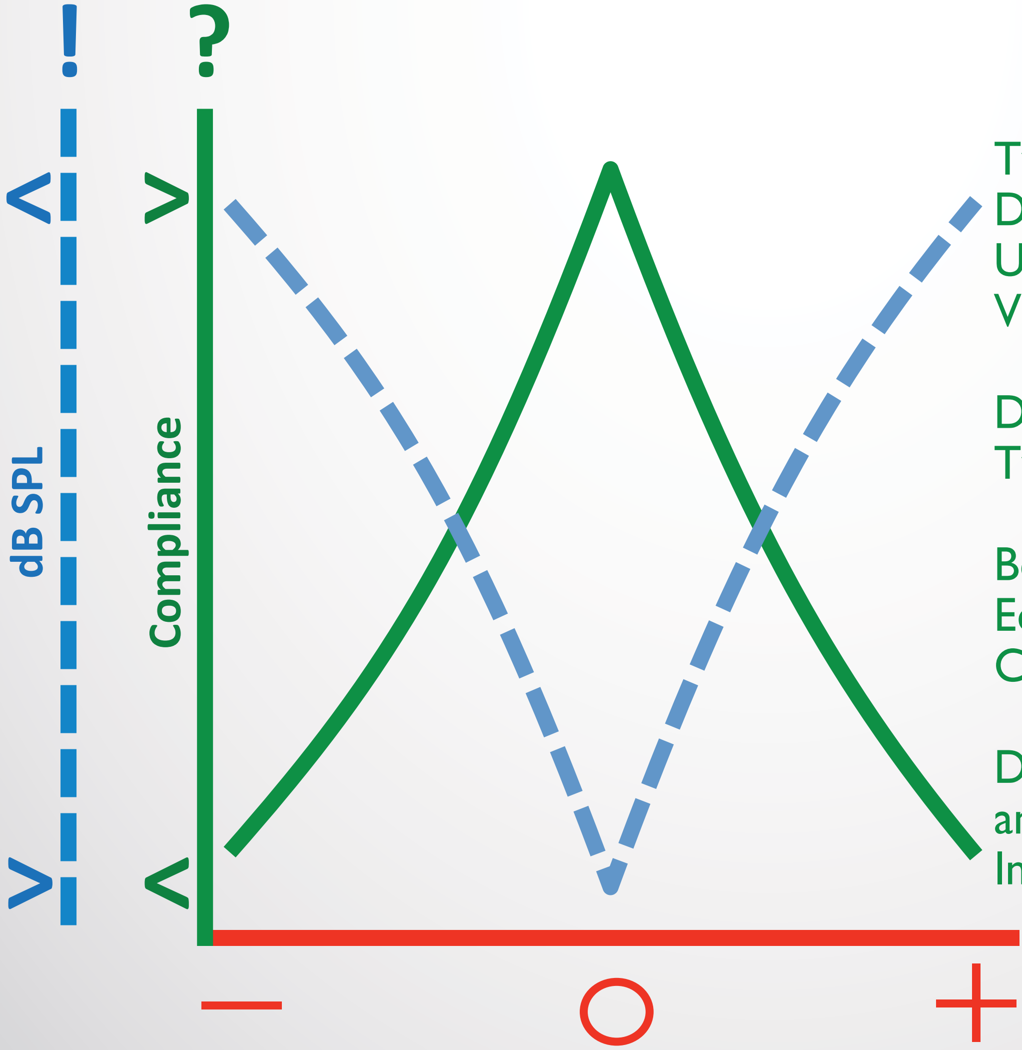
Canadian
Hearing Report
Revue canadienne d'audition

Vol. 10 No. 2
2015



Tympanometry: Do We Really Understand Its Vertical Axis?

Deconstructing Tympanometry

Best Practice Education at Conestoga

Digital Hearing Aids and Electromagnetic Interference

Publications Agreement Number 40025049 | ISSN1718 1860

Published by
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Well, well, well (3 holes in the ground) perhaps it's time we looked at tympanometry. It's recently become a rather hot topic in both Canada and the US, especially among hearing instrument practitioners. On their recently updated Standards of Practice, the Association of Hearing Instrument Practitioners (AHIP) in Ontario is making tympanometry an equipment requirement and a routine part of their assessment protocol. As clinicians however, do we really understand how tympanometry actually works and what it does? Please let's not say it "examines how much the eardrum wiggles." No, what we actually measure is the amount of sound bouncing off the eardrum as a function of air pressure. OK, but if we do that, then why does the vertical axis not read in "how much sound is bouncing off the eardrum?" Why does it read instead in units of "compliance?" Readers will find out when they read the article by Lisa Hunter PhD: "Deconstructing Tympanometry: How to Get More Out of this Common Diagnostic Test." As curators or custodians of hearing health care, let's make it our business to actually know what we are doing when we do Tympanometry.

Hunter addresses two very important words that describe the true worth of any test, such as tympanometry: these words are "Sensitivity" and "Specificity." Now I could simply say here, "Google these up," but the urge to explain just won't let me. Sensitivity is the ability of a test to identify someone who *has* some pathology. Specificity is the ability of a test to pass someone who does *not* have that pathology. Tests that are 100% sensitive and specific are called "gold standards," and there are very few of those around in our field – or in any medical field for that matter. We all know the importance of doing a test battery, because individual audiometric tests (pure tone testing, speech audiometry, etc) cannot truly stand alone. That's why it is so important to back up findings of pure tone air-bone gap with tympanometry! Hunter concludes with a discussion on a new addition to tympanometry called Wideband Acoustic Immittance. Have a read here; it's the future coming fast.

"And now for something completely different…" We've all heard that cell phones and digital hearing aids don't exactly get up and ask each other to dance. There are some major compatibility issues here. So, have you ever wondered how electromagnetic compatibility (EMC) is controlled in hearing aids today? Xubao Zhang PhD explains it all in his article: "Techniques and Effectiveness of EMC Control of Digital Hearing Aids." Xubao and I have known each other from our past employment at Unitron Hearing in Kitchener. I am an audiologist, he is an engineer, and we've both enjoyed teaching each other our respective languages. You should have seen our many email exchanges as he wrote his article! It took me a while to digest what he has to say, but he was patient with me, and I must say that I learned a lot about EMC. Take the time to read it; read it slowly or read it a few times. Wow!

A blast from the past came its way to me from Calvin Staples, who coordinates the Hearing Instrument Specialist (HIS) program at Conestoga College in Kitchener. He writes on "Best Practice Education at Conestoga: Meeting the Emerging Needs of Tomorrow," where he outlines changes in the playing field of our profession and the corresponding response of the HIS program to these changes. The end goal is to train "best practice" clinicians. It is a challenge, but that's what makes teaching in our field a dynamic profession. Muhammed Ali said it much better; to do it well, you've got to "float like a butterfly and sting like a bee." I think about Conestoga a lot these days, and miss the place terribly. Still, I know it's in good hands with Calvin and the new hire of Ross Harwell AuD; two full-time instructors in a two-year, full-time program.

Hey, summer's coming! So's Christmas, but let's not think of that. Enjoy this issue!

Ted Venema, Editor-in-Chief

Canadian Hearing Report 2015;10(2):3.

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Vol. 10 No 2 • 2015

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Ed. Note: Please note that Figure 3 on page 14 of Canadian Hearing Report Volume 10, Issue 1 should have been credited to Dr. Neil Bauman. We would like to thank Dr Bauman for the use of his figure and apologize for the oversight.

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Tympanometry: Do We Really Understand Its Vertical Axis?

By Ted Venema, PhD

About the Author

Ted Venema taught at Conestoga College in Kitchener, Ontario, and was the founder and director of its program for hearing instrument specialists. He has a PhD in audiology from the University of Oklahoma. Ted frequently gives presentations on hearing, hearing loss and hearing aids and is author of the textbook Compression for Clinicians, *published by Cengage and now in its second edition.*

I believe there is a huge gap between the science of middle ear transmission and the clinical application of tympanometry. This is especially apparent for the clinician who attempts to make the leap from typical tympanometry to multi-frequency tympanometry. It concerns the vertical axis of the tympanogram. Obfuscation (look it up) offers lots of Impedance but little Admittance to an understanding of Tympanometry.

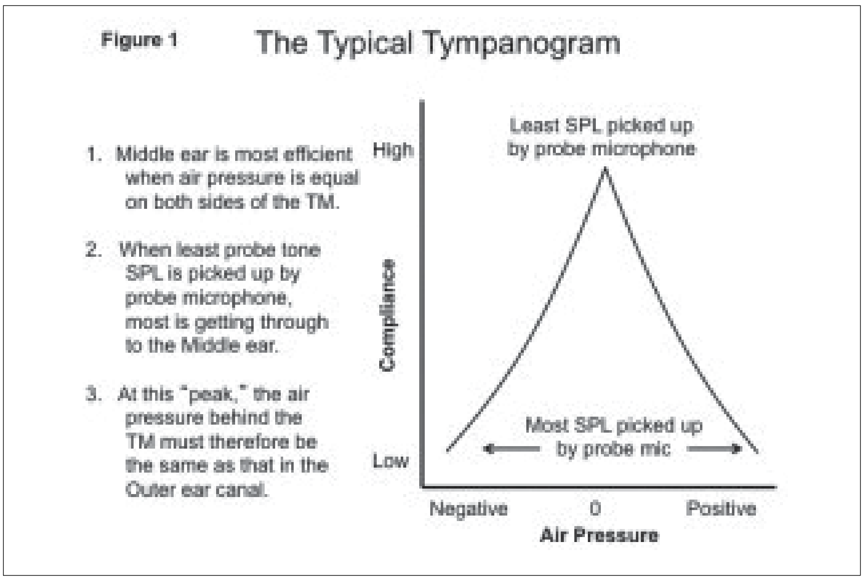


Figure 1. During air pressure changes from positive to negative, a steady 226-Hz tone at 65-70-dB sound pressure level (SPL) is presented through the probe speaker, and the probe microphone picks up whatever sound bounces back from the tympanic membrane (TM). The air pressure at which the least amount of the tone is picked up by the probe microphone is also the air pressure at which more of the tone is going through the TM and middle ear system.

The horizontal axis on the tympanogram is always "friendly." It shows positive, neutral, and negative air pressure, in units of mm H_2O or dekaPascals (these units are essentially the same in value).

The vertical axis, in my opinion, is a source of audiometric consternation. Tympanometry measures the amount of sound bouncing back off the TM (tympanic membrane) and being picked up by the probe microphone as a function of changes in air pressure (Figure 1). Why then, does the vertical axis not simply read in "dB SPL that bounced back"?

Let me tell you why. The vertical axis does not read in dB SPL that is picked up by the probe microphone because, if it did, the resultant values would vary hugely across individuals, and so would the size of their tympanograms! This huge variation results from things like different probe insertion depths that would change the ear canal volume in any one person. In addition, ear canals themselves vary in size across individuals.

An alternative, then, is to measure the *physical* properties of the middle ear. The middle ear is a "stiffness-dominated system," and so it makes sense that we would want to quantify its stiffness (or its inverse, compliance) per se. This actually does allow for a fairly standard range of tympanogram sizes and shapes to be used as normative. It also renders similar-sized tympanograms independently from the depth of probe insertion or ear canal size. In tympanometry then, the less sound picked up by the probe microphone, the more compliance you have.

The confusion to me, however, stems from the fact that while we actually measure dB SPL picked up by a probe microphone, we do this in order to quantify something else, namely, compliance!

COMING TO TERMS WITH SOME TERMS

To better understand *compliance and the vertical axis of a tympanogram*, we had best look at some things that impede the transmission of sound through a system like the middle ear:

- Stiffness: opposes transmission of low Hz and passes high Hz; the chief factor in middle ear impedance
- Mass: opposes transmission of high Hz and passes low Hz
- Resistance: like simple friction; in any system it is the same for all Hz
- Impedance: combination of the above

Since the middle ear is stiffness dominated, mass and resistance do not play much of a role in its overall impedance; the ossicles are tiny, and the ligaments holding the ossicular chain in place don't give much friction. Today's tympanometry, however, measures what the middle ear *admits*, rather than what it impedes. Here are some admittance terms:

- Inverse of stiffness is compliance; audiology textbooks often call it "compliance susceptance"
- Inverse of mass is not given a short name (since the middle ear is stiffness dominated); audiology textbooks often call it "mass susceptance"
- Inverse of resistance is called "conductance"
- Inverse of impedance is called "admittance"; it's a combination of the above

For admittance then, the "camel" in the room is Compliance, along with two "mice" called Mass Susceptance and Conductance. The ohm is a unit used to describe Impedance; for admittance, the word "ohm" is simply flipped around to read "mho." Since the ear is small, it is more practical to use thousandths of a mho or millimhos (mmho's) to indicate units for compliance on the vertical axis of the tympanogram.

MULLING OVER MULTI-HZ TYMPANOMETRY

The fun really begins when we attempt to move to multi-frequency tympanometry. The chasm here is filled with opaque concepts and, in my opinion, the bridge to take you across the chasm is hard to find. But let me give it a try:

In multi-frequency tympanometry, not only is the probe tone Hz manipulated, but *three* different tympanograms can be measured for each Hz! The combined contributions of the "camel of compliance" and a "mouse of mass" are called "susceptance." These are plotted as what is called a "B" tympanogram. The other "mouse," called "Conductance," is plotted as a 'G" tympanogram. The sum total of these is admittance, which is plotted as "Y" tympanogram.

Note: For the normal middle ear, the Y tympanogram will be quite similar to the B tympanogram, because the main component of admittance is compliance. With multi-frequency tympanometry, however, the course of various middle ear pathologies can be tracked by the interactions among these three tympanograms at any one probe Hz.

The interaction of middle ear susceptance and conductance is often shown as vectors, much like those that would be drawn to show how a blowing wind might affect the passage of a boat floating along with the water current (Figure 2). Regarding the middle ear, the vector normally radiates upward, showing that it is mainly controlled by its stiffness; if the vector radiates downward it is mainly controlled by its mass. The vector length would show the overall strength by which any sound transmission system is controlled by all of these three interacting elements.

The resonance of a sound transmission system like the middle ear is found when its admittance due to compliance (compliance susceptance) is equal to its admittance due to mass (mass susceptance). When these cancel each other out to give an admittance of 0 mmho, the only player in overall admittance is conductance (Figure 3). Multi-frequency tympanometry shows that the normal middle ear has an overall resonance to Hz just above 1000 Hz.

Various types of middle ear pathology affect middle ear resonance. Negative middle ear pressure or otosclerosis will stiffen the system, resulting in a higher resonating Hz. A monomeric TM, PE tubes, or disarticulated ossicles will decrease the stiffness and accordingly, lower the resonating Hz.

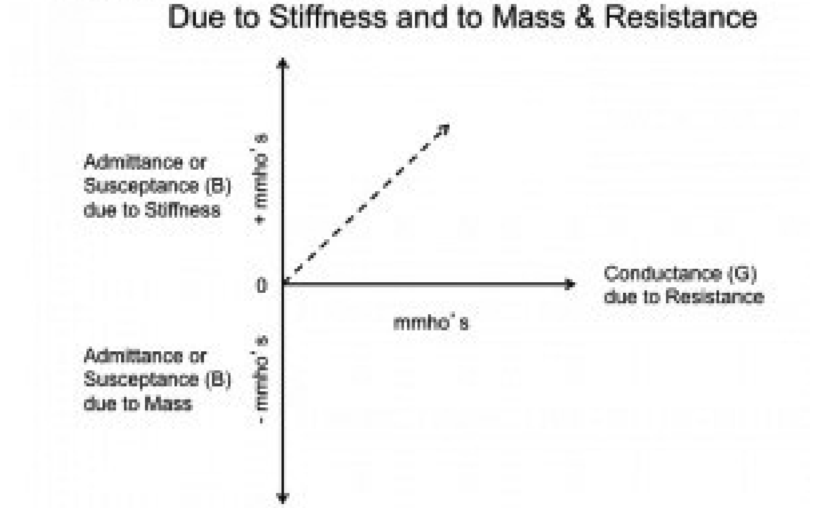
Figure 2


Figure 2. Admittance (susceptance or B) due to compliance is shown on the upper positive half of the Y axis and admittance (susceptance or B) due to mass is shown on the bottom negative half of the Y axis. The third variable here, conductance, is shown along the X axis. Together, these three comprise admittance. Note that the resultant vector (dotted line) radiates upward. This shows that for the normal middle ear, stiffness plays a bigger part in admittance than does mass.

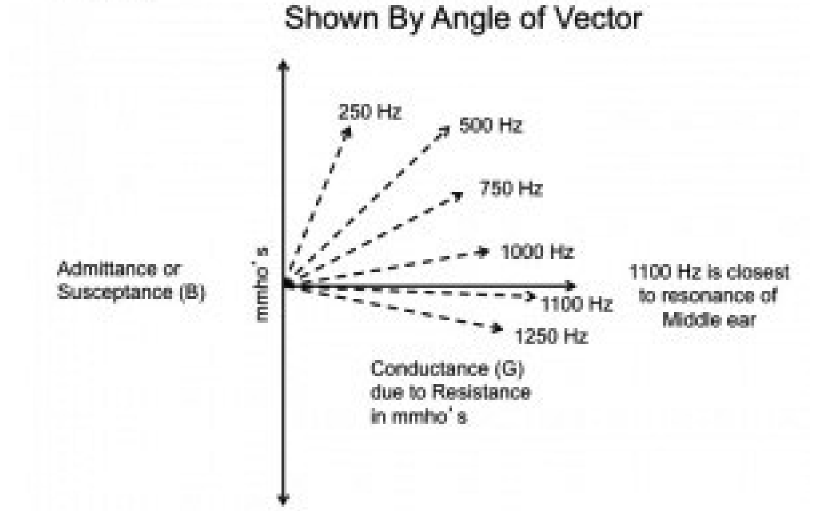
Figure 3


Figure 3. When admittance or susceptance (B) due to stiffness is equal to that for mass, the resonating Hz is found. Note that at the resonating Hz, the vector radiates horizontally, showing that here, only conductance (g) plays a role in the admittance of the middle ear.

FINAL QUESTION

Why doesn't typical tympanometry separate these three elements of admittance? He reason it doesn't is that the effects of most middle ear pathology, such as otitis media, are so gross (not at all subtle) that the three contributing components of admittance *do not need to be analyzed separately*. Typical tympanometry with its 226-Hz probe-tone frequency sticks to the overall Y (admittance) tympanogram, which we know to be governed mainly by the camel named "Compliance," along with its two mice friends named "Mass Susceptance" and "Conductance."

Typical tympanometry, even by itself as a test of middle ear function, is still a fascinating story. It assumes that in order for the middle ear to be *most efficient* at passing incoming sounds through it, air pressure must be even on both sides of the TM. If the least amount of sound bounces back off the TM when the air pressure in the outer ear canal is at regular room air pressure, this means the air pressure *behind* the TM is the same. In this indirect way, tympanometry measures conducted in the outer ear canal can actually tell us about the middle ear air pressure *behind* the TM!

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Canadian Hearing Report 2015;10(2):7-9.

Deconstructing Tympanometry: How to Get More Out of this Common Diagnostic Test

Is Tympanometry Still Useful In 2015?

By Lisa Hunter, PhD, FAAA

About the Author

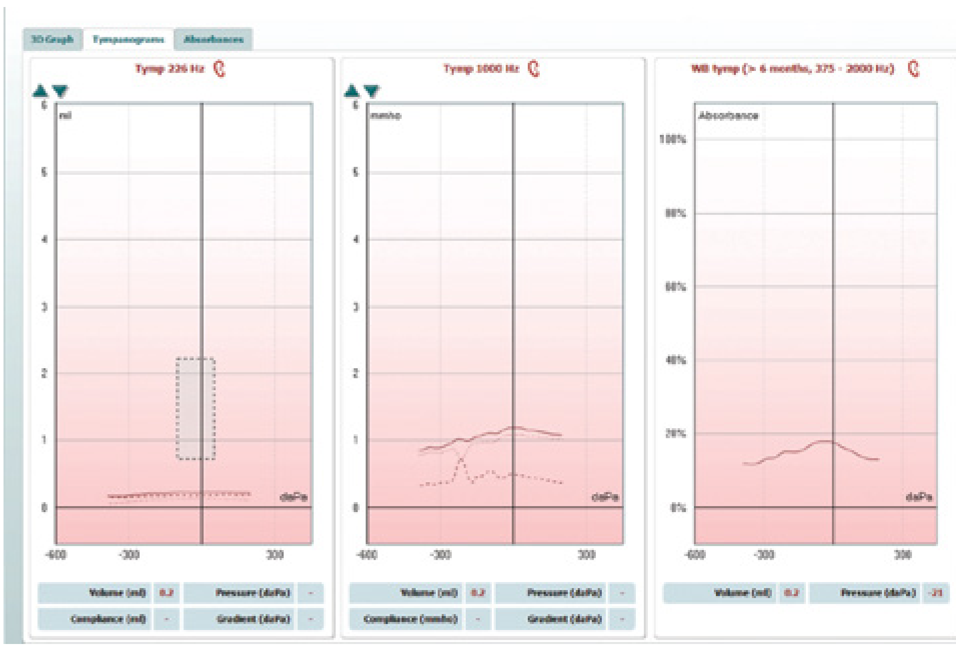
Lisa L. Hunter, PhD FAAA is the scientific director for audiology in the Communication Sciences Research Center at Cincinnati Children's Hospital Medical Center, and associate professor of Otolaryngology and Communication Sciences and Disorders at the University of Cincinnati. An avid commuting cyclist and painter, Lisa has over 25 years of clinical, research and teaching experience, and a passion for audiology education. A graduate and former faculty member of the University of Minnesota, she developed and directed the AuD program in at the University of Utah. Lisa has authored over 60 peer-reviewed articles, chapters and books in pediatric audiology, has given over 120 national and international presentations. She is currently directing a longitudinal study of newborn hearing loss, funded by the National Institute on Deafness and other Communication Disorders, collaborating with Dr. Douglas Keefe and Dr. Patrick Feeney. Lisa is currently the chair of the Accreditation Commission for Audiology Education (ACAE) and is a past member of the Board of Directors of the American Academy of Audiology.

Tympanometry is at once one of our most basic and necessary, yet neglected and misunderstood clinical tools. Tympanometry was invented before almost anyone writing or reading this article was born, by Otto Metz in 1946.[1] In the 50s and 60s, tympanometry provided a new window into the opaque middle ear, previously accessible only with myringotomy or exploratory surgery. Otoacoustic emissions (OAE) were discovered 30 years later by David Kemp. Kemp noted the linkage between the middle ear and the cochlea, "*if there were physical resonances occurring inside the cochlea it should be possible to detect these from outside, acoustically in the ear canal, because of the way the middle ear links the cochlea and the ear drum.*"[2]

Comparisons between these two physiologic measures in patients soon revealed an intimate relation between middle ear function as revealed by tympanometry; and cochlear function, as revealed by OAE. Because the middle ear is the doorway to the cochlea, anything significant happening there affects transmission of stimuli to generate OAE. As a result, middle ear problems as benign as positive or negative pressure may obliterate OAE responses, meaning that cochlear function cannot be ascertained. A frequent problem in screening and assessing infants and children is that middle ear effusion eliminates measurable OAEs in approximately 70% of ears. Significant conductive hearing loss of any cause nearly always eliminates OAEs. Even when hearing is normal, the presence of a perforation or a PE tube can reduce OAEs in 25–50% of cases, depending on the size and location of the perforation or tube. The middle ear doorway is an apt analogy, because it swings bi-directionally. Thus, not only is the stimulus reduced getting to the cochlea, but the OAE is reduced traveling back through the middle ear to the outer ear, where it is detected clinically. This is why OAEs are so affected by fairly small middle ear problems – they are affected both coming (stimulus into the ear) and going (emission from the cochlea).

HOW ARE TYMPANOMETRY MEASURES MADE?

An understanding of this is necessary in order to properly interpret the results. We start with a pure tone stimulus, traditionally 226 Hz, but any pure tone up to about 1000 Hz can be used. Above that frequency, standing waves cause problems with the measurement. New reflectance techniques allow us to measure up to 10,000 Hz, but more on that later. The pure tone stimulus is calibrated for sound pressure level (SPL) and phase angle in a hard-walled metal cavity. The stimulus is introduced into the human ear, which changes both the SPL and the phase angle due to the impedance load of the middle ear. A large part of the change is due to the ear canal characteristics. In order to determine how much of the change is due to the ear canal versus the middle ear, we have to compensate out the outer ear canal effects. This is most easily done by pressurizing the ear canal to a high positive or negative pressure, which makes the ear canal act like a hard-wall cavity (except in newborns, but we'll get to that later). The tympanogram is measured by varying the ear canal air pressure, and monitoring the SPL and phase as the pressure is varied. So, we end up with the familiar admittance as a function of pressure graphs as in Figure 1. As Venema noted, the magnitude



Left Ear:

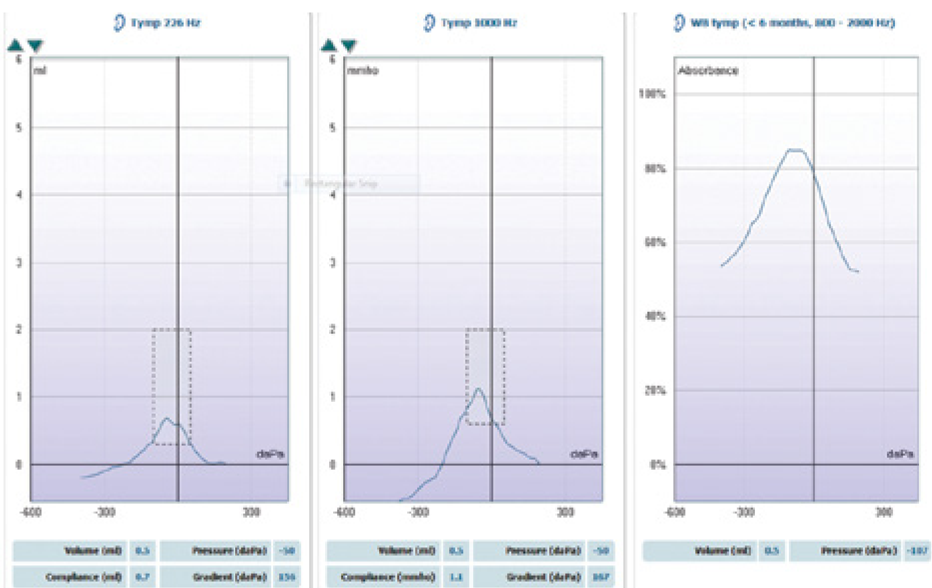
Eq Vol 0.3 ml — Peak -50 daPa

Admittance 0.7 mmho — Width 156 daPa

measurement (y-axis) is not plotted in SPL, rather it is plotted in physical units that correspond to the ear volume (cc) or admittance (mmho), relative to the probe tone (SPL).[3] The term "admittance" can be remembered with the doorway analogy (the middle ear is the doorway, admitting sound to the cochlea). This is because we are trying to measure the physical properties of the ear, not the sound level of the probe tone. At 226 Hz, cc and mmho are equivalent units. What is a mmho (millimho) anyway? Well, a mmho is the inverse of the more well-known ohm. An ohm is a unit of impedance, while a mmho is a unit of admittance (the inverse of impedance). = The mmho measures the *total admittance* to the middle ear. =Have a look at your immittance instrument's vertical axis plot to see if it is plotted in cc, mL, or mmho. Some manufacturers choose to plot cc or mL because this is the unit of equivalent ear canal volume. Other manufacturers choose to plot mmho, because this is the unit of middle ear admittance. You can simply convert one unit to another with a 1:1 ratio, meaning 1 cc = 1 mL = 1 mmho. Easier than Pi!

HOW CAN I ANALYZE (DECONSTRUCT) TYMPANOMETRY?

There are two main components to the height of the tympanogram, known as acoustic admittance (Y). These two components are conductance (G), and mass + compliant susceptance (B). Clinicians often use the term "compliance" when they really mean admittance. Tympanometry actually does not measure compliance as a separate term, although it can be figured out by checking out the phase angle. Some instruments provide a separate plot for conductance (G). *"Gee whiz,*



Right Ear:

Eq Vol 0.2 ml — Peak - None

Admittance 0 mmho — Width - flat

Figure 1. Tympanograms recorded at 226 and 1000 Hz for a normal ear (left) and an ear with OME (right).

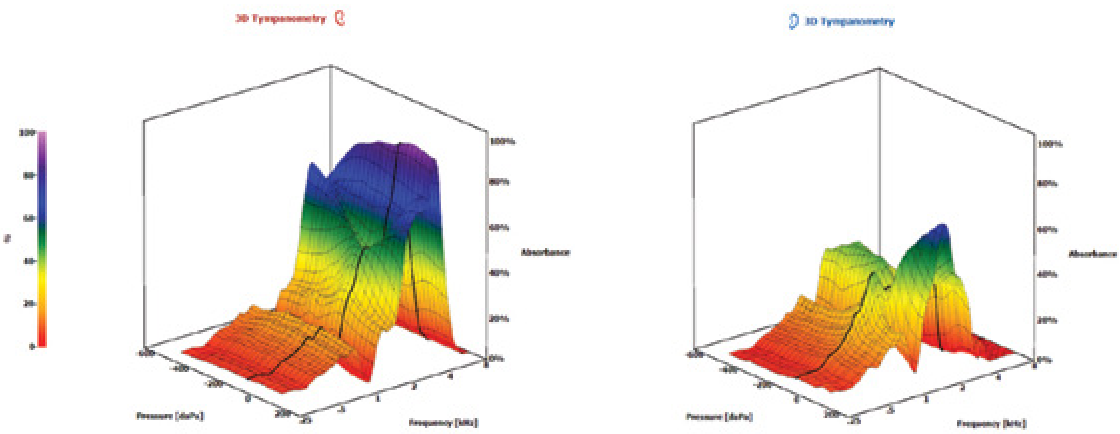


Figure 2. Wideband absorbance 3D tympanograms. The left horizontal axis is ear canal pressure (daPa), the right horizontal axis is frequency (Hz), and the vertical axis is absorbance (%). The right ear has normal absorbance across frequencies, while the left ear has reduced absorbance due to OME.

this ear conducts sound great." The plot thickens, because mass + compliance (B) is always plotted as a combined tympanogram. Remember (B) for *BOTH mass and compliance*. The B and G tympanograms can tell you when (probe frequency) and where (pressure range) notching occurs, which is an indicator of with resonant frequency. If there is a notch in admittance (Y), to see if this is real, look at the individual B and G tympanograms. B should also have a deep notch, below the positive tail of the tympanogram, and G may be starting to show a notch too. If the B and G patterns are chaotic and don't match up with a notch in the same pressure range as the notch in Y, the notch is probably due to artifacts or noisy recordings.

To figure out if the ear is mass-dominated or compliance-dominated, take a look at the phase angle, if your instrument provides this measure. At 226 Hz, a normal adult ear will have a phase angle of greater than 70 degrees, indicating it is compliance-dominant. The phase angle moves closer to 0 degrees as the probe frequency is increased. When it reaches 0 degrees, compliance and mass are balanced, and the ear is at resonant frequency. Resonance is normally reached between 800 and 1400 Hz. Some instruments provide a plot of phase angle as a function of frequency, which is helpful to determine resonant frequency. In ears that are mass-loaded due to cholesteatoma, ossicular disarticulation, monomeric tympanic membrane or viscous OME (glue ear), the peak admittance and resonant frequency may be abnormally low. If compliance is reduced due to OME, ossicular fixation or TM grafting, the resonant frequency may be abnormally high, and the tympanogram gradient will be wider, with reduce peak admittance. The picture can be complicated because often, mass, compliance and resistance are all affected. This is usually the case in

OME. In such cases, the tympanogram flattens out and resonant frequency is abnormally high. Figure 1 illustrates 226-Hz and 1000-Hz tympanograms in a normal ear and one with OME. It is important not to try and diagnose a middle ear condition on the basis of tympanometry alone. Combining tympanometry with history, otoscopy, acoustic reflexes, and audiometry can usually track down the most likely cause.

HOW SENSITIVE AND SPECIFIC IS TYMPANOMETRY?

While standard 226-Hz and now, 1000-Hz tympanometry has stood the test of time in terms of convenience, simplicity, comfort, time, and cost, it is not terribly sensitive to many middle ear disorders that matter. Additionally, it is impossible to relate 226 or 1000 Hz tympanometry to other audiologic tests which are across a wider range of frequency. Otoacoustic emissions are not the only audiologic tests affected by middle ear changes. In fact, all "upstream" measures, be they behavioral (pure tone audiometry, speech thresholds and recognition in quiet and noise) or physiologic (acoustic stapedial reflexes, OAE, ABR, ASSR, etc.) are affected. Thus, audiologists need a highly sensitive and maximally specific middle ear measurement to be able to accurately detect middle ear disorders that affect the patient's functioning and other test results.

In infants under 4 months old, the sensitivity and specificity of 226-Hz tympanometry to middle ear effusion (MEE) is only about 50%, so you might as well flip a coin instead. A more sensitive measure is 1000-Hz tympanometry. Why does 226-Hz tympanometry fail to detect MEE and OME in newborns? The reason is that the infant's flaccid ear canal walls transmit low frequency probe tones, so that as pressure changes in the ear canal, the sound is transmitted through the canal walls rather than the eardrum or middle ear. At frequencies of 1000 Hz and above, the sound does not get absorbed so easily, and the true state of the middle ear can be measured.

A wider, clearer window into the middle ear via a test called Wideband Acoustic Immittance (WAI) is now available to audiologists. WAI uses click or chirp stimuli, and improved calibration principles that allow accurate determination of the absorbance (or reflection) of the middle ear across a wide frequency range from 200 to 10,000 Hz.[4–6] WAI is quite simply a ratio measure of energy reflected from the TM and middle ear, compared to energy due to the calibrated stimulus in the ear canal. WAI takes standing waves into account in the calibration technique, and is generally independent of the location of the probe in the ear canal and to ear canal characteristics (in adult ears) between 250 and 8000 Hz. Thus, baseline compensation methods that are necessary for standard tympanometry are not necessary for WAI. WAI can be done either at ambient pressure or with pressurization, and a wideband absorbance tympanogram can be obtained, as shown in Figure 2. Absorbance is a ratio measure of the energy absorbed by the middle ear divided by the energy that was put into the ear (the clicks). Thus, no absorbance into the middle ear = 0, and maximal absorbance =1.0. Both magnitude and phase measurements can be obtained using absorbance.

Very different wideband absorbance patterns are observed in normal ears (2a), ears with OME (2b), ears with negative pressure and ears with patent PE tubes. Compared to standard tympanometry, these measures are across all audiometric frequencies, so can be compared to OAE, ABR, and audiometry. Normative and pathology data are available from a number of studies.[7] These wideband measurements are easily converted into admittance units and phase, so that individual tympanograms can also be seen for reference. But, there is really no need since the absorbance tympanograms have several advantages to conventional tympanometry. These include: simple ratio measurement, no need for ear canal compensation, wide frequency range, better reliability due to averaging and uses of clicks rather than pure tones.

SUMMARY

A better understanding of the physical units and principle underlying tympanometry can help audiologists to get more useful diagnostic information from this tried and true test. In order to advance our understanding, new techniques are available that allow us to see how the middle ear transfers energy across a wide frequency range. No longer do we have to be limited to 226, 660 or 1000 Hz. Even better, only one test that takes a few seconds can give us the whole frequency range, as well as multiple measures (absorbance, reflectance, phase angle, admittance).

Canadian Hearing Report 2015;10(2):11-16.

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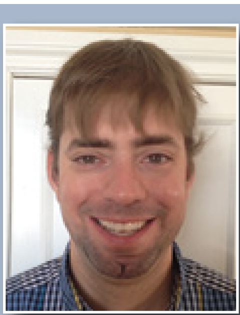
Best Practice Education at Conestoga: Meeting the Emerging Needs of Tomorrow

By Calvin Staples, MSc



About the Author
Calvin Staples has been an audiologist for over 10 years. His employment history covers a wide range of experiences and skills. Currently, he is the Hearing Aid program coordinator and faculty member at Conestoga College and lead audiologist and owner of Grand River Hearing Centre. His teaching responsibilities include: Professional Ethics, Audiometric Testing, Hearing Aid Technology, Hearing Aid Verification, Anatomy and Physiology of the Ear and Counselling. Professionally his interests are hearing aid technology, hearing loss and aging, and tinnitus. Previously, he was employed at Bernafon Canada Ltd. as their technical support and educational audiologist. His clinical experience developed through time spent at Hamilton Health Sciences (McMaster Hospital), Eastern Oklahoma Ear, Nose, and Throat and his current position at Grand River Hearing Centre. Calvin's role as a clinical audiologist dealt primarily with paediatric and adult audiology and hearing aids.
Calvin provides monthly submissions to the Canadian Audiologist online publication and routinely lectures across the country. His education was completed at Missouri State University whereby he received a Master's Degree in Communication Sciences and Disorders with an emphasis in audiology

Just under six years ago I was recruited to come and work at Conestoga College Institute of Technology and Advanced Learning in the Hearing Instrument Specialist (HIS) program. At the time, Ted Venema was the program coordinator, and he told tales of his adventures and the rewards of teaching which not only inspired me, but also helped solidify my belief that teaching at Conestoga College was the next step in my career. A few years later Ted left to "go west, because life is peaceful there," and I was tasked with holding the reigns for the program – all the while attempting to figure out how to make it even better: no easy chore!

The first step to that task is thankfully, already complete. The direction of the program was to foster an evidence-informed, patient-centered approach to hearing health care, and the plan was to find and a faculty member who aligned with this ethos, and who was also an incredible teacher. Ross Harwell (AuD) fits that bill. Ross comes to Conestoga College by way of Hear Toronto (an independent hearing health care provider) and Oticon Canada Ltd. As a Doctor of Audiology, Ross is now a full-time professor at Conestoga College. The program has benefitted significantly from his experience and knowledge and Ross demonstrates an extremely thoughtful and intentional approach to teaching. In his short time here, his contribution to the Conestoga HIS program is undeniable. It would be hard to argue against the incredible education the Conestoga College HIS students are receiving.

This leads me to my second point. At Conestoga we often consider what the appropriate goal of the HIS Program should be. Is it to teach the students to simply sell hearing aids and pass a licensing exam, or is it to teach the students to "think about what they just thought about"; to critically evaluate the clinical situation and use best evidence within a sound clinical reasoning framework to serve their patients? We categorically believe it should be the latter, and our intention is to create graduates that are valued contributors and respected amongst their peers. A hearing instrument specialist should engender trust and confidence in their patients. This is the foundation of the therapeutic relationship which allows the HIS to enrich the lives of those they serve. Further to this point, the HIS student at Conestoga has both *didactic learning and experiential training*. The Cowan Health Sciences Centre at Conestoga College houses the Hearing Health Lab (see photos), where students practice their skills in a formal and informal manner.

Figure 1. The new Health Sciences wing at Conestoga College. The lab is housed inside.

Figure 2. This corner booth is largest sound booth in the lab. There are four other much smaller (telephone booth) sized. They are on wheels and can thus be moved.

Our industry is changing rapidly and has morphed from a private practice model where clinicians were the dominant owners – to a corporate retail model where sales appear of utmost importance. No matter what the context, however, well trained hearing health care providers must have patient care as their highest accountability. Our goal is to train "best practice" clinicians. I believe the goal of an academic institution is to prepare students for practice today, and also equip them for the emerging needs of tomorrow. This model suites our program and I am hopeful encourages our students to invest wisely in their experiences at Conestoga, so their patients will be best served in their communities. Conestoga College's model is "What you do in here, counts out there," I could not agree more! (Good!)

In looking to the future of our program, we are embarking on our first major program review; to that end, the Conestoga HIS program is investigating exactly how we evaluate and thread the themes of the industry throughout the program. Conestoga's HIS program must continue to emphasize the highest standards of patient care and experience, based on best practice standards. In most of the literature we read as clinicians, the outcomes reflect "best practice". It is our goal to ensure best practice is threaded throughout our program in order to ensure our graduates are equipped with the tools to best serve their patients. Our commitment to the field is to continue to uphold this position. I am excited to show the province the new Conestoga HIS program in the not-so distant future.

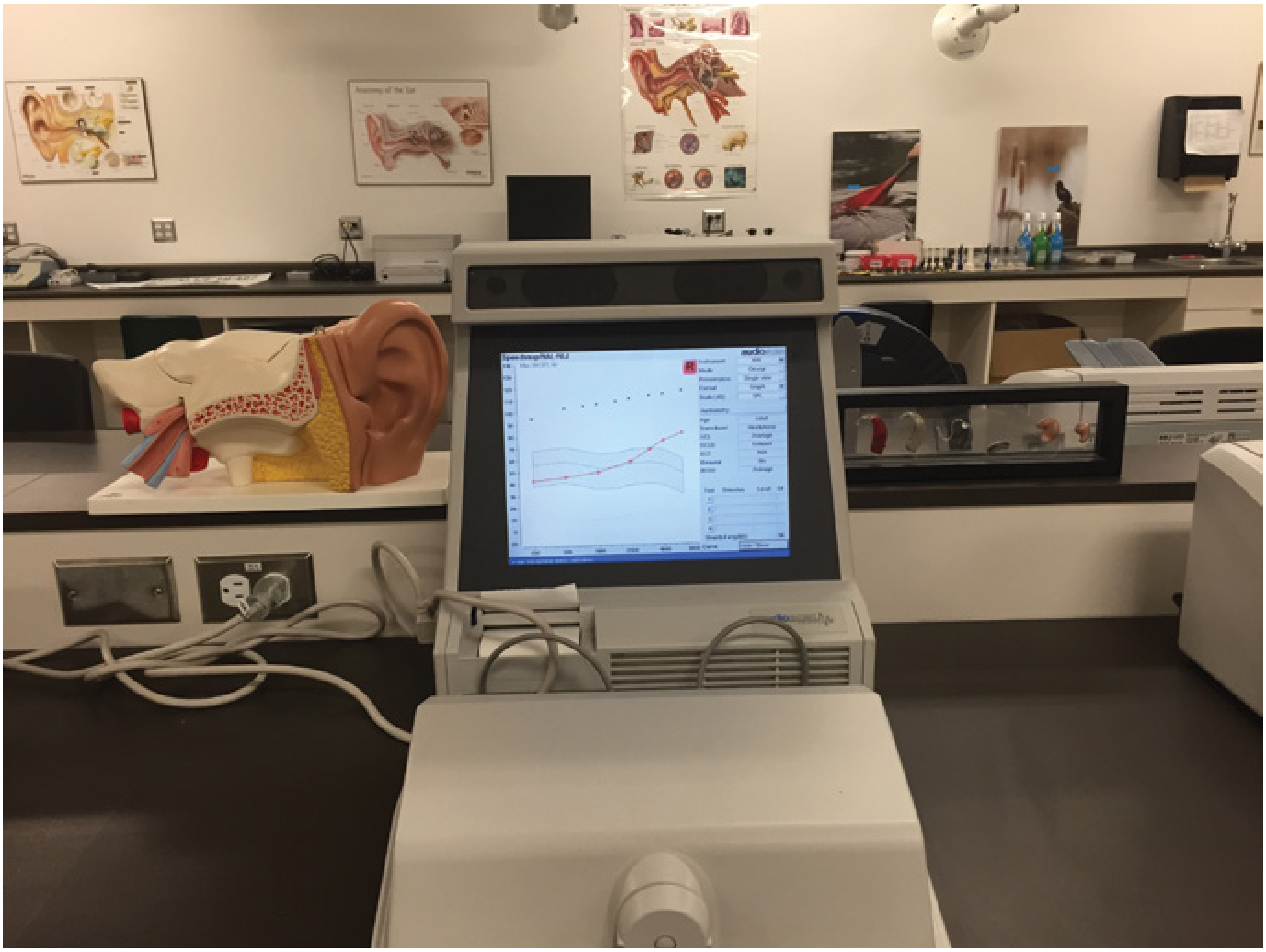


Figure 3. One of several Real Ear systems (Audioscan) in the lab.

In the short time I have been at Conestoga I have witnessed significant change. I have seen a change in the type of student that attends the program and the vision the college has for its graduates. When I arrived, the HIS program still had part-time industry-related students that dominated the flare and feel of the program. Now the program is a full-time 2-year program that has everything from students directly out of high school to students with years of prior post-secondary education and experience. It truly is an amazing canvas for the workplace our students will be exposed to upon graduation. The combination of the above ingredients makes Conestoga College a fascinating and great place to work and provides our students a wonderful learning experience. The future is an exciting one…..

Below is the website to Conestoga's HIS Program. It will lead the interested reader to program details, course descriptions, etc.
http://www.conestogac.on.ca/fulltime/1176.jsp

Canadian Hearing Report 2015;10(2):18-20.

CONESTOGA COLLEGE POST SCRIPT

By Ted Venema, PhD

The very idea of the Hearing Instrument Specialist (HIS) program at Conestoga College stirs strong memories. I say that because the program began as an idea in my head while barbequing sockeye salmon in my backyard in Kitchener some 10 years ago. At the time, I was teaching audiology full time at Western University and also in the HIS program at George Brown College on a part-time basis. As I stared at the salmon it occurred to me that Conestoga College was 2 kilometres down the road from where I stood; 2 kilometres in the opposite direction were two hearing aid manufacturers (Unitron and Bernafon). Hmmm. The next day I jammed a rug under my office door at Western and made a cold call to Conestoga's dean of health sciences. The rest is history. It was a labour of love over the next couple of years, and with the support from the Association of Hearing Instrument Practitioners (AHIP), the dream slowly became a reality. With the help of the manufacturers and some private donations, we got a humdinger of a lab going. It was initially housed in a 30 by 15 foot room in the Business wing but in 2012 the lab was moved into a fantastic room two to three times as large, in the new Health Sciences wing.

The first two years we ran a part time evening program, and then in year three the full time program began. I taught full time, with the assistance of several part time lab instructors (Barb Kovach, Karyne Steele, Kelly Morgan-MacKenzie, hope I haven't forgot anyone…). After a few more years the program grew enough to be able to accommodate two full time instructors as well as a part time lab instructor (Adam Perrie). I wanted to concentrate solely on teaching, instead of both teaching and coordinating, and so I looked around (and around) and finally enticed Calvin Staples to come on board. The proviso was that he'd assume the duties as coordinator of the program! I was lucky; he took the bait.

Canada now has five non-audiology hearing health sciences programs. Two of these are audioprothesiste programs in Quebec; one at Rosemont College in Montreal and a new one has recently begun further east, at Ste Anne De La Pocatiere. Canada's three English-speaking programs consist of an online program at Grant MacEwan in Edmonton, a three-year-full time program at George Brown College in Toronto, and a two-year full-time program at Conestoga College in Kitchener. The latter two programs are "face-to-face" programs, meaning they require mandatory full-time attendance.

Considering that AHIP is the Association of Hearing Instrument Practitioners, it is interesting to me that I named Conestoga's program an HIS program, and not an HIP (hearing instrument practitioner) program. Out west where I now live, the HIS is called an HIP. In hindsight, I think I might have named Conestoga's program…well, I digress. Here's some facts about the Conestoga program that distinguish it from Canada's other programs. Conestoga is a 2-year, 4-semester program, where HIS courses each semester are augmented with a few electives. Conestoga thus has students in 1st and 2nd year cohorts. Each fall, they accept about 40 students.

The HIS program folds out as follows:

Semester 1: Acoustics/Psycho-acoustics, Anatomy/Physiology of the Ear, and Professional Ethics

Semester 2: Intro to Audiometry (lectures & lab), Hearing aid Components (lectures & lab), and Counselling

Semester 3: Advanced Audiometry (lectures & lab; Compression and Digital features, Fitting methods; Real Ear measures (lectures & lab)

Semester 4: Clinical Practicum 495 hrs.

For further information, do check out the website at the end of Calvin's article!

CHR would be glad to publish similar reports of progress and program description from Canada's other college training programs!

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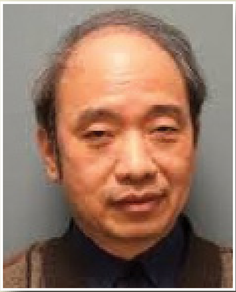
Digital Hearing Aids and Electromagnetic Interference: Techniques to Control Electromagnetic Compatibility

By Xubao Zhang, PhD



About the Author

Xubao Zhang was an associate professor at Xidian University in Xi'an China, where he specialized in digital signal processing (DSP) for radar. In 1993 he did post-doctoral studies in DSP at McMaster University. Since 1997, he has worked with Beltone Canada, Oticon Canada and Unitron in the production, development, research and evaluation of hearing aids. His specific focus has been on electromagnetic compatibility control, and electro-acoustic engineering.

ABSTRACT

This paper analyzes the causes of electromagnetic interference (EMI) of mobile phones to hearing aids. It also introduces major specifications and basic evaluation procedures of two new standards for electromagnetic compatibility (EMC) with hearing aids: International Electrotechnical Commission (IEC) & American National Standards Institute (ANSI). A new generation of electromagnetic components and radio frequency (RF) printed circuit board (PCB) design has become available; based on these several control techniques for EMC with hearing aids are proposed. Practical examples are highlighted which show these new techniques can effectively suppress various types of EMI in hearing aids.

Mobile cell phones are popular and it is estimated that the number of these devices will rapidly be increased to 3 billion sets worldwide.[1] Peak transmitting power of common mobile cell phones can reach 2 Watts, and the transmitting frequencies are within ultrahigh frequency (UHF, 0.3~3 GHz) range; their emissions are modulated by pulses or digital signals.[2] Hearing aids are tiny electroacoustic devices with connected wires and PCB tracks. As such, they can act as effective antennae, receiving these UHF signals which in turn, may cause annoying audio frequency interference. Researchers and designers of hearing aids have studied EMI for many years, and at present, have been successful at solving many of the problems caused by EMI.

Since 1997, IEC has been creating standards of EMC between hearing aids and cell phones.[3] From 2001 to 2011, ANSI has released 3 versions of measurement methods of EMC between wireless communications devices and hearing aids.[2] In 2010, the Hearing Loss Association of America (HLAA) announced the newest version of measuring EMC between hearing aids and mobile cell phones by the Federal Communications Commission (FCC), and the list goes on…

Reports on such control/design techniques for hearing aid application; however, are rarely open to the public. The good news is that new standards for electromagnetic compatibility, along with new arts of PCB design, can take advantage of a whole new generation of electro-magnetic components. This paper studies/proposes some of these techniques whereby to control EMI for various hearing aids. It is hoped that designers of hearing aids, hearing care professionals who fit them – and ultimately end users of hearing aids – can benefit from it.

ELECTROMAGNETIC INTERFERENCE OF CELL PHONES TO HEARING AIDS AND IEC/ANSI STANDARDS

The EMI referred here means the interference from mobile devices, such as cell phones, which produce the most unavoidable and most severe EMI in the hearing aid environment. It is well known that electro-magnetic signals have the property of radiation, and the higher the frequency of the signal, the higher the radiation efficiency. For any signal of some specified wavelength, a conductive wire of ¼ of that wavelength makes for a high-efficiency antenna. With UHF range, capacitors in electrical circuits act as serial resonant circuits, inductors act as parallel resonant circuits, resistors… etc.[5] The complexity of hearing aid circuits cannot be ignored when analyzing EMI causes. Several wires or PCB tracks connected to AF components will often form effective wideband EMI receiving antennae. They even form resonances to certain EMI and thus cause very high EMI output.

As previously mentioned, a 1/4 wavelength wire is a high-efficiency antenna, it should be stressed here that for EMI signals of specified wavelength, a wire of only 1/20 of the signal wavelength can already begin to receive the.[6,7] Common mobile devices transmit signals in a range of about 800 MHz to 2 GHz, while the newest products have an even wider frequency range. Roughly calculating, 1/20 wavelength of transmitting signal of the mobiles are from 1.9 cm to 0.7 cm. Inside a hearing aid, there are many PCB tracks as well as connected wires, most of which can reach these lengths! Thus, concerning UHF circuits of hearing aids are composed of many antennae of different frequencies, which can effectively absorb transmitting signals of nearby mobile devices. From there, the nonlinear circuits inside hearing aids demodulate them into audible noises, sounding like a chatter, quack or hum. When such noises are not strong, they make the hearing aid users annoyed; when strong, it becomes difficult for hearing aid users to understand speech. Accordingly, it is not hard to understand why an analog BTE hearing aid behaves badly with EMI. Because these circuits are composed of many long wires and many big components, it is a challenge for BTEs to meet user's EMC requirements. In comparison, it is easy for modern ITE hearing aids to achieve EMC performance that the users require, including dealing with the interference from the user's mobile, because these hearing aids are composed of not only smaller components but also shorter wires/tracks.

To better understand IEC and ANSI measures of compatibility between mobile devices (eg cell phones) and hearing aids, it will be helpful to digest some terms and concepts here. When a person using a mobile device is nearby a hearing aid user, immunity of the hearing aid is referred to as "bystander compatibility." When a person using a mobile device is wearing a hearing aid, immunity of the hearing aid to the mobile device interference is referred to as "user compatibility."[3] In compliance with ANSI and IEC standards, an essential specification of EMC is called "input related interference level (IRIL)." Here, the hearing aid is exposed to an input consisting of an EMI field where the continuous wave amplitude is modulated (changed) by 80% at 1 kHz. In this situation, the resultant noise in the hearing aid output is measured. IRIL is considered to be the sound pressure level of an audio frequency input (in dB SPL) that would cause the same amount of output noise as the modulated EMI field did. Consider that input plus gain equals output, and output minus gain equals input. Accordingly, while subjected to the 1 kHz modulated EMI field, the unmodulated AF noise in the hearing aid output minus its acoustic gain at 1 kHz yields the IRIL.

What is an acceptable IRIL? Usually, sound pressure of speech in common conversation is at least 55 dB SPL, so if the IRIL is <55dB, the hearing aid under test can be passed on EMC evaluation. To this end, the IRIL can be simply calculated by the equation below:

IRIL(f)=Hearing aid output (f, 1kHz) – Hearing aid gain (at 1kHz, with a 55 dB input).

Here, f is the carrier frequency of EMI, and 1 kHz is the modulation frequency of the EMI.

In compliance with IEC and ANSI measurement standards mentioned earlier, the major hearing aid manufacturers have all established their own EMC laboratories, so as to measure their own products and to conduct various experiments for EMC control. Although ANSI and IEC specify strict regulations for IRIL, in practice, each of the major manufacturers are hard pressed to obtain consistent and satisfactory results. In addition, there tends to be a rather large standard variance in measured IRILs.[8]

ANSI suggests that an audio signal-to-EMI noise ratio of 20 dB is sufficient to enable audibility, and that a signal-to-noise ratio of 30 dB provides optimal audibility. EMC specifications of ANSI have a category of 4 rating sets for both Microphone (M) and Telecoil (T) usage; they are listed in Table 2 as: M1/T1, M2/T2, M3/T3 and M4/T4, where "1" is the worst and "4" is best. The EM field is adjusted with a fixed IRIL of 55 dB SPL; ratings number (EMC performance) depends on the EMI field strength where the noise in the hearing aid output is at an equivalent 55 dB SPL. The higher the EM field strength is, the higher will be the EMC rating; i.e. the better the EMC performance.

ANSI has also adopted a EMC criteria of *combination evaluation* for hearing aids and mobiles, it specifies that when hearing aid rating + mobile rating > 5, the EMC evaluation of the two devices will be passed. ANSI also indicates that M3/T3 is excellent hearing aid EMC.

It should be noted that the test methods and specifications of ANSI and IEC standards are different and thus, the evaluation conclusion of the same hearing aid from the both standards can be different. Although the both authorities (IEC and ANSI) created the regulations for their own different methods and specifications, both also recommended the regulations of the other party.

Table1 lists the main specifications of 3 versions of IEC standards that have evolved over the last decade.

To measure EMC in hearing aids, IEC uses GTEM (gigahertz transverse electromagnetic), a type of electromagnetic compatibility (EMC) test chamber that generates an electromagnetic field.

IEC 60118-13 Versions	Bystander compatibility. User compatibility Mic mode, T-coil mode, Dir mode**		
	LB V/m (0.8~0.96GHz)	HB V/m (1.4~2.0GHz)	HBE V/m (2.0~2.48GHz)
Version 1, 1997	3, N/A*	2, N/A*	N/A
Version 2, 2004	3, 75*	2, 50*	N/A
Version 3, 2011	3.5, 90*	2, 50*	1.5, 3.5*
*The 1st specification is for bystander compatibility, the 2nd specification is for user compatibility **Evaluation in Dir mode is conducted for bystander compatibility.			

Table 1. Specifications of Hearing Aids EMC of IEC Standard 60118-30

EMC Ratings	RF field strength input to hearing aid* (Conditions: HA IRIL <55dB SPL and HA gain change <6dB)			
Near-field	E-field immunity (continuous wave)		H-field immunity (continuous wave)	
M1/T1	30.0~35.0	dB(V/m)	-23.0~-8.0	dB(A/m)
M2/T2	35.0~40.0	dB(V/m)	-18.0~-13.0	dB(A/m)
M3/T3	40.0~45.0	dB(V/m)	-13.0~-8.0	dB(A/m)
M4/T4	>45.0	dB(V/m)	>8.0	dB(A/m)
*When determining the largest interference field-strength, HA orientation is to be rotated continuously and transmit-frequencies to be scanned continuously.				

Table 2. EM Fields of Near-Field EMC of ANSI C63.19 for HAs

Table 2 shows the ANSI specifications for ratings of compatibility between wireless communication devices and hearing aids. ANSI measures involve the use of a Dipole, a type of antennae which generates the electromagnetic field for measurement. In order to unify the two types of measurement, it is useful to know how to measure with one method only, and then be able to predict results that would be obtained by the other method. Accordingly, ANSI specifications provide a table (8.2) which give EMC ratings from using the Dipole method, and which then also shows equivalent EMC results to E-field strength when measured via the GTEM method. Interested readers are encouraged to look up ANSI specifications for EMC in hearing aids.

TECHNIQUES AND EFFECTIVENESS OF EMC OF HEARING AIDS

GROUNDING THE PRINTED CIRCUIT BOARD TRACKS AND CONNECTED WIRES

Ground in circuits is used for returning signal current; it can also be used to short out interference and noise. However, if the ground circuit configuration is not designed properly, the ground circuit itself becomes RF antenna and thus receives interference. Improperly grounded components and/or overlong connected wires and tracks are the most common causes of the hearing aid EMC trouble. When *beginning design*, however, it is relatively simple to control the EMC well. Twice the results can be achieved with the half effort. The ground tracks of PCB can be designed as wide as possible; if there is room enough, ground tracks designed can act as ground straps, ground nets or ground islands (see Figure 1). PCBs are built upon surface mounted devices (SMD), which have very little "stray parameters;" it is best if the tracks can be arranged to be as short as possible. In hearing aids, PCB always arranged in multilayers, Figure1 shows an excellent layout of front and rear layers of a hearing aid PCB. We can see inside, ground "nets, islands and straps." The analog ground of each layer is electronically connected by many VIA, and the analog ground also is well connected with the battery ground, so as to form a stable reference ground. In addition, if the ground wires connected from the PCB to outside devices are kept as short as possible (even connected with 2 wires twisted together), this will further serve to ground the EMI. To test the procedures here, we evaluated a BTE hearing aid which did not pass the EMC requirements; we found that there were 4 long and thin ground tracks. After, we modified them into thick ground.

Figure1 Front and rear layers of a PCB layout excellent at EMC straps, the obtained IRIL were improved, enabling the BTE to pass the EMC evaluation.

UTILIZATION OF UHF CAPACITORS AND SHIELDING WIRES

If it is confirmed that the EMI arises from the components outside of the PCB, then the EMC control techniques described above are limited. For example, a receiver in canal (RIC) hearing aid has its receiver connected to its body through a twin wire with the length 3.5~5.5cm, which acts only too well as an antenna for EMI. Although this wire is connected to the *output stage of amplification*, it was verified that the twin wire caused the EMI of the hearing aid not to pass EMC evaluation. The solution was to connect two UHF capacitors (which act as high-pass filters) to ground at the two ends of the twinned wire where they are connected to the PCB tracks. This served to short the EMI to ground. These capacitors create no loss for frequencies in the audible range but they do reduce the EMI. Figure 2 shows two charts of the hearing aid output before and after the capacitors were used. The RIC hearing aid was mid power, and was measured in compliance with IEC standards. The dark horizontal solid lines of this figure show the EMC criteria. With the hearing aid set to Reference Test Gain and an input of 55 dB SPL, the outputs of the hearing aid are shown at 0^0, 90^0, 180^0 and 270^0 orientations. After calculated, the top panel without the capacitors shows the maximum IRIL of 55.3 dB at 270^0; the bottom panel with the capacitor used shows the maximum IRIL is 45.7 dB, at 0^0. It is to be noted that the EMI is still improved by 9.6 dB.

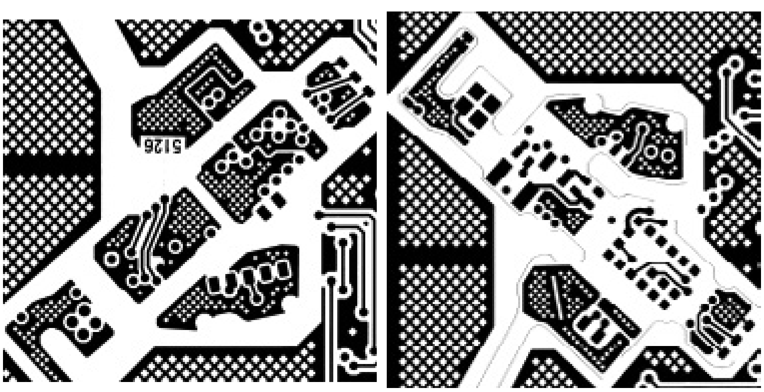


Figure1 Front and rear layers of a PCB layout excellent at EMC straps, the obtained IRIL were improved, enabling the BTE to pass the EMC evaluation.

The EMI trouble arising from outside the circuit can also be solved with a shielding wire, with good effectiveness. The two twinned core wires carry AF output signals from the PCB to the Receiver; grounding can be achieved if one end of a shielded wire connects to shell of the Receiver, and the other end to the PCB ground. The tracks of PCB ground should be selected reasonably; that is, one can try to connect the wire to a few different grounds, and select one which behaves with the best result.

UTILIZATION OF UHF CHOKES

The twin wire is not the only component outside the PCB that can lead to EMI; sometimes the problem is the microphone. When this is the case and one cannot use UHF capacitors to short EMI, because there are no proper ground tracks for capacitor connection, then, UHF "chokes" can be used to suppress the EMI. Their working principle is to absorb the EMI and to convert it into heat energy, so that there is no need to short the EMI into ground. New-generation UHF chokes can work in a frequency range up to a few GHz, meeting the requirement of EMC for hearing aids. These chokes are of tiny size and the cores of them are made of ferrite (nickel-zinc) material. One UHF choke always is made of two wiring coils together, so it can be connected into a circuit to achieve common mode rejection (such as that employed when

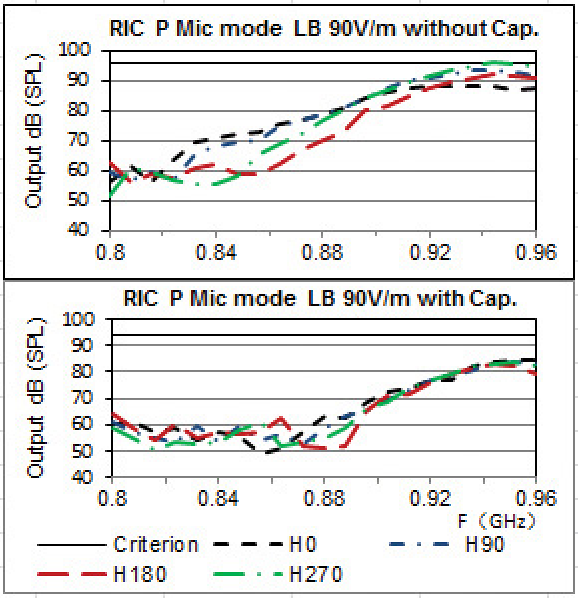


Figure 2. EMC performances without and with capacitors.

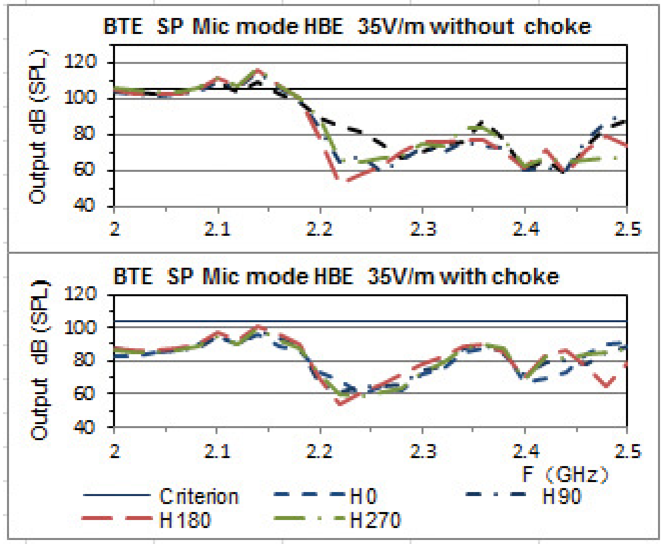


Figure 3 EMC performances before and after choke inserted.

recording the Auditory Brain Stem Response) or differential mode rejection, whichever the case may suppress EMI more. The size of UHF chokes is a little bit larger than the CHF capacitors.

The tracks for chokes need to be designed according to the principles illustrated in Figure 1. To test this proposal, we used a high power BTE hearing aid that did not pass the EMC evaluation. After measuring and analyzing, it was concluded that the EMI was coming from the two signal wires of directional Mics (each length about 2 cm). In this example, the AF signals in the wires were at the inputs of the hearing aid; since the EMI flowing out of the two wires were at the same direction, the common mode was selected. Figure 3 shows that EMC of the hearing aid was improved after using a UHF choke. The choke was connected from the signal leads of Mics to the Mic tracks of PCB. The curves in Figure 3 represent the same concepts as those in Figure 2. The top and bottom panels respectively show the output curves of the hearing aid EMI when the choke was not inserted and inserted. The performances of the EMC with the connection of common mode for the two Mics signals are better than that of differential mode. We can calculate that the maximum IRIL in the top panel is 67.5 dB, while the IRIL shown in the bottom panel is 51.3 dB; this indicates an improvement of 16.2 dB, which enabled a pass for the EMC evaluation.

UTILIZATION OF RF SHIELDING FILMS

If the EMI cannot be reduced from any of the above 3 EMC solutions, an approach can be taken whereby to shield the hearing aid shell itself. In the years of analog hearing aids, this was very difficult to achieve. Today, some manufacturers of EMC have developed a type of shielding material known as Fermifilm, which can adhere to the inside surface of a hearing aid shell, so as to shield the EMI from outside. Fermifilm has good conductivity and reflection, and the effectiveness of the shielding is almost unrelated to the film thickness. As such, it does not increase the size of the hearing aid.

Several years ago, we measured the several different Fermifilm products and many of them performed well. Figure 4 shows the EMC effectiveness of a mid-power, digital BTE hearing aid where the PCB was wrapped with a type of Fermifilm. The top and bottom panels respectively show the output curves of the hearing aid without and with the film wrapped. Again, the concepts show here are the same as those for Figures 2 and 3. The maximum IRIL calculated in the top panel is 70.8 dB, which was not sufficient to pass the EMC evaluation. The IRIL calculated in the bottom panel is 38.2 dB, an improvement of 32.6 dB, which enabled a pass for the EMC evaluation. It must be noted that the slots of the hearing aid shell were

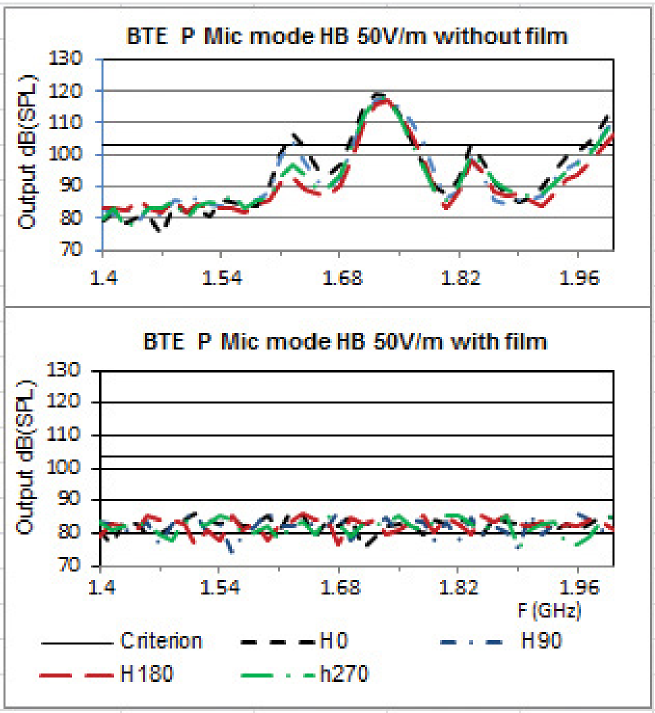


Figure 4. EMC performances without and with film UIP.

also shielded by the film, otherwise, the EMC performance may not have been as successful. Open slots can cause leaking in of EMI, depending on their size; slot sizes that are 1/20 of the signal wavelength can result in leakage enough to cause EMI. Today's digital hearing aids shells often have a few slots on the top; if possible, the connected wires inside the shell can be removed as far away from the slots as possible so as to avoid the leakage out of EMI. An advantage of this technique is that there is no need to worry about EMI when designing the PCB because there is excellent EMI suppression. The disadvantage is a cost of several US dollars on the production of each hearing aid.

Lastly, the usage of UHF "ferrite beads," which act as passive high-frequency noise suppression in electrical circuits can work in a range up to a few GHz. These behave much like UHF resisters; they are of tiny size, flexibility and very low cost. In a PCB circuit, if some track with strong EMI is found, a suitable ferrite bead can be inserted to intercept it. The bead does not need to connect to ground, as it converts the EMI into heat energy. Sometimes, when a single UHF capacitor is not shorting an EMI enough (and thus not enabling a pass for EMC evaluation), we can try to add a UHF bead to work with the capacitor. We even experimented with a ferrite bead and a capacitor together to suppress the EMI, and found that their effectiveness was better than that of the single capacitor. This scheme may require slightly more "real estate," or room, and so the layout may need to be finely modified.

CONCLUSION

Uses of today's mobile phones cause the unavoidable interference to hearing aids. Both IEC and ANSI have created standards for the comprehensive measurement methods and specifications of EMC evaluation of both types of devices (IEC, hearing aids only). Regarding mobile phone RF signals, a hearing aid is composed of many receiving antennae of different frequencies. It is thus subject to interference by mobile signals, causing the hearing aid user to hear the annoying noise of EMI. This paper proposed several techniques of EMC control for hearing aids:

1. Minimization of PCB track ground impedance and connected wire impedance is the basic technique of EMC control; it is suitable and effective for layout designs of various hearing aids.
2. Utilization of UHF capacitors/ shielding wires can effectively short/ block the EMI from outside the PCB. These capacitors are tiny, and are of very low cost; furthermore, the shielding wires don't require extra room or "real estate."
3. A new generation of UHF chokes works in the frequency range up to a few GHz, and they do not need to connect to ground tracks at all. Their options of common mode or differential mode can further suppress the EMI. What's more, they are small in size and are of low cost.
4. UHF Fermifilm is a new type of shielding film material that is conductive to UHF signals and isolative to AF signals. The film is adhered to the surface inside hearing aid shell and does not need to connect to ground. Its advantage is that there

is no need to modify layout designs of PCB and the connected wires. The effectiveness of its EMC control is excellent, but its cost is very high.
5. The combination of UHF capacitors and ferrite beads can solve the troubles of more complex EMI, but require more room for the PCB.

Today's EMC control techniques show great progress, and a new generation of EMC components has been developed, with increased working frequency range and improved anti-interference immunity, along with reduction in size, These progresses are all beneficial to EMC control in hearing aids.

Canadian Hearing Report 2015;10(2):23-29.

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NEW FULL FAMILY OF HEARING AID DESIGNS (SHOWN IN ACTUAL SIZE)