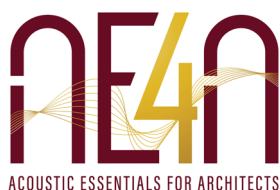


Acoustic Essentials *for* ARCHITECTS

Michael Fay



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To my wife Elaine, daughter Meredith, and brother Lew.
Without their love and steadfast support, this book would not exist.

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FOREWORD

Acoustics is architecture!

You have no idea how much I love seeing this phrase in print. As you will learn early in this book, this three-word phrase is attributed to my mentor in acoustics, architect and acoustician Russell Johnson. Russell was trying to express his frustration and change the way that acoustics were (or were not) being prioritized in the design of *sound-critical* spaces, such as concert halls and theaters.

In the mid-twentieth century, architects would lay out the design of sound-critical spaces and then engage an acoustical consultant to “do acoustics to the facility.” This limited the ability of the acoustical consultants to influence key issues, such as room-shaping and other elements, that impacted the perceived acoustics of the space and defined the acoustics of the facility under design.

For many architects, acoustics was considered one of the *dark arts*, an unfathomable morass of spells and incantations suitable for the yet-to-be-written Harry Potter novels. Russell rejected this design method as fundamentally flawed. He dedicated his career to the idea that (as you will read early in this text), “You do *not* do acoustics to a room. Rather, you design a room to have the acoustics it needs.”

Today, more and more architects are adopting this *design-in-the-acoustics* approach. “Why is this?” you may ask. Well, as you may have heard, the older method was not working so well, with many halls designed and built during the 1950s through the 1980s not living up to expectations for quality of sound. During this time there were also some spectacular failures, where rooms were opened and then had to be tweaked, twisted, renovated, and re-renovated to achieve even barely acceptable acoustics. A change in the design process was needed.

Since architects are the primary audience for this book, it is important to note that there are other people who play a huge role in prioritizing the

focus of the architect's design efforts, including performers, audiences, production professionals, systems integrators, and facility owners. These groups are linked together by sharing an ever-increasing expectation for sound quality in every facility, be it new or a renovation.

During the last 70 or more years, work in acoustics has been driven forward by the military (~1950s through the 1970s), the automotive industry (1960s through the 1980s), the cinema industry (1970s through the 1990s), the music industry (1990s through the 2010s), and, of course, the telecommunications industry. Telecom has been the steady proponent for sound quality from the time of Alexander Graham Bell through today. A result of this wide range of industries working in acoustics is that the spaces we define as sound-critical have grown to include offices, conference rooms, teleconferencing centers, performing arts centers, home theaters, cars, cinemas, worship spaces, theaters, lecture halls, restaurants, opera houses, concert venues, corporate C-suites, and more.

All this brings us to Michael Fay, and his reference guide, *Acoustic Essentials for Architects*. As a pro audio and acoustical consultant who has worked on a wide range of projects, Michael also recognized early on that acoustics is not something that can be easily or effectively done to your room after the basic design has been defined. The architect needs to be engaged from the beginning of the design process.

Often, in order to create the space you want visually—and one that meets your client's needs—you need to lead (or at least be an active participant) in the discussion about acoustics. And to do that, you need to understand the essential topics included in this book.

So, this is a guidebook—similar to a well-valued travel guide. Michael has compiled a set of essential topics for architectural acoustics, presented in a clear, outlined format. These are not deep dives into the esoterica of acoustics, but rather, they are short, clear explanations of topics that come up when you are working through the design of a sound-critical space. The topics addressed include: what sound is; sound propagation; an acoustical lexicon of key words and phrases; echo, reverberation, and resonance; room geometry; noise; computer modeling; human hearing; speech intelligibility; variable acoustics; modern materials; applied acoustics; and many more.

This book explains and demystifies much of the acronym-filled world of acoustics. He has compiled a set of 21 short chapters, each providing useful and practical insights into what he thinks are the essential acoustical topics for members of the architectural and design community. As a working acoustical consultant, I plan to make this book a gift for every architect I am currently working with and, perhaps more important, for every architect to whom I have spent hours explaining and re-explaining many of the topics included here! As this book reaches a wider and wider audience, no longer will we in acoustics have to explain that *acoustic isolation* and *acoustical treatment* are two different topics.

In closing, it is important to note that just as audience expectations for sound quality are ever-increasing, the architectural and electronic technology and materials you are able to use to create the correct acoustical environments are also ever-changing. So, I will not be surprised if I hear that Michael has interrupted his retirement at some point in the future to update this primer. But fear not, most of the topics included here are foundational and will help you work more effectively today and into the foreseeable future—hopefully, with a cooperative and constructive acoustical consultant at the table by your side.

HAVE FUN!

—Sam Berkow, Founder, SIA Acoustics

Sam Berkow is an Acoustical Consultant/Designer based in NYC. He has worked on sound-critical spaces, including concert halls and production spaces, longer than he cares to admit. Mr. Berkow started his career working under the tutelage of architect and acoustical designer Russell Johnson. In addition to his work in facility design, Mr. Berkow is the developer of the Smaart™ Acoustical Measurement system, a leading acoustical measurement tool for over 30 years. In 2022, Mr. Berkow was awarded the Parnelli Lifetime Achievement Award for Innovation in Audio and Acoustics.

INTRODUCTION

I love working with open-minded architects. This book is inspired by the many architects I have had the privilege to work with during my long career as a pro audio and acoustical design engineer.

As both a *sound* and *acoustics* guy, I often felt and experienced an acoustical disconnect between those who design buildings and those who must live and work in them. During countless interactions, I realized how many architects are unknowing or unclear about how their designs impact a room's acoustics.

I tried sharing some of the basic concepts, but realized there was so much more for them to know and understand than what a few brief conversations could unveil. I then thought I could find and share some reference materials, but soon realized the absence of any suitable content. Everything was geared toward those practicing or studying to become acousticians, but nothing addressed the big picture, low-tech needs of the architectural community.

In 2010, I began writing the first edition of this tutorial as a white paper. While it was shared, presented at the 166th meeting of the Acoustical Society of America conference in 2013, and embraced by a few, it lacked the scope and graphic support needed for further publication. In 2022, I felt compelled to revisit this material with renewed enthusiasm.

One distinguishing feature that can be found in every room is its acoustical characteristics. Unfortunately, this thing we call *acoustics* is not well-known, understood, or even covered in most architectural schools (see Appendix A). Because of that fact, this reference guide is tailored to the one group of people having more influence over a building's acoustics than any other—*architects*.

Underpinning the core of many architectural projects is a foundation. The foundation must be strong enough to support all structural, functional,

and creative ideas the owner and architect may need or want to consider. Yet, far too often, an acoustical foundation is not defined, approved, or implemented. Ultimately, architects are the drivers and coordinators of all construction decisions being made—somewhat like the *conductors* of an orchestra consisting of the owner(s) and many diverse consultants and contractors.

Formally, the subject being covered is called *architectural acoustics*. This is a field that is much deeper than most people imagine. To do justice to the theme, we must briefly touch on many subordinate topics, most having a synergetic relationship bonding architecture and sound.

This commentary is based on fundamentals and my 45+ years of experience—not perfection. It covers most of the basics, while also exploring several modern and esoteric matters. You will be introduced to interesting and analytical subjects; some you may know, some you may never have considered or understood.

Others may also find this reference enlightening. For example, most audio practitioners have to work in acoustical environments that are out of their control because of past decisions made by an architect, interior designer, and/or owner. Also, there are probably many new and veteran sound techs that have yet to accrue a solid acoustical foundation that allows them to understand what and why their sound is behaving well or badly. Most certainly, there are knowledge gaps on both sides of the designer/user relationship.

When opportunities arise, this commentary will help almost anyone better understand, discuss, and apply good acoustical principles.

EXAMPLES OF WHAT YOU WILL FIND IN THIS BOOK

- What is sound, and why is it so hard to manage or control?
- The length of commonly heard, low- and high-frequency sound waves vary by as much as 400:1. Why does this disparity matter?
- How and why do various audible frequencies behave differently when interacting with various materials, structures, shapes, and finishes?

- There are three acoustical tools available to both the architect and acoustician. What are they? How can they benefit or hinder the work of each craft?
- What is the wave/ray duality of sound?
- Is pure random accident part of your business model?
- Large rooms versus small rooms: How and why do acoustical challenges change as rooms become larger or smaller?
- Room geometry: Why some shapes are much better than others. Examples and explanations.
- Reverberation and echo: How do they differ? Which is better or worse and why? How much reverberation is too much or too little?
- New reverberation design goals for twenty-first century performance venues.
- What is the Parametric Method of Acoustic Treatment?
- Speech intelligibility: We all know it matters. What can architects do to help or hinder?
- Three simple tests: Quick, easy ways to evaluate the basic acoustical merits of a room without any fancy test equipment or training.
- Opportunities and trade-offs: Blending architecture, acoustics, and pragmatism.
- Applied acoustics: The four key feasibility questions.

THIS BOOK HAS FOUR MAIN GOALS

First—It will endeavor to put the essential terminology and concepts of architectural acoustics into the hands of the architect, owner, interior designer, end user, or anyone else who would like to have a better understanding of this subject.

Second—It will introduce the incredible dimensional range of wavelengths that exist between the lowest and highest audible sounds. Once defined and established, we can overlay this spatial understanding of sound waves onto the physical structures they touch.

Third—It will help architects better understand and visualize the relationship between the physical shapes, textures, and dimensions of their

work, and why those design decisions impact the qualitative behavior of sound. For example, architecture requires three-dimensional thinking and implementation, yet sound is a four-dimensional experience that must co-exist within a three-dimensional structure. The fourth dimension, time, being significant because the speed of sound is so slow that the size and shape of a built environment can often dictate the quality and clarity of all sounds within.

Fourth—It will explain the importance of interior seating symmetry for medium and large rooms. Sound propagation is an amazingly flexible phenomenon but not something that is easily controlled once a group of sound waves begin to move in any particular direction. As a result, seating symmetry is an extremely important component related to achieving high-quality dispersion and reception of sound. Conversely, in small rooms, overall structural asymmetry becomes a priority.

It is easy to think that sound is completely removed from the fundamental principles of architecture. Nothing could be further from reality. Consider this: If a person were seated in an amazingly beautiful structure at night—one without illumination—they would see few, if any, of the features, shapes, materials, colors, textures, or workmanship that was created. However, given that same dearth of light, all audible *sounds* remain unaltered . . . for better or worse.

Note: Each chapter is presented in outline form to facilitate the numerous cross references being tossed between the various chapters and sections.

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In first name alphabetical order, others who have notably impacted or influenced my career and this work:

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David Pfeifer—Domusstudio Architecture
John Groth—Groth Architects
Manuel Oncina—Manuel Oncina Architects
Mike Sebbins—CO Architects
Stan Andrade—Andrade Architects
Wayne Holten—Domusstudio Architecture

ABOUT THE AUTHOR

Michael Fay is owner/principal at GraceNote Design Studio, a pro audio and acoustic design consultancy. He is also a member of Syn-AudCon, the Audio Engineering Society (AES), the Acoustical Society of America (ASA), AVIXA, the Miramar College Audio Program Advisory Board, and former member of the Art Institute Audio Program Advisory Board.



Mike's experience includes more than 45 years of professional AV and acoustical systems design, systems engineering, recording studio engineering, live audio mixing, and technical writing. Now semi-retired, he spent the last 25 years of his full-time career as a senior-level systems design engineer, executive project manager, technical integration manager, technical sales engineer, and acoustician.

His pro audio experience sprung from a foundation of classical music training and performance (trumpet) in his youth and continued to develop in college with an emphasis on music theory, broadcasting, and electronics. From an early age, he was drawn to the quality (or lack thereof) of the recordings he listened to. So much so, that at the age of about 12 he was convinced he could do a better job mixing most of the pop records he heard. At that time his favorite recordings were motion picture soundtracks.

His passion for music and sound eventually led him into the recording studio where he worked primarily on corporate/industrial recordings for TV, radio, film, and theme park shows. Within just a few years he was

considered the first call independent studio engineer in San Diego. While working in some of the top studios in Southern California, he also developed a fascination for studio design and acoustics, which ultimately led him into the field and study of architectural acoustics.

In 1987, Mike became the editor of Recording Engineer/Producer (RE/P) magazine, a highly regarded, internationally distributed, technical trade magazine servicing both the recording and touring sound industries. In the early 1990s, he moved back into the applications side of pro audio, making the transition into systems design and integration.

His work history includes time as: Owner of Michael Fay & Associates, Technical Director at College Avenue Baptist Church, Director of Engineering at Audio Associates, and Senior Design Engineer and General Manager of Sound Image's Integration Division, which was and continues to be listed as one of the country's top 50 AV integration firms.

In late 2017, he retired from full-time employment and launched Grace-Note Design Studio. From here, he continues to design, consult, write, and mentor the next generation of audio and acoustical professionals, architects, owners, and end users. For the past three and a half decades, he has considered his deep knowledge, understanding, appreciation, and commitment to music and sound to be his *spiritual gift* from God.

For more information, Mike can be reached via his website: www.gracenoteds.com.



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Downloads for *Acoustic Essentials for Architects* include the T_{60} Slope Ratio Thesis (New Reverberation Design Goals for Modern Architectural Acoustic Environments), Parametric Acoustics, Second Edition (The Case for the Parametric Method of Acoustic Treatment), and Acoustic Shadowing (Unpacking Wave Numbers and Introducing the Wave Ratio Thesis).

ARCHITECTURAL ACOUSTICS DEFINED

- 1.1 Architectural acoustics (AA) can be defined as the science, study, and application of acoustical principles as they are implemented inside a building or structure. In the context of this book, the terminology focuses on built environments that will be used for live, amplified, creative performances, or the audible presentation of other useful information. In other words, medium and large room acoustics. To a lesser extent, small room acoustics will also be covered.
- 1.2 As defined by the architecture dictionary, “Acoustic design refers to the strategic planning and implementation of elements within a building to achieve optimal sound quality and control. This involves managing how sound is generated, transmitted, and received within a space to enhance clarity, reduce unwanted noise, and create an acoustically pleasant environment.”¹
- 1.3 Architectural acoustics and sound have an interdependent relationship. Once established by design, right or wrong, they are inseparable. They coexist as a bidirectional cause-and-effect engine.
- 1.4 While AA includes topics such as interior noise control and managing sound transmission in and out of a room or building, the focus of this reference is managing reverberation and resonances that directly affect the quality and clarity of sound in any venue.

1. <https://www.architecture.org/learn/resources/architecture-dictionary/entry/acoustic-design/>

- A. Too much reverberation causes speech and music clarity to suffer greatly. If there is too little reverberation, things like acoustic instruments, musical vocals, and congregational singing are dull, lifeless, or unblended—like they often are when performing outdoors.
 - B. Room resonance is often problematic at the lower end of the frequency spectrum, but can rise into the low to mid speech frequencies in small rooms.
 - C. Reverberation and resonance are covered in much more detail in Chapter 5.
- 1.5 Intentional or not, acoustics are a crucial byproduct of architectural and interior design. The product of those disciplines significantly influences our auditory experiences in all spaces. “By striking a balance between aesthetics and functionality, architects and designers can shape architectural spaces that engage our senses and enhance our connection to sound. From concert halls to classrooms, offices to residences, the art and science of acoustics continues to shape the way we experience the world of sound.”²
- 1.6 As legendary architect and acoustician Russell Johnson³ often said, “You do *not* do ‘acoustics’ to a room. Rather you design a room to have the acoustics you need!” Refined even further, he proclaimed, “Acoustics is architecture!”

2. <https://www.easternengineeringgroup.com/acoustics-101-understanding-the-basics-of-sound-control-in-architectural-spaces/>

3. https://en.wikipedia.org/wiki/Russell_Johnson_%28acoustician%29



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WHAT IS SOUND?

- 2.1 Have you ever stopped to consider just what sound is? Of our five senses, hearing seems to be the one receiving the least consideration, though some modern research¹ suggests it's the most important for our overall well-being and lifestyle. Why then do our listening environments garner so little attention and respect? The answer is at least threefold.
- A. Sound and acoustics are relatively complex subjects that are poorly understood by most people.
 - B. Sound systems and acoustical treatments must be customized for each room. There is no such thing as a *one-size-fits-all* solution. To reach a room's desired audio quality and clarity, different sizes, shapes, locations, and quantities of loudspeakers and acoustical finishes are often required.
 - C. Quality loudspeakers and acoustical treatments are often perceived as being expensive, bulky, and/or generally unsightly. While historically true, the size and appearance of these products are becoming more aesthetically appealing.
- 2.2 Sound is not a tangible thing; it is a transformative experience.
- A. Sound is a relatively slow-motion, push/pull, molecular chain reaction that starts with a simple oscillation or vibration. These vibrations are created by any number of humans, animals, or objects.

1. <https://www.acousticbulletin.com/our-visual-focus-part-2-the-eye-versus-the-ear>

- B. The vibrations become a sound we can hear if they stimulate the nearby air molecules with enough energy to be detected. Given a very early age and optimal conditions, the audible spectrum for humans is generally considered to be 20 Hertz (Hz) (named after German physicist Heinrich Hertz) to 20,000 Hz.
- C. As any object vibrates, there is an energy transfer between adjacent air molecules that corresponds to the frequency of its vibrations. To visualize this energy transfer, think about Newton's cradle (see Figure 2.1) of steel balls. Regardless of how many, the balls in the middle really don't move. Only the first and last can be easily seen to move because they are the beginning and end of a chain reaction. At the molecular level, the electrons in air squeeze together just enough to transfer their *new-found* energy along, then return to their original position—via compressions and rarefactions in the air



Figure 2.1 The Newton cradle is an excellent visual example of the energy transfer between energized and static air molecules. Said another way, the conversion of potential energy to kinetic energy.

molecules—thereby creating small areas of higher and lower air pressure (see Figure 2.2).

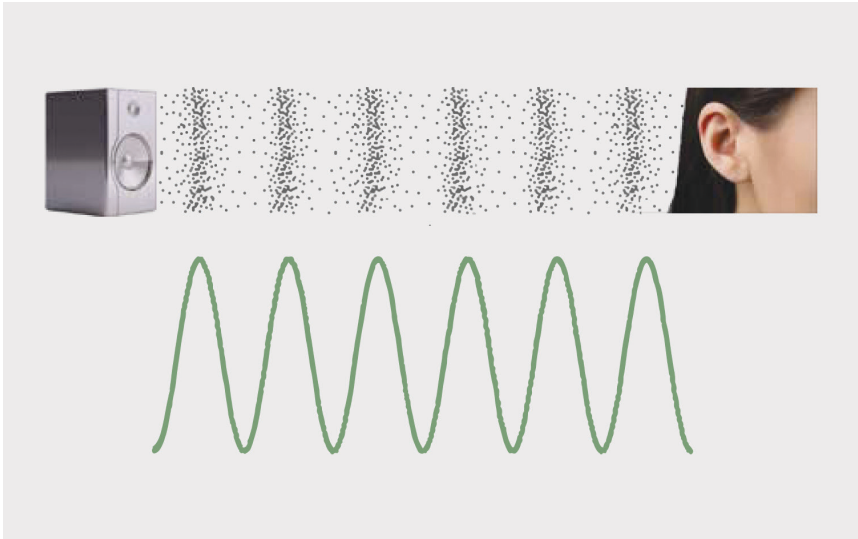


Figure 2.2 This graphic shows an overly exaggerated view of a sound wave moving through the air—from source to ear. Graphic by Atiq Ahmed

1. The stronger or more violent the oscillating motion, the greater the change in pressure. This results in a louder version of the vibration or sound.
- D. Barring obstruction, these tiny changes in air pressure move away from the source of the vibrations and travel through the air rather slowly, until they strike another set of objects that sympathetically vibrate. For us humans, those sympathetically vibrating objects are our eardrums.
- E. In its most rudimentary form, the transformative circuit that culminates in audible sound looks like this: A vibrating object → a chain reaction of air molecules pushing toward and pulling away from one another → one or more

sympathetically vibrating eardrums → brain → *qualia*²; the subjective human experience. Individual air molecules make no audible sound.

- 2.3 Sound can also be thought of as a force, somewhat like gravity or magnetism. But unlike gravity with its ubiquitous downward force or magnetism with its *sticky* bipolar forces, think of sound as a force that generates molecular chain reactions. When man-made and intentional, it is a force that can easily be activated or deactivated, when and if required.
- A. Intentional sound waves can easily move through air in any direction; they can be manipulated and steered into relatively definable areas; and with proper care and handling are generally adaptable and responsive to our needs.
 - B. However, sound waves cannot be bent around corners or penetrate solid objects without significant quality, quantity, and/or temporal changes; usually unwanted.
 - 1. When sound waves bend around objects or corners, it is called diffraction.
 - 2. When sound waves strike solid objects, some of that energy may be transferred via structure-borne vibrations, which can plague noise isolation efforts out of or into a room.
- 2.4 There must be some type of *compressible medium* for sound to exist. It doesn't matter what type of medium or atmosphere, so long as there are molecules that can be pushed around or stimulated into distinct patterns of greater and lesser pressure.
- A. Water is a good example of a medium that easily transmits sound; so too are steel and concrete, under the right conditions.
 - B. A vacuum has no atmosphere; therefore, sound does not exist in a vacuum.

2. <https://en.wikipedia.org/wiki/Qualia>

2.5 Frequency, wavelength, and the speed of sound:

- A. Sounds can be defined by either their *frequency* or *wavelength*. Every discrete frequency has a corresponding wavelength. While frequency and wavelength are directly correlated and interchangeable, each word defines something different.
 - 1. When identifying a specific frequency in cycles per second, the unit of measurement is Hz.
 - 2. To say that a sound has a frequency of 500 Hz means something is vibrating, back and forth, 500 times each second.
 - 3. As any discrete vibrating frequency is produced and propagates or moves outward at the speed of sound, the linear distance required to complete one full, sinusoidal wave or cycle is its wavelength. Thus, the wavelength of a pure 500 Hz tone is about 2.25' and a 2.25' wave is a 500 Hz tone. They are identical in size and sound.
- B. When traveling through air, the speed of sound is a *generalized* constant. The number used here, and referenced throughout, is 1,127 feet per second (FPS). This number will fluctuate slightly based on temperature and humidity, but not enough to be meaningful in the context of this tutorial.
 - 1. The complex waves of music and speech all travel through air at the same speed, regardless of frequency.
 - 2. If you're interested, the math conversion from frequency to wavelength is very simple: divide the speed of sound (1,127) by whatever frequency you are interested in. For example: $1,127 \text{ FPS} \div 320 \text{ Hz} = 3.52'$.
- C. Now compare the speed of sound, at 1,127 FPS, to the speed of light, which is about 186,282 miles per second.
 - 1. Because the wavelengths of visible light are so small, directing, shaping, and containing light is many orders

of magnitude easier than shaping, containing, and controlling sound. Why? Because the longer the wavelength, the more difficult it is to control, dissipate, and/or stop once it is in motion.

2. It is relatively easy to completely block or limit the visibility of any unwanted light. One way is to simply close a door between two rooms. If needed, and with little effort or specialized planning, the light in room *A* can be completely eliminated from room *B*.
 3. This same exercise is much less effective if you want to block or limit some or all audible sounds between the two rooms. Low and mid frequency sounds (LF and MF) can easily penetrate doors, walls, and windows, usually via the transference of structural vibrations. Managing speech privacy between two adjacent rooms is a perfect example of such challenges.
 4. Only with very careful structural planning and/or specialized acoustical treatments can we completely stop and/or block all sound.
- D. Understanding how audible frequencies relate to wavelengths is a vital link between sound, acoustics, and architecture. Once sound is translated into physical dimensions that architects or interior designers can easily understand, they can begin to unlock the mystery of why effective acoustical treatment needs to be applied in so many sizes and shapes.



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