DIGITAL SATELLITE COMMUNICATIONS - SYSTEMS, COMPONENTS, AND LIMITATIONS

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ABSTRACT

Digital satellite communications is conducted in a bandwidth and power limited system of noise contributors, filters, nonlinear amplifiers, and adjacent channel interference. This paper will discuss the overall system architecture, identifying all types of filters, amplifiers, and modulation techniques in a system involving a transmitting earth terminal and up-link, a satellite transponder, and a down-link and receiving earth terminal which includes the receivers. The parameters relating to overall link performance will be discussed for a wide variety of modulation techniques and for various bandwidth efficiencies.

Introduction

The satellite communications link differs from the terrestrial radio communications link in that the satellite communications link is power-limited and bandwidth-limited. In this link, the system must be configured to maintain the minimal link margin for required bit error rate in a system of noise contributors, filters, and nonlinear amplifiers which can, in aggregate, produce signal to noise ratio degradation at the receiver which can render the link inoperative. This paper considers the wide variety of digital communication systems being used or considered for use in satellite communications today. The number of parameters which influence the total link from transmitting earth terminal to the satellite transponder, to the receiving ground terminal include the following: (1) the choice of modulation technique; i.e., BPSK, QPSK, SQPSK, MFSK, and PASK; (2) the bandwidth limiting employed for systems such as the MARISAT and projected SBS system with approximately one bit per Hertz, to the INTELSAT V 72-MHz channel, which will handle 120 Mbps with almost 2 bits per Hertz, to systems using 2.5 and 3 bits per Hertz; (3) the number of nonlinear elements employed, including the transmitting earth terminal HPA, the satellite TWTA, and the nonlinear elements in the receiver; and (4) the types of filters employed, including the type of data filter and bandpass filter employed in the transmitter to the pre-TWT and post-TWT filters employed in the transponder, to the IF bandpass filters and matched filters used in the receiving earth terminal receiver.

Digital Satellite Communications

Historically, satellite communications has used FDM/FM techniques to provide point to point communications for both voice communications and television transmission. However, the use of digital techniques in signal transmission has grown slowly from the introduction of the SCPC SPADE system several years ago by INTELSAT, and the transmission of an increasing amount of digitized voice, television, and data, and today, digital satellite communications has come of age with the use of TDMA by TELESAT, the approval of Comsat's DIGISAT (combined low) medium/high speed digital communications by the FCC for the Atlantic Ocean region, the transmission of newsprint and electronic mail via WESTAR and SATCOM, the plans of both Satellite Business Systems (SBS) and Western Union to provide high speed digital data services via the SBS and TDRSS satellites now in construction, and the testing of 100 Mbps digital systems in Japan through the Japanese Communication Satellite (CS) launched in December 1977. Soon the European Space Agency will conduct digital transmission tests via the Orbiting Test Satellite (OTS) due to fly in 1978, INTELSAT will conduct field trials for TDMA in the Atlantic hemisphere, and digital satellite communications will become a world-wide communications medium.

Digital satellite communications differs from terrestrial digital radio in that it is essentially a power-limited point-to-point system, operating with narrow margins of link operation due to the large space loss of over a 22,000 mile path, around 200 dB between the earth terminal and satellite and the limitations in both satellite sensitivity and radiated power, and earth terminal sensitivity. The terrestrial radio system on the other hand, can space repeaters close together for repeater distances from a few kilometers typical of K-band digital radio to as far as 50 kilometers for microwave digital radio and must cope with unique problems of distance, terrain, right of way, interference, and weather.

The Digital Satellite Communications Link

The communications satellite link is a multichannel set of communication paths consisting of, as shown in Fig. 1, a transmitting earth terminal, an up-link, and a receiving earth terminal. Each transmitting earth terminal includes a modulator, a high power amplifier, and an antenna, which provide the modulated radiated power into the up-link. The communication satellite receives this radiated power which has traversed a space loss in the 200 dB range depending on the frequency, uses its receiver sensitivity or G/T to provide the modulated carrier into the proper channel in which it is amplified and propagated into the down-link to the receiving earth terminal. The earth terminal G/T (where G is the antenna gain and T is the system noise temperature) is designed to apply the modulated carrier to the receiver and demodulator with a signal to noise ratio consistent with the link margin and the final signal bit error rate. As shown in Fig. 1, many types of digitally-modulated carriers (QPSK, TDMA, etc.) can occupy channels adjacent to an FDM analog-modulated carrier. The bandwidths of the various channels of various satellites vary from the 36 MHz which has been a virtual standard for satellites such as ANIK, INTELSAT IVA, WESTAR and COMSTAR, to 72 MHz for INTELSAT V and 80 MHz for Symphonie, to 120 MHz for the European OTS, to 240 MHz for TDRSS and to 11/14 GHz channels in INTELSAT V. In the transmission of digital data through these channels, various users program the maximum data rates consistent with user requirements and link margin. It is planned to pass, for example, 120 Mbps TDMA carriers using QPSK through INTELSAT V, and Table 1 describes the operation of a typical INTELSAT V link for this mode of operation, showing an overall link margin of 4.3 dB at C-band for a 10^{-5} bit error rate.

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TABLE 1

LINK ANALYSIS FOR 120 Mbps QPSK THRU 72 MHz CHANNELS

UP-LINK (6.22 GHz, 29.9 M DIAM. 10. DEG EV.)
DOWN-LINK (4.00 GHz, 29.9 M DIAM. 10. DEG EV.)

Transmitting Station	**Antenna Diam. 29.9 Meter**
a) Up-Link Frequency	6.22 GHz
b) Transmitter RF Output	30.0 dBw
c) Line and Filter Loss	0 dB
d) Antenna Gain	63.2 dB
e) Pointing Loss	0 dB
f) Polarization Mismatch	0 dB
Path Losses	
a) Space Attenuation	-201.4 dB
b) Atmospheric Attenuation	0 dB
c) Rainfall Attenuation	0 dB
d) Scintillation Loss	0 dB
e) Multipath Fading	0 dB
Spacecraft Receive	
a) Receive Avg. Antenna Gain	14.9 dB
b) Receiver Noise	196.3 dBw-Hz
Net Up-Link C/No	102.9 dB-Hz
Spacecraft Transmit	
a) Power Amplifier Output	12.3 dBw
b) TWT to Antenna Loss	-1.8 dB
c) Transmit Avg. Antenna Gain	14.9 dB
Path Losses	
a) Space Attenuation	-197.6 dB
b) Atmospheric Attenuation	0 dB
c) Rainfall Attenuation	0 dB
d) Scintillation Loss	0 dB
e) Multipath Fading	0 dB
Receiving Station	
a) Down-Link Frequency	4.0 GHz
b) Antenna Gain	59.3 dB
c) Noise Density	208.3 dBw-Hz
d) Pointing Loss	0 dB
e) Polarization Mismatch	0 dB
Net Down-Link C/No	95.4 dB-Hz
Combined Up and Down C/No	94.7 dB-Hz
Ideal Modulation Loss	0 dB
Resulting BER	0.102E-11
Required C/No for 10**-5 BER	90.4 dB-Hz
Overall Link Margin above 0 dB	4.3 dB

TABLE 2

LINK CAPACITY SUMMARY

	10**-5 BER	10**-4 BER
0 dB Link Margin	326.22 Mbps	429.03 Mbps
1 dB Link Degradation	259.13 Mbps	340.79 Mbps
2 dB Link Degradation	205.83 Mbps	270.70 Mbps
3 dB Link Degradation	163.50 Mbps	215.02 Mbps
4 dB Link Degradation	129.87 Mbps	170.80 Mbps
5 dB Link Degradation	103.16 Mbps	135.67 Mbps
6 dB Link Degradation	81.94 Mbps	107.77 Mbps
7 dB Link Degradation	65.09 Mbps	85.60 Mbps
8 dB Link Degradation	51.70 Mbps	68.00 Mbps
9 dB Link Degradation	41.07 Mbps	54.01 Mbps
10 dB Link Degradation	32.62 Mbps	42.90 Mbps

The Digital Satellite Circuit

Fig. 2 shows the nature of an actual data transmission channel of a communication satellite system through which a digitally modulated carrier is transmitted. As shown, two critical bandpass filters are involved, one in the transmitter and one in the satellite. Also, three nonlinearities are involved; i.e., the ground terminal HPA, the satellite TWTA (the HPA can be described by the same network as the satellite TWTA), and the data filter in the receiver. Resolution of any bandlimiting produced by these filters of a carrier using some form of PSK modulation, and the effect of the AM-to-PM and the AM-to-AM characteristics of the HPA and TWTA on the varying amplitude envelope of a TDMA carrier or a bandlimited continuous QPSK carrier, will determine the overall bit error rate which can be expected of the system. Fig. 3 shows how both FM and QPSK signal spectra are handled by a multiple channel transponder. As shown for a BT product (B is the 3-dB bandwidth of the filter and T is the bit duration period) of 2, the entire sin x/x main lobe of a QPSK carrier fits within the filter passband. For BT products approaching 1, only the central portion of the main lobe passes through the filter. The effect of bandwidth limiting on various types of PSK modulated carriers (2-4-8 ØPSK, SQPSK and FFSK) are shown[1] in Fig. 3, showing that as bandwidth limiting is performed the link signal to noise degrades, as seen at the receiver, to subtract from the basic link margin budgeted by the system. As seen from Fig. 4, SQPSK and FFSK are the modulation techniques least affected by bandwidth limiting of the spectrum. The two basic microwave components of Fig. 2, which determine the overall link performance; i.e., the filters and the power amplifiers are described in Figures 5 and 6, in terms of basic characteristics. As shown in Fig. 5, two types of filters are used - Tschebychev and dual-mode ellyptic - to provide the filtering required, consistent with the guard bands and adjacent channel isolation required of the system. At the modulator, baseband data filter and the receiver data filter will also have roll-off characteristics which will contribute to the determination system performance. The fundamental effect of this bandwidth limiting by filters, as a function of link margin, is illustrated in Table 2 for a QPSK carrier through the system of Table 1, using the BT vs SNR curve for QPSK (4Ø CPSK) in Figure 4. Note that as the link margin of 4.3 dB is reduced or increased, the link data capacity changes, whereby to increase the link degradation based on from 4.3 dB to 10 dB, reduces the data capacity at 10^{-5} bit error rate from 120 Mbps to 32.6 Mbps. The TWT power amplifier characteristics will have amplitude and phase delay characteristics as shown in Fig. 6, and one effect of these nonlinearities on a heavily bandwidth modulated carrier is also to "restore" previously filtered sidebands as shown in Fig. 6. When only one nonlinearity (satellite TWTA) is considered (earth terminal HPA linear) then a set of curves, shown in Fig. 7, will describe link performance for the particular data channel described for various conditions of power backoff from TWTA saturated power output. Note that degradations for 1 dB to 5 dB can be produced which subtract from link margin. If the nonlinearity of the earth terminal HPA is also considered, in addition to the TWTA, an additional link degradation from 2 to 5 dB can also be introduced, depending on the nonlinearity of the HPA and the roll-off characteristics employed in the initial modulator data filter; i.e.:

		TWTA Linear	TWTA Nonlinear
HPA	Linear	1.1	1.5
	Nonlinear	1.2	2.8

1. H. Chan, D. Taylor, S. Haykin, Third International Conference on Digital Satellite Communications, Kyoto, Japan, Nov. 1975.

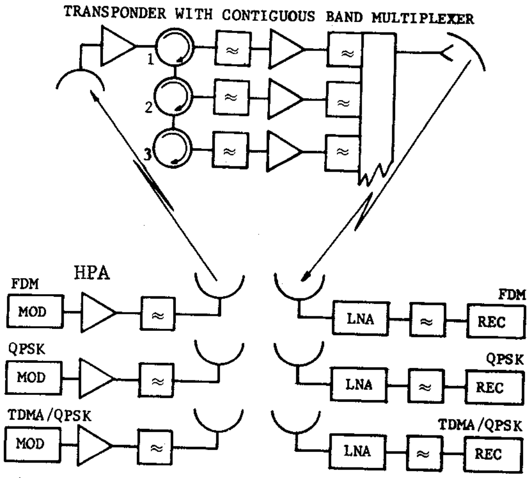

Fig. 1 Typical Digital Satellite Communications System Using 3 Transponder Channels

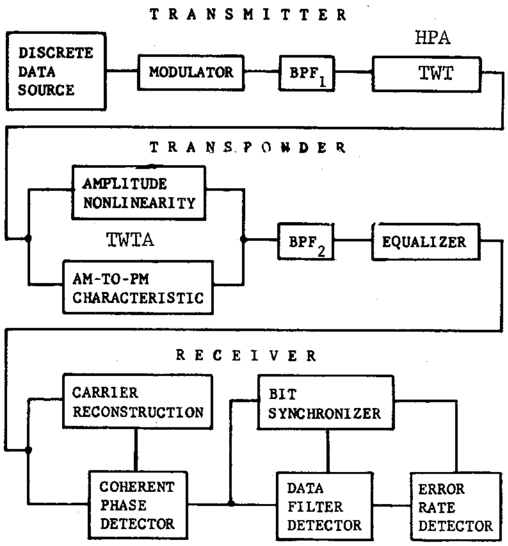

Fig. 2 Basic Data Transmission Channel of Digital Satellite Communications

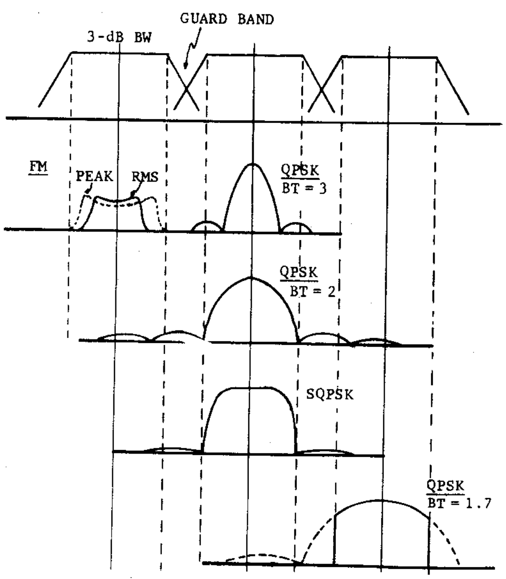

Fig. 3 Typical Types of Signal Spectra Through a Multiple Channel Transponder

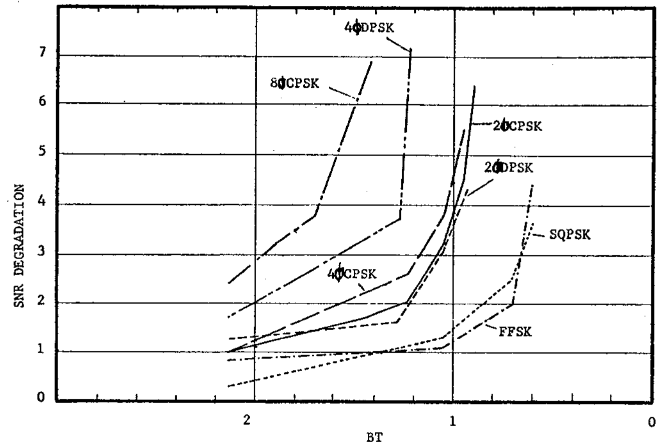

Fig. 4 SNR Degradation at 1 dB Input Power Backoff as a Function of BT

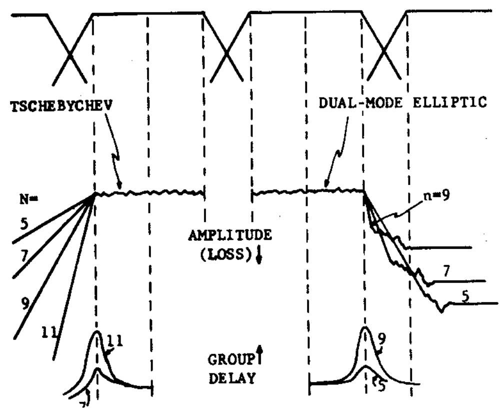

Fig. 5 Pertinent Characteristics of Tschebychev and Dual Mode Ellyptic Filters

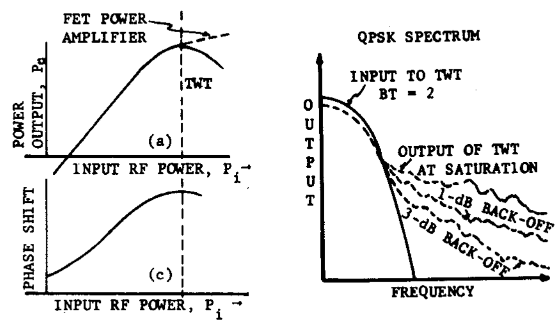

Fig. 6 TWT Power and Phase Characteristics (Left) and TWT Spectrum Spreading (Right)

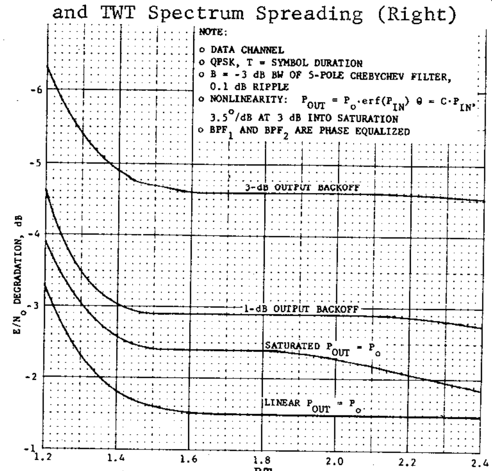

Fig. 7 QPSK E/N_0 Degradation vs BT for Various TWT Backoff Conditions