APPLICATION NOTES

Application Note AN-1

"MULTI-TAP DIGITAL DELAY IN BROADCASTING"

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Reverberation is a universal acoustic phenomenon, part of every person's daily experiences. We very rarely hear sounds without some accompanying reverberation, even if it's only the short decay pattern of a living room or the pleasing assistance from the bathroom walls when we sing in the shower. We are so conditioned to hear speech and music in a reverberant acoustic space that we have learned how to use delays, echoes, and reverberation to tell where a sound is coming from, how large it is, how large the room is, what the walls are like, etc. When we hear a voice or music totally lacking delays or reverberation, we are at once struck by its unnaturalness, by it thinness and lack of body. Only in a specially constructed room (anechoic chamber), or out on a large, open field do we ever hear sounds with no accompanying reverberation. The point for broadcasters, as for recording engineers and acousticians, is that good sound requires a tasteful and supportive use of reverberation to sound natural and full-bodied. As we shall see, reverberation has other advantages of more obvious commercial significance.

But first, let's look at some important aspects of the reverberation process.

Direct Sound: You are in a room, hall, or some acoustic space with reflective boundaries, and nearby is a sound source, say a pianist. The pianist strikes a chord and pauses; immediately, the piano produces sound waves that radiate in all directions at the speed of sound (roughly one foot per millisecond). Some of this direct sound, as it is called, comes in a bee-line toward you and reaches your two ears, whereupon you have your first "audition" of the pianist. As soon as the chord stops, this direct sound stops as well. This is good, "high fidelity" sound, suffering only a modest amount of high frequency dulling due to air absorption, and possessing complete transient information that tells us a lot about the source and how it was played. This direct sound, thanks to our well-developed binaural hearing ability, also tells us where and how far away the source is.

Early Reflections: Remember that the piano radiated sound in all directions. So far we've only heard a small portion of that sound; the rest goes off in other directions and eventually strikes a room boundary, such as floor, wall, or ceiling. The boundaries reflect the sound, after absorbing a portion of it, and some of these reflections reach

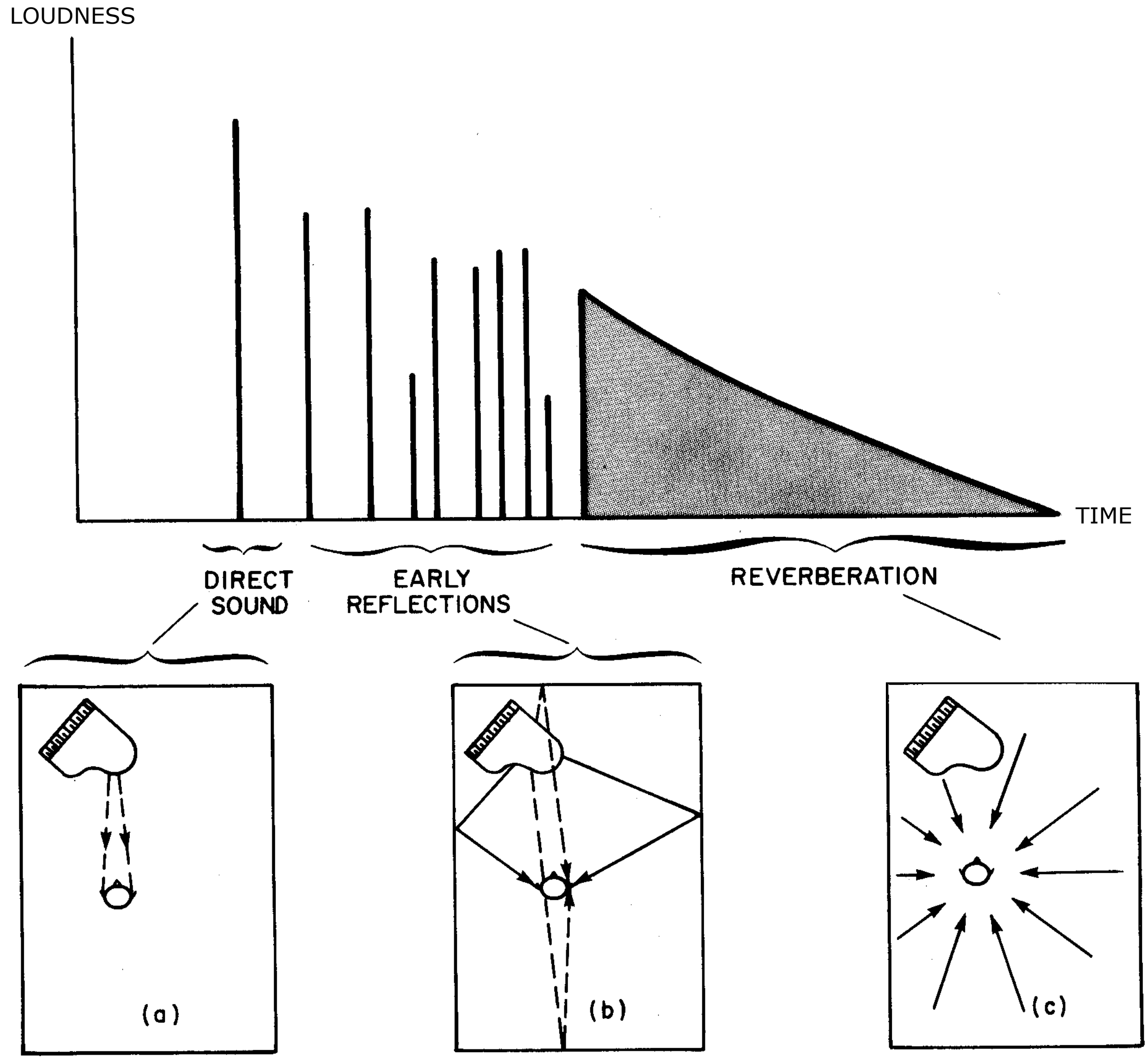


Fig.1: The Reverberation Process Viewed in Time and Space.
a.) The Direct Sound travels by line-of-sight and arrives at the listener first.
b.) Early Reflections arrive next, gradually increasing in temporal and spatial density.
c.) Reverberation is very dense, smoothly decaying tail end of the process.

our ears a short time after the direct sound. These reflections will eventually build up into the extremely dense, omni-directional reflection pattern that is properly called reverberation, but for a short time after the direct sound and before the reverberation has really built up, there is a group of reflections called the early reflections. This time extends from perhaps 5ms in a small room to as late as 200ms or so in a large hall, and is an extremely important part of the reverberation process. Although we generally can't pick out individual reflections in this period and say "Aha! Echoes!" we process the reflections psychoacoustically and extract some important information. We learn a lot about the room: hard walls produce loud, crisp reflections; big rooms produce later-starting, longer-lasting patterns; tiny rooms produce such a brief pattern that we hear frequency response coloration instead.

Reverberation: After the early reflections have built up to a very high density, we pass into the reverberant period of the process, with so many reflections arriving that we hear a pleasingly diffuse and randomly organized version of our piano chord that gradually dies out. The reverberation tells us a lot about the room by how long it takes to die out (the RT60, or decay time to -60 dB), by how the spectral character of the decaying sound changes, and by how evenly the overall sound energy follows the classic exponential curve. If the high frequencies decay much more rapidly, we hear a more classical kind of concert hall; if instead they decay nearly as slowly as the mid and low frequencies, we may well wonder if we're in a concrete parking garage instead of a concert hall.

These three aspects of sound occur in virtually every hearing experience we have. First, the line-of-sight **direct sound** arrives; next, a pattern of **early reflections;** and, finally, the dense, decaying **reverberation** process occurs. This process is so universal that it has contributed to the development of several interesting and relevant aspects of our hearing, covered in the study known as psychoacoustics.

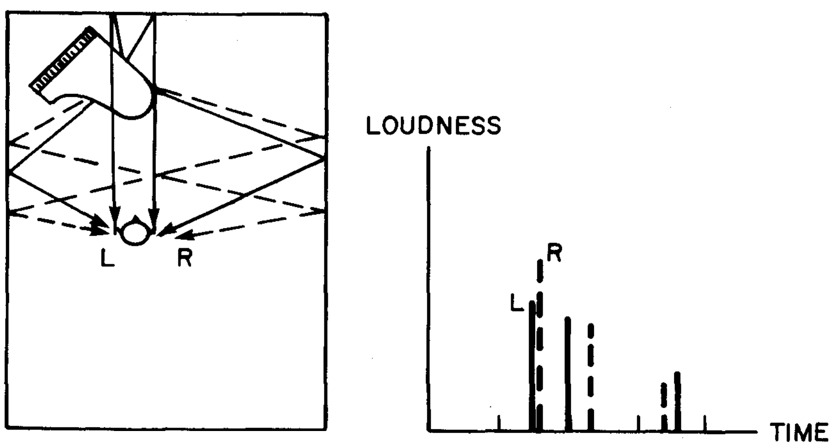


Fig.2: Role of Early Reflections in Creating Stereo Ambience.
Time Delay and amplitude differences of reflections arriving at left and right ears embed direct sound in a stereo space.

Stereo: Another important aspect of sound in acoustic space is its stereo nature, or, strictly speaking, its **binaural** nature. Acoustic sources exist in three-dimensional space, with width, height, and depth, and we deduce these characteristics largely from the direct sound. But have you considered how a solo performer, confined to a narrow position on the stage, can be a "stereo" source? Such a source is essentially monaural, although one nearly always receives a slightly different left and right direct sound at each ear due to the line-of-sight direction to the source not being exactly on-axis to your head. A more important contribution to stereo comes from the stereo early reflection pattern and reverberation that follow the direct sound: each ear hears a slightly different pattern of reflections, coming from different directions at different times. You can think of the room as processing the mono sound source into stereo by virtue of left and right early reflection pattern differences. This is a natural way of spreading out a small sound source into stereo space, and is another universal

listing experience. We never hear truly mono voices or music in nature. But broadcasters regularly air truly mono sounds: every announce mike or spot transmitted in mono results in a narrow, flat, and unnatural acoustic image.

We don't hear every sound as distinctly as it occurs, fortunately. Otherwise, wed be innundated by a hopelessly confusing group of echoes. Instead, we have learned to **fuse,** or combine, a sound and its early reflections into one perception. Our success in performing this psychoacoustic fusion depends on the nature of the sound (it is harder to fuse impulsive sounds), and the time delay of the reflections. Up to about 30ms delay, we can fuse quite well, but beyond that, if there is no intervening echo, the delayed signal breaks loose from the direct sound and is perceived as an echo. With music, we can tolerate longer delays in the early reflections and longer decay times of the reverberation, but with speech, these can severely degrade intelligibility.

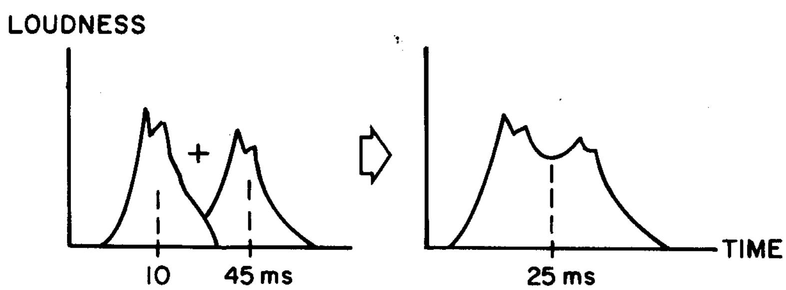


Fig.3: Temporal Fusion Increases Perceived Loudness.
Here the additional delayed sound occurs soon enough (25ms) to allow temporal fusion, resulting in a louder, more intelligible sound. Multi-Tap Digital Delay can be used to give up to 8 delayed sounds, adding presence and apparent loudness to voices without incurring the wrath of the FCC.

It is an intriguing and significant fact that speech intelligibility is actually improved by short early reflections in the range of 5ms, to as much as 80ms, whereas it is significantly degraded by longer delays that we cannot fuse and thus hear as disturbing echoes. So in acoustic situations with strong reflections and reverberation, the earliest reflections help speech intelligibility and naturalness, whereas the later reflections and reverberation hinder it. Once an echo passes beyond the limit of fusion, we "re-hear" it, the mask is lifted so to speak, and we pay attention to it, leading to confusion and loss of intelligibility. Long reverberant decay times likewise cause a problem because the lingering reverberant decay lasts into the next utterance and provides a noise floor of useless acoustic mud.

Fusion of the shorter reflections has another benefit; it increases the apparent loudness of a sound by extending it in time and raising its average level. Thus adding delayed versions of a sound to the original will increase the perceived loudness more than the actual peak increase in sound level shown on the monitor. This is a well-known application of delay in recording and sound reinforcement, and is of obvious interest to the broadcaster as well.

In an acoustic situation such as a lecture hall, it would be nice to design the architecture to emphasize early reflections so that speakers will be louder and more intelligible, but there is a problem. Attempts to project stronger reflections to the audience call for good reflecting surfaces, but they will inevitably also increase the later reflections and the overall reverberant decay time. In the last eight years or so, however, electronic delay time units have become a successful and popular means to synchronize PA speakers with the acoustic source and, in effect, provide the desired reflections without incurring as much of a penalty in later reverberation.

Of course, dealing with the acoustics of a lecture hall is a relatively straightforward process, and calls for fairly simple time delay effects. In a recording or broadcast studio, the variables - not to mention the opportunities for creative manipulation - become much greater.

Thus, several years ago we set out to design a sound processor that would duplicate virtually every naturally occurring reverberation effect, as well as some that were definitely unnatural. The result was the Space Station SST-282, a moderately-priced unit that incorporates a proprietary technique called Multi-Tap Digital Delay. Multi-Tap Digital Delay is an algorithm for reverberation synthesis that closely parallels the acoustic phenomenon of reverberation just reviewed. In this technique, a mono sound source is fed through a mixer and equalizer into a random access digital memory with maximum storage capacity of 256 ms of sound. Off of this memory there are many taps (over 20), each of which is a point where the memory contents are extracted with a particular time delay and converted to a delayed version of the input sound. These taps are arranged in two completely independent groups, each optimized to a particular function, resulting in tremendous versatility of acoustic stimulation.

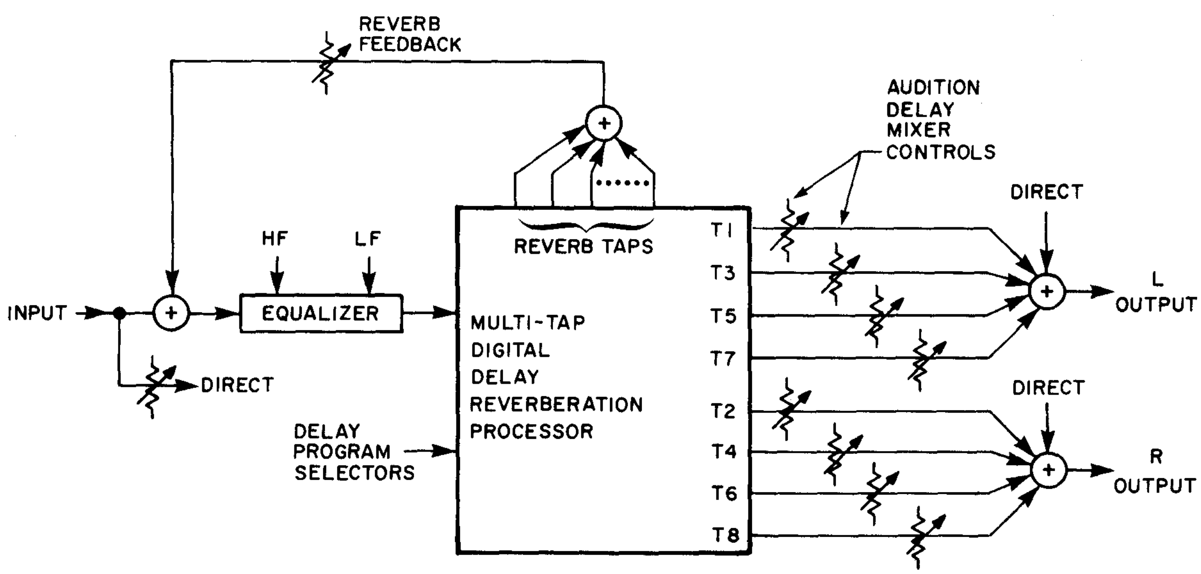
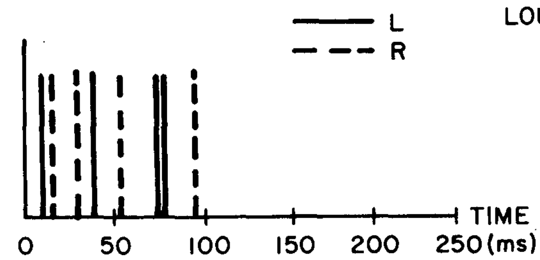


Fig.4: Multi-Tap Digital Delay Block Diagram.
This proprietary algorithm results in a versatile, low-cost reverberation unit that allows complete control over the three phases of reverberation outlined in Fig.1.

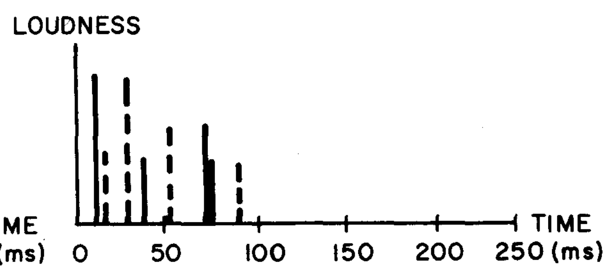
Audition Delay Taps: One group of the taps is called Audition Delay Taps, and is brought to 4 stereo mixing controls of the built-in mixer, while a fifth control mixes the Direct Signal into both of the stereo outputs. The 4 pairs of Audition Delay Taps provide the early reflection pattern of any acoustic simulation, and can be mixed in any desired ratio. Furthermore, the delay times of these taps can be positioned in any of 16 patterns by front panel switches to simulate the reflection pattern of a wide variety of spaces, from very small rooms to large echoing rooms. Most delay units have only one or two taps, and so cannot model the early reflection pattern of even simple acoustic space.

Feedback Taps: The second and much larger group of taps is arranged to give a series of random and dense delay signals simulating many more reflections. These are internally combined and fed to a control which permits the user to turn them down completely (no feedback, no reverberant decay), or to gradually increase the strength with which they are fed back into the mixer at the memory input to provide for reverberant decay times up to 3.5 seconds. Furthermore, an equalizer connected at the memory input can be used to modify the decay time of higher frequencies and/or low frequencies to model spaces with more or less high frequency absorption.

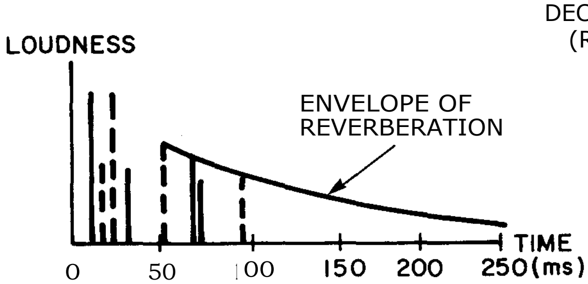
Fig.5: Four Steps to Better Reverb. The Multi-Tap Digital Delay Algorithm allows separate control over each important aspect of reverberation - Direct Sound, Early Reflections, and Reverberation.



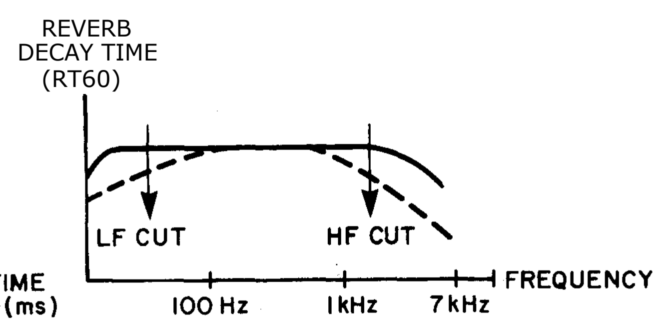
ONE: Select a delay, or early reflection pattern from the 16 available. Room 1 is shown. Direct Sound at t=0 omitted for clarity.



TWO: Adjust the mixer for a pleasing balance of reflection amplitudes. Stop here for delay-only processing.



THREE: Increase feedback to provide extended, dense reverberation.



FOUR: Trim the equalizer to desired acoustic "liveness". **HF** cut gives warm acoustic character; **LF** cut is crisper, harder sounding, like plate reverb system.

Although originally designed with the needs of recording studios in mind, Multi-Tap Digital Delay has proven to be new and extremely useful to the broadcaster. For instance, broadcasters have found that they can add strong, short early reflections to a voice or music without adding the later reflections and reverberant decay that destroy intelligibility and muddy up the sound. The separated yet integrated functions of the Audition Delay and feedback tap groups provide separate control over reflections and feedback. Live acoustic spaces don't permit this, neither do spring or plate reverb units; they give you early reflections only if you're willing to have the long reverberant decay tail come after.

In addition, it's possible to adjust the reverberation decay time continuously down to zero. Short decay times, even on the order of 0.3-1.2 seconds produce clearly audible reverberant enhancement of voice without impairing intelligibility. Spring or plate systems, even if adjustable, are limited to decay times of about 1 to 4 seconds.

Other, more specific applications of reverberation to broadcast needs include the following:

Loudness Enhancement: Announcers, musical instruments, and commercials can be given extra loudness and punch by adding a very short pattern of Audition Delays, with no reverb, or with very short reverb decay time. The gain in apparent loudness will be greater than the increase in peak energy and will yield a signal with better coverage of a station's market.

Stereo Ambience: Additionally, if the reverberation signal is returned to the audio chain in stereo, a spatial enhancement will occur: the voice or instrument will be given stereo presence and will no longer sound sterile and boxy.

Reverberation: Dry studio recordings of music, location events, commercials, etc., can be given professional quality reverberation as done in today's multi-track recording studios. The reverberation resulting from a Multi-Tap Digital Delay algorithm is particularly useful because of the complete control over all phases of the reverberation process, from direct sound, early reflection pattern and amplitude, to reverberation decay time. Unlike fixed plate or spring systems, a digital reverberator of this sort can be tailored to match the requirements of virtually any source.

Mono-to-Stereo Processing: Any mono source, whether the announcer's voice, film sound tracks, older lp's, 45 rpm records, remote sound pickups, or closely miked studio pickups can be turned into pleasing stereo the natural way, by adding a stereo early reflection pattern and/or reverberation. The resulting sound still has the strong mono center of the original, but has the reverberation of a stereo space. Because the delay and reverberation is limited to a 7kHz bandwidth, there are no unpleasant "flanging" or comb filter effects when the station's stereo signal is heard in mono on car or portable radios. Instead, the processed stereo signal folds gracefully into mono, with the loudness enhancement of the delays still effective, and with a pleasing mono reverberation. When processing many old recordings, there will already be enough natural or artificial reverberation in the recording so that only delays need be added for stereo processing. But if the recording is very dry, then the decay time can be increased to add the missing element as well. It is simply amazing what this can do to breathe new life into the huge resources of older mono program material: it sounds far better processed into stereo this way.

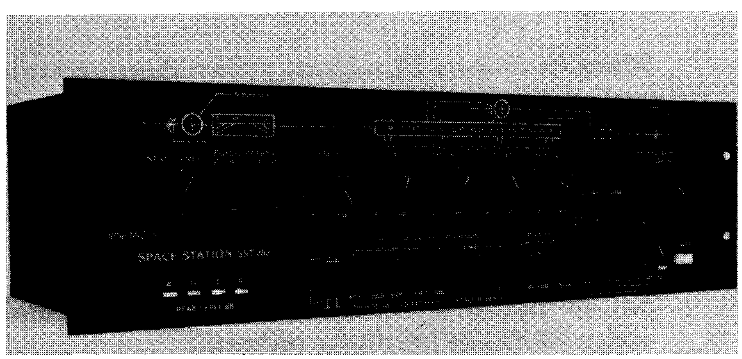
Special Effects: Multi-Tap Digital Delay can also give a wide variety of less-than-natural signal processing effects for occasional use in commercials, radio drama, rock and popular music recording, etc. There are two methods for doing this: one is to use a special, more regular pattern of time delays for the Audition Delay taps. This can give a deliberately colored comb-filter sound to the source; or, if the pattern has larger delays, can give several distinct repetitions of the source moving left-to right in stereo space. Other patterns can provide a dense cluster of reflections all arriving at large time delays, such as 150 or 250 ms to give slap and echo effects enhanced by multiple taps.

The second route to special effects with Multi-Tap Digital Delay is to use an unnatural pattern of feedback delay, namely, just one tap. If only one tap is fed back, the effect can range from the familiar "hello.. hello.. hello.." echo, to a violently tuned resonant filter that "tunes" all percussive or noise-like sounds to a particular group of pitches. Of course, once a special feedback pattern is established, it can be further explored with any of the 16 Audition Delay Programs and with modified settings of the mixer and equalizer. The possibilities are infinite: a sharply tuned filter heard ricocheting left and right four times, a slowly decaying echo where each repetition is heard through the reflection pattern of a large room, a room with normal reverberation decay time of 3.5 seconds, but heard through a comb filter or with a ricocheting pattern or with an initial delay of 255ms ...

In fact, it's probably no exaggeration to say that broadcast sound is just on the verge of a creative revolution. Reverberation effects can produce a more exciting, warmer, and more alive quality to virtually any sound a station produces-and these improvements mean good business.

URSA MAJOR

URSA MAJOR is the only manufacturer of moderately-priced digital reverberation systems. Its SPACE STATION SST-282 Digital Reverberation System is a low-cost, highly versatile unit based on our proprietary Mutli-Tap Digital Delay technique (patent pending). It will process a mono input signal into stereo in all the ways discussed in this article, and takes up only 5 1/4" of rack space. The unit is field proven with world-wide sales into broadcast stations, recording studios, touring rock bands, stationary sound reinforcement installations, and film studios.



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