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Shedding Light on Communications

Nanette Halliburton

Courtesy of Nanette Halliburton

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If you've ever sent an e-mail, you've experienced the "magic" that happens when you click "send." Your message zips away and may travel hundreds or even thousands of miles in a few minutes to show up in your friend's inbox. Of course, it's hardly magical. You already know that information can travel as sound, as radio waves, and through wires as an electrical signal. Today, a relatively new technology can use light to transmit information over distances. Yes, visible light—the colors of the rainbow! In fact, most e-mails travel encoded as a light signal for some portion of their journey.

Before I explain why light is such a popular way to move information around, let me tell you a bit about myself. My name is Nanette Halliburton, and, as a test engineer with Cisco Systems, Inc., I evaluate the equipment that converts encoded analog and digital signals into light signals.

I've always had a passion for technical subjects. When I was young, I used to follow my uncle around while he worked. He liked to fix cars and tinker with things. Because I had small hands, he was always asking me to reach into places where his hands didn't fit. I was curious and inquisitive, always asking questions about how things worked. I was a willing student as my uncle explained the inner workings of a carburetor or an air conditioner. Each new machine that he worked on was like a puzzle, and I asked questions until I understood how the pieces fit together. I found it fascinating how the laws of physics applied to the tools and machines that we use every day. I still do.

Because of my interest in technology, I decided to go to a specialized high school in New York City, the Murray Bergtraum High School for Business Careers, where I studied computer science. After graduation, I applied to a very competitive engineering program at Syracuse University in New York, but I was only accepted into their Liberal Arts program. I was disappointed, but I decided not to let that stop me. At Syracuse, I took every computer and electronics course that the engineering majors took. Hard work paid off. I eventually was accepted into the engineering program and finished my degree in electrical engineering.

The Long Haul

At Cisco, my department develops and manufactures long-haul equipment—devices that transmit data in the form of light over long distances. Using fiber-optic cables, our equipment transmits light signals for thousands of miles, even across the ocean floor. But the signal must be regenerated every so often. After 50 or 60 miles, the light signal is amplified and retransmitted using an optical regenerator.

Typically, these long-haul cable lines run between major cities—from New York to Washington, D.C., for instance. Cisco installs these systems for telephone companies all over the country. Every day fiber-optic cable is replacing good ol' copper telephone lines for sending data over long distances.

Why use fiber-optic cable instead of copper wire? Each phone line consists of a bundle of wires, and each wire carries different signals. Telephones transmit encoded signals using an electrical current and, as you know, any time you run current through a wire, it creates a magnetic field around the wire.

The magnetic fields created by these wire bundles may interfere with the signals traveling in the wires. This interference, called ***noise,*** can garble words and cause hissing and static. Due to this noise, the electrical signal must be regenerated every mile or so along the wire. Fiber optics eliminate this noise, improving the clarity of the signal.

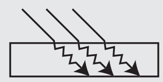
Noise is anything that interferes with the clarity of a message.

Bouncing off the Walls

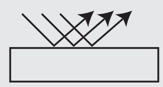
So how do we get light to travel through a cable? Thanks to the basic physics of how light travels, it's not nearly as complicated as it sounds. As a small part of the electromagnetic spectrum, visible light moves at a very high speed, around 300,000 kilometers, or 186,000 miles, per second in a vacuum. Light slows down in denser mediums such as our atmosphere and travels a little slower in water.

Light radiates in all directions until it strikes an object, where it can be absorbed, reflected, or refracted. An object that ***absorbs*** light heats up. A blacktop road gets very hot because much of the light energy from the sun is transferred to the road. When light bounces off objects, we see the color that the object ***reflects.*** Different materials reflect different frequencies of the visible light spectrum. A red apple reflects light in the red frequency, while a green apple reflects light in the green frequency. Each object absorbs the other light frequencies that are not seen. The black road appears black because it absorbs all of the visible light that hits it, reflecting no color at all. On the contrary, a page of white paper reflects all frequencies of visible light and therefore appears white.

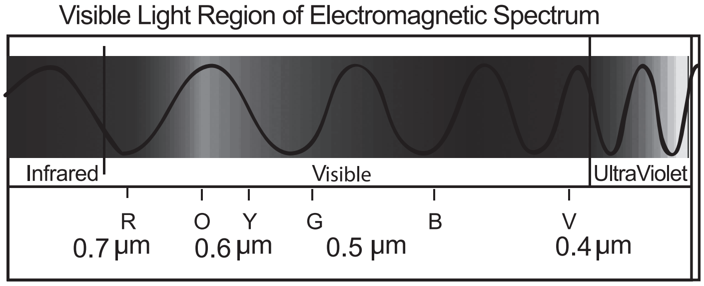
During ***absorption*** the energy of a light wave is transferred to and heats up an object.



During ***reflection*** the energy of a light wave bounces off an object.



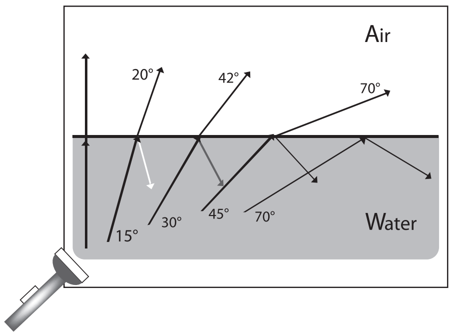
Visible Light Region of Electromagnetic Spectrum



> ***Refraction***
> is when light traveling in one medium passes into another and bends at the intersection of the two materials.

During ***refraction,*** light passes from one medium into another. Imagine shining a flashlight into a tub of water in a dark room. The light beam travels through the air into the water. The refracted light bends as it moves from the air into the denser water, because the speed of light decreases slightly. The amount that the light bends is called the angle of refraction.

Now imagine a light being directed through water to the air. Water is denser than air. As the angle of the light beam gets closer to being parallel to the surface of the air, you'll find that, at a certain angle, the light does not enter the air but reflects back. When the angle of the light is large enough to bend all the light back into the water, it is called ***total internal reflection.*** The minimum angle for total internal reflection is called the critical angle. The critical angle is 48.6 degrees for light passing from water to air.

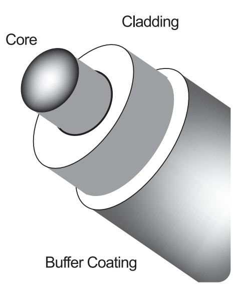


Refraction occurs because the speed of light in one material is different than the speed of light in the second. You can see that as the light-beam angle becomes greater, more light is reflected instead of refracted. Past a certain critical angle, all of the light is reflected. To have a critical angle, light must pass from a denser medium to less dense medium. There is a critical angle for water to air but not for air to water.

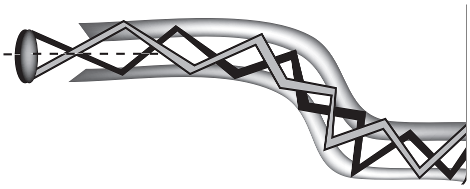
An optical fiber takes advantage of this property. A cable is a bundle of individual fibers, or long, thin strands of glass. A single fiber is no thicker than a human hair, which measures, on average, about 80 microns, or 0.000080 meters. The solid glass fiber is called the core, which is coated with a glass material called cladding.

When a light beam is flashed at one end of the fiber, the light enters the fiber and angles toward all the sides of the tubing. When the light hits the cladding, it is reflected. Because the speed of light in the fiber is significantly different from the speed of light in the cladding, total internal reflection occurs and the light is directed right back into the core. The cladding acts like a mirror, reflecting the light back toward the center of the core, keeping the beam focused and strong.

If the glass in the fiber were 100 percent pure, the light signal would never degrade or weaken as it travels down the cable at the speed of light. But no matter how carefully we manufacture the fiber, we can't make it perfectly pure. Other elements mix in with the glass and absorb some of the light. The cladding may contain impurities as well, which allows some light to leak out, weakening the signal. To combat this, optical regenerators strengthen the signal every fifty or sixty miles.

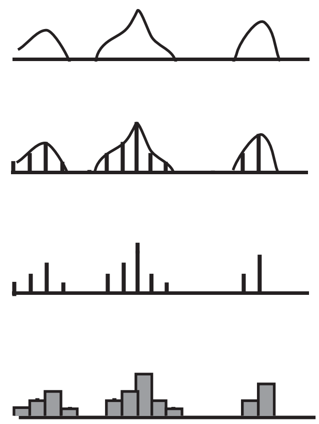


An added advantage of using light is that each fiber can carry multiple signals by using different light frequencies. Optical fibers are also smaller than wires, so even though hundreds of fibers make up each optical cable, noise is eliminated. This means that the phone calls you make are clearer, data moves faster, and video streams—television signals and video you watch on a computer—are crisper and look more realistic.



From Analog to Digital

While I've explained how light travels through optical fiber, you may be asking, how do we encode messages as light signals? To send a light signal, a transmitter translates an analog electric signal into a matching digital pattern that turns a laser on and off. The flashes of light last for only a small fraction of a second, so many thousands of encoded bytes can be sent very quickly. At the end of the cable, a light-sensitive cell receives the light signal and translates it back into an electrical signal.

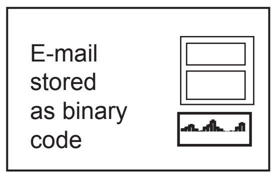


Analog to digital conversion

Now that you have a sense of how fiber optics carry light information, you can start to understand how an e-mail can travel hundreds and thousands of miles in a matter of minutes. The signal containing the e-mail message may change forms many times along the way. Say you are visiting Washington, D.C., and you send an e-mail to a friend in Raleigh, North Carolina, telling her about your trip to the Smithsonian. In order for the e-mail to travel from your computer to your friend's computer, it takes a very long journey in a very short time. Let's trace the journey.

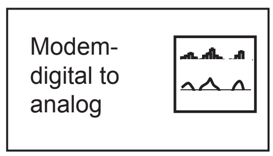
Step 1: Typing the E-Mail

When you type and save your message, the computer stores it as a binary code.

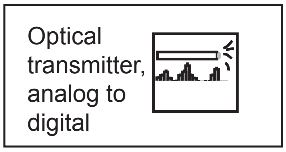


Step 2: Sending the Message

When you click "send," the computer sends out an encoded digital signal containing your e-mail and the address of the recipient to the modem. If you connect to the Internet using a telephone, your modem converts the digital signal into an analog signal that can travel as electrical current along telephone wires.

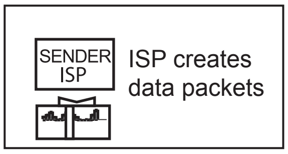


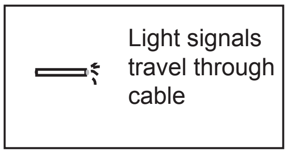
Step 3: Going Optical



The message, now an encoded analog signal, moves through the telephone wires to the local telephone company in Washington, D.C. There the signal meets an optical transmitter, perhaps one that Cisco designed and manufactured. The optical transmitter first converts the signal to a binary encoded digital signal. It then turns a laser light on and off to match the sequence of the signal. The light beam, created by a laser, shoots down the fiber-optic cable toward your Internet service provider (ISP) at close to 186,000 miles per second.

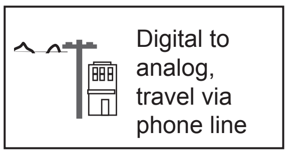
Step 4: Getting on the Information Super Highway

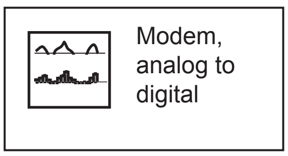


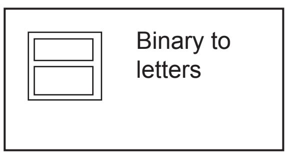


Your ISP now breaks the data into discrete packets small enough to be sent over the Internet. Each data packet is labeled with the Internet address of your friend's computer. Devices called routers act as network connectors. They determine which way to send data so that it follows the fastest path to your friend's ISP in North Carolina. Once again, these packets are sent as light signals through the fiber-optic cable. Every 50 or 60 miles, the packets are received, amplified, and retransmitted. This regeneration continues until the signal is received at your friend's ISP in Raleigh, which converts and stores the message in binary code.

Step 5: Back to the Computer







When your friend in Raleigh connects to her ISP to receive her e-mails, your e-mail is translated again into an analog signal and sent over the local phone line to her home. The modem receives the signal, converts it to a digital signal, and transmits it to the computer. The computer decodes the signal one last time, and the e-mail becomes text that your friend can read. When you think about it, there is one more conversion: Her eyes convert the graphics, the letters, numbers, and even pictures into electrical signals that her brain can understand!

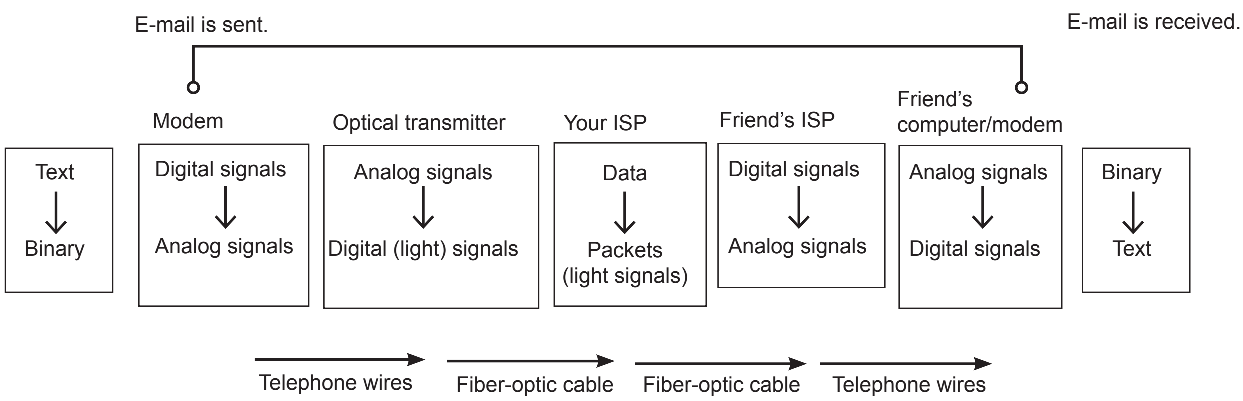
Phew! Talk about a long journey!

Amazingly enough, the system can move e-mail to anywhere in the world in a matter of minutes. If you're connected to the Internet using a cable connection to your ISP, it happens even faster. That's because your message bypasses the telephone system and connects directly to your ISP and the Internet.

So, what makes my job interesting and important? At Cisco, I test optical transport systems. I write computer programs that trick devices into encoding, regenerating, and delivering signals as if actual data had been received. That way I can make sure that each device will have the appropriate response before we hook it up to the network. Imagine if these devices often failed on the job. That would create a terrible information traffic jam!

My role in maintaining the information superhighway may seem pretty specialized. Afterall, I only work on a small part of the information super highway. But testing is just as important as designing and building. If I don't do my small part well, the communications infrastructure on which so many individuals, businesses, governments, and research institutions depend could come to a screeching halt. That's one thing I love about working with technology. Every system is like a puzzle, and all of its pieces must fit—and work—together properly.

The E-Mail Journey



What's the Story?

1. What does noise refer to in this chapter?

2. Why are fiber-optic cables better than telephone wires for transmitting information over long distances?

Designing with Math and Science

3. Explain how light travels through a fiber-optic cable, using the terms "reflection" and "total internal reflection."

4. Why does the light signal have to be regenerated?

5. How can ones and zeros be encoded in a light signal?

Connecting the Dots

6. Nanette talks about how every technological system is like a puzzle, that all of its pieces must fit—and work—together properly. Describe how this applies to at least two other technological systems you've studied in this course.

7. Nanette is a test engineer. Why is testing a critical part of the development process? Describe how at least two other engineers you've learned about test the technologies they've designed.

What Do You Think?

8. Do some library and Internet research to find the disadvantages of optical cables. Consider the cable materials and the installation processes in your response.