Synth History - Ep 3 - Oscillators

This episode was written by Danz CM. All references and sources of information can be found at the bottom of this transcript. If you find any information inaccurate or have any questions please email danz@synthhistory.com Musical cues are for podcast editing purposes.

Hi there, and welcome

To Episode Three of Synth History

a podcast on synthesizers, drum machines and the musicians who use them.

I'm your host Danz.

Today's episode is pretty special.

Rather than talk about a specific music pioneer and their story.

We're going to talk about a specific component found inside of your synth.

Oscillators.

But we'll go even further than that.

Because in order to understand what an Oscillator does inside of your synthesizer,

You need to understand what an oscillator is.

What does it mean to oscillate?

Without further ado…

May I present,

Oscillators.

CHAPTER ONE: WHAT IS AN OSCILLATOR?

Think of an oscillator as a fancy word for something moving back and forth. [1]

A great example of this is a pendulum.

PENDULUM SOUND BEGIN

Thanks to gravity and other factors

It moves back and forth, back and forth.

If you're at a park-

PARK SOUNDS / KIDS LAUGHING BLEND IN WITH PENDULUM

And you're on a swing,

You're moving back and forth between two positions.

You're… oscillating.

Here's another example.

This one can be found in you right now.

PENDULUM & SWING BLENDS INTO HEART BEAT

Inside your heart is a little natural pacemaker, the sinoatrial node. [2]

[3]

It sends out electrical signals that initiate each heartbeat.

These oscillations keep you alive.

You might not believe how many things oscillate.

Circadian rhythms, the production of the human voice [5] (*ahhh harmony*

strings on a guitar (*guitar pluc*k)

periodic firing of nerve cells in the brain (*pew pew*) [4]

business cycles [6]

Tuning forks, electric and magnetic fields.

Subatomic particles, Black holes, the surface of the sun. [9][81][82]

[7]

When thinking about oscillations, it helps to visualize waves.

You've probably dropped a stone into a pond before.

[10]

When the stone drops into the water it creates a disturbance that sets the nearby water molecules into motion. [*motion sounds*]

Each little water molecule moves back and forth, oscillating.

The combined motion of all the molecules oscillating creates the waves you see.

Ripples.

When the stone dropped in, it also made a sound.

[PLOP]

Like the stone needed water molecules to vibrate in order to make the waves you see, sound needs molecules in a medium, like air. [13]

[pluck]

When you pluck a guitar string, you cause it to vibrate.

A type of oscillation that's very fast.

[12]

A sound pressure wave travels through the nitrogen and oxygen molecules in air. [15]

When these waves of vibrating molecules hit your ears -

They vibrate your eardrums.

They're converted into electrochemical impulses that our brains perceive as…

Sound.

These are examples of an oscillation of matter itself.

[14]

CHAPTER 2: OUT IN SPACE

[Space Sounds, music]

JOEL GREEN SPEAKS

Hi, I'm Joel Green. I am an astronomer and instrument scientist working at the Space Telescope Science Institute, where I work on the Hubble Space Telescope. We also operate the James Webb Space Telescope.

So space is in some ways like the cleanest way to see an oscillator. If you talk about anything that goes back and forth and oscillates, it basically creates a wave, a wave pattern, something that repeats.

One really good example -
If you want to think about the ripples in a pond thing - one of the things that Webb has looked at is a pair of - they're called Wolf-Rayet stars - basically two very large dying stars that were once massive, but more like the sun. And they are in the process of dying.

And as they're dying, they're kind of wobbling and expelling stuff.

[space sounds, wobbling, expelling]

And in this case, there's two of them, and they're orbiting each other.
And every time - exactly - every time they go around, they sort of release a puff of material like a smoke ring out every eight years, there's another ripple and there's a beautiful image of this and it looks exactly like a perfect image in a pond that the James Webb took.

Do black holes oscillate?

So, first of all, a pair of black holes will oscillate exactly like the way I just described with the two Wolf-Rayet stars as two black holes instead. And as they orbit each other, they'll create a ripple.

But those ripples are much bigger. They'll be detectable even if the black hole isn't surrounded by stuff because they're so strong, they're actually rippling space itself. And these are called gravitational waves. When they merge into each other, they create a really big black hole.

That's what all these famous gravitational wave detectors are picking up like Ligo and soon, Lisa. They're looking for the rippling and stretching of the space around themselves by basically being really large and being sensitive to slight changes and the ripples of space, so small that we wouldn't notice them, but this instrument is so precise it could pick them up.

So anything that like pulses internally makes ripples that oscillate.

What are some of the instruments that you use to detect waves?

So that's a super good question. I should say there's two different kinds of ripples. So you could ripple in space. So you picture like, you know, the ripples in a pond or you can, oscillate in time, which would be like a police siren going back and forth.

You need a different kind of instrument to measure waves that are in space, where you really are looking at a picture and waves that are in time where you're kind of looking at the same thing repeatedly. You're trying to make a sort of a curve like a sine wave, like a chart or a spectrum or a time series. So you want slightly different instruments for each of those, but telescopes have scientific detectors on them that can do both of those kinds of things.

So it depends exactly what you want to study. Do you want to study the surrounding medium around the star? Do you want to understand the dust and the gas? Do you want to see the pulses of light and how high energy they get? Then you might need an x-ray telescope. Do you want to see what the mass loss is and where it all goes?

It's all slightly different experiments. The point is they're all built into telescopes, and telescopes are essentially gigantic light buckets that collect the information from whatever they're looking at and with extreme accuracy and then they can sort of do whatever scientific study they want.

[PAUSE WITH JOEL]

As Joel is talking to me about telescopes, I think of oscilloscopes.

An oscilloscope graphically displays waveforms on a screen. [16]

The name kind of gives away its function.

OSCILLO-SCOPE.

You’ve probably seen a type of oscilloscope before

in the form of an electrocardiogram, or EKG.

These are used in doctor's offices and hospitals.

[17]

As your heart beats the trace shows the electrical activity of your heart over time.

As your heart’s electrical activity changes, so does the signal.

[20]

Doctor’s learn a lot about your heart just by looking at the waveform.

A waveform is simply a graphic representation of the shape of a

Wave, that indicates its characteristics. [9]

[BACK TO JOEL]

Would telescopes be similar to oscilloscopes?

Absolutely. So an oscilloscope right, if you picture that little wave form in it, that stereotypical sine wave, right, that's the time variation of a wave and it's repeating.
So an oscilloscope is like the kind of data that you would pull out from one of these data sets from a telescope or an interferometer, an interferometer is like a fancy name for a huge oscilloscope, basically, or at least a huge instrument that feeds data to a telescope..

Does sound exist in space?

Sound waves themselves exist in astronomy, so sound just means the movement of some ripple through a physical medium of stuff. Sound is inherently changed and different based on what generated it, but also what kind of medium it is propagating through. And that's true of astronomical waves too. They actually have a great video of the sound of a black hole. And I think it has to do with the pulsing - of the spin of the black hole. It's like sound is a compression wave through medium. Anything that pulses is going to emit particles that go through the material around them. And then this actually creates out. There's actually a sound speed. So you know, about sonic booms and the mock barrier or whatever.

All that stuff is based on air. Air has a specific density pressure. We're used to things moving through air and they can even change based on how thin the atmosphere is where you are, the speed at which sound moves that 600 miles an hour or whatever the sonic boom is, is specific to air on earth in that density.

So the sound speed is much different in astronomical environments. It could be faster. Usually it could be slower inside of dense things and so the sound speed is like something that we're interested in and can calculate astrophysically from observations like looking at oscillations.

How do you find new planets orbiting stars?

You would look for that planet to sort of eclipse the star as it passed around every source. And that's one way of putting it. And if a planet was really close to the star, it would appear much faster and it would sort of look like a repeating oscillator, right? A brightness to the dimness on the star's frequency itself. And the denser, denser the star, the smaller the planet, the closer is the star, the easier it would be to see something like that.

If you imagine a planet around a super dense thing like a neutron star, a pulsar planet, specifically, its years as it spins around the star could be really fast, so fast that it could kind of look like a continuous signal and the very first planet ever discovered around another star was discovered around one of these dense pulsars, and it was found by basically the gravity effect of the interference pattern on the pulse, which is basically like pushing an oscillator back and forth.

It's like tweaking it, it's an overtone or something.

What was neat was they found, I think, three or four planets that way, each one putting a different tone on top of the oscillation of the main star. It's like a chord, I guess. I don't know. It feels musical to me. Like each planet is sort of one bit of the chord in tone on top of the instrument that is generating the main sound, which is the pulsar.

CHAPTER THREE: FREQUENCY

How often do you check your phone?

Three times an hour?

Five times an hour?

Twenty times an hour?

That’s frequent!

That's way too much.

Frequency is how often something occurs in a certain amount of time.

Think of a pendulum again.

When the pendulum swings back and forth, imagine a pencil is attached to it

and you're moving paper underneath at a constant speed.

As the paper moves beneath the pendulum, the pencil would draw

smooth hills and equal valleys.

A sine wave.

If the pendulum swings faster, you'd see more waves.

Every time the pendulum swings back and forth, it completes one cycle, one oscillation.

How we can measure the frequency is with Hertz.

Hertz measures how many cycles happen in one second.

If the pendulum completes one cycle in one second, its frequency would be 1 Hertz.

If it completes two cycles in one second, its frequency would be 2 hertz.

3 hertz..

4 hertz…

If the pendulum goes fast enough

You get to Kilohertz.

Then Megahertz

Several other orders of magnitude

And then, if the pendulum completes one quintillion cycles per second, its frequency would be one 1 Exahertz.

One quintillion, that's one with eighteen zeros, that's really fast.

Obviously a pendulum couldn't do this, but a gamma ray on the other hand.. [40]

Think about it.

Now think about it twice, in one second.

The frequency of you thinking about frequency is 2 hertz.

[21]

[example]

Now it's interesting in the context of music production [22]

Because the frequency of a sound wave is linked to our perception of the pitch of a sound.

To our ears,

Higher frequencies have a higher pitch.

And lower frequencies have a lower pitch.

Higher pitched sounds also have shorter wavelengths,

lower pitched sounds have longer wavelengths.

What affects the waves height is its amplitude,

To amplify something means to make it louder.

For audio signals, the amplitude is a sounds' loudness.

[whispering] My whisper will have a small amplitude.

[yelling] This plane flying over my head has a big amplitude.

When you pluck or bow a violin string, it vibrates at a certain frequency and you can hear a certain pitch.

A violin can produce frequencies over 3000 Hz [26][27]

A bass on the other hand has frequencies around 60 to 250 Hz range.

My voice right now is in a particular frequency range.

So is the ping of your text alert.

And the sound you hear from the buzz of an office light.

When playing a violin, the more tension a string has, the higher the frequency of the vibration. [55]

Over time the tension of the strings might change, making the pitch shift a little bit.

And so you have to tune it.

Well, there is a specific frequency used for that purpose.

The frequency of 440Hz corresponds to the musical pitch of A440. [23]

The A note above middle C.

This frequency is commonly used as a reference

to tune pianos, violins, and even your analog synth.

Once A440 is in tune, the other notes on your instrument can then be tuned in relation, following a mathematical pattern.

The A one octave below 440hz would have half the frequency, 220Hz,

and the A one octave above 440 hz would have double the frequency, 880Hz.

Going up one octave is always the same as doubling the frequency and vice versa. [60]

Your human ear can detect sounds from 20Hz to 20,000Hz.

But as we age, so do our inner ears.

We hear less frequencies as we get older.

There are some frequencies kids can hear that adults can't.

[dog barks]

Why is your dog barking

at absolutely nothing?

Dogs can hear frequencies as high as 47,000 to 65,000Hz.

We wouldn't be able to hear those frequencies at all. Maybe that might explain the barking. [29]

You think a dogs' hearing range is crazy?

Let me tell you about bats.

Bats use echolocation, reflected sound, to determine the size, shape and texture of an object in their environment.

[30]

The frequencies bats use to do this can be upwards of 200,000Hz.

They use Ultrasound.

On the other hand, deep In the ocean, certain whales use infrasound.

They can communicate thousands of miles away from each other.

[31] [32] [33] [34]

Not even your subwoofer can produce some of the sounds whales make.

Infrasound frequencies are way below the range of human hearing.

While Ultrasound frequencies are way above the range of human hearing,

"infra-" means "below" and "ultra-" means "beyond" in latin. [37]

Nature is a wild place.

And just like there are sounds we can't hear, there is light we cannot see.

[Oscillators, oscillating]

Light waves are different from the waves that you see on the surface of water.

They're also different from sound waves.

In order to hear sound, you need some kind of medium,

like air or water, you need molecules to… vibrate.

Sound wouldn't be able to travel through a vacuum or empty space.

But light, light on the other hand is able to travel through empty space without the need for a medium at all.

Light waves don't cause a physical disturbance in the medium through which they are traveling

Like a sound wave would.

Instead they oscillate electric and magnetic fields.

That's why light waves are called electromagnetic waves. [35]

Thanks to light waves, you can see colors.

Like how the frequency of a sound wave corresponds to its pitch.

The frequency of a light wave corresponds to its color.

Green has a specific frequency.

So does yellow.

Visible light consists of the colors of the rainbow, ranging from red to violet.

Beyond red and violet are forms of light you can't see.

Just like there is ultrasound, there is ultraviolet.

And just like there is infrasound there is infrared.

[36][39]

The oscillations of electric and magnetic fields enable radio waves, x-rays, visible light and the rest of the waves found across the Electromagnetic Spectrum to exist. [85]

CHAPTER 5: FIXED FREQUENCY OSCILLATORS

MAX KATZ SPEAKS

My name is Max Katz. I studied at Rensselaer Polytechnic Institute and then at Stony Brook University. I am an astrophysicist by training. I became as much a computer scientist as a physicist I would say. Most processes in the world produce light at many different wavelengths. It's not one pure color, but there are some things out there in the world that do produce light at specific frequencies, red laser pointers that you might be familiar with.

You rarely see pure colors in the world.

Most of what you see is a mixture of light at varying frequencies.

But a laser light is said to be coherent,

This means the wavelengths of the laser light are in phase in space and time. [62]

This allows them to stay narrow over great distances and be focused.

They're used in surgery - like vision correction and dermatology, in cutting materials and on weapons to mark targets.

Can you imagine if lasers weren't stable or accurate?

What makes them stable is found inside, fixed frequency oscillations of atoms, emit light at specific wavelengths.

They take a bunch of atoms put into a cavity, just a tumor, basically in a vacuum. Heat them up, excite the atoms, run a current, and they will then emit light, but only at specific frequency. The light that is being emitted from the electrons in the atoms is actually being trapped in between two mirrors and it's bouncing back and forth.

And each time the light passes by another neon atom, it has a chance of creating more light with the same wavelength. You have light bouncing back and forth, generating more light, and eventually have very high amplification of the light through this oscillation process.

That's why you get a pure nice red color.

The next oscillator we'll talk about is a quartz crystal oscillator.

It's another example of fixed-frequency oscillator, the devices that use these need stable, accurate signals. [38]

They're technically harmonic oscillators, meaning they're able to vibrate at specific frequencies or at multiples of that frequency.

But we'll get to harmonics. Let's just see how quartz crystal oscillators work.

If you compress the quartz crystal in the right way, a mechanical force applied to the crystal generates an electric force. That effect occurs in reverse, too. If you apply a voltage across the crystal, the crystal deforms in response. And I think this is a pretty fascinating fact about nature. If you're looking about this online, the official name for this effect is the piezoelectric effect.

If you keep applying a voltage to the crystal set up in a circuit so that the output signal of the crystal is fed back into itself, you can actually keep the crystal oscillation going indefinitely at a particular frequency.

In early radio, the use of quartz crystals to generate very specific transmission of frequencies was a pretty important advance.

You typically want to transmit at a specific frequency, suppose you want to transmit at 730 Khz, 730 AM. If we don't have a way to generate a very specific frequency, our transmission can drift by a few kilohertz. We can actually end up interfering with other stations and get static.

The oscillation of the atoms in quartz crystals occurs at a very precise frequency.

If you want to use a quartz crystal to power a watch, you want the watch hand to move at one second per second. But if you look at the quartz crystals in watches, they actually oscillate at a different frequency. That frequency very often is exactly 32.768 kilohertz.

That's, of course, very fast. You can take the oscillation frequency coming out of the quartz crystal and run it through some sort of frequency divider that makes it slower, you eventually get from a frequency of 32.768 kilohertz to a frequency of one hertz, or that is, once per second.

You get the normal watch movement that you want.

Imagine that, you know, 32 kilohertz quartz crystal. What if I want to use it for some other purpose, not for powering a watch hand, which has a frequency of one hertz, which is very, very slow. What if I need something very fast? A CPU in your computer also uses the same process.

Tiny quartz crystals are your computer's heartbeat.

A watch might only need a Quartz Crystal Frequency of 1 hertz to power its clock, but a computer needs frequencies upwards of several gigahertz.

For this, the fundamental frequency of the quartz crystal is multiplied a number of times.

[56]

When you are buying a CPU or looking at a laptop and it says that the CPU runs at some number of gigahertz, like three or four or five gigahertz, it means the fundamental frequency of operation, the information processing rate and the CPU runs at a particular frequency.

It's kind of amazing that something very simple, a simple piece of rock that's made of the same stuff that you can get on a beach allows a CPU to have very precise timing for processing information many billions of times per second.

CHAPTER SIX: FROM TUBES TO TRANSISTORS

Before we jump into Voltage Controlled Oscillators, the ones found inside your analog synth, let's travel back in time a little bit.

The year is 1876.

Colorado is admitted as the 38th U.S. state, Heinz Tomato Ketchup is introduced and inventor Elisha Gray is currently tinkering around in his workshop.

Probably best known for developing a telephone prototype, [41]

The legend goes, that if he'd have gotten to the patent office a little earlier than Alexander Graham Bell, you might know him as the inventor of the telephone.

One day he

Bam

accidentally invents a basic single-note oscillator.

That he uses to create an instrument called, A Musical Telegraph.

This instrument used a set of tuned steel reeds, each suspended over an electromagnet.

When you think of a metal reed, think of a very flat strip of metal.

Actually - Wurlitzers and Rhodes pianos use thin metal reeds or tines that produce oscillations produced when a hammer hits them.

But the Musical Telegraph worked slightly different;

When a key was pressed, instead of a hammer hitting a metal reed, it opened or closed a circuit, and an electromagnetic current would make the reeds oscillate instead.

These oscillations could then be transmitted over telephone lines.

[64]

Elisha would stage in New York.
Frederick Boscovitz would perform on the Musical Telegraph remotely in philadelphia via telephone line in Philadelphia.

The New York audience was astonished.

The National Republican paper called it:

A novelty. It was highly entertaining, yes, though unless an almost incredible improvement be effected, it is difficult to see how the transmission of music over the new instrument can be of permanent practical value.

It would be a while til you get to the synthesizer.

Many inventions and innovations that we'll save for another episode.

But we will touch on something revolutionary that came around in the early 1900s, it was one more step to the voltage controlled oscillator.

Vacuum tubes,

[*Bells Labs Archival*]

Vacuum tubes were able to amplify electronic signals in a circuit.

Not only that, but if you fed the amplified signal back into itself it'd create an oscillation, a waveform, that could be used as a sound source.

[65] [67] [66] [52] [77-excerpt in podcast]

The RCA Mark II synthesizer installed at New York's Columbia University used a series of vacuum tube oscillators to generate its sound.

So did early versions of the Theremin and Westinghouse organ. [73]

Vacuum tubes were used in almost every kind of electronic device.

Radios, sound systems, even computers.

I mean the computers were big and not very practical.

But this was partly because vacuum tubes were big, delicate and consumed a lot of power.

[43] [69]

Eventually, something smaller, more reliable, and more efficient would be invented.

[46]

The transistor.

[*Excerpts of transistors*]

Vacuum tubes would become yesterday's news.

By the time the 60s rolled around,

transistors would replace vacuum tubes in becoming the foundation for nearly every electronic device, electrical system and industry around the planet.

A chip inside your computer today might contain billions of transistors.

Quartz crystal oscillators work together with transistors.

The transistors amplify the quartz crystals' clocks signal for other parts of your computer.

[70][71]

These tiny revolutionary devices would be used by engineers like Don Buchla, Peter Zinovieff and Robert Moog,

In 1964, Moog would use silicon transistors to create the voltage-controlled oscillator found inside the very first commercial synthesizer.

CHAPTER SIX: VCOs

The purpose of a voltage controlled oscillator is to act as an analog synthesizer's sound source.

They can generate a waveform whose pitch, or frequency, can be controlled by the amount of voltage applied.

Pressing different key changes voltage, driving the oscillator to produce different pitches. [72]

[STEVE DUNNINGTON SPEAKS]

Hello, I'm Steve Dunnington, Vice President of Product Development here at Moog Music.

The interesting part is the part where it's voltage controlled. If you have an oscillation and it's just one frequency, you would hear that kind of a droning tone that doesn't change. Music is not made of those. I mean, it can be. Actually, there's some really great music that's made with that now that I think about it, but a lot of music requires a lot of changing frequencies.

If you think about your voice going up and down in pitch, or a violin string going up and down and pitch.

You need some means of controlling the frequency of an oscillator, how many cycles per second it's vibrating at. On Moog synthesizers, analog synthesizers, there's a circuit called an exponentiator, that sounds really complicated. What it does is, it allows a one volt difference at the input of the circuit to change the frequency over one octave. If you recall, human ears can hear from 20 hertz, 20 kilohertz.

That's like ten octaves. With this system, you can change basically the entire frequency spectrum of what you can hear with just a ten volt difference. That was one of Bob's really big patents, actually was a means of controlling pitch over octaves, using regularly changing voltages.

Voltage Controlled Oscillators or VCOs are where your analog synthesizer's sound comes from.

But there's another oscillator on your synth.

This one you can't hear it all.

It’s called a Low Frequency Oscillator.

You use a Low Frequency Oscillator to modulate your

Voltage Controlled Oscillator.

The purpose of an LFO is to create repeating motion. So a good example of that might be vibrato. If you're stopping a violin string and you wiggle your hand back and forth, you're modulating the amount of length of the string which modulates the pitch of the string.

So an LFO, if you have it somewhere between six cycles per second and eight cycles per second, and you modulate the frequency using voltage control, apply that amount just so and it sounds like the pitch is vibrating up and down like vibrato.

Another thing you might want to do is tremolo, which is sort of more of an amplitude based effect. You can apply an LFO to what's called a VCA, which is a voltage controlled amplifier and have the dynamics go up and down automatically.

So the oscillators we were talking about before, as sound sources need to be between about, like I said, 20 hertz, 20 kilohertz, something like that. Things that we hear. Not all oscillators are for listening to. Some of them are for creating motion and expression and electronic sounds.

The various oscillators found in synthesizers can produce many different types of waveforms.

They each have a characteristic sound and appearance.

a sine wave produces a pure tone with smooth, rounded edges.

If you looked at a sine wave up close, it would look like ripples.

We've mainly been referencing these throughout the episode.

A square wave has a bit of a buzz sound.

Instead of being smooth, they have sharp edges.

They’re considered a type of pulse wave.

[46] Old Nintendo game soundtracks are good examples of this kind of sound.

A triangle wave’s shape looks like pyramids.

And a sawtooth wave looks sort of like a triangle wave, except the wave ramps upward then drops down very sharply.

A sawtooth wave resembles the teeth of a saw. [47]

The Voltage Controlled Oscillator in your Moog synth is actually a relaxation oscillator.

It produces a sawtooth wave that is manipulated to get other types of waves. [48]

A cool thing about a relaxation oscillator is that its basic wave shape is a sawtooth wave. It's kind of a simple circuit, from that sawtooth wave you can create circuits that then process it in different ways to get different waveforms.

You might think that these sounds are very similar. They do have the same pitch. But I can promise you, if you look at the waves, they look very different from each other.

Combining these various waveforms can create rich complex sounds.

CHAPTER 9: HARMONICS

Why does the 440Hertz A played on a piano sound different from the same note played on violin?

Both of them are vibrating at 440Hz, the A note above middle C.

The easy answer would be because they're different instruments.

But why do they sound… different?

Well, for one, the fundamental frequency of 440Hz is not the only frequency you're hearing.

Actually, there are other, faint, higher pitched frequencies you're hearing too, in addition to the fundamental.

These are called harmonics and overtones and give a sound its character.

I guess you could compare it to painting.

Imagine you're painting a blue ocean.

You might add a little white for seafoam on the wave tops, a little yellow to reflect the sun rays on the water, you add some black here and there for areas you want to appear deeper.

The main color of the ocean painting is blue, however it's the different shades and highlights that give the painting its unique color characteristics.

Let's build a sound.

What started out as a simple sine wave now sounds a little bit like an organ, thanks to the varying frequencies we added.

Your synthesizer might have three oscillators in it.

You can create a harmonically rich sound by adding those together.

It's uncommon to hear pure tones in the world, just like it's uncommon to see pure colors.

[57]

Harmonics are multiples of the fundamental frequency.

Even and odd harmonics can have different effects on a sound.

A piano has a classic ringing sound, able to generate both even and odd harmonics. [84]

And a clarinet has a mellow, woody quality and produces only odd harmonics.

You might play these instruments in an empty cathedral, causing tons of reverberation.

sound waves reflect off multiple surfaces.

Generating overtones might not be multiples of the fundamental frequency at all.

The shape of an instrument, its size, what it's made out of and the way that you play it all

influence the harmonics and overtones it has.

Did you talk about Fourier? Okay. Well, I'll drop him in here and we'll give you a little bit of that.

The sine wave is like the simplest waveform. It's what they call simple harmonic motion that can be approximated by a pendulum. Throwing a rock and a pond is another way you can approximate a sine wave. Going back into the 1800s.

There's a guy named Joseph Fourier. He was a physicist. He wrote a book about thermodynamics, which you wouldn't think would have anything to do with sound, but one of the things he proposed was that a function of a variable can be expressed as a sum of sines of multiples of that variable. That sounds pretty, how shall I say, obtuse, perhaps.

Here's the thing. When thinking about harmonics of a sound, you're talking about multiples of a fundamental frequency. So very astute observers and great math nerds and acoustic nerds learned a lot from this idea and studied it, and it turns out that you can take any sound and break it down as a sum of a bunch of-

Sine Waves

A note played on a piano can be expressed as a sum of sine waves,

So can a note played on a clarinet.

Even a square wave and a triangle wave can be expressed by the sum of sine waves.

Even my voice.

They are the building blocks of sounds.

Think about oscillations in nature.

The universe as we know it might be a chaotic and unpredictable place if there weren't cycles, rhythms or patterns.

[79]

CHAPTER 8: ONE BIG HARMONIC OSCILLATOR

Oscillations determine the sound of an instrument, the color of a rainbow, the ticking of a clock.

Whether it's a voltage controlled oscillator producing the sound found in your synthesizer or the string vibrating on a guitar, you have to admit it's pretty amazing.

Even your state of consciousness is associated with neural oscillations found inside your brain. [88][89]

Out there in space, massive astronomical objects oscillate, producing gravitational waves that ripple the fabric of space-time.

[18]

Patches on the surface of the sun oscillate up and down roughly every 5 minutes. [75]

And as the light from our sun moves through space as an electromagnetic wave,

It oscillates electric and magnetic fields. [53]

[61]

I’m always wondering about everything all around me.

Wondering about how my synth worked led me down this oscillator rabbit hole.

Philosophers like Pythagoras and Johannes Kepler believed in

[80]

the concept of Harmony of the Spheres.

That each planet had a musical tone related to its distance from the sun and that together they formed a celestial harmony.

That mathematical relationships express tones of energy which manifest in numbers, visual angles, shapes and sounds – all connected within a pattern of proportion.

Everything in our universe is constantly in motion.

Constantly in process.

Even objects that appear to be stationary

Are vibrating, resonating, oscillating.

Thanks to oscillations in nature, we hear sound, we experience light.

We create music and can see colors.

Molecules in the air, stars out in space.

Heart beats and brain waves.

Ocean tides and earthquakes.

[76]

Some people theorize that the universe itself is just one big harmonic oscillator [54][58][59]

[oscillators, oscillating]

Think about that the next time you turn on your synth.

OUTRO

And that's a wrap on episode three of Synth History, Oscillators.

It was written, researched, recorded, produced, edited, sound designed and scored by yours truly.

I spent about a year making it.

I know that's a long time, but it is just me and this isn't my day job,

So if you enjoy this podcast, please consider supporting it.

Not only would I appreciate it, but having more support means that I can make more of these episodes more often.

Visit the 'Podcast' section of the Synth History to learn how to do that. .

On the site you'll also find a transcript of this episode containing references.

In case you didn't know, Synth History is also an independently published magazine.

Featuring exclusive curated interviews I've conducted with legends like John Carpenter, Trent Reznor, Jean-Michel Jarre and more.

Selected music from this episode and past episodes is available on an album called Berlin Tokyo Shopping Mall Elevator by Danz CM.

Synth History is on all the social media channels.

Before I go I want to thank my voice actors for this one, who all swiftly responded to my random voice memo requests.

Cody Crump. Jessie, Manny and Jaden. And Matthew James Reilly.

And a very special thanks to my guests, astrophysicist Joel Green.

Physicist Max Katz, who is a legislative fellow in the US Senate focusing on science and technology policy.

And engineer Steve Dunnington, VP of product development at Moog Music

So, that's it.

I hope you learned something new from this episode.

And I'm excited to start working on the next one.

Until next time.

Thanks for listening.

I'm Danz, signing off from Synth History.

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