Presenter: **Professor Arthur James Lowery - *2017***

Title: Musical instruments inspire engineering - (13:21)

Time	*Dialogue*
00:08	Hello everybody. I'm Arthur Lowery and I'm an electrical engineer from Monash University. I'd like to show you the relationship between communications technologies and music and how my love of music turned into a worldwide business. This introductory slide has a picture of me I found in my Dad's attic last year and you can see it's rather dated. I'm rather dated also. What I'd like to do is show you that creativity in engineering can be inspired by many things. If you learn physics then it becomes a common language for practical things like telecommunications systems but also fun things like musical instruments.
00:56	Let's look at guitars and lasers and how they share common physics and how the modelling of a laser can be inspired by the playing of a guitar. This picture has a picture of a guitar rather like this one from the side and at the bottom is a laser. I'll first describe the guitar. The guitar has strings obviously and it has a nut at this end and a bridge at this end which holds the strings in a stationery position. Between those the string is able to vibrate in a variety of ways. The lowest vibration is the fundamental shown here as the red curve on the picture.
01:41	I can sort of illustrate this with this guitar by just plucking one of the strings of the guitar as so. That mainly contains the 'Fundamental note' however I can produce other harmonics which are double the frequency and treble the frequency by doing that. I'm plucking it while stopping it here …. You get a whole series of higher harmonics … which is better. Now those harmonics make a guitar sound interesting and warm. In a laser they are not really wanted.
02:33	A laser has two mirrors and between those the light travels back and forth. The light has to have an integer number of wavelengths between those two mirrors in order to sustain. This can actually happen at a series of harmonics just as (in) the guitar but in the laser each wave between the two mirrors has a different frequency or a different colour in light terms.
03:05	The issue with this is the colours travel at different speeds along the optical fibre, for example if I had two colours a red and a blue which initially were on top of one another, as they travel along they separate out and this can muddle a message. If the message is dots and dashes or ones and zeros, they will all merge into one another and be difficult to sort out at the other end. So many people of the last forty years or so have wanted to make lasers that only produce a single note.
03:42	And you can do this in a number of ways, but first how do we make a laser continue once it is turn on? How can we get it to produce a pure note that lasts for ever? Well one of the inspirations is from a guitar. In 'rock' guitar you can hold your guitar very close to the amplifier and be very loud and you might get some 'feedback'. I've made this a little easier on the ears for this demonstration by taking the output of the amplifier and putting it through a coil of wire here, like an electric motor and I can actually hold that near the string and make the string sustain forever.
04:31	If I move it away the note goes away and if I put it closer, it stays stronger. And I can move the position of the amplification to pick out different notes (harmonics) on the same string. [Demonstration] … Like so. Similar tricks can be played with lasers by placing the amplification along the laser at certain points. Generally through a laser is like a diode. You pass current through it from a battery and this current gives the laser high energy electrons which lose their energy to become new photons within the cavity and that keeps the light going even though quite a lot of it is escaping out of the end.

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05:22	When I started a PhD I chose to do laser modelling. This used a lot of inspiration from the guitar. A laser model is a piece of computer code. That's part of my PhD code there which simulates how a laser works and what sorts of notes it produces. You can break the computer code down into blocks and in my case there was a bunch of blocks … the green ones called delays which represented the string.
05:56	They represent the energy going backwards and forwards, and then every so often there was some amplifiers; the red triangles which keep the note strong as it's going along and compensate for the losses out of the end. And there is also a counting involve in here because you need to make sure that the amount of energy that you get out of the end is equal to the amount of energy or less than the amount of energy that you are putting in from the electric current.
06:26	And they are represented by 'leaky buckets of water'. The current fills the bucket. The light when it takes photons empties the bucket. So you can see that by treating a laser as a string with energy going backwards and forwards you can create some computer code which is highly efficient. Another thing that I was interested in as a child and a teenager was guitar 'stomp boxes' or 'effects boxes'. These are interesting to make but they are also interesting to rearrange because changing the order of the boxes can change what the sound is coming out of them.
07:09	So it is completely different putting a fuzz box which creates a lot of distortion before or after a phaser which filters out some of that distortion. So this was the inspiration to how I got my job at Melbourne University which was I went to Bell laboratories in New Jersey and I showed them a prototype of a computer modelling system for lasers. The prototype was little more than pieces of plastic on an overhead projector and I could lay these in different orders to illustrate that you could swap around the models which are the square blocks in order to model different types of laser.
07:53	For example the green bits are the laser itself but at the far end I have a mirror and that mirror acts like feedback to make the notes more pure. I moved to Melbourne University and we developed a computer software package called 'Opals' for simulating lasers. This had a graphical user interface (GUI) where you could move around icons on the computer screen and connect them in different orders. This is a model of a laser again. A tuneable laser and we are going to tune it through a series of notes when I press this button. (Sound plays).
08:42	And you can hear that that is tuning up through a series of cavity resonances just like can tune up the harmonics on a string on a guitar. We got lots and lots of customers for this. A lot of the telecommunications boom was powered by our software so people could design links that circumnavigated the world and really supported globalisation. More recently at Monash University I have been looking at different types of communication systems that can send more data through an optical fibre.
09:19	And again this is a 2015 idea. Quite a few people had this around the world simultaneously but my take on it was it was a musical problem. This is a recent example which uses a musical analogy of chords to send three data stream along an optical fibre. The trick is the receiver has to separate out the information at the end. Rather like when you are listening to music you can pick out the base guitar, the rhythm guitar and the lead guitar. And the reason you can do this is because each instrument has its set of the harmonics.
10:06	Now if you are a young guitar band and you only have one amplifier and everyone else comes to your garage and brings their instruments, often everyone plugs into the same amplifier and its sounds terrible and that's part of the inspiration for that technology here. I'll first show you the good example. This is where you are a rich band and you can afford your own amplifiers for the base guitarist, the rhythm guitarist and the lead guitarist.

Time	***Dialogue***
10:39	The thing about an amplifier is it distorts the sound. So does the speaker. Now that can be pleasant as long as there is one amplifier per instrument because the distortion is all harmonics, just like you normally get on a string. We can see that or hear that actually if I press the button here. [Sound plays]. It's quite a nice mellow sound. That's three instruments all through a lot of distortion but then added together.
11:13	However if you put all three instruments through one amplifier and distort them all altogether you get a far more complex and perhaps annoying sound. [Sound plays]. It's got a lot of higher frequencies and a lot of those higher frequencies aren't very musical. So in conclusion I'd like to say that the physics behind many things is very similar. In fact a lot of modern physics is based on vibrations and waves. The vibrations in a laser which is only say a millimetre long are the same sort of vibrations and equations that are in this guitar.
11:59	The feedback in the laser to make it more pure and to keep it going is rather similar to in this guitar. The signal processing that we use to make our guitar more interesting or tune our pitch correctly or perhaps to produce this video is very similar to the models within that computer program. So you can draw inspiration by making analogies between interesting things in the world like music and art and you can use physics to bridge through into something that is useful like designing new telecommunications systems that allow us to communicate more easily and effectively throughout the world.
12:49	There has been a few examples where I have pressed the button here to hear different sounds and if you look at my webpage down at the bottom there are some more that you can listen to. [https://eces.monash.edu/staff/lowery/Light_Rock.html] Thank you very much and I hope you liked my presentation.