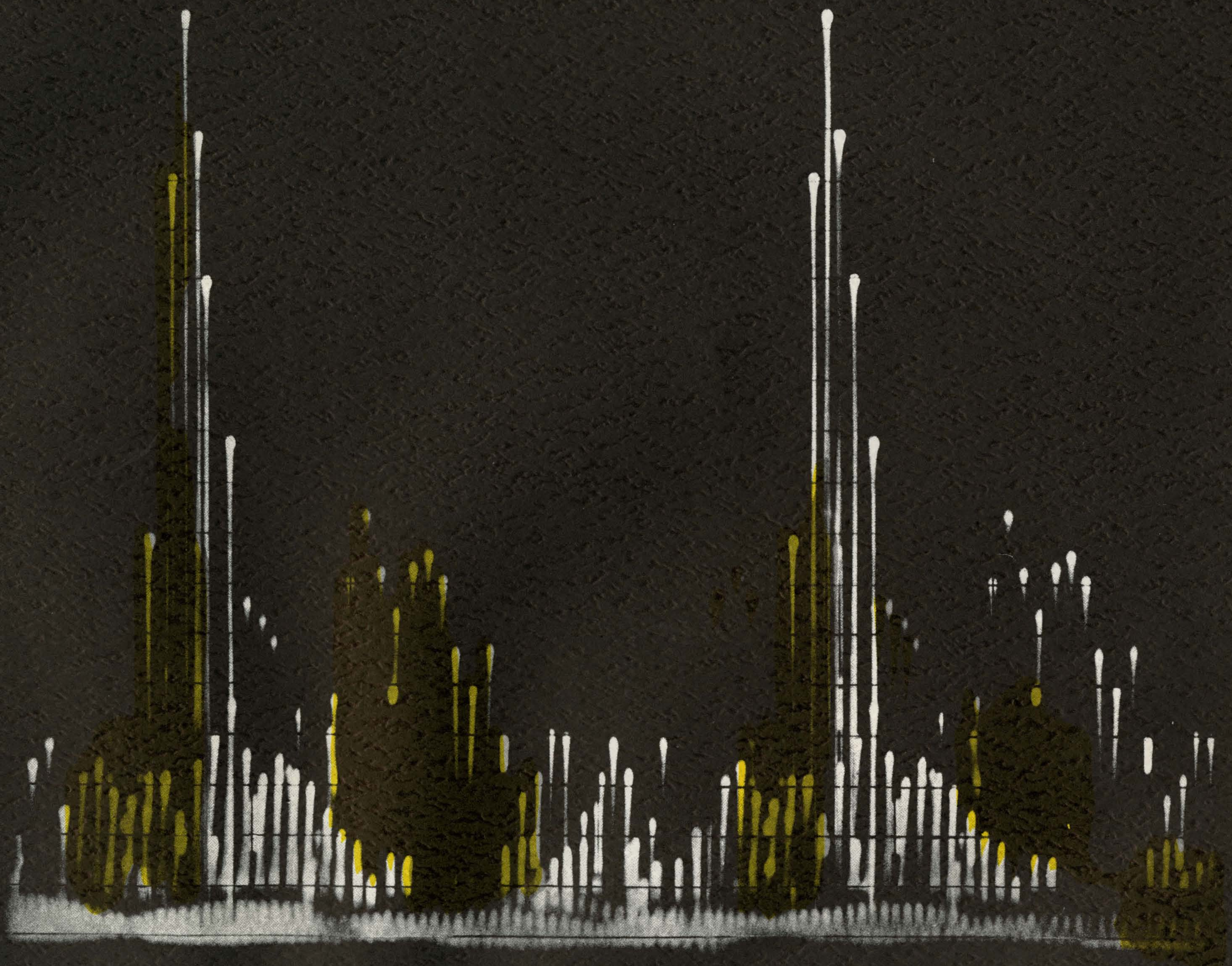
THE SCIENCE OF SOUND



HOW WE HEAR, FREQUENCY, PITCH, VIBRATION AND RESONANCE, INTENSITY, LOUDNESS, NOISE MEASUREMENT, MASKING, QUALITY, ECHO AND REVERBERATION, DELAY DISTORTION, MUSIC OR NOISE, FUNDAMENTALS AND OVERTONES, SUBJECTIVE TONES, FILTERED MUSIC AND SPEECH, DISSONANCE AND CONSONANCE, MUSICAL SCALES, VIBRATO AND TREMOLO, THE DOPPLER EFFECT.

Produced by Bell Telephone Laboratories Incorporated
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FX 6007

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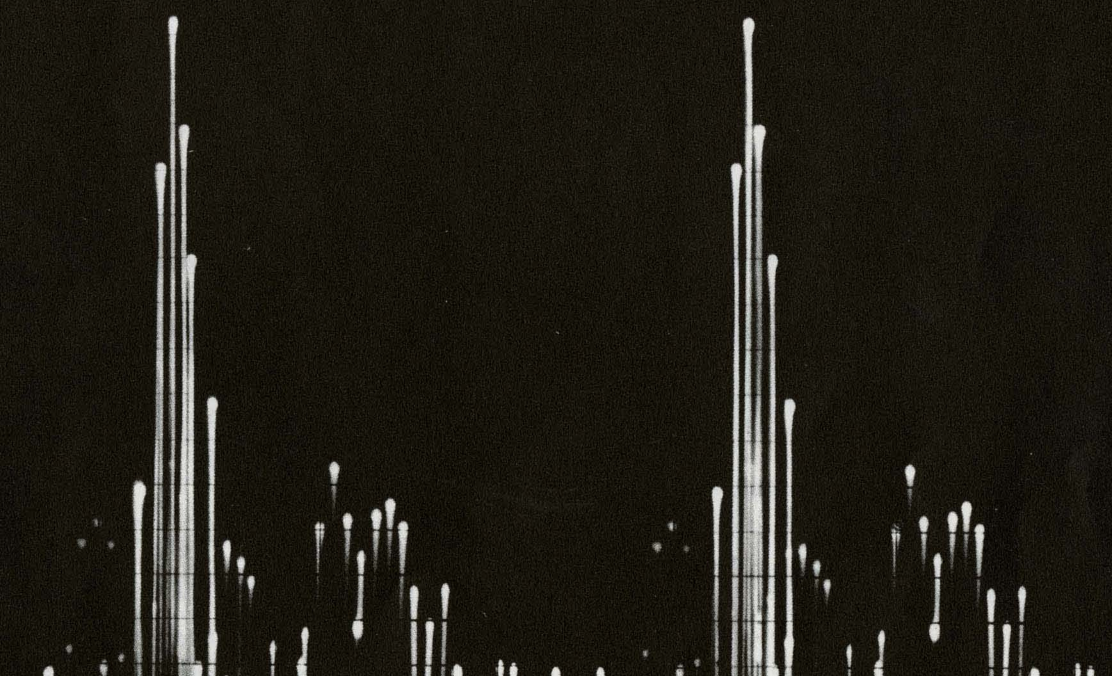

THE SCIENCE OF SOUND

Revised September 1959

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These records describe and demonstrate various phenomena of sound as an aid to understanding how sound is put to work for the benefit and pleasure of man.

Produced by
Bell Telephone Laboratories, Inc.

Distributed by
Folkways Records and Service Corp.
117 West 46 Street
New York, New York

CONTENTS

HOW WE HEAR

NARRATOR: One of nature's greatest wonders is the ability of the human ear to distinguish among the millions of sounds around us. Listen:

SOUND: GUN SHOT; TRUMPET FANFARE; NIGHTINGALE SONG; FOG HORN.

NARRATOR: Recognize those sounds? Surely. Each sound has a distinctive pitch, loudness, and quality. You will hear later how these characteristics are determined by the frequency, intensity, and form of sound waves in the air...waves which your ears pick up and analyze. But first, let's investigate what causes sound.

The source of every sound is a vibrating body. Take, for example, a drum:

SOUND: A DRUM ROLL

NARRATOR: The vibrating drumhead pushes against the air every time it moves outward. It shoves the air molecules against other air molecules, compressing the air. This compression moves away, as the drumhead moves inward, leaving a region where the air is slightly thinner than normal. On the next outward push of the drumhead another region of compression is formed and started on its way outward. We call these pulses of compressions and rarefactions, "pressure waves." As long as the drumhead vibrates, pressure waves will be generated and sent through the air. When waves of sufficient strength reach your ears, they push on your eardrums, setting them to vibrating, too. It's these vibrations which your brain interprets as sound.

FREQUENCY

NARRATOR: Despite your ears' sensitivity to minute changes in air pressure, it is only when the changes are repeated in rapid succession, at least twenty times a second, that your brain perceives them as sound. On the other hand, vibrations that occur more frequently than about 20,000 times a second, cannot be heard by the average human ear. This audible frequency range varies considerably with different people and different ages. Generally, as a person grows older the delicate membranes of the ears grow stiff. Then it becomes more difficult to hear the very high frequencies. Listen as we produce a series of vibrations starting at thirty cycles per second and gradually increase the frequency until it is 15,000 cycles per second.

SOUND: SWEEP TONE WITH NARRATOR'S VOICE ANNOUNCING FREQUENCIES: 30 to 15,000 cps.

NARRATOR: Your ears are most sensitive to vibrations in the frequency range between about 1000 and 4000 CPS. Changes in atmospheric pressure about one part in ten billion, if repeated about 3500 times a second, will send an audible sound to your brain. At this minute pressure variation, the eardrum moves less than one hundred thousandths the wave length of light, one tenth the diameter of the smallest atom. If your ears were very much more sensitive, you would probably be able to hear the motion of the molecules of the air as they vibrated with thermal energy.

PITCH

NARRATOR: Some sounds appear higher or lower to our ears than others. The term we use to describe this relative characteristic is pitch. Pitch depends chiefly on the number of times each second that the air pressure fluctuation on your ear is repeated. Listen as we cause a stretched string to vibrate 440 times a second.

SOUND: VIOLIN SOUNDING A440.

NARRATOR: Here is a human voice with vocal cords vibrating at the same frequency.

SOUND: SINGER A440.

NARRATOR: Now, listen as we hold a piece of cardboard against a revolving gear. The gear teeth are striking the cardboard 440 times a second.

SOUND: CARDBOARD VIBRATING 440 CPS AS GEAR TEETH STRIKE IT.

NARRATOR: Here are these same sounds again. Notice that the pitch of each sound is the same although the sources are different.

SOUND: REPEAT THREE SOUNDS CONSECUTIVELY.

NARRATOR: The pitch is the same because the vibrations striking your ears are repeated the same number of times per second. Now, if we double the frequency, to 880 times a second, the pitch sounds higher.

SOUND: REPEAT THREE SOUNDS CONSECUTIVELY AT 880.

NARRATOR: But the pitch of an 880 cycle tone does not sound exactly twice as high as one at 440. Of course, some persons have been conditioned by their familiarity with musical intervals, such as octaves, to think that doubling or cutting frequency in half is the same as doubling or cutting pitch in half. However, psychological tests have shown that pitch and frequency of pure tones do not have a simple one-to-one relationship. For example, many persons would judge that this tone

SOUND: PURE TONE AT 200 CPS

NARRATOR: ...is one-half the pitch of this tone...

SOUND: PURE TONE AT 500 CPS

NARRATOR: Although the pitch may sound one half, the frequency is not. The frequency of the higher tone is 500; the lower tone is 200 cycles per second. Apparently we cannot depend on our ears to determine relative frequency; nor can we use frequency numbers to designate relative pitch. The two are not linearly proportional. Science has, however, worked out a subjective pitch scale for pure tones. The commonly chosen reference frequency is one thousand cycles per second.

SOUND: PURE TONE 1000 CPS

NARRATOR: The tone you heard is designated to have a pitch of 1,000 subjective units, sometimes called m-e-ls, from the word melody. A tone with a pitch twice as high is designated 2,000 mels.

SOUND: (PURE TONE OF 3120 CPS)

NARRATOR: Actually its frequency is 3120 cycles per second. A tone which sounds to our ears three times as high as the reference is said to have a pitch three times as high, 3,000 mels.

SOUND: (PURE TONE AT 9,000 CPS)

NARRATOR: Actually its frequency is 9,000 cycles per second. As you can see, a mel scale provides an objective means for comparing pitches of various pure tones.

NARRATOR: Although pitch depends chiefly on frequency, it also varies slightly with the loudness of a sound. Listen as we play two pure tones, one softly, then one loudly.

SOUND: (200 CPS TONE, THEN SAME TONE 20 DB LOUDER)

NARRATOR: Which tone has the lower pitch?

SOUND: (REPEAT 3 TIMES)

NARRATOR: Actually both tones have the same frequency, 200 cycles per second, but the louder tone sounds a little lower pitched to most persons. In fact, experiments have shown that in general, low frequency tones seem lower pitched when played very loudly. On the other hand, high frequency tones seem higher pitched, when played very loudly. To be sure the difference in pitch is very slight; nevertheless it is discernible to some persons.

VIBRATION AND RESONANCE

NARRATOR: Many sources of sound have certain frequencies of vibration that are determined entirely by their inherent properties, such as dimensions, the material they are made of, and shape. If set in vibration and left by itself, such a source will continue to vibrate freely and produce a tone of constant frequency which will gradually die away as the vibrating energy dissipates. For example: A tuning fork struck and left by itself...

SOUND: TUNING FORK AT 433 CPS

NARRATOR: and a stretched string that is plucked...

SOUND: GUITAR STRING

NARRATOR: ...are examples of free vibration.

It's also possible to force a sound source to vibrate at frequencies not natural to it. For example the tuning fork you just heard has a natural frequency of 433 cycles per second. We will now place an electromagnet between the prongs of the tuning fork and pass through the coils of the magnet an alternating current of some other frequency, say 428 cycles per second.

SOUND: SWITCH CURRENT ON; DRIVEN FREQUENCY.

NARRATOR: That's the sound of the tuning fork vibrating at 428 cycles per second. What happens is this; the alternating current changes the magnetization of the magnetic core which in turn alternately pulls on the prongs of the tuning fork at the same frequency as the current. So the fork, although it has a natural frequency of 433 cycles if forced to vibrate at 428 cycles. Listen again as we switch the driving frequency on and off. You will hear the fork attempt to vibrate at its natural frequency, then you will hear beats as the fork vibrates both at its natural frequency and the driven frequency; then you will hear it settle down to vibrating only at the driven frequency. When we switch the current off, the fork is set free to vibrate at its natural frequency again.

SOUND: SWITCH FORK ON AND OFF TWICE.

NARRATOR: Now, let's change the frequency of the current in the magnet gradually. First we'll drive the fork at 420 cycles. As we increase the frequency of the current, the pitch of the tuning fork will also increase. Notice that as we near 433 cycles the sound becomes louder, then as we pass higher than 433 the sound becomes softer.

SOUND: (TUNING FORK SOUND IS UNDER THE NARRATION)

NARRATOR: That was an example of a phenomenon called resonance. When the forcing vibrations have the same frequency as the natural vibrations, they coincide and reinforce each other. Here's another example of resonance. We'll strike a tuning fork and hold it near another tuning fork that has the same natural frequency. Then we'll stop the first fork from vibrating.

SOUND: (STRIKE TUNING FORK; HOLD NEAR SECOND TUNING FORK; DAMP FIRST FORK)

NARRATOR: That's the sound of the second fork continuing to vibrate freely after being started in resonant vibration by the first fork.

INTENSITY

NARRATOR: Sound vibrations may be generated by many different sources. Whether they originate in the orifice of a modern jet engine...

SOUND: JET ENGINE

NARRATOR: ...or the throat of a 400 year-old tortoise calling its mate...

SOUND: TORTOISE

NARRATOR: ...or an electrical buzzer...

SOUND: SQUARE WAVE OSCILLATOR

NARRATOR: The vibrations have essentially the same effect: they fluctuate the pressure of the atmosphere on our eardrums, causing them to move rapidly back and forth. This pressure variation is measured in terms of a unit called a microbar, which is one dyne per square contimeter. We can decrease the pressure variation, and thereby make the sound less intense, by decreasing the amplitude of the source's vibrations. Listen as we decrease the power of the buzzer.

SOUND: DECREASE POWER OF BUZZER

NARRATOR: If we increase the power, the sound intensity will increase.

SOUND: INCREASE POWER OF BUZZER

NARRATOR: What we are doing is varying the amount of sound energy which stimulates your ear each instant. This can be accomplished another way, too: by varying the distance the pressure waves have to travel to your ear. If we move our microphone away from the source, the intensity will decrease.

SOUND: (MOVE MICROPHONE AWAY FROM OSCILLATOR)

NARRATOR: Intensity may also vary according to the characteristics of the room in which you are listening. If we play a pure tone of constant intensity, you can, by moving your head slightly to the right and left, make the sound seem less or more intense. Try it:

SOUND: (PURE 1000 CPS TONE AT CONSTANT INTENSITY AND FREQUENCY)

NARRATOR: This phenomenon occurs because sound waves that have been reflected from the walls interfere with sound waves that are coming from the loudspeaker. They combine to produce pressure waves that seem to stand still, thus forming areas of high and low intensity in the room. However, ideally, in free space where there are no reflecting walls, the energy at your ear will vary inversely as the square of your ear's distance from the sound source. Listen:

SOUND: (I AM NOW SPEAKING TO YOU FROM A DISTANCE OF ONE FOOT FROM THE MICROPHONE.)

(I AM NOW SPEAKING TO YOU FROM A DISTANCE OF THREE FEET FROM THE MICROPHONE.)

NARRATOR: You see, by making a sound travel three times as far, we have decreased its intensity to about one ninth. Listen again:

SOUND: I AM NOW ONE FOOT FROM THE MICROPHONE

I AM NOW THREE FEET FROM THE MICROPHONE

NARRATOR: To sum up, the intensity of a sound depends chiefly on the energy of the source and its distance from your ear. Thus intensity may be measured in energy units (ergs per square centimeter) or converting to power units, in watts per square centimeter. For most purposes, however, it is more useful to measure the intensity of sound on a comparative scale. It's customary to express this relative intensity in a unit of measure called a bel, b-e-l, named after Alexander Graham Bell. Listen to these two sounds; they have an intensity difference of one tenth of a bel...one decibel:

SOUND: (TWO TONES; ONE DB APART; LOUD TONE FIRST)

NARRATOR: As you heard, a difference of one decibel is so small as to be barely perceptible. If one tone has one fourth the power -- that's one half the sound pressure -- of another, it is said to be six decibels less intense.

SOUND: TWO TONES 6 DB APART

NARRATOR: If one tone has one sixteenth the power or one fourth the sound pressure of another it is said to be 12 decibels lower.

SOUND: (TWO TONES 12 DB APART.)

NARRATOR: If one tone had one hundredth the power, or one tenth the sound pressure of another, it is said to be 20 decibels less intense.

SOUND: (TWO TONES 20 DB APART)

NARRATOR: As you can see, the decibel scale is logarithmic and the decibel expresses a relative quantity; the ratio between two acoustic powers. When it is desired to express the intensity of only one sound, a scale is used in which the reference intensity for zero decibels is ten to the minus sixteen watts per square centimeter. A person with very good hearing in an extremely quiet location can just barely hear a 1000 cycle tone at this zero level of intensity. The corresponding pressure variation is only about point zero zero zero two dynes per square centimeter. That's less than one billionth normal atmospheric pressure; you see then: your ear is extremely sensitive.

So that you can become familiar with the decibel scale, listen as we vary the intensity of my voice. NOW I'M SPEAKING TO YOU IN A VOICE WITH AN INTENSITY ABOUT SIX DECIBELS LOWER THAN NORMAL.

NOW MY VOICE HAS AN INTENSITY LEVEL ABOUT TEN DECIBELS LOWER THAN NORMAL CONVERSATION.

TWENTY DECIBELS LESS INTENSITY SOUNDS LIKE THIS.

THIRTY DECIBELS LESS INTENSITY SOUNDS LIKE THIS.

END SIDE I

II-6 LOUDNESS

NARRATOR: Don't make the mistake of confusing the intensity of a sound with its loudness. Intensity is an objective, physical characteristic which is determined by the pressure variation and velocity of the air particles. It is not the same as loudness, which is the subjective, psychological impression a listener experiences. Loudness depends not only on sound intensity but also on the frequency of the sound vibrations. To illustrate this, we will sound two tones simultaneously with intensities so low you can't hear them. Then we will gradually increase the intensities equally. Notice you will begin hearing the higher frequency before you hear the lower frequency tone.

SOUND: (TWO TONES 150 AND 1000 CPS. INCREASE INTENSITY FROM BELOW THRESHOLD TO ABOUT -8 V.U. METER)

NARRATOR: Although both tones were recorded to have the same intensity the low frequency tone sounds considerably quieter to most persons. On the other hand, if we play the same two tones at a very high intensity level you probably will notice that there is less difference in loudness.

SOUND: (PLAY 150 AND 1000 ALTERNATELY AT 0 V.U.)

NARRATOR: So you see, your ear judges loudness differently for different frequencies and different intensity levels.

NARRATOR: You may ask, if the human ear is that inconsistent, how can we compare the loudness of sounds of different frequencies? One way of establishing relative loudness levels is by using a one thousand cycle tone as a standard reference. The term phon, p-h-o-n, phon, is used as a unit of loudness level. The loudness level in phons of a sound is numerically the same as the intensity level in decibels of an equally loud one thousand cycle tone. Perhaps this example will make that statement clearer. In our laboratories we had a 600 cycle pure tone of unknown loudness.

SOUND: (600 CYCLE TONE AT -13 V.U.)

NARRATOR: We found its loudness level by adjusting the intensity of a one thousand cycle tone until it sounded just as loud as the 600 cycle tone. We discovered that the thousand cycle tone had an intensity level of about 70 decibels above zero. So, by definition, the 600 cycle tone was said to have a loudness level of 70 phons.

SOUND: (REPEAT 600 CYCLE TONE AT -13 V.U.)

NARRATOR: Similarly we found the loudness level of a two thousand cycle tone...

SOUND: (2000 CPS AT -3 V.U.)

NARRATOR: by adjusting the intensity of a one thousand cycle tone until it sounded equally loud. The thousand cycle tone had an intensity level of about 80 decibels above zero, so the 2000 cycle tone was said to have a loudness level of 80 phons.

SOUND: (REPEAT 2000 AT -3 V.U.)

NARRATOR: Then, we had a basis for comparison. The 2000 cycle tone was 80 minus 70 or ten phons louder than the 600 cycle tone.

SOUND: (PLAY THE TWO TONES ALTERNATELY 600, 2000, 600, 2000)

NARRATOR: The phon scale is convenient for determining loudness level, but most persons prefer a loudness scale with numbers more directly related to what they hear than the arbitrary numbers of a phon scale. So scientists devised another scale with a unit called a sone, s-o-n-e, sone. One sone is defined as the loudness experienced by a typical listener who is listening with both ears to a thousand cycle tone at 40 phons.

SOUND: (1000 CPS TONE AT 1 SONE)

NARRATOR: A tone which sounds twice as loud is designated 2 sones. It was determined by tests that to make a tone sound twice as loud to most persons, we must increase the loudness level about 10 phons. So the reference tone for two sones is at a loudness level of 50 phons.

SOUND: (1000 CPS AT 2 SONES)

NARRATOR: A tone twice as loud again is about ten phons greater and is designated 4 sones.

SOUND: (1000 CPS AT 4 SONES)

NARRATOR: Here is the reference tone twice as loud again, 8 sones.

SOUND: (1000 CPS AT 8 SONES)

NARRATOR: Here is the reference at sixteen sones...

SOUND: (1000 CPS AT 16 SONES)

NARRATOR: and so on. We compared the 600 cycle tone to the sone scale and discovered it had a loudness of 8 sones. The 2000 cycle tone had a loudness of 16 sones. So the high frequency could be considered twice as loud as the lower frequency.

SOUND: (600, 2000, 600, 2000)

NARRATOR: Before we leave the topics of loudness and loudness level, let's summarize by playing some music. If you are about ten feet from your loudspeaker, the loudest passages of the music will have a loudness of about 64 sones. The intensity range from the very soft passages at the beginning to the very loud at the end is about 30 decibels:

SOUND: (BARTÓK-SERLY - MIKROKOSMOS SUITE)

NOISE MEASUREMENT

NARRATOR: How loud is a sound? It's apparent that this noise...

SOUND: TRAFFIC NOISE AT ZERO V.U.

NARRATOR: is louder than this noise.

SOUND: TRAFFIC NOISE AT -14 V.U.

NARRATOR: But how much louder? And how can we measure it? Traffic noise, like most common noises, is not a pure tone. It is made up of many frequencies and intensities. So, you can imagine, measuring the loudness of a complex noise is not a simple matter. Here is one way to go about it. We can, by means of filters, divide the noise into fairly narrow frequency bands and then measure the sound pressure level in decibels for each band. For example, in the noise you just heard, the frequencies between 250 and 500 cycles per second have an average sound pressure level of about seventy-three decibels.

SOUND: PLAY NOISE BAND BETWEEN 250 AND 500 CPS

NARRATOR: The noise frequencies between 500 and 1000 cycles have an average sound pressure level of about sixty-seven decibels.

SOUND: PLAY NOISE BAND BETWEEN 500 AND 1000 CPS

NARRATOR: The noise frequencies between 1000 and 2000 have an average sound pressure level of about 69 decibels...

SOUND: PLAY NOISE BAND AT 69 DECIBELS

NARRATOR: ...and so on. Usually the noise is divided into eight bands, each band an octave wide. But we can't add the decibels of the eight bands to get a total loudness for the entire noise because the decibel scale is logarithmic. Instead we must first convert the decibels into sones. From standard tables we find that the first octave band has a loudness of about ten sones. The second octave band is about seven sones. The third is about nine sones.

If we add the sones of all bands, giving appropriate weighting to the various bands, we can get a fairly accurate idea of the total loudness. It comes to thirty-two sones.

Then if we wish, we can convert the total loudness in sones to loudness level in phons. The loudness level of the traffic noise is 90 phons.

SOUND: (TRAFFIC NOISE)

NARRATOR: Recently, interest in noise measurement has increased, probably because it is a first step in devising ways of quieting the loud noises of modern machines such as jet engines and high-powered trucks. For example, the sound pressure level of a jet airplane firing its engine on the ground some distance from our microphone was measured and found to be about 110 decibels above zero.

SOUND: (JET ENGINE)

NARRATOR: The same engine connected to a ground run-up suppressor consisting of intake and exhaust mufflers was measured to be about twenty decibels lower. Listen:

SOUND: SAME ENGINE WITH SUPPRESSOR

NARRATOR: Are you surprised that lowering sound pressure level only twenty decibels will reduce the loudness so much? This was accomplished by taking advantage of your ears' sensitivity to certain frequencies more than others. The suppressor attenuated the frequencies in the sensitive range more than others; so the over-all reduction in loudness level was almost 28 phons. Here is another example: a truck without a muffler passing fifty feet from our microphone:

SOUND: SOUND OF TRUCK

NARRATOR: Here is the same truck with a muffler installed:

SOUND: TRUCK WITH EXHAUST MUFFLER

NARRATOR: The muffler reduced the sound pressure level 15 decibels. As you can see, noise measurement and noise reduction are fields of considerable current interest in the science of sound.

MASKING

NARRATOR: Ever tried to carry on a conversation above the roar of a train or airplane engine? Then you know that one sound may make it difficult to hear another sound. This drowning out, or masking, occurs because the auditory nerves in your ear can carry only so many impulses to your brain at one time. When the lines are already loaded, any further stimulation is lost. Let's investigate this phenomenon more closely.

If a tone with a frequency of 1200 cycles per second...

SOUND: PURE TONE AT 1200

NARRATOR: ...and another tone with a frequency of 2000 cycles per second...

SOUND: PURE TONE AT 2000

NARRATOR: ...are sounded together very softly, and then the 1200 cycle tone is increased in intensity, eventually it may mask the higher tone.

SOUND: SOUND BOTH TOGETHER SOFTLY; THEN INCREASE 1200 CPS TONE 35 DB

NARRATOR: On the other hand, it is exceedingly difficult for a tone of high frequency to mask a tone of lower frequency. We will now try to drown out the 1200 cycle tone by increasing the intensity of the 2000 cycle tone.

SOUND: BOTH TOGETHER: THEN INCREASE INTENSITY OF 2000 CPS TONE

NARRATOR: Eventually it can be done but the high frequency tone must be extremely loud. In general we may conclude that a tone can mask sounds of higher frequencies more effectively than it can mask sounds of lower frequencies.

ECHO AND REVERBERATION

NARRATOR: The old proverb "Empty vessels make the most noise" is an ancient observation of the phenomena of echo and reverberation. When sound waves impinge on hard, surfaces, they are reflected. Often we may hear the reflected waves or echos a short time after we hear the original source of sound. Like this:

SOUND: (VOICE: "HELLO") (ECHO: HELLO)
(VOICE: "HELLO") (ECHO: HELLO)
(VOICE: "ARE YOU THERE, ECHO?") (ECHO: ARE YOU THERE, ECHO?)

NARRATOR: The time lag between the original sound and the echo depends upon the distance between the sound source and the reflecting surface. Here is how speech sounds accompanied by echo from reflecting surfaces at various distances:

SOUND: (500 FEET. YOU ARE NOW LISTENING TO SPEECH ACCOMPANIED BY AN ECHO FROM A REFLECTING SURFACE 200 FEET AWAY.)

(50 FEET. YOU ARE NOW LISTENING TO SPEECH ACCOMPANIED BY AN ECHO FROM A REFLECTING SURFACE 50 FEET AWAY.)

NARRATOR: The echo sounds fainter than the source because the original sound energy is spread out and lost traveling to and from the surface. It's quiet possible for echos to have echos. Large auditoriums or halls -- like empty barrels - often have more than one reflecting surface. Sounds may bounce from wall to wall, that is reverberate, like this:

SOUND: (HELLO) (ECHO - HELLO, HELLO, HELLO)
(HELLO, LADIES AND GENTLEMAN)
(ECHO - HELLO, LADIES AND GENTLEMEN, HELLO, LADIES AND GENTLEMEN)

NARRATOR: When echos are numerous and overlapping, they may merge into a babel of noise, making normal speech difficult to understand.

SOUND: (HELLO LADIES AND GENTLEMEN. I AM SPEAKING IN A HALL THAT REVERBERATES WITH MANY ECHOS.)

NARRATOR: Biblical legends tells us that inside the famous Tower of Babel even the words of learned men sounded like nonsense. This could have been a case of poor acoustical design. The Tower was made of sun-baked bricks and tiles which reflected sounds from one wall to another, setting up reverberations that scrambled speech until it was unintelligible.

SOUND: "THE TOWER OF BABEL MAY HAVE SOUNDED LIKE THIS."

NARRATOR: Reverberation is responsible for the slowness with which sound fades away. It may be controlled by carefully selecting wall materials and coverings to absorb the sound energy.

The time it takes a sound to diminish sixty decibels -- or one millionth of its original intensity -- is called reverberation time. We use reververation time as a measure of the acoustic characteristics of a hall. LISTEN: I AM NOW SPEAKING IN A ROOM THAT HAS A REVERBERATION TIME OF SEVERAL SECONDS. Rooms which have a reverberation time of several seconds or more may be suitable for some forms of music but generally they are undesirable for speech.

NARRATOR: Reverberations fade away more rapidly in small rooms because it takes less time for the sounds to bounce back and forth between the walls and be absorbed.

I AM NOW SPEAKING TO YOU IN A ROOM THAT HAS A REVERBERATION TIME OF ONLY A FEW TENTHS OF A SECOND.

Rooms which are moderately reverberent, that is having reverberation times of about 1 sec for a small auditorium and about two seconds for a large auditorium -- are usually pleasant for both speakers and listeners.

I AM NOW SPEAKING IN AN AUDITORIUM THAT HAS A REVERBERATION TIME OF ABOUT ONE SECOND. THIS AUDITORIUM HAS BEEN SPECIALLY DESIGNED TO GIVE SATISFACTORY ACOUSTICS NO MATTER WHERE THE LISTENER IS SITTING.

As you can hear, speakers rely on some reverberation to give resonance and sustenance to their voices. If you've even sung in a bath tub you will understand how reverberation may make a voice sound better than it really is.

DELAY DISTORTION

NARRATOR: When speech or music is transmitted along communication lines, sometimes the various frequencies may not travel with equal velocities. They arrive at the receiving end with a type of distortion known as delay distortion. This sounds similar to the following demonstration in which frequencies above 3000 cycles are delayed one tenth of a second behind frequencies lower than 3000 cycles:

SOUND: THE UPPER FREQUENCIES OF THIS SPEECH ARE ARRIVING ONE TENTH OF A SECOND LATER THAN THE LOWER FREQUENCIES.

NARRATOR: That much delay distortion rarely occurs. Here is how a delay of seven hundreths of a second sounds:

SOUND: THE UPPER FREQUENCIES OF THIS SPEECH ARE ARRIVING SEVEN HUNDRETHDS OF A SECOND LATER THAN THE LOWER FREQUENCIES.

NARRATOR: Now, listen to the effect of a delay of thirty-five thousandths of a second.

SOUND: THE UPPER FREQUENCIES OF THIS SPEECH ARE ARRIVING THIRTY-FIVE THOUSANDTHS OF A SECOND LATER THAN THE LOWER FREQUENCIES.

NARRATOR: In transmitting music, the distortion that results from small delays or phase shift is usually not noticeable. This is because the various sounds are sustained longer in music than in speech.

Listen as we delay the upper frequencies of music seven hundredths of a second.

SOUND: MUSIC SELECTION - TRUMPET FANFARE (PHASE DELAY 0.07 SEC)

NARRATOR: On the other hand, longer delays are quite noticeable in music. They give an echo effect. Listen as we play the same selection so that frequencies above 3000 cycles are delayed three tenths of a second.

SOUND: SAME MUSIC (DELAY .3 SEC)

END SIDE II

FUNDAMENTALS AND OVERTONES

SOUND: TUNING FORK

NARRATOR: That was the sound of a tuning fork. It is practically a pure tone; that is, the vibrations are of only one frequency and they have a smooth, regular wave form.

Sounds from other sources, such as musical instruments, the human voice, or noises, have wave forms that are less smooth and more complicated. For instance, if we pluck a stretched string, it will vibrate not only as a whole, but also, at the same time, in parts... in segments that are a half, a third, a fourth, and so on, of the whole string. These segments vibrate at two, three, four, and so on, times the frequency of the entire string. Listen:

SOUND: PLUCK A STRETCHED STRING 200 CPS

NARRATOR: The lowest frequency present in a complex sound is called the fundamental; frequencies higher than the fundamental are called overtone frequencies. The frequencies of a musical sound are simple multiples of the fundamental and are called harmonics. For instance, the fundamental frequency of the musical tone you just heard was 200 cycles per second.

SOUND: (PURE TONE AT 200)

NARRATOR: The first overtone, sometimes called the second harmonic, was 400 cycles per second.

SOUND: (PURE TONE AT 400)

NARRATOR: The second overtone, or third harmonic was 600.

SOUND: (PURE TONE AT 600)

NARRATOR: The third overtone or fourth harmonic was 800 cycles per second.

SOUND: (PURE TONE AT 800)

NARRATOR: ...and so on at intervals of 200 cycles per second.

SOUND: (PURE TONES 1000, 1200, 1400, 1600, 1800, 2000)

NARRATOR: Some sounds have thirty or forty overtones in the audible frequency range of the human ear. For many sounds the pitch of the entire tone is the same as that of the fundamental, but the overtones add distinctive qualities. Listen as we play a fundamental tone and then add its overtones one by one;

SOUND: (FUNDAMENTAL, THEN OVERTONES ONE BY ONE)

NARRATOR: Did you notice; a fundamental with only a few overtones sounds empty and uninteresting. A fundamental with many overtones sounds full and rich. It's the relative number, pitch and intensity of a sound's overtones which determine its quality.

QUALITY

NARRATOR: All sounds have characteristic qualities which your ear learns to recognize. Listen:

SOUND: (WE HEAR CONSECUTIVELY A FACTORY WHISTLE, A PIANO AND A HUMAN VOICE, ALL AT THE SAME PITCH)

NARRATOR: We're sure you had no difficulty distinguishing these sounds -- a factory whistle, a soprano and a piano -- even though they all had the same pitch and intensity. That's because the distinguishing characteristics of a sound, by which we recognize an instrument or voice, is due largely to the proportions of the overtones in the sound, as well as its pitch and intensity. Listen as we play the same sounds, only this time we will filter out the overtones and allow only the fundamental notes to reach your ears.

SOUND: FACTORY WHISTLE, SOPRANO, PIANO, WITH OVERTONES ELIMINATED.

NARRATOR: The slight difference in the sounds is due to their dynamic characteristics such as attack and decay and vibrato, but the tonal qualities are almost indistinguishable. Listen again.

SOUND: (REPEAT)

NARRATOR: Now we'll allow you to hear the fundamental and the first overtone. We will filter out all the other overtones. Notice just the beginnings of a difference in tonal quality.

SOUND: FIRST OVERTONE

NARRATOR: Now we'll allow the fundamental and first four overtones to reach your ear. Listen how the overtones help distinguish a sound.

SOUND: FIRST FOUR OVERTONES

NARRATOR: If we cut out all filters, permitting all overtones to be heard, the sounds will again sound normal and distinctive.

SOUND: ALL OVERTONES

SUBJECTIVE TONES

NARRATOR: When you are presented with one pure tone, you hear one pure tone. You might expect that if you were presented with two pure tones simultaneously you would hear just two tones. Surprisingly, this is not always so. If the two tones are in the mid frequency range and are close enough together you may hear a third sound. For example, here is a soprano singing a note.

SOUND: (SOPRANO SINGS SINGLE NOTE (c))

NARRATOR: Now, another soprano will sing a note an interval of a fifth higher.

SOUND: (SOPRANO SINGS (g))

NARRATOR: Now both together...

SOUND: (SOPRANOS TOGETHER SHOWING SUBJECTIVE TONES)

NARRATOR: Notice the barely audible note that is pitched lower than either of the notes sung. Listen again:

SOUND: (SOPRANOS SING SEVERAL DIFFERENT NOTES TOGETHER SHOWING SEVERAL SUBJECTIVE TONES)

NARRATOR: You have just heard what are called subjective tones. When two tones are present in the air at the same time they may interfere with each other...sometimes reinforcing, sometimes partially cancelling. The intensity of the combined sounds rises and falls...at a rate which is the difference between the frequencies of the two sounds. Your hearing mechanism interpretes this rising and falling intensity as a third sound...a subjective tone. Here is another example, a London police whistle:

SOUND: (THE WHISTLE IS BLOWN)

NARRATOR: The whistle is made of two short pipes. If we blow only one of them, the whistle emits a high-pitched tone with a frequency of twenty one hundred and thirty six cycles per second:

SOUND: (ONE PIPE IS BLOWN)

NARRATOR: If we blow the other pipe, the whistle emits another high-pitched tone of different frequency, nineteen hundred and four cycles per second.

SOUND: (THE OTHER PIPE IS BLOWN)

NARRATOR: If we blow them together you may become aware of a lower pitch in addition to the two original tones.

SOUND: (WHISTLE IS BLOWN WITH BOTH PIPES OPEN)

NARRATOR: This lower pitch corresponds to the difference in frequency between the two original tones, two hundred thirty two cycles per second. Thus the tone is called a difference tone. Under certain circumstances this difference tone provides a useful function. Listen as we sound on a trombone a note having a fundamental frequency of two hundred twenty cycles per second.

SOUND: (TROMBONE AT A220)

NARRATOR: As we know, not only the fundamental, but a complement of overtones are heard having frequencies of 440, 660, 880, 1100 and so forth. The difference in frequency between any two adjacent overtones is 200, which is the frequency of the fundamental component. Now by means of a filter, we will cut out the fundamental component from the sound.

SOUND: WITHOUT FUNDAMENTAL

NARRATOR: Did you notice that although there was a slight change in quality, there was no difference in pitch between the full tone and the filtered tone. Listen again. First the full tone:

SOUND: REPEAT FULL TONE

NARRATOR: Now the tone with the fundamental filtered out.

SOUND: REPEAT WITHOUT FUNDAMENTAL

NARRATOR: The pitch is the same. Now what happened? The difference tone supplied by one or more pairs of the overtones produced the sensation of two hundred twenty cycle pitch, even though the two hundred twenty cycle component of the sound was omitted.

SOUND: (FUNDAMENTAL, THEN WITHOUT FUNDAMENTAL)

NARRATOR: Now we will eliminate the fundamental and the first two overtones. Notice that the pitch still corresponds to that of the non-existent fundamental.

SOUND: WITHOUT FUNDAMENTAL AND FIRST TWO OVERTONES

NARRATOR: The same phenomenon can be observed in speech. First, listen to this voiced sound:

SOUND: (NARRATOR SINGS AH)

NARRATOR: Now we will repeat the sound with the fundamental component filtered out.

SOUND: (NARRATOR SINGS AH THROUGH A FILTER THAT ELIMINATES THE FUNDAMENTAL)

NARRATOR: Notice that although there is a slight difference in quality, the pitch remained the same. As before, the sensation of pitch was produced by the difference between the overtones of the voice. Listen again:

SOUND: (AH ah AH ah AH ah)

NARRATOR: Now we'll try filtering out the fundamental and the first two overtones:

SOUND: (AH)

NARRATOR: Notice the pitch is the same. Listen again, first the full sound, then without the fundamental and the first two overtones.

SOUND: (AH ah AH ah AH ah)

NARRATOR: This phenomenon is relied on for the manufacture of ordinary radio loudspeakers. These loudspeakers are generally small and they have a poor response in the low frequency range. The radio engineer relies on this subjective effect to give you the sensation of correct pitch.

MUSIC AND NOISE

NARRATOR: The sounds to which our ears respond may be classified as either music or noise. The sound of a harp...

SOUND: (HARP ARPEGGIO)

NARRATOR: ...the song of a bird...

SOUND: (WOODTHRUSH SINGING)

NARRATOR: ...even the sharp whistle of a tug boat...

SOUND: (TUG BOAT WHISTLE)

NARRATOR: ...are usually quite pleasing to our ears. We call these and other sounds that have definite pitch, loudness, and tone qualities; "musical sounds." Musical sounds cause our eardrums to vibrate with more or less regular, periodic motion. Viewed on an oscilloscope they show wave patterns that are fairly smooth and repetitive.

SOUND: (RIVETER OR STREET DRILL)

NARRATOR: ...or this...

SOUND: (LOUD CRASH OF INDETERMINENT ORIGIN)

NARRATOR: ...are unpleasant. We call these sounds "noises." Often, however, the distinction between noises and musical sounds is not sharp. For example, listen as we hit two blocks of wood together.

SOUND: (HIT TWO BLOCKS OF WOOD TOGETHER)

NARRATOR: Would you call that music or noise? Before you answer, let's hit several blocks of different length together.

SOUND: (PLAY YANKEE DOODLE)

NARRATOR: Obviously that was a musical melody; and the xylophone is a musical instrument based on the principle that pleasant sounds can be produced by striking pieces of wood of different length. Here's another example. Listen to the unusual sounds, commonly considered to be noises, that are incorporated in this piece of music...

SOUND: (BAHNFAHRT)

NARRATOR: You see, under certain conditions many noises may be considered musical. Under other conditions, musical sounds may be considered noises.

Apparently, one criterion for distinguishing between music and noise is whether we like it or not. If it disturbs us or is unwanted, the sound is noise. If it is desirable, the sound is music to our ears.

FILTERED MUSIC AND SPEECH

NARRATOR: If for any reason your ears are prevented from vibrating throughout the entire normal range of frequencies, either because they have some physical defect, or because the phonograph equipment is of low fidelity, sound quality will be quite different from normal. Listen to the orchestra as it might have sounded on an early phonograph record.

SOUND: (GRIEG'S WEDDINGDAY AT TROLDHAUGEN, BAND PASS BETWEEN 375 AND 2000)

NARRATOR: By means of filters we eliminated high and low frequencies and allowed only those frequencies between about 375 and 2000 cycles per second to be heard. Now listen to the improved tonal quality when all frequencies reach your ears.

SOUND: (SAME MUSIC, NO FILTERS)

NARRATOR: If we cut out only the low frequencies, all those below 375 cycles per second, the music sounds like this.

SOUND: SAME MUSIC FILTERED

NARRATOR: Now we'll cut out all frequencies below 2000 and let only the higher frequencies get through to your ears.

SOUND: SAME MUSIC FILTERED

NARRATOR: If we eliminate high frequencies, all those above 4000, and let only the lower frequencies through, the music sounds like this.

SOUND: SAME MUSIC FILTERED

NARRATOR: Now let's cut out some more high frequencies. All those above 2000 cycles are prevented from reaching your ears.

SOUND: SAME MUSIC FILTERED

NARRATOR: Here again is how the orchestra sounds with the full range of frequencies.

SOUND: SAME MUSIC, NO FILTERS

NARRATOR: Speech, too, sounds different if some of the frequencies are prevented from reaching the ear. My voice is now coming through with a normal range of frequencies.

(PAUSE)

NOW, MY VOICE SOUNDS AS IT DOES BECAUSE WE HAVE FILTERED OUT ALL FREQUENCIES BELOW 375 CYCLES PER SECOND. ONLY THOSE FREQUENCIES ABOVE 375 CYCLES PER SECOND ARE REACHING YOUR EAR.

(PAUSE)

IF WE ALLOW ONLY THOSE FREQUENCIES ABOVE 2000 CYCLES PER SECOND TO REACH YOUR EAR, MY VOICE SOUNDS LIKE THIS. YOU ARE BEING PREVENTED FROM HEARING FREQUENCIES BELOW 2000 CYCLES PER SECOND.

(PAUSE)

and here's how my voice sounds with all frequencies above 2000 cycles eliminated from it.

YOU ARE NOW HEARING ONLY THOSE FREQUENCIES BELOW 2000 CYCLES PER SECOND

(PAUSE)

now we have filtered out all frequencies above 375 cycles per second.

YOU ARE NOW HEARING SPEECH MADE UP OF ONLY THOSE FREQUENCIES BELOW 375 CYCLES PER SECOND.

(PAUSE)

NARRATOR: Here's how my voice sounds if we eliminate both very high and very low frequencies.

IF WE ALLOW ONLY THOSE FREQUENCIES BETWEEN 375 AND 2000 CYCLES TO BE HEARD, MY VOICE WILL SOUND LIKE THIS.

(PAUSE)

NARRATOR: As you can hear, there is quite a difference in the quality of the filtered voice and the normal voice that you are now hearing.

End Side III

DISSONANCE AND CONSONANCE

NARRATOR: When two or more musical tones are sounded together their blending may sound unpleasant or dissonant, like this...

SOUND: (TROMBONES AT C AND C#)

NARRATOR: But there are times when the tones may produce a pleasing sound called consonance:

SOUND: (TROMBONES AT C AND E)

NARRATOR: Let's see if we can determine when and why dissonance occurs. We'll set two oscillators going so that they both emit pure tones at the same frequency...256 cycles per second.

SOUND: (START ONE OSCILLATOR AT 256, THEN SECOND OSCILLATOR AT 256)

NARRATOR: Now, we'll increase the frequency of one while keeping the other constant.

SOUND: (INCREASE ONE TO 258)

NARRATOR: Notice the throbbing sound. The sound gets louder, then softer with perfect regularity.

SOUND: (WE HEAR A BEAT OF TWO)

NARRATOR: This phenomenon is known as beating. It occurs when sound waves of slightly different frequencies and wavelengths are superimposed. When the two waves are in phase; that is, when their compressions and rarefactions arrive at your ear at the same instant, they reinforce each other and the sound becomes louder. However, the sound wave with the slightly shorter wavelength begins to arrive sooner than the longer wave. Eventually a compression of one wave arrives at your ear at the same time a rarefaction of the other wave arrives; they neutralize each other and the ear hears nothing, or at most a very faint sound. As the shorter wave continues to arrive more early it regains step with the longer wave and reinforces it. So we hear alternately a loud and then a soft sound... a beat.

SOUND: (SOUND OF TWO-BEAT FREQUENCY REPEATED FOR 5 SECONDS)

NARRATOR: In the example you are hearing the number of beats per second is two: the difference between the pure tone frequencies of 256 and 258. If the two pure tones are twice as far apart, say of frequencies of 256 and 260, you will hear four beats per second.

SOUND: (INCREASE FREQUENCY DIFFERENCE TO HEAR FOUR BEATS FOR 3 SECONDS)

NARRATOR: The greater the difference in frequencies the more beats we hear.

SOUND: PAUSE AS THE SOUND GOES TO 10 BEATS

NARRATOR: A beat frequency of more than about ten cycles per second becomes difficult to count and the beats merge into a roughness or discordant sound.

SOUND: INCREASE FREQUENCY DIFFERENCE TO 17

NARRATOR: However, if we continue to increase the frequency difference the sound becomes less dissonant. (PAUSE) The sound seems consonant to our ears when the two frequencies have simple ratios, such as six to five...

SOUND:

NARRATOR: Five to four

SOUND:

NARRATOR: Four to three

SOUND:

NARRATOR: Three to two

SOUND:

NARRATOR: And two to one.

SOUND:

NARRATOR: It's been comparatively easy for us to demonstrate points of consonance by using pure tones. However, musical tones are not so simple. What sounds consonant to some people may sound dissonant to others. Listen to this orchestral selection...

SOUND: (TANNHAUSER OVERTURE)

NARRATOR: That was certainly consonant to our ears, but when the Tannhauser Overture was first played, critics called it a display of noise and extravagance and they complained of its dissonance. Now listen to a more recent composition...

SOUND: (BARTOK-SERLY, MIKROKOSMOS SUITE.)

NARRATOR: Whether it sounds consonant or dissonant to your ear depends on how your ear has been trained to hear it. People of different eras and different cultures have different ideas as to what is musically pleasing and what is not. It requires an open mind as well as an open and trained ear to decide.

MUSIC SCALES

NARRATOR: Through the ages man has come to like the sound of certain tones that are played together or in sequence. Originally he chose the notes spontaneously. Later on, some civilizations selected and arranged them in various musical systems. Fundamental in the music of almost all ages and countries is the octave, the interval between two notes that have a frequency ratio of two to one. This is an octave:

SOUND: C; THEN C AN OCTAVE HIGHER

NARRATOR: Also basic are the intervals of a fifth, with a frequency ratio of three to two:

SOUND: C; THEN G

NARRATOR: ...and a fourth, with a frequency ratio of four to three:

SOUND: C; THEN F

NARRATOR: During the middle ages musicians used a scale consisting of seven tones within an octave that were derived from progressions of fifths and fourths. This scale was called Pythagorean because it was based on the findings of the Pythagorean school of Ancient Greece. It sounded like this:

SOUND: PYTHAGOREAN SCALE

C = 260.8 D = 293.3 E = 330.1 F = 347.6 G = 391.1
A = 440 B = 495 C = 521.5

NARRATOR: The notes are separated by five large intervals called whole tones and two smaller ones called semitones. A whole tone has a frequency ratio of nine to eight. A semitone has a frequency radio of two hundred fifty six to two hundred forty three.

The Pythagorean musical scales was found to be quite suitable for purely melodic music. But when more than one note were sounded together, the effect was often not perfectly harmonious. Listen as we play several simultaneous notes or chords from the Pythagorean scale:

SOUND: C MAJOR AND MINOR TRIADS AND CFA TRIAD

NARRATOR: Various attempts were made to modify this scale so that polyphonic music would sound more pleasant. One variation, the so-called natural diatonic scale, was introduced in the 16 century. Listen:

SOUND: DIATONIC SCALE C, D, E, F, G, A, B, C

NARRATOR: Between the notes of the scale there are three different intervals: 3 major whole tones with a frequency ratio of nine to eight, 2 minor whole tones with a ratio of ten to nine, and 2 semitones with a ratio of 16 to 15. This tonal structure seems more harmonious than the Pythagorean. Listen as we play several chords from the natural diatonic scale:

SOUND: C MAJOR AND MINOR TRIADS AND CFA TRIAD

NARRATOR: As you can hear, the natural scale is quite suitable for harmonic composition. However, it also has some disadvantages. Suppose we wanted to start our diatonic scale on another note; when playing on a violin or singing there'd be no problem, but on a piano, we'd have to insert various additional notes to keep the same interval relationship. As a matter of fact, in order to provide for all possible transitions, we would have to introduce up to 72 notes into the octave. To avoid this complication, the natural scale has been modified into what is known as the equally-tempered scale. In this system each of the three major and two minor whole tones has been replaced by an interval called a tempered whole tone. Each of the two semitones has been replaced by an interval called a tempered half-tone. Also each of the tempered whole tones has been subdivided into two half-tone intervals by adding a new note. This results in the equally-tempered twelve tone chromatic scale. Listen as we play it on the piano.

SOUND: PIANO CHROMATIC SCALE

NARRATOR: In this scale, there are twelve equal half-tone intervals in the octave. Thus we are able to start a scale on any of the 12 notes in the octave and the intervals will be suitable for all. Listen:

SOUND: SCALE OF C, D, E, F, ETC. AND FADE OUT.

NARRATOR: Of course, none of those scales is exactly pure anymore, and music using an equally tempered scale is not quite so pleasant to our ears. The difference, however, is slight to any but the most critical. Listen as we play alternately the notes of the natural major scale of C and the equally-tempered scale of C:

SOUND: BOTH SCALES ALTERNATELY

NARRATOR: The musical scales with which we are familiar are by no means the oldest or the only possible arrangement of musical intervals. For example, the Chinese divide their musical scale into twelve steps, as we do, but usually only five notes are used, corresponding to the black notes on our piano keyboard. It is called a pentatonic scale.

SOUND: BLACK KEYS ON PIANO

NARRATOR: Chinese music using a pentatonic scale has a distinctive sound. Listen:

SOUND: CHINESE MUSIC

NARRATOR: Hindu music is based upon the division of the octave into twenty two steps but the melodic structure is usually based on seven notes. The intervals between the notes correspond to ours; however, in addition, Hindu music uses some very small intervals as grace notes. Listen to this Hindu music being played on a pipe by a snake charmer:

SOUND: HINDU MUSIC

NARRATOR: There is an amazing variety of musical scales on record, each sounding as pleasant to its originators as our musical scales sound to us. So you see, although musical scales have a mathematical and scientific basis, they have come about through usage and custom and they vary with the culture and the tastes of the people.

VIBRATO AND TREMOLO

NARRATOR: I am now going to sound a pure tone and then rapidly vary its frequency slightly. Listen:

SOUND: PURE TONE: THEN VIBRATO

NARRATOR: That wavering sound you heard is known as vibrato. Its distinctive sound depends not only on how much we fluctuate the frequency but also on how fast. Listen as this violinist produces a vibrato on a violin by moving his finger so that the length of the vibrating string changes. The note is changed about a quarter of a tone, six times a second.

SOUND: VIBRATO ON VIOLIN

NARRATOR: Here is a trombone, first with a steady note, then with a vibrato.

SOUND: TROMBONE VIBRATO

NARRATOR: Sometimes when the frequency fluctuation is small you may not be able to detect a variation in pitch at all, however, the quality of the tone may sound different. Can you detect a vibrato in this singer's voice?

SOUND: SOPRANO VIBRATO

NARRATOR: Generally the vibrato frequency fluctuation seems to be smaller in opera singer's voices than in singers of popular music. At the same time the vibrato rate is generally faster for opera singers. Too much or too rapid vibrato, in any case, may sound unpleasant, like this:

SOUND: SOPRANO WITH FORCED VIBRATO

NARRATOR: Although singers call this large vibrato a tremolo, actually a tremolo is something quite different. While vibrato is created by a rapid variation in pitch, tremolo is created by a variation in loudness. Listen as we produce an example of tremolo in a pure tone by fluctuating its loudness.

SOUND: PURE TONE TREMOLO

NARRATOR: In ancient music, a vocal tremolo was a very important ornamentation. It was produced by rapidly reiterating the same pitch; and sounded, some persons think, like a bleating lamb. Even today, in some cultures, vocal tremolo is considered to be a desirable and difficult vocal feat. Here is an Iranian singer purposely creating a tremolo in his voice.

SOUND:

NARRATOR: Actually most voices have both pitch and loudness variations at the same time, and the ability of a singer to control these fluctuations is a measure of his training and talent.

THE DOPPLER EFFECT

NARRATOR: Did you ever notice how the pitch of a train whistle suddenly lowers as the train rushes past you?

SOUND: TRAIN-WHISTLE DOPPLERING AS IT RUSHES PAST

NARRATOR: Or if you are on a moving train going past a clanging crossing bell, how the bell's pitch changes?

SOUND: BELL DOPPLERING - COMING AND GOING

NARRATOR: These are two examples of a phenomenon called the Doppler Effect in honor of the Austrian physicist, Christian Doppler, who first explained it in 1842. What happens is this: When you are on the moving train approaching the clanging bell, you are actually meeting the sound waves before they would ordinarily reach you. So more sound vibrations impinge on your ear each second than if you were not moving. Consequently your ear drum is made to vibrate faster, giving you the impression of higher pitch when you are moving away from the bell -- in effect, running away from the sound waves -- fewer vibrations reach you during any interval and the pitch that you hear is lower than it would be if you were not moving. Listen again!

SOUND: (REPEAT BELL)

NARRATOR: In the case where you are stationary and the train whistle moving, the sound waves ahead of the whistle are crowded together and made shorter, while the waves behind the whistle are spread out and made longer. This change in wave length does not change the speed with which the waves travel, but it does change the number of waves that hit your ear in a second. So as the train approaches you, more vibrations per second reach your ear and you hear a higher pitch than you would if the whistle wasn't moving, and as the train goes away, fewer vibrations per second reach your ear and the pitch you hear is lower than it would be if the whistle wasn't moving.

SOUND: (REPEAT TRAIN WHISTLE)

NARRATOR: Here is another example of the Doppler effect: racing cars.

SOUND: (RACING CARS AT WATKINS GLEN)

NARRATOR: The roar of the first car you heard changed pitch almost a musical fifth as it passed close by. The slower cars, bringing up the rear, changed pitch about a minor third. Obviously, the Doppler effect can be used to measure the speed of a sound source. The greater the change in pitch, the faster the source is moving.

End Side IV

NARRATOR: These records of acoustic phenomena were produced by Bell Telephone Laboratories as an aid in understanding the Science of Sound. We hope you have found them entertaining as well as instructive.

SCIENCE ON RECORDS

Folkways' series of science recordings provides a unique documentary of the world around us. This ever-growing catalogue of long-playing records, captures the sounds, both natural and mechanical, of man's physical world. These sounds -- the documentation of animals, insects, man-made satellites, railroads, etc. -- are all recorded in geographical context. All of the recordings are edited under the supervision of leading scientists. Each record is accompanied with a set of extensive documentary notes, providing background on the subject plus additional information on the circumstances of recording and the significance of the sounds recorded.

FX6007 The Science of Sound Demonstrations of acoustic phenomena with an explanatory narration written by scientists and engineers of Bell Telephone Laboratories, How We Hear, Frequency, Pitch, Vibration and Resonance, Intensity, Loudness, Noise Measurement, Masking, Echo and Reverberation, Delay Distortion, Fundamentals and Overtones, Quality, Subjective Tones, Music or Noise, Filtered Music and Speech, Dissonance and Consonance, Music Scales, Vibrato and Tremolo, The Doppler Effect.
Produced by Bell Telephone Laboratories Incorporated Distributed and manufactured by FOLKWAYS RECORDS & SERVICE CORP. 2-12" 33-1/3 rpm long play records .. $11.90

FX6100 Sounds of Frequency The purpose of this record is to provide a standard by which record playing equipment can be checked for frequency response and distortion. 78 RPM:... Frequency test run; square waves; and three variations of music to check longplay phonograph record characteristics. NOTES BY PETER BARTOK The purpose of this record is to provide a standard by the use of which record playing equipment can be checked for frequency response, and distortion, without equipment other than an oscilloscope and volume indicator. The portion of the record intended for frequency-response measurement provides test signals which are always the same musical distance apart. Accompanying descriptive notes.

FX6101 Science in Our Lives narrated by Ritchie Calder, from the Signet Key Book. Includes Science began, Science terms, Edison effect, Atoms, Agriculture, Food from the desert, Food from the jungle, Millions of men without teaspoons, Rip Van Winkle comes to town.

FX6105 The Sounds of Camp the picture of a children's camp painted in the voices and sounds of its children. Recorded at Camp Killooleet, Hancock, Vermont, 1958 by Ed Badeaux. Includes Riding, Shop Swimming, Jingle, Before lunch music, Filing into tables, Eating, Happy Birthday, Jacks, Dance Class, Baseball, Theatre Backstage, Front porch before hikes leave, Hike reports, Girls after a dance, Riflery, Last campfire.

FX6120 Sounds of A Tropical Rain Forest in America As a dramatic presentation, and because enough sounds were available it was decided that the approach would be.. for every hour of the day from one to two minutes of sound would be used on the record. Thus in sixteen minutes of play an idealized condition was possible in depicting a dawn to dusk period. Includes, THE DRY SEASON Cricket and Dove, Violaceous Jay, Black Howler Monkeys, Parrott, Swainson Toucan, Cicadas, Great Rufus Motmot, Cicada, Spotted Chachalaca, Great Tinamou, Wattled Guan, Red Wattled Curassow, Toucan and Jay, Monkey Chatter, Toucan Barbetes, Flock of Parrots, Waglers' Toucan, Macaw talk, With Crickets, Crested Guans in Thunderstorm, Chestnut Headed Tinamou and Crickets, Crickets and Parakeet, Crickets and Mourning Dove, Small Tree Toad, Peepers, Flight of Parrots, Giant Toad (Bufo Marinus), Many Toads, Rain Sequence with Crickets, And Toads, Three Wattled Bell Bird, Black Howler Monkeys, Tree Fall With Screaming, Monkeys, Parrots and Macaw, Tree Toad, and Big Toad.

FX6121 Sounds of the Sea Actual SOUNDS of fish species recorded in isolated tanks and at varying depths - from 5 feet in sheltered areas to 2,000 fathoms 200 miles out - in tropical waters of the Atlantic and Pacific Oceans, Recorded by the Naval Research Laboratory. INTRODUCTION AND NOTES BY C. W. COATES Includes, Normal water noises - Pac., 10' deep - snapping shrimp - toadfish - Atl., 11' water - 5' deep - Atl. - snapping shrimp - croakers - toadfish - Atl., 20' water - Pac., One mile offshore (crabs) Pac., 45' water - snapping shrimp; Afternoon - Atl., 45' water; Evening - Atl., 1 1/2 miles out above water - Pac. - snapping shrimp - sea robin - croakers, 50' 60' 70' water - Pac., 12 miles out - 48' deep - Atl. - drum fish (bastard trout), 600 fathoms down 18 miles out - Pac. - croaker family 600 fathoms down - unknown sounds - Pac., 2000 fathoms down, 200 miles out - Pac., Spot fish, Sea robin, (5) Catfish, (400) Croakers, (150) Snapping shrimp, (40) Cancer crabs, Spotfin croaker, Black croaker, Croaker and snapping shrimp chorus in open water, Drum fish, and Toadfish.

FX6122(FPX6122) Sounds of the American Southwest recorded in Arizona near Tucson, Cave Creek, Chiricahua Mountains and Rustlers Park. In New Mexico, San Simeon Valley and in California, Mandevilla Canyon, Santa Monica Mountains and Lake Fulmar, by Dr. Charles M. Bogert, Chairman and Curator of the Department of Amphibians and Reptiles of the American Museum of Nat. Hist., N. Y. The sounds recorded are those that anyone traveling in the arid portions of southern California, Arizona and New Mexico might hear during a single summer. Includes, Morning doves, mocking birds, woodpecker, owls, rattlesnakes, bob cats, crickets, beetles toads, frogs, etc. Thunder storm and flashflood. Illustrated Text.

FX6123 Vox Humana recorded in England. Alfred Wolfsohn's experiments in extension of human vocal range with an Introduction by Dr. Henry Cowell. Includes Female voice in a range of seven octaves, Female duet in ne vocal sound range, Boy's voice in seven octaves, Four and five octave leaps, Double and multiple stopping by the voice, New registers (male and female voice), Male voice in nine octaves, "String Quartet" for four female voices, and Voice versus instrument.

FX6124 Sounds of Animals audible communication of zoo and farm animals. These various recorded sounds suggest that just as man has his own special language, so animals have their own special means of vocal communication which help them to solve their own living problems. Includes, ZOO: Puma, Lion, Indian Elephant, Rhea, Hippopotamus, Chimpanzee, Peccary, Rhesus Monkeys, Rhinoceros, Tiger, recorded by Arthur M. Greenhall. FARM: Chicks, Goat, Sheep, recorded by Nicholas Collias.

FX6125 Sounds of Sea Animals Vol. II Florida This record contains representative of typical underwater sounds produced by several species of fishes and by the sea cow or manatee. RECORDED BY W. N. KELLOGG OCEANOGRAPHIC INSTITUTE, FLORIDA STATE UNIVERSITY. Includes Snapping shrimp, Toadfish, Trigger Parrotfish, Sea catfish, Single catfish, White grunt, Drumfish, Cowfish, Manatee, One porpoise, Four porpoises, School of porpoises, "School" at 1/2, 1/8, 1/32, and 1/64 speed.

FX6126(FPX126) Sounds of Carnival The Midway and Merry-Go-Round Music. Recorded at the Royal American Shows by students of the Chicago Institute of Design. This record is for young and old. It is a documentary of typical sounds nostalgic and true of an American scene... The Carnival. Includes the Crowd, Merry-Go-Round, Barker, Outside the fun house, Animal barker, Ferris Wheel, Motordrome barker, Roll-O-Plane, Strange people barker, Laughing clown, Interviews, and the famous repertoire of merry-go-round music, including Calliope; Over the Waves, Ta-ra-ra-boom-der-e and others. Notes.

FX6127 Sounds of Medicine recorded on location. Contains Operation; Supervised surgical operation on a small boy with a cyst in his neck, Stethoscope Sounds; Heart murmurs and lung sounds - A woman with Rheumatic Heart Disease, Normal heart and lung sounds, Heart murmurs and lung sounds - A woman with Valve Disease of the heart before surgical operation, Breath sounds, Sounds of the bowels - A normal hungry man smoking a cigarette before dinner, Heart sounds - A man with inflammation of the heart due to active Rheumatic Fever.

FX6130 Sound Patters Taken out of content these sounds "stand" by themselves in their uniqueness, and create new auditory dimensions. NATURAL SOUNDS: Wood Thrush--natural speed, slowed down to 1/2 speed, slowed down to 1/4 speed, Crickets--natural speed, slowed down to 1/2 speed, slowed down to 1/4 speed, slowed down to 1/8 speed, Thunder Storm (with toad and bird), Alligator Chorus (American, and one Asiatic), Two Lions (Atlanta, Zoo), Monkey (happy), Monkey (same monkey - angry), Tortoise Mating Call, MUSICAL SOUNDS: Musicians Tuning-up, SOUNDS: Animal Imitations by an Eskimo, Heartbeats, LOCATION SOUNDS: Chorcha, Honduras, Talking Drums, Africa, Taxi Trip, Through Traffic to Airport, Street Cries -- N. Y. C. Lineman, N. Y. C. gardenias!, Hot Dogs in Times Square, Flower Vendor, Charleston, S. C., Cow Ceremony in Yugoslavia, Dawn Chorus, East Africa, MAN MADE SOUNDS: Jet Flight, Railroad to Atlantic City, Short Wave Radio, Pump Drill, Electronic Feedback -- 7 1/2 inches tape, and 15 inches tape.

FX6136 The Science of Sound (Short versions of FX6007) This record describes and demonstrates various phenomena of sound as an aid to understanding how sound is put ot work for the benefit and pleasure of man. How We Hear, Frequency, Pitch, Intensity, The Doppler Effect, Echo and Reverberation, Delay Distortion, Fundamentals and Overtones, Quality, Filtered Music and Speech.
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FX6140(FPX140) Sounds of the Annual International Sports Car Races of Watkins Glen N.Y. The Schuyler, Carrera, Glen Trophy and Grand Prix. Recorded on location by Henry Mandler and Robert Strome Includes: lining up, practice, winner O'Shea in the victory lap, technical inspection, cars in the races: Maserat, Jaguar, Austin, MG's, Porsches, Mercedes. With ill. notes.

FX6151 Sounds of A South African Homestead Recorded in the Land of the Zulus by Dr. Raymond B. Cowles Containes DAWN CHORUS: Doves, Thrush, Cuckoo, Weaver. BUSH BIRDS: Hornbills, Doves, Barbet, Shrikes, Monkey, Warblers, Cicadas, Orioles, Bulbul, Robbin, Starling, Ibis, Trogon, Drongo. LATE AFTERNOON UNTIL DARK: Partridge, Drongo, Bulbul, Cricket, Amphibian chorus, Toads, Frogs. ZULU MUSIC: with guitars, jew's harp, fighting sticks, gourd-and-bow, horns, in songs, wedding chants, beer-drink, praises, dances. Accompanying notes and illustrations.

FX6152 Sounds of Steam Locomoties No. 1 Stack Music Sampler: The U.P., C.B.&Q., I.C., C.N.W., D.R.G.W., etc. 2-8-2, 4-8-4, 4-12-2, 4-6-0, 4-6-6-4, 4-8-8-4, 4-8-2, 2-10-2 and switchers 0-6-0. 2-8-0, narrow gauge 2-8-2. These recordings were made by Vinton Wight who wrote the accompanying notes.

FX6163 Sounds of Steam Locomotives No.2 Stack music sampler edited and recorded by Vinton Wight. Includes No. 510 Switching, No. 4958 Leaving Yards, No. 5116 Climbing to Elevator, No. 5112 Struggling spotting Cars, No. 4958 Returning to Yards with Empties, No. 5344 Simmering on Ready Track, No. 5351 Up to Crossing and Back, No. 5504 Leaving Yards with Train, No. 5355 Passing, No. 5505 Switching at Ashland, No. 5504 Woodlawn Run, No. 5347 and Helper No. 7000 near Firth, No. 5335 Pulling into Yards, No. 5504 Light to Roundhouse, No. 5351 from RH Simmering and Switching.

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