SYSTEM CONSIDERATIONS IN APPLICATIONS OF 18 GHz MICROWAVE TO CATV

T. M. Straus and R. T. Hsu

Hughes Aircraft Company
Microwave Communications Products

ABSTRACT

When compared to the conventional 12 GHz CARS band microwave, 18 GHz systems suffer from substantially higher rain attenuation and somewhat reduced equipment capability. However, in those instances when an interference free CARS band frequency allocation cannot be obtained, 18 GHz microwave systems can in many cases offer a viable alternative. High power transmitters utilizing specially developed klystron amplifiers have been utilized at a 17 mile range with acceptable link margin. Both 6 MHz wide VSB-AM and 20 MHz wide FM video channels can be accommodated with this type of equipment. Comparisons between 12 GHz and 18 GHz equipments and system performance are presented.

INTRODUCTION

The FCC originally assigned the 12.7 - 12.95 GHz frequency band to the Community Antenna Relay Service (CARS). The utilization of microwave in this frequency band, particularly since 1971 for Local Distribution Service (LDS), has steadily grown until today there are over 100,000 VSB-AM channel paths in the United States. Despite a later expansion of the band to 13.2 GHz, the resulting frequency congestion, particularly in major urban markets, has in some instances led to actual or potential interference between neighboring systems. Recently, the FCC established an 18 GHz frequency plan which provides for both 6 MHz channels suitable for VSB-AM distribution and 20 MHz wide channels suitable for FM. Figure 1 shows this frequency plan. Although the total bandwidth provided in this "18 GHz" plan is 2 GHz wide, the frequencies of greatest interest for U.S. CATV operation would presumably be the 18.14 to 18.58 GHz frequency band allocated to 6 MHz wide channels suitable for VSB-AM video carriage. The wider band FM video channels can be readily accommodated in the adjacent 17.70 to 18.14 GHz band.

While the types of CATV signals which may be carried at 18 GHz are the same as those carried in the 12 GHz CARS band, the propagation conditions at the higher frequency are considerably more severe. Studies are available to provide a fairly firm basis for predicting the affects of rain and multipath at 12 and 18 GHz.[1,2] These are reviewed in the following paragraphs. There follows then a comparison of the recently developed 18 GHz equipment with the more familiar AML transmitters and receivers utilized at 12 GHz. Other factors affecting the microwave link such as antenna performance and waveguide and multiplexing losses are also discussed.

A knowledge of all of the above factors is required to predict the performance of an 18 GHz microwave link. Several typical applications are described. These

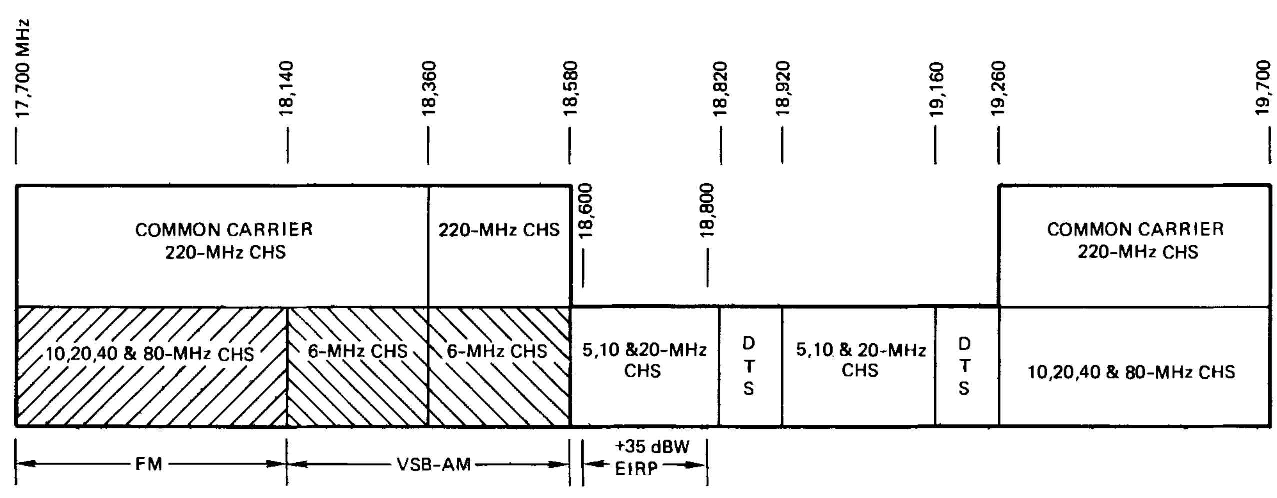

Figure 1 18 GHz spectrum allocation.

illustrate that acceptable link margins can usually be obtained for CATV systems.

PROPAGATION

Extensive experience has been gained in the past 15 years with 12 GHz microwave paths carrying VSB-AM video signals in CATV LDS systems. Video signals are carried in the VSB-AM format in microwave LDS because of the overriding advantages of cost, compatibility with the cable distribution, and spectrum efficiency. Moreover, despite the lack of an "FM S/N improvement" in an AM system, the general experience has been that fade margins as low as 20 dB (to 35 dB C/N) could provide acceptable signal quality and availability in most instances. Exceptions were primarily associated with long paths which paralleled prevailing storm fronts. With this exception, the empirical models used to predict path reliability statistics at 12 GHz have, if anything, been conservative.

Propagation at 18 GHz, although much less familiar to the CATV industry, is not entirely an unknown. Indeed, the initial experiments having a microwave LDS for CATV specifically in mind were carried out at 18 GHz.[3] It was found that even relatively short paths (4.25 miles) in an average weather environment (New York City) were subject on occasion to very deep fades (40 dB). The test results are however compatible with the predictions of the empirical models. What, then, do these models tell us about the relative performance of the atmospheric path at 12 and 18 GHz?

Figure 2 shows the attenuation per mile at 12 and 18 GHz as a function of rain rate. It can be seen that for a given rain rate the attenuation in dB is roughly twice as large at 18 GHz as it is at 12 GHz. Other factors which enter into the calculations for rain-induced path fades include the probability of occurrence of a given rain rate and probable length of the rain cell. Another factor related to the rain attenuation is polarization. At 18 GHz where the rain attenuation is more severe it may be expected that vertically polarized microwave paths will suffer significantly less attenuation than horizontally polarized paths. The difference, although less than 20 percent could be of importance in marginal applications.

The probability of occurrence for a multipath fade is given by Barnett[2] as

$$P(L) = abfR^3L^2 \quad \text{for } R \geq R_{min}$$

where (a) and (b) are constants related to the terrain and humidity, f is frequency, R is range, and -20 logL is depth of fade. Thus at 18 GHz multipath fading can be expected occur 50 percent more than at 12 GHz. Moreover, the minimum path length, R_{min}, at which fading can occur is reduced by a factor of $f^{-1/3}$ according to Ruthroff's model.[4] Still, at 18 GHz, rain attenuation will be the predominant path reliability factor in most instances. Figure 3 shows the expected hours per year that path fade exceeds 20 dB as a function of path length. Three sets of curves compare predictions at 12.9 GHz with those at 18 GHz. The sets of curves correspond to most favorable, average, and most severe climate regions in the U.S. Figure 4 shows similar calculations for 30 dB

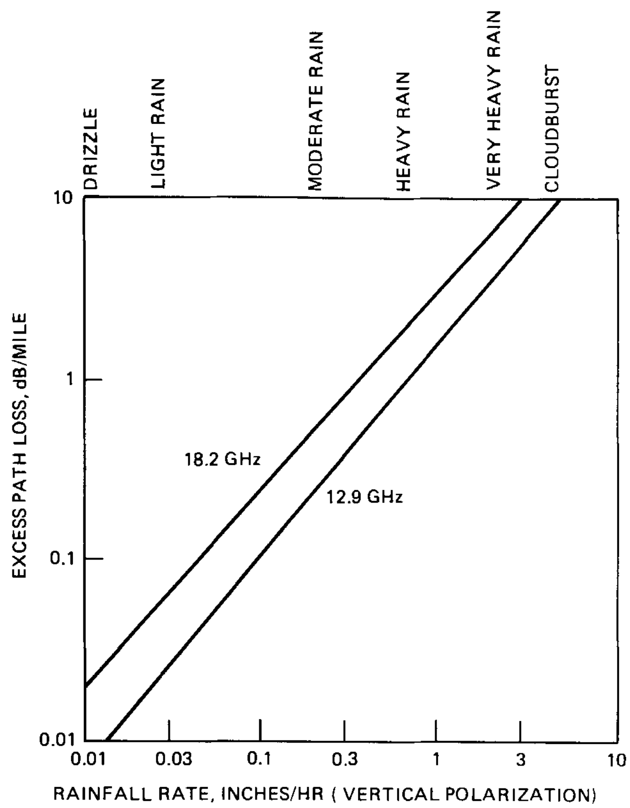

Figure 2 Attenuation vs rainfall rate.

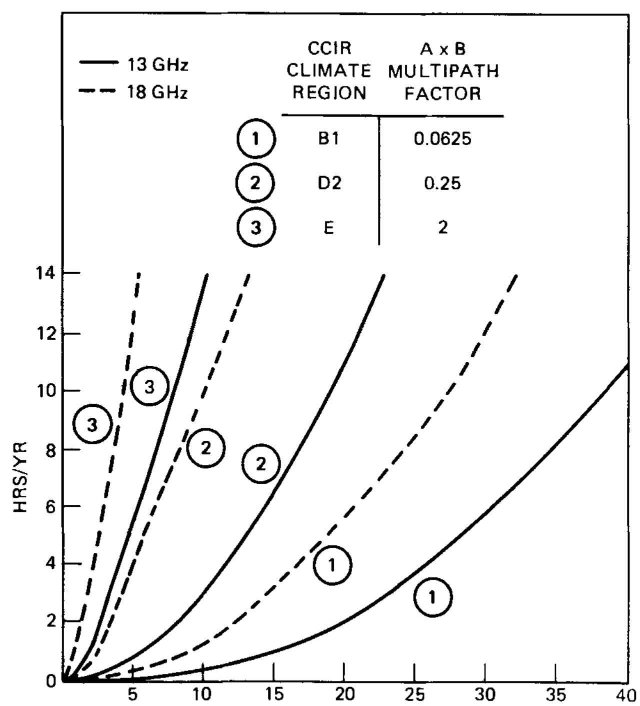

Figure 3 Path outage for 20 dB fade margin.

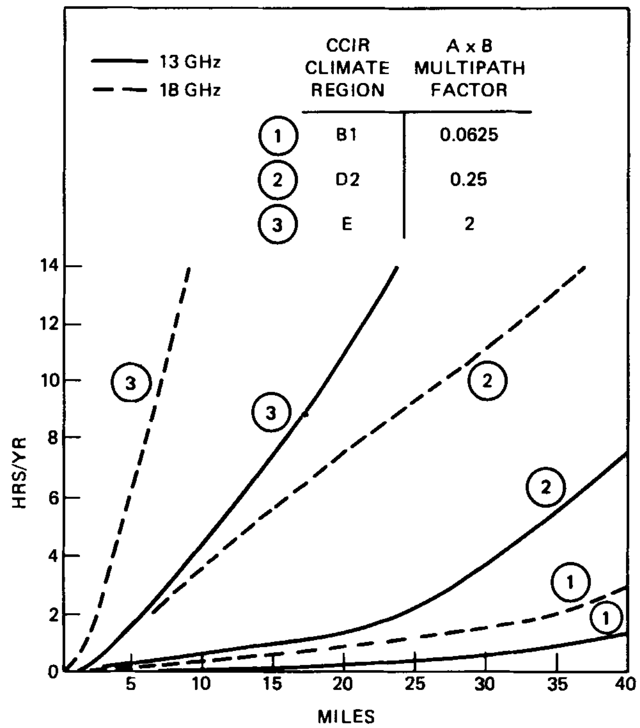

Figure 4 Path outage for 30 dB fade margin.

fade. Clearly, propagation limitations will play a bigger role at 18 GHz than at 12 GHz but substantial path lengths can still be achieved at 18 GHz if the equipment provides requisite performance.

HARDWARE DESCRIPTION

The preceding discussion shows that a higher system gain is needed in the 18 GHz band than in the 12 GHz CARS band to keep the system performance the same. Therefore, emphasis in the hardware development has been placed on the high power transmitter. Even matching CARS band equipment performance with similar performance at 18 GHz is however not an easy matter.

Figure 5 is the block diagram of an 18 GHz high power AML transmitter. A 5-cavity klystron has been specially developed for this application. It has the same type of package as the 12 GHz 4-cavity klystron and preserves almost all characteristics of the latter. Thanks to the improved gun design, the noise figure is even reduced by 3 dB. With this klystron, the transmitter can deliver over 10 W output power for FM application and 2 W for VSB-AM application. Very long service life can be expected because of the advanced cathode technology. Of course, operating at 18 GHz, a 3 kV beam voltage is necessary instead of the 2.2 kV required for 12 GHz. This causes 31 percent more dissipation than at 12 GHz, but the heatsink has enough capability to accommodate this additional dissipation.

The insertion loss of the channel filter goes up with the increasing frequency. At 18 GHz, it becomes a real problem. Although the low loss TE011 circular cylindrical cavity mode was used in the filter design, the actual insertion loss is 1 dB for 20 MHz bandwidth FM application and 4 dB for the 6 MHz bandwidth VSB-AM application. Therefore, the available power at the output of the 18 GHz transmitter is only 1 W for VSB-AM signals, even though the klystron actually delivers only slightly less power than the 12 GHz version. However, by using predistortion techniques,[5] the 18 GHz VSB-AM transmitter can easily deliver 2 W power at its output.

Phase noise is another problem of concern. Because of the higher frequency multiplication factor, it can be understood that the phase noise would increase by 2.8 dB if the other conditions were the same. Therefore, a low phase noise crystal oscillator and solid state source must be used in the 18 GHz equipment.

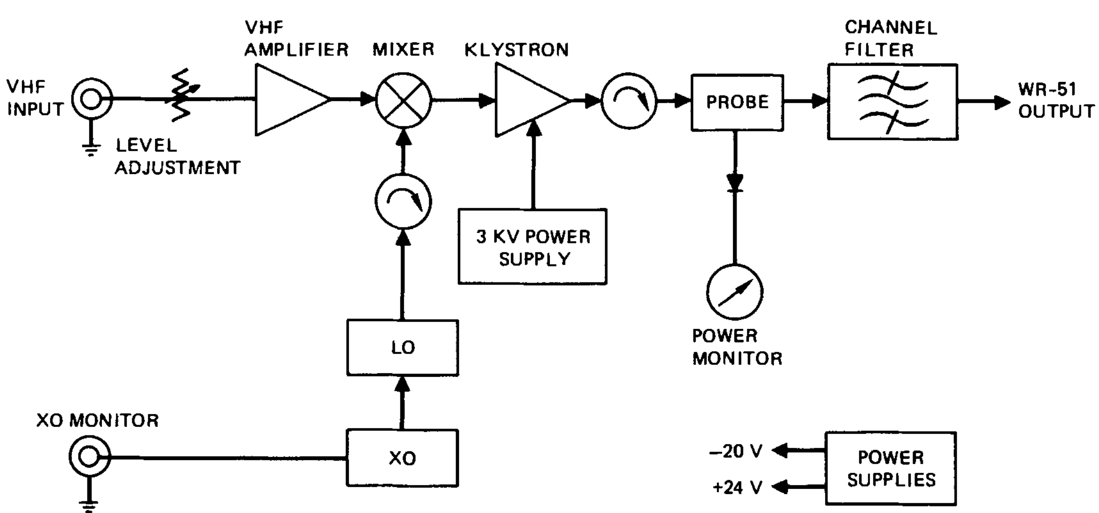

Figure 5 Block diagram of 18 GHz high power transmitter.

TABLE 1

TYPICAL PERFORMANCE PARAMETERS OF THE HIGH POWER VSB-AM TRANSMITTERS

Transmitter Parameters	18 GHz (No Predistortion)	18 GHz (With Predistortion)	12 GHz (No Predistortion)
Output Power, dBm	30	33	33
C/IM, dB	58	66	58
Freq. Response, dB	1	1	1
Diff. Gain, %	5	4	4
Diff. Phase, Degree	2	1.5	1.8

Table 1 summarizes the key performance parameters of the 18 GHz high power VSB-AM transmitters in comparison with the 12 GHz counterpart.

In contrast with the VSB-AM transmitter, the 18 GHz FM video transmitter can make full use of the klystron's capability. 40 dBm output can be easily obtained. 20 MHz wide channel allocation allows higher deviation and thus higher S/N improvement. Actually S/N of 68 dB has been achieved through an 18 GHz FM system. Moreover, the microwave transmitter-receiver link is almost "transparent" to the baseband parameters.

Besides the high power transmitters, an all solid state FM video transmitter with output of 20 dBm is also available. A GaAs FET amplifier is used in this transmitter in place of the klystron amplifier. The solid state transmitter may be suitable for short path length applications.

Two kinds of standard rigid rectangular waveguides, WR-51 and WR-42, can be used in 18 GHz systems. WR-51 was selected in the hardware design because of its lower attenuation at the frequency of interest. For WR-51 brass waveguide, the attenuation is about 0.1 dB/ft. at 18 GHz, while for WR-42, it is almost 0.2 dB/ft. By way of contrast, WR-75 waveguide loss at CARS band is only 0.5 dB/ft.

Circulators and magic tees are used for tranmitter channel multiplexing. Four high power transmitters can be mounted in a single rack. The circulator has an insertion loss of 0.3 - 0.4 dB, again almost double the loss of its CARS band equivalent. In a typical 4-channel circulator multiplex chain as much as 4 dB allowance must be made for the bottom transmitter. The magic tee has an insertion loss of 0.2 dB plus division loss of 3 dB. Considering the inevitable waveguide loss, two chains combined with a magic tee will suffer a loss of 3.5 dB. These values are also somewhat higher than in the 12 GHz system and must be considered in the link power budget. In addition, a transition to WR-42 is presently required to connect to available elliptical waveguide at 18 GHz. EW 180 guide loss is 5.9 dB/100 ft. vs 3.7 dB/100 ft. for EW 127 at CARS band.

The theoretical antenna gain increases as the square of the frequency. Table 2 lists the specified gain g and 1/2 power beamwidth for both 4 ft. and 6 ft. antennas at 12.9 GHz and 18.2 GHz. Although a 3 dB greater antenna gain is theoretically available at 18 GHz, the antenna surface tolerance must be held more tightly, while the beamwidth dictates that alignment and tower stability requirements are also tighter for a given size antenna diameter. Standard low cost antennas with diameter in excess of 6 feet are presently unavailable at 18 GHz.

The 18 GHz receiver design is similar to the standard CARS band AML receivers. Figure 6 shows the block diagram. Both the composite AGC and the phaselocked pilot tone AGC receivers are available. Because of the higher front end waveguide and ferrite attenuator loss and mixer conversion loss at 18 GHz, the receiver noise figure is 11 dB which is 1 dB worse than the CARS band AML receiver.

Two tone third order intercept point at the input of the receiver was measured to be 10.7 dBm. If the input carrier level is limited by AGC to -44 dBm for a C/N of 53 dB, the carrier to composite triple beat ratio C/CTB would be 80 dB for a 54 channel system, about as good as the CARS band receiver.

In case lower noise figure is required, a LNA and an image noise reject filter could be incorporated in the

TABLE 2

ANTENNA GAIN AND BEAMWIDTH COMPARISONS

Antenna Diameter (ft)	12.9 GHz		18.2 GHz	
	g (dB)	Φ_b (Degree)	g (dB)	Φ_b (Degree)
4	41.5	1.36	44.5	0.96
6	45.1	0.89	48.0	0.63

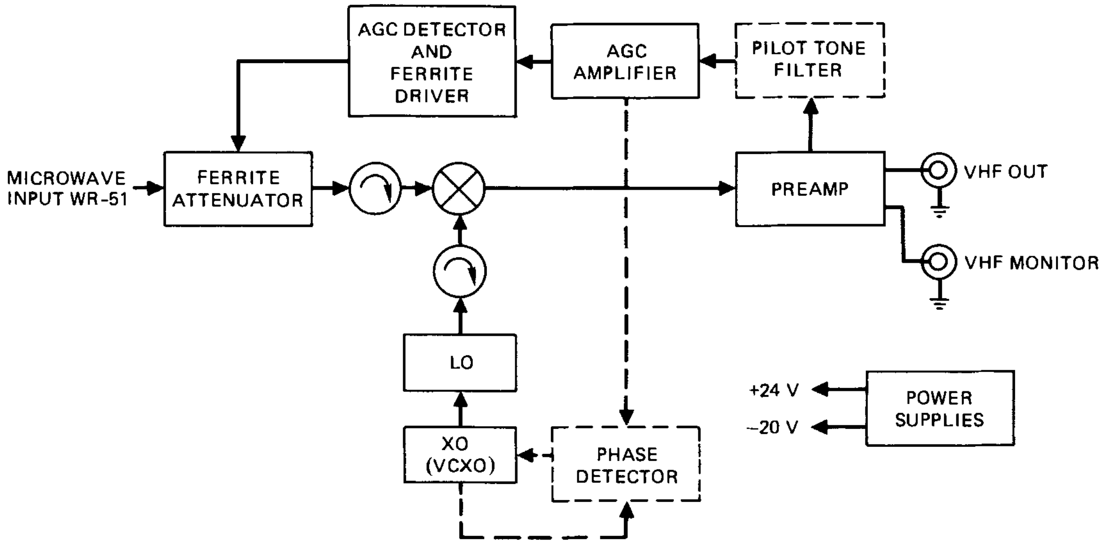

Figure 6 Block diagram of 18 GHz receiver (dashed line indicates phase-locked option)

receiver front end.[6] A receiver noise figure of 8 dB could be expected with a single stage LNA. Even lower noise figure would be achievable with a dual stage LNA.

PRACTICAL CATV APPLICATIONS

Some practical 18 GHz transmission systems have been evaluated for CATV applications.

The first example is a 32 channel LDS system with eight receiving sites in the Los Angeles area. The maximum path length is assumed to be 12 miles. Using 18 GHz high power transmitters with predistortion, 33 dBm/channel can be delivered at the output of each transmitter. The output circulator and magic tee multiplexing network losses then result in a minimum 18.5 dBm at each of the eight combined outputs. Table 3

TABLE 3

18 GHz AM PATH CALCULATIONS FOR TWELVE-MILE PATH IN LOS ANGELES

Transmitter Output Power (per channel after combining)			18.5 dBm
Transmitter Waveguide	50	Ft. Elliptical	-3.0 dB
Transmit Antenna	6	Ft.	48.0 dB
Free Space Attenuation	12.0	Miles	-143.4 dB
Receive Antenna	6	Ft.	48.0 dB
Receiver Waveguide	50	Ft. Elliptical	-3.0 dB
Atmospheric Absorption			-1.9 dB
Field Factor			-3.0 dB
Received Carrier			-39.7 dBm
Noise Per MHz			-114.0 dBm
4 MHz Correction			6.0 dB
Receiver Noise Figure			11.0 dB
Receiver Thermal Noise			-97.0 dBm
Receiver Carrier to Noise Ratio without AGC			57.3 dB

STATISTICAL ESTIMATES

MULTIPATH FACTOR (A x B) = 0.25
CCIR CLIMATE REGION = F

Hours Per Year Below 35 dB Carrier-to-Noise: Multipath	1.0
Hours Per Year Below 35 dB Carrier-to-Noise: Rain	2.8
Total Hours Per Year Below 35 dB Carrier-to-Noise	3.8
Percentage Reliability	99.956

TABLE 4

18 GHz FM PATH CALCULATIONS FOR EIGHTEEN-MILE PATH IN NEW YORK

Transmitter Output (per channel after combining)			32.5 dBm
Transmitter Waveguide	100	Ft. Elliptical	-5.9 dB
Transmit Antenna	6	Ft.	48.0 dB
Free Space Attenuation	18.0	Miles	-146.9 dB
Receive Antenna	6	Ft.	48.0 dB
Receiver Waveguide	100	Ft. Elliptical	-5.9 dB
Atmospheric Absorption			-2.9 dB
Field Factor			-3.0 dB
Received Carrier			-36.1 dBm
Threshold for 33 dB S/N			-78.0 dBm
Fade Margin to Threshold			41.9 dB

STATISTICAL ESTIMATES

MULTIPATH FACTOR (A x B) = 0.25
CCIR CLIMATE REGION = D2

Hours Per Year Below 35 dB Carrier-to-Noise: Multipath	0.04
Hours Per Year Below 35 dB Carrier-to-Noise: Rain	3.39
Total Hours Per Year Below Threshold	3.43
Percentage Reliability	99.961

summarizes the path calculation. The standard 3 dB field factor is included in the calculation to allow for small misalignment of various system components and miscellaneous losses which may otherwise not be accounted for. In this respect and also in the method of predicting hours below the 35 dB C/N quality level, the calculation copies the format utilized for CARS band LDS applications.

A second example is a FM microwave link for the transmission of 8 TV channels. The path length is 18 miles. 18 GHz high power FM video transmitters are used in this system. The calculation is similar to the first example, and Table 4 lists the results.

It is seen that for both examples the reliability is better than 99.95%. Thus, despite the negative impacts of increased propagation and equipment losses, reliable 18 GHz systems for CATV applications can be implemented. The developed 18 GHz AML equipment offers a viable solution of TV signal transmission for those areas where CARS band has already become overcrowded.

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