt

Advances in technology can have a profound effect on a field. Audiology, in particular, has been markedly dependent on technological innovation. The vacuum tube amplifier, transistor, and digital technology, for example, have had a remarkable and far-reaching impact on the field. So much so, that it is often thought that audiology is parasitic (in the biological, not social sense) on developments in other fields, most notably that of communications technology.

This is not the case. The two fields have a symbiotic relationship. It is true that, for the most part, advances in communications technology have benefited the field of audiology, but there are also cases where advances in audiology have been of benefit to other fields, including communications technology.

Early Developments

Methods for diagnosing hearing loss and aural rehabilitation—that is, the field of audiology before it was given a name—existed long before the era of electronic communication. Although the techniques and instruments used at the time were crude by today's standards, the engineering involved was in many cases quite brilliant given the limited technological resources available. The speech-training episode in the play "My Fair Lady" provides a revealing glimpse of some of the clever instruments used for speech training in the 19th century.

The development of a practical telephone was a direct result of Alexander Graham Bell's work on a speech training aid. His wife was deaf and he was trying to develop an instrument that would provide a visible representation of the speech signal for purposes of speech training. The problem was that of converting acoustic vibrations in air to mechanical vibrations of a mechanical object, in this case a stylus that would trace out an oscillographic representation of the speech signal on glass covered with lamp black. This was essentially the same problem limiting the development of a practical telephone. After studying how the ear worked, Bell came up with a solution. By analogy with the functioning of the eardrum, he developed a diaphragm that would integrate acoustic energy in air over a wide area so as to drive a small mechanical object. Thus, one of the most important inventions of the 19th century owes its development to work on an instrument for speech training.

Telephone engineers soon developed electrical methods of amplifying speech signals. One method of electrical amplification used the principle of the carbon microphone as the key element. When carbon granules are compressed, their electrical resistance changes. The electrical signal to be amplified is passed through a coil that drives a diaphragm pressed against a body of carbon granules. A battery is used to drive a second electrical current (the output current) through the carbon granules. Fluctuations in the input electrical signal cause the diaphragm to vibrate causing pressure fluctuations on the carbon granules producing corresponding changes in their electrical resistance that, in turn, cause the output electrical signal to vary. The fluctuations of the output signal mirror those of the input signal, but are of larger amplitude.

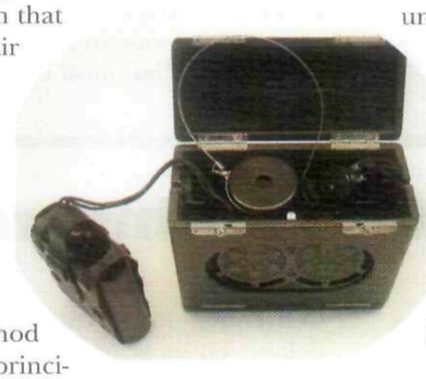

Photo courtesy of Central Institute for the Deaf

An electrical hearing aid using this method of amplification was patented at the end of the 19th century, a revealing forerunner of the technological revolution to follow (see sidebar, line 3).

Electrical hearing aids were large and unwieldy. They also introduced considerable distortion and were not widely used.

Everything changed with the invention of the vacuum tube and the subsequent development of the vacuum tube amplifier by Lee DeForest of the Western Electric laboratories (later to become Bell Telephone Laboratories). Electronic amplifiers not only provided more gain than the older electrical amplifiers, they had much greater bandwidth with low internal noise and relatively little distortion. More importantly, signals could be processed with great flexibility, such as filtering to obtain a desired frequency response or generating test signals by means of an oscillator. The audiometer was invented soon after the development of the electronic oscillator and the electronic hearing aid was introduced soon after the development of a practical electronic amplifier (sidebar, line 4).

Telephone engineering improved steadily over the years and by the 1920s telephones were being manufactured that were both serviceable

Photo courtesy of Central Institute for the Deaf

> The pioneering research performed at Bell Telephone Laboratories was perhaps the most important contribution of the communications industry to the field of audiology.

and rugged. It was discovered that if one placed one's fingers on the diaphragm in the earpiece of a telephone, it was possible to feel the vibrations of the diaphragm. This led to a flurry of research on the perception of sound by tactile means. The tactile perception of speech was of particular interest. Although it was found that relatively little speech information could be transmitted in this way, this limited information was nevertheless very useful if used properly. This research spurred the development of a range of tactile assistive devices such as tactile supplements for speechreading, wearable speech training aids, and alerting devices (sidebar, line 5).

Researchers working on the tactile perception of speech soon recognized that a single vibrator provided very limited information and that several vibrators could provide substantially more information. This research led to the development of the tactile vocoder in which speech is subdivided into a set of contiguous frequency bands and the signal in each frequency band is delivered to a separate vibrator, that is, one for each finger. Although the tactile vocoder did not prove to be as successful as initially envisioned, the importance of the underlying concept was recognized leading to the subsequent development of channel vocoders for low bandwidth speech transmission. In this case, an advance in communications technology resulted from an advance in audiology (see the direction of the arrow in line 6 of the sidebar).

The invention of the cathode ray tube in the 1930s revived interest in the use of visual displays for speech training. These early oscilloscopic displays, however, proved to be too complex for this application. In later years, improved video technology coupled with innovative ways of representing speech facilitated the development of practical speech training aids (line 7).

The explosive growth of both telephone and radio during this period created an enormous demand for smaller, more efficient electronic components. Miniature vacuum tubes with low power requirements were developed as part of this process. The cost of these and other electronic components was also low because of large-scale mass production. The availability of inexpensive miniature electronic components allowed for the development of hearing aids that were not only small enough to be wearable, but also affordable to large numbers of people (line 8).

This development marked a turning point for audiology. The need to fit wearable hearing aids to a large and growing number of individuals presented a challenge to the field, particularly since the audiological considerations involved in fitting wearable instruments were little understood at the time.

World War II and the Evolution of Audiology

The Second World War also produced a substantial increase in the number of individuals requiring acoustic amplification. Nationwide efforts were made to address this problem, and major studies were undertaken to determine the most effective way of providing acoustic amplification for the many war veterans with hearing loss. New audiological techniques were developed and the field evolved substantially.

Researchers at Bell Telephone Laboratories engaged in a number of secret research projects during the war. One of these projects, the development of the sound spectrograph, had important implications for audiology. Of the many peacetime applications envisioned for the sound spectrograph, its possible use in providing a visual representation of speech for people who are deaf was particularly intriguing. An instrument for analyzing and displaying the speech spectrum in real time was developed for this purpose (the Visible Speech Translator, line 9). Although experimental evaluations of the device showed that it was not practical as a means of communication, there were other applications for which the sound spectrograph was eminently well suited. The visual representation of speech provided by the sound spectrograph has proved to be invaluable for the field of acoustic phonetics as well as for teaching and research in audiology.

Another secret wartime development was the digitization of speech. The purpose of this project was to develop an unbreakable code for transatlantic telephone calls between Roosevelt and Churchill. Although the digital encoding of speech was not eventually used as planned, the methods developed for digitizing speech—processing speech in digital form, and then converting it back to an analog signal—would be used again many years later (line 10).

Both of the above wartime projects resulted in technological advances that benefited the field of audiology. There was, however, one wartime development where an advance in audiological engineering was of great value to military

See ***Audiology Technology*** *page 17*

Advances in Audiology and Communications Technology

A summary of the symbiotic relationship between advances in audiology and advances in communications technology (and related technologies). Line 1, for example, shows that a major advance in communications technology (the telephone) resulted from an advance in the emerging field of audiology. Note the direction of the arrow between the two columns. Line 2 in the table shows that the invention of the phonograph provided the means for developing standardized speech tests. The direction of the arrow in this case shows that an important advance in audiology resulted from an advance in communications technology.

Advances in Technology		Advances in Audiology
1. Telephone	←	Speech training aid
2. Phonograph	→	Recorded speech tests
3. Electrical amplifier	→	Electrical hearing aid
4. Electronic amplifier	→	Audiometer, Electronic hearing aid
5. 1920's telephone	→	Tactile aid
6. Vocoder	←	Multi-channel tactile aid
7. Oscilloscope	→	Electronic speech training aid
8. Miniature vacuum tubes	→	Wearable hearing aid
9. Sound spectrograph	→	Visible speech translator
10. Speech encryption	→	Digitization of speech
11. Military applications	←	Robust hearing aid components
12. Transistor	→	BTE hearing aids
13. Integrated circuits	→	ITE, ITC hearing aids
14. Computers and digital technology	→	Digital aids, new diagnostic tools
15. Biomedical technology	→	Cochlear implants
16. Wireless technology	→	Assistive listening devices
17. Low power digital technology	←	Wearable digital hearing aids
18. Serendipitous advances	→	TTY, telecoils, basic research findings

Photo courtesy of Central Institute for the Deaf

Audiology Technology *from page 5*

communications and other technologies. The vacuum tubes used in wearable hearing aids were designed to withstand shock and vibration and were found to be invaluable for wartime applications in which conventional vacuum tubes proved to be too fragile (line 11). The successful development of the proximity fuse, for example, was due in large measure to the use of robust miniature vacuum tubes developed initially for use in hearing aids.

The Transistor and Beyond

The invention of the transistor at Bell Telephone Laboratories and the subsequent development of integrated circuits had as profound an impact on audiology (as well as on almost every other field) as the invention of the vacuum tube amplifier almost 50 years earlier. As before, this crucial development was driven by the needs of the communications industry. The transistorized hearing aid was the first commercial application of this new technology outside of the communications industry. The small size and low power consumption of the transistor allowed for the development of hearing aids small enough to fit behind the ear. The subsequent development of integrated circuits allowed for even greater reductions in the size of hearing aids leading to the development of hearing aids small enough to fit entirely in the ear canal (lines 12 and 13).

Cosmetic considerations were the driving force behind the trend toward smaller hearing aids. Now that they are small enough to be virtually invisible, a new trend has emerged, that of developing improved methods of signal processing. Modern hearing aids now include advanced methods of amplitude compression, feedback cancellation, beamforming microphone arrays for increased directionality, and other methods of speech enhancement.

The solid-state revolution spawned another major advance—digital signal processing. This technology has had a profound impact on virtually every field. The development of tiny solid-state circuits of massive complexity reduced the size of digital computers from huge mammoths used for research in the 1950s to small, relatively inexpensive devices that are widely used in clinics, schools, and homes as well as in industry, commerce, and research. The full impact of this technology on audiology has yet to be realized, but the field has already undergone significant changes with the development of digital hearing aids and computer-based diagnostic techniques (e.g., ABR, EEG, fMRI, otoacoustic emissions, line 14).

Advances in biomedical engineering coupled with micro-miniature circuitry and signal processing techniques developed for speech transmission (e.g., the channel vocoder) facilitated the development of the cochlear implant (line 15), which, in turn, has opened up a whole new area in audiology.

The latest development of digital wireless communication is just beginning to have implications for audiology. Wearable hearing instruments that are integrated with other communication devices represent one intriguing possibility (e.g., cell phones with built-in hearing aids, wireless alerting devices, line 16).

Audiology has benefited substantially from these advances in computer/communications technology. There is, however, one area in which audiology has taken the lead. Micro-miniature, low-voltage digital chips were developed specifically for digital hearing aids. This technology is now finding other, more general applications (such as micro-miniature digital devices for hearing people) that are subject to the same size and power constraints (line 17).

Serendipity has also played a role in this symbiotic relationship (line 18). Early telephone receivers used a fairly powerful electromagnetic field to drive the diaphragm in the earpiece. It was observed that if a coil was placed close to the handset, the electromagnetic field would induce a measurable voltage across the coil. This observation led to the development of the telecoil, which allows a hearing aid to connect to a telephone electrically thereby avoiding any acoustic noise that would otherwise be picked up using a microphone input. Modern telephones no longer need a strong electromagnetic field, but they are now required by law to provide such a field for the benefit of hearing aid users who use telecoils.

The telephone was designed for transmitting speech, but it can also be used for transmitting other signals provided they can be encoded in acoustic form. The Baudot code, which uses tonal signals to encode text, was the first code of this form. Teletypewriters embodying the Baudot code were used extensively in commerce and industry until they were replaced by computers using more efficient codes. The teletypewriter or TTY was initially too expensive for personal use by people who are deaf, but with the invention of the acoustic coupler, it was possible to use a conventional telephone for transmitting text using an inexpensive variation of the TTY. This invention opened up the telephone network to deaf people and the TTY, including computer-based versions, has since become the second most widely used assistive device after the hearing aid.

The pioneering research performed at Bell Telephone Laboratories was perhaps the most important contribution of the communications industry to the field of audiology. The early, classic research of Harvey Fletcher and his colleagues will remain a legacy for all time. Their research included psychoacoustics; speech analysis, synthesis, and perception; methods for quantifying and predicting speech intelligibility, including the effects of hearing loss on speech intelligibility; and the development of the most basic audiological tools (audiometer, electronic hearing aid). The shortened name, Bell Laboratories, is now used to reflect the broader contribution of these laboratories to science and technology.

***Harry Levitt** earned his PhD from London's Imperial College of Science and Technology in 1964 and then joined Bell Laboratories. In 1969, he joined the faculty at the City University of New York (CUNY). Levitt retired from CUNY in January 2000, but is still affiliated with the university as a Distinguished Professor Emeritus.*