Acoustics

A Discussion of Timbre

When we talk about the sound qualities of a particular sound, like a musical instrument, we're talking about the Timbre (pronounced TAM'ber). *Color*, *tone*, or *texture,* are timbral qualities.

Most listeners can distinguish between many different timbres. An electric guitar has a different timbre from an acoustic piano. A 53' transport truck has a different timbre from a Honda hatchback. A baby's voice has a different timbre from an adult's voice. An experienced recording engineer can hear the difference between a tenor or alto sax, a real or sampled piano, or a high tom or low tom. Even on a single instrument, the Timbre changes (compare the low and high notes played by a trumpet, for example).

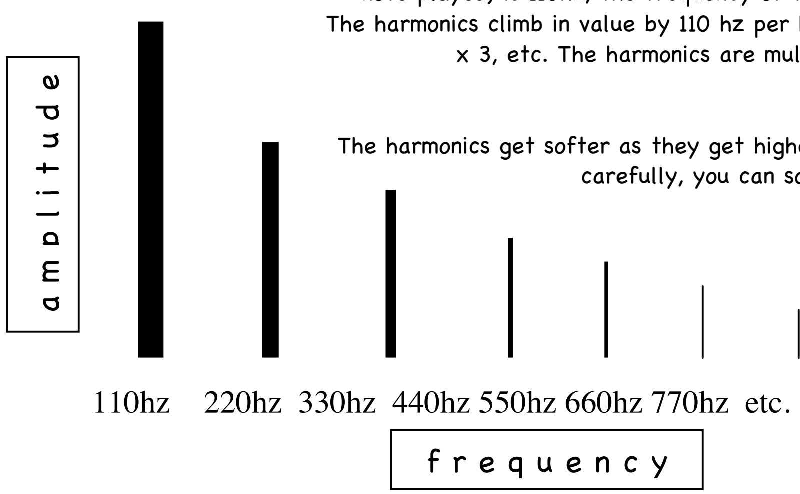
Let's use 5 categories to describe any timbre: Harmonic Spectrum; Non-pitched Elements; Noise Content; Envelopes; and Pitch Range.

Harmonic Spectrum - the color and brightness of the sound.

The harmonic spectrum is a mix of the ***fundamental*** pitch (the note being played), as well as higher, softer pitches that are blended in at lower volume levels. These 'ghost' notes are called ***harmonics***. The harmonic spectrum of an instrument depends on the design of the instrument. For example, flutes and trumpets vibrate in very different ways because of differences in their construction. The flute makes softer sounds, and the trumpet is known for being bright or brassy. This is what we mean by the harmonic spectrum of a sound.

In this example of a harmonic spectrum, the *fundamental* pitch (the note played) is 110hz, the frequency of the low 'A' string on a guitar. The harmonics climb in value by 110 hz per harmonic, 110 x 1, 110 x 2, 110 x 3, etc. The harmonics are multiples (x1, x2, x3, etc) of the fundamental frequency

The harmonics get softer as they get higher in pitch. If you listen very carefully, you can sometimes hear the harmonics.



The note you hear being played on an instrument is called the ***fundamental***. If I play Middle C on a piano, you'll hear a frequency of about 262 Hz. But you'll also hear other frequencies, called harmonics. Harmonics are higher in pitch than the fundamental pitch, and we hear them blending in with the fundamental. A dark sound like a bass doesn't have many harmonics. A bright sound, like a trumpet, has lots of harmonics.

When you pluck a guitar string, it vibrates from end to end (the fundamental). **The fundamental is the first harmonic.** This is the pitch you'll hear. The string also vibrates in divisions. The divisions are simple fractions (the string vibrates in halves, thirds, quarters, etc). These divisions are called the ***harmonic series***. You hear them too, but they don't really sound like notes, they just add tonal color to the sound.

The frequencies in the harmonic series are mathematically related to the frequency of the fundamental. Just take the fundamental frequency, and multiply it by simple numbers – 1, 2, 3, 4, etc. For example, if the fundamental frequency is 110 Hz (a low A on the guitar), the first harmonic will be 110 Hz, the fundamental frequency times 1. **The first harmonic is the fundamental itself.** The second harmonic will be 220 Hz (2 X 110 = 220 Hz. The third harmonic will be 330 Hz (3 X 110 = 330 Hz).

Look at this chart for some other examples.

If the Fundamental Frequency is…	1st harmonic	2nd harmonic	3rd harmonic	4th harmonic
100 Hz	100 Hz	200 Hz	300 Hz	400 Hz
110 Hz	110 Hz	220 Hz	330 Hz	440 Hz
130 Hz	130 Hz	260 Hz	390 Hz	520 Hz
200 Hz	200 Hz	400 Hz	600 Hz	800 Hz

What do you notice about octaves in the harmonic series? Remember, an octave is a doubling of frequency. So, if you look at the chart, you'll see that the 2nd harmonic is one octave above the fundamental. And the 4th harmonic is two octaves above the fundamental. As you count up, you'll find lots octaves.

In some timbres, certain harmonics are weak or missing (an oboe and a clarinet have weak even-numbered harmonics). In other timbres, certain harmonics are stronger than we would expect. The rich resonance of the human voice is caused by very strong harmonics near the fundamental.

And in some sounds, the simple math (2 X, 3 X, 4 X) doesn't apply. Instead you might get something weird like 2.3 X, 3.7 X, 3.9 X). This kind of harmonic series is called ***inharmonic***. Bell sounds are inharmonic sounds (like church bells or a triangle).

Non-Pitched Elements – Noises that an instrument makes

Musical instruments produce pitched sounds that we call notes. We write melodies out of the notes. But instruments also make other noises at the same time as they're being played. A singer has to breathe; the guitarist can be heard dragging fingers along the fretboard and sometimes making it squeak. A saxophone player may slap the keys on the sax. On a piano, the sustain pedal thumps, and the keys make a thud sound.

Things rattle, and shake. Small surfaces vibrate in odd ways. The result is a lot of very musical, and sometimes rhythmic, noise. Clicks and thumps, bangs, whishes, etc. These ***non-pitched elements*** are an important part of the timbre of the instrument. Some people prefer to keep the volume of non-pitched elements very low. Some musicians struggle to reduce these noises. Some engineers prefer not to record them. But non-pitched elements are a natural part of music making!

Listen closely to musical instruments, particularly live musical performances. Listen closely for the non-pitched elements.

What is Noise?

The word ‘noise’ suggests a negative opinion about a sound. If something is ‘noise’ then it’s not ‘musical’. But in audio production, noise is used to create sound effects, to test equipment, or to analyze room acoustics. ***Noise*** is a random mix of *all* the frequencies in the audible range. It can sound like wind, or static, or hissing, or cymbals in a drum kit.

If all audible frequencies have the same intensity, it is called ***white noise***. White noise is bright and ‘hissy’, like static on the TV.

If each octave band has the same intensity, it is called ***pink noise***. Pink noise is darker than white noise, like deep ocean waves.

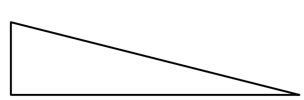
If you want to synthesize some nice fat ocean waves, you might start with some good loud pink noise, and then filter and shape the noise. If you want to synthesize a bright cymbal crash, you could start with white noise instead. And if you want to synthesize a snare drum, you can combine white noise with a pure sine tone.

Envelopes – A shape for the volume of the sound.

The ‘shape’ of a sound’s amplitude is called the ***envelope***. An envelope is a picture of the volume of the sound over time. Envelopes show the way a sound starts, how it sustains, and how it ends.

The start of the sound is called the ***attack***. The sustained portion of the sound, particularly noticeable on an organ, is called the ***sustain***. And the dying-away or release of the sound is called the ***release***. Most synthesizers offer lots of control over envelopes, allowing the sound designer to create their own shapes.

When you play a note on the piano and hold the key down, the sound starts loud and then dies away. The envelope could look like this:



attack r e l e a s e

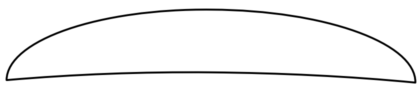
We would say this sound has a fast attack and a slow, steady release.

The dial tone on your phone would have a fast attack (picking up the phone), a steady and full sustain, and then an instant release (hanging up). The sound is sustained at full level as long as receiver is in your hand. A dial tone envelope could look like this:

This sound has a fast attack, a full sustain, and a very fast release.

attack   s u s t a i n   release

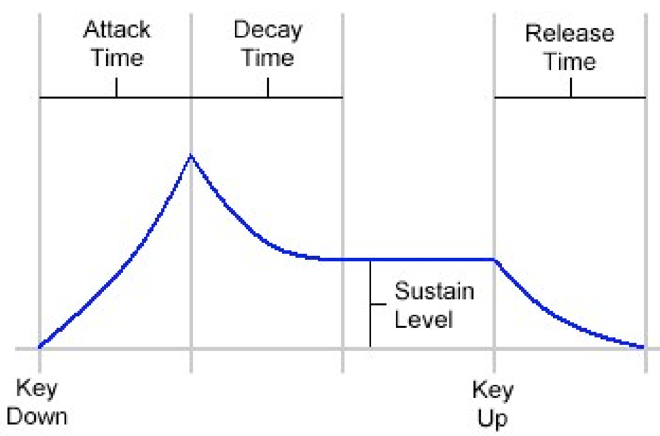
A passing automobile would have a more rainbow-shaped envelope, with a slower attack (fades in from the distance), a fairly short but changing sustain (it flies past in front of you), and a gentle decay (fades off into the distance).



This sound has a slow attack, a variable sustain, and a slow release.

a t t a c k   s u s t a i n   release

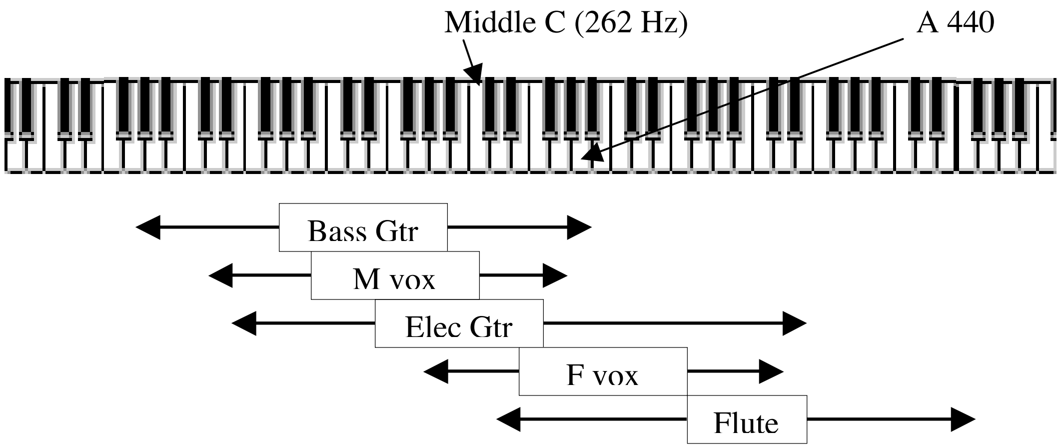
Synthesizers were designed with envelopes that have one more stage, the decay stage. So they're called ADSR envelopes. They're more versatile than simple ASR envelopes. When you press the synth key, the sound evolves through an attack and decay stage, then holds on at the sustain level until you release the synth key. Then the release stage plays out to the end.



Pitch Range

Most acoustic instruments (and even electric instruments) have a specific range of notes that can be played comfortably. An easy place to start is the piano, which has 88 keys. Its lowest note, an A several octaves below Middle C, has a frequency of about 27 Hz. Its highest note, a C several octaves above Middle C, has a frequency of about 4186 Hz. It covers about 7 octaves (7 octaves **x** 12 notes per octave **=** about 88 notes).

Most other instruments have smaller note ranges. A flute has a range of about 3 octaves starting at Middle C (Middle C is 262 Hz). The lowest note on a guitar is 82 Hz (E two octaves below Middle C). A bass guitar starts one octave below an electric guitar, and because it only has 4 strings, it has a smaller note range.



A few musical instrument ranges

Other Timbral Qualities

There are other aspects of musical sound that might be useful when you're talking about timbre. Consider polyphony, transients, and plosives.

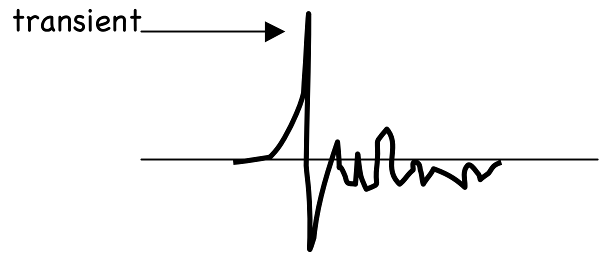
Polyphony

Sometimes there's the question of how many notes are played at the same time. On a piano, *with one person playing*, we could say that the polyphony is 10 (10 fingers, one finger per key). If you had lots of friends, the polyphony of a piano could be 88! So the question is, how many notes can possibly be played at once? On a piano, it would be 88. But on a flute, it would be just 1! A guitar can play 6 notes at the same time, because it has six strings. The number of notes that can be played at the same time is called the *polyphony* of the instrument.

The piano and guitar in this case are called ***polyphonic***, which means 'many voices'. We say the guitar has a ***polyphony*** of 6. The flute is called ***monophonic***, which means 'one voice'. We say the flute has a polyphony of 1. Many orchestral instruments, such as woodwinds and brass, are monophonic. Keyboard instruments and fretted or stringed instruments are usually polyphonic.

Transients

Transients are short, high intensity audio spikes. Usually, a transient is found in the attack portion of the envelope. Drum sounds, notably snares and kicks, start with sharp transients. The ‘snap’ of hitting the drum would be a transient, followed by a short decay; the ringing of the skin and the snares after the drum is hit. A fingersnap is a good example of a transient. Nice sharp transients mean a nice snappy sound.



Plosives

Plosives (a form of what linguists call a ***stop***) are syllables in human speech, vocal events that output blasts of sometimes-noisy air. The dreaded popped-P is a well-known example of a plosive. The result is an unwanted thud. A similar problem lies with F’s and H’s, which can output fairly strong bursts of air. A small disc of special fabric (a pop-screen) placed between the singer’s mouth and the microphone can help this problem.