NUTS and BOLTS

PART 17

Reverb, Part 1

A Look under the hood

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What does space sound like?

Deep space, where NASA probes and Hollywood stars have often ventured, doesn't sound like much. Sound travels through air, water, stone... anything. The only thing that doesn't propagate sound is... nothing. That is, a room full of nothing, a vacuum, will not have sound, which needs an elastic medium through which to travel. Outer space is therefore completely silent.

Forget outer space then. What does the sound of a physical,architectural space sound like? What does a cathedral sound like? An opera house? A hall? A club? As you no doubt have experienced, all these spaces add their own signature to whatever sound happens within them. When we listen to music in anything other than an anechoic chamber, we listen to the sound of the music plus the sound of the room.

The room acts like a signal processor: music in, music plus effects out. In fact, thanks to many different music-gear makers, architectural spaces have essentially been squeezed into rack spaces. Reverb units are signal processors acting like acoustic spaces.

Blueprint

An understanding of the sound of a physical space begins with a look at the floor plan of a room. Figure 1 shows a source (S), which might be a singer, cello, or didgeridoo. It makes a sound in the room. Time passes and the receiver (R) hears it.

As the rays show, we hear first the direct sound from source to receiver. It's the shortest path. But the reflections are audible too. So that direct sound is followed by a quick volley of reflections. Shortly after the sound commences the listener is immersed in a field of these reflections—too many to be identified discreetly. This reflected sound energy in a room is reverberation.

These reflections are different from the direct sound in time of arrival, angle of arrival, and spectral content. Since the reflected sounds travel along a longer path than the direct sound, they reach the receiver after the direct sound. Bouncing off walls,floor, and ceiling (and furniture, music stands, and other musicians), they also generally arrive at a different angle than the direct sound.

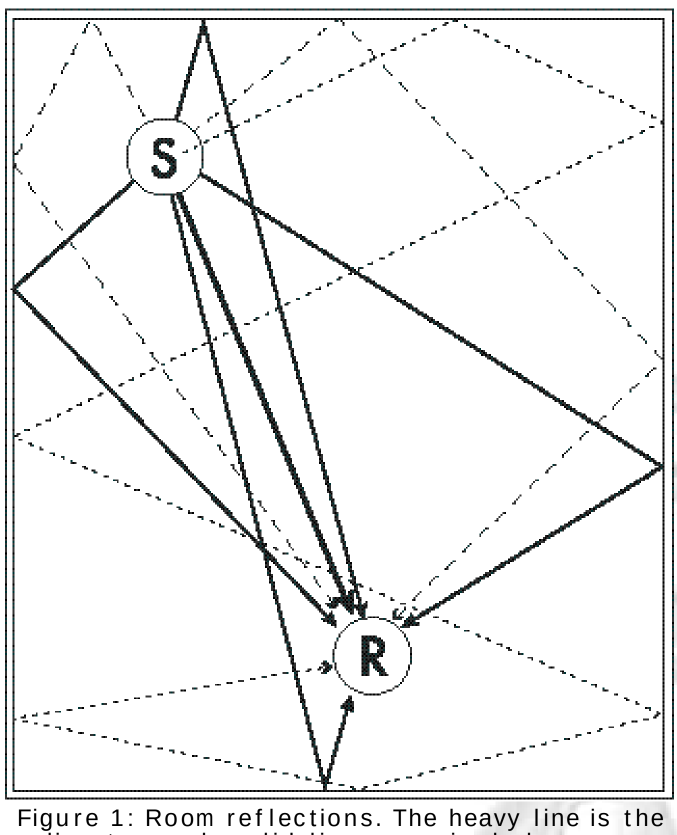

Figure 1: Room reflections. The heavy line is the direct sound, solid lines are single bounces, dashed lines double bounces, and the dotted line shows one of millions of multiple-bounce paths that make up the reverberant sound.

Finally, due to the energy the sound loses as it travels through the air and bounces off various room boundary surfaces, the amplitude of the signal at different frequencies changes. Air and fuzzy surfaces (like carpet, fiberglass and foam) tend to absorb high frequencies. Flexible surfaces (like very large windows or panels of wood) tend to absorb a good amount of low frequencies.

All said, the room introduces delay, changes the angle of arrival, and manipulates the loudness and spectral content of a signal.

Time

How delayed are the reflections? It depends on the room size and geometry. The reflections in larger rooms take longer to reach the listener than the reflections in smaller rooms. If the source or receiver is particularly close to a room surface, that changes the pattern of reflections.

Listening to a sound followed immediately by its reflections seems likely to be a review of the Nuts & Bolts Delay Trilogy just completed (July–October 2000). We discussed how a delay of about 5 milliseconds introduces comb filtering when combined, in approximately equal parts, with the undelayed signal.

Because sound travels at roughly one foot per millisecond, that means that a signal whose reflected path is about five feet longer than the direct path will create comb filtering. Right? Not necessarily.

Try taking a harmonically rich sound like a piano patch or track. Send it to a short delay of about 5 milliseconds. Monitor both at about the same volume. With both signals panned to the same location in the stereo landscape, hard left for example, the comb filter alteration to the frequency content of the signal is unmistakable.

Now pan the delay to hard right. Presto—the comb filtering seems to disappear. Instead we get a localization cue: the delay seems to shift the image of the piano toward the undelayed signal.

Follow that thought and slowly decrease the delay time. As the delay time approaches zero, the placement of the stereo image heads toward the center. All the while, the comb filtering effect is gone.

This points out an enigmatic property of short delays: the angle of arrival matters! Short delays directly combined with their undelayed brethren will create comb filtering. Short

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delays reaching the listener from a very different direction do no such thing. In our look at reverberation, this leads us to ask:

Where do the room reflections come from? This too depends on the physical geometry of the room. You need only patience and a ruler to figure out which reflections reach the receiver.

Figure 1 shows the first handful or so of reflections. Some reflections we hear after a single bounce off a surface. Other reflections strike two, three, or more surfaces before finally reaching our ears. The direction from which they come seems to be a lot about luck, statistics, and/or the physical geometry of the room.

Yet our personal audio analysis systems (ears and brains) can make sense of this. Though it isn't intuitive, it is important to know that we aren't distracted or confused by these reflections.

Let's make the source a singer, singing your recently penned tune, "Insulate the Attic." We zoom in on the first word of the catchy chorus for this hit-waiting-to-be-discovered. She sings "Fiberglass..." and for the sake of analysis we slow time down like a Hollywood movie. The receiver hears the word first direct from the source,"Fiberglass." Then a reflected version of the word arrives from one side, then the other, then from behind, "fiberglass...fiberglass...fiberglass."

This ought to be confusing, but it isn't. As you know from listening to music and conversations in real spaces, the reflections coming from all around do not stop us from knowing—at all times—where the singer is and what she's singing.

Researchers have teased this out of various experiments. We localize the source based on the angle of arrival of the first waveform and the pattern of reflections that immediately follow; we synthesize an opinion about the room in which the sound event happens based on the amplitude, quality, and angle of arrival patterns of these supporting reflections.

It's tempting perhaps to think that the reflections from all around are ignored so as not to confuse our personal audio analysis system. Quite the opposite. Sounds without the support of reflections are difficult to listen to, difficult to localize, and sound just plain strange.

We don't hear sounds in anechoic chambers very often, after all, so our hearing mechanism isn't tailored to that experience. If you've heard sound in an anechoic environment, you know it's unnerving and a little confusing. In fact, research has shown our localization abilities suffer without some additional reflections, even though they come from directions different than the direct sound.

Using amplitude, time of arrival, and spectral content, we make use of the clues these reflected sound waves offer. Our personal audio analysis system has developed the ability to absorb a complex sound field, extract the direct sound, incorporate the reflected sound field, and add it all up into a complete perception of a sound in a space. Pretty darn cool.

> The room acts like a signal processor: music in, music plus effects out.

Synthesized space

To create the sound of a room without the use of an actual room one need only assemble the set of reflections a room would add to a direct sound.

A grotesque oversimplification. But even simplified, the illusion works. Each reflected sound suffers a bit of delay and attenuation having traveled farther than the direct sound, and a bit of equalization due to air and boundary energy absorption.

The only processes at work are changes of amplitude, eq, delay, and angle of arrival. Good news, because effects racks and pull-down menus are full of that sort of capability—traditional studio signal processing can, cleverly employed, simulate reverberation. Rackmount units display the word 'hall' and do a fun job of sounding like one.

Digital reverberators are, to summarize, very shrewd volume adjusters, spectrum manipulators, changeable panners, and variable delays. An audio waveform goes in and triggers a nearly infinite set of faded, equalized, panned, and delayed versions of itself.

Naturally, some equalizers sound better than others, some delay units sound better than others. And the whole algorithm used to simulate the complex pattern of sound energy is going to have an audible effect on the sound of the reverb.

Not surprisingly then, some reverb devices sound better than others. At the very least, most reverb devices sound different from most others on the market. Each manufacturer offers its own approach, creating its own sound; our studios benefit from having many different reverbs. There is no single best, just a broad palette of reverbs awaiting our creative use.

Reverbus ex machina

Living as we do at the edge of a new millennium in a thriving digital economy full of dot com mirages, we may forget about life before audio was digitized. But somewhere between the time all those critters boarded ship with Noah and the present day, we had a period of non-digital audio.

While it is fairly trivial today for a computer to do a decent job simulating the sonic character of a space, it is very difficult to do so with analog electronics. Resourceful equipment designers looked for physical systems that could sustain a sound like a decaying acoustic space would. They found some success using two devices: the spring and the plate.

The spring reverb offers an intuitive approach. Initiate subtle vibration in a spring using your audio waveform, and boing,let it go. The spring continues to vibrate for a time, a bit like a hall sustains a single violin note.

Well, sorta. The fact is, springs don't exactly behave like rooms. They are elastic and can respond to music, but the simulation ends there.

However, the musical value doesn't! Just because a spring doesn't sound like the Musikvereinssaal in Vienna doesn't mean it isn't good enough for Jimi or Stevie or You. Leo Fender put spring reverbs in electric guitar amps, and there's been no turning back.

Spring reverb rings with its own distinct character. Subtly used, it fills in underneath a track, adding support and shimmer. Overdriven, it crashes and wobbles (ever move a guitar amp while it was cranked and—crwuwawuwawoing—the spring gets jostled?).

Taking the spring idea and making it two-dimensional leads us to the plate reverb. This device is essentially a sheet of metal with a driver attached to it to initiate vibration and a sensor or two or more to pick up the decay that ensues. (Will surround sound lead to multichannel plates? I fear the answer is yes.)

The plate is another mechanical simulation of an acoustic space. Bang on a sheet of metal and it rings for a while, again somewhat like the solo violin in a symphony hall. And like the spring, as a simulation of an actual space the plate falls short.

But as a pop music effect it is a sweet success.

Sweet sound, funky smell

When an actual large hall isn't feasible and a spring or plate reverb isn't available, there's always the bathroom. Large spaces are reverberant in part because they are large spaces (I get paid to say this sort of thing?). That is, the reverberance of a space is directly proportional to the size of the room. Make the room wider, longer, and/or higher, and the reverb time increases (because the reflections have farther to travel).

The other key driver of reverberation in a physical space is the absorptivity of the room surfaces. Absorptive materials on the floor, walls, or ceiling will lower the reverb time. Hard reflective surfaces increase the reverb time.

The trouble with using reverb from a hall during a studio production is that there isn't usually a hall around. So lacking a large space with its associated long reverberation time, we go to the only room around with really hard shiny surfaces: the tiled bathroom.

Because the tiles reflect sound energy more than your typical room finish treatments like gypsum wall board or carpeting, the bathroom has a little reverberant kick.Kitchens sometimes are a close second place. Rarely carpeted,they have a decent amount of hard surfaces: countertops, appliances, wood cabinets, and such. Elevator shafts and high rise fire stairs have contributed a big reverb to the studio that could get away with it.

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Naturally, some studios built reverberant bathrooms on purpose.Lose the plumbing fixtures and make the room a little bigger and you've got a reverb chamber. Put in loudspeakers (inputs) and microphones (outputs) and you've got a physical space reverberator.

What it lacks in physical volume—it's nowhere near the size of an opera house—it makes up for in highly reflective surfaces of stone, tile, cement, beer bottles, and such. The result, of course, isn't an opera house simulation on the cheap, but a wholly different kind of reverberation.

Chambers offer their own unique signature to the audio sent to them. The art of building and maintaining them has distinguished a select few studios that get bookings partly for the sound of their chambers.

an impulse (e.g. a sharp clap, gun shot, balloon pop, or electronically synthesized click) until you can't hear it anymore (roughly 60 dB quieter).

Some of the most famous symphonic halls have reverb times averaging just under two seconds; opera houses extract better speech intelligibility by shortening reverberation to just over one second. Digital reverbs,springs, and plates empower you to dial in any reverb time you like. Have fun.

Spectrum

Listen, in your mind, to the sound of a room decaying. Cut that sound up into different frequency ranges and create a reverb time measurement for each spectral region of interest.

RT60 typically refers to the decay of the octave band centered on 1 kHz.

Real spaces always have some predelay. If they have it, why shouldn't reverb patches?

Breaking it on down

Reverb in all its flavors—physical performance spaces, digital effects devices, mechanical resonating systems, and acoustic chambers—can be broken down into a few parameters. But I must preface it with this: all reverbs offer unique and subtle sonic contributions to your audio that defy measurement. Take two different reverbs and set them to the same patch, dialing in the same values for all their adjustable parameters, and they'll still sound different.

No symphony hall sounds exactly the same as any other. No plate sounds exactly like any other. Always listen for what you like; it's just the sound of the added, synthesized ambience that matters, not the reverb time, not the algorithm, and certainly not the reverb make and model number.

Reverb time

Easily the most cited descriptor of reverberation is Reverb Time. Sometimes called RT60, reverb time measures the number of seconds necessary for the sound in a room to decay by 60 dB. Practically and historically speaking, RT60 measures how long a sound lingers in a room after

But there is nothing stopping us from measuring the RT60 at the octave bands below and above 1 kHz.

In fact, architectural acousticians measure and calculate the reverb time at all audible frequency bands. Like using a tone control, acousticians design spaces with different reverb times at different frequencies to satisfy musical taste, not scientific purity.

Actually, halls are distinctly not flat in the spectral content of their reverb. Halls for classical and romantic music repertoire typically have low frequency reverb times that are a bit longer than the mid frequency reverb times. This gives the halls a degree of warmth that seems to support the type of music that will be played there.

You'll see this expressed in acoustics literature and reverb signal processor manuals as Bass Ratio. Bass Ratio mathematically compares two octaves of low frequency reverb (125 Hz and 250 Hz) to two octaves of mid frequency reverb (500 Hz and 1000 Hz). The resulting ratio quantifies a hall's warmth, what we might call its Phatness.

Hall designers are finding what works for a Gorecki symphony and a Puccini opera. But only you know the color of reverberation that works for tonight's track, "Insulating the Attic." Experiment with the tone color of your reverb by adjusting its Bass Ratio if it offers one. A Bass Ratio of 1.2 will warm up the reverberant wash of ambience by telling the reverb to create a low frequency reverb time that is 1.2 times as long as the mid frequency reverb time.

Some reverbs don't offer bass ratio control. Shape the color of your reverb by using eq on the reverb returns on your mixer or on the send to the reverb. Control the low end to add warmth, not muddiness. Or if you are going for a brighter reverb (why not?), find some magic shimmer and airiness but avoid painful sizzle and sharpness.

In general, the simplest units let you control the proportion of the early reflections by setting their relative volume. Their pattern depends on the shape of the room you've selected

What good do these parameters do? The answer is built in two worlds: physical acoustics and psychoacoustics. First, real spaces always have some amount of physical predelay because it takes time for the sound to travel out to all the room boundaries and bounce back at the listener, first in distinct early reflections and then in an enveloping wash of reverb. If real spaces have it, why shouldn't reverb patches?

Second,predelay is very valuable to our personal auditory analysis system. Listen carefully to the sound of a fixed amount of reverb with and without predelay. As predelay separates the reverberant decay from the initial sound in time, it also separates them in our mind. It is easier to hear the reverb after a bit of predelay. Without predelay, the direct sound masks the reverb, making it less apparent.

Bass Ratio = RT Lows divided by RT Mids = (RT60@125Hz + RT60@250Hz) / (RT60@500Hz + RT60@1000Hz)

Predelay and Early Reflections

Beyond the length and color of the reverb, two other fundamental properties of reverberation are the time it begins (predelay) and the timing of the first few bounces—single bounces from the source to a wall to the listener (early reflections). If you use a spring or plate reverb, the wash of decay commences the instant your sound starts. In a large hall (or gymnasium, or canyon, or domed stadium) it takes an instant before the reverb begins, and there are one or more distinct bounces before the wash of reverb sets in.

By adjusting the parameter identified on most devices as Predelay, we can adjust the time gap between sound start and reverb start. Predelay simply inserts a delay between the direct sound and the reverberation algorithm. In the world of digital audio, adding a delay is fairly trivial, so predelay controls are found on almost any digital reverb device.

In the realm of analog audio, delay isn't so easy. Plates and springs therefore rarely give you this feature. When using a plate or spring reverb—or a bathroom—have the best of both worlds by inserting a digital delay on your reverb send so that you can add a controllable amount of delay before the reverb begins. Tape delay is a common feature in this role as well.

Early reflection control is common even on the most inexpensive digital reverbs, and has been for a long time.

This suggests two important courses of action when you want a touch more reverb on a track: raise the reverb send so that the reverb gets louder, or lengthen the predelay so that the reverb that you've already put in the mix becomes more audible. It isn't always the case, but often you can add the feeling of reverb by adding some predelay. This approach is clever as it adds more of the desired effect without adding clutter to a mix.

Early reflections do their part by suggesting the rough shape of the reverberant space: is it a toilet stall or a cathedral? Selecting a room shape becomes a critical choice in creating realism due to these reflections.

Next month we stir up these reverb ingredients—chamber, plate, spring, RT60, bass ratio, predelay, etc.—into a few different concoctions and see how they combine to create a terrific variety of pop music flavors.

Even in kindergarten, Alex Case was more interested in reverb time than play time. Sustain N&B articles through case@recordingmag.com.