IEEE Spark

IEEE

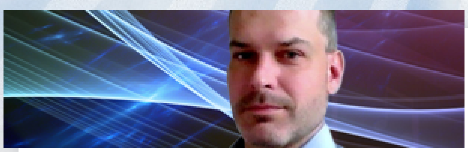
ENGINEERING INSIDE: MUSIC

2014, Issue 2

The Sweet Sounds of Engineering

June, 2014

Think of your favorite song. The steady beat, the crescendos, the layered vocals, the way the different pieces fade in and out perfectly. Behind every musical recording you hear is the work of many engineers.



Meet Alexander Lerch!

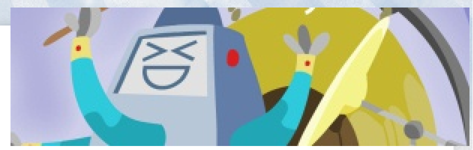
June, 2014

Alexander Lerch is Assistant Professor at the Georgia Tech Center for Music Technology. He works on the design of new digital signal processing algorithms for music analysis and synthesis. He is co-founder of the company zplane.development – a research-driven technology provider for the music industry.

Build Your Own Speakers

June, 2014

Speakers are in all sorts of objects you see and use every day—stereos, telephones, movie theaters, concert halls, iPods, and more. Speakers work by turning an electrical signal into a sound you can hear. In this activity, you can create your own speaker by creating an electromagnet and using a Styrofoam plate as your cone.



Techno Music

IEEE SPARK CHALLENGE

Think you know IEEE Spark? Test your knowledge of engineering, computing and technology with the IEEE Spark Challenge! Answer questions correctly to help your team move to the top of the leaderboard.

About IEEE Spark

IEEE Spark is an online publication intended to inspire students ages 14-18 to learn more about engineering, technology, and computing, and raise excitement about careers in these disciplines. *IEEE Spark* features articles on technological innovation, university preparation tips, professional career profiles, at-home activities, comics, and more! *IEEE Spark* is brought to you by IEEE with generous funding from the IEEE New Initiatives Committee.

About IEEE

IEEE is the world's largest professional association dedicated to advancing technological innovation and excellence for the benefit of humanity. IEEE and its members inspire a global community through IEEE's highly cited publications, conferences, technology standards, and professional and educational activities.

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The Sweet Sounds of Engineering

June, 2014
by Robin Hegg

Think of your favorite song. The steady beat, the crescendos, the layered vocals, the way the different pieces fade in and out perfectly.

Behind every musical recording you hear is the work of many engineers. Engineers research and develop new music technology and instruments, alter spaces to manipulate the behavior of sound waves, electronically alter audio signals when recording music or during live performances, and select and set up musical equipment to obtain the desired acoustic effects.

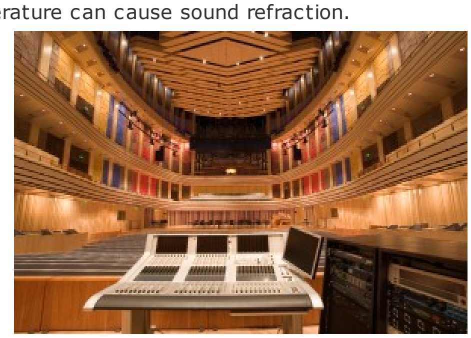
Sound is a vibration in the form of waves that move through a medium, like air or water. These waves enter the human ear and the brain perceives them as sound. Four basic behaviors of sound waves are absorption, reverberation, diffraction, and refraction.

Sound waves reflect off of surfaces just like light waves. Each time a sound wave reflects off a surface, some of its energy is lost. Absorption is the sound energy that goes through a material and is absorbed by it.

Reverberation is the sound that continues after the source of the sound stops, which is caused by repeated reflections off of surfaces. Reverberation is similar to an echo, but not the same. The perception of a sound usually lasts in a person's memory for only 0.1 second. With an echo, sound waves bounce off a surface distant enough that we notice a time delay between the original sound and the reflected sound. Reverberation, on the other hand, is perceived when the reflected sound wave reaches the listener's ear in less than 0.1 second. The original sound and the reflected sound tend to combine together into one fuller, drawn out sound, like what you might hear when singing in the shower.

Sound waves will also bend around obstacles in their path. This bending is called diffraction.

Changes in the medium through which sound waves travel can also cause sound waves to bend. This bending is called refraction. Changes in temperature can cause sound refraction.



In the field of architectural acoustics, engineers work to design a space that produces the best sound for its purposes, whether that be designing a concert hall with optimal acoustics or deadening a recording room from reverberation so the original sound waves are all that are picked up.

Audio engineers who work to record music use audio signal processing to control and adjust these natural sound wave behaviors in order to produce a desired sound. The goal can be to make the recorded music sound as if it was played in a world renowned concert hall, or to make the music sound futuristic and strange. Being an audio engineer involves both artistry and technical skill. Each decision an audio engineer makes effects the final sound, making their contribution a musical one as well as a technical one. Audio engineers also work to create music and sound for

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television, movies, and video games.

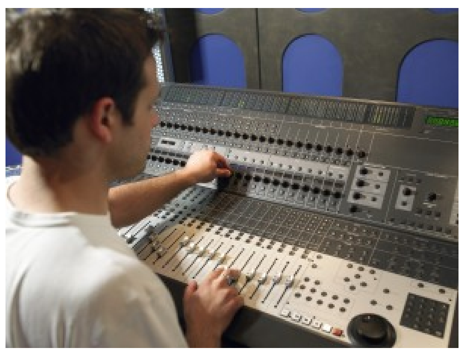
Recording music involves turning audible sound into electronic signals. Audio engineers can then work with these audio signals to create effects.

Time delay effects involve combining the original audio signal with a delayed version of the same signal. These can create the sound of reverberation a listener would hear in a concert hall. Flanger and phaser effects use continuous, variable delays that can make a wooshing or synthesized effect. A time delay can also be used to create the sound of a chorus of voices singing from one recorded voice. By adding a signal with a constant delay to the original signal, making sure the delay is longer than a flanging effect but short enough that it isn't perceived as an echo, the effect of a chorus of voices can be obtained. Adding a pitch shift to the altered signal can help as well.

A pitch shift effect shifts an audio signal's pitch up or down. This can be used to create harmonies from one voice by combining a shifted vocal signal with the original signal. It can also be used for pitch correction, shifting wrong notes to the correct pitch.

Audio engineers can also use a time stretching effect to adjust the speed of an audio signal without affecting the signal's pitch.

In post-production, audio engineers mix together multiple recorded tracks to create the final recording and use equalization and audio level compression to create the cleanest, most balanced finished product possible. Equalization involves boosting certain frequency bands to produce a desired sound, allowing the engineer to adjust the tone quality of a recording. Compression involves reducing the dynamic range (reducing the volume of loud sounds and amplifying quiet sounds) of a sound to avoid unintended fluctuations in volume.



Engineers use mathematical algorithms, computers, electronics, and mechanics to control, alter, and manipulate sound waves in order to create the music that reaches us through recordings and live performances. Acoustical engineering is a field of science and artistry that impacts the sound and music we hear every day.

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Meet Alexander Lerch!

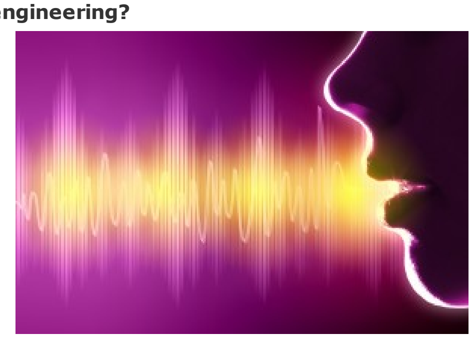
June, 2014

Alexander Lerch is Assistant Professor at the Georgia Tech Center for Music Technology. He works on the design of new digital signal processing algorithms for music analysis and synthesis. Lerch studied Electrical Engineering at the Technical University of Berlin and Tonmeister at the University of Arts Berlin and received his Diplom-Ingenieur degree and his PhD in 2000 and 2008, respectively. He is co-founder of the company zplane.development – a research-driven technology provider for the music industry. His book "An Introduction to Audio Content Analysis: Applications inSignal Processing and Music Informatics" has been published in 2012 by Wiley/ IEEE Press.

Were you interested in both music and engineering as a child? Did one lead to the other?

As a kid, my main interest was in making music. Computers (at that time it was not yet standard for every household let alone person to have one) held a certain fascination, and I wrote a few small programs at that time, but I wouldn't say I spent a lot of time at the computer. However, later in high school I started to ask questions that relate music to engineering: how do acoustic and electric instruments produce sound, and how can I record an instrument and get the sound I want, how do microphones and speakers work?

Why did you choose to study both music and engineering?



I started with Electrical Engineering mostly because at that time the EE programs offered the most advanced classes in acoustics and sound. But I have to admit I wasn't very happy with the focus of my undergraduate studies. I did fine but I was bored by the subjects taught and wanted to learn something more related to audio and sound. I decided to apply at the University of Arts for their Tonmeister-program. Tonmeister is a very specific German degree which is probably best translated with music producer – classes focus on music history, theory, performance, and ear training. But just when I started at the University of Arts the EE classes suddenly also became quite interesting with topics like signal processing, signal theory, and acoustics; I ended up studying at both universities simultaneously.

How has the interaction between music and engineering changed since you've started?

Technology was used to automate processes or to increase audio quality, and often was complicated to use correctly. Nowadays, engineers begin to teach computers to listen to and to understand music; the computer interacts with listeners and musicians on a musical and not on a technical level. It recommends music representing your current mood, it suggests the pitches for a vocal arrangement, it extracts a lead sheet from a recording, and it accompanies live performances, just to name a few examples.

What do you love about the combination of music and engineering?

USEFUL LINKS:

Technical University of Berlin
University of the Arts Berlin
zplane.development

EDUCATIONAL BACKGROUND:

PhD; Music Performance Analysis; Technical University of Berlin

Tonmeister; University of the Arts Berlin

Diplom-Ingenieur; Electrical engineering, Digital signal processing, Acoustics; Technical University of Berlin

ADVICE TO STUDENTS:

There are many ways of combining engineering and music…It should be relatively easy to find a program that fits your goals. But my main advice is: try to identify a career path that you feel passionate about.

It is great to work in interdisciplinary teams with musicians, developers, engineers, and others. It is great to design tools that musicians and producers can use to create new music.

What challenges do you face working in the field you are in?

One of the characteristics of music is that there is no absolute or objectively measurable scale of quality. What is the right sound? What is good music? Which music performance is better? What emotions are being evoked when you listen to specific songs? These are examples of things that are highly subjective and subject to change. To derive models that can be both general but also adapt to the individual user, and to evaluate these models in a meaningful way is challenging.

Over the last several decades, how we listen to music has changed considerably…from records to tape, to CDs to mp3 players, and digital distribution – what do you think will come next?

Listening habits have indeed changed; nowadays, we have access to any kind of music anytime and everywhere. What I hope to see in the future are more creative listening environments: What if you speed up and slow down music based on your work-out pace? What if you I like a song, but want to hear it with the drum track from another song? What if you, even without playing a musical instrument, could easily create a new and unique piece of music?

Can you share a little about the work you do and how you see the field changing over time?

I work on two facets of music technology: algorithms to change or produce music, and algorithms to analyze music. The first category encompasses audio effects and related processes. Examples are algorithms to create a whole chorus from one vocal recording, automatically correcting a singer’s wrong intonation, or to synchronize the tempo of two songs. The analysis of music – a research field that is referred to as Music Information Retrieval – aims at extracting information such as tempo, chords, and musical mood from the audio signal and to use this information for, e.g., music recommendation systems and intelligent music software in general.

Were there other career paths you thought about following? What impacted your decision?

It was always very clear to me that I wanted to work in a field that has at least a vague relation to music. In school I was very interested in musical acoustics and room acoustics. After university, I could have easily made the choice to be an audio engineer or music producer. But, and I know that sounds a bit geeky, the final decision to focus on signal processing and music technology in my career was because I found the work on music processing algorithms to be more creative and more fun.

What programs or activities would you recommend to pre-university students wanting to know more about how engineering and music interact?

Get your hands dirty. Play around with DJ software, digital audio workstations, and audio plugins on your computer. Make music, record it, and share it with your friends. If you are into programming, try out tools that let you create your own processors (Max/MSP, PD, Reaktor, etc.). If you are a hardened programmer already, consider developing your first audio plugin (e.g., a VST or AudioUnit). There are tutorials that can get you started with something simple such as a delay effect. You can explore the world of music technology and software on many different levels, and each level gives you plenty of creative options.

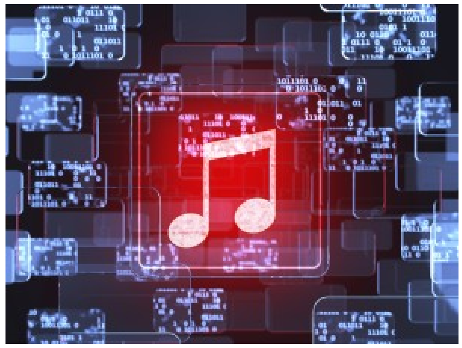
How long have you been a member of IEEE? What prompted you to join?

I have been a member of the IEEE since I was a graduate student. The main reason for joining IEEE was the possibility to get in touch and to interact with a huge international network of professionals.

What has been the most rewarding thing about your work?

It is terrific to see musicians and producers using the tools you helped developing and creating a musical work or sound effect that is new and unexpected. It is rewarding to see your algorithms used by millions of people worldwide, even if they don’t know you have been involved.

Can you share a story about how the work you do has impacted the world?



Creating tools for music production is fun and rewarding, but although music plays an important role in our everyday life, the impact on the world will only be indirect and hard to measure. But you can make a difference in related areas. One minor example: we looked into using our music analysis in language training and found that visualizing the pitch, the timbre, and the tempo of the students speech in comparison with the teachers, greatly improved the students' pronunciation and natural melody of speech compared to students with traditional learning methods.

What advice would you give a pre-university student who was interested in working in blending a career in engineering and music or entertainment?

There are many ways of combining engineering and music. To name a few examples: Mechanical Engineering might open your way to room acoustics, bio-acoustics, etc., Electrical Engineering can give you the fundamentals to develop new hardware and software for music production, and Audio Engineering teaches you how to produce a record. There is a growing number of Music Technology Bachelor and Master programs with varying focus – some target the creation of music with technology while others put more weight on the technological part. It should be relatively easy to find a program that fits your goals. But my main advice is: try to identify a career path that you feel passionate about.

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Build Your Own Speakers

June, 2014
by Robin Hegg

Speakers are in all sorts of objects you see and use every day—stereos, telephones, movie theaters, concert halls, iPods, and more. Speakers work by turning an electrical signal into a sound you can hear. Speakers contain an electromagnet (a magnetic coil that creates a magnetic field when electricity flows through it). An electromagnet's poles can be reversed depending on the direction of the current in the coil. In a speaker, the electromagnet is placed next to a (regular) permanent magnet. As electricity flows through the coil of the electromagnet, its poles change rapidly, alternately attracting it to and repelling it from the permanent magnet, causing it to vibrate back and forth. A cone is attached to the magnets that amplifies the vibrations, sending sound waves into the air.

Activity #1: Make Your Own Speaker With a Styrofoam Plate

In this activity, you can create your own speaker by creating an electromagnet and using a Styrofoam plate as your cone. Please have an adult help you when attaching wires and plugging in your speaker.

If you have trouble finding the materials for this activity, a second, simpler activity (Paper Cup iPhone "Speakers") is available at the bottom of the page.

Materials

- Two strips of paper, ½" x 11" each
- Neodymium magnets, small, enough to create a small cylinder
- Flat square of cardboard, larger than the plate
- Audio plug
- Glue
- Tape
- 2 business cards
- Copper wire, 32-gauge, enameled
- Styrofoam plate
- Ruler
- Scissors
- Wire cutter/stripper

Steps:

1. Roll one strip of paper lengthwise into a coil around the magnet and tape the roll of paper closed.
2. Roll the second strip of paper around the first one and tape it closed as well. One roll of paper should sit snugly inside the other, but they shouldn't be attached.
3. Remove the magnet from the rolls of paper.
4. Glue the paper cylinders onto the back of the plate, positioning them right in the center. Once the glue has dried, put the magnet back inside the cylinders.
5. Leaving some extra wire length at each end, wind the wire around the cylinder about 50 times. When you've finished winding the wire, secure the wire coil with tape.

DID YOU KNOW?

1. The first commercial loudspeakers were made available by RCA in the 1920s.
2. The call of the blue whale can reach 188 decibels, which is louder than a jet engine.
3. The European Space Agency uses a massive 154 decibel speaker to test how satellites can withstand atmospheric noise.

FIND OUT MORE:

You can also visit **TryEngineering.org** to explore other engineering activities and resources. Additional activities and lessons can be found **here**.

6. Remove the magnet from the cylinders. Then remove the inner paper cylinder. It's okay if the inner cylinder tears, but it's important not to damage the outer cylinder.
7. Fold the two business cards accordion-style widthwise, creating W shapes.
8. Glue one end of each business card to the back of the plate so the cards are parallel to one another and stick up on either side of the cylinder.
9. Return the magnet to the cylinder.
10. Put some glue on the ends of each business card. Place a little glue on the magnet as well, making sure it's not enough to touch the inside of the cylinder.
11. Position your piece of cardboard on top of the speaker, with the plate underneath. The cardboard will serve as your speaker's base. Flip everything over so the cardboard base is on the bottom and the plate is facing up. The magnet should fall down and glue itself onto the cardboard base. Push the glued ends of the business cards onto the cardboard to help support the plate and the cylinder. You want the cylinder to hover around the top of the magnet.
12. Make sure the two wire ends of the coil are separated and aren't touching anything.
13. Cut and strip the wires from the audio plug and connect them to the coil.
14. Allow all the glue on your speaker to dry.
15. Your speaker is ready to use! You can plug it into your mp3 player, computer, or phone and give it a listen.

Troubleshooting

Make sure the business cards are parallel. You can try gluing them closer to or farther from the coil until you find the distance that produces the best sound.

Check that the coil is tight and secure and that nothing is touching the loose ends of the wire.

Make sure the business cards are glued on completely and that they are the only things touching the foam plate.

The coil shouldn't touch the magnet or the base of the speaker. If it does, try making the coil wider or fold the cards more loosely so they hold the speaker further from the base.

Activity #2: Paper Cup iPhone "Speakers"

This activity creates a "speaker" system for your iPhone or iPod. The "speaker" works by using the cone shape of plastic cups like an acoustic horn (or megaphone) to amplify the sound coming from your phone's speakers.

Materials:

Two plastic cups

Paper towel roll

Scissors

Pen or pencil

Steps:

1. Use the scissors to cut three sides of rectangular hole in the paper towel roll for your iPhone to fit into. Leave one of the long sides attached so that the flap can support the back of your phone.
2. Using the ends of the paper towel roll, trace circles on the sides of the cups using a pencil or pen. Cut the circles out of the cups, creating two paper towel roll-sized holes.
3. Insert the paper towel roll into the cups.
4. Place your iPhone into the slot you cut in the paper towel roll and press play. Listen to the sound come through your "speakers"!

Questions:

1. Why do you think the cone shape of speaker cones (like the Styrofoam plate or the plastic cups) matters in speakers?
2. Do you think the material your cone was made of makes a difference in the sound that's produced? Why or why not?
3. In the Styrofoam plate activity, why do you think it was so important that the paper cylinder hover above the magnet and not touch the base of the speaker?

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Mix New Music Online!

June, 2014
by Robin Hegg

ToneBender is a collaborative online game from the Music Entertainment Technology Laboratory (MET-lab) at Drexel University that allows players to adjust the timbre of musical instrument sounds by modifying the sound's amplitude and overtones. Players can either create new sounds based on real instruments or test their ability to recognize the original instrument by listening to other players' altered sounds.

Dot Mixer from the Exploratorium in San Francisco lets users play around with "mixing" like audio engineers do in post-production. "Mixing" involves electronically adjusting and combining sounds from more than one source into a single piece of music. The Dot Mixer lets you adjust the volume and timing of different tracks to create your own unique song.

Notessimo is an online music composition program that allows users to create music electronically by simply dragging instruments they choose onto a musical staff. There are hundreds of instruments to choose from. Users can make a note flat or sharp, decide how many beats the note should be held, and adjust the song's tempo. Users can even save their compositions within the program and share them with others.

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How IEEE Makes Music Better

June, 2014
by Robin Hegg

IEEE members across disciplines research and develop music, music technology, computer programs, and more, all of which lead to our being able to understand music better and do more with it.

The very first IEEE society to be founded is the **Signal Processing Society**. The Signal Processing Society supports research and development among signal processing professionals. Signal processing is the technology that enables information to be generated, transformed, and interpreted. Signals (information) can take many forms, including audio, music, speech, and language. Audio engineers are able to electronically manipulate audio signals by developing algorithms to process them. These algorithms are what allow them to use make changes to recorded tracks, like adding reverberation or Auto-Tuning vocals.

In 2009, IEEE 1599 became a new standard to encode music with XML symbols. Using these symbols allows them to be read by both machines and humans. IEEE 1599 also introduced the use of layers, allowing all aspects of musical information to be accessed individually and as parts of a whole. The information encoded in music can include audio and sound, graphics, historical data, and performance information.

IEEE has three music-related journals, which publish research about music, music technology, psychoacoustics, algorithms, computer science, and more: **IEEE Multimedia Magazine**, **IEEE Signal Processing Magazine,** and **IEEE Transactions on Audio, Speech and Language Processing**.

One of IEEE's top members working with audio and music was Amar G. Bose. In 1972, IEEE named Amar G. Bose an IEEE Fellow for "contributions to loudspeaker design, two-state amplifier-modulators, and nonlinear systems."

Bose started out repairing model trains and home radios for money as a teenager. He attended MIT for his bachelor's degree, became a Fulbright Scholar at the National Physical Laboratory in New Delhi, then returned to MIT for his PhD in electrical engineering.

An electrical and sound engineer, Bose found himself disappointed with the quality of the high-end stereo equipment that was available and set out to design equipment that would give the listener a more lifelike experience. Having learned that in a concert hall 80 percent of sound reached the listener indirectly (by bouncing off walls and ceilings rather than traveling directly to the ear), he set out to replicate the experience of listening to live music. He invented the Bose 901 Direct/Reflecting speaker system, which was one of the first to use the space around a room and remained an industry standard for 25 years.

Bose founded Bose, Corp., which is famous for its speakers and noise-canceling headphones. The company has been able to funnel most of its money into long-term research in acoustical engineering. At age 68, Bose held more than two dozen patents. His products are used in theaters, Olympic stadiums, and even the Sistine Chapel. His noise cancellation system was even used in space shuttles to protect astronauts' hearing from permanent damage, and is used by

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military and commercial pilots to cancel out noise from airplanes.

Bose also donated to the IEEE Foundation, IEEE's philanthropic foundation.

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IEEE Spark Challenge: Music

Think you know IEEE Spark? Test your knowledge of engineering, computing and technology with the IEEE Spark Challenge!

1) The first commercially available electric guitar was nicknamed:
    a. Lucille
    b. Muddywood
    c. The Frying Pan
    d. The Duck

2) What was the title of the first song ever recorded?
    a. Der Handschuh - 1889
    b. Mary Had a Little Lamb – 1878
    c. Daisy Bell - 1892
    d. Au Clair de la Lune – 1860

3) Frequency, or measurement of a sound wave's repetition rate is measured in:
    a. Hertz
    b. Phons
    c. Decibels
    d. Sones

4) The first portable Mp3 player was known as the:
    a. Rio PMP300 by Diamond Multimedia
    b. MPMan by Saehan Information Systems
    c. Ipod by Apple
    d. CW100 by Cowon Systems

5) Who developed the first commercially successful radio transmission system?
    a. Guglielmo Marconi
    b. Jagadish Chandra Bose
    c. David E. Hughes
    d. Roberto Landell de Moura

6) The decibel, or unit used to measure the intensity of a sound is named after:
    a. Thomas Edison
    b. Albert Einstein
    c. Emile Berliner
    d. Alexander Graham Bell

7) A type of microphone used for music recording that works using electromagnetic induction is known as:
    a. Fiber optic microphone
    b. MEMS microphone
    c. Dynamic microphone
    d. Electret microphone

8) Electronic pianos create sounds using a type of circuit known as an electronic oscillator.
    a. True
    b. False

9) MIDI the, standard for interconnecting electronic musical instruments and computers stands for:

    a. Memory infinite data interpreter
    b. Music instrument digital interface
    c. Melody interchanging dynamic invention
    d. Minor interval discrete instrumentation

10) Speakers transform ___________________ into _________________.
    a. Audible signals; electronic signals
    b. Quantum signals; discrete signals
    c. Digital signals; analog signals
    d. Electronic signals; audible signals

IEEE Spark Challenge: Music Answer Key

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