MULTI-CARRIER OPERATION OF SPACENET TRANSPONDERS FOR FM/TV APPLICATIONS

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ABSTRACT

System trade-offs for FM/TV multi-carrier operation for each of the three classes of SPACENET transponders (narrow C-Band, wide C-Band and Ku-Band) are examined. A variety of link configurations are constructed, assuming representative earth station characteristics (antenna diameter, HPA power, LNA temperature, etc.), to provide link performance estimates which satisfy a variety of user requirements. Results indicate that multi-carrier use of the SPACENET transponders may be a cost effective alternative to single-carrier use of two transponders.

INTRODUCTION

The objective of this paper is to present representative link performance characteristics (C/N, S/N) for dual-carrier-per-transponder use of SPACENET transponders. This is accomplished by examining each class of transponders for various uplink and downlink earth station configurations for a variety of user requirements.

In 1984, the Southern Pacific Satellite Company will be launching two communications satellites, SPACENET I and SPACENET II, into geostationary orbit at 119°W and 70°W, respectively. Launch of a third SPACENET satellite is planned for 1985.* These satellites will operate at both C-Band (4/6 GHz) and Ku-Band (12/14 GHz) and will provide video programming distribution capacity, as well as voice and data transmission services, to a variety of customers.

This capacity will be provided among three classes of transponders:

1. Narrow C-Band transponders (12 @ 36 MHz)
2. Wide C-Band transponders (6 @ 72 MHz)
3. Ku-Band transponders (6 @ 72 MHz)

The frequency and polarization plan for the SPACENET transponders is depicted in Figure 1.

Narrow C-Band Transponders

The narrow C-Band class of transponders is comprised of twelve operational and two spare RCA solid-state power amplifiers (SSPA's). Because of their inherent linearity, SSPA's may be operated near their single-carrier operating point for multiple-carrier applications without incurring harmful intermodulation interference or crosstalk.

Wide C-Band and Ku-Band Transponders

The SPACENET satellites will operate with six wide C-Band transponders and six Ku-Band transponders. Seven-for-six redundancy is provided for both of these classes of transponders. These transponders will utilize 16-watt TWTA's manufactured by Hughes Electron Dynamics Division. The 72-MHz of bandwidth available using these transponders provides ample spectrum for the transmission of two "full transponder" (i.e., FM deviation = 10.75 MHz) video signals without incurring harmful intermodulation and crossmodulation interference and using only a moderate level of input and output backoff.

SUMMARY OF RESULTS

The performance results for the various uplink and downlink earth station configurations considered in the link analyses are provided in Table 1. As shown, the clear weather video signal-to-noise ratio's for these configurations range from 41.7 dB (for "half-transponder" video using a SPACENET narrow C-Band transponder) to 50.7 and 53.7 dB (for "full-transponder" video using the SPACENET wide C-Band and Ku-Band transponders, respectively). For comparison, expected single-carrier performance using the SPACENET narrow C-Band transponders is provided.

The carrier-to-noise and signal-to-noise ratio's shown are expected to be exceeded for actual links, since the predicted adjacent-satellite interference levels incorporated into the calculation of link performance were based on worst case orbital spacing and geometric assumptions, discussed in the final section of this paper.

* On April 27, 1983, the FCC adopted a revised orbital deployment plan. This plan provides for SPACENET I deployment at 122°W, SPACENET II deployment at 69°W and SPACENET III deployment at 91°W.

For dual-carrier "half-transponder" video transmission using the narrow C-Band transponders, typical receive earth station antenna diameters on the order of 7-meters would be required to achieve video signal-to-noise ratios greater than 41 dB and threshold extension would be required.

Transmission of "full-transponder" video signals using the SPACENET wide C- and Ku-Band classes of transponders provide higher quality signals (video S/N = 49-51 dB) than the half-transponder signals available using narrow C-Band transponders and, in general, provide only slightly lower performance (3 dB) than for narrow C-Band single-carrier transmissions.

DESCRIPTION OF THE ANALYSIS

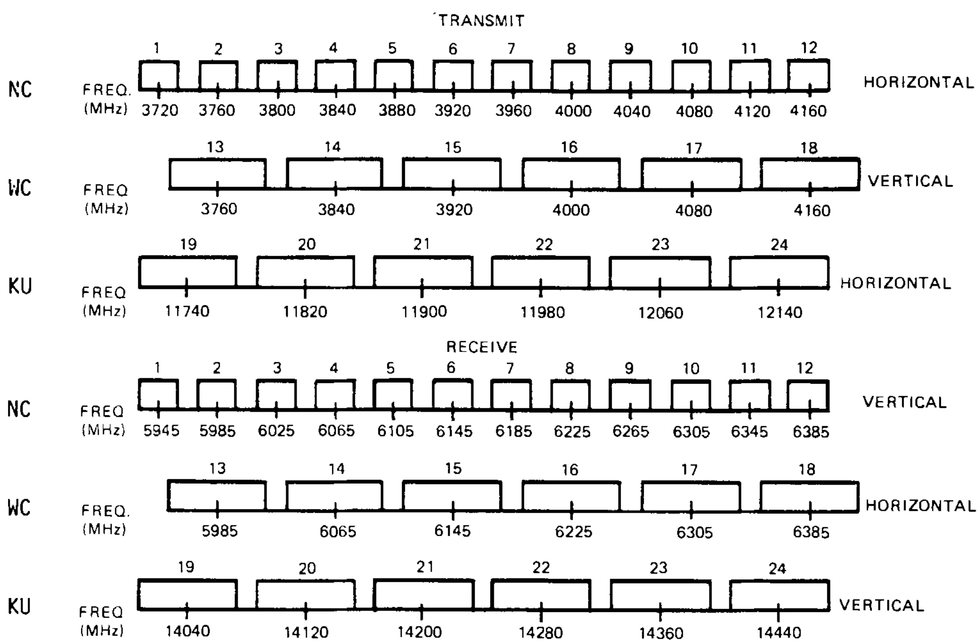
In this section, (1) a list of the basic assumptions used in the analysis is provided, (2) the assumed and calculated link performance parameters are identified, and (3) the analysis results for each class of transponder are discussed.

Basic Assumptions Used in the Analysis

The following assumptions are incorporated into the various link performance analyses:

- Video Peak Deviation: 10.75 MHz, for full-transponder video transmission and 6.7 MHz for half-transponder video transmission
- IF Bandwidth: 32.5 MHz, for full-transponder video transmission and 17.5 MHz for half-transponder video transmission
- Required Dual-Carrier Input Backoff: 1 dB assumed for narrow C-Band transponders and 2.0 dB for wide C-Band and Ku-Band transponders.
- Resultant Dual-Carrier Output Backoff: 1 dB for narrow C-Band transponders and 1.5 dB for wide C-Band and Ku-Band transponders

FIGURE 1. SPACENET FREQUENCY AND POLARIZATION PLAN



NC - Narrow C-Band
WC - Wide C-Band
KU - Ku-Band

TABLE 1

SUMMARY TABLE OF SPACENET SINGLE AND MULTI-CARRIER LINK RESULTS

EARTH STATION DIAMETER (m)		NARROW C-BAND CNR/SNR		WIDE C-BAND CNR/SNR	KU-BAND CNR/SNR
UPLINK	DOWNLINK	SINGLE	DUAL	DUAL	DUAL
10	10	16.2/53.8	12.6/43.4	13.1/50.7	--
10	7	14.6/52.2	10.9/41.7*	11.7/49.3*	--
7	7	14.6/52.2	10.9/41.7*	11.7/49.3*	--
7	5	12.4/50.0	--	9.8/47.3*	--
7.7	7.7	--	--	--	16.1/53.7*
5.5	5.5	--	--	--	14.5/52.1*

* Assumes use of threshold extension

Parameters Used or Derived in the Link Analyses

The following parameters of operation are used in calculating the link performance for the various earth station configurations:

° Uplink location
° Downlink location
° Saturation flux density (dBW/m^2)
° EIRP at saturation (dBW)
° EIRP/carrier (dBW)
° Required uplink high power amplifier (HPA) power (Watts)
° Uplink carrier-to-noise ratio (dB)
° Downlink carrier-to-noise ratio (dB)
° Link carrier-to-noise ratio (dB)
° Link margin above threshold (dB)
° Video signal-to-noise ratio (dB)

Each of these items is discussed below.

Uplink Location - Three uplink earth station locations are considered:

A. New York, NY
B. Houston, TX
C. Los Angeles, CA

Representative uplink earth stations at these locations are assumed to be accessing a SPACENET satellite at 119°W.

Downlink Location - The three downlink earth station locations considered are:

A. New York, NY
B. Houston, TX
C. Los Angeles, CA

Representative downlink earth stations at these locations are assumed to be accessing a SPACENET satellite at 119°W.

Saturation Flux Density - This parameter identifies the expected required flux density for transponder saturation from an earth station at each of the various uplink locations.

For each of the C-Band transponders, the nominal power flux levels required at the satellite to achieve transponder saturation are ground commandable to -80 dBW/m^2 or -86 dBW/m^2. These levels correspond to narrow C-Band transponder G/T levels of -5 dB/K and wide C-Band transponder G/T levels of -2 dB/K. For each of the Ku-Band transponders, the nominal levels required are ground commandable to -74 dBW/m^2, -80 dBW/m^2, or -86 dBW/m^2. These levels correspond Ku-Band spacecraft G/T levels of -2 dB/K.

Nominal SPACENET satellite G/T contour levels are depicted in Figure 2.

EIRP at Saturation - This parameter identifies the expected spacecraft downlink EIRP at saturation for each of the downlink earth station locations considered. Nominal SPACENET satellite EIRP contour levels are depicted in Figure 3.

EIRP/Carrier - This parameter identifies the power-shared EIRP-per-video-carrier and also incorporates any resultant output backoff required to preclude harmful intermodulation interference.

Required HPA Power - This parameter depicts the high power amplifier power required to satisfy the saturation flux density requirements (including input backoff) and provide a sufficient uplink carrier-to-noise ratio. The equation and corresponding assumptions used to calculate this parameter are described in detail in the Appendix.

FIGURE 2. SATELLITE G/T CONTOURS FOR THREE CLASSES OF SPACENET TRANSPONDERS

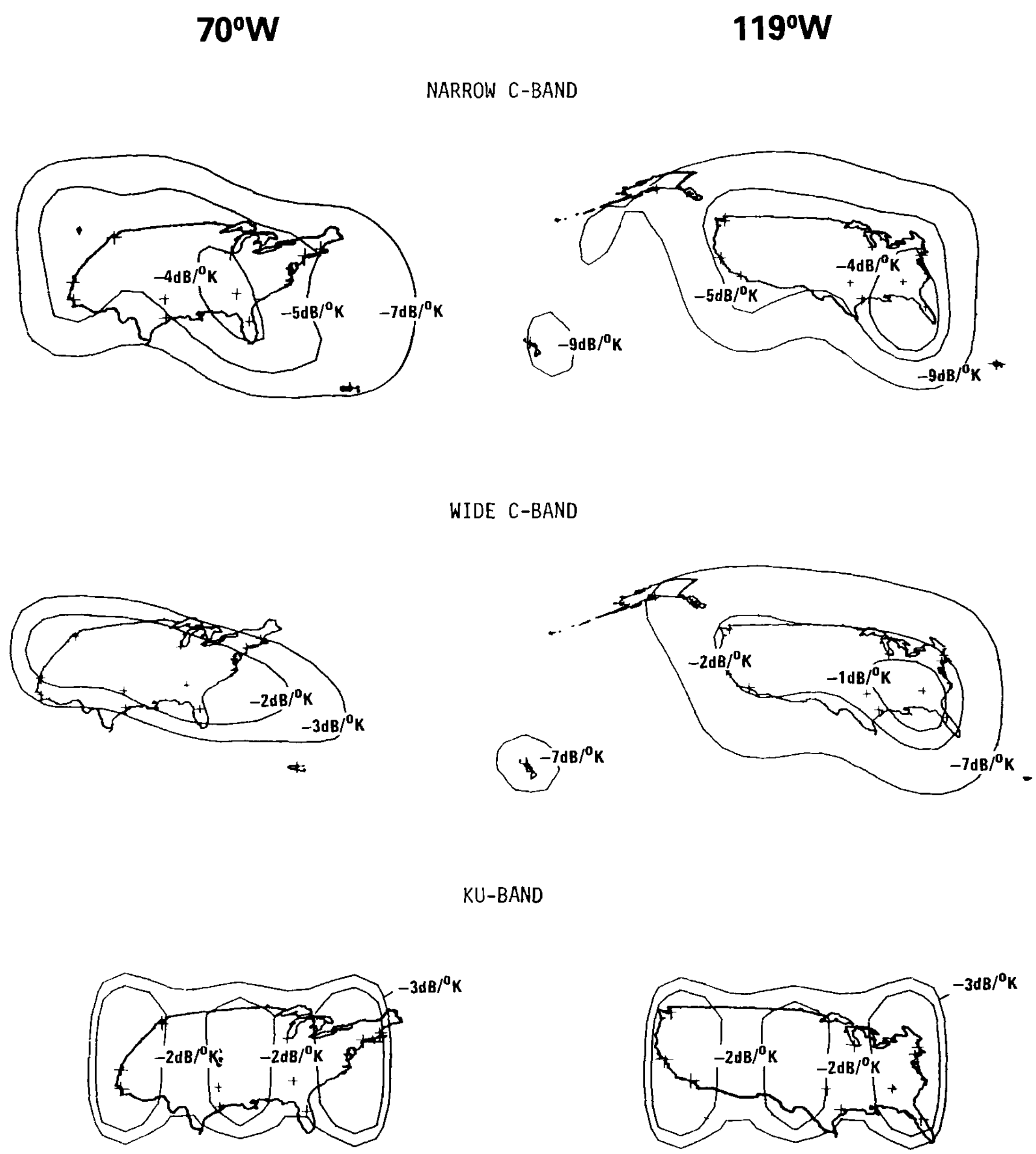
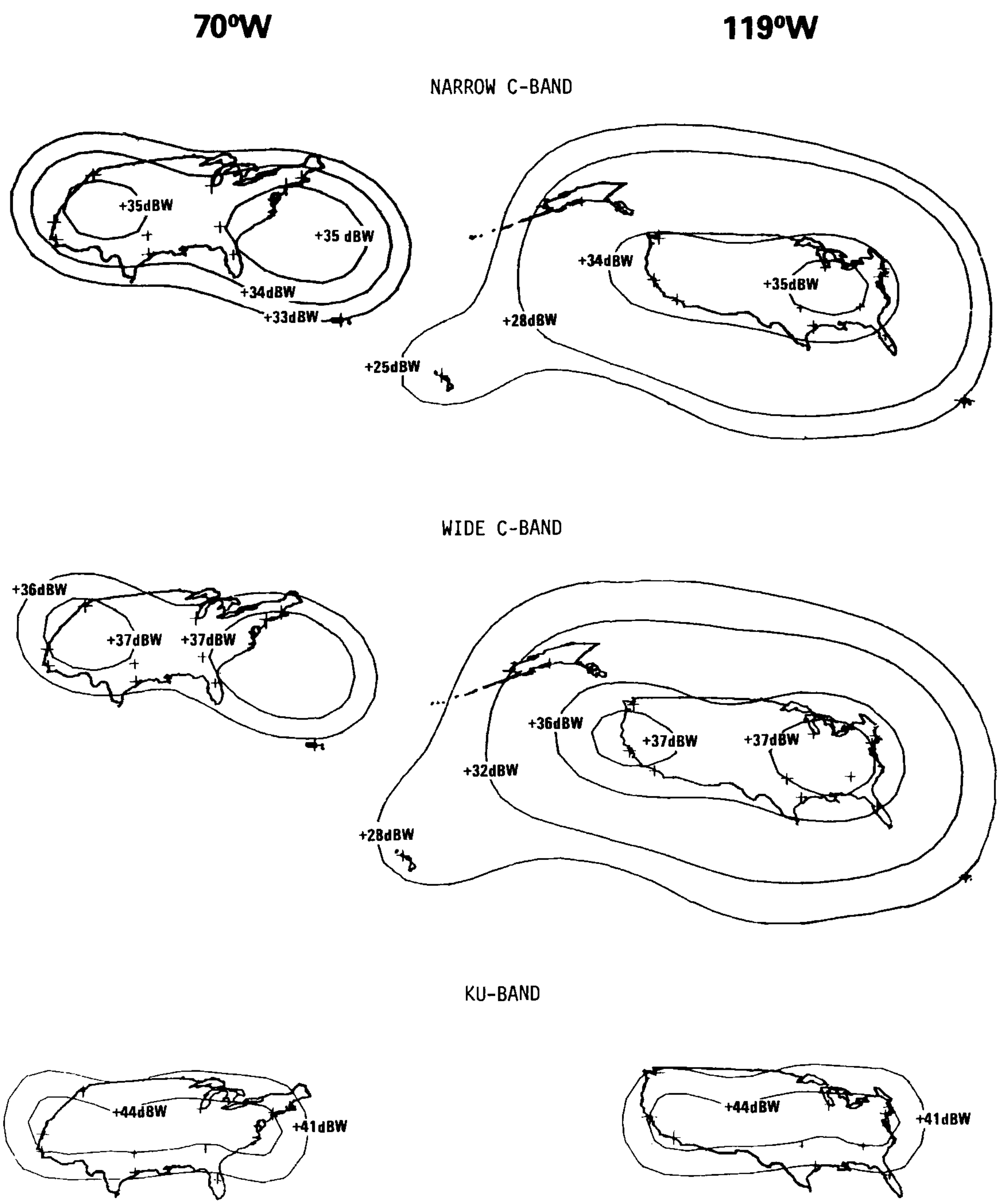


FIGURE 3. SATELLITE EIRP CONTOURS FOR THREE CLASSES OF SPACENET TRANSPONDERS



Uplink Carrier-to-Noise Ratio - This uplink performance characteristic is calculated based upon the earth station EIRP (per carrier), transmission losses, and satellite G/T (which is referenced to the required saturation flux density, described previously). The equation and assumptions used for its calculation are provided in the Appendix.

Downlink Carrier-to-Noise Ratio - This downlink performance characteristic is calculated based upon the spacecraft EIRP (per carrier), transmission losses, and earth station G/T. The equation and assumptions used for its calculation are provided in the Appendix.

Link Carrier-to-Noise Ratio - This performance characteristic is calculated from the power summation of the uplink carrier-to-noise ratio, the downlink carrier-to-noise ratio and all interference contributions. The equations and assumptions used for its calculation are further detailed in the Appendix.

Link Margin Above Threshold - This value was calculated by subtracting the FM threshold carrier-to-noise ratio from the calculated link carrier-to-noise ratio described above. Normally, a 12-dB carrier-to-noise FM threshold was assumed. For certain link configurations, threshold extension was assumed. For these cases, the margin was calculated based on a threshold carrier-to-noise ratio of 8 dB.

Video Signal-to-Noise Ratio - This performance parameter was calculated based upon the calculated link carrier-to-noise ratio (described above) and the FM deviation that was assumed. The equation and assumptions used in its calculation are detailed in the Appendix.

Narrow C-Band Transponder Analysis

Table 2 lists representative performance characteristics for three transmit/receive (T/R) C-Band earth stations. The characteristics of these earth stations are used in the examination of FM/TV link performance for both the narrow C-Band and wide C-Band classes of transponders.

Single-Carrier Case - For reference, a single-carrier FM/TV link configuration is considered for the narrow C-Band transponder link analysis. The link consists of a 7-meter uplink earth station and a 5-meter downlink earth station. The link performance results for this configuration are depicted in Table 3. As shown, HPA powers from 1175-1300 watts are required, providing an uplink carrier-to-noise ratio of 25.3 dB. The resultant total carrier-to-noise ratio is 12.4 dB, providing a clear weather video S/N of 50.0 dB. Use of the 7-meter receive earth station characterized in Table 2 will increase the $(C/N)_t$ to 14.6 dB and provide a "studio quality" video S/N of 52.2 dB.

TABLE 2

C-BAND EARTH STATION CHARACTERISTICS

Earth Station Diameter/ Type	Antenna Gain (dBi)	LNA Temp. (K)	Station G/T (dB/K) (@ 20° elev. & clear)
10-meter T/R	50.85 @ 3.95 GHz	100	29.4
	53.5 @ 6.175 GHz	-	-
7-meter T/R	47.5 @ 3.95 GHz	80	26.9
	49.4 @ 6.175 GHz	-	-
5-meter T/R	44.5 @ 3.95 GHz	80	24.0
	47.3 @ 6.175 GHz	-	-

TABLE 3

SINGLE-CARRIER NARROW C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/5-m. DOWNLINK EARTH STATION.

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
NY	Houston	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
NY	LA	-86.6	34.4	34.4	1175	25.3	14.6	12.4	0.4	50.0
Houston	NY	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
Houston	Houston	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
Houston	LA	-86.5	34.4	34.4	1200	25.3	14.6	12.4	0.4	50.0
LA	NY	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0
LA	Houston	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0
LA	LA	-86.2	34.4	34.4	1300	25.3	14.6	12.4	0.4	50.0

SATELLITE @ 119°W

Dual Carrier Case - For the dual-carrier narrow C-Band case, two link configurations are considered: a 10-meter transmit earth station to a 10-meter receive earth station link and a 7-meter transmit earth station to a 7-meter receive earth station link.

Table 4 depicts the link performance parameters for the first configuration -- a 10-meter uplink earth station and a 10-meter downlink earth station. For this configuration, HPA powers of 375-400 watts are required. The resultant clear weather total carrier-to-noise and video signal-to-noise ratio levels are 12.6 dB and 43.4 dB, respectively.

For the second configuration, depicted in Table 5, 7-meter uplink and downlink earth stations are assumed. For this example, higher uplink HPA powers are required (950-1025 watts). A $(C/N)_t$ of 10.9 dB results and threshold extension (down to 8.0 dB) provides a 2.9 dB margin above threshold. The corresponding video S/N (clear), however, is only 41.7 dB, which may only be acceptable for certain applications.

For both configurations above, the substantially lower S/N levels (in comparison with the single-carrier narrowband case) are a result of the combined effects of power sharing, input backoff and reduced FM improvement (a result of the reduced deviation which must be employed to meet RF bandwidth constraints). The link margin values may be increased through the employment of threshold extension.

TABLE 4

DUAL-CARRIER NARROW C-BAND LINK PERFORMANCE: 10-m. UPLINK EARTH STATION/10-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
NY	Houston	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
NY	LA	-86.6	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	NY	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	Houston	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
Houston	LA	-86.5	34.4	30.4	375	21.3	16.0	12.6	0.6	43.4
LA	NY	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4
LA	Houston	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4
LA	LA	-86.2	34.4	30.4	400	21.3	16.0	12.6	0.6	43.4

SATELLITE @ 119°W

TABLE 5

DUAL-CARRIER NARROW C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/7-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK * MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
NY	Houston	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
NY	LA	-86.6	34.4	30.4	950	21.3	13.5	10.9	2.9	41.7
Houston	NY	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
Houston	Houston	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
Houston	LA	-86.5	34.4	30.4	975	21.3	13.5	10.9	2.9	41.7
LA	NY	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7
LA	Houston	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7
LA	LA	-86.2	34.4	30.4	1025	21.3	13.5	10.9	2.9	41.7

SATELLITE @ 119°W

* Assumes threshold extension to permit operation at $(C/N)t \geq 8$ dB

Wide C-Band Transponder Analysis

For the dual-carrier wide C-Band analysis, three configurations are examined, based on the earth station characteristics previously-listed in Table 2.

- ° 10-meter uplink e.s./10-meter downlink e.s.
- ° 7-meter uplink e.s./7-meter downlink e.s.
- ° 7-meter uplink e.s./5-meter downlink e.s.

For all three configurations above, transponder input and output backoff levels of 2 dB and 1.5 dB, respectively, are assumed to maintain an acceptable level of carrier-to-intermodulation interference.

Table 6 depicts the link performance results for the first configuration, a 10-meter uplink earth station and a 10-meter downlink earth station. This configuration provides a clear weather $(C/N)_t$ of 13.1 dB and a video S/N of 50.7 dB. HPA powers on the order of 300-350 watts are required.

Table 7 depicts link performance for the second configuration, a 7-meter uplink earth station and a 7-meter downlink earth station. The resulting required HPA powers range from 750-875 watts. Threshold extension is assumed, and the resultant clear weather $(C/N)_t$ and video S/N are 11.7 dB and 52.0 dB, respectively, for all links examined.

The third configuration is that of a 7-meter uplink earth station and a 5-meter downlink earth station. The link performance predictions for this configuration are shown in Table 8. Threshold extension is assumed and a $(C/N)_t$ of 9.7 dB is predicted, with a corresponding S/N of 47.3 dB.

Ku-Band Transponder Analysis

Table 9 lists representative earth station performance characteristics for two T/R Ku-Band earth stations that are presently manufactured.

TABLE 6

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 10-m UPLINK EARTH STATION/10-m DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
NY	Houston	-86.0	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
NY	LA	-86.0	36.4	31.8	350	23.3	17.4	13.1	1.1	50.7
Houston	NY	-86.6	36.4	31.9	300	23.3	17.5	13.1	1.1	50.7
Houston	Houston	-86.6	36.4	31.9	300	23.3	17.5	13.1	1.1	50.7
Houston	LA	-86.6	36.3	31.8	300	23.3	17.4	13.1	1.1	50.7
LA	NY	-85.9	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
LA	Houston	-85.9	36.4	31.9	350	23.3	17.5	13.1	1.1	50.7
LA	LA	-85.9	36.3	31.8	350	23.3	17.4	13.1	1.1	50.7

SATELLITE @ 119°W

TABLE 7

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 7-m UPLINK EARTH STATION/7-m DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK* MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	850	23.3	15.0	11.7	3.7	49.3
NY	Houston	-86.0	36.4	31.9	850	23.3	15.0	11.7	3.7	49.3
NY	LA	-86.0	36.3	31.8	850	23.3	14.9	11.7	3.7	49.3
Houston	NY	-86.6	36.4	31.9	750	23.3	15.0	11.7	3.7	49.3
Houston	Houston	-86.6	36.4	31.9	750	23.3	15.0	11.7	3.7	49.3
Houston	LA	-86.6	36.3	31.8	750	23.3	14.9	11.7	3.7	49.3
LA	NY	-85.9	36.4	31.9	875	23.3	15.0	11.7	3.7	49.3
LA	Houston	-85.9	36.4	31.9	875	23.3	15.0	11.7	3.7	49.3
LA	LA	-85.9	36.3	31.8	875	23.3	14.9	11.7	3.7	49.3

* Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

SATELLITE @ 119°W

TABLE 8

DUAL-CARRIER WIDE C-BAND LINK PERFORMANCE: 7-m. UPLINK EARTH STATION/5-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK * MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-86.0	36.4	31.9	850	23.3	12.1	9.7	1.7	47.3
NY	Houston	-86.0	36.4	31.9	850	23.3	12.1	9.7	1.7	47.3
NY	LA	-86.0	36.3	31.8	850	23.3	12.0	9.7	1.7	47.3
Houston	NY	-86.6	36.4	31.9	750	23.3	12.1	9.7	1.7	47.3
Houston	Houston	-86.6	36.4	31.9	750	23.3	12.1	9.7	1.7	47.3
Houston	LA	-86.6	36.3	31.8	750	23.3	12.0	9.7	1.7	47.3
LA	NY	-85.9	36.4	31.9	875	23.3	12.1	9.7	1.7	47.3
LA	Houston	-85.9	36.4	31.9	875	23.3	12.1	9.7	1.7	47.3
LA	LA	-85.9	36.3	31.8	875	23.3	12.0	9.7	1.7	47.3

SATELLITE @ 119°W

* Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

TABLE 9

KU-BAND EARTH STATION CHARACTERISTICS

EARTH STATION DIAMETER/TYPE	ANTENNA GAIN (dBi)	LNA TEMPERATURE (K)	STATION G/T (dB/K) (@ 20° ELEV. & CLEAR)
7.7-meter T/R	57.9 @ 11.95 GHz	180	33.8
	59.2 @ 14.25 GHz	-	-
5.5-meter T/R	55.0 @ 11.95 GHz	180	30.9
	56.3 @ 14.25 GHZ	-	-

To provide a sufficient uplink carrier-to-noise ratio, 6-dB transponder input gain attenuation is assumed for all configurations examined for the Ku-Band class of transponders. Threshold extension is also assumed for all cases to provide sufficient fade margin.

For the dual-carrier Ku-Band analysis, the following configurations are examined:

- 7.7-meter uplink e.s./7.7-meter downlink e.s.
- 5.5-meter uplink e.s./5.5-meter downlink e.s.

For the first configuration above, the link performance parameters and results are depicted in Table 10. Required HPA powers range from 300-450 watts and provide uplink carrier-to-noise ratios of 22.0 dB. For New York and Los Angeles downlinks, a clear weather $(C/N)_t$ of 16.1 dB results along with a video S/N of 53.7 dB. For a Houston downlink, a clear weather $(C/N)_t$ of 14.2 dB is provided along with a video S/N of 51.8 dB.

Link performance predictions for the second configuration, a 5.5-meter uplink earth station and a 5.5-meter downlink earth station, are depicted in Table 11. To provide equivalent uplink performance as a 7.7-meter uplink earth station, HPA powers from 575-875 watts are required. Overall link margins are not high as for the first configuration, however. Clear weather video S/N's of 52.1 dB are predicted for New York and Los Angeles, while an S/N S/N (clear) of 49.8 dB is predicted at Houston.

TABLE 10

DUAL-CARRIER KU-BAND LINK PERFORMANCE: 7.7-m. UPLINK EARTH STATION/7.7-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION [1] FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK [2] MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-81.0	44.0	39.5	300	22.0	20.0	16.1	8.1	53.7
NY	Houston	-81.0	40.4	35.9	300	22.0	16.4	14.2	6.2	51.8
NY	LA	-81.0	44.0	39.5	300	22.0	20.0	16.1	8.1	53.7
Houston	NY	-79.2	44.0	39.5	450	22.0	20.0	16.1	8.1	53.7
Houston	Houston	-79.2	40.4	35.9	450	22.0	16.4	14.2	6.2	51.8
Houston	LA	-79.2	44.0	39.5	450	22.0	20.0	16.1	8.1	53.7
LA	NY	-79.6	44.0	39.5	425	22.0	20.0	16.1	8.1	53.7
LA	Houston	-79.6	40.4	35.9	425	22.0	16.4	14.2	6.2	51.8
LA	LA	-79.6	44.0	39.5	425	22.0	20.0	16.1	8.1	53.7

SATELLITE @ 119°W

1 6-dB transponder input gain attenuation employed
2 Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

TABLE 11

DUAL-CARRIER KU-BAND LINK PERFORMANCE: 5.5-m. UPLINK EARTH STATION/5.5-m. DOWNLINK EARTH STATION

UPLINK LOCATION	DOWNLINK LOCATION	SATURATION [1] FLUX DENSITY (dBW/m^2)	SATURATED EIRP (dBW)	EIRP/ CARRIER (dBW)	HPA POWER REQUIRED (Watts)	$(C/N)_u$	$(C/N)_d$	$(C/N)_t$	LINK [2] MARGIN (dB)	VIDEO S/N (dB) (CLEAR)
NY	NY	-81.0	44.0	39.5	575	22.0	17.1	14.5	6.5	52.1
NY	Houston	-81.0	40.4	35.9	575	22.0	13.5	12.2	4.2	49.8
NY	LA	-81.0	44.0	39.5	575	22.0	17.1	14.5	6.5	52.1
Houston	NY	-79.2	44.0	39.5	875	22.0	17.1	14.5	6.5	52.1
Houston	Houston	-79.2	40.4	35.9	875	22.0	13.5	12.2	4.2	49.8
Houston	LA	-79.2	44.0	39.5	875	22.0	17.1	14.5	6.5	52.1
LA	NY	-79.6	44.0	39.5	800	22.0	17.1	14.5	6.5	52.1
LA	Houston	-79.6	40.4	35.9	800	22.0	13.5	12.2	4.2	49.8
LA	LA	-79.6	44.0	39.5	800	22.0	17.1	14.5	6.5	52.1

1 6-dB transponder input gain attenuation employed.
2 Assumes threshold extension to permit operation at $(C/N)_t \geq 8$ dB.

SATELLITE @ 119°W

OTHER CONSIDERATIONS

Adjacent-Satellite Interference Levels

For the consideration of adjacent-satellite interference, two satellites are assumed to be located 2° on either side of the SPACENET satellite. These "worst-case" adjacent satellite interference levels are based on interference signals that are assumed to be co-frequency and co-polarized to the SPACENET signals. In addition, geocentric angles were assumed in the calculation of off-axis earth station antenna gain. As a result, actual link performance will exceed the pessimistic values shown in the tables.

Downlink Rain Fade Effects and Link Availability at Ku-Band

The effect of uplink fading on the downlink is basically a function of the point of operation on the transponder power transfer characteristic curve (specifically, the increase or decrease in downlink power due to variation in received uplink power levels). Uplink fading can be controlled to a significant extent by monitoring the received downlink power levels at the uplink location and compensating for rain attenuation by increasing the uplink power.

Table 14 depicts the attenuation due to down link rain fading that is not predicted to be exceeded for the availabilities shown. These predictions are based on Rice-Holmberg rain statistics and Olsen rain attenuation parameters.[1,2] The reader is referred to References 4 and 5 for a detailed description of their derivation. Basically, the statistical model by Rice and Holmberg calculates the percentage of an average year for which the rainfall rate exceeds a give rain rate R, based on the average annual rainfall and relative percentage of annual rain produced by thunderstorms for a particular geographic location.

TABLE 12

KU-BAND DOWNLINK RAIN ATTENUATION, IN dB

DOWNLINK LOCATION	AVAILABILITY (%) 99.9	99.8	99.7	99.5
New York	3.3	2.3	1.9	1.3
Houston	5.4	2.4	1.6	0.9
Los Angeles	1.2	0.7	0.5	0.3

SATELLITE @ 119°W

Sufficient link margin is required to accommodate the values shown in Table 14 for a particular desired availability as well as the additional margin required to accommodate the effective increase in the receive earth station system noise temperature as a function of rain fading.

ALTERNATIVES FOR MULTI-CARRIER USE OF THE SPACENET TRANSPONDERS

In addition to the straight-forward approach which has been addressed in this paper for the transmission of multi-carrier FM/TV signals on the SPACENET transponders, other approaches should be considered. In some cases, alternative approaches could effectively double the signal capacity that could be provided by a single narrow- or wide-band SPACENET transponder.

Encoding systems have been manufactured (Thomson-CSF, CBS) which time multiplex the odd and even fields of two synchronous video signals. At the receive end, the two "half-pictures" are digitized and each of the 262.5 lines of the half-picture is averaged with the next to produce an additional 262.5 lines to complement the transmitted information and produce 525-line video for each signal.

In addition to the above, a "time-frequency multiplexing" (TFM) technique has been developed[3] which may be used to transmit two high-quality NTSC signals in a 36-MHz transponder. Theoretically this would provide for the transmission of four good-quality signals in a wide C-Band or Ku-Band SPACENET transponder.

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1 Rice, P. L. and Holmberg, N. R., "Cumulative Time Statistics of Surface-Point Rainfall Rates," IEEE Transactions on Communications, October, 1973.

2 Olsen, R. L., et al, "The aR^b Relation in the Calculation of Rain Attenuation, "IEEE Transactions on Propagation, March 1978.

3 Schmidt, R. L. and Haskell, B. G., "Transmission of Two NTSC Color Television Signals Over a Single Satellite Transponder via Time-Frequency Multiplexing," GLOBECOM 1982, November 30 - December 2, 1982.

APPENDIX

EQUATIONS USED IN THE ANALYSIS

The following equations were used in the examination of SPACENET transponders for single and multi-carrier FM/TV carrier applications:

1. Required earth station HPA power calculation.

2. Link performance equations.

   A. $(C/N)_u$
   B $(C/N)_d$
   C $(C/N)_t$
   D. $(S/N)_v$

REQUIRED EARTH STATION HPA POWER CALCULATION

The required earth station HPA power to satisfy specified operational performance may be determined from the following equation:

$$P_{HPA} = SFD_{s/c} - IBO + A_{iso} + L_s + L_a + L_{pt} - G_t + L_{tl} \quad (1)$$

where

P_{HPA} = the required HPA power, in dBW.

$SFD_{s/c}$ = the spacecraft saturation flux density, in dB/K.

IBO = the required transponder input backoff to maintain an intermodulation carrier-to-interference ratio between 20-25 dB:

IBO = 0 dB (for single-carrier narrow C-Band operation)

1 dB (for dual-carrier narrow C-Band operation), and

2 dB (for dual-carrier wide C-Band or Ku-Band operation)

A_{iso} = the effective area of an isotropic antenna aperture; -37.2 $dB\text{-}m^2$ @ 6.175 GHz and -44.5 $dB\text{-}m^2$ @ 14.25 GHz.

L_s = free-space loss in dB; a function of wavelength and earth station slant range to satellite (i.e., $L_s = 20 \log 4\pi R/\lambda$).

L_a = atmospheric absorption loss; 0.2 dB @ C-Band and 0.4 dB @ Ku-Band.

L_{pt} = pointing loss in dB; a function of frequency, satellite drift, and earth station diameter (0.5 dB assumed for both C- and Ku-Band).

G_t = earth station mainbeam gain in dBi

L_{tl} = transmission line loss between HPA and antenna feed input, in dB (3.0 dB assumed for both C- and Ku-Band).

LINK PERFORMANCE EQUATIONS

Uplink Carrier-to-Noise Ratio

The uplink carrier-to-noise ratio, $(C/N)_u$, may be expressed by the following equation:

$$(C/N)_u = SFD_{s/c} - IBO + A_{iso} + (G/T)_s - 10 \log k - 10 \log B - L_{ps} \quad (2)$$

where

$SFD_{s/c}$ = the spacecraft saturation flux density, in dB/K.

IBO = the required transponder input backoff to maintain an intermodulation carrier-to-interference ratio between 20-25 dB;

IBO = 0 dB (for single-carrier narrow C-Band operation),

1 dB (for dual-carrier narrow C-Band operation), and

2 dB (for dual-carrier wide C-Band or Ku-Band operation)

A_{iso} = the effective area of an isotropic antenna aperture in $dB\text{-}m^2$; A_{iso} = -37.2 $dB\text{-}m^2$ @ 6.175 GHz and -44.5 $dB\text{-}m^2$ @ 14.25 GHz

$(G/T)_s$ = the spacecraft receive system figure-of-merit, in dB/K

k = Boltzmann's constant, in j/K

B = transmission bandwidth (17.5 MHz for dual-carrier narrow C-Band operation; and 32.5 MHz for single-carrier narrow C-Band, dual-carrier wide C-Band, and dual-carrier Ku-Band applications).

L_{ps} = power-sharing loss (0 dB for single-carrier applications, 3 dB for dual-carrier applications).

Downlink Carrier-to-Noise Ratio

The downlink carrier-to-noise ratio, $(C/N)_d$, may be calculated from the following equation:

$$(C/N)_d = EIRP_{S/C} - OBO - L_s - L_a - L_{pt} + (G/T)_{es} - 10 \log k - 10 \log B - L_{ps} \quad (3)$$

where

$EIRP_{S/C}$ = the spacecraft saturated EIRP, in dBW.

OBO = the resultant transponder output backoff in dB, a function of the transponder input backoff (IBO); for a narrow C-Band IBO of 1 dB, OBO = 1 dB; for a wide C-Band or Ku-Band IBO of 2 dB, OBO = 1.5 dB.

L_s = free-space loss, in dB

L_a = atmospheric absorption, in dB (0.2 dB at C-Band and 0.4 dB at Ku-Band).

L_{pt} = pointing loss, in dB (0.5 dB assumed for C-Band and Ku-Band)

$(G/T)_{es}$ = earth station receive system figure-of-merit, in dB/K.

Carrier-to-Adjacent-Satellite Interference Ratio

The carrier-to-adjacent-satellite interference ratio, $(C/I)_{as}$, for a wanted satellite from a single adjacent-satellite, assuming a co-frequency, co-polarized, similar interfering signal may be calculated from the following equation:

$$(C/I)_{as} = [(SFD)_w - (SFD)_i + \Delta G_u] \oplus [EIRP_w - EIRP_i + \Delta G_d] \quad (4)$$

where

SFD_w = the power flux density of the wanted signal, in dBW/m^2

SFD_i = the power flux density of the interfering signal, in dBW/m^2

ΔG_u = the off-axis discrimination of the uplink interfering earth station in the direction of the victim (wanted) satellite, in dB (calculation of this parameter is based on a 7-meter uplink interfering earth station at C-Band and a 5.5-meter uplink interfering earth station at Ku-Band; a 29-25 log Θ antenna sidelobe pattern is assumed).

$\oplus$ = power summation calculation

$EIRP_W$ = EIRP of the wanted satellite; in dBW

$EIRP_i$ = EIRP of the interfering satellite, in dBW

ΔG_d = the off-axis discrimination of the wanted satellite downlink earth station, in dB (29-25 log Θ antenna sidelobe pattern is assumed).

Link Carrier-to-Noise Ratio

The link, or total, carrier-to-noise ratio, $(C/N)_t$, is calculated from the following equation:

$$(C/N)_t = (C/N)_u \oplus (C/N)_d \oplus (C/I)_{as} \oplus (C/I)_{terr} \oplus (C/I)_{xpol} \oplus (C/I)_{im} \quad (5)$$

where

$(C/I)_{as}$ = carrier-to-adjacent-satellite interference ratio, in dB

$(C/I)_{terr}$ = carrier-to-terrestrial interference, in dB (25 dB assumed at C-Band; not applicable for Ku-Band)

$(C/I)_{xpol}$ = carrier-to-cross-polarized channel interference ratio, in dB (26 dB assumed)

$(C/I)_{im}$ = carrier-to-intermodulation interference ratio, in dB (26 for dual-carrier narrow C-Band transponders; 22 dB for dual-carrier wide C-Band and Ku-Band transponders)

$\oplus$ = power summation, i.e., $(n/c)_t = (n/c)_u + (n/c)_d + (i/c)_{as} + (i/c)_{terr} + (i/c)_{xpol} + (i/c)_{im}$

Video Signal-to-Noise Ratio

The peak-to-peak luminance signal-to-noise ratio, $(S/N)_v$, may be expressed by the following equation:

$$(S/N)_v = (C/N)_t + 10 \log 3(f_d/f_m)^2 + 10 \log (B_{if}/2B_v) + W + CF \quad (6)$$

where

f_d = peak composite video deviation, in MHz (6.7 MHz for dual-carrier narrow C-Band operation, 10.75 MHz for dual-carrier wide C-Band and Ku-Band applications)

f_m = highest baseband frequency, in MHz (4.2 MHz)

B_{if} = IF noise bandwidth, in MHz (32.5 or 17.5 MHz)

B_v = video noise bandwidth, in MHz (4.2 MHz)

W = emphasis plus weighting improvement factor (12.8 dB)

CF = rms to peak-to-peak luminance signal conversion factor (6.0 dB)