Analog and digital

Back in the late 1970s, one of the most exciting things you could own was a **digital** watch. Instead of trying to figure out the time from slowly rotating hands, as you had to do with an old-style **analog** watch, you simply read the numbers off a digital display. Since then, we've got more used to the idea of digital technology. Now pretty much everything seems to be digital, from television and radio to music players, cameras, cellphones, and even books. What's the difference between analog and digital technology? Which is best? Let's take a closer look!

Photo: Analog and digital technology: Above/left: This elegant Swiss watch shows the time with hands moving round a dial. Below/right: Large digital clocks are quick and easy for runners to read. Photo by Jhi L. Scott courtesy of US Navy.

What is analog technology?

People accept digital things easily enough, often by thinking of them as electronic, computerized, and perhaps not even worth trying to understand. But the concept of analog technology often seems more baffling—especially when people try to explain it in pages like this! So what's it all about?

What does analog actually mean?

If you have an analog watch, it tells the time with hands that sweep around a dial: the position of the hands is a *measurement* of the time. How much the hands move is directly related to what time it is. So if the hour hand sweeps across two segments of the dial, it's showing that twice as much time has elapsed compared to if it had moved only one segment. That sounds incredibly obvious, but it's much more subtle than it first seems. The point is that the hand's movements over the dial are a way of *representing* passing time. It's not the same thing as time itself: it's a representation or an **analogy** of time. The same is true when you measure something with a ruler. If you measure the length of your finger and mark it on the surface of a wooden ruler, that little strip of wood or plastic you're looking at (a small segment of the ruler) is the same length as your finger. It isn't your finger, of course—it's a representation of your finger: another analogy. That's really what the term analog means.

Photo: This dial thermometer shows temperature with a pointer and dial. If you prefer a more subtle definition, it uses its pointer to show a representation (or analogy) of the temperature on the dial.

Analog measurements

Until computers started to dominate science and technology in the early decades of the 20th century, virtually every measuring instrument was analog. If you wanted to measure an electric current, you did it with a moving-coil meter that had a little pointer moving over a dial. The more the pointer moved up the dial, the higher the current in your circuit. The pointer was an analogy of the current. All kinds of other measuring devices worked in a similar way, from weighing machines and speedometers to sound-level meters and seismographs (earthquake-plotting machines).

Analog information

However, analog technology isn't just about measuring things or using dials and pointers. When we say something is analog, we often simply mean that it's not digital: the job it does, or the information it handles, doesn't involve processing numbers electronically. An old-style film camera is sometimes referred to as example of analog technology. You capture an image on a piece of transparent plastic "film" coated with silver-based chemicals, which react to light. When the film is developed (chemically processed in a lab), it's used to print a representation of the scene you photographed. In other words, the picture you get is an *analogy* of the scene you wanted to record. The same is true of recording sounds with an old-fashioned cassette recorder. The recording you make is a collection of magnetized areas on a long reel of plastic tape. Together, they represent an *analogy* of the sounds you originally heard.

What is digital technology?

Digital is entirely different. Instead of storing words, pictures, and sounds as representations on things like plastic film or magnetic tape, we first convert the information into numbers (digits) and display or store the numbers instead.

Digital measurements

Photo: A small LCD display on a pocket calculator. Most digital devices now use LCD displays like this, which are cheap to manufacture and easy to read.

Many scientific instruments now measure things digitally (automatically showing readings on LCD displays) instead of using analog pointers and dials. Thermometers, blood-pressure meters, multimeters (for measuring electric current and voltage), and bathroom scales are just a few of the common measuring devices that are now likely to give you an instant digital reading. Digital displays are generally quicker and easier to read than analog ones; whether they're more accurate depends on how the measurement is actually made and displayed.

Digital information

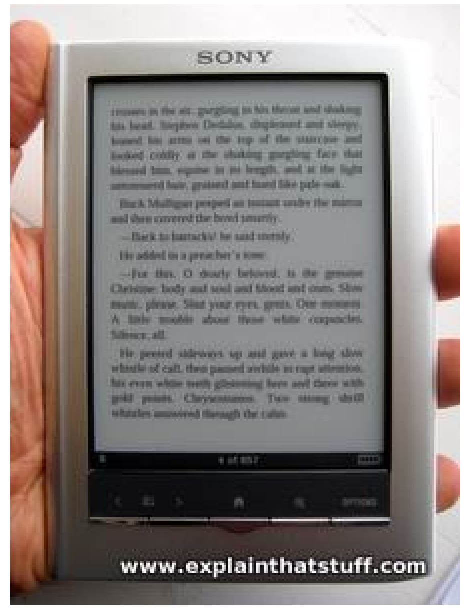


Photo: Ebooks owe their advantages to digital technology: they can store the equivalent of thousands of paper books in a thin electronic device that fits in your book. Not only that, they can download digital books from the Internet, which saves an analog trek to your local bookstore or library!

All kinds of everyday technology also works using digital rather than analog technology. Cellphones, for example, transmit and receive calls by converting the sounds of a person's voice into numbers and then sending the numbers from one place to another in the form of radio waves. Used this way, digital technology has many advantages. It's easier to store information in digital form and it generally takes up less room. You'll need several shelves to store 400 vinyl, analog LP records, but with an MP3 player you can put the same amount of music in your pocket! Electronic book (ebook) readers are similar: typically, they can store a couple of thousand books—around 50 shelves worth—in a space smaller than a single paperback! Digital information is generally more secure: cellphone conversations are encrypted before transmission—something easy to do when information is in numeric form to begin with. You can also edit and play about with digital information very easily. Few of us are talented enough to redraw a picture by Rembrandt or Leonardo in a slightly different style. But anyone can edit a photo (in digital form) in a computer graphics program, which works by manipulating the numbers that *represent* the image rather than the image itself.

Which is better, analog or digital?

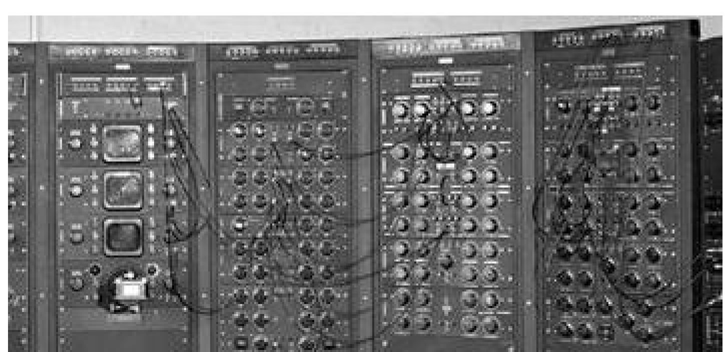


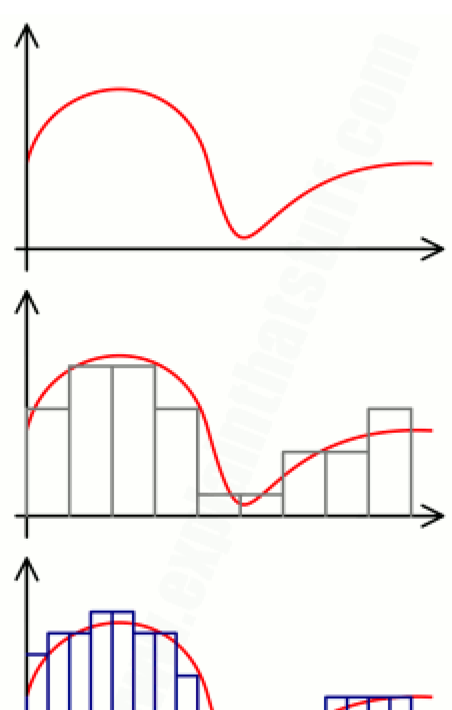
Photo: An early analog computer from 1949: machines like this represented numbers with analog dials, levers, belts, and gears rather than (digital) numbers stored in electronic memories. Picture courtesy of NASA on the Commons.

Just because digital technology has advantages, that doesn't mean it's always better than analog. An analog watch might be far more accurate than a digital one if it uses a high-precision movement (gears and springs) to measure time passing, and if it has a sweeping second hand it will represent the time more precisely than a digital watch whose display shows only hours and minutes. Surprisingly, analog watches can also keep time better than quartz ones: the day-to-day variations in a mechanical, analog watch tend to cancel one another out, while those in an electronic quartz watch tend to compound one another (here's why). Generally, the most expensive watches in the world are analog ones (of course, that's partly because people prefer the way they look), though the world's most accurate atomic clocks show time with digital displays.

One interesting question is whether information stored in digital form will last as long as analog information. Museums still have paper documents (and ones written on clay or stone) that are thousands of years old, but no-one has the first email or cellphone conversation. Open any book on the history of photography and you'll see reproductions of early photos taken by Niepce, Daguerre, and Fox-Talbot. But you won't see any pictures of the first digital photo: even though it was much more recent, probably no-one knows what it was or who took it! Lots of people own and cherish plastic LP records that are decades old, but no-one attaches the same importance to disposable MP3 music files. A lot of information recorded on early computer memory devices is completely impossible to read with newer computers; even floppy disks, commonplace as recently as the mid-1990s, are impossible to read on modern computers that no longer have built-in floppy drives.

That's why, though the future may be digital, analog technology will always have its place!

What is sampling?



It's easy to convert analog information into digital: you do it every time you make a digital photo, record sound on your computer, or speak over a cellphone. The process is called **analog-to-digital conversion (ADC)** or, more informally, **sampling**. Sampling simply means "measuring at regular intervals"—and it's easiest to understand with an example.

Let's suppose I'm talking to you on my cellphone. The sound of my voice is really waves of energy that travel through the air to the phone's microphone, which converts them into electrical signals. The sound waves and the signals are both continuously varying waveforms—they're analog information— and they look like the upper graph in the diagram.

Artwork: Top: A crude analog sound wave. Middle: A low sampling rate produces a crude digital approximation to the original wave. Bottom: Doubling the sampling rate produces a more accurate digital version of the wave, but generates twice as much digital information (data) that we need to store and transmit.

A cellphone transmits sound in digital form, so those analog waves need to be converted into numbers. How does that happen? A circuit inside the phone called an analog to digital converter measures the size of the waves many times each second and stores each measurement as a number. You can see in the middle figure that I've turned the first graph into a very approximate bar chart. If each bar represents one second of time, we can represent this chart by nine numbers (one number for the height of each bar): 5-7-7-5-1-1-3-3-5. So by sampling (measuring) the sound wave once per second, we've successfully turned our analog sound wave into digital information. We could send those numbers through the air as radio waves to another phone, which would run the process in reverse and turn the numbers back into sound we could hear.

But do you see the problem? Some information is going to get lost in the process of converting the sound to digital and back again, because the measurement I've made doesn't precisely capture the shape of the original wave: it's only a crude approximation. What can I do about this? I could make *more measurements*, by measuring the sound wave twice as often. That means doubling what's called the **sampling rate**. Now, as you can see in the bottom chart, I get twice as many measurements and my sound wave is represented by eighteen numbers: 6-7-7-8-8-7-7-5-2-1-1-2-3-3-4-4-4-4. The more I increase the sampling rate, the more accurate my digital representation of the sound becomes—but the more digital information I create and the more space I need to store it.

Sampling rate and bit rate

When you download digital music, you might be given the option of downloading the same track at what are called different **bit rates**. Broadly speaking, the bit rate is the amount of information captured each time the music is sampled. So a higher bit rate means more information is captured and the analog information is turned into digital information more accurately. Higher-quality music tracks may have a higher bit rate, but the tracks will take up far more space on your computer and take longer to download.

Typically, music is digitally converted for CDs and MP3 tracks with a sampling rate of 44.1kHz (about 44,000 times per second). Why such a high rate? For technical reasons that I won't go into here, the sampling rate needs to be about twice the highest frequency of sound in your wave, and since human hearing is limited to about 20kHz, that suggests we need a sampling rate of at least 40kHz. The typical bit rate for MP3 tracks is around 128kbps (128,000 binary digits or bits per second), though higher quality tracks have a bit rate between 128kbps and 256kbps (up to 256,000 bits per second).