A SECOND GENERATION AML

by

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INTRODUCTION

Community antenna television began as a service to isolated communities without television programming. In the ensuing years, the scope of cable TV has increased to the point where now large metropolitan areas find it expedient to use CATV to provide high equality television. Figure 1 illustrates how large metropolitan areas may be serviced from a single transmitter site using microwave links to carry television signals to individual microwave receivers located strategically within the metropolitan complex. From these receivers, cable systems deliver the television programming to individual subscribers.

In the suburban areas, located in television fringe areas or unable to receive signals from nearby metropolitan areas, microwave links can connect headend sites to the specific communities without the expense and picture quality loss of many miles of cable. Such an application is illustrated in Figure 2.

The advantage of microwave frequency links to distribute television programming to the user has been recognized for some time. The capabilities that such links must provide are tabulated in Table I which indicates that up to 20 channels per link are required to match the FCC rulemaking for local distribution systems. To meet the highest quality television standards, intermodulation distortion produced by such links must be 57 db below the video carrier. A nominal range of 10 miles for such links will meet the majority of the applications considered. Furthermore, the output VHF radio frequencies which carry the actual TV transmission, must be identical to the input frequencies if local stations are to be retransmitted on the microwave link. (For instance,

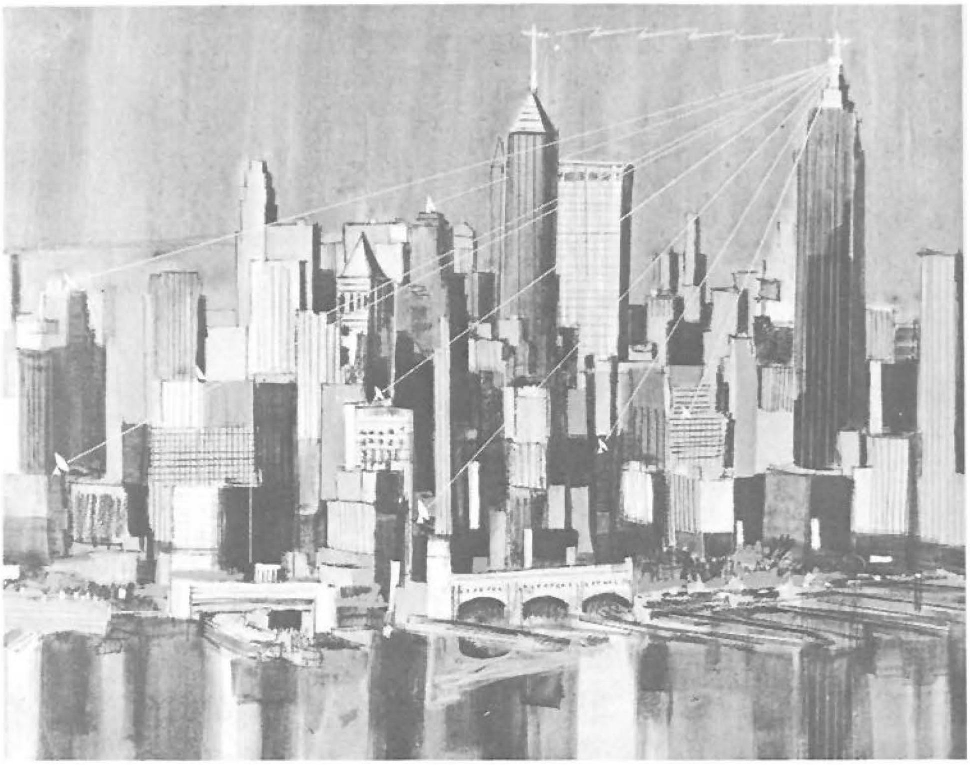


Figure 1. Artist Concept of Urban Use of AML System

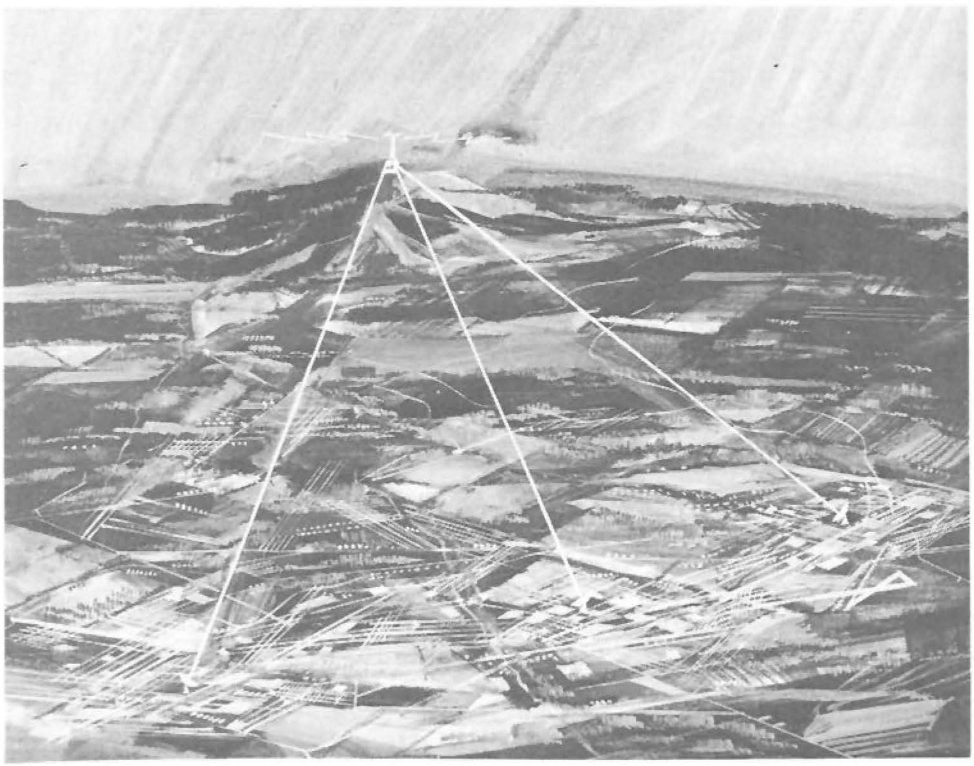


Figure 2. Artist Concept of Suburban Use of AML System

• MULTIPLE CHANNELS (UP TO 20 CHANNELS)
• LOW INTERMODULATION PRODUCTS
• RANGE OF AT LEAST TEN MILES
• OUTPUT FREQUENCIES IDENTICAL TO INPUT FREQUENCIES
• MULTIPLE RECEIVERS WITH SINGLE TRANSMITTER

Table I. Microwave Link System Goals

if Channel 2 from the microwave receiver is carried on the Channel 2 carrier, this carrier must have exactly the same frequency as a local Channel 2 transmitter. If this is not true it is possible for the Channel 2 carrier transmitted from the local VHF transmitter to interfere with the output of the microwave link and cause undesirable effects in the television picture.) It is also desirable that many receivers be used with a single transmitter since most local distribution systems have this requirement.

ECONOMIC ANALYSIS OF MICROWAVE SYSTEMS

CATV is clearly established as an economically desirable venture. The question remains whether a CATV system operating with a microwave link will maintain and improve this economic advantage. For this reason a number of cities have been analyzed to determine the overall profit and the yearly return-on-investment that would be provided by a CATV system using a microwave link. In this economic analysis (see Table II) the number of receiving sites required by each city was determined. Furthermore, the size of community and the number of homes in the community were tabulated and estimates of penetration into this community were made. Monthly rates were defined. The yearly costs to the system include the equipment amortization, the cable costs, and the effect of signal quality on income. In addition to these financial considerations, the technical considerations such as required transmitter power and the effects of rain were included in this analysis.

• NUMBER OF RECEIVING SITES
• COMMUNITY SIZE
• COMMUNITY PENETRATION
• MONTHLY RENTAL
• EQUIPMENT AMORTIZATION
• CABLE COSTS
• SIGNAL QUALITY
• RANGE
• RAIN OUTAGE

Table II. Considerations Used in Economic Analysis for Each City

The results of this economic analysis are shown in the next three figures. The first figure, Figure 3, plots yearly return-on-investment. A large number of cities had a return-on-investment of greater than 20 percent per year. A considerable number were between 30 and 40 percent a year and one had a return-on-investment as high as 92 percent per year. The actual revenue per year is indicated in Figure 4. A cumulative plot of these profit values are given in Figure 5. The indication is that the total profit from the 34 cities investigated exceeds 3 million dollars per year. Hence community antenna television systems that incorporate the convenience of microwave links are seen to maintain attractive profits.

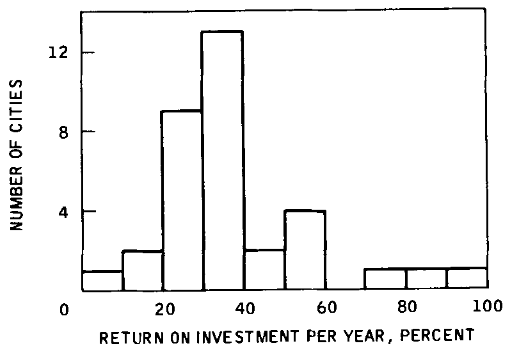


Figure 3. Distribution of Return-on-Investment

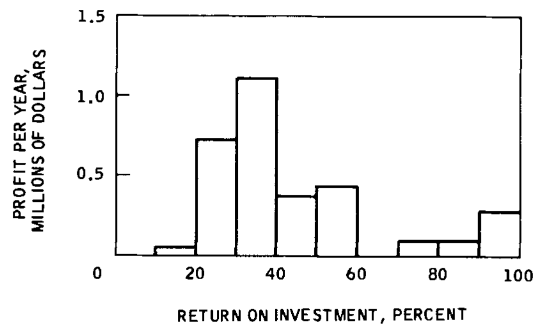


Figure 4. Distribution of Total Profits

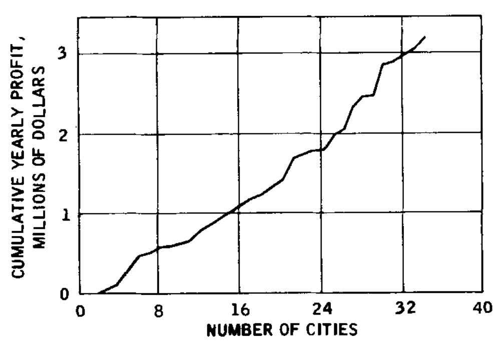


Figure 5. Cumulative Yearly Profits for 34 Cities

MICROWAVE SYSTEM SELECTION

Candidate Systems

The previous analysis demonstrated that CATV systems operating with microwave links maintain a high profit position. It remains therefore to determine the best type of transmission method to use in these microwave links. Figure 6 illustrates three candidate systems. The first system is a single-carrier, amplitude-modulated link. This system accepts the output of the headend equipment directly, which in turn drives a single-sideband, amplitude-modulated transmitter. In this case the baseband VHF signals are effectively shifted to a microwave frequency for transmission. The microwave receiver detects the incoming signals and shifts them to their original spectral positions for local distribution.

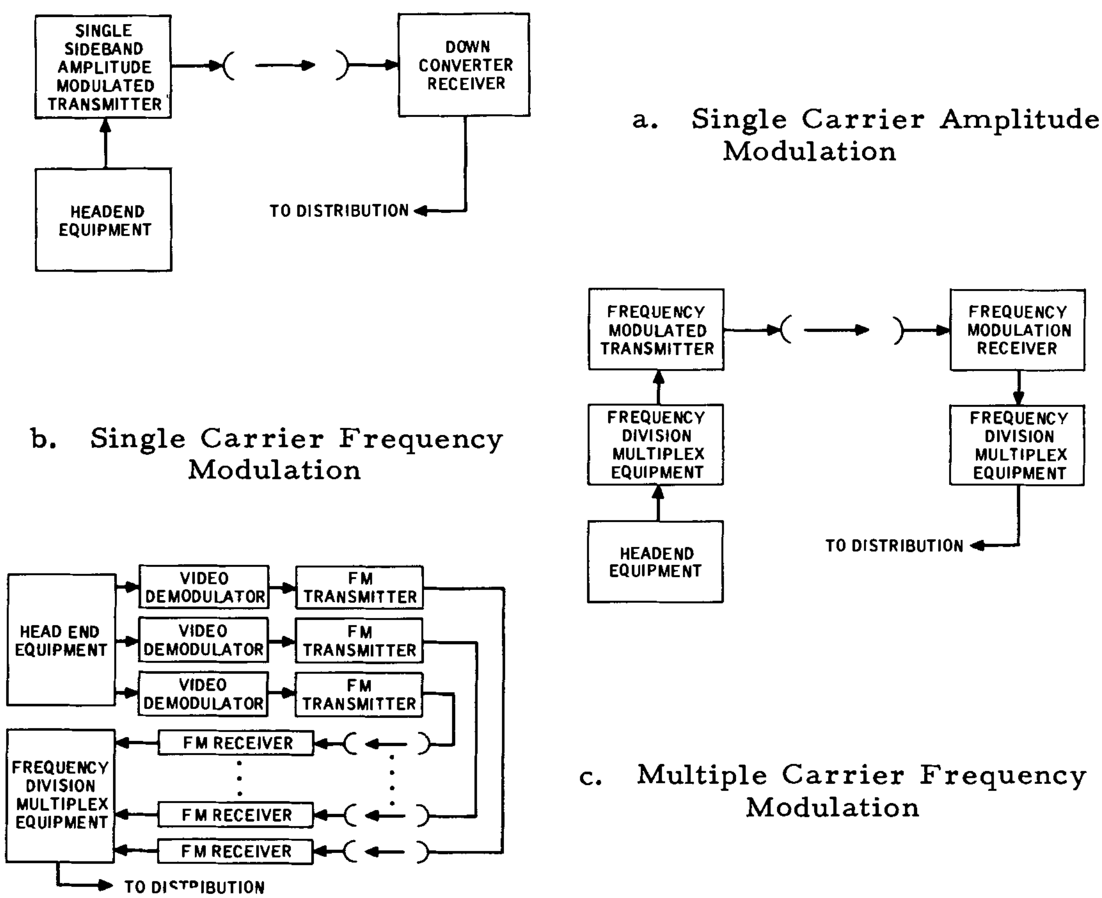


Figure 6. Candidate Local Distribution System

The second system, Figure 6b, illustrates a single-carrier, frequency-modulated system that accomplishes the same task with increased complexity. Again the headend equipment is required to normalize the television channel signals. However, a frequency division multiplex process is required to shift these frequencies from the normal television channels to a baseband structure which begins at approximately 6 MHz. This baseband structure then frequency modulates the transmitter, is transmitted to the microwave receiver, and is demodulated to recover the input baseband structure. Again, the output of the microwave receiver must be shifted back to the VHF frequencies that are acceptable to the local user by means of a frequency division multiplexer. Thus frequency division multiplexing at both the transmitter and receiver is required. This is an additional equipment requirement to that of the single-carrier, amplitude-modulation system.

The third system, indicated in Figure 6c, is the multiple-carrier, frequency-modulation system. This system, also quite complex, requires headend equipment and demodulation equipment to detect the individual video signals from the television channels. The individual demodulated video signals then frequency modulate individual transmitters. The transmitted signals are individually received by microwave receivers to recover the video signals. The video signals must finally be remodulated upon a set of carriers corresponding to the normal channels used by a home TV receiver before the signals may go to the local distribution system.

Clearly a microwave link that is to be used in a community antenna television system must provide the required performance in a cost effective manner. From the discussion above, the single carrier amplitude modulation system requires considerably less hardware than either of the other systems. It remains then to discuss the ability of an amplitude modulated link to provide the necessary TV picture quality and number of TV channels required by industry standards.

Amplitude versus Frequency Modulation

The configurations shown in Figure 6 illustrate two basic modulation methods, amplitude and frequency modulation. A comparison of these two types of modulation (see Table III) is needed to determine their suitability 1) to maintain the desired quality for a community antenna television system and 2) to provide the desired number of TV channels. It should be noted that the quality specifications for such a system are by no means trivial. It is required that the intermodulation products be kept to extremely low levels, that the signal-to-noise ratios be maintained at high levels and that cross modulation also be kept to extremely low levels while maintaining a minimum RF occupancy.

Amplitude and frequency modulation have different characteristics relative to these several considerations. Single sideband amplitude modulation, for instance, provides a minimum RF bandwidth occupancy for a given baseband. This is extremely important in the newly reassigned CARS band where a limited bandwidth, 250 MHz, is available for all transmissions. Amplitude modulation is also more efficient than frequency modulation for a given transmitted power, when the frequency modulation index is less than 1.4. Furthermore, amplitude modulation is not as susceptible as frequency modulation to transmission phase distortions. Disadvantages of amplitude modulation include the requirement for very linear circuits to maintain low cross modulation and third order intermodulation distortion. Amplitude modulation is also more susceptible to amplitude noise than is frequency modulation.

Table III. Comparison of Amplitude and Frequency Modulation

ADVANTAGES	DISADVANTAGES
• LESS SUSCEPTIBLE TO AMPLITUDE NOISE THAN AMPLITUDE MODULATION	• REQUIRE 4 TIMES BANDWIDTH OF SSB-AM SYSTEM TO ACHIEVE THE SAME PERFORMANCE
• CAN TRADE SIGNAL-TO-NOISE RATIO FOR BANDWIDTH	• SUSCEPTIBLE TO PHASE AND DELAY DISTORTION

a. Frequency Modulation

ADVANTAGES	DISADVANTAGES
• MINIMUM BANDWIDTH OCCUPANCY	• REQUIRES LINEAR CIRCUITS
• MORE EFFICIENT THAN FM WHEN FM MODULATION INDEX IS LESS THAN 1.4	• SUSCEPTIBLE TO AMPLITUDE NOISE
• NOT SUSCEPTIBLE TO PHASE DISTORTIONS	

b. Single Sideband Amplitude Modulation

Frequency modulation has an advantage in that it can trade signal-to-noise ratio for bandwidth. This advantage is used widely in most frequency modulation systems. However, it is difficult to apply such an advantage to the CARS band in that there is a limited bandwidth available for all transmissions. With a requirement to transmit 20 television channels, wide frequency deviations simply are not possible. In fact in the CARS band, extending from 12.7 to 12.95 GHz, the absolute maximum number of TV channels that may be transmitted with frequency modulation is 20. This requires a frequency division multiplex baseband structure of video signals starting at 0 MHz. If the baseband structure starts at 6 MHz, a suggested value, only 19 channels of television may be transmitted.

Frequency modulation has the disadvantage of requiring a wide RF bandwidth in order to have the same power efficiency as single sideband amplitude modulation. For instance, all other things being equal, the RF bandwidth for an FM system must be at least 4 times the bandwidth of a single sideband AM system for the same output signal-to-noise ratio.

Frequency modulation is also highly susceptible to phase delay distortions which produce cross-modulation and intermodulation products. The phase and delay distortion characteristics must be carefully maintained throughout the entire transmission system. This includes amplifiers, mixers and intermediate frequency amplifiers, that must maintain a very careful phase control in order to prevent undesirable distortion products. In fact, to maintain the phase distortion requirements, phase delay compensation networks must usually be added to the overall system in order to provide the necessary phase control. With careful adjustment, phase distortion can be minimized, however absolute control cannot be maintained over the phase distortion because of varying atmospheric effects such as fading, multipath and rain.

The relative costs of a single-carrier, amplitude-modulation system and a multiple carrier frequency modulation system are compared in Figure 7. A significant factor in the cost of these two systems is the requirement for multiple receivers at each receiving site for the

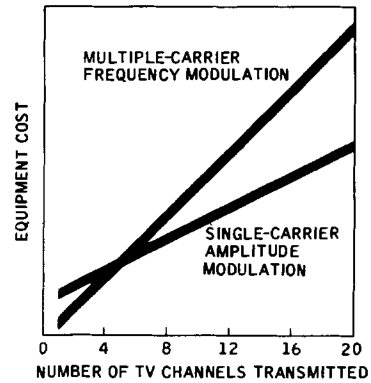


Figure 7. Local Distribution System Cost Comparison

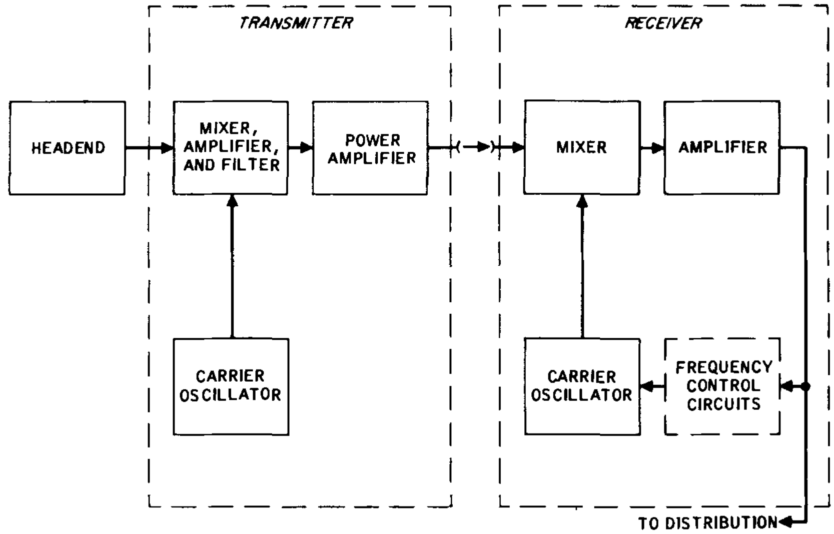
multiple-carrier, frequency-modulation system. The single-carrier, amplitude-modulation system requires only a single receiver, independent of the number of television signals being transmitted. Thus, the cost for the multiple-carrier, frequency-modulation system rises at a much faster rate, as a number of TV channels transmitted increases, as compared to the rate of increase with a single-carrier, amplitude-modulation system. For this reason, the multiple-carrier, frequency-modulation system will not be considered further.

Because of the relative simplicity of the single-sideband amplitude-modulated system over the single-carrier FM system and because of the ability of a SSB-AM system to provide 20* channels of television of the required quality, it has been chosen as the best microwave link configuration.

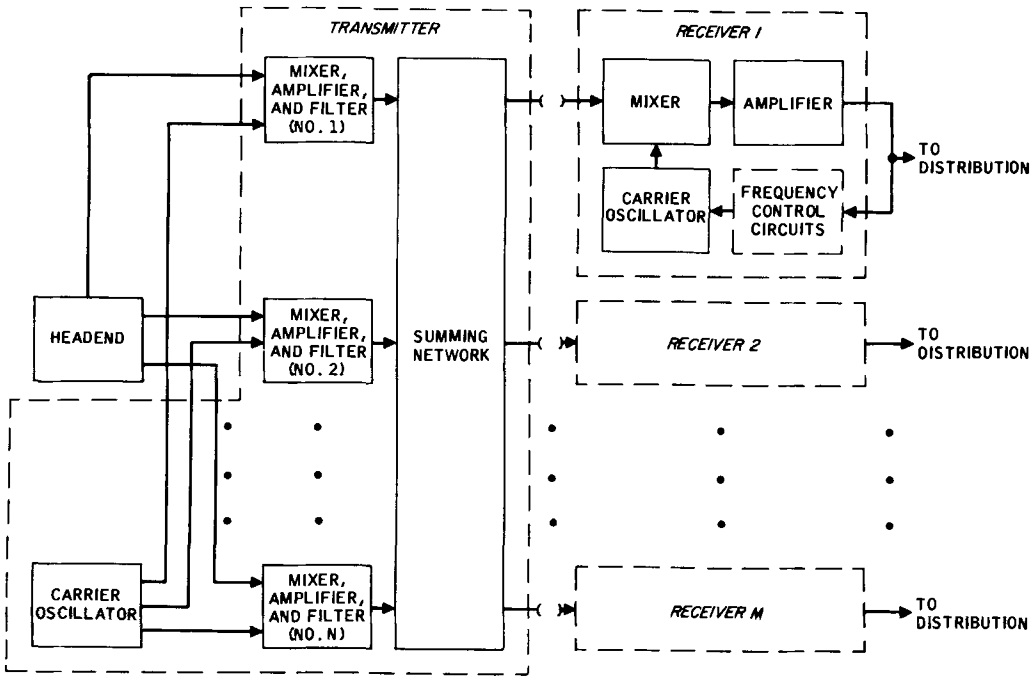
Amplitude Modulation Configurations

Two possible configurations of an Amplitude Modulation Link are given in Figure 8. Figure 8a depicts a single transmitter using a power amplifier. In this configuration, the normalized output of the headend receivers is applied directly to a mixer-amplifier-filter combination which, with the carrier local oscillator, provides the single-sideband amplitude modulation. The SSB-AM output is the same spectral configuration as the baseband input but is shifted to the desired microwave frequency. This shifted spectrum is then amplified in a linear power amplifier before transmission. The receivers consist of: 1) a heterodyne down converter to shift the microwave input spectrum to its

*The theoretical maximum is 41 channels in the present CARS band.



a. Single Transmitter Using a Power Amplifier



b. Multiple Channel Solid State Transmitter

Figure 8. Amplitude Modulation Link, Local Distribution System Configurations

original VHF spectrum, 2) an amplifier to amplify the VHF signals suitably for the local distribution system, and 3) an optional pilot tone transmitted to allow the receiver to sense the exact carrier frequency of the transmitter suppressed carrier. This allows the receiver to return the original spectra, which entered the transmitter, to exactly the same frequencies at the output of the receiver. The maintenance of input and output frequency relationships eliminates the undesirable beat notes between a locally transmitted television channel and the signal being received via the microwave/cable system.

A second SSB-AM configuration is shown in Figure 8b. Here each television signal, after it has been normalized to the proper amplitude by the suitable headend equipment, is applied to a single mixer-amplifier-filter combination. Each individual television channel is then shifted to a microwave frequency. These shifted frequencies are summed in a microwave network and are transmitted. As indicated in the figure, the number of transmitting antennas is more than one, usually 4 or 8. The receiver in Figure 8b is identical to the receiver configuration of Figure 8a and, again, merely shifts the microwave signal back to its original RF baseband spectra allowing it to be received directly by a home receiver.

The equipment indicated in the block diagram form of Figure 8a has been constructed and operated for 4 years. The actual hardware is shown in Figures 9, 10, and 11. Figure 9 is the low level mixer-amplifier-filter which performs the single-sideband function. This equipment is mounted in the rack as indicated in Figure 10 with the required power supplies and metering circuitry. The matching receiver used by this RF transmitter is shown in Figure 11, mounted on the back of the receiving antenna. The receiver is encased in a weatherproof box allowing it to be mounted externally as shown, requiring only a power supply and a coaxial cable connection.

Operation of the AML System

The AML system has been constructed and has been operating since the spring of 1966. This operation has been conducted under an experimental license and under an experimental research license as noted in Table IV. The Federal Communications Commission has granted these licenses but has not made a permanent rulemaking for the 17.7 to 19.7 GHz band at this time. However the FCC has authorized the operation of the AML system in New York City, in Farmington,

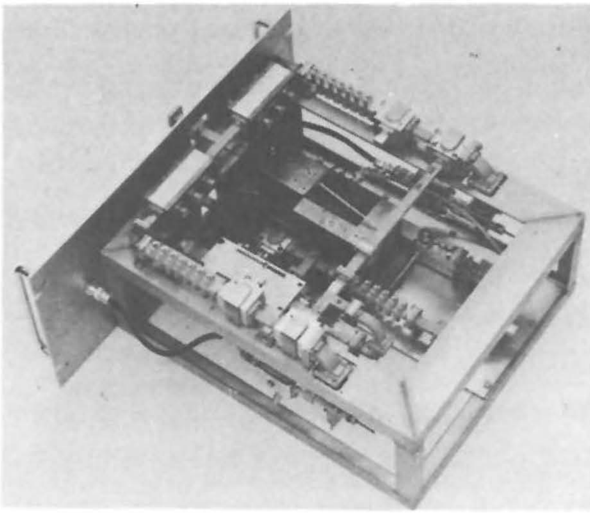


Figure 9. 18 GHz Experimental Transmitter

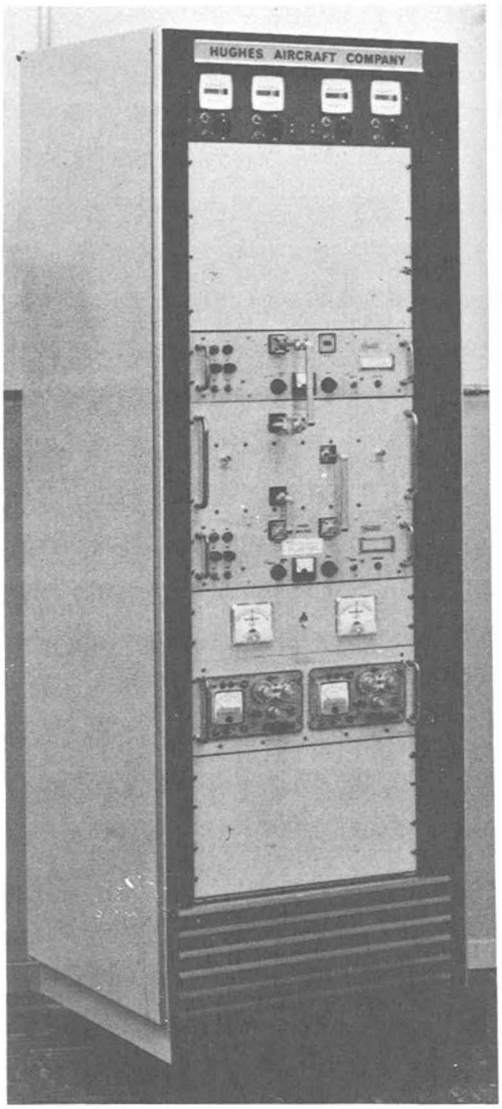


Figure 10. 18 GHz Rack-Mounted Experimental Transmitter

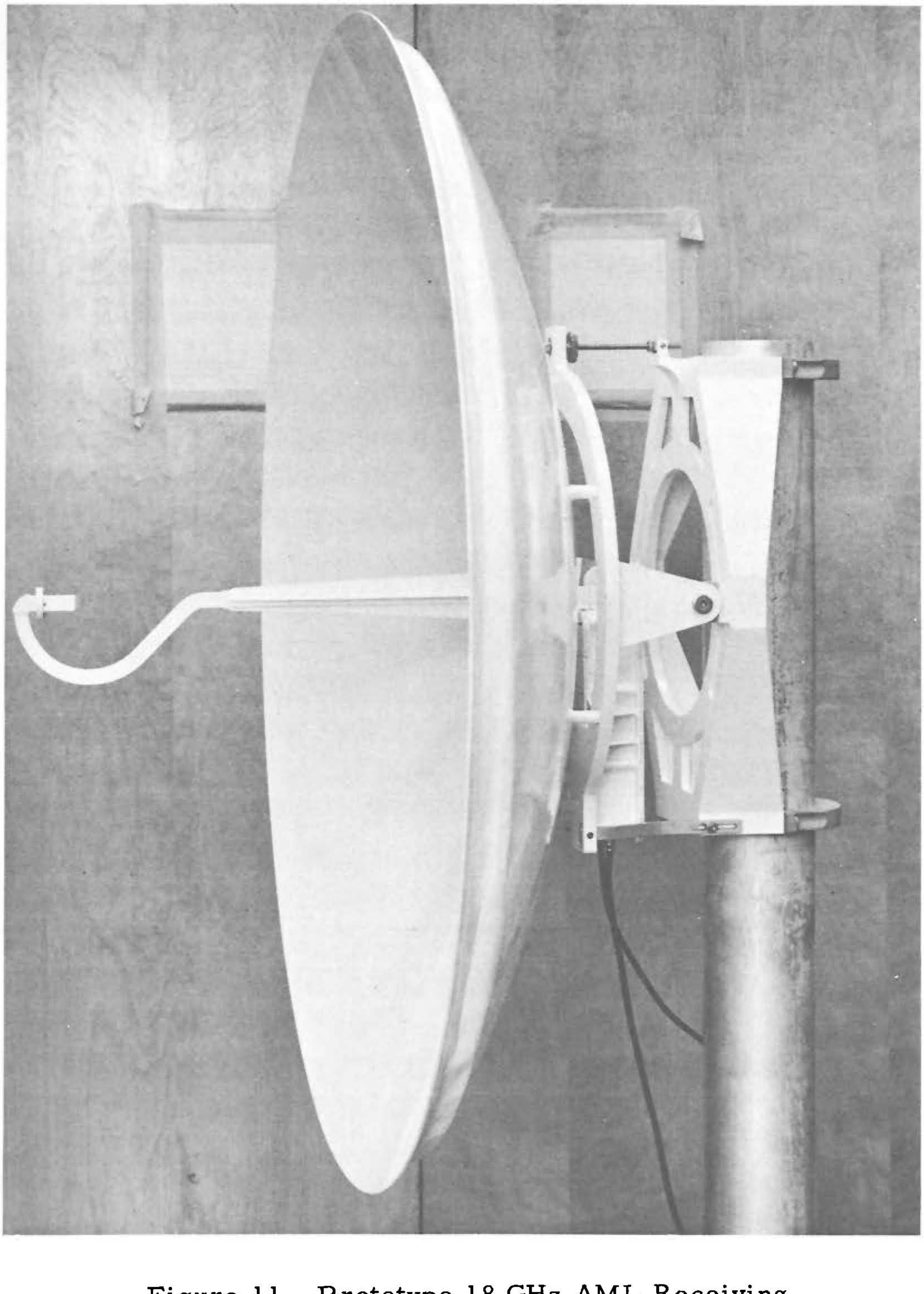


Figure 11. Prototype 18 GHz AML Receiving
Antenna and Receiver

• GRANTED EXPERIMENTAL RESEARCH LICENSE
• NO PERMANENT RULEMAKING
• GRANTED TEMPORARY COMMERCIAL WAIVER
• NEW YORK CITY, NEW YORK
• FARMINGTON, NEW MEXICO
• EUGENE, OREGON

Table IV. FCC Action on 17.7–19.7 GHz Band for Local Distribution System

New Mexico, and in Eugene, Oregon. The AML has been operating in New York City since May of 1966 and has operated for a lesser time in Farmington, New Mexico.

The total operational time under the experimental license in New York City has been 33 months; the New York City operations are summarized in Table V. During this time the AML system has transmitted 12 channels of television. Operational measurements have been made on the performance of the system during this extended period of testing and considerable data relative to weather and operational procedures have been obtained. In February, 1969 a temporary commercial waiver was granted for the operation of the AML system. Since that time the AML has provided television channels to two CATV companies in the New York City area. This 16 month test used 12 channels of video transmitted over three different links. The data have confirmed the initial projections of the technical and economic feasibility of this system.

LOCAL DISTRIBUTION SYSTEM AT 12.7 TO 12.95 GHz

FCC Action

The Federal Communications Commission authorized the operation of the Amplitude Modulation Link in the 12.7 to 12.95 GHz CARS band in November, 1969 (see Table VI). This action was a permanent

EXPERIMENTAL OPERATION IN NYC • 33 MONTHS • 12 CHANNELS • OPERATIONAL MEASUREMENTS
TEMPORARY COMMERCIAL WAIVER IN NYC • JOINT USERS • 16 MONTHS (JUNE 1970) • 12 CHANNELS, 3 LINKS • CONFIRMED PROJECTIONS • TECHNICAL • ECONOMIC

Table V. 18 GHz Local Distribution Operation

- PERMANENT RULEMAKING (DOCKET 18452) GRANTED FOR AMPLITUDE MODULATED LINK, ON 7 NOV 1969
- 20 CHANNEL OPERATION
- OPERATES WITH EXISTING CARS SYSTEMS

Table VI. FCC Action on 12.7 – 12.95 GHz Band for Local Distribution System

rulemaking that allowed up to 20 TV channels for Amplitude Modulated Links. The FCC action required the compatible operation of both the AML and the existing CARS single-channel, frequency-modulated systems. Only these two systems are presently authorized to operate in this band.

With this new FCC action, the effects on the Amplitude Modulated Link were examined and the role for such systems was reconsidered. Table VII tabulates these effects. Since the frequency had been lowered from the 18 GHz band, considerable hardware simplifications resulted. In addition, a larger number of transmitter configurations became possible, in particular the use of solid state transmitters. The lower frequency also provided much better weather performance, which reduced the required link margin.

Local Distribution System Parameters

Local distribution system parameters, such as the design range, the number of receivers required per transmitter, and rain attenuation margin needed to be determined. An analysis was made of 34 different cities to determine these design parameters for a local distribution system. Figure 12 plots the number of individual links as a function of the ranges of these links. A nominal range value of 10 miles has been chosen based upon these statistics.

- FREQUENCY EFFECTS
  - HARDWARE SIMPLIFICATION
  - AVAILABILITY OF A LARGER NUMBER OF TRANSMITTER CONFIGURATIONS
  - BETTER WEATHER PERFORMANCE
- ROLE OF LOCAL DISTRIBUTION SYSTEM
  - RANGE REQUIREMENT
  - NUMBER OF RECEIVERS PER TRANSMITTER
  - APPLICATION TO INDIVIDUAL CITIES
  - BANDWIDTH CONSERVATION CRITICAL

Table VII. Effects of FCC Rulemaking at 12 GHz on AML

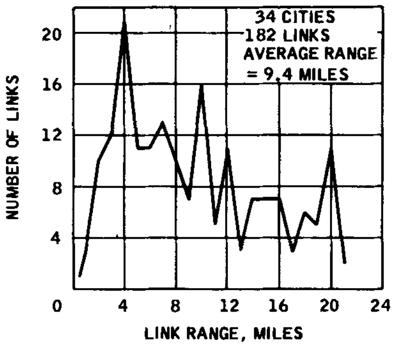


Figure 12. Local Distribution Link Range Statistics

The transmitter configuration of the AML system depends upon the number of receiver sites to be used with each transmitter. A statistical analysis of the number of receiving sites required is given in Figure 13. These data are taken for 34 different transmitting sites and include 182 receiving sites. A majority of the systems require 4 or more links from a given transmitter site. For this reason the transmitter has been designed to have either 4 or 8 outputs in order to accommodate the expected number of links at a given transmitter site.

The transmitter configuration shown in Figure 8b has been chosen for the local distribution system in the 12 GHz band. This system conveniently provides a transmitter having multiple outputs, 4 or 8, and can provide the necessary output power with solid state amplifiers.

Rain Margin at 12 GHz

The new frequency allocation reduced considerably the amount of link margin needed for rain attenuation. This is indicated in Figure 14 in which the rain attenuation is compared for 12 GHz and 18 GHz. At the nominal design range of 10 miles a 25 mm/hour rain produces 13 db of attenuation for 12 GHz and 26 db of attenuation for 18 GHz. This illustrates a marked advantage of 12 GHz over 18 GHz.

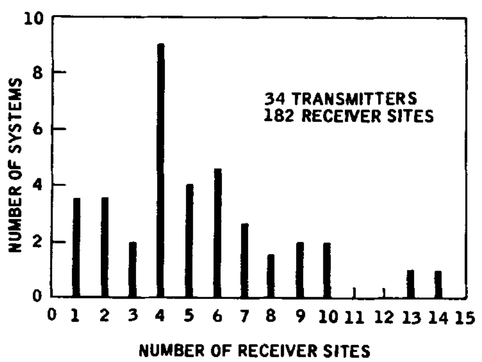


Figure 13. Number of Receivers per Transmitter Site

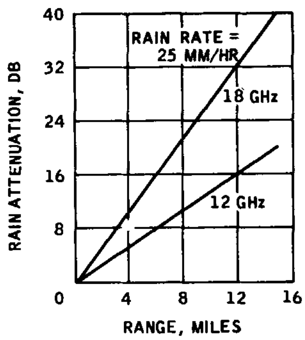


Figure 14. Comparative Rain Attenuation at 12 and 18 GHz

Rainfall data must also be correlated with the number of hours per year which exceed a given rainfall rate in order to determine the yearly performance of a link. Table VIII gives the rainfall statistics of the heaviest rainfall rate that was recorded in 5 different cities. This table indicates that the rainfall rate in Corvallis, Oregon exceeded 8.8 millimeters of rain per hour for only one hour per year while in Miami, Florida the rainfall rate exceeded 210 millimeters of rain per hour for at least one hour per year. Thus not only is the average rainfall in a given year important, but also the statistics for an hour-by-hour basis must be known to make proper attenuation estimates.

A summary of rainfall rates, given in Table VIII, is expanded in Figures 15, 16 and 17, the expected weather performance for Los Angeles, Washington, D. C. and Miami. The figures indicate the number of hours per year where the signal-to-noise ratio is expected to fall to less than a given peak video signal-to-RMS noise ratio as a function of link range. As may seen, the Los Angeles performance shows essentially no rain problem. The same is true for the expected Washington, D. C. performance. The Miami performance, with its heavy rainfall, does reduce the performance below the specified value of 45 db for about 10 hours per year if the link range exceeds 8 miles. However,

CITY	MM/HR (EXCEEDED 1 HOUR/YEAR)
CORVALLIS, OREGON	8.8
LOS ANGELES, CALIF.	10.9
ISLAND BEACH, N. J.	37.0
WASHINGTON, D. C.	50.8
MIAMI, FLORIDA	210.0

Table VIII. Rain Rate Distribution

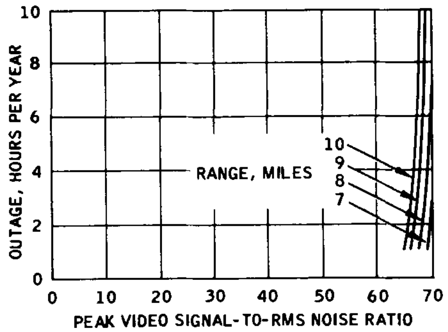


Figure 15. Expected Los Angeles Weather Performance

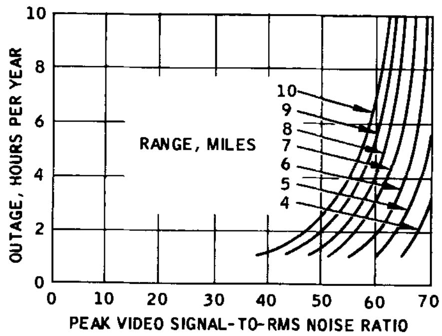


Figure 16. Expected Washington D. C. Weather Performance

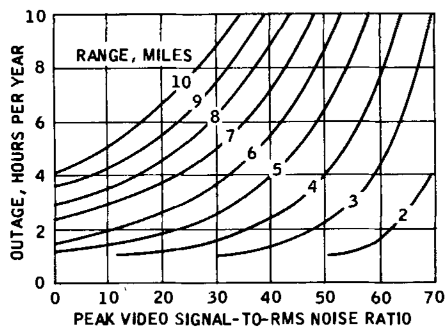


Figure 17. Expected Miami Weather Performance

the signal-to-noise ratio does not go below 35 db for ranges as large as 10 miles for more than 10 hours per year. Thus quality pictures are available even though the signal-to-noise ratio of the picture may be reduced by rain for brief periods.

To provide link margin to cope satisfactorily with rain attenuation it is possible to increase the size of both the transmitting and receiving antennas. The cost of this increase is indicated in Figure 18 which plots the relative cost of link antennas as link performance requirements increase.

12 GHz Amplitude Modulated Link

A typical link installation of a 12 GHz Amplitude Modulation Link is indicated in Figure 19. The transmitter installation, consisting of

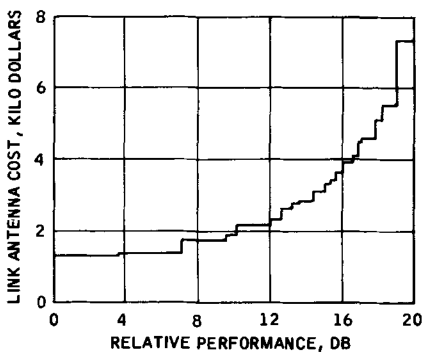


Figure 18. Antenna Cost Versus Performance

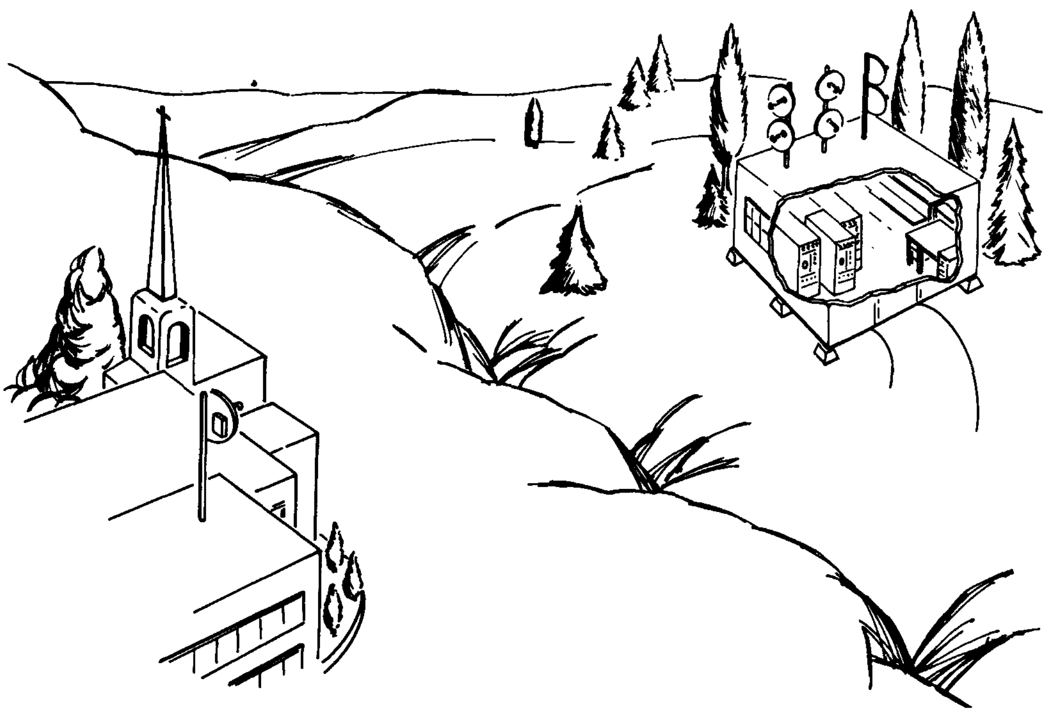


Figure 19. AML Receiver – Transmitter Installation

three modular transmitters, services receivers located in the customer communities. The receivers are then connected by cable to the distribution network.

The transmitting modules indicated in Figure 19 are each capable of transmitting 5 or 6 TV channels, depending if a pilot tone is used or not. A greater or lesser number of these transmitter modules may be used. The output of the individual transmitter modules are added before the power is divided among the several antennas that transmit to individual receivers. The present configuration of transmitting antennas uses a single transmitter to transmit the audio signals and a second antenna to transmit the video signals. All of these signals are received on a single receiving antenna.

AMPLITUDE MODULATED LINK SYSTEM PERFORMANCE

The AML system concept summarized in Table XI, has been proved both on a technical and economic basis through 4 years of field testing. The AML has provided 12 channels of simultaneous video and audio transmission while maintaining the highest technical standards. This performance has been accomplished with the use of the 18 GHz experimental band. Present FCC authorization in the 12 GHz band has provided new benefits for the AML system. These include the ability to use a different transmitter configuration with a considerable saving in input power. Furthermore, better weather performance has considerably increased the reliability of the system and removed the need for high power amplifiers. The 12 GHz system is presently in production and is available for early delivery.

Table IX. AML

PROVEN SYSTEM CONCEPT • TECHNICAL • ECONOMIC • MULTIPLE CHANNELS
AUTHORIZED FOR 12 GHz BAND • NEW BENEFITS • SOLID STATE TRANSMITTER MODULES • BETTER WEATHER PERFORMANCE • MINIMUM PRIME POWER • IN PRODUCTION