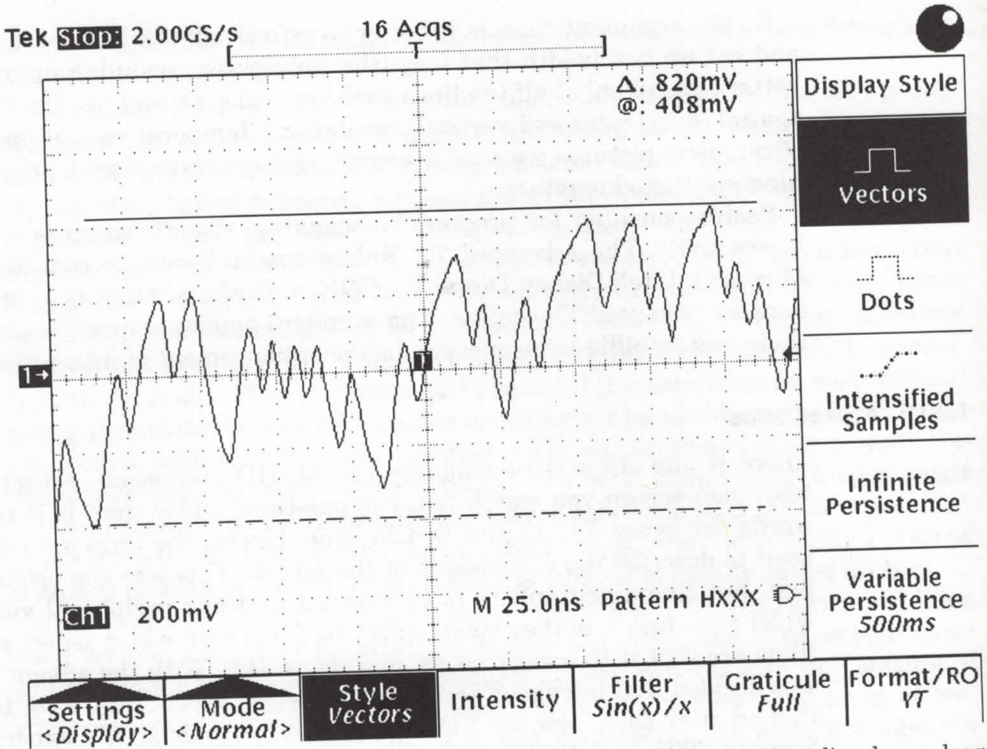

Figure 1.11 Digital signal that has lost its high-frequency components after traveling down a long coax cable.

sharp edges that should be at the transitions disappear. The edges become prolonged slopes so that the receiving device has a hard time determining the state of the incoming signal. Although coax that carries only NTSC needs a few megahertz, for SD digital that coax should carry at least 500 MHz or all bets are off. In fact, if the coax was only capable of carrying 500 MHz, the signal could not travel very far down that cable, maybe 100 ft maximum. If you want to send the signal down 1000 ft of coax, the coax has to be capable of passing frequencies above 1 GHz. With HD digital it gets far worse. To be able to send the digital signal through a few feet of coax, you need frequencies over 2 GHz. To get it over 100 ft, you're looking at frequencies over 3 GHz (Fig. 1.11).

These frequencies are considered baseband frequencies, which means that the signal is not riding on a carrier. If baseband digital is modulated onto a RF carrier, the baseband frequencies end up as sidebands. If a 3-GHz carrier is chosen to modulate a digital baseband signal onto, the sidebands, in theory, would use up most of the usable RF spectrum. Shortwave, AM, very high frequency (VHF) TV, FM, ultrahigh-frequency (UHF) TV, and some satellite channels would all be occupied by this one signal. Of course, no transmitter or receiver could be built that would be able to handle this bandwidth. Direct transmission of digital signals just isn't going to work.

1.3.1 High bit rates

In analog AM and FM NTSC transmission, the sharpness of the edges is limited so that the transmitted information stays inside its allocated channel. The information in digital signals gets so high because of the number of bits that must be carried. With SD digital-component video, there are 1440 digital samples or number values per horizontal line. This number sequence is comprised of 10 bits, and these bits are sent serially, one after another. First, the 10 bits of the first sample, then the next 10 bits of the second sample, etc., for a total of 14,400 bits of video per horizontal line. Besides the video bits, there are approximately one-third more bits sent that aren't part of the picture but are used for synchronization and identification, and to carry audio data along with the video. Over the course of 1 s it works out to be 270 million bits. That's 1 bit every 3.7 ns, which doesn't leave much time for the edges, or transitions, to occur when needed. As a very general rule of thumb, the minimum frequency needed to keep the edges sharp enough is 1½ times the bit rate. That means that, for SD digital, component frequencies in the range of 405 MHz are the minimum. By the way, digital composite is not used much because it has many of the same artifacts that analog composite NTSC has, only in digital form. Its only real benefit is that its bit rate is lower, 144 million bits/s. Plus, since it is digital, if no processing is done, the quality will remain constant.

So, we can pass baseband digital down reasonable length cables, but not through the air. Another problem is that the frequencies are too high for reasonably priced videotape machines to handle. Also, if we want to record them straight onto computer hard disks, we will use up 27 Mbytes of storage every second (overlooking the fact that SD digital video is generally 10 bits and a byte is 8 bits). A 9-GHz drive would be filled up in under 6 min. Compression to the rescue! It was discovered that if we put each picture in memory and broke it up into blocks, we could use techniques to throw away some information that wouldn't be missed too much. We do this by taking the block out of the time domain and into the frequency domain. What that means is that instead of having values that describe each pixel in the block, we come up with values that represent which combination of frequencies would be needed to regenerate the block in the space and time domain. Now the values, or coefficients, generated are numerous, but we usually find that only a few are of any magnitude, with the rest being very small in value. If we throw the ones with small values away, we can describe a block with far fewer values then before. Now those values that are thrown away will cause a slight degradation of the picture but, as it turns out, not by much. This is known as *lossy compression.*

1.3.2 Joint Picture Experts Group (JPEG)

The compression you perform on your computer, such as when you use a program like PKZIP™, is lossless. This means nothing is lost or thrown away. Lossy compression won't work on software because it would corrupt the program and make it useless. After the lossy compression is completed, we can also use lossless compression techniques on the strings of frequency coefficients generated. This lossy, followed by lossless compression, process is exactly what a group known as the Joint Picture Experts Group developed. This compression scheme is known as *JPEG*. Each picture or frame is compressed; it worked well for still photographs and greatly helps with moving ones like television. Compression ratios of 4:1 can be achieved with essentially no degradation at all. Compression ratios of 10:1 yield results that are not objectionable to most people, but as you approach 20:1 the results start to look frayed. At 10:1, we've gotten our bit rate down to 27 Mbits/s for SD digital. Now our disk drive can hold almost 1 h of video. At 2:1 compression, videotape technology can handle the resulting bit rate at a reasonable price.

1.3.3 Motion Pictures Expert Group (MPEG)

It was soon realized that JPEG compression didn't quite take the process far enough. JPEG performed only spatial compression, that is, two-dimensional compression. But motion pictures, including television pictures, often do not change much over time. Essentially, the same picture is sent over and over again, with small amounts of change. A group came together known as—yes, you guessed it—the Motion Pictures Expert Group. It developed a way to perform *temporal compression,* or compression over time. This process requires a lot of memory. A series of pictures are stored, and each is analyzed to determine what is different. A signal which represents only the change is developed. That differential picture is then compressed just like a normal JPEG picture. It also has what is known as motion vectors, which represent the direction and magnitude of objects that are moving in the picture. To reset the picture differential process, a normal JPEG frame, compressed only with reference to itself, is sent as a sort of anchor frame. Then a series of the different pictures are sent before another anchor frame is sent. MPEG compression, therefore, uses spatial and temporal compression. Compression ratios of 50:1 yield reasonable results. MPEG allows even HD to be brought down to reasonable bit rates. One common flavor of HD has a bit rate of 1.5 Gbits. MPEG allows a reasonable rendition at 19 Mbits (recent developments have put this bit rate as low as 12 Mbits/s). Now, if some of the same modulation techniques are applied that let us use 56K modems over 3K-bandwidth phone lines are applied, we can fit one HD picture into a 6-MHz-wide television channel. Or several, say five, SD pictures into the same channel.

MPEG compression is not transparent. You will see some artifacts—some bad, some good. What could be good? Well in the process of cutting up the picture for compression, a lot of edges in the picture become very sharp and pronounced. People like this because it makes everything look sharper and, in some cases, harsher. This sometimes goes against what the program's producer had in mind. Viewers liked the Trinitron™ picture tube introduced by Sony over 20 years ago because it tended to make things appear sharper than they really were. The bad aspects are generally what are known as motion artifacts. Fast action and motion can sometimes swamp the compression circuitry and cause sample blocks to be wrong or out of place. This is called *blockiness.* The interesting thing is that if you could analyze the motion artifacts in slow motion, the ones you would find most objectionable are not usually the ones you find irritating at normal speed. In many instances of compression, motionless video is extremely clear, but when objects move, blocklike features blur the picture. Clear stationary pictures that morph into unrecognizable forms when motion starts might be disconcerting to a viewer who is used to his or her brain discarding action that is too fast to follow, not the broadcaster doing it.

1.3.4 Native formats

ATSC has a 70-member Top-Down Implementation Subcommittee whose goal was to identify all the typical systems and interfaces that could exist at a station moving to digital, depending on its implementation scenario. A large chunk of the panel's work dealt with possible conversion scenarios, and the impact these would have on quality. No one is yet quite sure how many conversions are OK. The Top-Down Committee's final report examines four different implementation scenarios for plant native formats: NTSC, combination of analog and digital, SMPTE 292M (baseband HD; see Chap. 6), and MPEG/DV. Many stations are considering a plant native format since so many different formats are available. All incoming material will be converted to that format. It is still undecided as to who will specify a plant native format: networks, advertisers, program suppliers? Also, keep in mind that receivers convert to their own native format. Audio is a whole other issue. Dolby Labs states that there is no native format for audio. You can't take six channels to two and then back to six with anywhere near the same result. Experiments have also shown that conversion from interlaced to progressive is more likely to degrade the signal than conversion of progressive to interlace. Therefore, some have argued that a progressive scan native format is better.

Other groups are wrestling with what the television station will look like in the future. A group called the National Institute of Standards and Technology (NIST) was formed by broadcast and computer interests to tackle problems encountered in implementing MPEG and computer technologies in the television plant. This group is looking at technologies quite foreign to most broadcasters on which to build the plant's technical infrastructure.

1.4 The Agreement to Disagree

So, at this point, we have a number of groups, each of whom has a stake in the DTV game, but most of them can't agree on the rules of the game. The computer industry wants interactivity and lots of data delivery to progressive scan PCs. They have no initial interest in HD. The PC folks suggest a phased-in approach to HD after their SD/data goals are met. But some members of Congress believe the second television channel handed to the broadcasters was for HD, not SD or data delivery. Cable isn't happy about carrying the additional DTV signals.

Besides the PC folks, broadcasters, cable, and Congress, four other groups will affect the rollout of DTV: the content providers such as production houses and studios, advertisers, professional equipment manufacturers, and consumer electronics manufacturers.

If the content providers decide that HD isn't worth the effort or investment, HD will not happen. An additional issue that is being worked out is fee charges, if any, needed for airing programs on two separate channels during the NTSC/DTV transition phase. Advertisers have to decide if they will foot the bill for HD, and when they will consider the broadcaster's additional DTV channel worthy of payment for advertising on it. Most of the early DTV broadcasters are doing little more than simulcasting their NTSC video and audio on the DTV channel. These stations are not charging their advertisers anything for the additional channel. The professional equipment manufacturers have to decide which DTV formats they will support. Whereas 1080i@60 equipment seems to be fairly well supported already, 1080p@24 and 720p@30 equipment is still in development. It is still unclear as to whether any of the other formats, such as 480p@60 or 480p@30, will have much in the way of product offerings. Finally, the TV set manufacturers will decide how to display the various formats. They will also decide on how cable and terrestrial broadcasters will interface with their products.

CBS says the biggest issues facing DTV programming are

1. A 59.94- versus 60-Hz field rate.
2. Number of concatenations of audio compression that can occur.
3. The number of audio channels.
4. Which tape formats to use.

DTV issues fall into three categories:

1. *Production.* Content creation, choice of "native" DTV production format, distribution from the producer through the network to the affiliate.
2. *Transmission.* Towers, antennas, transmitters, studio-to-transmitter links (STLs), DTV transmission format, ATSC encoders.
3. *Display.* Choice of DTV display size, choice of native DTV display format, set-top boxes (STBs).

For consumers to want DTV there must be program content, good picture portrayal, and great sound. DTV has created a decoupling of production, transmission, and display formats. Different sets of winners and losers will evolve, based on how the issues just mentioned play out. Cable wins if DTV fails, especially if they are trying to implement some sort of advanced television. The PC industry derives no benefit from DTV since there are Internet alternatives to broadcasting. Early adopters will pave the way for the rest of us. They will pay a premium to use, or have access to, the technology first. The feature set will improve with each new iteration of product and the price will drop. This is not fair, but necessary.

1.4.1 Nothing's fair

Little in the broadcast industry has ever been fair. Historically, UHF stations have always had disadvantages when compared to their VHF counterparts (VHF and UHF stand for the band of frequencies of the broadcast stations). The VHF band is the frequencies between 30 and 300 MHz. Television channels do not occupy the whole band. Channel 2, which is the lowest VHF channel, has its lower channel edge at 52 MHz. The channels go up from there. There is actually a small gap between channels 4 and 5 (4 MHz), which is why you can find these channels adjacent to each other in the same or nearby markets.

Early television-receiver technology prevented the placement of channels adjacent to one another in the same market. Adjacent channel separation for VHF channels has been 60 mi. That means that channel 7 in San Francisco and channel 8 in Monterey, or Detroit and Cleveland, can exist because each station's transmit site is at least 60 mi apart. For UHF the separation is 55 mi. The FM radio band, aircraft, and some public safety services are located between channels 6 and 7. That is why broadcast facilities with channels 6 and 7 can be in the same or nearby markets. The FM radio channels are, therefore, in the VHF band as well. However, to avoid confusion, the radio stations that are found between 88 and 108 MHz are called FM after their method of modulation (frequency modulation). The VHF television channels start up again with channel 7 at 174 MHz and go to the top end of channel 13 at 216 MHz. Channels 2 through 6 are referred to as low-band VHF, and 7 through 13 are known as high-band VHF. There is a big gap between channel 13 (VHF) and 14 (UHF). The low end of UHF, channel 14, is at 470 MHz. The UHF television band runs uninterrupted up to channel 83, whose upper-channel edge is at 890 MHz.

Depending on your geographical location in the country (the FCC divides the country into three zones) and whether the station is UHF or not, broadcasters using the same frequency must never be closer than 155 mi from each other (northeast U.S. UHF), although spacing of up to 220 mi can be required (southeast VHF). As mentioned previously, early television receivers limited the combination of channels that could exist in a geographical area. In the UHF band you would think that you could have broadcast stations on every other channel, but that was not possible when channel assignments to the various markets were first handed out. The tuners, or front ends as they are called, in early sets could not filter out unwanted energy or signals from other stations or the harmonics and intermodulation from those other channels. Harmonics are basically multiples of frequencies in a signal. *Intermodulation,* or intermod for short, occurs when two separate signals mix together to create additional signals. This usually happens in the receiver because its tuner can't filter out, or throw away, all the unwanted signals and only keep the desired one. Additionally, sometimes when high-power broadcast transmitters are near one another, intermod can be created at the transmit end.

Except for adjacent channels in VHF this wasn't a major problem in the VHF band because the band was fairly narrow, barely over 150 MHz wide, with an 86-MHz hole between channels 6 and 7. However, the UHF band is 420 MHz wide. So besides the 55-mi adjacent channel taboo, a number of other taboos exist. Channels that were within five channels of each other had to be at least 20 mi from each other or intermod in the receiver could result. Additionally, channels that were 7, 8, 14, and 15 channels apart also presented reception problems to most early receivers. Channels that were 7, 14, and 15 channels apart had to have separations of 60, 60, and 75 mi, respectively, which is why there are not as many UHF stations as you might think. Television channels are a precious and, thus, often contested commodity.

1.4.2 Problems handling UHF channels

Cable systems have greatly added to the mix of programming available to the home, and we will examine them later in this chapter. However, early cable systems were limited as to the amount of programming capacity they could add. When cable began in earnest in the 1970s, the adjacent channel taboos were greatly suppressed by the receiver technology of the day. So channels could be packed next to one another on a cable system. The problem that the cable systems had was bandwidth. Most early cable systems had upper bandwidths that stopped at 300 MHz. The infrastructure of the cable system, mainly the amplifiers, splitters, and set-top boxes, was the limiting factor with regard to the size of the information pipe for a given cable system. Although early coaxial cable could pass higher frequencies, it had greater loss (especially at high frequencies), which required more amplifiers, and remember that each one slightly degrades performance to push the signal a given distance. A top end of 300 MHz covered the VHF but not the UHF band.

To add additional channels to the cable system, many systems down-converted the UHF channels 14 to 22 to the frequencies above the FM band and below the band where channel 7 begins (120 to 170 MHz). These frequencies were called midband VHF because they were between the low- and high-band VHF channels. UHF channels 23 through 36 were moved to the frequency range directly above the high-band VHF frequencies (216 to 300 MHz). These frequencies were called superband VHF. This shuffling of channels required cable customers to have set-top boxes from the cable company to view these channels. In the 1980s equipment became available to rebuild systems to allow top-end bandwidths of over 500 MHz, but many systems had bandwidths that topped out at 400 MHz. This still allowed over 50 television channels to be carried. Now, many systems are being rebuilt with fiber-optic cable. Thus, the roll-off due to copper (coaxial cable) will be eliminated. In addition, television sets that are "cable ready" are now universally available. A cable-ready set has two channel modes. The first one is the historical terrestrial television channel mapping. The second one tunes the channels based on the cable channel–shuffling scheme just described.

As you now see, UHF stations are at much higher frequencies than VHF stations, which poses a number of problems. The first problem that most early UHF stations had was that no sets could receive the channels. Even after color sets were in full production, most didn't have the ability to tune UHF. Most early UHF viewers did so with a UHF converter box sitting on top of the set. The set-top box, as it turns out, is not new and will probably make a return engagement with DTV. The lack of viewers wasn't the only problem the pioneer UHF broadcaster faced. Transmitters at higher frequency tend to be much less efficient, which means more incoming power is needed to get the same RF transmit power that you would at lower, that is, VHF, frequencies. Once the RF power is out of the transmitter, it must be sent to the top of what is typically a tall transmit tower to the antenna (Fig. 1.12).

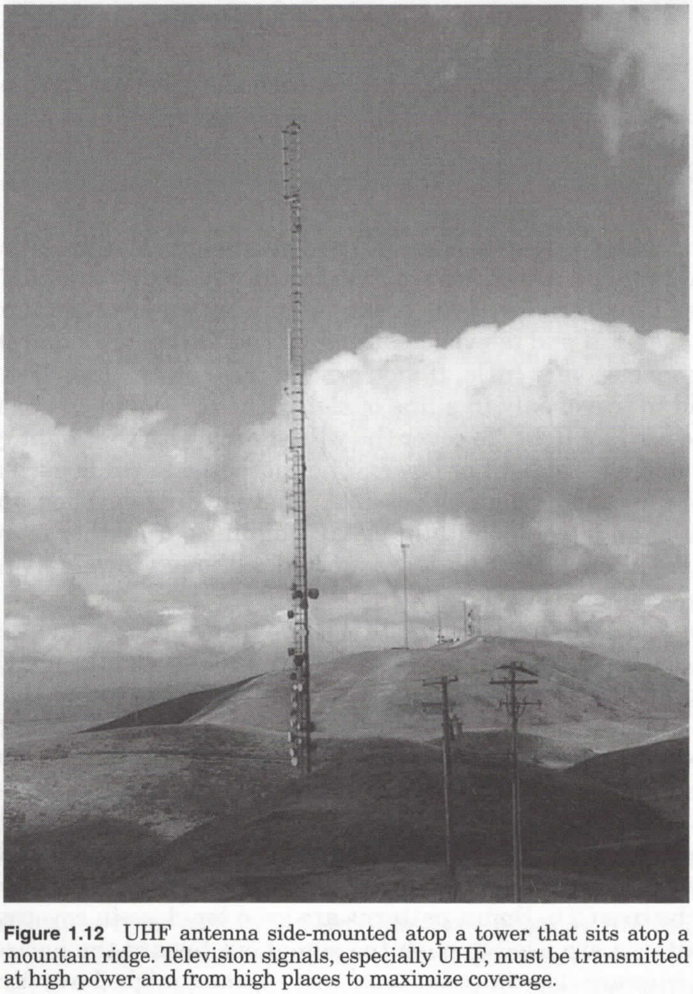

Figure 1.12 UHF antenna side-mounted atop a tower that sits atop a mountain ridge. Television signals, especially UHF, must be transmitted at high power and from high places to maximize coverage.