INTRODUCTION

This booklet is intended to help people in post-Communist countries design and assemble low-cost radio broadcasting stations. It tells what equipment is needed, describes some factors in site selection, and gives suggestions useful in station construction. It does not tell how to get a license or what to broadcast. Certainly it is no substitute for having a competent radio engineer on the project team.

We assume a license has been - or soon will be - issued for your station. But since this is a time of transition, we cannot be sure what regulations apply to new broadcasters. So a range of options is presented for most aspects of station design. Some are for "cutting corners" when money is scarce, and are otherwise not recommended when you can afford to do better.

Aside from rules, which vary from country to country, the kind of programming you plan to broadcast, the amount of money available for construction, and many other factors, affect station design. No one design is right for all situations. This booklet may help clarify what fits your needs and circumstances.

Just because an option is described here (such as a radio link between the studio and transmitter), that does not mean it is permitted in your country. Study the laws and regulations governing broadcasting before you acquire any equipment. If you are not authorized to use that equipment, you could encounter legal problems, penalties and added costs.

Technical standards for electronic media adopted earlier in the Communist countries differ in certain ways from those elsewhere. For example, the frequencies used for FM broadcasting were different from non-Communist countries. There are also regional differences in studio "line levels," audio tape equalization norms, and the signal that makes a telephone ring. Such incompatibilities can cause problems for new broadasters using imported equipment. Some points where such problems can occur are noted here, but there are surely others we overlooked. If you find any mistakes or bad recommendations here, please let us know so we can correct and improve later editions.

Many people helped in the preparation of this guide. The errors are my responsibility, but special thanks go to Jay Allison, John T. Arthur, Bjorn Bergsten, Brett Breitwieser, Andy Clews, Michael Covington, Kenneth Donow, Scott Dorsey, Jerzy Farner, Ingo Gunther, Kauto Huopio, Milan Jakobec, Leif Lonsman, Geert Lovink, Jorma Mantyla, Petr Marek, Ken Mason Jr., Evelyn Messinger, Lorenzo Milam, Tamas Pelzer, Mike Peyton, Skip Pizzi, Tamas Revoczi, Eric Sinclair, Leszek Stafiej, K. Dean Stephens, Sandor Szilagyi, Randy Thorn, Stansilaw Vnik, Jackie Washington, Dave Wilson, Ernest Wilson, Alvin Wong & Tracy Wood.

The opportunity to create new kinds of programming for audiences eager for change is precious. This booklet focuses on technology, but never forget it is the content that draws and holds listeners' attention, not the equipment. Good luck!

---Robert Horvitz

CONTENTS

BANDS FOR BROADCASTING

Broadcasters are not the only people who use radio to communicate. To prevent radio systems from interfering with one another, there are international agreements that allocate bands of frequencies to specific kinds of stations. Governments then assign a small portion of a band - a channel[1] - to individual licensees.

Different bands, and even different channels within a band, have somewhat different physical properties. That affects the design of the antenna and transmitter. You may have already been assigned a frequency; if so, your transmitter and antenna should be optimized for that frequency. The opposite is also true: the transmission system should be designed to minimize emissions outside of the assigned channel. Out-of-channel emissions can violate the terms of your license and interfere with other stations.

If you have not yet been assigned a channel and are able to choose one, this section describes the options. Band boundaries and channel spacings vary somewhat from one country to another, but in general the bands for audio broadcasting are:

148.5 - 283.5 kHz:[2] The "longwave" band is not a practical option for new broadcasters. Longwave signals have a very long range - hundreds or thousands of kilometers - so permission to broadcast requires international approval. In Europe it is unlikely that more stations can be accommodated without causing interference to existing stations. Also, longwave broadcasting involves huge antennas and lots of electric power, so it is expensive. Finally, the channels in this band are too narrow and noisy for broadcasting music with high fidelity.

526.5 - 1606.5 kHz; The "mediumwave" band has been used for broadcasting for decades. Mediumwave receivers are inexpensive and found in nearly every home and vehicle. In this band, sound is put on the radio "carrier waves" using a technique called amplitude modulation (AM).

In Europe this band has 120 channels. Assigned frequencies are divisible by 9 and are 9 kHz apart (531, 540, 549, 558,... 1602 kHz). Note that three channels are set aside for low-power stations: 1485, 1584 and 1602 kHz. Low-power, in this context, means 1000 watts (1 kW) or less. The International Organization

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1. The terms "channel" and "frequency" are used interchangeably here though they are not quite the same. A "channel" is the small sub-band where a station is authorized to broadcast. "Frequency" is the radio frequency that carries the station's audio output. In broadcasting, the carrier frequency is usually in the middle of the channel.

2. kHz = kilohertz = 1000 wave-cycles/second.

of Radio & Television (OIRT, whose members include the post-Communist countries) generally conforms to this plan: the few governmental stations using these channels have outputs of 1 - 2 kw (see box). Their presence could limit the licensing of new stations in nearby areas. However, there has been talk about shutting off some state owned mediumwave transmitters, or renting them to others. So check to see if these channels are available in your area, and under what conditions.

Mediumwave is good at covering hilly and rural areas. Large regions can be reached, especially at night, when signals radiating upward reflect back to Earth. Unfortunately, night-time range enhancement also means the band is crowded with interfering stations after sunset, many of them powerful and located in other countries. So interference and noise are more noticeable than in the FM bands.

If you have a choice, try to get a channel at the high end of the band. The antennas needed are smaller than at lower frequencies, and the night-time range enhancement is greater. But try to avoid assignment to a frequency that is twice that of any nearby mediumwave station. For example, if 792 kHz is already used in your area (as it is in both Prague and Bratislava) new low-power stations in those cities could suffer interference on 1584 kHz. This is because mediumwave transmitters tend to produce unwanted emissions on the carrier frequency's first harmonic.

In 1978, to control interference between stations operating in different countries, the International Telecommunication Union (ITU) adopted a plan limiting the field strength of mediumwave signals to 500 microvolts per meter (uV/m)[3] at national borders in Europe, unless the nation affected permits an exception. That restricts the power, location and antenna design of mediumwave stations near borders. So in some areas it may not be possible

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3. 1 microvolt = 1 uV = 1/1,000,000 volt. Field strength is described as the voltage induced in a wire 1 m long oriented perpendicular to the radio waves. In decibel notation, 500 uV/m = 54 dBu, where dBu = 20 $\log_{10}$ 500 uV/m. The "u" in "dBu" indicates that the dB value is relative to 1 uV/m.

to establish new stations - or more expensive directional antennas might be required to keep signals away from the border.

66 - 74 MHz[4] (OIRT FM low-band) : The OIRT nations have used this band for FM broadcasting since the 1960s. Most other countries use a higher band for FM broadcasting (discussed next). Many post-Communist nations now want compatibility with Western Europe, so they plan to move FM broadcasting to the higher band. This migration could take years: the state-owned networks will not abandon their existing transmitters immediately, and listeners will need time to acquire receivers which tune the higher band. The move begins when new stations are assigned frequencies at 87.5 - 104 MHz. The telecom ministry in your country can advise you on future plans for the OIRT FM low-band.

If new stations are allowed to use the low-band channels, consider the advantage of an already-equipped audience in the habit of listening there - against the disadvantage that broadcasting in this band could end later this decade. Also note that transmitters, antennas, and receivers for this band are made only in the OIRT countries - though some equipment made elsewhere may be adaptable.

87.5 - 104 MHz (EBU FM high-band);[5] This is the band most new broadcasters will probably use. It is more than twice as wide as the FM low-band and can accommodate many new stations.[6]

Radio waves in this band behave much as they do in the FM low-band. FM resists noise and interference much better than mediumwave-AM, and is superior for music. But FM signals do not flow over the contours of the earth as smoothly as mediumwave. Hills and large buildings cast FM "shadows" where reception is weaker, and reflect energy that can interfere with radio waves coming directly from the transmitter. Even at high powers, an FM station's range is limited to just beyond the horizon. Another difference from mediumwave is that FM signals behave the same at night as during the day.

In both the high and low FM bands, antenna height has a big impact on a station's range. An antenna mounted high above the ground can reach beyond the horizon. Height also reduces the size of radio shadows, the scattering effect of buildings and trees, and power lost to ground reflections. See the section on POWER, HEIGHT & SIGNAL RANGE for more details.

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4. MHz = megahertz = 1000 kHz = 1,000,000 wave-cycles/second.

5. EBU = the European Broadcasting Union, a regional organization which coordinates broadcasting policies and standards in Western Europe.

6. The American magazine Broadcasting cited studies indicating there is room for over 400 new FM stations in Poland, and over 250 in Czechoslovakia.

FM channels are much wider than medium-wave channels (200 kHz versus 9 kHz). Assigned frequencies are usually a multiple of 0.1 MHz, with nearby stations separated by at least 0.2 MHz (or more often, 0.4 - 2.0 MHz). Such wide channels and frequency separations reduce the number of stations which can use the band, but this is necessary because of the "FM capture effect": when two signals are too close in frequency, an FM receiver will process only the stronger one and ignore the weaker one. This is bad for low-power stations. Also, when the separation of frequencies is greater than 2 MHz, stations can broadcast from the same tower or rooftop without installing costly filters to stop mutual interference.

Because the OIRT countries did not use this band for FM broadcasting before, they built TV sets which happen to produce some radio noise at these frequencies. If you tune an FM receiver through the EBU high-band in neighborhoods where TV sets are on, you are likely to hear loud annoying buzzes. Sets tuned to TV channel Rl radiate FM noise most strongly at 87.7 - 87.8 MHz? sets tuned to TV channel R2 radiate on 97.2 - 97.3 MHz. If either TV channel is used in the area where you plan to broadcast, try to avoid being assigned an FM channel near the known noise frequency. It is a good idea to tune through the entire FM high-band to assess the local noise situation before you go on the air. Noise from TV sets will be a problem until they are replaced - a process that will take many years. Meanwhile, TV noise could reduce the effective range of some new FM stations.

A positive reason to start using this band is that there are many foreign sources of good equipment. The main drawback is that listeners either must buy new receivers, or get frequency adapters for their old radios.

EQUIPMENT REQUIREMENTS

The minimum equipment needed to broadcast is: a microphone, a source of electric power, a transmitter and an antenna. That description fits the "wireless microphones" sometimes used by film actors who need freedom of movement. Their range is measured in meters (m) and the public is not expected to receive the emissions. But increase the power, the transmitter gain, the antenna size, and the number of sound sources, and you have the seed of a broadcast station.

Colleges, factories and other institutions sometimes have broadcast stations that deliver audio signals to listeners by wire. Those usually have a studio with microphones, turntables and audio cassette players. If the wire distribution network was replaced by a radio transmitter and antenna, the studio could be used to broadcast to the general public for less cost than starting from zero.

So one way to reduce the cost of starting a radio station is to use an existing studio built for wire broadcasting. Check to see if one is available in your area. Is the equipment suitable for the kind of programs you want to create? Does everything work? Are spare parts available? Is the studio's signal output compatible with your transmitter's input (in terms of impedance, voltage, mono/stereo)? Can you put an antenna on the roof? Are there large buildings nearby which might block the signal? Can you reach the desired audience from that location within the power limit set by your license? If you cannot put the antenna there, can you afford a studio/transmitter link to another site?

Another cost-saving strategy is for stations to share facilities. It is possible for stations to share a production studio, for example. Sharing an antenna tower, rooftop, or even the antenna itself, is common in Western countries. A less ambitious, short-term cost-saving arrangement is for several stations to buy a large spool of coax cable together, or a large quantity of audio tape, then divide the purchase in proportion to the individual contributions. Buying in large quantities usually reduces the per-unit cost.

K. Dean Stephens has tested several minimum-cost configurations capable of broadcasting to an area the size of a village. His plan for a village radio station involves the following equipment:

50+ meters of multi-strand copper wire for the antenna
antenna tuner (can be built)
AM or FM transmitter of up to 100 watts
2 microphones with stands
2 audio cassette machines
2 phonograph turntables
2 sets of earphones
5-channel audio mixing console
audio cables and electrical wiring

...plus accessories like an on/off indicator for the transmitter, a studio lamp, etc. Such a small station can run on power from a generator or automobile batteries, if electricity is not otherwise available.

By relying on used, donated, scavenged and locally built equipment, Stephens says that the entire station can be put together for under $2000, not including the building which houses it. Unfortunately, he does not tell where to buy such an inexpensive transmitter. To fit that budget, it would probably have to be built by someone at the station.

In his design, a wire antenna for mediumwave broadcasting is strung horizontally between two tall posts. Since the signal radiates most strongly perpendicular to the wire, the antenna is oriented so most listeners are to either side of it. Stephens claims that in the absence of interference from other stations, "a 100 watt [transmitter] operating on 1000 kHz the middle of the standard broadcast AM band can penetrate up to 30 km distance from such an antenna; a similar 10 watt system can cover 15 km; 1 watt can be received up to 7 km away, and a 1/10 watt micropower unit can still penetrate to 3 km." FM transmitters yield similar ranges at similar power levels, although "both transmitter and antenna are apt to be more expensive."[7]

A local station better suited to the needs of a modern city might include the following equipment:

(Diagram Missing)

Sound sources
- 2 studio microphones (with stands)
- 2 field microphones
- 1 telephone interface
- 1-2 turntables
- 2-3 cassette tape players (with noise reduction)
- 2 compact disk (CD) players
- 2 open-reel tape machines
- 1 or more cartridge tape machines
- audio tapes and cartridges, phonograph records, CDs

Signal processors
- on-air mixing console
- mixer for producing pre-recorded material
- 2 sets of earphones
- loudspeakers
- audio interfaces to connect "balanced" & "unbalanced" devices
- filters and equalizers
- audio cable
- FM peak limiter/pre-emphasis unit (optional)

Studio-transmitter link
- coax or audio cable (if <30 m)
- wire or radio system (if >30 m)

Transmission system
- transmitter (AM or FM)
- SWR, power and modulation meters
- antenna feedline
- impedance matching network/antenna tuner
- tower or other support
- antenna
- grounding system

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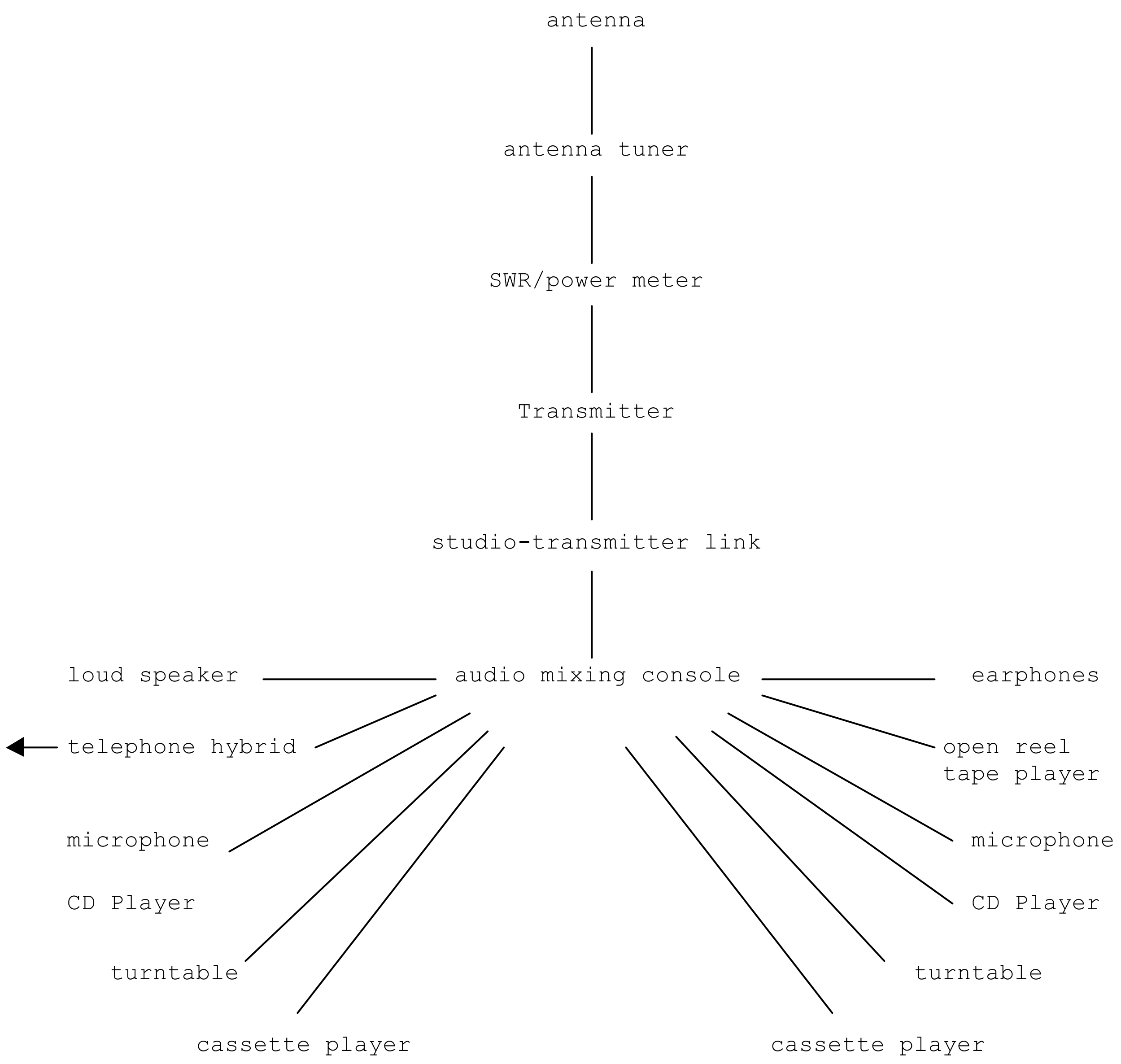
7. K. Dean Stephens, Village Radio Owner's Manual, p. 13. Available for $5 from: The Vanguard Trust, H C-02, Box 14765, Arecibo, Puerto Rico 00612 USA.

These elements are discussed in more detail below. Test equipment is also needed to ensure that everything is aligned and working properly. Studios and offices require space in a suitable building. And sources are needed for electric power and repair parts.

The cost of a local radio station is not easy to figure, as equipment prices vary so widely, especially mixing consoles, the studio/transmitter link, and the transmitter. But it should be possible to go on the air for as little as $15,000 - not including furniture, rent, import tariffs or fees imposed by the telecommunications ministry.



Equipment configuration for a small radio station

(Diagram Missing)

A radio station when funds are unlimited!

Design factors that push station costs above the minimum include: separating the studio and transmitter by more than 40 m; broadcasting in stereo; and increasing the transmitter power beyond a few hundred watts. There are also some devices that, while not absolutely essential, are useful if you can afford them: equalizers and cart machines, for example. These are discussed below, too.

The kind of programs you plan to broadcast influences the station's equipment needs. If you intend to produce a lot of news documentaries or advertisements, more production equipment will be needed than at a station playing only pre-recorded music. If music is your station's focus, good audio playback equipment is essential. If the station is primarily interested in news-reporting, funds might instead go for portable cassette recorders and field microphones.

STEREO OR MONO?

Most new FM stations want to broadcast in stereo. But stereo is not essential in broadcasting, and it creates some problems.

Stereo requires additional equipment in the studio, the transmitter, and the link connecting them. It also puts higher performance and maintenance requirements on that equipment. Getting better performance from more equipment increases the complexity and cost of the station.

For mediumwave stations, there are few benefits from the added cost of stereo. It does improve sound quality. However, mediumwave stereo receivers are not yet widely available, partly because incompatible modulation systems are promoted by various companies. Unless a station and its listeners are both equipped with the same stereo system, broadcasts will only be heard in mono. If different broadcasters in the same area adopt different stereo systems, listeners will need either a multi-standard receiver, or different receivers for each stereo type. Japan recently adopted the C-QUAM system as their national standard. That means Japanese production of C-QUAM stereo receivers will probably increase, which may help settle the standards issue.

FM stations also have hard choices, despite the fact that FM stereo is common in many parts of the world. Perhaps the most important consideration for low-power stations is that the range of an FM stereo signal is 15 - 30% less than a mono signal. That means much less coverage from the same amount of power. (See the section on POWER, HEIGHT & SIGNAL RANGE, below.)

Second, as in the mediumwave band, there is a problem of compatibility. In the 1960s the Soviet Union developed an FM stereo system based on "polar modulation." Many stereo receivers built in the OIRT countries employ this system for the 66-74 MHz band. However, the FM stereo standard in North America, Japan and the EBU countries is based on a "pilot-tone" system. Receivers designed for one stereo standard do not respond to stereo transmitted in the other.

Some of the first independent stations in Central Europe came on the air with Western stereo FM transmitters, even though few of their listeners were able to receive that kind of stereo. But pilot-tone stereo receivers are available now as imports for the 87.5 - 104 MHz band, and will be manufactured in postCommunist countries soon, if not already.

So in this period of transition, stereo is a tough issue for Central Europe. It raises costs while reducing FM coverage - yet FM listeners like stereo music. The best decision may not be the same for every station. Before buying a transmitter or a mixing console, try to find answers to these questions: Has your country adopted rules on the use of stereo by broadcasters? Are those rules currently enforced? What percentage of listeners in your area have stereo receivers? What stereo system are they designed to receive? What percentage of listeners say they would chose a broadcast in stereo over one in mono, if all other factors were equal? What stereo system (if any) do other broadcasters in your area plan to adopt?

Finally, compare the local cost and availability of mono, "polar modulation" stereo, and "pilot-tone" stereo receivers. You can learn a lot about listener preferences and trends in receiver sales by talking to people who work in stores that sell radios.

To sum up, the stereo modulation used in most 87.5 - 104 MHz transmitters and receivers is pilot-tone. That makes it likely this system will eventually be the norm in the FM high-band in OIRT countries. It is less clear what will happen in the FM low-band, and so far public demand for stereo in the mediumwave band has been slow to emerge.

STATION LOCATIONS

The first step in deciding where to build your station is to define the area you want to serve: draw the contours of the target area on a map. If possible, use a map that gives landscape data: the locations and heights of peaks, ridges, valleys, etc. The station's transmitter and antenna should be sited so the whole target area is in range of the signal.

Low-power stations may have only a few sites which give them the desired coverage. Since FM coverage increases with height, stations often put their antenna on a mountain, or on top of a tall building, with the transmitter in a top-floor room. The studio might also be on the top floor, or lower in the building. More than one station can use the same roof, so long as they cooperate to solve technical problems. If a higher mount for the antenna is available near the edge of the coverage area, that might be better than a lower mount near the center: a directional antenna can be used at an edge site to aim the radio energy toward listeners.

Mediumwave signals have more range if the antenna is tall but set at ground level, surrounded by a large electrical grounding system buried in wet soil. Such stations are often built on open land at the edge of a city.

While the transmitter must be near the antenna, you have some flexibility in where to put the studio. A separation of more than 30 - 40 m increases the cost and complexity of the studio/transmitter link (STL). Sometimes this is desirable anyway. Why? The best location for an antenna might not be convenient for a studio -it might be on top of a church steeple or a mountain. Perhaps there are no roads or buildings nearby. If the antenna is on a rooftop, maybe rooms in that building are too expensive to rent.

(See Diagram Lr2)

antenna

transmitter

studio & offices

Local FM station with rooftop antenna

The main drawback of separation has already been noted: the added cost and complexity of the STL. The station's signal still must get from the studio to the transmitter without sacrificing audio quality, and if the station is responsible for maintaining the transmitter, the engineer must be able to monitor its performance so technical problems can be solved quickly. That means either the engineer must be at the transmitter site, or the data he needs must be relayed to his location, which means a two-way STL. (The alternative is longer, costlier service interruptions.) Another potential drawback is dependence on the telecommunications ministry for the STL if they won't let you install your own.

STLs are discussed below. Here it is worth noting that when the connection is by wire, the cost is often related to length, and the telecom ministry's price can be very high indeed. Solidarnosc Radio in Warsaw found that the special phoneline connecting their studio to the transmitter was their biggest monthly expense, costing more than all of their staff salaries combined. Installing your own STL is often possible and very much cheaper.

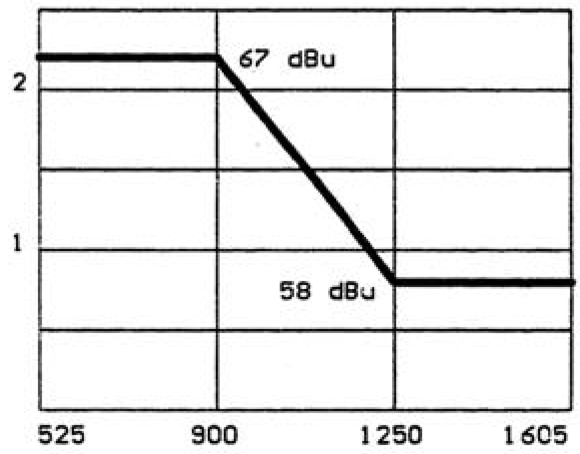
If the STL is a radio link - that is often the best option -having a clear straight path through the air is desirable: try to locate the studio where there is an unblocked view of the transmitter site.

To sum up: when it is practical to put the studio, transmitter and antenna at the same site, do so. But if the studio must be elsewhere, that is possible, too, with some added complications and costs.

POWER. HEIGHT & SIGNAL RANGE

When we speak of a station's range, what we really mean is the maximum distance from the transmitting antenna at which most listeners find an acceptable signal/noise ratio most of the time. Since range depends not just on transmitter power, but on local radio noise levels, landscape features, the design of antennas and receivers, etc., predicting what will be found in actual situations is an uncertain art. Nevertheless, here are some tools for predicting range.

For mediumwave stations, the International Consultative Committee for Radio (CCIR) recommends a minimum field strength of 2.2 mV/m[8] (= 67 dBu, in decibel notation) at the receiving antenna for signals between 525 - 900 kHz, and 0.8 mV/m (58 dBu) for signals between 1250 - 1605 kHz. The minimum values vary from 2.2 to 0.8 mV/m in the 900 - 1250 kHz band (see the chart).



For FM Stations, the CCIR recommends field-strengths of at least 0.05 mV/m (34 dBu) for mono, and at least 0.25 mV/m (48 dBu) for stereo, "in the absence of interference from industrial and domestic equipment." However, hills, buildings and trees weaken radio waves, and radio noise from TV sets, manufacturing, and other broadcasters raises the minimum needed for good reception. Therefore, the CCIR recommends these minimum field strengths for mono FM reception: 0.25 mV/m (48 dBu) in rural areas, 1 mV/m (60 dBu) in urban areas, and 3 mV/m (70 dBu) in big cities. For FM stereo the minimums are 0.5, 2 and 5 mV/m (54, 66 and 74 dBu, respectively).

Since radio signals generally weaken the farther they are from the transmitter, these minimums must be achieved at the limits of your coverage area. Then, listeners closer to the transmitter will probably get an adequate signal if there are no "shadows" due to obstructions. Measure the distance from any potential antenna site to the farthest point on the edge of the coverage area. Can the necessary minimum field strength be delivered there?

There are ways to calculate the power necessary to produce various field strengths at some distance from the transmitter. Unfortunately, each method is based on different assumptions and leads to a different answer. That is because no abstract model

8. mV/m millivolts/meter. 1 mV/m = 0.001 V/m = 1000 uV/m.

can account for all real variables without creating unsolvably complex equations or drawing on factors that are too hard to measure.[9]

To meet FM broadcasters' need for a practical way to predict the range produced by various combinations of power output and antenna height, the US Federal Communications Commission (FCC) performed tests in the 1950s and summarized their findings in charts. Today's radio receivers are more sensitive than those built back then, so the charts probably underestimate the ranges possible with modern equipment. But since most listeners in post-Communist countries do not yet have the latest and best equipment, the charts are still relevant. A simplified version of the most useful chart, extended to include lower antenna heights than are allowed in the US, is given on the next page.

The scale across the chart's bottom shows antenna height relative to the landscape 3 - 16 km away. (It is not enough to measure the antenna's height above the ground at its base. Hopefully, that ground will be one of the high-points in the coverage area. What matters is height relative to where the listeners are. To figure that, consult a map showing land elevations in the area. Draw 8 evenly-spread radial lines out from the antenna site and average the elevations found along those radials at distances of 3 - 16 km. If you cannot find such a map, survey the area as best you can.)

The vertical scale on the left of the chart represents the field strengths that can be expected more than half of the time at more than half of the receivers located 9 m above the ground. (Receivers closer to the ground will get a weaker signal, those higher up will get a stronger one.)

The drawn curves show the distances (km) at which various field strengths are found when an antenna of a certain height radiates 100 watts ERP. Each curve's distance is shown on the right edge of the graph.

Confused? It will all become clear when you start using the chart. Say your broadcasts are mono, the power allowed is 100 watts ERP, your target area is a medium-sized city/ and you want to reach listeners 20 km away. How high does the antenna have to be? For mono signals the CCIR's recommended minimum field strength is 60 dBu. Find 60 dBu on the left edge of the chart. Follow the horizontal line which starts there, and note where it crosses the "20 km" distance curve. Read straight down from that crossing to the bottom of the chart to find the antenna height, which appears to be about 350 m. So to deliver a mono FM signal to urban listeners 20 km from the transmitting site, the antenna should be about 350 m above the average terrain when the station's radiated power is 100 watts.

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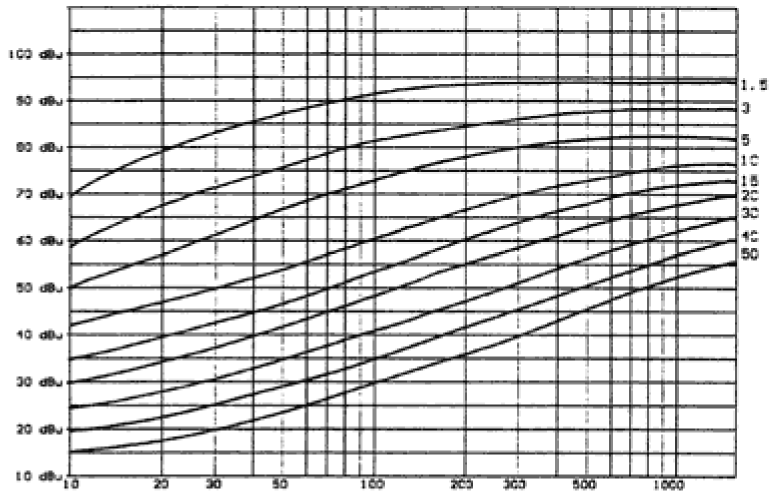
8. There are important differences between transmitter power and "effective radiated power" (ERP). ERP takes into account the feedline losses and antenna gain. In this section, when the terms "power" and "power output" are used, we always mean ERP

Adapted from an FCC chart showing probable FM field strengths at various distances and antenna heights when the effective radiated power is 100 watts:

(See Diagram Lr4)



Antenna Height (m)

That's quite high up. What if the antenna is lower, say 50 m above the coverage area? To find out, start with the 50 m height marker on the bottom edge of the chart. Read up that vertical to where it crosses the horizontal 60 dBu field strength line. The crossing occurs midway between the 5 and 10 km curves. So a mono FM station radiating 100 watts from an antenna 50 m above an average city probably could deliver an adequate signal to a distance of 7 - 8 km.

What if the station doubled its power to 200 watts ERP? How much would that increase the range?

Here is where the chart's "dB" notation proves useful: it gives us a way to modify the information in the chart for outputs other than 100 watts. This mathematical trick sounds more complicated than it is. If you grasp it, you will be able use the chart to estimate the range of nearly any combination of antenna height and power output. That can be a great aid in evaluating possible antenna sites and transmitter purchases.

Footnote 3 mentioned that dB = 20 times the $\log_{10}$ of one voltage divided by another. When dealing with watts, the formula is modified: dB = 10 times the $\log_{10}$ of one power level divided by another. (An electronics textbook can explain why.)

Returning to our example, 200 watts divided by 100 watts = 2. $\log_{10} 2 = 0.301$, which multiplied by 10 = 3.01. In other words, doubling the power is the same as adding 3 dB to the output. Quadrupling the power, from 100 to 400 watts ERP, is the same as adding 6 dB. Increasing the power from 100 to 1000 watts is the same as adding 10 dB to the output. A logarithmic table can help translate other power changes into dB, and dB changes into the equivalent powers.

Instead of redrawing all the distance curves on our chart, shifting them upward to reflect an increase in power, we get the same results by shifting downward the horizontal lines representing field strength at the receiver. Rather than redraw the lines, just subtract the dB equivalent of any power above 100 watts from the numbers along the left edge of the chart. For powers below 100 watts, add the dB equivalent to the dBu values.

So, doubling a station's radiated power is equivalent to reducing by 3 dB the field strength needed for good reception - from 60 to 57 dBu, in this case. The horizontal representing 57 dBu crosses the vertical representing a 50 m antenna height closer to the 10 km curve, but not by much. At this height, doubling the power to 200 watts only increases the range from about 7.5 km to 9 km. Increasing the power to 1000 watts (+10 dB) lets us subtract 10 dB from the field strength needed at the receiver. But that only boosts the range to 12 - 13 km.

So how much power <u>is</u> needed to deliver an adequate signal 20 km from a 50 m antenna in a city? The chart holds the answer. The vertical representing a 50 m antenna height crosses the 20 km distance curve at a field strength of 42 dBu. This is an 18 dB shift from 60 dBu. 100 watts + 18 dB = 6309 watts (18 dB = 10 $\log_{10}$ 63.09).

If the antenna was 100 m high, the 20 km curve would be crossed at 48 dBu, a 12 dB shift from 60 dBu. 100 watts + 12 dB = 1584 watts ERP. With the antenna at 200 m, the 20 km curve is crossed at 55 dBu, for a 5 dB shift equal to 316 watts ERP.

This illustrates how much more the antenna height extends signal range than a power increase. In our example, a 7-fold increase in height boosted the range as much as a 63-fold power increase. Keep that in mind when picking a transmitter site!

60 dBu may be recommended for good reception in cities, but that does not mean that beyond the predicted range the station won't be heard. It only means that beyond that limit, patches of poor reception will probably expand to more than 50% of the area. Remember the CCIR's finding that receivers can hear a mono FM signal as weak as 34 dBu "in the absence of interference..." According to our chart, 100 watts from 50 m antenna will deliver 34 dBu to a distance of 30 km.

Obviously there are situations where the chart's predictions will differ from reality. The most important variable is the roughness of the ground. If the area 3 - 16 km from the antenna is flat, signal ranges will be greater than the chart predicts. If the landscape is very hilly, the range will be less.

<u>MEDIUMWAVE</u> Predicting the range of mediumwave signals is harder than FM, and the results are less certain, so we won't explore the techniques in depth.

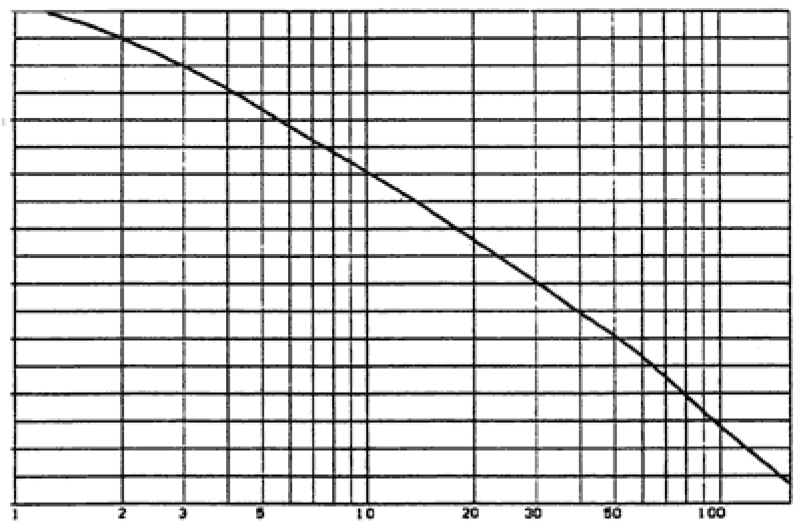
The chart below shows the relationship between field strength (vertical axis) and distance to the receiver in km (horizontal axis). The drawn curve assumes a transmitter output of 1000 watts, a frequency of 1500 kHz, good ground conductivity, and an antenna "gain" of 0 dB (the concept of gain is discussed in FM ANTENNAS, below). As you can see, the CCIR's recommended minimum field strength for this frequency (0.8 mV/m or 58 dBu) is found about 20 km from the source.

But as noted earlier, when people speak of range, they really mean an acceptable signal/noise ratio at the listener's receiver. Noise is the main factor limiting the range of mediumwave signals - especially interference from other stations operating in the same and in adjacent channels.

So it is not just a matter of calculating the field strength at some distance from the transmitter. With mediumwave one must also take into account the strength of signals from distant stations. The task is complicated not just by the number of distant stations, but by the unstable medium delivering those signals:
the ionosphere (the electrically-charged layers of the upper atmosphere) has seasons, "weather," and a day/night cycle that changes the strength of interference from one hour to the next.

(See Diagram Lr3)

Medium Field Strength vs. Distance



(1000 watts ERP at 1500 kHz over good ground)

Distance to receiver (km)

To overcome interference and increase coverage, mediumwave stations try to operate at the highest power allowed. Europe has dozens of stations with outputs of 50,000 - 500,000 watts. Most can be heard over 500 km away. But operating at high powers increases interference to other stations, so ultimately everyone loses from unlimited competition in transmitter power. As the CCIR points out, improving coverage now that the band is full of interference depends less on power increases and more on careful planning of which frequencies are used where.

Energy from distant stations comes down from the sky, but most mediumwave energy reaching listeners within 50 km of a station's antenna gets to them travelling near the ground. This is another important difference from FM: FM signals weaken near the ground, but mediumwaves are conducted along the earth's surface. Sea-water is the most efficient mediumwave conductor. Swamps are good, too. The worse soil types are desert and solid rock. Farm land is between these extremes. In general, the best place to put a mediumwave antenna is in low areas where water tends to collect.

The efficiency of the antenna and ground systems also affects the range. Physically efficient mediumwave antennas are very big and expensive: tall towers with lots of buried wires extending outward in an underground circle. The chart on the previous page assumed an antenna gain of 0. If the station cannot afford a full-scale antenna and ground system, the antenna will undoubtedly have a negative gain - that is, a power loss -reducing its range. So mediumwave coverage is limited not just by noise and soil conditions, but by economics.

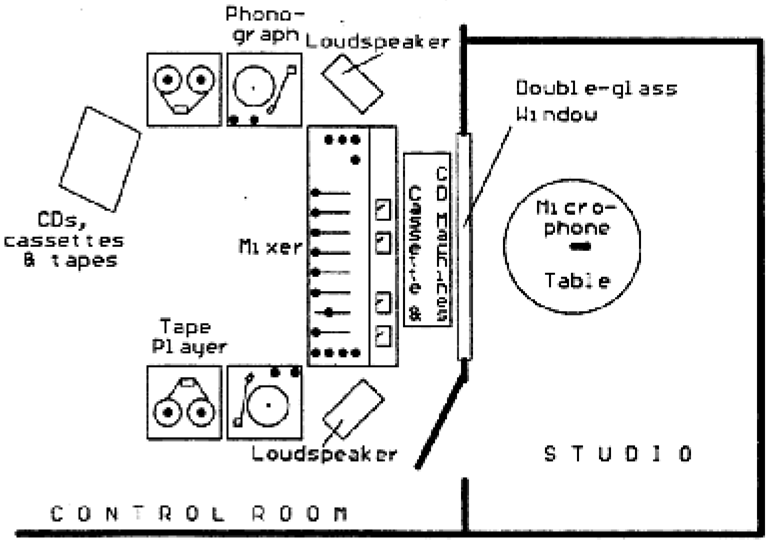
To sum up, putting a mediumwave antenna on a high mount yields little benefit. What does improve range is soil wetness, enlarging the antenna, and more transmitter power - though we seem to have reached a point of diminishing returns in power competition. The cost of an effective antenna could be a big obstacle for new mediumwave broadcasters.

STUDIOS AND OFFICES

How many people will work at the station? That, more than anything, determines how much space you need. The minimum equipment needed for a low-power station can fit in a one room. But unless your programs are completely pre-recorded, the on-air studio should be separated from other station activities. This is so the person on the air won't be distracted, and office sounds will not be picked up by the microphone. (An exception: some stations have an on-air microphone in the newsroom, believing that office sounds add a feeling of immediacy to news bulletins.)

Beyond that, it is a good idea to let only the technical staff have access to the transmitter. Unless the transmitter is at a different site, that means putting it in a room separate from the on-air studio and the nontechnical staff. A quiet room for producing pre-recorded material is also desirable.

Some radio station floor-plans



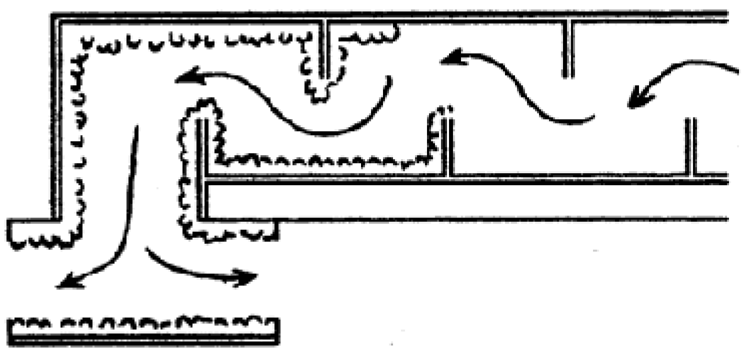
THE ON-AIR STUDIO

The on-air studio should not be bothered by sounds and vibrations interfering with program creation. It is better to pick a quiet location than to try to soundproof a noisy one.

No pair of wall, floor or height dimensions in a rectangular studio should form a ratio of 1:1 or 2:1, or else the space will resonate. Resonance is generally not a problem in irregularly-shaped rooms. It takes a lot of carpentry, but to get the best studio acoustics, some stations actually build non-parallel walls that are not physically connected to the walls of adjacent rooms. The studio then becomes a room inside a room, isolated from sound transmitted by contact with the rest of the station. An easier approach to soundproofing is to pad the walls with soft, textured material: cork, carpeting or drapes, for example. Floors should also be carpeted.

Studio acoustics are less critical when "cardioid" microphones are used (see MICROPHONES, below). In fact, cardioids can be a cheap shortcut to an acoustically acceptable studio when the programming is simply disk-jockeys (DJs) playing recorded music. However, stations planning to conduct interviews and discussions in the studio cannot ignore room acoustics.

While the studio must be quiet, it also must be ventilated and kept at a comfortable temperature. But ventilation can let in noise - or cause it, as with an exhaust fan. Noise entering the studio through a ventilator can be suppressed by lining the duct with soft material, or by building baffles in front of and inside the duct.



Ventilation duct with baffles and soft lining.

Will the person speaking on the air also operate the mixing console? This is common in smaller stations in the US: the control room and on-air studio are combined in a single cluster of equipment. But in larger stations, especially those with news/talk formats, the control room and on-air studio are often in adjacent rooms with a double-pane window in the wall between them for visual communication. Using two panes of glass improves the sound insulation. The glass on t-he studio side is often tilted so it is not parallel to the facing wall. This reduces sound reflection and conductance. (See diagram on next page.)

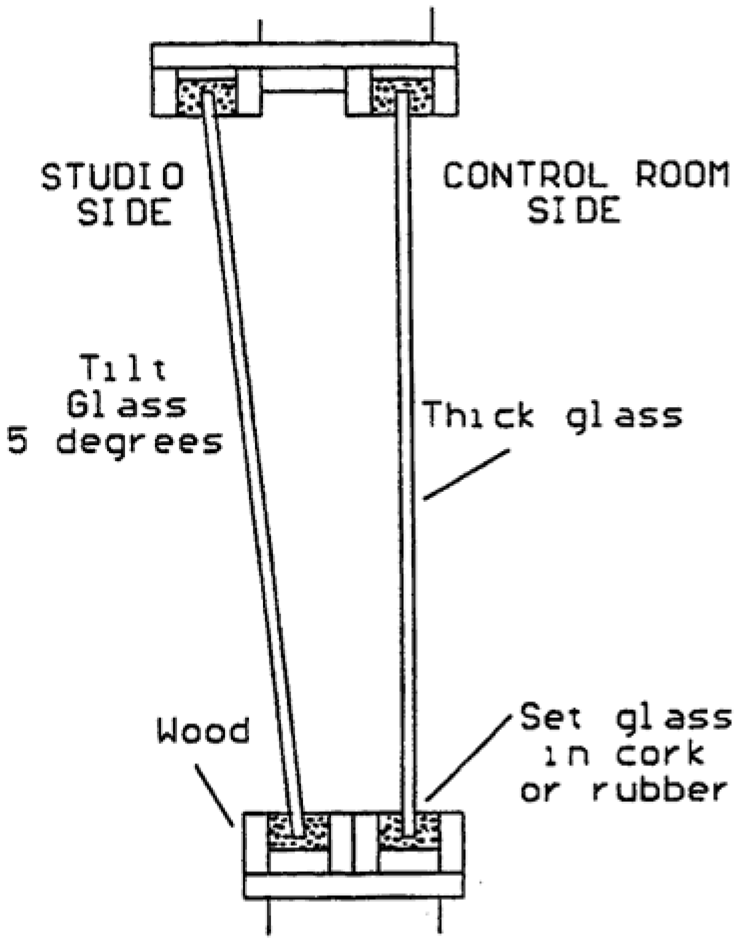
MICROPHONES

Microphones turn sound into electrical energy. There are many types.

They are classified by the shape of their sound sensitivity (omnidirectional, cardioid, shotgun, etc.), and by the method used to convert sound into electricity. Like musical instruments, different brands and models of microphones have different "personalities."

For studio announcing, most stations use a "cardioid," whose sensitivity is limited to the space nearest the front of the microphone. That makes it insensitive to sounds elsewhere in the room. A foam filter often surrounds the head of the microphone, to reduce popping sounds from the letter "p," the hiss of the letter "s," etc.

"Directional" microphones are most sensitive to sounds originating within a cone-shaped volume of air. The width of the cone determines how directional the response is. Such microphones are also used in the studio for interviews and panel discussions. If they are tough enough, they can be used outside the station, where their directivity helps reduce noise from the environment. At close range they are particularly sensitive to low frequency sounds. Many announcers take advantage of this to make their voice sound deeper and more intimate.



A window between the on-air studio and the control room allows visual communication.

Professional studio microphones range in price from a few hundred to a few thousand US dollars. Expensive models are usually "condenser" types, which reproduce subtle details so well that they are used to record classical music. The most highly regarded models for radio announcing are made by

Neumann and AKG. AKG's model C414B seems to be a favorite now at American radio stations. A switch on its base lets you change its spatial response for 4 different patterns: cardioid, hypercardioid, directional, and bi-directional.

There are two problems with condenser microphones: their high cost and their need for electric power. The power usually comes from a battery inside the microphone (which must be replaced every few hundred hours), or from an external source (up to 48 V, usually delivered via the microphone cable. Some mixers are designed to provide the "phantom power" needed by most condenser microphones. But a few European condensers use a different system called "A-B" or "T" power, which is not compatible with phantom power. If you decide to use a condenser microphone, first determine the kind of power it needs. Then check with your mixing console vendor to see if that kind of microphone power supply is available as an option and how much it costs.

"Dynamic" microphones[10] cost less and do not need a power supply: sound energy is enough to fuel their output. They are not as sensitive as condensers, but are easier to maintain and are quite satisfactory for human speech. AKG, Electro-Voice, Sennheiser and Shure are the most popular brands of studio dynamic microphone at American stations. The Electro-Voice RE20 is probably the most widely used model. The Sennheiser MD421 is also highly regarded.

When gathering news outside the studio, some sound from the environment is desirable, to provide authenticity and a sense of place. For this reason radio journalists use "directional," "bi-directional" or "omnidirectional" microphones: they do not isolate the speaker's voice as much as cardioids. "Shotgun" microphones are designed to pick up sounds from farther distances. Some field microphones have a switch on their handle, or different "capsule" inserts, to change their spatial response.

Field microphones must be able to take rough handling, even being dropped occasionally. Beyer model M58 is widely regarded as the best-sounding omnidirectional hand-held. Electro-Voice models RE50, 635A and D056 are also popular. They are insensitive to handling and wind sounds, and are nearly indestructible.

Microphones designed for newsgathering and broadcasting are "low impedance" (50-600 ohms).[11] In contrast, "high impedance" microphones are used at public events like concerts and political rallies, to drive big loudspeakers. High impedance microphones cannot be used with standard broadcasting equipment except through an adapter. Even then, the microphone cable must be short, well-shielded and grounded to avoid feedback, hum, and loss of the high audio frequencies. It is far better to use only low impedance microphones for recording and broadcasting.

PHONOGRAPH PLAYERS

Broadcasting turntables are a bit different from those for home use: they accelerate faster to full speed, and then sustain their speed more accurately. They are also designed so the turntable can be rotated by hand to the exact start of a song, and held in "cue" position without straining the motor. A nonprofessional record player will wear out quickly if used that way. While studio turntables have special traits, the tone-arms,

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10. In a dynamic microphone, sound causes a metal coil to move inside the field of a magnet. The coil's movement generates a current which is the microphone's output. In a condenser microphone, sound causes the capacitance of two electrically charged plates to vary. A power source is needed to charge those plates and amplify their output.

11. "Impedance" is to alternating current much as resistance is to direct current. Like resistance, impedance is expressed in "ohms."

cartridges and needles used with them are similar to those used at home.

Due to the growing popularity of compact disks (CDs), the demand for professional turntables is declining rapidly. As a result, the prices of used turntables are decreasing. A new station can save a lot of money buying a used turntable - but this is riskier than ever before. Equipment entering the resale market today has probably been kept in service longer than in the past, as stations invested in CD players rather than replacing their turntables at the first sign of wear. Some broadcast turntables have also had a "second life" in a discotheque or accompanying a "rap music" group. Those applications cause rapid wear which cannot be repaired. So check the condition of a used turntable carefully, especially the bearings, rubber parts and motor. For older models, be sure that replacement parts are still available.

Like the output of a microphone, the output of a phonograph cartridge is a tiny signal (1-300 mV) which must be boosted to levels similar to other signals in your program, in order to be mixed with them. A "pre-amplifier" (pre-amp) does this boosting. A pre-amp designed for home use can be used in the studio, so long as it meets two criteria:

1) it is not affected by radio interference. Pre-amps designed for broadcasting are shielded to protect their circuits from the intense radio fields found near transmitters. If your transmitter is low-power or far from the studio, this may not be a problem.

2) the pre-amp's output can be matched to your other equipment.

This “mobile studio,” manufactured by Sonotechnique of Montreal, Quebec, has all the elements of a broadcasting or production studio. It fits into 3 packing cases and assembles in 20 minutes. For more information, contact Jacks Lachance, c/o MediaHertz, 1453 des Pins, Sillery, Quebec, Canada GIS 4J7; phone (1 418) 883-6693. Photo courtesy of InteRadio.

Professional studio equipment has what are called "balanced" outputs, while non-professional equipment has "unbalanced" outputs. See BALANCED vs. UNBALANCED LINES for more on what this means. If your mixing console does not have inputs for "unbalanced" lines, you will have to use an "unbalanced-to-balanced" interface. This should be installed close to the pre-amp.

CD PLAYERS

Compact disks (CDs) are rapidly replacing phonograph records as the primary medium for recorded music. CDs offer a superior signal/noise ratio and longer playtimes in a damage-resistant format. In the United States, pop albums are no longer released as phonographs. A lot of great music is still available only on phonographs, but a radio station without at least one CD player will find its options in new music limited. CD players for home use cost much less than professional models. Can they be used in a broadcasting studio?

A survey of university radio stations in North America and Europe (conducted on the "Usenet" computer network last year) put that question to people using nonprofessional CD players in broadcast studios. There was wide agreement that some models do work well in the studio. Many respondents pointed out that buying two CD players for $200 - $300 each is far better than paying 5 times as much for one professional model. Even if nonprofessional models do not last as long, having two gives you a backup, and makes it easier for the DJ to set up the next disk while maintaining program continuity. The Technics brand won praise for their CD players, especially model SL-P477.

There was also agreement that multi-disk CD players should be avoided in the studio, even though they can be programmed for hours of music in varied sequences. Apparently they are more likely to develop mechanical problems, and many radio workers felt that they move from one disk to another too slowly.

BALANCED VS. UNBALANCED LINES

As the quality of audio equipment available to the public improves, more of it seems good enough to use in professional broadcasting and production studios. This is already the case with CD players. The temptation is increased by the lower cost of nonprofessional equipment.

But there is a problem: compatibility. Audio equipment for home use has "unbalanced" outputs delivering lower signal strengths than professional studio equipment (0.316 V [-10 dBm] versus 1.23 V [+4 dBm]). Unbalanced outputs are designed to feed coax cables containing a single wire conductor inside a grounded sheath. A "balanced" output, on the other hand, is designed for an audio line with two wire conductors, neither of which is grounded: when electricity flows in one direction in wire "A," an equal current flows in the opposite direction in wire "B." Connection to ground is often provided by a third wire in the

(See Diagram Lr9)

"Unbalanced" line connector "Balanced" line connector

cable. Therefore, different connectors are needed for balanced and unbalanced lines.

Balanced lines are less vulnerable to induced currents and interference from the electromagnetic fields found near transmitters. That is why broadcasting stations prefer them. Unfortunately, connecting an unbalanced output to a balanced input is likely to give unsatisfactory results - unless an "interface" (adaptor) is used.

As nonprofessional equipment becomes more common in studios, the problem of matching unbalanced outputs to balanced inputs arises more often. Many companies now sell "pro/non-pro" interfaces. These combine the needed connectors and wire-paths with either small amplifiers to boost the -10 dBm signal up to professional line levels, or resistors to reduce "pro" signals down to levels appropriate for unbalanced inputs. Many interfaces have audio transformers to match the input and output impedances.[12] The interface should be mounted close to the unbalanced end, to minimize the length of unbalanced lines in the studio. If you want to build your own interface, here are two basic alternatives for wiring the connection:

(See Diagram Lr10)

12. Most professional studio equipment is designed for audio line impedances of 600 ohms. The output impedance of non-professional equipment is generally much lower. If you use transformers to match impedances in a "pro/non-pro" interface, make sure they can pass the signals' full audio

Note that some newer professional audio devices have inputs or outputs for both balanced and unbalanced lines, eliminating the need for an interface. This flexibility is nice to have.

AUDIO TAPE MACHINES

There are three basic kinds of audio tape machines, defined by the way the tape is held: in cassettes, cartridges or open reels. There are also different kinds of tape coatings. Radio stations generally select one type of tape in each format and use it exclusively, so they won't have to keep changing the settings of their tape machines to get optimum performance.

CASSETTE MACHINES Audio cassettes are familiar to everyone. The tape width (3.1 mm) and size and shape of the plastic shell are the same everywhere. But the shell can hold different lengths and types of tape. There are also differences in the equalization and bias used with different magnetic coatings.[13]

The least expensive and most common tape coating is ferric oxide (Fe_2O). Chromium dioxide (CrO_2) provides a superior signal/noise ratio, and captures more high-frequency audio energy, making it preferable for music. But heat can undo that superior performance, so if you archive material on CrO_2 cassettes, keep them in a cool place. "Metal formulation" tape has an even better signal/noise ratio and is less sensitive to heat. But it is expensive and should only be used on machines designed for the stronger output produced during playback (check the machine's tape-type selector switch).

Cassettes are popular because of their convenience, but even the best add "hiss" to recorded sound. This is noticeable when a cassette recording follows a live presentation or a CD. Several techniques have been invented to suppress hiss. Cassette players for studio production or on-air use should have "Dolby," "HX Pro" or "dbx" noise reduction. Always record cassettes with the same noise reduction method that will be used during playback.

There are so many cassette players available that it is impossible to say which is the best. However, the number of portables suitable for newsgathering outside the studio is much

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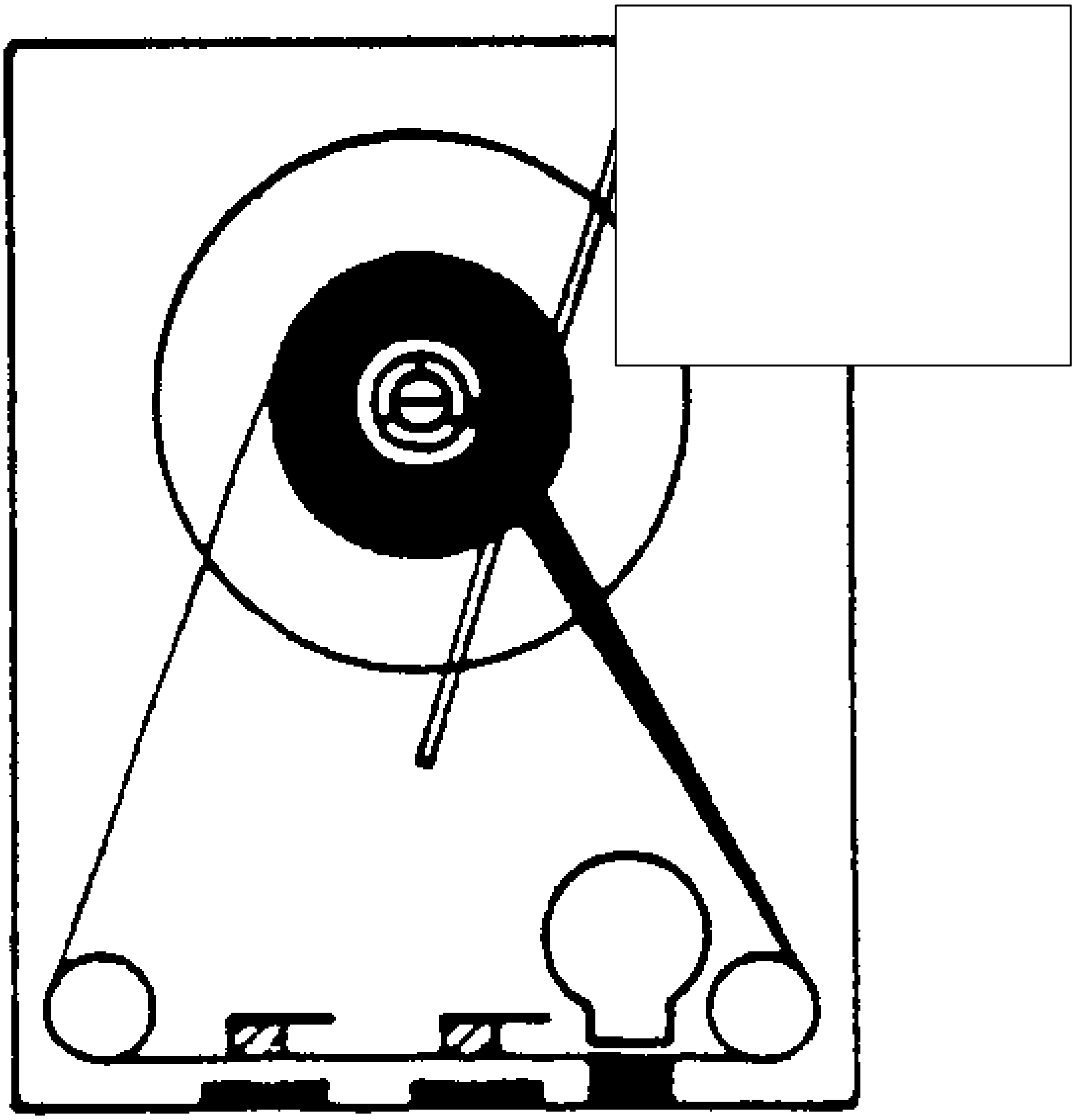
13. "Equalization" is the process of changing the emphasis given to various audio frequencies. It is necessary with audio tape, because the effect of magnetism on the tape coating is not uniform across the audio spectrum. Without equalization, even the first playback would not sound the same as the original.

"Bias" is an ultrasonic signal added to the audio during a recording. It cannot be heard, but it reduces distortion and the need for equalization. The bias frequency is usually 5-10 times the highest audio frequency to be recorded, and several times stronger than the loudest passage. Sophisticated tape machines let the operator adjust the frequency and strength of the bias for the best results.

smaller. Sony model TC-D5PRO-II is a favorite because of its excellent audio quality, lightness, durability and low battery drain. The Marantz PMD-430 costs less, offers similar performance, and has more features (including dbx noise reduction), but it is not as rugged as the Sony.

CARTRIDGE MACHINES Like cassettes, cartridges ("carts") hold the tape in a protective shell. But cartridges are bigger than cassettes, there is only one spindle inside, the tape is wider (6.3 mm), and the ends of the tape are spliced together to form a continuous loop. This means a cartridge never has to be rewound - it can always be advanced to the point where the recording begins again. (See Diagram Lr11)



Cart machines were developed specifically to meet the needs of broadcasters. Their main appeal is automatic cueing. When a cartridge is recorded, a "cue tone" is put on a separate track to mark where the recording begins. This tone is sensed by the player but not sent to the audio output,

so listeners do not hear it.
When the cart player detects the tone,
it stops automatically, leaving the tape
positioned at the start of the recording,
ready for the next playback.

How tape is wound inside a cartridge.

Carts are used for short, often-repeated sound pieces, such as regular announcements, program lead-ins, commercials, station signatures, sound effects, etc. Cart tape lengths are short, since the elements recorded on them are usually just seconds or minutes long. Some players hold several carts, letting the operator choose which one to play with a pushbutton.

Carts come in 3 standard sizes. Nearly all radio stations use Type A or AA, which fit the same machines and come in the same shell size (101 x 133 x 22 mm). They differ mainly in tape chemistry. Types B or BB, and C or CC, come in bigger shells, and are only used for long recordings.

Europe and North America have slightly different equalization standards for the 6.3 mm-wide tape used with both cartridge and open-reel tape machines. The difference is only noticeable when a recording made under one standard is played back on a machine set up for the other. Many studio recorders have a switch for selecting either standard (the European IEC or North America's NAB). It does not matter which you use, so long as it is consistent with the recording.

Cart machines are durable and very convenient to use. All of them have playback, but recording capability adds 50 - 100% to the price, so only some models have it. Cart machines cost so much ($1000+) that alternatives must be considered by stations with limited funds. Cassette machines can perform most of the same tasks at much lower cost, but more clumsily, with lower audio quality, and more chance for mis-cueing.

OPEN-REEL MACHINES A third type of audio tape machine is the "open-reel" (also called "reel-to-reel"). Here the tape is not inside a shell, but wound on a wide, flat spool. The kinds used for production and editing are different from those for simple recording and playback. Production machines let the operator move the tape back and forth freely, to find specific moments in the recording, and switch rapidly from playback to rewind and fast-forward without straining the mechanism. Models not designed for such treatment will wear out quickly if operated this way.

Open-reel machines are used in audio production because tape is so much easier to cut and splice when it is not inside a shell. Also, the wider tape-width (6.3 mm) and faster speeds (19 or 38 cm/sec) which are standard in this format yield better sound quality than cassettes. Most radio stations use 2-track recorders (stereo or dual mono), even when broadcasts are mono.

When a production is finished, it can be played on an open-reel machine or transferred to a cassette or cartridge for playback. It is not a good idea to play on the air repeatedly a tape which has splices. Imagine the embarrassment if it comes apart during the program. In general, the open-reel format is best for production, not for the on-air studio.

As already mentioned, Europe and North America have slightly different standards for audio equalization on 6.3 mm tape. Many open-reel machines let you use either the NAB or IEC standard. It does not matter which is your normal setting, so long as the playback equalization is the same as the recording's.

EARPHONES & LOUDSPEAKERS

Loudspeakers are found in nearly all on-air studios. It is more than convenient to be able to hear what is broadcast, and to audition material prior to its broadcast. Certainly the engineer should be able to hear the signal leaving the studio, to be sure it is free of defects.

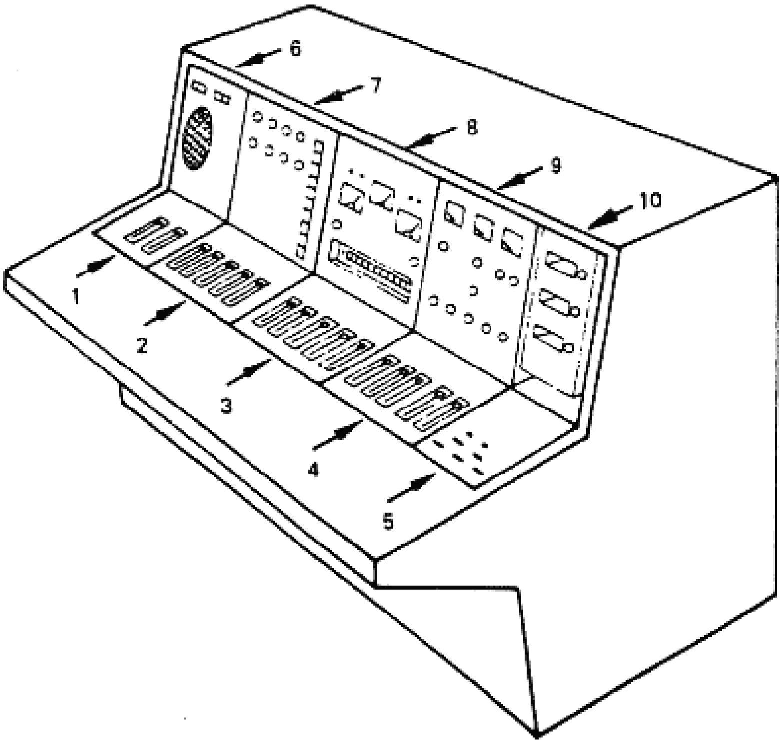
But loudspeakers can interact with an active microphone in ways distracting to listeners, so it is better to use earphones during live broadcasts. Non-professional earphones can be used in the studio, as can most high fidelity loudspeakers. However, loudspeakers that "color" the sound will not accurately represent the program being broadcast or recorded. For example, most popular loudspeakers for use at home exaggerate the strength of bass notes. If the operator is not aware of that, he can misjudge the best equalization settings. For this reason, loudspeakers designed for studio use have a "flat response." That is, they reproduce each audio frequency strictly in proportion to the electrical signal.

MIXING CONSOLES

Radio stations need mixers for at least two purposes: to combine sound sources in a live program for delivery to the transmitter; and to merge sound sources into a recording which can be part of a future program. Every station needs an "on-air" mixing console. It is possible to broadcast without a second mixer for production, although it is a severe limitation.

Picking a mixer is an important decision. It is often the most expensive item in the studio. Getting one with unneeded features is a waste of money, but not allowing for future growth can be even more costly, if you have to buy another one to implement your plans.

(See Diagram Lr12)



A mixing console based on the BBC's "Local Radio MK3" design, integrating many control room functions:

1) phonograph faders; 2) faders for sound sources outside the studio;
3) studio microphone faders; 4) tape and cart faders; 5) studio intercom and two-way radio system for calling news vans; 6) intercom loudspeaker;
7) selector for inputs outside the studio; 8) input and output meters, transmitter selector; 9) loudspeaker & headphone controls, remote controls for tape machines, and a limiter; 10) a three-cart machine. (Courtesy of BBC Engineering Information Department; from The Technique of Radio Production by Robert McLeish, Focal Press [2nd edition, page 14].)

On-air and production mixing are different enough that consoles designed for each purpose have somewhat different features. The main difference is that on-air mixers are designed for durability and simplicity. Replacing the on-air mixing console can severely disrupt station operations, so good ones are built to last for decades. Simplicity reduces the chance that an operator will make a mistake that listeners will hear. Production mixers tend to have more switches and knobs, as flexibility is a plus for them.

But let's not exaggerate the differences : most broadcasting consoles can be used for either on-air or production mixing. In fact, it is a good idea to connect them, so that if one fails, the other can quickly become a substitute. Stations that cannot afford two mixers can use the on-air console for production while the station is off on the air, of course, or

TOP: a small on-air mixer with rotary "pots" (BE model 5M150A).
MIDDLE: a large on-air mixer with slide "faders" (BE model Mix-Trak 90-18).
Both courtesy of Broadcast Electronics Inc.
BOTTOM: "The Newsmixer," a small mixer designed for radio news production, made by Pacific Recorders & Engineering Corp.

even during a broadcast. It takes skill, but it is possible to record and mix an announcement, using the on-air console while a series of records is playing, interrupting the production every few minutes to speak live to the listeners. There are usually enough mixing channels available to support two unrelated activities simultaneously.

You have probably seen mixers designed for recording live performances and feeding amplifiers at concerts. These are cheaper and more widely available than broadcast consoles. But performance consoles are usually designed for high impedance microphones, not the low impedance kind used in broadcasting. Some lack "balanced" connections. But some do have balanced inputs for both high and low impedance sources. Such a model could be used as an on-air or broadcast production mixer if there are enough low impedance inputs for your sound sources, and if the output of the console is compatible with your STL and transmitter. Check the specifications carefully before buying.

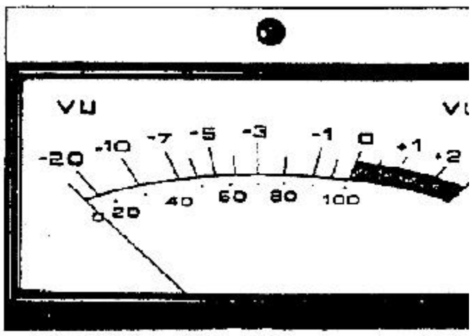
Not all stations have the same array of sound inputs or the same production needs. To meet differing requirements, many modern mixers are "modularized." That is, they are assembled from plug-in modules which are chosen at the time of purchase, to form a console specifically tailored to a station's needs and budget. Modularization also makes it possible to add inputs as the station grows, and to upgrade or replace individual modules rather than replacing the whole console.

Some modules are designed for "mic-level" (microphone) inputs, others for "line level" inputs (mono or stereo), for connections to telephone "hybrids," for remotely controlling tape recorders, for outputs to the control room monitoring systems, equalization, etc.

Each mix input passes through a "fader" (also called a "volume control," "potentiometer" or "pot") so that the incoming and outgoing signal levels can be adjusted. Precise control over levels is achieved by precise positioning of the faders. For that reason, the fader usually takes the form of a big knob or a long slide-lever.

Most broadcasting mixers have at least 5 faders - often 8, 10, 12 or more. In many models, each fader regulates 2-3 inputs, for combining sources or selecting among them.

(See Diagram Lr14)



A "VU meter": the needle's position should be near 0 VU (100 on the lower scale)

They also have meters to show momentary changes in audio signal strength. Unfortunately, the way they measure the signal varies from country to country, particularly in Europe. That means the same signal will produce different readings, depending on the type of meter. It matters little which type your console has. But an operator familiar with one type may need practice to learn to interpret correctly another meter type.

The types found most often on audio mixers are the American VU (Volume Unit) meter and the EBU's Peak Program Meter (PPM). This table summarizes the types you are most likely to encounter:

Standards for Some Peak Audio Level Meters Used in Radio Studios

Meter Name	Where Standard	Integration Time*(millisecs)	Time to 99% of Final Reading (millisecs)
OIRT Program Level Meter	East/Central Europe	10 ± 5 60 ± 10	<300 (needle type) <150 (light type)
EBU Standard Peak Program Meter	Northern & Western Europe	10 (-2db)	-
Peak Program Meter (PPM)	Netherlands	10 (-1 dB) 5 (-2 dB) 0.4 (-15 dB)	-
BBC Peak Sound Indicator	United Kingdom	10	-
Peak Level Meter	Italy	~1.5	~20
Maximum Amplitude Indicator	Germany	5	~80
VU Meter	France	207 ± 30	300 ± 10%
VU Meter	USA	~165	300

---based on CCITT Faxcicle III.6-Rec.J.15

*"Integration time" = how long the signal is sampled to determine its level. The longer the integration time, the more it represents an average, rather than a momentary, reading. 1 millisecond = 0.001 second.

The main cost factors in broadcast mixers are: the number of faders; the number of channels with equalization; whether the modules are mono or stereo; and the quality of construction. A stereo mixer with 24 faders, each with equalization, might cost 10 times as much as a mono mixer with 5 faders and no equalization.

Before choosing a mixer, figure out how many microphone inputs will be needed simultaneously; how many "line level" inputs; how many of those should be stereo or mono; and which require equalization.[14] A fader is not needed for every available sound source. As noted above, most faders have 2 or 3 inputs, and some mixers have additional "input selector" modules to bring more sources into a mix. A "patch-bay" can also overcome the limited number of direct inputs.

Will the station broadcast in mono or stereo? If stereo, then the console's output must be stereo. To start broadcasting in mono with the possibility of expanding to stereo later, get a stereo console with an optional "mono sum" output.

PATCH BAYS

Sometimes it is necessary to change the audio signal paths in the studio. A panel discussion might require extra microphones, then an hour later, copying open-reel tape recordings onto carts may take a different set-up. Or the studio might have one equalizer and several sound sources needing its services at various times.

A "patch bay" or "plug board" (two names for the same thing) makes re-routing easy. Like an old-style telephone switchboard, it has rows of "female" jacks which can be interconnected by short cables with "male" plugs at each end. Installing a patch bay increases the complexity and length of the studio wiring. But if you need to reconfigure often, consider the flexibility it provides, and how much time it can save.

Temporary configurations are common in a production studio, so a patch bay there is a practical necessity. Whether one is needed in the on-air studio depends on how many pieces of equipment there are, how much flexibility in source selection the mixer itself provides, and how varied your program needs are.

Patch bays are one of the cheaper elements of a studio. They are also easy to build. Here are some construction tips:

1. Use the best quality, easy-to-uncouple jacks and plugs you can find. They should all be the same type so that the same "patch cords" can connect any two jacks. Electrical contacts should be made of a metal that stays shiny and resists oxidation.

2. Install the jacks in rows so all the ground terminals can

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14. Equalization is nice to have in every channel, but that is expensive. A cheaper solution is to get one or two equalizers separate from the mixer, and use a patch bay to send sound sources through them as needed.

be connected with a thick, straight ground wire.

3. Install more jacks than the station needs. It is much better to have some as spares than to find out later there are not enough. Stations tend to add equipment as time passes, and discover needs that they did not anticipate.

4. Carefully work out on paper which input or output should attach to which jack before soldering any wires. Keep accurate notes about all the connections, and update your notes when changes are made. Clearly label each jack on the front panel.

5. Circuits carrying different signal levels should be in separate groups; sources and destinations should be in separate rows.

6. Be consistent in the way cables connect to the jacks so there will no difference in signal phasing when two devices are connected through different plugs and jacks.

WIRING

The wires connecting audio equipment are nearly as important to the station's output as the devices that process the signal. Actually, wires can "process" audio in ways that cause problems. They can act as antennas, absorbing and radiating energy, and very long runs of wire can weaken the high audio frequencies. So the kind of wire and how it is installed do matter.

Instead of buying different lengths and types, try to buy a large spool of one type of cable and use it for as many audio connections as possible. Buying in bulk not only reduces the cost per length, but that way you will be sure to have long pieces available when they are needed. (Splicing shorter pieces together for a long run is never wise. Every discontinuity is a chance for power to be lost, leaked or reflected.)

The section above on BALANCED vs. UNBALANCED LINES pointed out that in most stations, audio signals travel from one place to another on "balanced" pairs of wire. These copper wires spiral around one another, to help cancel noise caused by electromagnetic fields crossing them. In general, the more twists per centimeter, the less sensitive the cable is to external fields. It is helpful if the insulation around each wire in the cable is colored differently, to make it easy to see which is which when attaching them to plugs, jacks and other terminations as the station is built.

A third wire in the cable provides an electrical "drain" to ground. All of the wires should be inside a braided metal or foil sheath rated "100% shield coverage" and covered with flexible plastic or rubber insulation. The cable's capacitance per centimeter should be as low as possible.

The wire in audio cables does not have to be thick; it will probably only carry a few milliwatts. Most US broadcasters use stranded wire 0.51 - 0.64 mm in diameter (22 to 24 AWG ["American Wire Gauge" units]). Loudspeaker wire is stranded, too, but thicker: 1.29 - 2.05 mm (12 to 16 AWG).

When several cables link two areas of the studio, tape or tie them in bundles to prevent them from tangling. Audio cables carrying voltages that differ by more than 15 dB should not be bundled together. That usually means separating them into 4 groups: low voltages (below -20 dBm; microphone and phonograph cables, for example); "line level" signals (-20 to +18 dBm; the outputs of tape and CD players); high level signals (over 18 dBm; connecting audio amplifiers to loudspeakers); and control circuits and main power lines. Audio cable can be used for low-voltage control circuits, but never NEVER <u>NEVER</u> to carry mains power.

In addition to audio circuits, wiring is needed for three types of electrical grounding: for the equipment, for the cable shields, and for lightning protection. Grounding lets unwanted currents drain to the earth. It also provides a common voltage reference for circuits that need one. Grounding paths must not form closed "loops" where currents can circulate. To avoid ground loops, the shield around each audio cable should be grounded only at one end.

Each major piece of equipment - particularly the mixing console and the transmitter - should have a connection to ground that is as short and direct as possible. The connections must be low-resistance: thick copper wire (or better, a heavy woven copper strap) should be hard-soldered or clamped to copper ground rods driven into the earth. ("Hard-solder" means silver- rather than lead-based solder.)

Advance planning and accurate diagrams are essential for both studio wiring and grounding systems. They will save huge amounts of time later when problems arise and everyone has forgotten details about the installation.

<u>TELEPHONE CONNECTIONS</u>

A telephone connected to a broadcast station's audio system lets people outside the studio participate in the creation of programming. The audio quality of phone lines is usually poorer than other program sources, but the potential for unexpected or newsworthy contributions is reason enough to incorporate this medium in your design. The telephone is probably a station's most important news-gathering tool.

Most countries have rules restricting the direct connection of electrical devices to the phone system. Certainly the network must be protected from damage and interference. Fortunately, this is not difficult. The normal audio line impedance in broadcast studios is 600 ohms - same as the phone network's. That is no coincidence: it was intended to simplify studio/phone interconnections.

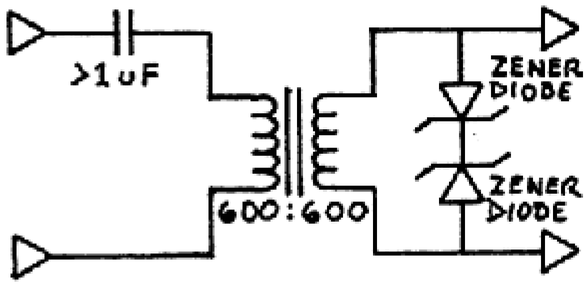
To connect a phone line to a studio audio system, tap the wires in the phone line (or inside the telephone, after the off-hook switch). Put a capacitor (minimum value: 1 microfarad) on one or both of the tap lines, to block the telephone network's DC voltage, and a 600/600-ohm audio transformer across the tap for additional isolation (See Diagrams).

Phone lines and broadcast studios have similar impedances, but phone audio signals are usually 10 -40 dB weaker. Audio from a properly isolated phone line will not harm the "line level" inputs of studio equipment. But a studio signal fed into a phone line can cause overloading and distortion, and could even harm the phone system if the signal strength is not first reduced. In the United States, phone companies require that 600-ohm audio signals entering their lines be limited to no more than -9dBm (0.28 volts).

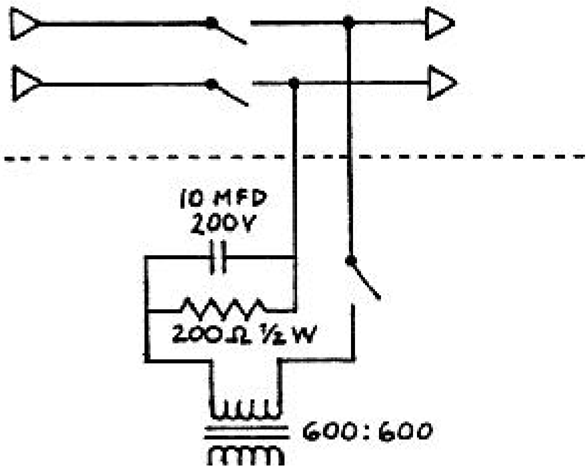
The signal levels and impedances actually found on phonelines vary from place to place and from one call to the next. So it helps to have additional tools in the circuit:
a switch to shut off the tap, a volume control, an amplifier, an equalizer, a limiter, etc. Increasing the quality of "phonepatches" is a broadcast industry obsession. It is possible to spend thousands

An easy way to connect a phoneline to the studio audio system, from the NAB Engineering Handbook (1985), pg 6.4-45. The front-to-front Zener diodes prevent too much studio audio from entering the phoneline. They are not needed on taps that only receive audio from the phone network:

(See Diagram Lr15)



Another phone/studio interface is shown below. Contributed by Scott Dorsey, it was successfully installed last year at a new local station in Estonia:



of dollars on this. Given the poor audio quality of post-Communist phone systems, high priced equipment designed for Western networks may not improve the intelligibility of voice signals much more than inexpensive measures. So you might "start cheap" and add improvements gradually.

A simple tap works fine if the audio is only coming from one direction: either into or out of the studio. But with a two-way conversation, the person at the station will sound much louder

(See Diagram Lr17)

TELEPHONE HYBRIDS

(Diagram Missing)

than the person at the far end. If the level is set high enough to make the person at the far end audible, the near-end person will be too loud. The solution, obviously, is to separate the incoming and outgoing signals so their levels can be brought into balance. That is harder than it sounds, because both signals travel on the same pair of wires.

Or is it? A simple way to separate the speakers is with an A/B switch. Any station can build one at minimal cost. It is based on the fact that in most conversations, people take turns speaking. Putting the switch in one position sends the incoming speech signal to one mix channel. Putting it in the other position sends the outgoing speech signal to another mix channel. That way they can be processed independently, then recombined in the program audio. The switching can even be automated, by putting a line-level sensor on the studio microphone's output.

The flaw in this method is that if both speak at the same time, or the switcher incorrectly guesses when the change from one speaker to the other will occur, a bit of conversation will be lost. This can annoy listeners, as some overlap is common as speakers alternate.

To overcome this shortcoming and maintain continuous access to the mix for both sides, while still processing each side separately, many stations use a "telephone hybrid." This is a device that frees the person in the studio from the telephone:
he listens to the other conversant on studio earphones or the loudspeakers, and speaks into a regular microphone. The person at the other end speaks and hears on the telephone as usual, but the studio microphone's output is blocked out of the combined audio going to the mixing console. Mixers often have a built-in circuit for further separating the two sides of a phonecall: a "mix-minus bus." With the studio microphone in one mixing channel, and the far speaker fed into another channel through the hybrid, the two halves of the conversation can be separately processed, then recombined in the program mix.

Another kind of device, called a "frequency extender," makes it possible to send high-fidelity audio signals over a phoneline without reducing them to phone system quality. Extenders are used to send back to the station live programs originating outside the studio. The least expensive kind work by raising all audio frequencies a certain amount at the remote input, and lowering them an equal amount at the studio, so that the range of frequencies passing through the phone system's filters sounds a little better to listeners. More effective extenders work by dividing the audio spectrum into 2 or 3 bands, sending each one down a separate phoneline. A receiving device at the studio recombines the bands, delivering the sum to the mixer.

Telephone systems can also install "dedicated" point-to-point lines to carry program audio from the studio to the transmitter. See STUDIO-TRANSMITTER LINKS, below, for more about them. The advantage over an ordinary phoneline is that the signals do not pass through switchboards or network filters, so a wider spectrum of audio frequencies can be delivered. The noise and distortion typical of the network equipment is also eliminated. The main disadvantage of a dedicated phoneline is the cost.

OPTIONAL STUDIO EQUIPMENT

It is possible to fill a broadcast studio from the floor to the ceiling with hardware. There is no shortage of manufacturers who will try to convince you that their product is necessary for a "professional sound." Actually, the fewer devices that a signal must pass through from its origin to the listener's ear, the less noise and distortion will be introduced, the less audio bandwidth will be lost, and the less chance for a link in the chain to break. That is worth emphasizing as we note some devices that are not absolutely necessary for broadcasting, though they can be helpful in some situations. The most useful items are listed first.

AUDIO FILTERS AND EQUALIZERS   Sometimes an audio signal does not sound the way you want. Filters are circuits that suppress unwanted frequencies. Types commonly used in broadcasting are:

Low-pass: allows all sounds below a certain frequency to pass, but no frequencies above the threshold. A low-pass filter can reduce background noise in an interview recorded at an airport, for example.

High-pass: allows frequencies above a threshold to pass, while frequencies below the threshold are blocked. This can sometimes improve the clarity of a phone interview.

Pass-band: lets through everything between a low and a high frequency, while blocking everything else.

Notch: suppresses a very narrow slice of audio spectrum, to eliminate hum, tones, whistles and similar sounds. The notched frequency is usually adjustable.

There are also more complex filters that change the distribution of energy among the frequencies in an audio signal. These are called "equalizers." They are especially useful in audio production, when sounds from different sources are combined. For example, moving a microphone during an interview can change the way the room sounds. That could become noticeable - and distracting to listeners - if statements made before and after the movement are edited together. Equalization can correct that problem. Another common application is to make specific tonal ranges more or less prominent in music (boosting the bass, for example).

There are two basic kinds of equalizer. Graphic equalizers divide the audio spectrum into bands whose limits are set by the hardware. The operator can boost or reduce the strength of individual bands by up to 10-15 dB. Parametric equalizers can additionally change the frequency coverage and width of each sub-band, along with the degree of boost or attenuation. Para-metrics are much more flexible, but also more costly. They are rarely found in hi-fi set-ups at home, while graphic equalizers are more common there. Nonprofessional equalizers can be used in the studio, with "pro/non-pro" interfaces where appropriate.

DISTRIBUTION AMPLIFIERS Maybe you want to send the mixer's output somewhere else than the transmitter - to a tape recorder, for example, or to a loudspeaker in the manager's office, or to a satellite uplink, or all of these. A distribution amplifier supplies the same signal to several destinations without changing the impedance load imposed on the mixer, and without reducing the strength of the signal sent to the transmitter. Distribution amps are fairly expensive. It is possible to make a cheap substitute out of 600:10,000 ohm "bridging" transformers installed across the path to each destination. That may not eliminate the need for amplification, but it does solve the impedance matching problem which arises when one source feeds several loads simultaneously.

COMPRESSORS Audio programs vary in loudness from moment to moment. These variations affect the structure of the broadcast signal. A signal that does not completely "fill" a listener's receiver - as can happen in a pause between announcements or during a soft passage of music - will allow some natural radio noise to slip into the receiver at the same time.

What compressors do is reduce the dB-span between the loudest and quietest parts of the program: they make the loud moments less loud and boost the audio level during quiet moments. That has the effect of raising the average modulation level, which lets less radio noise enter the receiver. In theory, that increases the signal/noise ratio, which is usually desirable. But too much compression sounds unnatural and causes a kind of psychological fatigue among listeners. Compressors usually have controls letting the operator fine-tune its response to rapid changes in signal level.

LIMITERS Limiters automate one of the responsibilities of the person running the on-air console: preventing the mix output from exceeding a certain signal strength. Broadcasters try to maintain a high signal level, to get the best signal/noise ratio and the most efficient performance from their transmitter. But bad things happen when the program signal exceeds the optimum high level: the sound received by listeners will be distorted, and in extreme cases, interference can be caused to other radio stations. These are obviously conditions to avoid.

FM stations turn to limiters because their transmitters achieve 100% modulation of the radio carrier with a relatively small audio input. "So the difference between under- and over-modulation is also small. And, as noted above, audio peak meters do not precisely track momentary signal levels. Nevertheless, an alert human can do what the limiter does. Indeed, when a limiter "clips" an audio peak that is too high, it has a momentary affect on sound quality that is not so nice. The best alternative is to monitor the studio's audio output carefully so that the level is neither too high nor too low.

STUDIO-TO-TRANSMITTER LINKS

The studio-transmitter link (STL) seems like it should be a minor part of the station. That is the case when the transmitter is inside the station: the STL is just another audio cable - or pair of cables/ for stereo. This is the best arrangement for broadcasters lucky enough to have one location suitable for both the studio and the antenna.

When the transmitter is outside the station's offices, the STL becomes a distinct factor in planning the station. For runs of less than 40 m, audio or coaxial cable is still fine for program delivery, though monitoring the transmitter's condition becomes a problem once it is out of view.

It is possible to broadcast without constantly watching the transmitter. But there are risks: unauthorized access and tampering by vandals, for example. The most serious risk is an electrical or mechanical problem that escalates undetected into a loss of service. Malfunctions getting that far are apt to be costly to repair. As a preventative measure, most stations install extension cables for the transmitter's meters, and control circuits leading back to the station for remote supervision.

When the STL is more than 30-40 m from the studio, several things happen. First, the signal strength decreases as the distance grows. The rate of loss can be looked up in charts describing the performance of various cable types or calculated with simple formulas.[15] The losses with phone line-type wires are normally very small, even when the line is several km long. Wires this long will probably have to be buried in the ground or strung through the air. Either way, their insulation should be suited to the environmental stresses.

Second, lengthening the STL gradually reduces the strength of high audio frequencies in the signal. Resonance effects can also boost or reduce certain frequencies but not others. The audio characteristics of an STL should be tested during installation as they are somewhat unpredictable. Many problems can be corrected with equalization: frequencies weakened in transmission are boosted before they enter the cable, and another equalizer can be put at the far end for final adjustments. Using transformers to

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15. For example:

$$\text{loss in dB} = 20 \log \frac{Z_1 + Z_2 + Z_3}{Z_1 + Z_2}$$

where Z_1 = the impedance of the line at the studio end
Z_2 = the impedance of the line at the transmitter end
Z^2 = the resistance of the wire in ohms/km

Clearly, the lower the wire's resistance, the lower the signal losses are.

lower the cable's beginning and ending impedances to 60 - 150 ohms greatly extends the distance signals can travel before they need equalization. If the program audio is stereo, two cables of the same length should connect the studio and transmitter.

A third potential problem on long wire STLs is the program audio picking up noise or interference from external electromagnetic fields. Shielding can help, as can changing the cable's route if the noise is caused by a locatable source. Another risk is the wire being cut or accidentally damaged. The chance for this to happen grows with the length, and obviously depends on the activities occurring nearby. All we can say is install the cable where you think it will be safe.

Despite these warnings, a wire STL poses no insurmountable technical problems, even when it is 10 - 25 kilometers long. For the best results, the wire should have no splices. In researching this book we learned that a Finnish company named Yutel Oy (phone [358 81] 50 08 01, fax [358 81] 50 08 10) sells reasonably priced wire STL equipment for local radio stations under the brand name "Telelink." These are widely used in Scandinavia, and combine equalizers and impedance-reducing transformers with a transmitter remote control system.

Beyond the technical issues, there may be legal or bureaucratic problems installing cables which cross public and private properties. Whoever owns or regulates each property can deny permission or charge fees for letting an STL pass through. Overcoming such complications is one justification for having long STLs installed by a government bureau: they are more likely to get their way quickly. But the fees some bureaus charge for STLs are so high that private arrangements between property owners and broadcasters could be cheaper. One can only hope that alternatives to government-provided STLs will develop, to compete with their prices and to let broadcasters operate without worrying about the government being able to cut their STL.

Many American stations have STLs that use radio waves instead of long cables. This is often less expensive than a wire system, and property owners may not even realize that the signal is there. Several radio bands are set aside in the United States for STLs. Most broadcasters use 942 - 952 MHz, because the antennas needed to focus these frequencies into narrow "spotlights" beams are small and inexpensive. For clear reception at the transmitter site, there should be an unblocked view from the studio - more precisely, from the STL antenna mounted at a high point near the studio.

Radio STLs are not considered broadcasts. Focussing the beam into a "spotlight" aimed at the transmitter limits others' ability to receive it. That also reduces the power needed to deliver an adequate signal, and lets other broadcasters use these channels on different beam-paths without interfering with each another.

Data concerning the transmitter can be sent back to the studio on a radio link in the opposite direction, or over a phoneline. In many cases, it is literally a phoneline, not a dedicated line separate from the phone network. An increasingly common arrangement in the US is for a computer at the station to call the transmitter at regular intervals automatically. A tone is sent to the device receiving the call, causing it to respond with tone-coded information about the transmitter. Additional tones sent from the studio by the engineer can direct the device to adjust the transmitter.

A complete mono 950 MHz radio STL system typically costs under $4000 in the US. Marti and Moseley are the two best-known American manufacturers. An Italian company, DB Elettronica Telecomunicazioni S.p.A., is also active in this market (Via Libona 14, Zona Industriale Sud, 35020 Camin - Padova, Italy; phone [49] 870 0588; fax [49] 8700747; telex 431683 dbe).

A clever, low-cost STL-type arrangement was devised by Radio Gazeta in Warsaw. They began broadcasting in 1990 with a French transmitter designed to operate on 89 MHz. At the time, few Poles had receivers capable of tuning that channel. So they removed the part of the transmitter that generates the carrier frequency (the exciter), and put it on the roof of their studio building. It was replaced in the transmitter with an exciter generating a 67 MHz carrier, which many more people could tune. Since an exciter acts like a very low power FM transmitter. Radio Gazeta used the original French exciter to deliver their program from the studio to their main transmitter on 89 MHz, where it was re-diffused at higher power on 67 MHz. Their STL signal could only be heard in the center of Warsaw - where, by fortunate coincidence, most visiting foreigners stay. Their radios were able to receive Radio "Z" in the band they normally tune at home, while Poles all over the city listened to the same transmission in the FM low band, where they were accustomed to tuning.

Such arrangements elsewhere could ease the transition from the low to the high FM band, while freeing new stations from dependence on wire STLs provided by the telecom ministry.

FM TRANSMITTERS

Transmitters have several distinct parts. Some are common to both FM and AM (mediumwave) transmission, but to avoid confusion we will focus first on FM.

The power supply takes power from an outside source (usually the mains) and turns it into the voltage and current levels needed by various circuits in the transmitter.

The FM exciter takes current from the power supply, makes it oscillate at a high frequency - a radio frequency! - and then combines it with the audio signals sent from the studio. When those audio signals are stereo, the exciter usually produces the FM "pilot-tone" or "polar" modulation needed for stereo transmission. Since the exciter generates radio frequencies, it can function on its own as a low power transmitter, as noted above. The output of a typical exciter is 5 - 30 watts.

Stereo signals require precise alignment of the exciter's circuitry and close attention to the modulation process.

Modulation is the process of adding programming to a carrier frequency. Turning two audio channels into a one composite radio signal, which a receiver can reseparate into two audio channels again, is still an impressive trick, though it is no longer a novelty.

In most radio programs, the high audio frequencies have less energy than the low frequencies. Engineers noticed that this lets radio noise from the environment enter FM receivers at the edges of a channel. To block some of the noise, many FM stations now boost the intensity of their high audio frequencies. This is called pre-emphasis. The proper sound balance is restored in receivers having circuits to "de-emphasize" the high frequencies by an equal amount.[16]

Pre-emphasis often takes place in the exciter, after the composite stereo signal is formed. De-emphasis in the receiver must mirror the process for the best results. The important variable is called the "time-constant." In OIRT countries, the pre-emphasis time-constant is 75 microseconds, as it is in North America. However, it is 50 microseconds in England and some other countries. Not many listeners would notice the difference, but if you buy a transmitter that includes pre-emphasis, the time-constant should match your listeners' receivers: 75 microseconds. (Some transmitters have a switch letting you pick either time-constant). In any event, pre-emphasis is not essential, although it does slightly improve the received sound.

One or more amplification stages boost the exciter's output to whatever level the transmitter is designed to produce. Each stage usually adds 5-20 dB and increases the transmitter's size. Until recently, only vacuum tubes (valves) could generate the highest levels of amplification. But solid-state technology has made rapid progress, and powerful transmitters are now available without tubes. The advantage is cooler, more reliable operation over a longer period of time, higher efficiency and ease of manufacture (meaning lower cost).

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16. Pre-emphasis is also used by some mediumwave stations. In that band it produces an even more noticeable drop in noise.

After the final amplification stage, the composite signal goes through a low-pass filter to remove energy that could cause interference outside the station's channel. A directional coupler or a Voltage Standing Wave Ratio (VSWR) meter[17] connect the transmitter to the antenna feedline. These devices measure the power fed to the antenna and how much is reflected back into the transmitter. If the reflection is too great, the final amplification stage can be damaged. An SWR meter lets a human operator see when the reflected energy is too high. A directional coupler acts automatically, reducing the transmitter's output before the reflection reaches a harmful level.

Other transmitter controls are usually provided: the on-off switch of course; knobs and switches for circuit adjustments; and on higher power models, a sequencer reduces the electrical surge and stress of turning the transmitter on and off.

According to a 1989 survey, broadcasting stations in Western Europe had about 20,000 radio transmitters on the air. Only about 7,500 were licensed. Some 4,500 of the 12,500 unlicensed transmitters were in Italy, which did not have a national broadcasting law from 1976 until last year. Other countries with large numbers of unlicensed broadcasters were Portugal, Spain, the Netherlands and Ireland.[18] Large numbers of these unlicensed transmitters were built by individuals. The next few pages give circuit diagrams for transmitters of various (low) powers. Since so much of a station's success depends on the transmitter's performance, building one is a big responsibility. Unless someone involved with your project has done it before successfully, you might want to consider other alternatives first.

Self-built transmitters obviously cost less than manufactured ones. But new manufactured models come with a warranty, so if technical problems arise during the initial period of use, the manufacturer will often fix them for free. They are also proven designs. The details which make the difference between success and failure have been found and refined. Some of the manufacturers specializing in low-power transmitters for Europe are listed at the end of this book.

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17. Also called a Standing Wave Ratio (SWR) meter, because the ratio found for voltage is the same for current. The ideal SWR is 1.0, but anything less than 2 is generally acceptable.

$$SWR = \frac{V_o + V_r}{V_o - V_r}$$

where V_o = voltage to the antenna

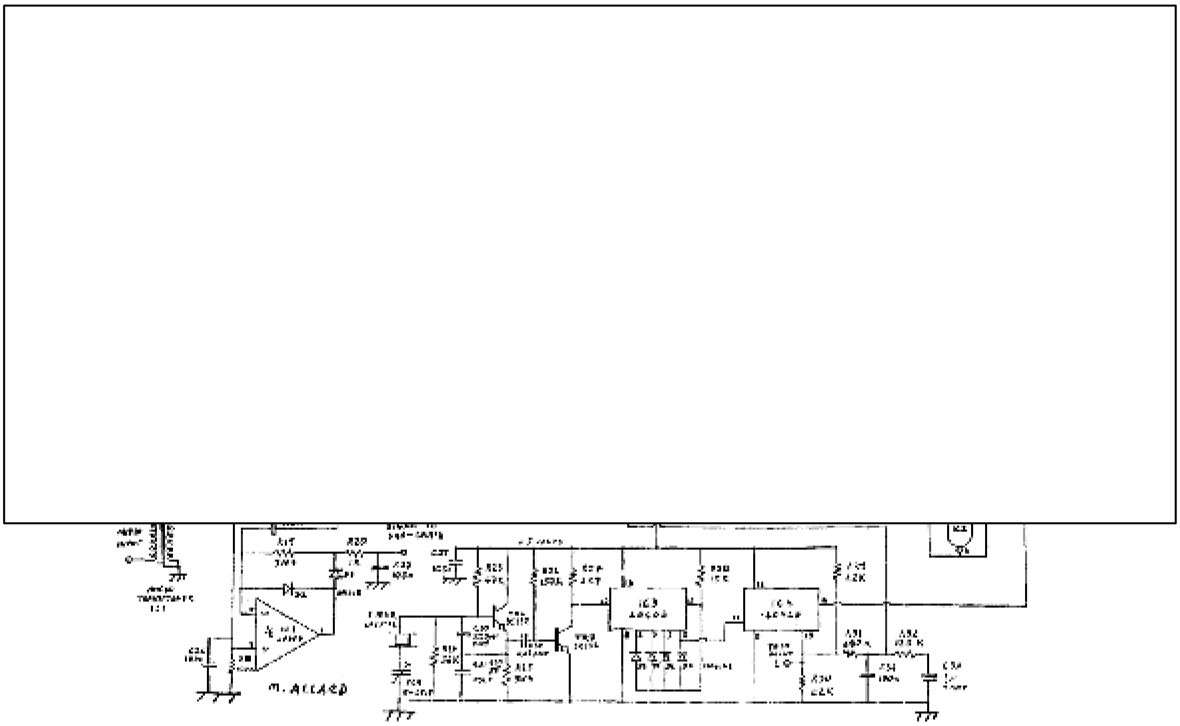
V_r = reflected voltage from the antenna

18. Leif Lonsmann, "The FM-Explosion: A Guided Tour Through the Radio Landscape of Europe," paper presented at the European Institute for the Media's Conference on Small-Scale Radio (Manchester, England), 19 January 1990, p. 1.

55-WATT FM LINEAR AMPLIFIER

This circuit is designed to boost a 4 watt input to about 55 watts output in the FM high-band. It requires a power supply of +12 to +14 volts / 6 amperes. Amplification comes from the SD-1278 power transistor made by Thomson; the design can also be modified for the Motorola MRF-238.

(See Diagram Lr19)



Parts List
Capacitors:

CV1, CV2	40pF foil trimmer
CV3, CV4	60pF mica trimmer
C1	10pF
C2	27pF
C4-6	100pF
C7-8	56pF
C9-14	10pF
C15-17	470pF
C18	1 N
C19	47 uF – 25 V

H1 15 turns of 0.3 mm copper wire wound around a 47-ohm 1-watt resistor

H2 FX1115 6-hole ferrite bead

L1 15 mm copper wire hoop:
(Missing Diagram)

L2 5 mm copper sheet:
(Missing Diagram)

L3 1 mm copper wire loop 10 mm diameter:
(Missing Diagram)

L4 4 turns of 1 mm wire, 7 mm coil diameter, 1 mm between coils

L5 3 turns of I mm wire, 5 mm coil diameter, 2 mm between coils

The 10-watt design shown on page 47 is one of several commissioned by UNESCO for use in developing countries. Their initial idea was to provide the transmitters in kit form, with a few hard-to-find parts included, but with the builder responsible for finding the rest. This was to keep costs to a minimum. With power outputs of up to 120 watts, the transmitters were designed to operate in harsh environments and be maintained by untrained people without access to sophisticated test equipment. In recent years, UNESCO's policy shifted to offering built transmitters instead of the kits, but still at much lower prices than a commercial firm ($1500-$3000). So Martin Allard's circuit is included here more to describe it than to encourage you to build it. For more information, contact Mallard Concepts Ltd., 13 Southdown Ave., Brixham, Devon TQ5 OAP, England; phone (44) 8045-6756; fax (44) 8045-2839.

We mentioned that Italy had no broadcasting law for almost 15 years. Without regulation, local stations engaged in the kind of "power war" noted above in the POWER, HEIGHT & SIGNAL RANGE section. Stations had to increase their transmitter output repeatedly, to hold their place in the spectrum and overcome increasing interference. As a result, we understand that many Italian stations still have transmitters that they outgrew but were unable to sell, because they had become as inadequate for other stations' needs as they were for their owners.

Now that Italy has passed a broadcasting law, its provisions are likely to force additional stations off the air, creating an even greater surplus of used transmitters.[19] Anyone interested in starting a low-power FM station should look into the possibility of buying a used transmitter in Italy. An obvious way to start is by contacting CoRaLLo, the association of local

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19. According to Kenneth Donow, fewer than 1800 of the 4500 Italian stations now on the air will qualify for a license. Donow, The European Media Mosaic, National Association of Broadcasters (Washington, DC USA; publication pending), p. 15.

community radio stations (c/o Franco Mugerii, Piazza della Liberta 13, 00192 Roma RM/ Italy), or one of the other Italian radio associations listed at the end of this booklet (see LOCAL RADIO ORGANIZATIONS IN WESTERN EUROPE AND NORTH AMERICA).

FM FEEDLINES

When the station's signal leaves the FM transmitter, it is very different from the one that came from the studio. The audio content is the same (we hope), but now it is much more powerful and imbedded in a radio signal. The audio signal was content to travel on a wire. However, a radio signal on a wire will tend to diffuse into the surrounding space unless something stops it.

A "feedline" delivers radio signals from the transmitter to the antenna. So that power does not leak out before reaching the antenna, the feedline should be either a coax cable, with a conductive sheath around the core conductor, or a "balanced" pair of parallel wires held a certain distance apart. Coax cable is usually more expensive, and even on short runs some power will be lost. In theory, balanced parallel wires lose less power over the same distance. But in practice, any sharp bend in them causes losses, and nearby metal objects (such as the antenna or the tower supporting it) interact with the signal. So most broadcasters use coax.

Sooner or later, weather ruins all outdoor coax. Water getting inside is particularly serious, as it increases signal losses and may cause a short circuit. Seal the ends of the cable carefully, with silicone plastic or waterproof putty around the connectors. At the frequencies in the FM high band, thicker coax is preferred, as the losses are less than with thin coax. High-power FM stations often use very thick, rigid, pressurized cables filled with nitrogen or dry air, to keep out moisture and minimize power losses. For low-power stations, flexible plastic foam-filled cable is fine, and substantially cheaper. Get a type whose "characteristic impedance" matches the impedance of your antenna and transmitter (see the table on the next page), and keep the feedline as short as you can.

The concept of "impedance" has come up a few times already. It worth more discussion here because it is essential for good feedlines: an impedance mismatch between the transmitter and antenna will reduce your radiated power, and could damage the transmitter.

The characteristic impedance of any line with two conductors is due to the size of those conductors and their separation. That goes both for coax as well as parallel wire-pairs. In general, thin wires that are far apart have a high impedance; thick wires and pipes which are close together have a low impedance. If there is a change in the size or shape of a line -as normally occurs where the feedline connects to transmitter and antenna - the characteristic impedances will differ, so some power will be reflected rather than sent through the connection. Fortunately, there are many ways to change the impedance

CHARACTERISTICS OF SOME COMMON ANTENNA FEEDLINES

VF = Velocity factor = the speed of radio waves on the feedline relative to the speed of light.

Dielectric = the material separating the core conductor from the conductive sheath.

which one line "senses" when it meets another. At the frequencies used in FM broadcasting, these ways are elegantly simple:
we can use measured lengths of wire, coax cable, or copper pipes as "transformers".

Say you need to match an antenna, whose impedance is 300 ohms, to a coax feedline with a characteristic impedance of 53.5 ohms. To find the impedance (Z) of the section that can match them, solve this equation:

$$Z = \sqrt{Z_1 Z_0}$$

where Z_1= the antenna's impedance and Z_0 = the impedance of the feedline. In this example, Z turns out to be 126.7 ohms. Here is the formula for calculating the characteristic impedance of parallel conductors:

$$Z = 276 \log (2s/d)$$

where d = the diameter of each conductor and s = the distance between their centers. If we have some copper plumbing pipe 2 cm in diameter, we can easily calculate how far apart the pipe sections should be to provide 126.7 ohms of impedance. According to the formula, the answer is 2.9 cm. How long does the matching section have to be? In the method we're describing, it is a 1/4-wavelength. But because radio waves travel more slowly through metal than in the air, we must take that into account. The formula is:

$$\text{Length} = \frac{75(VF)}{f}$$

where the Length is in meters, f = the frequency in MHz, and VF = the velocity factor of the medium. With self-built matching sections, the velocity factor is uncertain, but it is sure to be less than air, which is defined as 1.0. Let us assume it to be 1 for now, and cut off small lengths until we get a good match. If our operating frequency (f) is 100 MHz, Length would be .75 m.

To sum up, matching an 300-ohm antenna to a 53.5-ohm feedline for delivery of a 100 MHz signal can be done with two parallel copper pipe sections connected between the feedline and the antenna, when the pipes are 2 cm in diameter, .75 m long, and 2.9 cm apart. Since the impedance of all these elements may not actually be known with precision ahead of time, install the matching section so the separation between the conductors and their exact length can be adjusted to give the lowest SWR reading on the feedline.

There are many variations on this technique. There are even ways to use 1/4-wavelength stubs to block unwanted signals - for example, emissions produced by the transmitter that would cause interference if radiated from the antenna. But we leave this to you to investigate.

FM ANTENNAS

Antennas look like electrical cul-de-sacs. But that is not so when energy radiates into space, and currents in the ground "return" to the transmitter: transmitter, antenna, earth and air form a circuit with each listener's radio. It is more accurate to think of the antenna as an impedance matching device, matching the impedance of the feedline (usually 50-70 ohms) to the impedance of the surrounding airspace (377 ohms).

The right size for an antenna depends on the length of the radio waves it is supposed to radiate. Wavelength is the inverse of frequency: it is the distance between similar points in the wave-cycle. To calculate the wavelength in meters, divide 300 by the frequency expressed in MHz. If the frequency is 88 MHz, the equivalent wavelength is 3.4 m. If the frequency is 104 MHz, the wavelength is 2.88 m. So the radio wavelengths in the FM high band are all between 2.88 and 3.4 m.

As mentioned in the section on studio design, when the dimensions of a room form a ratio of 1:1 or 2:1, the airspace will resonate. Antennas are similar. When the length of an antenna is equal to a radio signal's wavelength - or half the wavelength, or some other harmonic ratio - a "standing wave" of energy forms on the antenna. Currents and voltages concentrate near the nodes of resonance, increasing the energy radiated. An antenna radiates most effectively when its size and shape make it resonate at the wavelength corresponding to the radio frequency produced by the transmitter.

Once radio energy leaves the antenna, it continues moving outward at the speed of light. Eventually, some small part of that energy may cross an antenna attached to a distant receiver, causing a small current to flow back and forth in that antenna, in sympathy with the current in the transmitting antenna. A maximum transfer of energy occurs between transmitting and receiving antennas when they are similarly oriented. Their orientation - and the orientation of the field connecting them -is called the "polarization."

In the early days of FM, transmitting and receiving antennas were usually horizontal; the radio field linking them was "horizontally polarized." But as FM car radios got popular, this changed, because car antennas are often vertical or tilted at an angle. When transmitting and receiving antennas are perpendicular to each other, energy transfer is minimal. To overcome that, and because broadcasters can no longer count on the listeners' antennas being oriented any particular way, "circularly polarized" transmitting antennas were developed. In essence, that means the field orientation rotates once each wave-cycle, so it is sure to match the receiving antenna's orientation during part of each cycle, however the antenna is oriented.

All these variations mean there now are many different designs for FM antennas. Those producing circular polarization are fairly complex: split rings with a spiral twist; clover-leafs mounted in front of a grid; wire cylinders on a lattice. Simpler designs are just as effective at radiating energy, although as we noted, the strength of the signal actually entering a receiver depends on the similarity of the transmitting and receiving antennas' orientations.[20] Is there a typical orientation for FM antennas on your listeners' radios? If so, try to match it with your station's antenna.

One thing is sure: energy emitted upward from an FM antenna is wasted. There are very few listeners in the sky. To reach listeners, the radio waves must be sent out across the landscape, or even aimed slightly downward from a high mount, toward the receivers. Thus, an important goal of FM antenna design is

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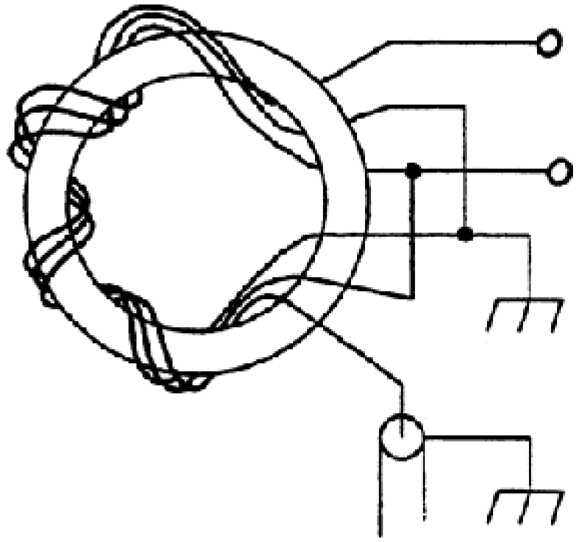
20. Polarization also affects range somewhat, as the landscape generally does not absorb as much energy from horizontally-polarized waves.

THE SIMPLEST FM ANTENNA

(A) The simplest FM antenna is the "half-wave dipole": two pieces of copper wire, each 1/4-wavelength long, pointing away from each other on a common axis. A dipole can be mounted horizontally, as shown here, or vertically. The simplest dipole has a flaw, though: it is a "balanced" antenna, while most antenna feedlines are "unbalanced" coax. Making a direct unbalanced-to-balanced connection lets energy from the antenna travel down the outside of the coax, weakening the symmetry of the radiation pattern.



B) One way to stop that is with a ¼ wavelength piece of coax, just like the feedline. Its outer conductor is soldered to the outer conductor of the feedline, and to the antenna wire that is attached to the feedline's outer conductor. This stops current from travelling down the outside of the feedline.

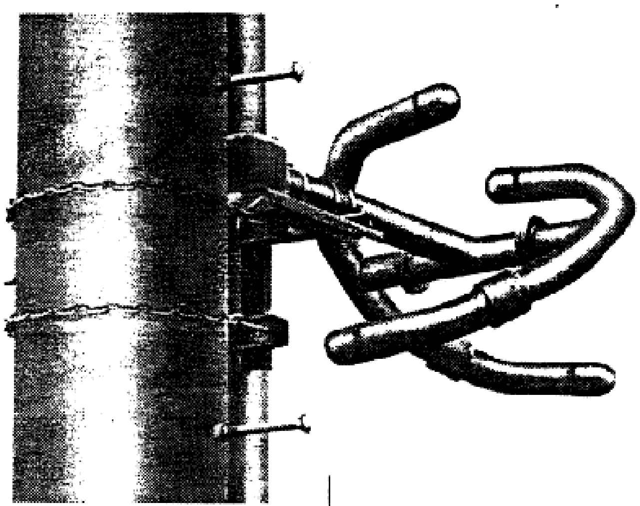
C) A better arrangement is to mount a small "balanced-to-unbalanced" transformer where the feedline and antenna meet. The "balun's" windings put the voltages fed to the 2 poles of the antenna exactly out of phase.

"Baluns" are usually wound around a ring or bead of ferrite, a compound of powdered iron.

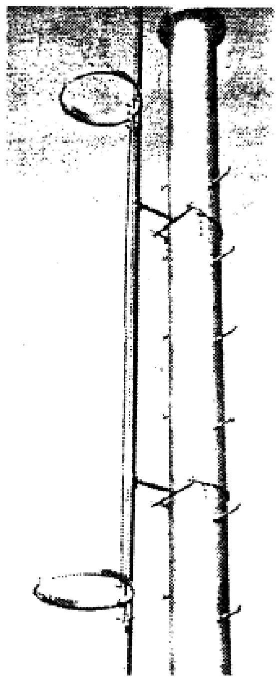
(See Diagram Lr20)

MORE COMPLICATED FM ANTENNAS

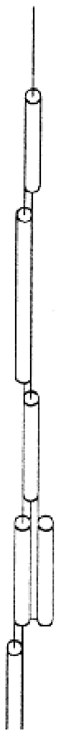
(D) Broadcast Electronic's model BESP shows a "split ring" made of copper tubing, designed to handle 50,000 watts and produce circular polarization. The copper tubing that plumbers use is perfect for FM antennas. Its thick form increases resistance to wind and ice, and increases the bandwidth. This design is meant to be mounted with similar split rings on a mast, for gain.



(E) A simpler ring design, also made by BE. This is designed for low-power stations. The rings are each separated by 1/2-wavelength.



(F) A "co-linear" FM antenna designed by Ernest Wilson of Panaxis Productions. It is made of RG-8 coax, with sections cut and soldered as shown in the diagram, so signals travel on the outside of the coax. Sectioning gives it a 3 db gain. To keep it rigid and aligned, it is sealed inside a long plastic tube or piece of bamboo.



concentrating the radiated energy in the horizontal plane/ regardless of the waves' polarization.

Concentrating the antenna's output in any direction increases its "gain" in that direction. Gain is always relative, like the dB in which it is measured. An antenna radiating the same amount of energy in every direction is a common standard for comparison. An antenna with a 3 dB gain in the horizontal plane means that twice as much power is diffused across the landscape as by an omnidirectional antenna fed with the same transmitter power. The ERP (effective radiated power) is doubled, and one may subtract 3 dB from the minimum field strength needed for reception, as discussed above in POWER, HEIGHT & SIGNAL RANGE.

So how does one increase gain in the horizontal plane? By stacking antennas vertically. When spaced an appropriate distance apart (the distance depends on the wavelength), energy from the stacked antennas combines in space to reinforce waves travelling in a horizontal direction and cancel the waves travelling in a vertical direction. Six to 12 stacked antennas can dramatically expand coverage - or give a 10-watt transmitter 100 watts ERP. In general, high gain antennas are best for reaching flat areas. Use a medium gain antenna in rolling terrain. In mountainous areas, a low gain antenna will get more energy into blocked and "shaded" areas.

Most FM antennas are mounted on the side of a tower or pole. The antenna support can affect the radiation pattern, especially when it is metal. Even experienced radio engineers do not know in advance where on a tower the antenna should be put for the best coverage pattern. For this reason, reception should be tested at various distances and locations while the antenna is being installed, so the best mounting is achieved. Energy reflected from the antenna mast can give a noticeable directional gain...and create shadow areas.

If the antenna is mounted on a structure supported by guy wires, the guy wires can also affect the radiation pattern. If there appears to be problem with metal guy wires, try nylon or rope instead. But be sure that any nonmetal support lines are strong enough to restrain the mast in high winds. If the antenna topples, your station will be forced off the air and someone might be hurt.

A peculiarity of FM transmission systems is their sensitivity to ice. Ice should not be allowed to accumulate on the antenna - not just because the added weight can bend it out of shape, but because its presence can change the antenna's resonant frequency so much that power reflected back into the transmitter can cause damage. Most expensive FM antennas come with built-in heating systems, to melt ice. Another solution is to keep the antenna inside a non-metal enclosure on the roof.

GROUNDING & LIGHTNING PROTECTION

Grounding is not as crucial to the performance of FM antennas as it is for mediumwave. The least-cost ground system is to take one or several old automobile radiators. Weld a copper strap to them, and fill the radiators with very salty water. Bury the radiators at the base of the antenna.

If your area has thunderstorms, lightning can destroy the station's antenna and damage the transmitter. Take precautions: Put a lightning rod at the top of the antenna mast. (This applies to both FM and mediumwave systems.) Connect the rod to a thick copper wire leading to a ground system buried at the base consisting of 6 thick copper wires, arranged radially underground with a common meeting-point in the center. That will give the lightning a low-resistance path to follow/ instead of the feedline to the transmitter. Make the ground radials as long as you can (up to 50 m). Bury them as deep as you can. The goal is to establish a ground path whose overall resistance is <10 ohms.

MEDIUMWAVE ANTENNAS

Mediumwave antennas are much bigger than VHF-FM antennas, because of the signals' much longer wavelengths. Using the formula given above, 300 divided by 1.5 MHz (1500 kHz) shows that the wavelength of signals around 1500 kHz is 200 m. The wavelength of 535 kHz (0.535 MHz) is almost 561 m.

The simplest mediumwave antenna is a copper wire 1/4-wavelength long, suspended horizontally at least 10 m above the ground, between two trees or poles. For frequencies around 1500 kHz, 1/4-wavelength is approximately 50 m. K. Dean Stephens found that this simple antenna provides a range of about 30 km from 100 watts ERP in the absence of interference from other stations (see pages 7-8). The antenna wire should not touch anything but the electrical insulators holding it up. Tie the insulators to the trees or support poles with nonmetallic cables (plastic or rope). The supports thus need to be more than 50 m apart. If that is not possible, the antenna can replace all or part of the feedline, so only part of it is between the supports.

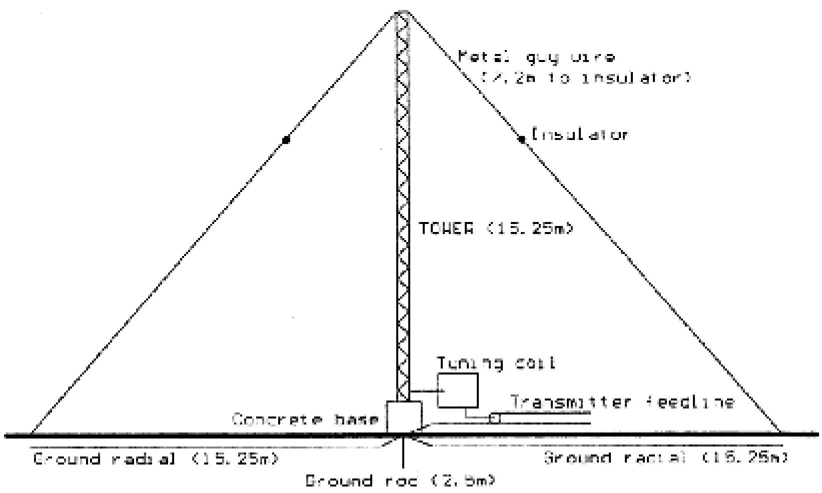
The disadvantage of this simple design is that so much of the energy radiates upward. Less would be lost if the antenna was vertical. But supporting a 50 m wire vertically is much harder than supporting it horizontally. The engineer's solution is to turn the wire into a slim metal tower, rigid enough to support its own weight, set on a concrete base for electrical isolation from the ground. The tower must be stabilized against the force of the wind with guy wires. As mentioned in the discussion of FM antennas, the guy wires can affect the radiation pattern. With mediumwave, the affect is often beneficial. Like the antenna, guy wires should be electrically isolated from the ground. Wooden or heavy glass connectors are used for this purpose.

Lengthening a vertical mediumwave antenna to about 0.6-wavelength pushes more of the radiated energy toward the horizontal plane. That is desirable because it increases the field strength at ground level. For signals around 1500 kHz, 0.6-wavelength is about 120 m. Shorter verticals can be used, but they yield less coverage from the same transmitter power.

The performance of a shorter antenna can be improved by "top-loading" - that is, by adding electrical capacitance to the top. Putting a horizontal metal disk or ring at the end of the antenna is one way: the bigger the diameter the better. Another way is to clamp 3, 6 or 12 metal guy wires to the tip of the antenna, sloping out May-pole fashion, to electrical insulators on lines anchored in the ground. Both top-loading methods can be combined by bonding the wires to the edge of a top-mounted disk.

In 1990, using computer-modeling techniques, the US National Association of Broadcasters (NAB) developed a short vertical antenna design for use with a smaller-than-usual grounding system.[21] It is a more precise formulation of the "top-loading" approach just described. They say it is best suited for stations using frequencies between 1000 and 1605 kHz, with transmitters of under 1000 watts. The theoretical "radiation efficiency" is only 20 - 45% of a 1/4-wavelength vertical, but the cost savings are substantial.

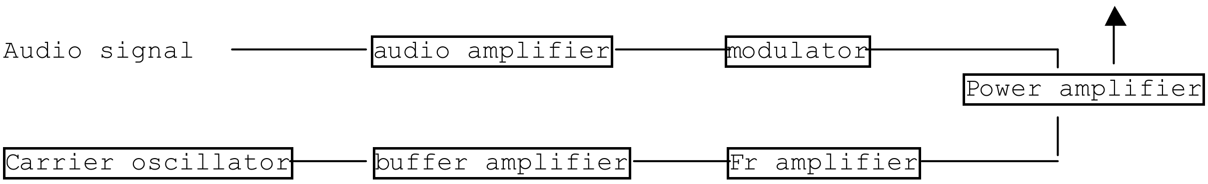
(See Diagram Lr22)



NAB "Low Profile" Mediumwave Antenna design

21. See David Pinion, James Breakall, Richard Adier and Alfred Resnick, "Low Profile AM Antenna Design Study, Phase II, Final Report," in <u>Report to the AM Broadcast Industry on the NAB AM Antenna Projects,</u> National Assn. of Broadcasters (Washington, DC USA), 15 September 1990. For more information, contact AGL Inc., P.O. Box 253, Pacific Grove, CA 93950 USA.

Block Diagram of an AM transmitter:



The NAB design is a triangular tower 15.25 m tall, with each face 60 cm wide and corner legs 5 cm in diameter. A "top hat" is created with 6 guy wires bonded to the tower top, sloping down to the ground at 45-degree angles. For 1485, 1584 and 1602 kHz (the European low-power channels), insulators 7.2 m down along each guy divide the wires so only their top part is electrically joined to the antenna. The tower sits on a concrete base over a 2.5 m buried vertical ground rod. The ground rod is joined to six wire radials 15.25 meters long, buried 15 cm below the earth surface, 60 degrees apart (see diagram).

It is also possible to use metal towers not originally designed to be mediumwave antennas: flagpoles, water tanks, and other tall metal structures in the landscape. But never NEVER NEVER use a tower carrying live powerlines.

To use a "found" structure as an antenna when it is not electrically isolated from the ground, you will have to experiment to find the best place to attach the feedline. An impedance matching network may also be needed. To find the best feed point, try bolting a wire to the structure several meters above the ground, making sure there is a tight metal-to-metal contact. Bring the wire down near to the ground at a 45 degree angle, where it connects to the coax cable coming from the transmitter. Do not touch the antenna, slant wire, or horizontal feedline while a test signal is fed from the transmitter. Drive around the area at different distances from the antenna to check reception quality. Note the received signal strength at various locations. Change the feed-point, and check the reception again.

GROUNDING

As important as height is for good FM coverage, grounding is even more important for good mediumwave coverage. Radio frequency currents in the ground around the transmitter and the antenna's base interact with the airwaves produced by the antenna to create the overall diffusion pattern. The ideal grounding system would be a copper sheet I/4-wave length in radius, buried at least 15 cm below the earth's surface. That is obviously impractical. But it can be approximated by burying a large number of radial wires. "Large number" means up to 120 radials, spaced 3 degrees apart. Four radials (90 degrees apart) is an absolute minimum. The radials should converge directly below the antenna, and be connected to the metal sheath around the coax feedline coming from the transmitter. All connections should be as low resistance as possible; silver soldering or welding is recommended. Failing that, clean the copper thoroughly and clamp the pieces together tightly.

The grounding system used with the NAB's short vertical is a less costly compromise which can be used with other antenna designs. Since the ground system won't be visible after it is buried, make an accurate map during the installation to guide future repairs.

GETTING EQUIPMENT

Lack of hard currency is a major problem for most new broadcasters in the post-Communist countries. But it need not kill your project.

Some pieces of equipment are not hard to build, if you can find the parts and someone who knows how to put them together -the antenna, for example. It is often easier to modify existing equipment than to build from zero. A power amplifier from an amateur radio or military radiophone system can be adapted for broadcasting - or might contain parts useful in a different design. Someone familiar with the used equipment available in your area can advise you on opportunities for "recycling."

It is possible to buy used equipment for much less than the cost of new gear. When buying used equipment, however, there are dangers that do not exist with new equipment, and fewer remedies for problems.

Some companies specialize in overhauling used equipment for re-sale. Some give warranties that the equipment will work for at least a specific duration. Before buying anything from a company that handles used equipment, talk with people who have bought things from them, to see if they are satisfied with their purchases.

Be sure that the equipment offered is what the seller claims. Dishonest sellers have been known to change a transmitter's label, for instance, to identify it as a newer model, or one with higher power output than it actually has. Certainly do not pay for an expensive piece of hardware until someone you trust - who is not on the seller's team - verifies that the equipment offered is actually the model described, and its condition is as described. If that is impossible, try to defer at least half of the payment until you can verify the product's identity and condition. Did the previous owner modify the equipment? Are circuit schematics and the operator's manual included? Are replacement parts are still available?

Peter Hunn, who built an low-cost FM station a few years ago, to serve a town in the northeastern part of the United States, recommends that buyers "concentrate on radio equipment that the seller is offering because he has no more need for it, not because it no longer operates well. For example, many AM [mediumwave] stations converting to stereo are marketing their mono equipment. These mono pieces are being sold to make way for a new technology. In this way, a small, new station might inexpensively acquire a reliable mono control board, tape cartridge machine, or signal processor."

Hunn adds, "A station just granted a power increase will probably have a useful lower power transmitter for sale. A functional, late-model transmitter can represent a tremendous savings for a beginning station. I found a fine FM transmitter available at a New York State station that was increasing its power from 400 to 3,000 watts. I bought the solid-state transmitter, just 3 1/2 years old, for about one-third of its original cost."[22]

New equipment is likely to work longer before failure than used equipment. Often a manufacturer will guarantee performance for a period of time, and either repair or replace the equipment if it fails in that period. A good warranty from a reliable company adds value to the equipment, since you must consider not just the purchase price, but how long it will last and the cost of repair and maintenance. Check the warranty as carefully as the technical specifications and price.

A device might have an attractive price and be in good condition, but be incompatible with other equipment already acquired for the station. To avoid being seduced into useless purchases, know the specifications of needed items before starting to shop.

The prices of broadcasting equipment tend to reflect what commercial stations can afford to pay, rather than the actual costs of manufacturing. That gives manufacturers a lot of room to negotiate price discounts to particular customers.

Even if you do not have enough money to pay for all the needed equipment right now, it is possible to negotiate with some suppliers to reduce the price, or to obtain the equipment before full payment is made. At this early stage in the development of broadcasting in post-Communist countries, manufacturers may be eager to have their equipment installed soon, so it will be seen by other would-be broadcasters, who might be inspired to buy it. In other words, they might be willing to plant "seeds" for future sales, by offering generous deals to a few stations now.

In broadcasting it is not unusual for a supplier to agree to a "deferred payment plan," with an immediate payment of 10 - 25 percent of the price and a signed agreement to pay the rest, plus interest, over a period of 3 - 5 years. In effect, the seller loans you most of the money needed for the purchase. Often the only security needed for such a loan is the equipment itself:
they reclaim it if you fail to pay. Under the normal payment schedule, the same amount is due each month until the debt is

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22. Peter Hunn, Starting and Operating Your Own FM Radio Station from License Application to Program Management, TAB Books, Inc. (Blue Ridge Summit, PA, USA), 1988.

paid off. But you might try to negotiate a rising scale of payments, so that the payments in the first year are low, with increases in each following year.

Another arrangement is leasing the equipment now, with the option of buying it later. You might work out an agreement for part of the lease payments to be subtracted from the eventual purchase price. This arrangement should only be made with equipment designed to last longer than the lease period. It makes no sense agreeing to purchase something at the end of its useful life.

Another approach is to tell an equipment vendor or manufacturer what your budget is, and have them prepare a list of equipment meeting the conditions of your license. Their list can be compared with those compiled by other vendors. The best list can be incorporated into a financing proposal shown to investors or lenders. A list of specific equipment, with sources and costs, adds realism to a proposal, and could help convince a donor that your project is serious.

Because you risk losing equipment and they risk losing money, any deferred payment or lease/purchase plan should be formalized in a written sales agreement. This is a contract stating the conditions for transfer of ownership, the schedule and amount of payments, the interest rate on money loaned, etc. The conditions under which equipment must be returned to the supplier should be spelled out very clearly, particularly as to late payments: how soon after nonpayment can the equipment be reclaimed? is it possible to miss a payment and make it up with a double payment next month?

Any time you ask a seller to give you something before it is fully paid for, you are asking them to trust you. That is a risk for them, since you may not be able to pay in the future anymore than you are now. The seller may still be willing to take that risk if:

* he believes you and your partners are responsible, competent people who keep their promises. Records showing previous debts paid on time, or success in managing a similar project, can help demonstrate your reliability.

* the project has a good chance of financial success. A well-thought-out plan that analyzes the potential audience, how the station will generate income, and what the costs will be, is not only a good way to appeal to donors, it can encourage an equipment vendor to accept deferred payment.

* you compensate the lender for his risk by paying interest on the loan built in to a deferred payment plan. A relunctant lender might become a willing one if the interest rate is high enough. Of course, if it is too high for the debt to be paid off, there is no benefit to either party.

STAYING ON THE AIR

It is possible to produce high-quality programs on cheap or old equipment, but only if it is well-maintained. In fact, you cannot expect to continue broadcasting without maintaining the equipment. A specific person at the station should be responsible for all equipment maintenance, whether or not they do the work themselves. Normally, that person is the Chief Engineer.

You can avoid problems before they happen, by not installing any more equipment than is necessary to produce your broadcasts. If you have a choice between a simple or complex device for some function, remember that the simple device has fewer ways to fail.

Systems for monitoring the "health" of equipment should be designed in from the start. Certain pieces of test equipment are too expensive and too rarely needed to be bought by everyone. Consider cooperating with other stations to split the cost of renting or purchasing an oscilloscope, for example. Similarly, several stations can sign contracts with one engineer to repair and maintain equipment at each station. That is a common arrangement in the US, and much costs less than having a full-time repairman on every station's staff.

Finally, banning cigarette smoking in all rooms where electronic equipment is installed will do more than anything else to prolong the life of the equipment.

GLOSSARY

[German, French and Russian synonyms, where known, follow the English definition. They come from the Technical Dictionary of Radio and Telecommunication Installations by Dok.-Ing. Hans Plohn, Wilhelm Preikschat and Ing. Marian Shwertner, VEB Verlag Technik (Berlin, Germany, 1963)]

Alternating Current (AC) -- electric current which periodically reverses its direction of flow through a wire; in contrast to Direct Current (DC). [Wechselstrom; courant alternatif]

Ammeter -- a meter showing the number of amperes present in a circuit. [Strommesser; amperemetre]

Ampere (Amp) -- a measure of electrical charge or current: 1 ampere is the amount of current that 1 volt can push through a resistance of 1 ohm. [Ampere; ampere]

Amplifier -- a device for increasing the power of a signal. [Verstarker; amplificateur]

Amplitude Modulation (AM) -- a technique for merging an audio signal with a radio signal by varying the strength ("amplitude") of the radio frequency at the rate of the audio frequency. AM is used by all stations in the Longwave and Mediumwave bands. [Amplitudenmodulation; modulation d'amplitude]

Antenna -- the part of the broadcast transmission system that is intended to diffuse radio energy to the station's listeners. Also the part of the receiver that detects radio waves. [Antenne/Luftleiter; antenne/conducteur aerien]

Antenna gain --an increase in the energy emitted by an antenna over what would be produced by a standard reference antenna with the same power input. Gain in one part of the spatial pattern is usually accompanied by a decrease elsewhere in the pattern. [Fernsehantennengewinn/Richtungsverstarkungsfaktor; gain d'antenne/coefficient d'amplification directive]

Antenna mast -- a vertical support for an antenna. [Antennen-mast; pylone d'antenne]

Attenuation -- reducing the power of a signal. [Schwachung/Damp-fung; attenuation/affaiblissement]

Audio Cartridge ("Cart") -- a plastic shell holding a continuous loop of 6.25-nim audio tape. Radio broadcasters use carts for short, frequently-needed sound elements.

Audio mixer -- a device for combining audio signals from more than one source. Mixers usually have controls for adjusting the strength of incoming and outgoing signals. [Mischtafel/Mischer; Melangeur]

Background noise -- noise in the environment that may be audible even though it is not part of a desired signal. [Grundgerausch; brut de fond]

Balanced line -- an electrical cable with two conductors, set up so that the current carried by one conductor is equal to the current flowing in the other conductor in the opposite direction. [Ausgeglichene Leitung;- ligne equilibree]

Balun -- a transformer which matches "balanced" and "unbalanced" lines.

Bias Tone -- a tone much higher than humans can hear (usually 50-150 kHz) which is often added to a tape recording to reduce audio distortion and the need for equalization.

Broadcasting -- sending out a signal to a wide area for free reception by anyone with the proper receiving equipment. [Rundspruch; radiodiffusion]

Capacitance -- A component's ability to store energy in the electrical field between two charged surfaces. Capacitance is measured in "farads." [Kapazitat; capacitance]

Cardioid -- This describes the shape of one type of microphone's sound sensitivity: it literally means "heart-shaped."

Carrier -- the radio frequency which carries programming from the transmitter to the receiver. In both AM and FM broadcasting, the carrier is a Channel's center frequency. [Trager; porteuse]

Cart — see Audio Cartridge.

CCIR -- The International Consultative Committee for Radio. A bureau of the International Telecommunication Union whose mission includes performing research relevant to standard-setting, and harmonizing the use of radio by various countries. [Inter-nationaler beratender AusschuB fur Funkverbindungen; Comite Consultatif International des Radiocommunications;

Channel -- the small band of frequencies in which a broadcaster is allowed to transmit. [Kanal; canal]

Coaxial (Coax) Cable -- a cable with two electrical conductors, concentrically arranged: a wire at the core and a tubular metal sheath are separated by insulation. Coax cable also usually has a layer of insulation on the outside. [Koaxialkabel/Koaxiale Leitung/konzentrisches Kabel; cable coaxial/ligne coaxiale]

Compressor --a device which reduces the dB difference between the loud and soft sounds in an audio program.

Condenser Microphone -- a microphone that turns sound into electric power when the sound-waves move the charged surface of a capacitor. [Kondensatormikrophon; microphone electrostatique]

Connector -- the termination of a cable designed for making a reliable electrical connection to another cable or device (for example, a plug or a jack). [Stecker/Verbindungsklemme; fiche/serre-fil]

Console -- see Audio Mixer.

Copper -- a soft, pink/orange metal with a very low resistance to electricity. [Kupfer; cuivre]

Cross-talk -- when two cables are close together, an audio signal carried by one of them can sometimes be heard on the other, even without a direct electrical connection. This is a type of audio interference. [Nebensprechkopplung; accouplement diaphonique]

Current -- a moving electrical charge. See Ampere. [Strom; Courant]

Decibel -- a logarithmic ratio between two signals; usually their relative wattage, sometimes their relative voltage. [Dezibel; decibel]

Direct Current (DC) -- an electric current that flows in only one direction, in contrast to Alternating Current (AC). [Gleichstrom; courant continu]

Distortion -- unwanted changes in an audio signal due to inaccurate reproduction of its wave-form; often caused by overloading a device with a signal that is too strong. [Verzerrung; distorsion]

Dummy Load -- a device used in transmitter tests that temporarily replaces the antenna which the transmitter normally feeds. A dummy load does not emit radio waves, even while presenting the transmitter with an impedance load like the antenna's. The transmitter's power output is dissipated as heat. [Kunstantenne;antenne fictive]

Effective Radiated Power (ERP) -- A measure of the power output of an antenna, used by stations to predict signal range, and by regulatory bureaux to limit a station's emissions. To calculate ERP, subtract all feedline losses from the transmitter's output, and multiply the remainder by the antenna's gain. [Wirkleistung; puissance reelle]

Elevation -- height. [H6he; hauteur/altitude]

Equalization -- changing the relative emphasis given to various frequencies in an audio signal. [Pegelausgleich; equilibrage]

Equalizer -- an audio filter for equalization. The two basic types are "graphic" equalizers (which allow fixed bands of audio frequencies to be boosted or attenuated), and "parametric" equalizers (which let the operator also vary the center frequency and width of any band that is boosted or attenuated. [Entzer-rungsfilter; filtre correcteur]

European Broadcasting Union (EBU) -- An organization of Western European countries that formulates regional agreements and standards concerning broadcasting in the member nations.

Exciter -- the part of an FM transmitter which generates the radio carrier frequency and combines it with the station's audio output. [Steuersendef; oscillateur]

Fader -- a mixer's audio signal strength control; also called a volume control, attenuator, potentiometer or "pot." [Regel-glied/Lautstarkeregelung; affaiblisseur/reglage de 1'intensite sonore/regulateur de volume]

Federal Communications Commission (FCC) -- the US Government bureau which regulates broadcasting.

Feedline -- a cable delivering the transmitter's output to the antenna; usually a coax cable. [Energieleitung; ligne de transmission]

"Female" Plug -- a Jack; the socket into which a "male" plug fits, to make an electrical connection. [Mutterstecker; fiche femelle]

Field Strength -- the intensity of a radio signal some distance from the antenna. In theory, it is the voltage induced in a wire 1 m long oriented perpendicular to the radio waves. Also called "field intensity." [Feldstarke; intensite de champ]

Frequency -- the rate at which a signal oscillates or a current alternates; usually measured in Hertz. [Frequenz; frequence]

Frequency Modulation (FM) -- A technique for adding audio to a radio carrier by varying the carrier's frequency in proportion to the audio frequency. FM is used for broadcasting in both the VHF high (EBU) and low (OIRT) bands. [Frequenzmodulation; modulation de frequence]

Gain -- an increase in signal strength or amplitude. See also Antenna Gain. [Verstarkung; amplification

Grounding -- connecting an electrical circuit or device to the Earth. This serves various purposes: to drain away unwanted currents; to provide a reference voltage for circuits needing one; to lead lightning away from delicate equipment; to improve the radiation pattern or efficiency of an antenna. [Erdung/Erden/Erdungsanlage; dispositif de mise a la terre]

Ground Rod -- a long copper rod driven into the Earth to ground an electrical system. Lengthening the rod, or using multiple rods spaced several meters apart, reduces electrical resistance, which is always desirable. Mineral salts and water added to the ground around the rods reduces the electrical resistance even more. [Erder; prise de terre]

Guy Wire -- a cable or cord to stabilize an antenna mast against movement in the ,wind. [Spanndraht; fil d'arret]

Hertz (Hz) -- named for the German scientist who first detected radio waves, this is a frequency measurement: the number of wave-cycles per second. [Perioden je Sekunde; periodes par seconde;]

Hybrid -- or telephone hybrid: a device which replaces the telephone handset in a studio, so the person speaking in the studio can use a microphone and still be heard by the person at the other end of the phoneline on their telephone. The hybrid also separates incoming and outgoing voice signals on the phone-line so that their audio levels can be adjusted separately]

Impedance -- a property which is specific to Alternating Current (AC). It is like Resistance, but it varies with the AC frequency. For a maximum transfer for power, the source impedance and the terminating impedance should be equal. [Impedanz; impedance]

Insulation -- a material which is a poor conductor of electricity. It is used to stop current from flowing where it is not wanted. [Isollerung/Isolation; isolement/isolation]

Interface -- a place where at least two different types of circuits are connected. Some sort of conversion is often needed at an interface, which makes it different from a simple connection

Intermodulation -- a kind of interference specific to FM. When two FM signals of different frequency enter a receiver simultaneously, they can interact with receiver circuits to create the illusion that the signals were transmitted in additional channels. These illusions can interfere with the reception of signals that actually were transmitted in those channels. [Gegenseitige Modulation; intermodulation]

Jack -- a "female" connector into which a "male" plug fits. They are often grouped together in Patch Bays. [Klinke; jack/cliquet;

KiloHertz (kHz)-- 1000 Hertz

Limiter -- a device that limits the strength of signals passing through it. Sometimes used with FM transmitters, which do not need much voltage to produce 100% modulation of the radio carrier. [Begrenzer; limiteur]

Line Level -- one of the three signal levels commonly found in broadcasting studios. (The other two are "microphone level" and "loudspeaker level".) There are several ways to measure it, but in North America, the normal studio line level is 0.775 V, with momentary peaks of up to 1.23 V. In Europe many stations have line levels of 1.55 V, with momentary peaks of up to 3.1 V. [Hauptspannung; tension principale]

Longwave -- one of the frequency bands used for AM broadcasting in Europe: 148.5-283.5 kHz. [Langwellenband; gamine d'ondes longues]

Loudspeaker -- a device which turns an oscillating current into sound waves; the opposite of a microphone. [Lautsprecher; haut parleur]

Mains Power Supply -- electricity from the power network serving a large area. In Europe, mains power is 220-240 volts with the current alternating at a frequency of 50 Hz. [Starkstromnetz;

reseau d'energie]

Mediumwave -- one of the frequency bands used for AM broadcasting: 526.5 - 1606.5 kHz.

MegaHertz (MHz) -- 1,000,000 Hertz.

Mixer, Mixing Console -- see Audio Mixer.

Modulation -- the process of adding one signal (an audio program, for example) to a Carrier signal (a radio frequency, for example). This is usually done to take advantage of the carrier's superior range and coverage. When a receiver detects the combined signal by tuning in the carrier, the signal is "demodulated" - the carrier is filtered out so only the audio remains. [Modulation; modulation]

Noise -- any unwanted energy detected along with a wanted signal. [Gerausch/Rauschen; bruit/craquement]

Ohm -- the unit of measurement for resistance in Direct Current (DC) circuits, and also for impedance in Alternating Current (AC) circuits.

OIRT -- the International Organization of Radio & Television: a technical association formed by Communist countries.

Oscilloscope -- a device that visually represents a signal's wave-form.

Patch Bay, Patch Panel --a group of jacks arranged in rows and wired to various input and output devices. Audio signals can be re-routed easily when short audio cables with plugs at each end are plugged into the jacks. [Klinkenfeld; panneau de jacks]

Power -- multiply the force in volts by the amount of current in amperes to figure the power in "watts." [Leistung; puissance]

Peak Program Meter (PPM) -- one of the devices that visually displays rapid changes in audio signal voltage. [Spitzenzahler; compteur a depassement]

Resistance -- the property of a material which limits how much current flows when a voltage is applied. Resistance is measured in "ohms." Resistance = 1 ohm when 1 volt causes a current of 1 ampere to flow. Materials with a very low resistance are called "conductors;" those with very high resistance are called "insulators." [Wilderstand; resistance]

Selectivity -- a device's ability to distinguish between signals that are close together in frequency. This enables a receiver to tune in one station without also tuning in those in adjacent channels.

Sensitivity -- a receiver's ability to detect weak signals.

Standing Wave Ratio (SWR) -- Also called a Voltage Standing Wave Ratio (VSWR).

Transformer -- a device with coils arranged so that an alternating current in one coil is communicated to the other coil by magnetic induction. Transformers are useful for maintaining electrical isolation between two circuits while transferring energy from one to the other, and for giving the output a different voltage and impedance than the input.

Transmitter -- an electrical device that generates, modulates and amplifies radio frequencies to be broadcast to distant receivers. [Fernmeldegerat/Sender; emitteur]

Vacuum Tube, Valve -- a sealed glass bulb containing a vacuum which enables various electronic processes to occur. [Rohre/Elektronenrohre; tube/valve]

Very-High Frequency (VHF) -- the band of radio frequencies from 30 to 300 MHz. [Ultrahochfrequenz/Ultrakurzwelle (UKW); hyper-frequences]

Voltage -- the electrical force that overcomes resistance and causes a current flow. [Spannung; voltage/tension/potentiel]

VU (Volume Unit) meter -- a gauge that shows fluctuations in the strength of an audio signal. Because it samples the signal for longer than a Peak Program Meter (PPM), the VU meter's reading is a short-term average rather than an instantaneous value. It is designed to approximate "loudness" as heard by the human ear.

Wavelength -- the distance between repetitions of a moving energy cycle, such as a radio wave. To calculate wavelength in meters, divide 300 by the frequency expressed in MHz. [Wellenlange; longeur d-onde]

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Holzberg Inc.
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Ram Broadcast Systems Inc. 346
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FURTHER READING

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