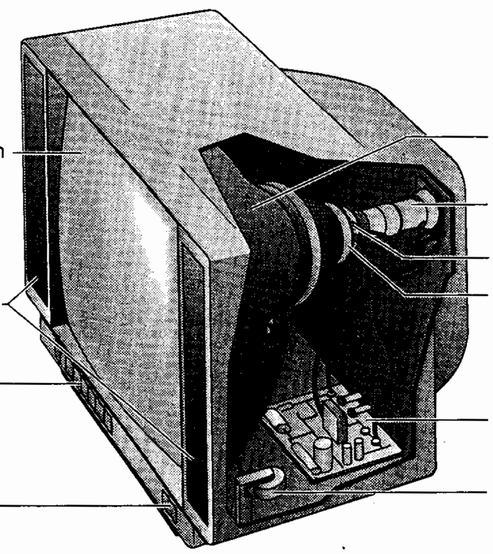

Section 14.2

Television

WARNING:
Televisions contain dangerously high voltages, even after they have been unplugged. Since a television uses beams of high energy electrons to create the images that you see, it needs high voltages. To avoid any risk of shock, you should never open a television while it's operating. But even turning the unit off doesn't necessarily make it safe. Because the television uses capacitors to store separated electric charge in its high voltage power supply, high voltages can persist inside it for minutes or more after you turn it off and unplug it. Don't open a television until you're sure that it has no more stored electric energy in its capacitors.

In the previous section, we learned how radio sends sound through space on an electromagnetic wave. But that process isn't nearly as complicated as sending pictures on an electromagnetic wave. Television performs this by breaking each picture up into tiny dots and handling these dots one by one at an incredible rate. In this section, we'll look at how a picture is represented by a video signal, how it's transmitted from one place to another, and how a television set turns that signal back into a picture.

Questions to Think About: *Why does it take a few seconds for a television set to warm up? Why are there tiny colored spots on the front surface of a picture tube? What happens when a picture tube "burns out"? Why is it so hard to make the front surface of a picture tube flat? Is it really possible to break a picture tube by hitting it with a shoe? If you take a photograph of the TV screen, why will you probably find that only part of the screen appears on the photograph?*

Experiments to Do: *One interesting but possibly costly experiment to do with a television set is to expose it to the field of a strong magnet. The magnet will deflect the stream of electrons flowing through the picture tube and create beautiful colors on the screen. However, just inside the surface of a color picture tube is a metal mask that is easily magnetized. If you hold a magnet to a color TV, this mask will probably have to be professionally demagnetized. But you can safely try this experiment with a black and white TV.*

A less risky experiment is to cut a narrow slot in a card and to watch a TV through this horizontal slot. Move the card up and down rapidly so that you only see the screen for a brief moment as the slot passes in front of your eye. You should see horizontal dark and light bands across the image. Can you explain why only part of the picture is illuminated? What happens when you hold the slot vertically and move it left and right?

Finally, use a magnifying glass to look at the screen of a color television set. You'll see a pattern of red, green, and blue dots or stripes. How can these simple colored dots create all of the colors that you see when you watch the television?

Creating a Television Picture

A television builds its picture out of tiny colored dots, arranged in a rectangular array on the screen. The number of dots in this array depends on the television standard, which varies with country. For the following discussion, we'll consider only the color television standard used in the United States (*NTSC*), which specifies an array that is 525 dots high by about 700 dots wide. Other television standards differ somewhat in the details but not in the concepts.

While the television illuminates these dots one by one, it finishes with all of them so quickly that it appears as though they're all illuminated at once. Your eye responds slowly to changes in light and you see the whole pattern of dots on the screen as a single picture, a television picture. To create this picture, the television starts at the upper left hand corner of the screen and scans through the dots horizontally from left to right. Every $1/15{,}750^{th}$ of a second, it starts a new horizontal line. Since there are 525 horizontal lines, the television completes the entire picture every $1/30^{th}$ of a second.

Actually, if the television worked its way from the top of the screen to the bottom in $1/30^{th}$ of a second, our eyes would sense a slight flicker. To reduce this flicker, the television builds the image in two passes from top to bottom: it illuminates the odd numbered lines during the first pass and the even numbered lines during the second pass. That way, the television scans down the screen once every $1/60^{th}$ of a second and there is essentially no flicker at all.

CHECK YOUR UNDERSTANDING #1: Horizontal Hold

If you take a photograph of a television screen, using an exposure time of $1/250^{th}$ of a second, the finished photograph will contain only a band of the television image, about a quarter of the screen high. Explain.

Black and White Picture Tubes

These dots of light are produced on the inside surface of a glass picture tube when electrons collide with a chemical **phosphor** (Figs. 14.2.1 and 14.2.2). These electrons are emitted by a hot surface in the neck of the picture tube and accelerate toward positive charge on the phosphor-coated screen. When the electrons strike the phosphor, they transfer energy to it and it glows brightly.

But the television exerts forces on the electrons as they fly through the empty space inside the picture tube. These forces focus the electrons into a narrow beam and then steer that beam to various points on the phosphor screen. This focusing and deflecting are done by components in the neck of the picture tube, a region that's shown in detail in Figs. 14.2.3 and 14.2.4. For the moment, let's consider only a black and white picture tube.

The electrons emerge from a negatively charged *cathode*, a device that emits electrons directly into space. In a picture tube, the cathode is hot, so that thermal energy tosses electrons from its surface. This cathode is heated by a nearby filament and takes a few seconds to warm up when you turn on the television. If the filament breaks or burns out, the picture tube is ruined.

Surrounding the cathode is a hollow *grid* with negative charge on it. Since this negative charge repels electrons, most of the electrons leaving the cathode

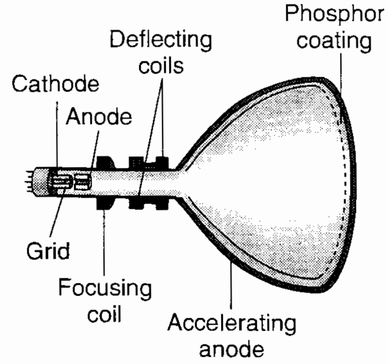

Fig. 14.2.1 - The main components of a black and white picture tube. Electrons travel from left to right and illuminate the screen.

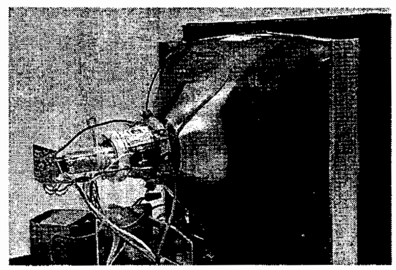

Fig. 14.2.2 - A small picture tube.

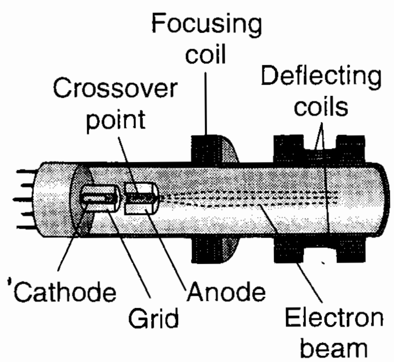

Fig. 14.2.3 - The neck of a picture tube, showing how the electron beam comes to a focus once inside the anode and again at the screen.

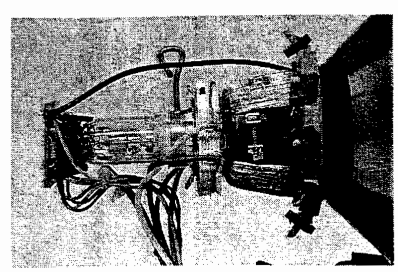

Fig. 14.2.4 - Electrons leaving the cathode, grid, and anode (in clear glass) pass through the focus coil (middle) and are steered by the wire deflecting coils (middle-right).

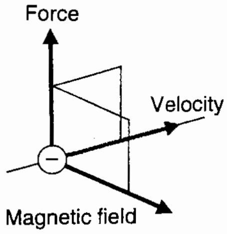

Fig. 14.2.5 - An electron moving through a magnetic field experiences a force that's at right angles to both its velocity and the magnetic field. A positively charged particle would experience a force in the opposite direction.

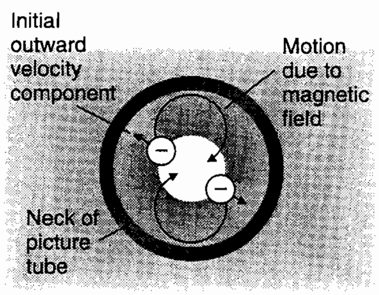

Fig. 14.2.6 - As diverging electrons move down the neck of the picture tube toward the screen, the focusing magnetic field makes them accelerate to their right. They travel in a spiral and return together just as they hit the screen.

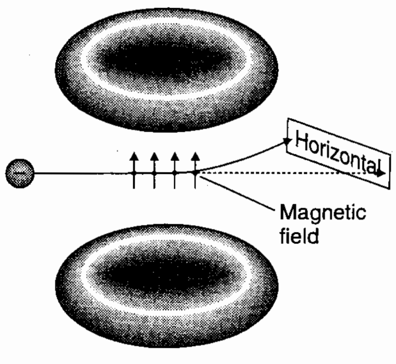

Fig. 14.2.7 - The horizontal deflecting coils are located above and below the neck of the picture tube. The vertical magnetic field they produce deflects the electron beam either left or right.

return to its surface. However, the grid has a small hole through which some of the electrons can escape. These escaped electrons are attracted by a positively charged *anode* and form a narrow beam.

The shape of the electric field between the cylindrical cathode, grid, and anode has an interesting effect on the electrons: it focuses them to an extremely narrow spot inside the anode. Regardless of which way they were heading when they left the cathode's surface, the electrons are all accelerated by the electric field and head toward the same point inside the anode, the *crossover point*.

But the electrons don't stop at the crossover point. Instead, they continue on through the anode and sail off toward the screen. After they have passed through the crossover point, the electrons are heading away from one another. They must be brought back together again so that they all strike the screen at exactly the same spot. This second focusing action is done by a magnetic field.

While it may seem surprising that a magnetic field can influence the path of an electron, we've already seen that moving charge is magnetic. A magnet pushes on charge flowing through the wires of an electric motor, so why shouldn't that magnet push on charges flying through an empty picture tube?

As it passes through a magnetic field, an electron experiences a force that's proportional to its charge and velocity, and to the strength of the magnetic field. This force also depends on the angle between its velocity and the magnetic field. The force is strongest when the velocity and field are at right angles to one another and diminishes to zero when they both point in the same or in opposite directions. Oddly enough, this force acts at right angles to both the electron's velocity and the magnetic field (Fig. 14.2.5).

The magnetic field that focuses electrons to a spot on the screen is created by a wire coil that circles the neck of the picture tube. This field points directly toward the screen. Since the electrons' velocities also point toward the screen, the forces on them are small. But if we look down the neck of the tube at the screen (Fig. 14.2.6), we see that these electrons have small outward components of velocity that take them away from the center of the tube and the crossover point they just left behind. These outward components of velocity are at right angles to the magnetic field, so the electrons experience magnetic forces.

Each electron accelerates toward its right as it flies through the magnetic field so that it travels in a spiral. Viewed down the neck of the tube, this motion appears circular and is called **cyclotron motion**, after the particle accelerator based on this motion. Remarkably, the time it takes each electron to complete one full circle of cyclotron motion doesn't depend on how large that circle is. All of the electrons complete exactly one full circle on their flights from the crossover point to the screen and hit the screen at the same spot!

The television also uses magnetic fields to steer the electron beam to different parts of the screen. A pair of coils above and below the picture tube's neck produces a vertical magnetic field that deflects the electron beam horizontally (Fig. 14.2.7). By adjusting the amount and direction of current in these horizontal deflecting coils, the television can control the horizontal position of the beam spot on the screen.

A second pair of coils mounted to the left and right of the tube's neck produces a horizontal magnetic field that deflects the electron beam vertically (Fig. 14.2.8). The amount and direction of current in these vertical deflecting coils determines the vertical position of the beam spot on the screen.

When the electron beam strikes the phosphor coating on the inside of the screen, it transfers energy to that phosphor, which then emits white light. Creating a bright image takes lots of energy, so the electron beam is accelerated on its way to the screen. A high voltage power supply (+15,000 V to +25,000 V) pumps positive charge onto the inside of the screen and the surrounding accelerating anode, and this charge attracts the electrons. By the time they hit, the electrons have enough kinetic energy to make the phosphor glow bright white.

But white isn't the only color in a television picture. To produce a gray or black spot, the television reduces the current of electrons in the beam. It controls this current by adjusting the charge on the picture tube's grid. The more negative charge on the grid, the harder it is for electrons to pass from the cathode to the anode and the fewer of them that strike the phosphor. The television carefully adjusts this grid charge as it sweeps the electron beam back and forth across the screen and thus creates a complete television picture, one dot at a time.

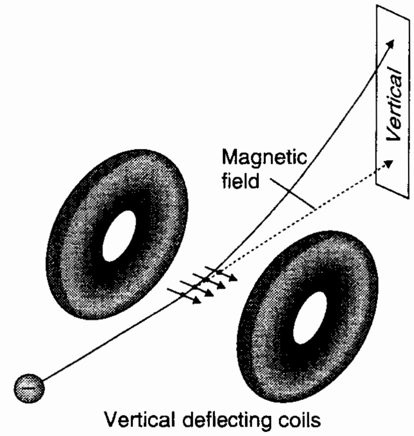

Fig. 14.2.8 - The vertical deflecting coils are located to the left and right of the picture tube's neck. The horizontal magnetic field they produce deflects the electron beam either up or down.

CHECK YOUR UNDERSTANDING #2: Currents in Time

The electron beam is swept from left to right by changing the current through the horizontal deflection coils. If each sweep takes 1/15,750th of a second, how does the current through these deflection coils vary with time?

About the Picture Tube

Unfortunately, not all of the light from the phosphor coating travels directly out into the room where you can see it. Some is emitted backward into the tube itself or gets caught up in reflections in the glass. This lost light tends to reappear where it's not wanted and reduces the picture's contrast. To prevent light from bouncing around inside the picture tube, the phosphor coating is itself coated with a thin layer of aluminum. The electron beam can pass through this aluminum layer but light cannot. This light is reflected directly out of the tube, where it brightens and sharpens the image. The aluminum layer also provides a path for electrons to return from the phosphor coating so that they can be reused.

The flatness of the screen is limited by the picture tube's ability to focus and sweep the electron beam. Although a perfectly flat, rectangular screen is the ideal, it's virtually impossible to achieve in practice. The corners of a flat screen are farther from the focusing coil than is the center of the screen and the television can't get the beam to focus simultaneously in both places. Furthermore, the horizontal and vertical deflections interfere with one another to create images that aren't rectangular. While special electronics can correct for some of these focusing and deflection problems, truly flat picture tubes are still not practical.

Because the picture tube contains a vacuum, it experiences enormous inward forces from the surrounding air pressure. Any crack in the tube would cause it to implode violently. The neck and back of the tube are protected by the case, but the screen is exposed. It has a thick plate of glass glued to its surface, forming an armored surface that's almost indestructible.

CHECK YOUR UNDERSTANDING #3: There's Really Nothing Inside

If a picture tube will implode violently when cracked, it must contain potential energy. Where did it get this potential energy?

Color Picture Tubes

Color picture tubes work much like black and white tubes, except that they have three electron beams and phosphors that emit red, green, and blue light. As we'll discuss in the next chapter, mixtures of red, green, and blue light can make you perceive any color. A color television appears full color by carefully mixing these three colored lights.

The inside surface of a color television screen is coated with thousands of

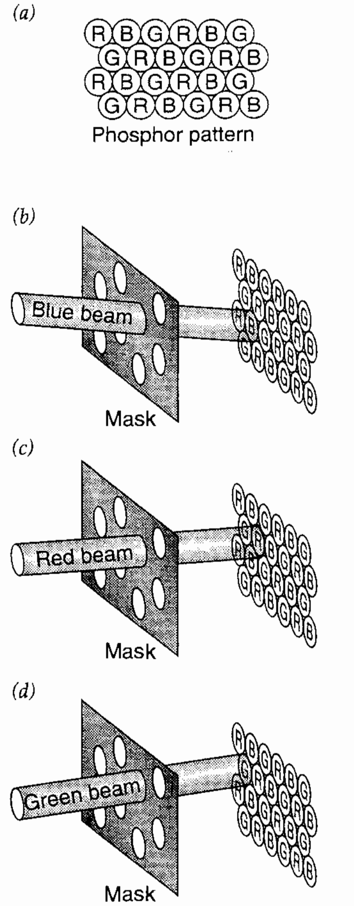

Fig. 14.2.9 - (*a*) The pattern of red, green, and blue phosphor dots coating the inside of a picture tube. The holes in the mask allow (*b*) the "blue" electron beam to illuminate only blue dots, (*c*) the "red" beam to illuminate only red dots, and (*d*) the "green" beam to illuminate only green dots.

tiny phosphor dots (Figs. 14.2.9*a* and 14.2.10). Some of these dots emit red light, some green light, and some blue light. The television directs electrons at these dots through holes in a metal mask. Three separate electron beams, coming from three slightly different angles, pass through the holes and strike the phosphors. Since each beam can only strike one color of phosphor dots (Fig. 14.2.9*b–d*), each beam controls the brightness of one of the three colors.

While some picture tubes use phosphor stripes rather than dots, and a grille rather than a mask, the basic idea is the same. Only one electron beam can hit a particular phosphor stripe. These masks and grilles are carefully aligned and mounted inside picture tubes and are made from special thermally compensated metals that stay aligned even when the temperature changes. These special metals are easily magnetized, which is why you shouldn't hold a strong magnet near a color television. The resulting magnetization would then deflect the electron beams and produce distorted images and colors.

CHECK YOUR UNDERSTANDING #4: The Blue and the Red

The three electron beams in a color picture tube always converge to a single spot on the screen, even when they're being deflected. How does the momentum transferred to electrons in the "blue" beam by this deflection compare to that transferred to electrons in the "red" beam?

Television Transmission

Representing a picture with a current or an electromagnetic wave is much more complicated than representing sound. This representation, which we'll call a *video signal*, must indicate the brightness and color of every dot in the picture 30 times a second. It must also indicate to the television which spot on the screen to illuminate at any given moment.

The basic structure of a black and white video signal is relatively simple. It just indicates how bright each dot on the screen should be as the television scans line by line through the picture (Fig. 14.2.11). To indicate when each line begins, the video signal briefly extends outside its normal range and takes a value beyond full blackness. The television responds to this *horizontal sync signal* by steering its electron beam back to the left edge of the screen and starting a new line. To indicate when a new picture begins, the video signal extends beyond blackness for a longer time (not shown in Fig. 14.2.11) and this *vertical sync signal* causes the television to steer its electron beam back to the top of the screen.

A color video signal contains the same brightness and synchronization signal, so that it's compatible with black and white televisions. But it also contains a separate color signal. To see how these two signals, called *luminance* and *chrominance* respectively, can be carried simultaneously by a single electromagnetic wave, let's look at how a television station produces that wave.

The luminance signal is transmitted in much the same way that sound is transmitted in AM radio—by allowing it to control the amount of charge sloshing in a tank circuit and moving up and down an antenna. When the luminance signal is off, the amount of moving charge doesn't change and the antenna emits a steady electromagnetic wave called the **carrier wave**. Figure 14.2.12*c* shows the

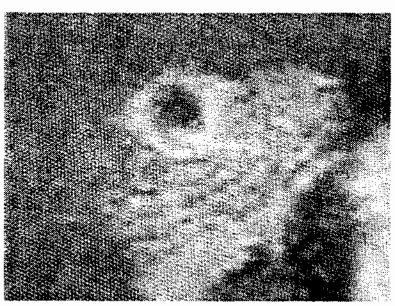

Fig. 14.2.10 - A color television creates its colored image with millions of tiny colored dots. This is a magnified photograph of those dots.

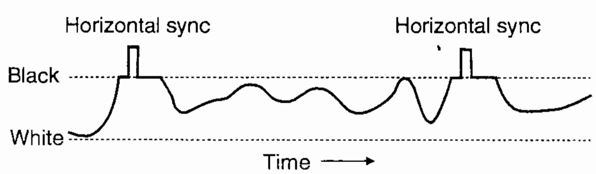

Fig. 14.2.11 - A black and white video signal represents the brightness of the picture line by line. A new horizontal line is indicated when the video signal briefly extends beyond black.

charge on the antenna as it emits this wave. When the luminance signal is on, it modulates the amount of charge moving up and down the antenna and the amplitude of the electromagnetic wave that the antenna emits. This **modulated carrier wave** (Fig. 14.2.12*b*) is just like the carrier wave itself, except shaped in amplitude by the luminance signal (Fig. 14.2.12*a*).

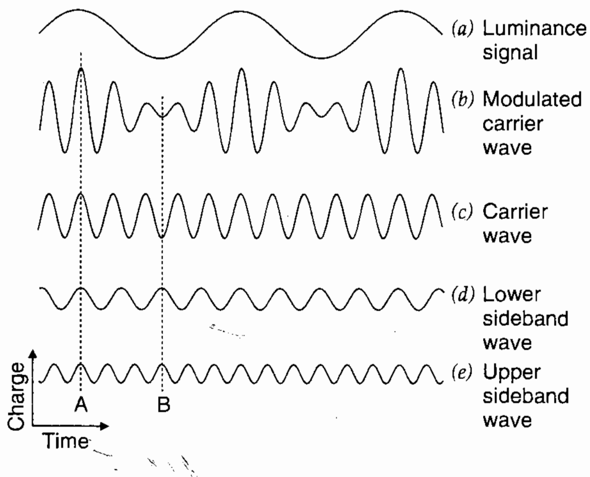

Fig. 14.2.12 - A television station represents this simple luminance signal by using it to amplitude modulate (AM) a carrier wave. This modulated carrier wave is actually the sum of the carrier wave and two sideband waves. Shown here are the amounts of charge on the transmitting antenna as it emits these various waves.

But we can also view the modulated carrier wave as the sum of three steady waves: the carrier wave and two **sideband waves** that have frequencies above and below the carrier wave (Fig. 14.2.12*d,e*). You can see this possibility in Fig. 14.2.12 by picking a specific time—such as *A* or *B*—and adding the antenna charge associated with the carrier, lower sideband, and upper sideband waves. They sum to the antenna charge associated with the modulated carrier wave! In effect, the modulated antenna charge can be thought of as three separate portions of charge that move up and down the antenna at slightly different frequencies.

This observation, that a modulated carrier wave actually contains several different waves at slightly different frequencies, has a profound impact on television and radio transmission. A television station that operates on Channel 2 and has a carrier wave frequency of 55.25 MHz also emits electromagnetic waves at other nearby frequencies! That's why competing television stations must be assigned widely different carrier wave frequencies—so that they don't accidentally emit sideband waves at the same frequency.

While the simple luminance signal in Fig. 14.2.12 has just one frequency and creates only one upper and one lower sideband, a more complicated luminance signal creates many upper and lower sideband waves. The range of frequencies present in upper or lower sideband waves is the same as the range of frequencies present in the luminance signal itself. Because it must specify all of the dots on the screen 30 times a second, the luminance signal includes frequencies as high as 5.5 MHz. Thus the sideband waves in a television signal extend as much as 5.5 MHz below and 5.5 MHz above the carrier wave frequency, giving them a total range of frequencies or a **bandwidth** of 11.0 MHz.

If television transmissions had 11.0 MHz bandwidths, competing stations would need carrier waves separated by at least 11.0 MHz. But that spacing would use up the precious spectrum of electromagnetic waves awfully quickly.

Consider radio stations for comparison. By international agreement, an AM radio station may use a bandwidth of 10 kHz, so its sideband waves can extend only 5 kHz above and below its carrier wave. Since the AM station is using an audio signal to amplitude modulate its carrier wave, that audio signal can't contain frequencies above 5 kHz. While this restricted frequency range is bad for music, it allows competing stations to function with carrier waves only 10 kHz apart, so that 106 different stations can operate between 550 kHz and 1600 kHz.

An FM radio station, which uses the frequency modulation technique (FM) to represent its audio signal, also produces sideband waves. In fact, the FM technique produces extra side bands and needs extra bandwidth. According to the international agreement, each FM station may use 200 kHz of bandwidth, 100 kHz on each side of the carrier wave frequency. This luxurious allocation permits FM radio to represent a very broad range of audio frequencies, in stereo, which is why an FM radio station can do a much better job of sending music to your radio than an AM station can.

The spectrum of electromagnetic waves is too valuable to allow a single television channel to occupy 11 MHz. The official allocation is 6 MHz, *including sound and color*. While this is like fitting an elephant into a shoe box, it turns out to be possible, although it does reduce the quality of the picture ever so slightly.

First, the upper and lower sideband waves carry redundant information. Since a particular frequency in the luminance signal creates both an upper *and* a lower sideband wave, only one of these sideband waves is really needed. So the television station uses electronic filters that stop it from producing most of the lower sideband waves. When this filtering is done, the lower sideband waves extend no more than 1.25 MHz below the carrier. Television receivers are able to compensate for the missing lower sideband waves.

To narrow the bandwidth of the television signal still further, the television station also filters out the highest frequency upper sideband waves. Instead of extending 5.5 MHz above the carrier wave, these upper sideband waves extend no more than 4.0 MHz. This filtering reduces the picture sharpness slightly.

The television signal now occupies 5.25 MHz of bandwidth about the carrier wave frequency—1.25 MHz below it and 4 MHz above it. The television station adds sound to its transmission by frequency modulating a separate carrier wave, just like in normal FM radio. This new audio carrier wave has a frequency that is 4.5 MHz above that of the video carrier wave.

With the inclusion of sound, the 6 MHz of allowed bandwidth is essentially full. Television channels are assigned to frequencies 6 MHz apart, although they are broken up into groups (VHF Low, VHF High, and UHF) in order to leave room in the electromagnetic spectrum for FM radio, cellular telephones, and other communication activities.

But what about color? The chrominance signal is inserted into the transmission by modulating an extra *chrominance subcarrier* wave located at a frequency 3.58 MHz above that of the video carrier wave. This new electromagnetic wave shares its bandwidth with the upper end of the luminance signal. For complicated reasons relating to the time structure of the video signal, these two electromagnetic waves don't interfere with one another and a black and white television doesn't even notice that the chrominance signal is there.

The chrominance signal controls the three electron beams in a color television. It contains two streams of color instructions which, together with the brightness instructions in the luminance signal, determine the coloring of the screen. Since your eyes are much more aware of brightness details than of color details, the chrominance signal is simplified so that it occupies only a modest bandwidth in the television transmission.

CHECK YOUR UNDERSTANDING #5: Beating the Bandwidth

Video tape recorders store video and audio signals on magnetic recording tape. The bandwidth available to the recording process is limited. Older VCR standards such as VHS, Beta, and 8 mm allow less than 6 MHz bandwidth for recording while some of the modern standards such as Super-VHS, Super-Beta, and Hi–8 mm approach or exceed 6 MHz. How does this recording bandwidth affect picture quality?

Cable Television

Cable television is similar to broadcast television except that it sends electromagnetic waves through a cable rather than empty space. Television cable consists of an insulated wire inside a tube of metal foil or woven metal mesh. This wire-inside-a-tube arrangement is called **coaxial cable** because the wire and the surrounding tube share the same center line. Electromagnetic waves can propagate easily through coaxial cable, following its twists and turns from the company that produces the waves to the television receiver that uses them.

Because the electromagnetic waves in a coaxial cable don't interact with those outside it, the whole electromagnetic spectrum inside the cable can be used for television channels. Since the cable can handle frequencies up to about 1000 MHz, it can carry about 170 channels.

To increase the number of channels, televisions are beginning to use compression techniques. Instead of transmitting the entire picture 30 times a second, a station can transmit only information about dots that have changed since the last picture. This compression narrows the bandwidth needed by each channel so that a coaxial cable can carry more than 500 of them simultaneously.

Compression is particularly important for high-definition television, which has about four times as many dots in each picture. To transmit this increased detail and remain within the allowed bandwidth for a television station, a high-definition television station must use compression techniques.

But compression becomes less important when coaxial cables are replaced by glass fiber cables (*fiber optic cable*) that guide light from one place to another. Light is also an electromagnetic wave and it can be amplitude modulated just like a radio wave. But light's frequency is extremely high; for visible light, it ranges from $4.5 \cdot 10^{14}$ Hz to $7.5 \cdot 10^{14}$ Hz. If we were to place television channels every 6 MHz throughout the visible spectrum, there would be about 50 million channels. Just imagine the newspaper television listings!

CHECK YOUR UNDERSTANDING #6: Networking

Computers often communicate with one another through networks of wire or glass fiber cables. How does this network resemble cable television?

Summary

How Television Works: A black and white television creates an image on its picture tube by scanning a beam of electrons rapidly across the inside of the screen. It starts at the top of the screen and scans left to right while gradually moving the beam down toward the bottom of the screen. It completes all 525 horizontal lines every $1/30^{th}$ of a second, but forms them in two passes down the screen. The brightness of any particular spot on the screen is determined by the current of electrons in the beam. The electron beam is focused to a tiny point on the screen by electric and magnetic fields and is scanned magnetically from left to right and top to bottom. A color television tube scans three separate electron beams across the inside surface of the screen, where they illuminate blue, red, or green phosphor patches through holes in a metal mask.

The electromagnetic waves that carry the television signal through space can be viewed either as three modulated carrier waves—luminance (brightness), chrominance (color), and audio—or as those carrier waves and their associated sideband waves. All of these waves fit within a 6 MHz range of frequencies. To operate in this narrow bandwidth, most of the lower sideband waves associated with luminance are filtered away, along with some of the upper sideband waves. This filtering reduces the detail of the television picture slightly but allows more television stations to operate simultaneously.

The Physics of Television

1. A moving charged particle experiences a force when it travels through a magnetic field. This force is at right angles to both its velocity and the field and is proportional to the particle's velocity and charge, and the strength of the field.

2. Moving electrons in magnetic fields tend to follow spiral trajectories.

3. Amplitude or frequency modulation of a wave introduces sideband waves at higher and lower frequencies.

4. The bandwidth of an amplitude modulated carrier wave is twice the bandwidth of the signal controlling the amplitude modulation. Half that bandwidth is upper sideband waves and half is lower sideband waves.

5. The bandwidth of a frequency modulated carrier wave is more than twice the bandwidth of the signal controlling the frequency modulation. Again, half the bandwidth is upper sideband waves and half is lower sideband waves.

Check Your Understanding - Answers

1. During the 1/250th of a second exposure, the television will only complete about a quarter of its scan from the top of the screen to the bottom of the screen.

Why: While the television's scanning process easily fools your eye into seeing a complete image, a camera records exactly what it sees. If the exposure time is too short, the television will only be able to build part of the screen image during the exposure, and the photograph will contain only a horizontal band of the picture.

2. This current changes smoothly and steadily from flowing in one direction around the coils to flowing in the other direction around the coils. Every 1/15,750th of a second, it restarts this process.

Why: The current flowing through the coils resembles a series of ramps when graphed as a function of time. It increases steadily up to a point and then suddenly returns to its starting value. As the current increases steadily, the electron beam is deflected less to the left and more to the right. Then the current is suddenly returned to its original value and the beam snaps back to the left. Because magnetic fields from this changing current can cause objects to move, some televisions emit an annoying tone at 15,750 Hz.

3. The machine that removed the air from the tube provided it.

Why: It takes mechanical work to remove air from the picture tube. The vacuum pump had to push the tube's air outward, into the surrounding atmosphere, and that air moved outward, in the direction of the pump's force. Thus rarefying the air in a container takes energy. When the tube cracks, the air rushes back into empty space and it can do work on the tube's walls. The tube is crushed violently.

4. They are exactly the same.

Why: The deflection process doesn't prevent the beams from coming together at a single point on the screen. Instead, it gives electrons in each beam exactly the same impulse, so that they all experience the same change in momentum and travel together to a specific point on the screen.

5. The higher the recording bandwidth, the finer the horizontal detail in the picture.

Why: A VCR that can record very high frequencies in the video signal will capture the finest details in each horizontal line of the picture. Recent high-bandwidth VCRs are able to record more detail than is currently present in broadcast television.

6. Both computer networks and cable television systems send information as electromagnetic waves in wires or glass fibers.

Why: The information that moves through a computer network travels as electromagnetic waves in cables. Sometimes those cables are coaxial cables, sometimes they are glass fibers, sometimes they consist of twisted pairs of wires (which can also carry and guide electromagnetic waves). A computer transmits information through the cable by creating and modulating an electromagnetic wave and another computer receives the information by detecting that modulated wave.

Glossary

bandwidth The range of frequencies involved in a group of electromagnetic waves.

carrier wave An electromagnetic wave with only a single frequency. This wave is modulated in order to represent an audio or video signal, or data.

coaxial cable A two-conductor electric cable in which an insulated central conductor is surrounded by a cylindrical outer conductor. Electromagnetic waves can travel inside a coaxial cable.

cyclotron motion The circular or spiral motion of a charged particle in a magnetic field. The charged particle tends to loop around the magnetic flux lines.

modulated carrier wave A wave that has been modulated so that it contains not only the carrier frequency, but also video, audio, or other information.

phosphor A solid that luminesces (emits light) when energy is transferred to it by light or by a collision with a particle.

sideband waves Waves at frequencies above and below the carrier wave that are produced when the carrier wave is modulated.

Review Questions

1. A television picture tube has a large surface, so why must the television focus its electron beam on a tiny spot?

2. Why do the electrons in a television's electron beam spread apart after they pass through the crossover point? Why can't they just stay together from then on?

3. Why is it important that all the electrons in the television's electron beam take the same amount of time to complete one full circle of cyclotron motion?

4. After the television's electron beam passes through the horizontal deflecting coils, its velocity points slightly to the left or right. Why can't the deflecting coils simply shift the beam to the left or right and leave its velocity pointing straight ahead?

5. Explain why less than a third of the electrons in the red beam of a color television strike the phosphors on the screen.

6. When a television station's carrier wave is amplitude modulated by the luminance signal from a camera, the station begins to transmit radio waves with frequencies that are slightly different from that of the carrier wave. Why does modulating the carrier wave introduce new frequencies?

7. To instruct a television to display alternating black and white dots, the video signal must shift from black to white to black 5.5 million times each second. If this video signal were used to amplitude modulate a carrier wave, why would the modulated carrier wave have a bandwidth of 11 MHz?

Exercises

1. A television's high-voltage power supply transfers electrons from the phosphor screen to the cathode for reuse. This supply does considerable work on the electrons it transfers. How is that work related to the light emitted by the screen?

2. The electrons in an electron beam experience forces as they pass through a magnetic field. How are those forces related to the forces electrons in a wire experience when they pass through a magnetic field?

3. Suppose you put a wire along the velocity arrow in Fig. 14.2.5 and send electrons through that wire in the direction of the arrow. Suppose also that there's a magnetic field pointing along the magnetic field arrow in that picture. Do the electrons in the wire experience a force and, if so, in which direction is that force?

4. A Penning ion trap suspends an ion (a charged atom or molecule) in empty space using electric and magnetic fields. In this trap, like charges on metal surfaces above and below the ion keep it from moving up or down, and a vertical magnetic field confines the ion horizontally by making it move in a circle. Why does the ion move in a circle?

5. A cyclotron is a particle accelerator invented in 1929 by American physicist Ernest O. Lawrence. It uses electric fields to do work on charged particles as they follow circular paths in a strong magnetic field. Lawrence's great insight was that all the particles take the same amount of time to complete one circle, regardless of their speed or energy. That fact allows the cyclotron to do work on all the particles at once as they circle together. Why is Lawrence's discovery also crucial to the sharpness of a television picture?

6. The force that a magnetic field exerts on a moving charged particle does no work on that particle. Use the definition of work to explain why there's no work done.

7. Computers and electronic games can tell where on a television screen you're holding a light sensor by studying when that sensor detects light from the screen. How is the time that the sensor observes light related to the sensor's position?

8. If the inside of the picture tube's screen didn't have a thin layer of aluminum on it, the electrons would accumulate there. Why would that be a problem?

9. X-rays are produced by a vacuum tube in which electrons from a hot, negatively charged cathode accelerate toward a positively charged metal anode. Collisions between the electrons and the metal atoms produce X-rays. Why is it important to shield the X-ray tube from magnetic fields?

10. The sun emits a stream of energetic electrons and protons called the *solar wind*. These particles frequently get caught up in the earth's magnetic field, traveling in spiral paths that take them toward the north or south magnetic poles. When they head northward and collide with atoms in the earth's upper atmosphere, those atoms emit light we know as the *aurora borealis*, or northern lights. These particles also interfere with radio reception. Why do they emit radio waves?

11. Some televisions whistle at a frequency of 15,750 Hz. Something inside the television must be moving back and forth 15,750 times each second. What television components exert forces on one another that fluctuate in strength at this frequency and thus might make the high-pitched sound?

12. When you put your hand near a picture tube that has just been turned on, negative charges flow from your hand to the glass screen. What attracts these charges to the screen?

13. If you hold a strong permanent magnet near the face of a color television picture tube, the image will be distorted in both shape and color. What causes this distortion? *(Warning: the distortion may not go away when you remove the magnet, so don't try this on a good television set!)*

14. Scrambled television stations (pay television) often remove or modify the horizontal synchronization signals. What happens to the picture if the television can't determine where each horizontal line starts?

15. When an AM radio station announces that it's transmitting at 950 kHz, that statement isn't quite accurate. Explain why it may also be transmitting at 948 kHz and 954 kHz.

16. The sidebands produced by AM radio broadcasts are legally prohibited from extending more than 5 kHz from the carrier wave's frequency. How does this limit affect the frequencies in the music that's transmitted by an AM station?

17. When a television signal travels through a coaxial cable, charge moves back and forth on both the central wire and the surrounding tube. Show that both electric and magnetic fields are present in the coaxial cable.