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Amplified Phones: More than Just Making Speech Louder

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As a young professor of physics, Wallace Sabine made his mark at Harvard University by studying the poor acoustics of two newly built lecture halls. His studies came at the urgent request of Harvard's president who fielded numerous complaints about the inability to hear and understand the lectures given in these halls. Professor Sabine had such a stellar career in studying acoustics, that he became known as the father of acoustics in the United States.

In 1895, Professor Sabine outlined the components necessary to achieve good hearing (Sabin, 1964). Essentially, he stated that:

1) the speech must be sufficiently loud,

2) the simultaneous components of speech (i.e., the vowel sounds vs. the consonant sounds) must maintain their relative properties,

3) the successive sounds of rapidly moving articulation should be clear and distinct from each other, and

4) the speech sound must be distinct from extraneous noise.

These elements of good hearing are as true today as they were when Sabine first enumerated them over 115 years ago. The difference is that today, we can measure and quantify these elements.

It was only 19 years earlier that Alexander Graham Bell uttered the first intelligible sentence over what he called the "acoustic telegraph:" "Mr. Watson, come here, I want to see you." In 1915, Bell made the first transcontinental call from New York to San Francisco. It was then that the telephone became a serious contender to the telegraph as a means of long distance person-to-person communication.

Alexander Graham Bell emigrated from Scotland as a teacher of the deaf. He later became a professor of Vocal Physiology and Elocution at Boston University and worked on ways to translate the human voice into vibrations. Although his work culminated in the telephone, the primary aim for his new invention was to help his hearing impaired mother. It turned out that his phone was better suited for long distance communication between normal hearing users than for helping those with hearing impairment. Back then, phones lacked amplification - so they unfortunately offered little help for those with a hearing loss. Today phones can be designed with amplification and can incorporate other types of technology to assist those with significant hearing loss.

In the early 1900's, owning a phone was a luxury. Today it is a necessity. So for those with a hearing loss who find it difficult to hear over the phone, their life becomes even more isolated. Good communication over the phone reconnects loved ones, friends, and associates and serves to overcome the isolation that so often accompanies hearing loss. The popular ATT&T advertising slogan to "reach out and touch someone" was meaningless to those with a hearing loss who could not hear and understand using a phone.

HEARING LOSS IN THE US

Hearing loss in the United States has been on the increase. A number of reasons have been implicated. These include:

1) AGING.

Because of better health and medical care, life expectancy has increased dramatically in the last 100 years. As a result, we are living longer. Unfortunately, aging is associated with hearing loss and the prevalence for those over 65 years of age is 3 in 10; for those over 75, it is nearly 5 in 10 (Bess and Humes, 2008).

2) OTOTOXIC MEDICATIONS.

The number of drugs is growing annually. Research and development has resulted in many new medications on the market to treat a variety of ailments. But every drug has its side effects; and the side effect of a number of medications includes hearing loss. Witness, for example, the recent link of Viagra and the long-term use of aspirin with hearing loss.

3) DECREASED MORTALITY RATES FROM BIRTH DEFECTS AND ACCIDENTS.

The advancements in medical science in sustaining the life of infants born with life-threatening conditions have been dramatic. Children that would have died decades ago are saved today; but sometimes, hearing loss is a condition that remains. And soldiers that would have died on the battlefield in Vietnam are now saved with prompt and advanced medical treatment in Iraq; but again, hearing loss can be a lingering issue.

4) NOISE EXPOSURE.

Our world seems to be getting noisier and noisier. With the advent of modern, mechanical equipment, there are greater chances of over exposure from noise. Despite the presence of OSHA, occupational hearing loss remains a serious problem. And recreational hearing loss from firearms, ski jets, snowmobiles, personal sound systems, etc, is on the rise. According to the National Institutes of Health, approximately 1/3 of all hearing loss can be attributed to noise exposure (NIH, 1990).

With the prevalence of hearing loss on the rise, the need for good amplifier phones will become more and more important.

THE SOUND OF SPEECH: How it's Generated and Transmitted in a Phone

Speech sounds are generated by the movement of the vocal chords and the turbulence created when air passes between the tongue and the pallet, lips, or teeth. When the vocal cords vibrate, they generate a set of low frequency tones. These tones are modified by the resonance formed by the throat, mouth, and nose. For example, while holding your vocal box and keeping the same pitch, vocalize the /ee/, /ah/, and /oo/ sounds. Notice how your vocal box vibrates. This is from the vibration of your vocal cords. Notice also how different they sound. This is because of the changing shape of your throat and mouth, which in turn, changes the resonance of this cavity and, hence, the spectral shape of the vocalized sound.

In contrast to the vowel sounds, consonant sounds are generated with air passing through the lips, teeth, and tongue, and pallet. There is no vocal cord vibration. For example, hold your vocal box and say the /f/, /s/, and /th/ sounds. Note there are no vibrations coming from your vocal box and there is no pitch-like quality to the sound. Instead, the sound is softer and has a noise-like character, such as a hissing sound. Yet each sound is a bit different because of the subtle way air leaves the mouth.

In a telephone, the microphone in the mouthpiece of the handset transforms voice into electricity. When the air vibrations of your mouth reach the diaphragm in the microphone, it vibrates. This vibration is much like the feeling you get in your hands when you are holding a can of soda or a bottle of water and a jet passes over or loud music is playing. Because the diagram in the phone is metallic, its vibration changes the surrounding electrical field, which in turn, creates fluctuations in electrical current that mimic the sound wave. Because these electrical currents are so tiny, a small amplifier is needed to boost their volume in order for the current to pass into the phone for processing. Once processed by the phone, these electrical fluctuations pass into the telephone wire, through your house wiring, and onto relay and switching devices installed and maintained by your local phone company.

The phone company has a series of boosters that ensure the signal volume is maintained. In addition, its switching equipment ensures that the signal is fed to the proper phone. As the signal enters the listener's phone, the electrical currents are transformed back into air vibrations by the speaker. This component is in the receiver of the handset, the part you hold up to your ear. When the electrical currents enter the speaker, they go into a coil that creates a magnetic field. The changing magnetic field causes a diaphragm in the speaker to move in exact synchrony with the voice at the transmitting end. The vibrating diaphragm generates sound waves which is the voice of the caller. (For a good video clip on how this works, visit http://communication.howstuffworks.com/telephone.htm)

Sound is characterized by its level and frequency. The level (or loudness) of a sound is given in decibels (dB) – which is 1/10th of a bell (in honor of Alexander Graham Bell). 0 dB represents the softest sounds that normal hearing individuals can hear. 60 dB is the level of conversational speech. 100 dB is the level of a loud rock group playing in a hall. 120 dB is the level considered uncomfortably loud. Hence, the range of hearing is 0 to 120 dB.

Frequency is the number of times every second that a vibration occurs. This is called hertz (Hz). A tuning fork is an example of a source that generates a single frequency or tone. A fork with the number "256 Hz" on it means that its tines vibrate back and forth 256 times per second, which is middle C on the piano. Because the range of hearing is 20 to 20,000 Hz, a tone of 256 Hz is considered a low frequency sound.

Voice is a complex, broadband source. In other words, voices generate multiple tones in a complex frequency pattern and air noise that fluctuates in a complicated temporal pattern. Voice sounds in normal conversation range from about 200 to 6000 Hz. Because of their design, telephones are unable to pass the full speech range. Instead, most phones only pass frequencies between about 300 and 3300 Hz. But this is not a big limitation because in sentence conversation, speech understanding for normal hearing individuals over the phone is better than 95%.

The tones of speech as generated by the vocal cords occur below 1000 Hz. Accordingly, vowels sounds are considered low frequency sounds. In contrast, the fricative noise of speech as generated by the movement of air through our mouths, occur above 1000 Hz. Accordingly, consonant sounds are considered high frequency sounds.

HOW WE HEAR

Human hearing involves the transformation of sound that propagates through the air to a series of electrical impulses that transmit to the brain. This transformation is a result of three anatomical components: the outer, middle, and inner ear. The outer ear consists of the pinna and the ear canal. Together, these organs protect the delicate parts of the middle ear and boost the level of speech in the 3000 to 4000 Hz range. This is important because certain consonant sounds, such as the /s/ and /f/ sounds, peak at these frequencies. This boost helps us hear these weaker sounds.

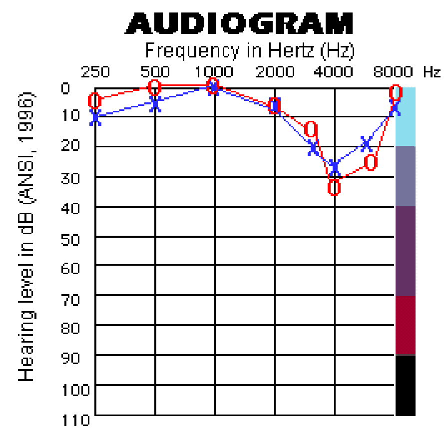
The middle ear is a cavity surrounded by bone and filled with air. It consists of the eardrum and the three smallest bones in the body called the hammer, anvil, and stirrup. The job of the middle ear is to boost and carry the sound from the air-filled ear canal to the fluid-filled cochlea. Sound does not penetrate fluid very well. For example, in a pool with children yelling and laughing, when your head sinks below the water, you barely hear them. In hearing, the middle ear serves as an effective bridge to help transfer the sound from air to fluid. The process works best when the air pressure on both sides of the eardrum is equal. Because the air pressure in the middle ear keeps dropping, one swallow will open the Eustachian tube – the long tube that connects our mouth with the middle ear – to allow air to rush back into the middle ear and restore the pressure balance.

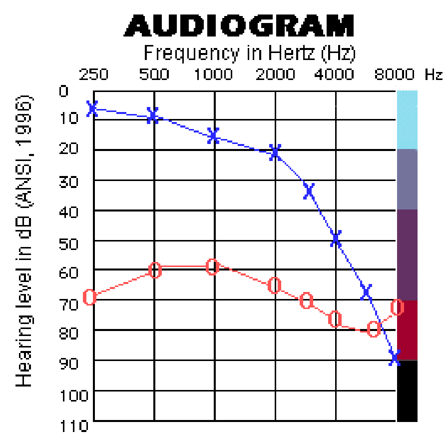
The inner ear consists of the cochlea and the auditory nerve. The cochlea is an organ the size of a pea and is shaped like a snail. Inside are three fluid-filled ducts that run the full length of the cochlea. When sound is introduced into the cochlea from the vibrating stirrup bone, it sends the wave through these long ducts. Each part of the duct is tuned to different frequencies such that the high frequencies peak near the entrance and the low frequencies peak near the end of the tube.

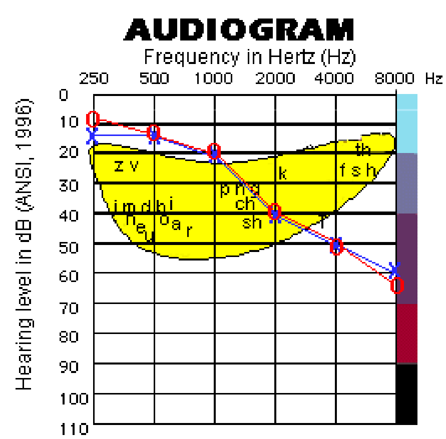
The middle duct is lined with thousands of cells that have hair-like filaments that project into the fluid. They are arranged much like the keys on a piano. When high frequency sound peaks near the entrance, only those hair cells in that area are stimulated. When a low frequency sound peaks near the end of the tube, only those hair cells are stimulated. In each case, the stimulated hair-cells generate neural impulses that transmit along the auditory nerve. These impulses are carried to the brain where they are perceived as sound.

HEARING LOSS AND AMPLIFIED PHONES

Much of what we know about speech production and hearing comes from the early research of the Bell Telephone system. This early research identified the normal range of hearing as extending from 20 Hz to 20,000 Hz and from 0 dB to 120 dB. Speech sound falls inside this range, say from 300 Hz to 6000 Hz and from 20 to 50 dB. When an audiologist conducts a pure-tone test, only the frequencies just outside this range are tested, i.e., from 250 Hz to 8000 Hz.







A graph that shows hearing sensitivity is called an audiogram. It is a plot with Xs for the left ear and Os for the right ear that indicate how loud a sound must be at each frequency for the patient to just hear it (called a threshold). The 0 dB line is the normal threshold line. As our hearing gets worse, the Xs and Os drop below this line and speech sounds get weaker. Hearing loss is defined as thresholds that fall more than 20 dB below the 0 dB line.

There are complications of hearing impairment other than just a loss of sensitivity. First, there can be a poor frequency balance. In most hearing losses, the high frequency thresholds (i.e., the tones above 1000 Hz) are significantly poorer than the low frequencies. With this pattern, consonant sounds are much weaker than vowel sounds. Consequently, speech sounds are muffled.

Another complication is recruitment. Recruitment is defined as an abnormal growth of loudness. This means that once a sound is loud enough to be heard, its loudness grows rapidly with further increases in level. There are audiological tests that measure or indicate if this is a problem. The presence of recruitment indicates that many outer hair cells in the cochlea are damaged.

If a lot of inner hair cells in the cochlea are damaged, then speech sounds undergo an aural distortion. In many cases, this distortion exists no matter how much amplification a person is provided to overcome a loss of sensitivity. Audiologists normally conduct speech recognition tests and speech in noise tests to determine the degree of cochlear or neural distortion that a patient experiences.

APPLYING SABINE'S FINDINGS FOR TELEPHONES

Sabine never had a telephone and his subjects did not involve the hearing impaired. So his research could not have included hearing over the phone by the hearing impaired. Nevertheless, his findings on what it takes to hear and understand speech are as relevant to communicating over the phone as they are in a lecture room. Let's take each "rule" individually.

1) The sound must be sufficiently loud. If speech from the phone is not loud enough, there is no hope of understanding. Hence, amplification is needed to overcome a loss of sensitivity. The decibel is used to represent the amount of amplification (or gain) of a signal. To a scientist, a gain of 3-dB is a doubling of the energy of the sound. But to a human, a 3-dB increase is just noticeable. A 6-dB increase would be four times the energy, but only a significant change in loudness for a human. Whereas a 10-dB increase is a 10-fold increase in energy, it is only a doubling in loudness. Going further, a 20-dB gain is a 100-fold increase in energy, but a quadrupling of loudness. A 30-dB increase would be a 1000-fold increase in energy, but a corresponding increase in loudness of eight times.

As discussed above, recruitment is a complication of most hearing losses. So using too much amplification can make speech sound uncomfortably loud. As a result, amplification must be limited or controlled in some manner in order for most hearing impaired people to hear comfortably over the phone.

2) The simultaneous components of speech must maintain their relative properties. If a person has a greater loss in the high frequencies, then the consonant sounds (e.g., /s/, /th/, and /f/) won't be as audible as the vowel sounds (e.g., /i/, /e/, and /o/) and speech will sound muffled. To meet Sabine's rule, the phone must have an equalization circuit that gives a greater boost to the high frequency sounds. How much of a boost depends on the degree of hearing loss. Some amplified phones have a "tone" control that is adjustable. This equalization process improves the clarity of the speech.

3) The successive sounds in rapidly moving articulation should be clear and distinct from each other. While this requirement of Sabine really applied to the reverberation in a listening room, in a more general sense, it has to do with the clarity of each syllable. In electronics, there is no reverberation; but amplification can produce distortion of the syllables. This means that extra sounds are generated that are not part of the original signal and this makes the speech fuzzy and distorted. To achieve high intelligibility, the quality of a phone must be such that it generates a clean signal with low distortion.

4) Speech sounds must be distinct from extraneous noise. Speech can be hard to understand when the background noise is high. So a quiet room is necessary for good phone conversation. But this concept is true of the "noise" from the phone as well. This noise can come from the background noise around the caller or the line-level noise within the telephone circuits. In psychoacoustics, we use the "signal to noise (S/N) ratio" as a way to measure the level of speech relative to the level of the noise – any noise. For normal hearing people, normal intelligibility can be achieved with a S/N ratio

better than 15 dB. But for hearing impaired individuals with cochlear or neural distortion, a greater S/N ratio is needed. In telephones, when the signal is amplified, so too is the line noise. So the S/N ratio remains the same. To improve the S/N ratio, a noise reduction circuit is required to suppress the line noise and enhance the S/N ratio.

In summary, here are the important performance parameters for amplified phones:

1) *Amplification (gain) – to make the caller's speech louder.*
2) *Compression (loudness limiting) – to ensure a comfortable experience talking over the phone.*
3) *Low distortion (clarity) – to ensure the clarity of the amplification.*
4) *High frequency enhancement (tone) – to enhance the high frequencies for better spectral balance and intelligibility.*
5) *Noise reduction (noise suppression) - to enhance the signal to noise ratio*

REALISTIC EXPECTATIONS

Every hearing impaired person will benefit from the five enhancement features listed above. But because of complications in some hearing losses, reduced cognitive function, or loss of neural function, even the best of signals can still be hard to understand and follow. In addition, the quality of the caller's voice can vary dramatically. A young grandchild may be shy and speak softly, a woman's voice may be high-pitched, or a friend's voice may be distorted from a vocal pathology or years of smoking. So when a phone does not seem to be working well, it may very well be a receptive problem with the listener's hearing or an expressive problem with the caller and not the phone.

One way to ensure the quality of the voice is to listen to a standardized voice; one that is produced and recorded professionally. This is important to ensure the voice is consistent in quality and the material is uniform in usage. While the telephone industry uses a set of standardized sentences for its own testing, audiology clinics commonly use the Quick SIN (Speech in Noise) test for testing patient's understanding of speech, especially in noise.

The Quick SIN uses short sentences with five target words in each sentence. Six sentences makes up a complete test. Normally, the background noise placed in the recording increases with each sentence to assess how well a patient performs with background noise. However, for the subjective test of telephone quality, these sentences can be delivered without the background noise. When listening to the sentences, the user can make adjustments in volume (amplification), frequency compensation (tone), and other features as instructed by the manufacturer to arrive at the optimum setting.

Comparing your performance using two sets of sentences gives you an indication of repeatability. Then comparing your performance with that of a normal hearing family member gives you an indication of your overall performance. The same type of test could be used to compare different phones.

Telephones were not part of Wallace Sabine's world or his research. However, the rules he gave for good speech understanding more than 100 years ago are essentially true today as they were back then. Amplified phone development will continue to improve. This will be more important as a great number of people will encounter hearing loss. An examination by an audiologist will help to demystify your hearing loss and give that audiologist important information for making recommendations. Just as understanding a person's hearing loss helps an audiologist prescribe the settings of a hearing aid, the same information will be useful in establishing the proper settings of the enhancement features on an amplified telephone.

REFERENCES

Bess, F. H. and Humes, L. E (2008). Audiology: The Fundamentals. New York, Lippincott Williams & Wilkins.
National Institutes of Health (1990). Noise and Hearing Loss. NIH Consensus Development Conference Consensus Statement 1990, Jan 22-24: 8 (1)
Sabine, W. C. (1964). Collected Papers on Acoustics. New York, Dover.

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