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MMDS Technical Planning Guide

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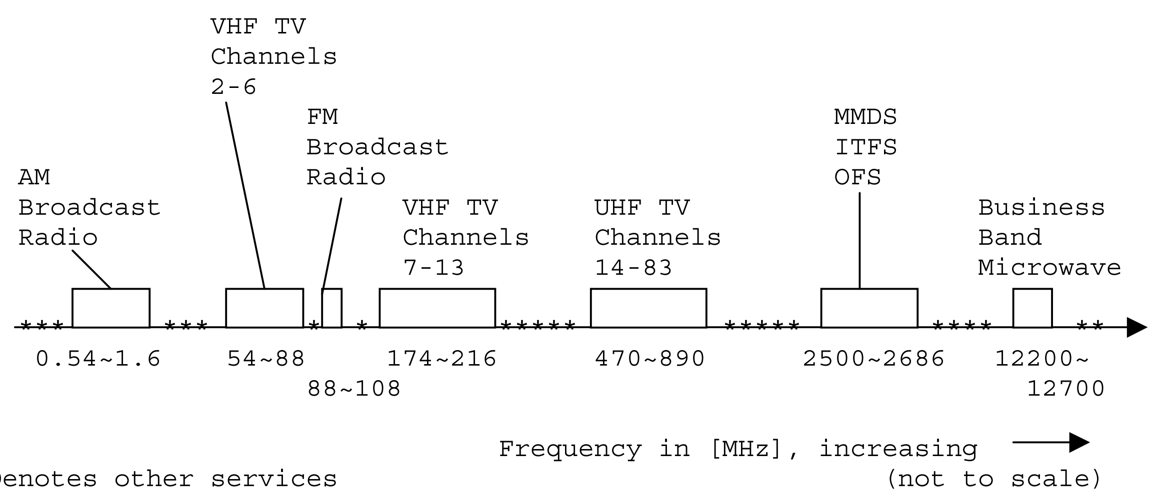
TABLE OF CONTENTS

SECTION I   MMDS TECHNOLOGY

A. GENERAL DESCRIPTION

1. Multichannel Multipoint Distribution Service, MMDS, is a name designated by the US FCC. It would be more appropriate and understandable to the public if we had called the service Multichannel Broadcast. But, historically broadcast television services are found on the radio dial at VHF and UHF frequencies. And, since MMDS is in the microwave frequency range it was believed to be more appropriate to regulate the service as a traditional point-to-point (or in this case point-to-multipoint) microwave service. The choice and worldwide popularity of names such as MMDS, Wireless Cable, Open Circuit Private and other designations are unimportant: in simplest terms MMDS is a broadcast service (hence Wireless). Since there is inherently more spectrum bandwidth (or electronic real estate) as we move higher up the radio dial we can secure more channels for simultaneous transmission of information and entertainment (hence Multichannel).

   Before proceeding with comparisons and television broadcast technology in general, it may be instructive to display the basic part of the electromagnetic frequency spectrum (i.e., the radio dial) that is important to MMDS and related services. The spectrum is regulated and managed by worldwide governmental agencies, usually in concert with each other. Variations in service and formats do exist between countries; but, international conferences try to establish and maintain certain minimum standards. The spectrum is a natural resource, we did not invent it, we can only hope to regulate and use it wisely. The following spectrum is shown by way of illustration for use in the US; other countries use similar patterns.



*** Denotes other services

MMDS Channel Assignments

SERVICE	GROUP	CHANNEL NUMBER	BAND LIMIT MHz
ITFS	A	A-1	2500-2506
		A-2	2512-2518
		A-3	2524-2530
		A-4	2536-2542
ITFS	B	B-1	2506-2512
		B-2	2518-2524
		B-3	2530-2536
		B-4	2542-2548
ITFS	C	C-1	2548-2554
		C-2	2560-2566
		C-3	2572-2578
		C-4	2584-2590
ITFS	D	D-1	2554-2560
		D-2	2566-2572
		D-3	2578-2584
		D-4	2590-2596
MMDS	E	E-1	2596-2602
		E-2	2608-2614
		E-3	2620-2626
		E-4	2632-2638
MMDS	F	F-1	2602-2608
		F-2	2614-2620
		F-3	2626-2632
		F-4	2638-2644
ITFS	G	G-1	2644-2650
		G-2	2656-2662
		G-3	2668-2674
		G-4	2680-2686
OFS	H	H-1	2650-2656
		H-2	2662-2668
		H-3	2674-2680
Voice and Data Response	All	A-1 to G-4	2686-2690

In the U.S. MMDS Operators may apply for operation of ITFS and OFS channels to implement all 31 channels from one location. Operators in other countries are now implementing similar systems with similar totals. For less than 31 channels it is popular to construct systems in groups of four; it is now commonplace to implement either adjacent or non-adjacent channel systems.

2. The evolution of this service worldwide is discussed elsewhere. But the simple fact is that operators can now implement MMDS systems and derive all the benefits of broadcast (serving mass populations from a single location) over many television channels simultaneously (similar to hard wire cable). The similarities to broadcast and cable are more striking than the differences. In the most important ways MMDS takes advantage of both broadcast and cable technologies.

   a. MMDS transmitters are similar to broadcast transmitters and are available in any worldwide format (NTSC, PAL and SECAM). To achieve satisfactory service MMDS transmitters are relatively small, solid state items of equipment and consume very little electricity (350 watts for the most popular size).

   b. Channels can be combined into a common broadcast antenna with little waste of signal levels. Sixteen transmitters (one for each channel) feeding one broadcast antenna is now commonplace technology.

   c. Broadcast antennas are now available with a wide variety of patterns from omnidirectional to narrow shaped beams for particular communities.

   d. Broadcast coverage is based upon well understood physics. At turn-on the entire service area is covered.

   e. Home reception antennas vary in size depending on the distance from the transmitter, just like VHF and UHF. The greater the distance the greater the antenna gain required to overcome signal loss through free space. Gain is aperture, aperture is size: therefore the greater the distance the greater the size required. The most popular size of antenna is about the shape of a dining room place mat.

   f. MMDS, unlike VHF and UHF, requires a single multichannel down converter. Microwave services normally require FM or other specialized type receivers: but, recall that the transmitter was chosen with a format to be similar to the broadcast service. This most innovative idea results in enormous economies at the home. The down converter changes the microwave signal to a lower VHF or UHF signal (hence down converter) for processing through standard cable television products. And, the signal is then connected to a standard TV receiver tuned to a VHF or UHF channel. MMDS enjoys all the benefits of high volume, low cost cable TV products after down conversion. Popular down converters are now available for under $100 so this one component does not unduly distort capital costs or stress family budgets.

g. The one significant difference between MMDS and other broadcast services is the critical need for line-of-sight between the transmit and receive antennas. All waves bend or defract through normal atmosphere depending on moisture and other elements (based upon the coefficient of refractivity) and this phenomenon results in an "apparent" increase in the visual path or line-of-sight. However, the shorter wavelengths of MMDS signals, which approximate the dimensions of natural and manmade objects, provide little or no penetration through trees or building walls. The longer wavelengths of VHF signals generally provide good penetration through solid objects. UHF waves provide variable results, the higher frequencies (e.g. channel 69) require more clear lines-of-sight similar to the requirements for MMDS.

B. HEADEND

1. Today's providers of multichannel television services can choose from a wide array of live and pre-recorded program sources. Unlike early cable services, which relied almost exclusively on distant broadcast signals for relay to unserved homes, today's operators seem to have access to a limitless number of products (program sources).

a. Satellite: For purposes of this discussion, MMDS operators will be concerned with any of several geostationary or synchronous satellites now or soon to be in orbit around earth. The orbit is circular, the distance from earth to satellite approximately 22,300 miles. If the satellite is launched to the east (direction of earth rotation) the period of the satellite is 24 hours and it will appear to stand still over one point on earth.

Satellite reception is by far the most convenient and widest in variety of all program sources. A major portion of the civilized world can enjoy excellent quality, low cost reception of hundreds of television programs by satellite. After processing and possible decoding of signals the programs are then broadcast on MMDS terrestrial systems.

b. Off-air reception of distant broadcasts is still a significant source of product, particularly for communities unserved by cable, direct broadcast or television low power translators.

c. Locally originated programming is only limited by the operator's budget and imagination. Simple studio facilities, at modest cost, can provide live broadcasts of everything from City Council meetings to high school sporting events. Pre-recorded materials on video cassette, video disc, film or other sources can be broadcast repeatedly. Information, entertainment, school education, University instruction, public safety, training and endless varieties of other sources are available.

2. Equipment technology has kept pace with all other system components required by the MMDS operator.

a. Large or small aperture antennas are available to suit most latitudes and longitudes of the globe. There are extensive publications that will guide the designer in selecting the appropriate size TVRO earth station antenna. After size, a few of the most important antenna features requiring decisions by the operator include:
1) Polar or equatorial mount
2) Motorized or manual steering
3) Protection from terrestrial interference, TI. In many parts of the world TVRO frequencies are shared with other microwave services. This potential for TI must always be considered by the designer.

b. Similar in concept to the MMDS down converter, a satellite TVRO antenna usually feeds a low-noise block converter, LNB. Perhaps surprisingly, today's LNB is low in cost, has excellent noise figure and has sufficient gain to establish the overall signal to noise performance of the headend reception equipment. And, all this at ambient temperature, no need for cryogenic cooling! Typical C-Band LNB specifications at low cost are:

Noise temperature	40°K at 25°C
Gain	60dB minimum

Satellite receivers accept the multichannel satellite feed from the LNB. One receiver is required for each channel to be retransmitted by the MMDS station: but, each receiver is agile and can be tuned to any satellite channel instantaneously by a touch pad.

c. All premium services and most network and basic cable services are encoded (also called encrypted or scrambled) to prevent unauthorized viewing. To decode a satellite program the MMDS operator must enter a service contract with the program supplier and use a decoder that is provided or authorized by the supplier. Different suppliers have adopted different standards for encryption such as Video Cipher, B-MAC, etc. The MMDS operator, by necessity, must use the standard provided. Do not confuse this scrambling system with that required for retransmission. Satellite channels are broadband, frequency modulated video and audio signals. MMDS channels are NTSC, PAL or SECAM and must be re-encoded in this different modulation format for final reception and decoding at the home terminal.

d. Many MMDS operators are serving markets demanding products from various countries that use different formats. Until recently, it was very expensive to convert from one standard to another (e.g. NTSC to PALB, PAL-N to SECAM, etc.). There is now a standards converter (sometimes called transcoder) on the market that will convert any standard to any other standard at a very moderate cost. There is some jitter viewable in the picture caused by the inexpensive circuitry that, for example, samples, stores and/or inserts scanning lines when converting from 525 to 625 line formats. The jitter is most noticeable in bright scene changes such as high contrast printed sub-titling in the crawl mode of a character generator. The benefits of low cost standards conversion seem to outweigh the minor annoyance of some picture jitter.

e. A significant cost, in the decision to implement an MMDS system, is where to locate the control point. The least costly system of mixing satellite, off-air and locally originated programs would typically include colocation of all facilities at one site (e.g. a mountaintop, high building, etc.). Complete and convenient interconnection of all equipment is possible through short video, audio and RF cables.

If the office, control point and studio are to be remotely located from the MMDS transmitters then decisions need to be made as to placement of the headend equipment. If the headend is placed at the studio, a studio to transmitter link, STL (usually another band of point-to-point microwave) is required. A 16 channel STL can be a significant cost. If the headend is placed at the transmitter site then video taping must be done there or a transmitter to studio link, TSL (a return microwave) is required. A typical solution for remote location systems is to place the satellite and off-air facilities at the transmitter site and implement an STL-TSL for the live studio feed (STL) and recording of selected headend programs (TSL).

Once the decision as to location of facilities is reached the design of switching, signal routing, remote control and telemetry can be finalized.

C. MMDS TRANSMISSION SYSTEM DEMANDS

1. Encoding Systems

a. History of Pay TV. There are two basic choices open to the for-profit, MMDS television broadcaster: advertiser supported "commercial" television (CTV) or user fee based "subscription" television (STV). There are, of course, combinations of the above, where commercials appear on STV programs, but public resistance to the intrusion of advertising into a contract for uninterrupted entertainment has been high, and most popular business plans have relied on one but not both of these sources of revenue. Educational, instructional, ecclesiastical, and other television broadcasting systems do generate "excess revenue" (as it is sometimes called in the industry) but all of these are classified as non-profit so will not be discussed here.

It is interesting to note that the very first proponents of television broadcasting contemplated the adoption of a subscription service. Unfortunately, origination, transmission and reception technologies were difficult and were evolving between the late 1920's and 1953 (when the NTSC color compatible system was conceived in the US) and 1967 (when the PAL variant of NTSC found regular service in England). It was difficult enough to faithfully process video; it would not have been economically feasible to implement a reliable encryption system in the first half of television's 60 years of evolution!

With the extensive growth of cable, satellite, UHF, MMDS and other services to paying subscribers there are encode-decode systems that are now reliable, secure and low in cost.

b. Decision to Proceed. For the commercial operator to succeed, the origination (video tape, film, satellite, etc.) and transmission facilities should be adequate to provide clear, noise-free pictures and sound to the viewer. For the subscription operator to succeed, demands on the technical facilities increase several fold. Program quality remains important although content may change depending upon tastes of the community and competitive offerings in the area. Station engineering personnel must not only maintain peak performance in the origination and transmission facilities, but must ensure that equipment and installation details at the subscriber meet minimum standards. Increased viewership depends on continuing station involvement with the technical performance of subscriber equipment.

c. Choice of Alternatives

1) Reliability. Those with experience in MMDS operations will place reliability of the encode-decode system at the top of the list of priorities. When equipment fails, viewers are lost or do not pay and revenue declines. No amount of technical tinkering can overcome the irritant of periodic breakdown. Viewers have paid for a service and expect trouble free performance. Perhaps surprisingly, it does not cost much more for reliability but many would-be STV operators neglect this most crucial element when selecting equipment and their encode-decode system.

2) Security. There are many scramble systems now available on the world market. For video there are simple to fairly complex systems including sinewave, gated sync suppression, simple or random inversion of lines or frames, etc., and of course, combinations of encryption techniques. Notice that analog methods are listed; although digital video encoding (conditional access) techniques are coming on the market, and hold promise of greater security, the forecast for economics comparable to analog encryption continues to be very long term.

   Similarly for audio, there are simple to complex systems such as moving the main channel audio carrier in frequency, masking, etc. Digital audio systems are now so well developed that very secure encryption of audio is possible.

3) Cost. The direct relationship between cost and security is unequivocal. The greater the security desired, the greater the cost. Decoders are usually the largest component of the capital investment in an STV operation. If the business plan suggests that $125.00 decoders can be justified then that will fix the level of security. If $75.00 decoders must be chosen then less security will be the result. And, assuming a small market with less threat of piracy, this lower security may be adequate. But, operators should not purchase poor quality, low reliability, used or other low cost decoders just for the purpose of meeting cost goals of business plans: you must pay for the security needed and that you can afford.

4. Addressability. Subscriber control is essential to the expectation for positive cash flow. There are some aspects of security but addressability has one fundamental purpose: to terminate service when there is a failure to pay fees (impulse pay per view, tiering, etc. are features available in some systems). Many schemes have been tried such as rotating decoders to the operator for updating, cycling smart cards to subscribers for insertion into the decoders, etc. All these systems suffered due to too much logistical handling, poor postal service, poor reliability, etc. The industry has evolved and electronic addressability is now the norm. Individual decoders must be addressed to maintain control. Systems of decoders (assuming a region may choose the same manufacturer for two different communities) are sometimes addressed to prevent decoders from being used in other than the intended market. There are many addressing schemes now available that have very reliable software packages, personal computers to address the decoders and straightforward circuits in the decoders to detect authorization or deauthorization data streams. Remember, addressability is primarily for subscriber control: although elaborate and sophisticated data mechanisms can be offered, it may not be cost effective to add these complications above certain minimums since security derives mainly from the method of scrambling, not the data control.

d. Success or Failure. Many would-be STV operators study the market, prepare business plans, raise capital, secure licenses, hire staff, locate studio space and otherwise prepare for a new broadcast enterprise. The missing element is that little or no systems engineering is undertaken for the project. Success or failure relates to many factors. But, no amount of hard work or tinkering during operations can overcome the lack of good systems engineering design before construction.

2. Program Source

Whether video tape, satellite, film, microwave or other source, the video waveform and audio signal should be satisfactory in CTV service. Sync pulses, front and back porches and other timing and frequency relationships should be up to acceptable standards or processed and corrected. Noise on active video may cause problems with some systems so that source material may need to be improved (e.g. can the system tolerate VHS tapes played back on consumer quality VCRs, both of which have hundreds of passes on the tape and heads?).

3. Transmitters

The heart of an MMDS broadcast operation is the television transmitter. Within itself a transmitter is a system, embracing most of the challenges of modern physics and engineering, including microelectronics, mechanics, thermodynamics, low and high voltages, metallurgy, magnetics, etc. (fortunately all solid state designs have eliminated vacuum technology from the list of disciplines). The MMDS broadcaster should select the most linear transmitter design available. Low cost designs using class AB amplifiers may be satisfactory in CTV service but will introduce distortion products during encryption that may render STV decoding impossible. As stated above, under Decision to Proceed, the technical demands on the transmitter increase significantly for STV service and compatibility with the encoding system is essential.

a. Amplifier stages should operate in their linear regions without compression or danger of saturation. Separate visual and aural carrier amplifier designs, with high level diplexing, are usually to be preferred. There are certain scrambling systems that can tolerate the lower cost, internally combined carrier design (i.e., visual and aural carriers combined at IF and amplified through common amplifiers) but overall linearity is now even more critically important. Beware of designs that require extensive pre-correction and pre-distortion of visual parameters in the modulator to compensate for non-linear amplifiers, a sure sign of trouble for STV operations.

b. Up-converters, mixers, filters and other signal processing circuits should be linear and have margin sufficient to handle all signals without phase delay, noise introduction, frequency instability, visual to aural cross modulation, etc.

c. Modulators can be simple, easy to maintain and adjust if the following stages of conversion and amplification are of the ultra-linear design. There should be little or no need for complex, pre-correction circuits that require sophisticated test equipment and highly technical, maintenance personnel.

4. Transmission Equipment

a. Investment in transmitter power is almost always wiser than expenditures in receiver equipment to increase signal levels. As an illustration, simple arithmetic for a typical, full growth, MMDS system of 10,000 subscribers reveals the logic. Raising transmitter power from 10 watts to 50 watts (an increase of 7dB) increases headend cost approximately $15,000 per channel. By contrast, if the 7dB is to be made up at the home terminal instead of the transmitter the MMDS home equipment would increase in cost by $15.00. And $15.00 times 10,000 subscribers is $150,000, an offset of 10 channels of higher power transmitters. A design feature of LOMA SCIENTIFIC equipment is that higher power amplifiers can be added at any time without waste in the initial investment. If you are not sure that the business plan can afford higher powers it is possible to start at a lower transmitter power and add amplifiers later: a slight downside is that initial homes will need larger antennas than they might have required after amplifiers are added.

b. MMDS Channel Combiners have followed a complete circle of evolution. In 1956 the concept of a directional waveguide filter became a well developed product. When multichannel microwave systems were first implemented in the 1960's this combining scheme was the system of choice. Vector Industries pioneered the idea into production but demand was low and they dropped the product. For years multichannel providers had to use alternative schemes until the industry decided to reenter the market. In chronology:

Late 1960's	-	Directional waveguide filter
All of 1970's	-	3-port ferrite circulators,
to early 1980's	-	Magic T's, T-filters, etc.
Late 1980's	-	Directional waveguide filter

MMDS operators invest significant capital costs in transmitter power, low loss transmission line, high gain broadcast antennas and home reception equipment. Combining transmitters into a common broadcast antenna can now be accomplished at low cost, at low insertion loss per channel and with high isolation between alternate channels. A whole chapter on the physics of channel combining and expectation for performance could be written. Authoritative references are available for the serious designer but the key specifications to be expected, based upon the 1956 design are:
Single channel insertion loss, 0.7dB
Alternate Channel isolation, 35dB
Flatness of loss over 2500-2700, O.1dB
and the combiner should perform well over a wide range of temperatures.

c. As noted above, under channel combining, it is important not to waste transmitter power in the cable between the transmitter and the broadcast antenna. Manufacturers now offer a variety of coaxial cables and waveguide (e.g. rigid rectangular, circular, and semi flexible elliptical) for handling transmitter powers at low loss. At MMDS frequencies most any coaxial cable rated for the frequency, power and proper 50 ohm impedance will work but losses vary considerably with diameter. Also, coaxial cable is available filled with a foam material as a dielectric separation between the inner and outer conductors or with dry air (pure nitrogen is best) and a teflon or other non-conductive material to hold the separation. The advantage of dry air is lower signal loss; but, pumps, valves and gauges are required. The advantage of foam is no requirement for pumps; but, signal losses are higher.

The lowest signal loss line is waveguide (always requires dry air or nitrogen pressurization) and the most popular is elliptical. This pure copper line is corrugated, is slightly flexible so that it can be wound on a reel for shipment and installed in one continuous run. Rigid rectangular or circular must be cut in shippable lengths of approximately 20' and then bolted together with special hangars on the tower.

As you might suspect waveguide is by far the most expensive choice and when comparing loss of signal level (which means loss of broadcast coverage) there is a trade off of choices. A general rule of thumb is that if the transmission line run exceeds 100' in length then use elliptical waveguide; if the run is somewhat less than 100' use 7/8" coaxial cable. Remember if the antenna needs to be pressurized then select air dielectric line (or coaxial cable that has the provision for using the inner tubular type conductor for carrying air to the antenna) so that the antenna can be pressurized through the line. Running an extra length of air handling tubing or pipe is a poor alternative to using the cable for both signal transmission and air handling. If the antenna does not need to be pressurized then the lower cost, slightly higher loss foam dielectric line might be adequate.

d. Broadcast antennas are now available with a wide variety of coverage patterns and gains that can be custom tailored to almost any community. More engineering and thoughtful consideration should probably be given to this one transmission component than any other by the system designer. It would require volumes to describe the actual designs and their advantages and disadvantages. Vertical, horizontal and circular polarization designs are permitted by most world governments to foster growth of the service without interference between co-channel and adjacent channel operators in the same community (remember that VHF and UHF broadcasters are usually limited to either circular or a choice between either horizontal or vertical polarization in the entire country).

The polarization will generally fix the basic design (e.g. waveguide slot array, dipole array, traveling wave, helical, etc.). After this choice is made the designer must make a number of engineering and cost tradeoff decisions to serve the community most cost effectively. The tradeoffs are extensive because of topography, demographics, capital budgets, equipment limitations, etc. But, a few of the more important items to consider are:

1) Location. If the antenna is in the center of the community then an omni-directional horizontal radiation pattern is suggested, if off to one side then a directional pattern may be appropriate. If off to one side the directional antenna saves gain in the non-wanted direction and effectively adds it to the wanted direction; the only disadvantage is that the home on the other side of the community is farther away and the signal received is weaker. But, of course, the higher gain of a directional antenna toward that home may more than compensate for the extra path loss.

2) Elevation. More significant than transmitter power or any other transmission equipment selection criteria is the broadcast antenna height above average terrain, HAAT. This HAAT is so important that governments typically require plots of the number in the form of a polar diagram from the proposed transmit site. The added benefit of maximizing HAAT to the MMDS broadcaster is the critical need for line-of-sight as discussed previously.

   Once the site is chosen and HAAT to the subscriber community is known (and this may vary around the compass heading) then the designer must decide on the best gain and tilt specifications.

3) Gain. As stated previously, gain is aperture and aperture is size; so the greater the gain desired the larger the antenna. Of course, the larger the antenna the higher the cost. With any antenna the higher the gain the narrower the half power beamwidth, HPBW (a technical way of describing antenna focus). To visualize the concept think of a flashlight with either a spot beam (high gain, narrow HPBW) or a flood pattern (low gain, wide HPBW). In broadcast antennas the dimension that is effected by the tradeoff between gain and HPBW is the vertical pattern (remember we already decided on an omni or directional design for the horizontal pattern).

At this moment the antenna system designer really earns his fee. If the gain is very high and the resultant HPBW is narrow and the HAAT is high the entire broadcast signal could radiate into space (straight out to the horizon) and miss all the homes. There are, unfortunately, some of these antenna systems in the world and engineers call them "cloud warmers". The essential need then is to focus or direct this energy to the homes in the service area. The choices to solve this are between gain, tilt, null fill-in and, of course, cost. The lower the gain the wider the vertical HPBW; if wide enough all homes will be served but the levels might not be adequate due to the lower gain.

Tilt of an antenna can be above or below the horizon but in most communities the transmit site is above the community so we will discuss solutions only requiring downtilt. Downtilt can be electrical or mechanical. Electrical downtilt is incorporated in the antenna during manufacture and the signal is radiated uniformly downward in all directions. Mechanical downtilt is simply pointing the antenna mechanically at the community. This may be a very important solution for certain communities with directional antennas; but, do be aware that with an omni-directional antenna, mechanical down tilting in one direction results in up tilting in the opposite direction. Electrical downtilt adds very little cost to the antenna; mechanical downtilt involves the steel mounting bracket so cost is negligible. Combinations of electrical and mechanical tilt are commonplace and are important tools for the system designer.

A side effect of high gain is that there are nulls of varying depth in the vertical pattern. The gain curve from the horizon to several degrees above or below the horizon are not normally smooth. The designer must know where these nulls fall and if there are homes in the service area that might be effected by these nulls, which produce weak signals. If the ultimate decision is for a high gain antenna then these nulls must be dealt with. Fortunately, the antenna manufacturer can fill in these nulls in a variety of ways. There is some reduction in peak gain for null fill but the tradeoffs are usually favorable between servicing close in homes (in the null) and distant homes needing the peak gain characteristic of the broadcast antenna.

4) Other Specifications. Many other factors need to be considered before the designer specifies the best choice for the service. VSWR, channel bandwidth, mechanical characteristics (such as top mount, side mount, obstruction lighting, possible ice formation), etc. The choices are based on good engineering practice, cost issues are relatively modest.

5. Transmission Facility

a. Location. As previously discussed the location of the transmit site is of primary importance. HAAT is always to be preferred over higher power radiated from the antenna in any cost benefit analysis. High mountains are usually the most attractive sites for a transmission facility but many of the following issues need to be considered also. The rooftop of high buildings can also be an excellent choice. Like mountain sites there is usually no need for long transmission line runs and all equipment, including the broadcast antenna, is easily accessible. The most expensive way to achieve height is with a tower. Real estate is expensive, especially if the tower must be guyed. Self supporting towers use less space than guyed towers but have to be stronger so are inherently more expensive. High towers mean long cable runs and as discussed in C.4.c this usually means waveguide is needed. Antennas don't often need service but when they do it is difficult to troubleshoot them on top of a tower. They may need to be taken out of service and either brought down to the ground by qualified tower riggers and possibly returned to the factory if major repairs are indicated.

b. Electrical power. The primary electrical service should be reliable, without transient impulse voltages, adequate for the initial demand and growth needed and generally well regulated and stable. Most current transmission equipment includes power line regulation, but additional outboard regulation and transient suppression may be required. Delicate transistor stages in modern equipment provide excellent characteristics as low noise amplifiers, etc. but they are susceptible to damage caused by excessive overvoltage or line surges.

c. Air Conditioning. All solid state transmitters, encoders, satellite receivers, components and related MMDS facilities are typically air-cooled. Clean, dry and cool environments are always to be preferred. For headend equipment simple window type air-conditioners are usually adequate. If studio equipment is included, with high intensity stage lighting and the necessity for on screen talent comfort, then special air-conditioning must be designed into the system.

d. Access. The ability to service the transmitter site all year round is important, and if co-located with the studio then access is critically important to efficient operation of the station. The high building choice of C.5.a. might be the best of all possible alternatives. If a mountain is chosen then roads, fences, farm gates and many other practical concerns need to be considered.

e. Lightning. Depending on location, lightning can be a potential source for major damage to delicate equipment. Lightning is not a well understood discipline of natural physics. For generations engineers just grounded the tower or broadcast antenna through heavy copper conductors to the earth. The thought was to just take the lightning strike and hope to shunt it to ground. Unfortunately some of the enormous energy in a lightning discharge finds its way into the electronic equipment and not all is directed to earth ground. Also, the ground may not be a perfect conductor (soil conditions need to be studied to determine electrical conductivity properties).

Newer approaches in the battle with lightning are based on diffusing the energy during buildup before it can reach the necessary threshold for discharge. At low energy levels the currents can be dissipated when as low as a few milliamperes; and, small wire conductors can be fabricated into collectors that will shunt the energy to ground. Designs are now available to fit most any tower, building or mountain location.

D. PROPAGATION

1. Many tools are available to deal with terrain, atmospheric absorption, foreground and multipath reflections from man made and natural objects. Broadcast antennas are available in a wide selection of horizontal and vertical patterns and gains, null fill and electrical and mechanical tilt to fit most any area to be served. With transmitter power, low transmission line and channel combining losses, and relatively high broadcast antenna gain the operator can serve the MMDS audience very effectively. Certain cities can present more serious challenges than others (e.g. systems transmitting address data in the vertical interval may produce unacceptable bit error rates due to phase delays caused by multipath reflections from high rise buildings). An analysis of the topography, coverage requirements and location of the broadcast antenna can usually minimize prospects for problems.

2. Free Space Calculations

a. Definitions and Assumptions:

TPO	=	Transmitter Power Output
	=	10 watts (+40 dBmW), 50 watts (+47 dBmW) or 100 watts (+50 dBmW)
Gt	=	Transmit antenna gain
	=	14dBi for 16 bay omnidirectional
Gr	=	Receive antenna gain (varies with size)
FSL	=	Free space loss (varies with distance)
L	=	Line and miscellaneous losses
	=	-4dB typical design
S/N	=	Signal to noise ratio
	=	40dB minimum for good picture
N	=	-114 dBmW + BW + NF = -106dBMW
BW	=	Video Bandwidth = 4MHz = 6dB
NF	=	Noise Figure of receiving down converter = 2dB for low cost unit

S/N = TPO + Gt + Gr - FSL - L - N

b. Trial calculation, assume:

1) No fading due to atmospheric effects or foreground reflections
2) Frequency = 2600 MHz
3) TPO = 50 watts = +47dBmW
4) Range = 20 miles, FSL = -131dB
5) Receive antenna gain = 18dB (low cost semi-parabolic)

S/N = +47 +14 +18 -131 -4 -(-106)

S/N = 50dB (during short term fades of 1OdB, picture would still be excellent).

3. Selection Guide

The following table lists various transmitter powers and the necessary receive antenna gains for good picture reception at the ranges shown. An allowance for atmospheric fading is included, other conditions are as listed in D.2 above. All calculations assume clear line-of-sight exists.

TRANSMITTER POWER OUTPUT

Range	10watts Gr(dB)	50watts Gr(dB)	100watts Gr(dB)
5 miles	11	6	2
10 miles	18	11	6
20 miles	24	18	11
30 miles	28	21	18
40 miles	31	24	21
50 miles	33	28	24
60 miles	35	31	28

Note: Typical antennas for gains shown are:
2-Dipole
6-Base cavity
11-Corner reflector, base cavity
18-Semi-parabolic, horn, disc-rod on base cavity
21-Semi-parabolic, dual disc-rod
24-Semi-parabolic
28-Parabolic, 4' diameter
31-Parabolic, 6' diameter
33-Parabolic, 8' diameter
35-Parabolic, 10' diameter

E. RECEIVE SYSTEM

1. Just as for transmitters, linearity is important in STV receivers so as not to introduce distortion. The decoder will be preceded by an antenna (and sometimes a filter), down converter and amplifier combination. After investing in high quality studio, encoding and transmission equipment it is not wise to cut corners in any of the receiver equipment. Some decoders will require higher levels than would be sufficient for CTV operation. Roof top antennas will be required: except for "through the window" close in homes, indoor antennas will probably not be adequate. Down leads and jumper cables should be of low loss and shielded to prevent local interference: this is probably the least costly part of the whole linkage to the subscriber but one where some may look for savings (a pennywise decision).

2. Receive Antenna
   a. Gain is published by the manufacturer and can usually be relied upon. But, remember that these low cost antennas (about $1.00 per dB of gain is the rule of thumb) are mass produced so there will be a variation in expected performance.
   b. Antenna Types
      1) Semi parabolic is the most popular, easy to mass produce, low in cost, of good durability, and easy to mount. Beamwidth is greater in one plane than the other and this can be used to advantage in certain situations.

2) Parabolic is one of the oldest designs and physics are very well understood. Electrical performance of gridded and solid reflectors is similar. Gridded designs offer low wind load but a minor inconvenience is that the mount is mechanically more difficult, i.e., the entire antenna must rotate to change polarization, whereas for the solid reflector only the dipole feed need be rotated.

3) For low gain, close-in homes the corner reflector is a small unobtrusive solution for good reception.

4) Many designs are possible and have been produced for microwave services such as the horn (conical shaped), disc-rod, ring-loop, dipoles on panel, helical, multiple arrays of any of the above, etc. But many suffer mass production difficulties, are difficult to mount, don't do well in heavy weather, are susceptible to short life problems due to birds (called the pigeon effect), etc.

3. Pre-amplifiers are only necessary where the down converter is of a poorer quality with high noise figure. Low cost down converters with exceptionally good noise figures are now available: a pre-amplifier in this case would add complexity and probably not improve performance commensurate with cost.

4. Down Converter

The primary function of a down converter is the conversion of high frequency microwave signals to lower, more manageable frequencies in the VHF or UHF television range. Practically speaking, the use of lower frequencies allows the use of standard coaxial drop cable for transporting the received signals from the antenna to the viewing area where the signals are readily usable by conventional set-top converters or television receivers.

The down converter also performs some additional functions which allow the received signal to be improved during the conversion process. The signals can be filtered to remove any unwanted signals, or high gain models can be used to compensate for drop cable losses when the receive site is located far from the television receiver. As a down converter is an outdoor device and subject to all aspects of the environment, it is important that the housing be environmentally secure to protect against moisture which can damage circuit components.

The most important criteria of a down converter are dynamic range, gain, noise figure, and frequency response (gain flatness).

These characteristics, along with other systems parameters, such as I.F. rejection, establish the noise floor, which in turn determines the minimum receive level that can be considered useful.

a. Dynamic Range

Dynamic range is the difference between the minimum signal and maximum signal the down converter can accept before it introduces interference in the pictures due to overloading. Dynamic range becomes more important as systems with a large number of channels are introduced because signal handling capacity decreases as the number of channels increase. Each additional channel transmitted increases the amount of potential interference that can be created by generating more carriers that can combine with other carriers, resulting in negative effects in the received signal spectrum.

If a down converter will accept a lower signal level and deliver a noise free picture, and a high signal level without overloading, it has a high dynamic range. The smaller the spread between these two variables, the smaller the dynamic range rating. A high dynamic range is preferred.

b. Gain

Gain in a down converter is required to establish overall receive system noise figure, to overcome loss of the lead-in cable and to ensure that good signal is delivered to the decoder, or television receiver. Gain of 20 to 30dB is common and sufficient for most applications. Many gain options are available depending on the manufacturer, whether or not filters are used, and the number of stages of amplification built into the unit.

c. Noise Figure

The noise figure rating of a down converter determines the lowest input level that will prevent the down converter from contributing noise to processed signals. In general, the lower the noise figure the better. It is sometimes necessary to use input filtering which may increase noise figure slightly. Noise figure is a direct function of manufacturing quality, components used and design. It is a very important consideration in the selection of this piece of equipment; each 1dB reduction of noise figure is equivalent to 1dB increase in receive antenna gain.

d. Frequency Response

The frequency response is a rating of the uniformity of amplification across a wide frequency band. Failure to maintain flat gain may result in adjacent carriers mixing together and creating interference. Frequency response is measured in two manners. The response of a single channel (6MHz, 7MHz or 8MHz) is important to maintain a proper relationship between the video and audio components of the signal. This should not exceed 0.5db. More importantly, the frequency response across the entire spectrum of converted frequencies should not exceed 1.5db. If the response is not maintained extremely flat, an individual channel may cause interference with other channels in the received group by altering the dynamic range characteristics of the unit.

F. SIGNAL REDIRECTION TECHNOLOGY

1. Beambender

Low power, low cost MMDS repeaters may be used to provide clear signals to shadowed or obstructed areas. This system, popularly called a beambender, is installed at a point of clear reception where it receives, amplifies and retransmits MMDS signals at very low power into previously unserviceable areas. The system serves an approximate pie shaped area out to a range of 2 kilometers.

A practical use for this technology would be to provide signal to a subdivision located behind a small mountain or hill. The beambender is comprised of a receive antenna, a low noise receive amplifier, transmit amplifier and transmit antenna. The receive equipment is coupled to the transmit equipment by low-loss coaxial cable. The composite assembly is installed in an area of clear reception, usually at a higher elevation site than the obstructed area.

The unit can be mounted on a small mast. Powering of the unit is by either standard electrical service or batteries. Remote sites can also be powered by a solar powered battery system. Selection of the receive antenna gain is critical to prevent the receive amplifier from becoming overloaded by excessive input levels. The beambender is designed for use anywhere in the service area.

2. On Frequency Repeaters

On-frequency repeaters are available with more powerful output levels than the beambender. These units are able to serve larger areas of blocked reception such as a small community of several hundred homes. These units operate in essentially the same manner as the beambender, but offer increased output levels and cover an area of up to 8 kilometers in size. On-frequency repeaters may generally be used throughout the entire service area, but their higher output and coverage usually limit them to large areas of potential homes.

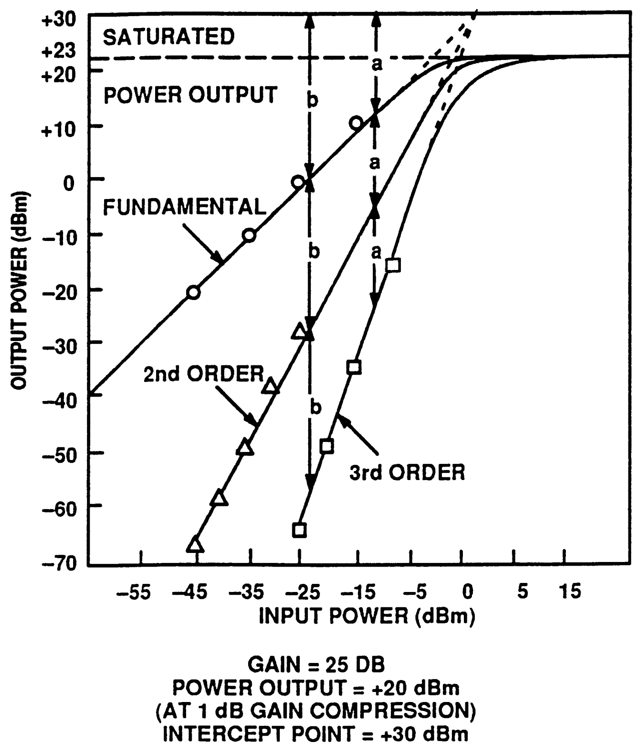
LOMA SCIENTIFIC manufactures a complete line of ultra-linear on-frequency repeaters.

SECTION II EQUIPMENT EVALUATION CRITERIA

A. TRANSMITTERS

1. Linear Amplifiers. Be sure to specify ultra-linear class A amplifier operation. Loma Scientific is the only manufacturer that has adopted a true ultra-linear design philosophy. The technical challenges are greater and costs are slightly higher: but the benefits are very significant. One manufacturer chooses a low cost approach and incorporates an extremely complex array of pre-distortion circuits to reverse compensate for known degradation in the video RF amplifiers. Offers of envelope delay precorrection, sync stretch, differential phase and differential gain compensation, etc. are sure signs of poor amplifier design. And, since these specifications interrelate it is extremely difficult to maintain concert in overall performance (it is difficult at the factory under controlled conditions and nearly impossible in the field).

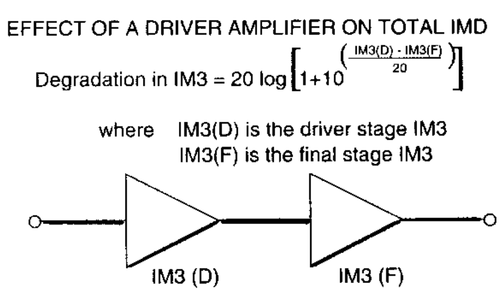
   Two other manufacturers compromise linearity for some cost reduction. For example the Loma ultra-linear design involves one amplifier driving two, driving four amplifiers. The compromise of others involves one driving four amplifiers. Elimination of the second stage does reduce cost but the driver and final stages are now pressed to their design limits (no headroom and no margin for change over life between adjustments). Pictorially amplifier characteristics follow classical curves:

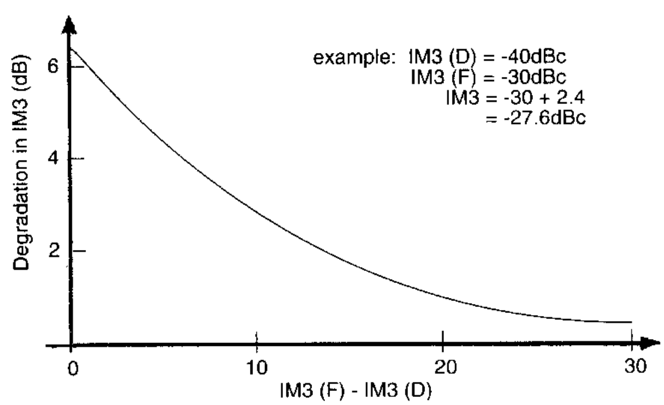


Theoretical Amplifier

HEADROOM

Effect of headroom in driver stages using ultra linear design amplifiers





The Loma ultra-linear design operates final amplifiers at greater than 1dB below P(1dB). Prior stages of amplification include increasing headroom which follows a conservative design curve. The compromise design of others operates final amplifiers at P(1dB) or above and allows little headroom in previous stages. The low cost design of others operates near saturation with no headroom in previous stages (remember distortion is to be precorrected by reverse compensation).

A few of the more important benefits of the Loma ultralinear design are:

a. No introduction of waveform distortion, amplifiers are transparent to the video signal.

b. All amplifiers can be modular and broadbanded. Field replacements are quick and easy with no tedious tuning requirements. One spare module package can back up 31 transmitters, no need for custom components.

c. Simple low cost modulators and up-converters are usable. No requirements for complex pre-correction circuits.

d. With simple modulators and ultra-linear amplifiers any known encode-decode system is possible. Introduction of slight distortions in compromise or low cost designs render decoding at the home impossible.

2. Some manufacturers stress miniaturization and sacrifice ease of service, replacement of parts and good cooling. As noted in A.1 above least cost and ease of service are a benefit of broadband modular construction. A reasonable trade-off should be made between conservative architecture that is easy for human hands, tools and test equipment to have access during service and yet still be relatively compact. Reliability and continuity of broadcast operations to the community are the critical goals to be achieved.

3. Self test diagnostics. You should expect and demand that the diagnostic circuits and indicator panel truly convey useful technical information. All critical amplifier functions should be monitored; lamps should warn of failure as well as state good and bad conditions (e.g. tri-color LED's of red, yellow and green are offered by LOMA SCIENTIFIC). Beware of "light shows" or lamps that flash for no real diagnostic value.

4. Proven reliability. The test of reliability is time. You should expect fast and courteous response from the manufacturer's service personnel: but, ideally you will not want to have to call on them. In addition to fundamentally reliable designs discussed previously, ask for and expect built in protection components. Gate interlock system readyline, sequential power supplies, protection against antenna failure, etc. are commonplace features in most reputable designs such as are provided by LOMA SCIENTIFIC.

5. Serviceability. Ease of servicing the equipment is vitally important to continuity of operation and to maintaining peak performance. Operators of many systems, and particularly those in rural communities, fail to realize that good technical staff is difficult to find and/or retain. Sophisticated electronic test equipment is expensive and is usually not included in capital budgets. The ultra-linear design, simple modulator philosophy minimizes service requirements. True self-test diagnostics and modular construction eliminate the need for sophisticated test equipment and ease the requirement for highly skilled technicians. Good, well thought out designs should result in regular operational staff being able to maintain peak performance with built in features.

   Only one manufacturer, LOMA SCIENTIFIC, currently supplies complete and comprehensive technical manuals with every shipment. Thoroughgoing block and level diagrams, parts lists, source lists, and detailed schematics should be given to the owner of the proposed transmitter. One of a technician's greatest frustrations occurs when the owner demands instant repairs or adjustments and the technician has no documentation to read, study or follow. To inform and educate the technical staff is a sound investment by both the owner and the manufacturer. Excellent technical manuals are not without cost; but, the dividends of having them on site for routine or emergency use far more than offset the cost of preparation.

6. Growth. MMDS operators will almost always wish to grow and extend the range of the system as installed. The system designer should select components such as transmitters, channel combiners and antennas (e.g. extra channel bandwidth, higher total signal power) that grow with the system without waste in the initial investment. If higher power amplifiers are anticipated in the future they should be easy to add to existing transmitters. Loma offers stand alone, ultra-linear power amplifiers (that have all necessary internal protection components included) that can be added to any brand of transmitter. Other manufacturers require so many interlocks and interconnections that performance cannot be guaranteed with any combination but their own transmitter and amplifier.

B. DOWN CONVERTERS

When evaluating a down converter it is important to balance all of the parameters detailed in I.E.4 above. A combination of electrical, mechanical and environmental specifications determines the overall criteria when selecting a down converter. It is not always necessary to use a down converter with the lowest possible noise figure. A slightly higher noise figure rating, in conjunction with a high dynamic range, for example, may yield comparable results in the viewed picture.

In cases where there are interfering carriers from other sources such as a second system in the market, or radar signals, it may be practical to sacrifice a minor amount of noise figure for the removal of the undesired signals by filtering. The proper choice of a down converter is a systems engineering compromise. Many combinations of antennas, preselection filters, low noise amplifiers and down converters are possible to effect satisfactory reception.