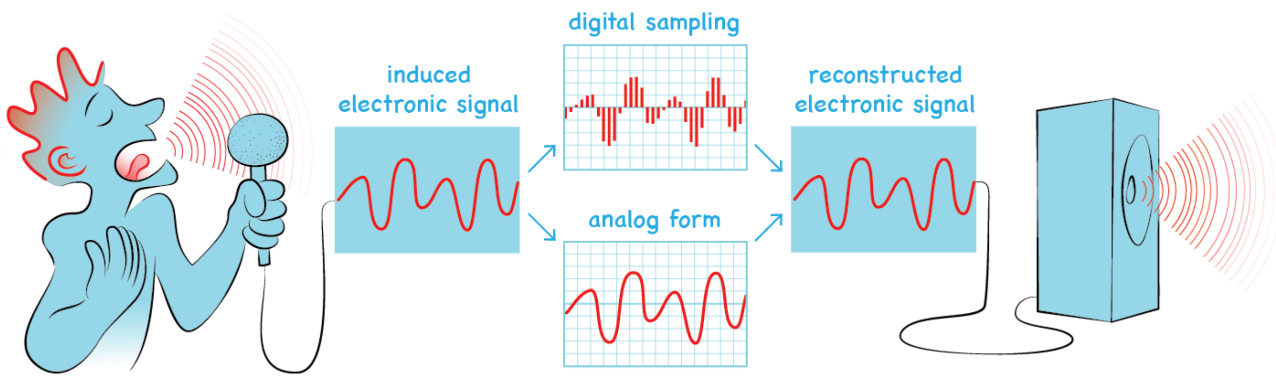
Teacher Tune-up

Quick Content Refresher for Busy Professionals

How are digital signals a more reliable way to encode and transmit information than analog signals?



The Next Generation Science Standards call for middle school students to gain some basic understanding of how waves can be used to transmit information, and in particular to understand why “digitized signals are a more reliable way to encode and transmit information than analog signals” (NGSS performance expectation MS-PS4-3).

Whether they realize it or not, students manipulate the flow of energy in waves all the time to convey information. We’ve all done so since we uttered our first words—or before that, since our first cry of distress or delight. When we talk, our vocal cords send vibrations through the air, forming spoken language.

Over a century ago, people figured out how to store and transmit such sounds using electric telephone wires, broadcast radio waves, phonograph recordings, etc. Later, when digital options for recording and transmitting sound were developed, people started referring to the earlier methods collectively as “analog,” because they work by converting vibrations in the air into similar—or analogous—variations in some other medium. For storage, the variation might be in the pattern of the spiral groove on a vinyl disk, or variations in magnetization on a strip of magnetic tape. For transmission, variations in electrical current (through wires) or in electromagnetic waves (through the air or fiber optic cables) parallel the variations of the sound waves to be reconstituted by a receiver or player.

Digital recording and transmission works quite differently. Instead of relying on some physical analogy between sound and the medium of storage or transmission, digital technology uses essentially arbitrary (non-analogous) code. This code is called digital because it represents sound as a series of digits, i.e. numbers. Computers use binary code, with only two code characters (0 and 1), grouping them together to represent all sorts of information—numbers, alphabets, computer instructions, images, and yes, sound.

Is analog or digital better?

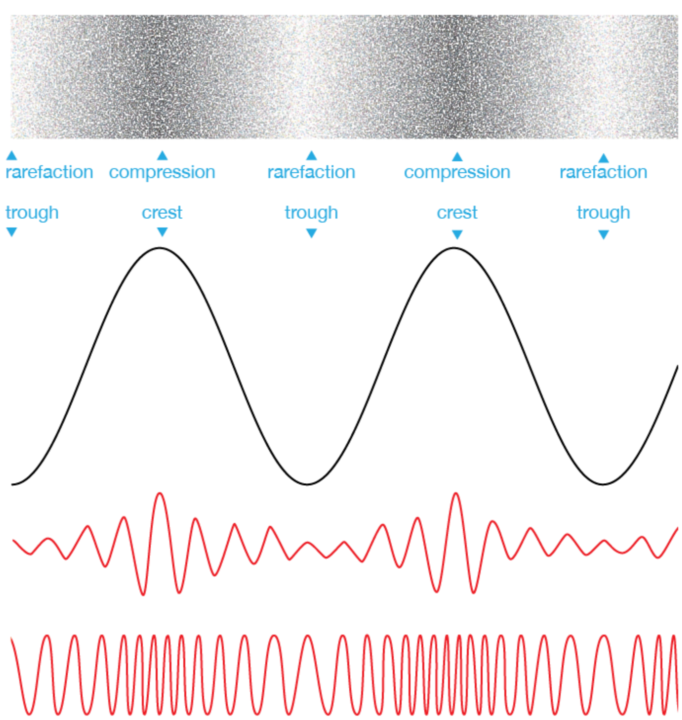
Each approach has its advantages and advocates. Vinyl records, for example, have made a comeback among fans who enjoy the romance of vinyl, and who sometimes insist that the warmth and slight hiss of analog sound gives it its own special presence. There can be an added enjoyment to knowing that the sound you are listening to is a kind of sonic thumbprint, a direct physical impression of what live musicians did, recorded and transmitted by the ingenious means people developed before digitization became routine.

On the other hand, the code used in digital methods has great advantages in storing, preserving, and distributing information. Whereas vinyl records are easily scratched, directly and permanently changing the sound you can extract from them, a digital recording is as faithful as its pattern of 1s and 0s. (CDs can be scratched too, and hard drives can be corrupted, losing information; but with suitable backup, digital storage offers a different kind of permanence than analog storage.)

Everyone has heard garbled digital sound and seen fuzzy digital images, but the quality and exactitude of digital information has no theoretical limit: advancing technology offers sampling at ever higher rates and ever finer levels of distinction, and at some point improvements in quality disappear beyond the threshold of human perception. High-speed computers handle giant data files easily, especially because sophisticated mathematical algorithms analyze and compress data while minimizing or eliminating loss of quality. Many people feel that with digital, you can have it all—everything analog methods can store and transmit, and then some.

Are electromagnetic waves analog or digital?

When it comes to electromagnetic signals, the messenger is analog, but the message can be analog or digital. The physical transmission of electromagnetic radiation, such as a radio wave or microwave, is always an analog process, regardless of whether it carries a digital message, an analog message, or no message. Whether we call such a transmission “digital” or not depends on how the information is structured and interpreted. If the amplitude modulation (AM) or frequency modulation (FM) of an electromagnetic signal is analogous to the pattern of the recorded sound waves, and reproduces those sound waves by directly manipulating the electrical signal fed to a loudspeaker, then the transmission is analog.



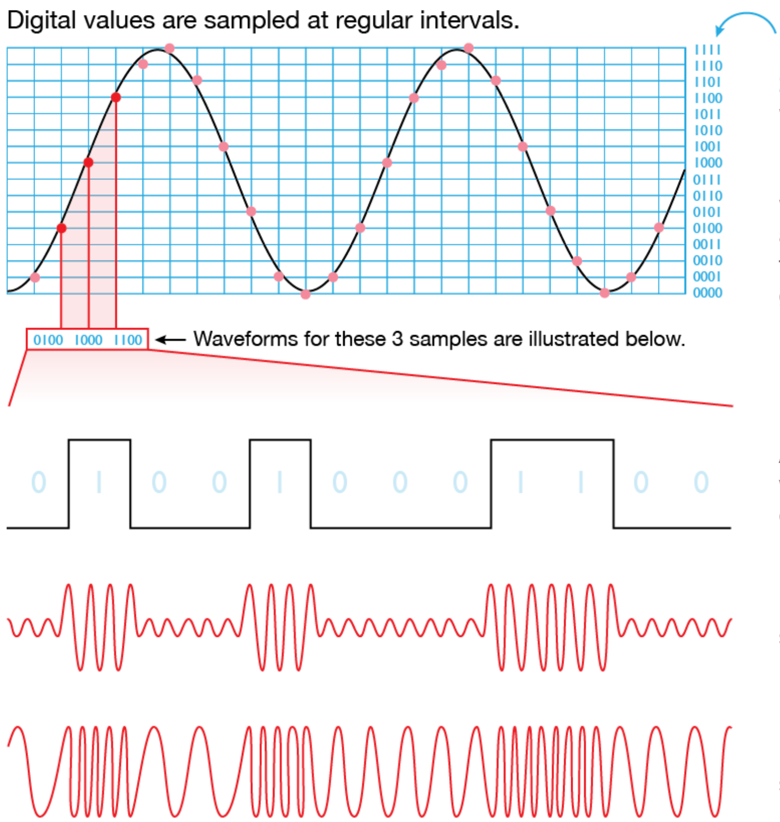
Sound waves are particulate compression waves. As waves pass through air, molecules in the air move back and forth, repeatedly striking each other and rebounding. (Both wave and particle motion are horizontal in this representation.)

Abstract representation of sound signal in transverse form. When you “see” sound waves llike this on an oscillosope, you are actually seeing the graph of a sound-induced variation in electrical voltage (vertical) against time (horizontal). This analog electrical current is the raw material for both analog and digital processing.

Electromagnetic wave carrying **analog** signal via **amplitude modulation (AM)**.

Electromagnetic wave carrying **analog** signal via **frequency modulation (FM)**.

But if an AM or (more commonly) FM electromagnetic signal transmits a code of 1s and 0s that are then interpreted by a computer and reconstituted as sound (or images, words, etc.), then the transmission is digital.



Note that 4 bits (4 binary digits) give $2^4 = 16$ values. At the crests of this wave, you can see how the information has to be rounded to the nearest codable value. More bits would give finer distinctions of value, and, in combination with more frequent sampling, would allow greater fidelity to the original information.

Abstract representation of digital waveform to be imposed on an electromagnetic transmission.

Electromagnetic wave carrying **digital** signal via **amplitude modulation (AM)**.

Electromagnetic wave carrying **digital** signal via **frequency modulation (FM)**.

How is digital music made and transmitted?

A song that is digitally recorded and then distributed online typically goes through the following sequence of transformations and quality checks.

1. The vocal cords of the singer vibrate, making sound waves that travel to a microphone.
2. The sound waves cause a thin diaphragm in the microphone to vibrate, and this mechanical motion induces an analogous pattern of electrical resistance in the microphone.
3. The microphone resistance is measured 40,000 times each second to form a computer file with millions of numerical values (typically called a WAV file).
4. The numerical values are changed into a shorter form by the MP3 compression method; this compressed form of the song is stored on a "server" computer that will eventually send it to the "client" computers of people who request the song.
5. When the server receives a request for the song from a client, the server divides the MP3 file into packets of several hundred numbers. Each packet has a unique ID number and a "checksum" (a special error-detection code computed and added to the end of the packet—sort of like a packing slip that might accompany a physical shipment).

6. The packets are sent to the client computer.

7. The client computer examines the packet, recalculates the checksum, and compares its own result to the checksum the server sent with the packet. If the client and server checksums do not match for some packet, the client requests that the server resend that packet. This process goes on—extremely quickly!—until the checksums match, verifying the fidelity of the transmission.

8. When valid copies of all the packets have been received, the client computer changes the compressed MP3 numbers back into the WAV-format sequence of 40,000 numbers per second.

9. The uncompressed numbers are used to change the voltage on an electrical circuit so that its wave pattern closely matches that of the original microphone.

10. The circuit is used to shake the diaphragm on a speaker, generating sound waves that closely match those produced by the singer.

11. The sound waves reach the ears of the listener.

Because of the error-detection process, the sound will not contain noise like the static that is common on AM radio. Similar methods are used to send images (including video) via infrared light over optical cables, Wi-Fi radio networks, and in cell phone messages.