

## RECOMMENDATION ITU-R S.1425

**TRANSMISSION CONSIDERATIONS FOR DIGITAL CARRIERS USING  
HIGHER LEVELS OF MODULATION ON SATELLITE CIRCUITS\***

(Questions ITU-R 73/4 and ITU-R 230/4)

(2000)

The ITU Radiocommunication Assembly,

*considering*

- a) that the radio spectrum and geostationary orbit are limited resources;
- b) that there is spectrum congestion in certain frequency bands allocated to the FSS;
- c) that due to the rapid development of different radio services, sharing conditions in many frequency bands are becoming increasingly difficult;
- d) that the spectral efficiency of satellite networks can be increased through the use of higher level modulations such as 8-PSK and 16-QAM as compared to QPSK;
- e) that the power efficiency of satellite networks can be improved through the use of appropriate encoding techniques;
- f) that there is a continuous need to update the information available on the characteristics of satellite transmissions and their related performance;
- g) that different transmission techniques can be implemented to transport the same information stream,

*taking into account*

- a) that satellite circuits transmitting higher level modulations and in particular QAM such as 16-QAM are more sensitive to linear and non-linear distortion than those transmitting QPSK signals;
- b) that satellite circuits transmitting higher level modulations such as 8-PSK and 16-QAM are more sensitive to phase noise than those transmitting in QPSK format;
- c) that use of higher level modulation techniques improve the bandwidth efficiency for a given  $E_b/N_0$  at the cost of more transmitter power or higher earth station  $G/T$  and greater earth station e.i.r.p.,

*recommends*

- 1** that the information contained in Annex 1 be used as a guide for implementation of transmission quality for satellite circuits using higher level modulations such as 8-PSK and 16-QAM.

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\* This Recommendation should be brought to the attention of Radiocommunication Working Parties 4 SNG and 10-11S.

## Transmission considerations for carriers using higher levels of modulation on satellite circuits

### 1 Introduction/purpose

This Annex provides information regarding the development of new technologies intended for use on, but not limited to, FSS networks. The initial purpose of these developments are to increase the throughput capacity of the available spectrum that is allocated to that service. This could be achieved by utilizing more efficient modulation processes for the transmission of information.

### 2 Background

#### 2.1 Purpose/objective

With the increased satellite transponder power and concatenated error correction techniques, higher modulation schemes such as 8-PSK and 16-QAM have become feasible for implementation in geostationary satellite orbit (GSO) satellite communication systems. These high order modulations significantly improve the transponder bandwidth efficiency which suits the needs of broadband format structures and applications, such as asynchronous transfer mode (ATM), frame-relay and HDTV. In order to achieve acceptable quality of service as characterized by low BER and higher data rates with the higher order modulations, there is a requirement for not only a higher  $C/N$  ratio at the input of the demodulator, but also a need to control interference and limit distortion within the satellite transmission circuit.

This Recommendation describes the nature of the higher order modulations considered applicable to geostationary-satellite networks and details the reasons for their susceptibility and increased sensitivity to transmission impairments. It will also describe the tests and results of 8-PSK and 16-QAM circuits implemented to determine their operational requirements in a typical satellite network.

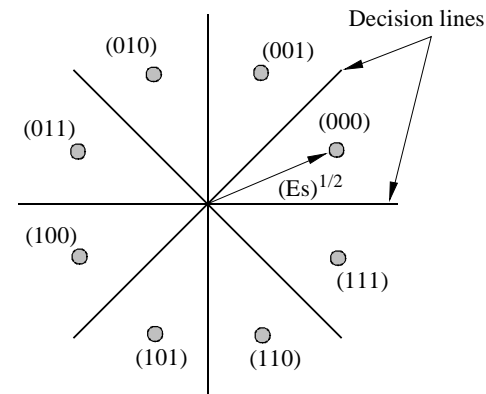
#### 2.2 8-PSK and 16-QAM modulations

In 8-PSK the transmitted symbol is a sinusoidal carrier with eight equally spaced phases. The signal-space diagram is shown in Fig. 1.

Every 8-PSK modulated symbol represents three user bit occupancies, as opposed to 2 bit occupancies for QPSK modulation, thereby improving bandwidth utilization by 50%. On the other hand, each symbol is  $45^\circ$  closer to each other in phase compared to the QPSK symbols which introduces more difficulty to the decision-making processes of the receiver. Theoretical calculations shows that without any error correction techniques, 8-PSK requires 7 dB more energy per bit than QPSK in order to achieve  $1 \times 10^{-8}$  BER.

Figure 2 is an example of a  $4 \times 4$  QAM (16-QAM) signal-space. Each symbol represents four information bits and requires that the receiver distinguish between the different combinations of both the phase and amplitude modulation process. As shown in Fig. 2, the receiver must distinguish between the possible 12 phases and four amplitudes in order to make a decision. As the separation between the signal states are even closer together than for 8-PSK, both amplitude noise and phase noise will have a more pronounced affect in the decision-making process. However, although more vulnerable to transmission impairments than 8-PSK, the bandwidth utilization is improved by 100% compared to QPSK.

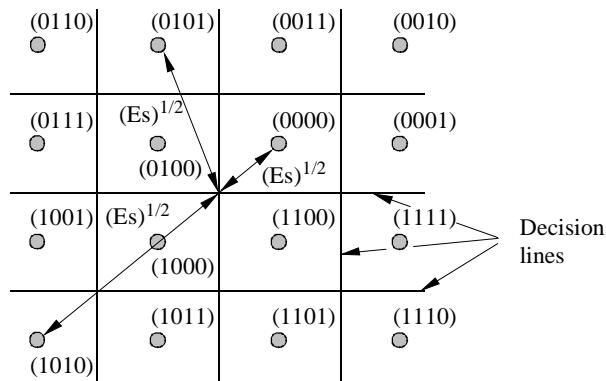
FIGURE 1  
Signal-space for 8-PSK



$E_s$  : Energy per symbol

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FIGURE 2  
Signal-space for 16-QAM



$E_s$  : Energy per symbol

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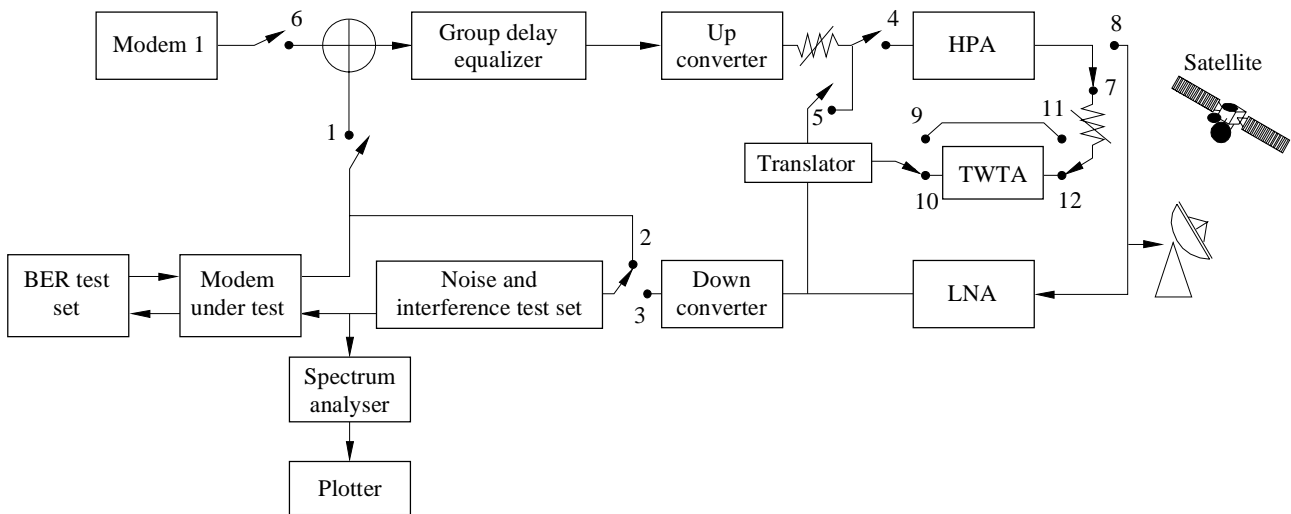
### 3 Transmission test methods and measurements

#### 3.1 Description of test facility

Tests were conducted to investigate the capability and circuit limitations necessary for 16-QAM broadband transmissions in a satellite network. To that purpose a flexible test configuration was implemented which also allowed the determination and optimization of intermediate transmission level points associated with the non-linear transmission elements in the network. Figure 3 presents a block diagram representation of the test configuration used. The switch points indicated in this Figure are shown to convey the variety of the test configurations used.

FIGURE 3

Test facility for data transmission tests



HPA: high power amplifier  
 LNA: low noise amplifier  
 TWTA: travelling wave tube amplifier

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The transmission bandwidth of any of the network configurations was limited to that of a 36 MHz transponder. In all tests the digital transmission rate was chosen to be 45 Mbit/s (DS-3). The spectral bandwidths of the 8-PSK and 16-QAM data modems used in these tests were determined to be about 26 MHz and 15 MHz. This allowed multicarrier transmission in a single transponder for 16-QAM modulation. All modems, for all rates, used in the tests depicted here incorporated FEC rate 3/4 and concatenated 188,204 Reed-Solomon (RS) outer coding.

BER measurements made during these tests were actually made with respect to  $E_b/N$  ratios. For presentation purposes here the results were converted to a  $C/N$  format. Conversion between the two formats can be accomplished with the following formula:

$$C/N = E_b/N_0 + 10 \log (p \times FEC \times RS/1.2)$$

where:

$p$  = 2 for QPSK  
 = 3 for 8-PSK  
 = 4 for 16-QAM

$FEC$ : FEC code rate (e.g. 3/4)

$RS$ : Reed-Solomon code rate (e.g. (188,204))

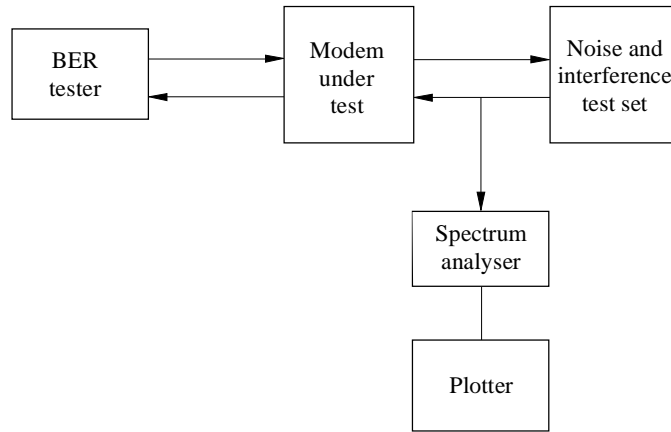
1.2: bandwidth/symbol rate ratio.

## 3.2 Test configurations and results

### 3.2.1 Baseline IF loopback test

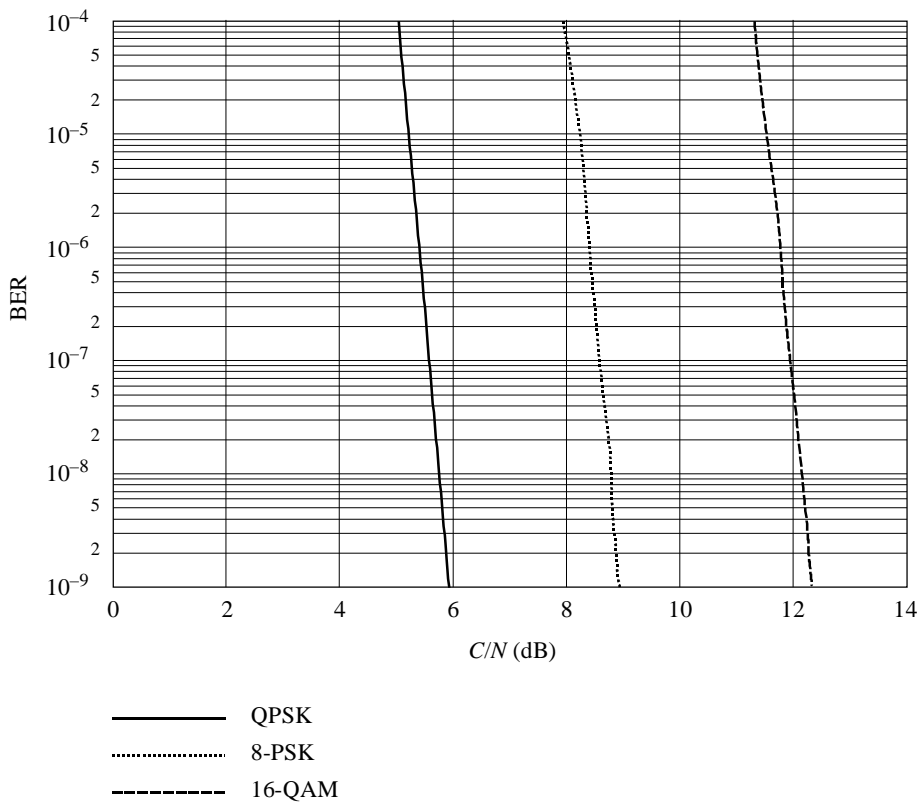
An initial test configuration was established to test the modems in an IF loopback facility. This was achieved by figuratively closing switch point 2 and opening switch point 1 of the facility shown in Fig. 3, resulting in the test configuration shown in Fig. 4. The purpose of the tests was to achieve a baseline for the following RF test measurements. Measurements were performed for QPSK, 8-PSK and 16-QAM modulations. The resulting BER performance for each modulation scheme is shown in Fig. 5.

FIGURE 4  
Block diagram configuration for the IF loopback test



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FIGURE 5  
If loopback test results



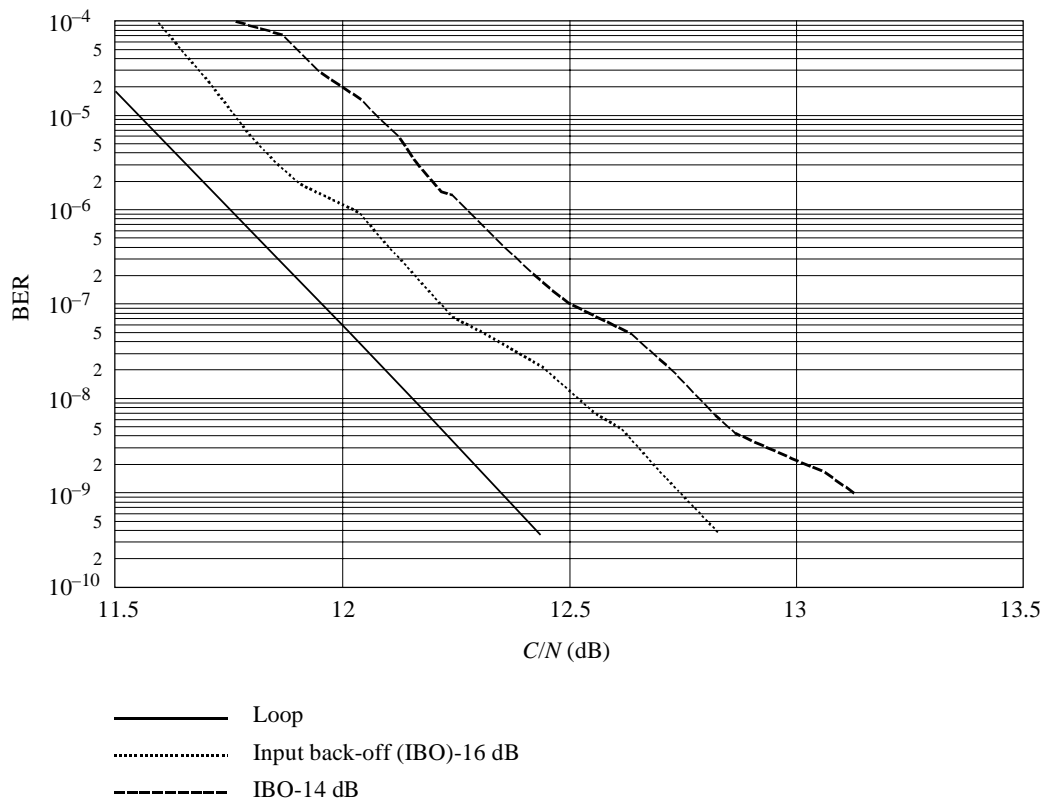
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It is seen from Fig. 5 that for a BER of  $1 \times 10^{-8}$  the required circuit  $C/N$  for QPSK, 8-PSK and 16-QAM modulated transmissions are 5.5, 8.7 and 12.2 dB respectively.

### 3.2.2 RF baseline test

In order to quantify the effects of the earth station HPA non-linearity, the test facility was configured (figuratively by closing switch points 3, 4, 6 and 7) so as to provide a path that excluded the space components. Tests were conducted to determine the linearity distortion effects on 16-QAM modulation by backing off the signal input from the HPA saturation level until an acceptable operating point was obtained. A series of tests indicated that between 14 and 16 dB of input backoff from the saturation level was required before acceptable non-linearity levels could be achieved. Figure 6 presents a graph depicting performance impairments due to the HPA non-linearity as compared to the IF loopback case. The results show that operating the HPA at a point equal to 14 to 16 dB input back-off increases the required  $C/N$  by 0.4 to 0.6 dB at a  $1 \times 10^{-8}$  BER point.

FIGURE 6  
Earth station HPA linearity  
16-QAM carrier input back-off

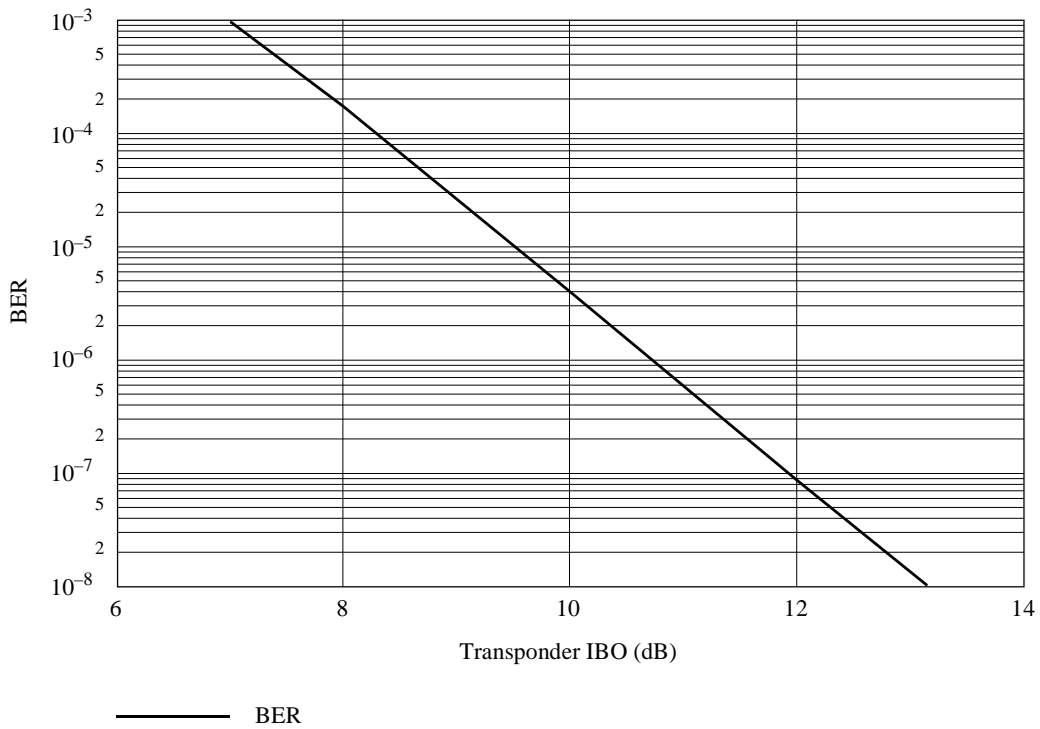


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### 3.2.3 Satellite transponder linearity

In order to determine an acceptable operating point to the satellite TWTA, the network facility was configured to include an RF path component (figuratively by closing switch points 3, 4, 7, 10, and 12). This routed the RF signal through the TWTA. The test consisted of varying the level of a single 16-QAM carrier input to the TWTA while input to the HPA was maintained at a 16 dB backoff with a constant  $C/N$  ratio of about 14 dB. Figure 7 shows the 16-QAM BER performance at the TWTA output versus signal input back-off from its saturation point. Table 1 relates the transfer characteristics for a typical TWTA.

FIGURE 7  
**Satellite transponder linearity**  
 Earth station HPA-IBO = 16 dB, TWTA input C/N = 13.8 dB



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TABLE 1  
**Typical TWTA transfer characteristics**

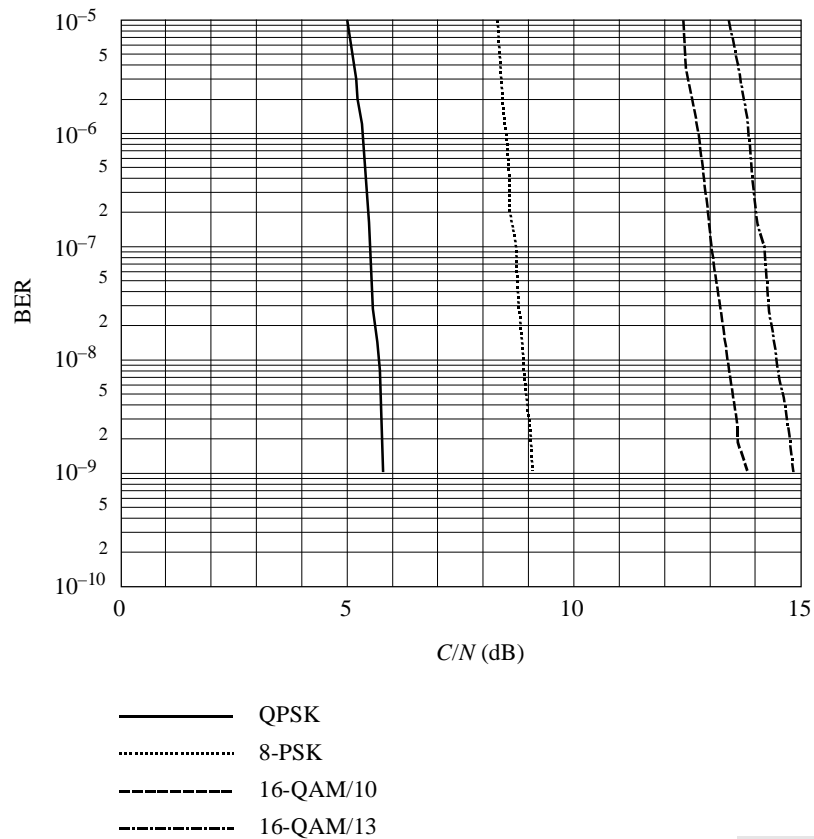
IBO (dB)	Output back-off (dB)
0.0	0.0
1.0	0.1
2.0	0.3
3.0	0.6
4.0	1.0
5.0	1.4
6.0	1.8
7.0	2.4
8.0	3.0
9.0	3.8
10.0	4.6
11.0	5.5
12.0	6.5
13.0	7.6

**3.2.4 Full system tests**

Figure 8 presents the BER performance for single QPSK, 8-PSK and 16-QAM carriers through a complete network. Test results are shown for two levels of input to the satellite receiver corresponding to a 13 dB and 10 dB input level back-off

operating point to the satellite TWTA. The operating point of the earth station HPA was kept at a constant back-off of 16 dB. A comparison of Figs. 5 and 8 shows that there is a degradation of BER performance of the complete network from the IF loopback configuration of about 1.1 to 2.5 dB depending on the back-off input to the satellite TWTA.

FIGURE 8  
Full system  
HPA/TWTA IBO = 16/10 and 16/13 dB



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### 3.2.5 Multicarrier configuration and test results

A multicarrier test facility was configured by adding a second modem into the network (closing switch points 3, 4, 6 and 8). Tests were performed on an RF path configured with two 16-QAM carriers operating at 45 Mbit/s loaded in a single transponder. Centre frequencies of the carriers were adjusted for 17 MHz separation when centred in the 36 MHz transponder. The total input power into the HPA/TWTA was maintained at a 16/13 dB backoff point. Figure 9 compares the BER results of the IF loopback case with the one and two-carrier situation. The results show that at a BER of  $1 \times 10^{-8}$  the per channel performance of two 16-QAM 45 Mbit/s carriers operating in a single transponder is degraded by only 1.7 dB when compared to the IF loopback baseline configuration.

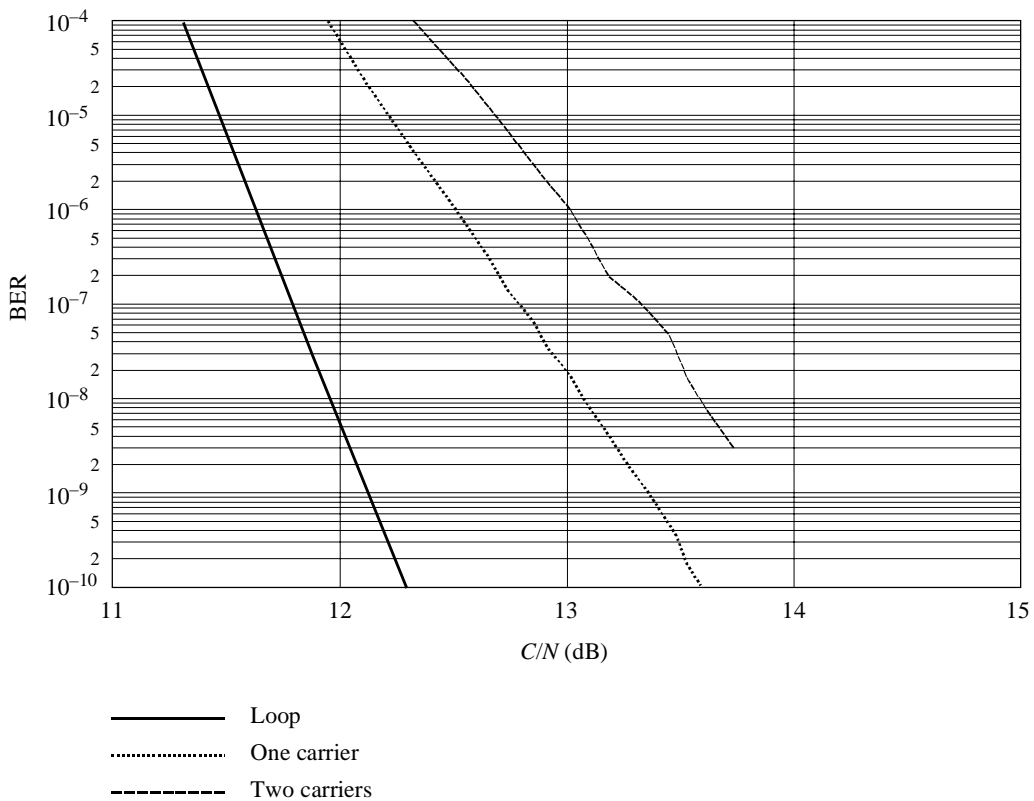
### 3.3 Summary of performance results

BER performance tests for single 45 Mbit/s carriers were conducted on a satellite circuit for QPSK, 8-PSK and 16-QAM modulations. Each carrier used an inner convolutional code of rate 3/4 and a RS outer code of 188,204. The BER performance results for the three modulations are shown in Fig. 8. Figure 9 compares one and two 16-QAM carrier BER performance.

Table 2 summarizes the  $C/N_0$  requirements at the receiver demodulator for a BER of  $1 \times 10^{-8}$  for all three schemes.



FIGURE 9  
Multiple 16-QAM carriers  
TWTA IBO = 13 dB total



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TABLE 2  
C/N required for  $1 \times 10^{-8}$  BER for QPSK, 8-PSK and 16-QAM carriers

Configuration	QPSK	8-PSK	16-QAM
FEC + RS	3/4 + 188,204	3/4 + 188,204	3/4 + 188,204
IF loop (dB)	5.7	8.7	12.2
One carrier, HPA/TWTA IBO = 16/13 (dB)	5.7	8.8	13.2
Two carrier, HPA/TWTA IBO = 16/13 (dB)			13.6

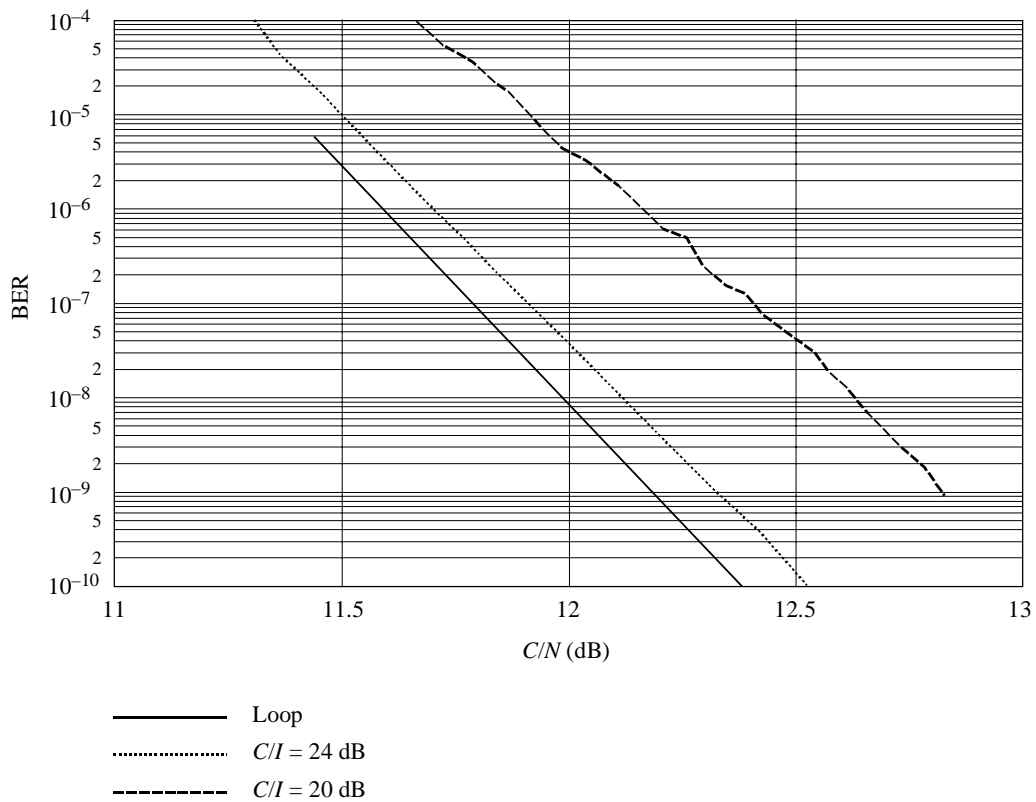
### 3.4 Effects of co-channel interference

In order to investigate the effects of co-channel interference, a digitally modulated interfering signal was introduced into the test configuration when implemented in the IF loopback test set-up mode per Fig. 2. Interference was adjusted for C/I levels of 20 and 24 dB. BER was measured for various  $C/N_0$  levels in the presence and without the presence of the interfering signal.

Figure 10 shows the BER performance for a single 16-QAM carrier for the various interference scenarios. It is apparent that interference into a 16-QAM circuit must be carefully controlled.

FIGURE 10

## 16-QAM interference sensitivity loopback test



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## 4 Conclusions

From the above results it is apparent that higher order modulations such as 16-QAM improve bandwidth efficiency for a given  $E_b/N_0$  at the cost of more transponder power, greater earth station e.i.r.p. Besides the major contribution of rain losses in 14/11 GHz and 30/20 GHz bands, the non-linear characteristics of the satellite network plays an important role in the received signal distortion at the receiver demodulator.

One of the important considerations of applying higher order modulations for satellite operation is a requirement to control the input level into the satellite TWTA or the resulting distortion emanating from it. This might suggest the possible need for earth station power control.

It is also noted that neither amplitude or phase equalization was employed during any of the above tests suggesting that some further improved performance may be possible through the use of linearizers and equalizers, either on the spacecraft or in the uplink path.

The test results indicate that all three carrier modulation schemes are, in a relative sense, equally affected to the changes in operating  $C/N$  level. For example, for all three situations, if the BER operating point is at  $1 \times 10^{-10}$ , it will drop to  $1 \times 10^{-3}$  if the network  $C/N$  drops by less than 2 dB. For many applications a BER of  $1 \times 10^{-3}$  is unacceptable.