Digital transmission experiments with the orbital test satellite

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by
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Abstract

Digital satellite communication experiments in the 11/14 GHz band were performed on a link of 115 km between Eindhoven and Huizen in the Netherlands by means of the Orbital Test Satellite. Equipment was developed and tested via a translator loop. For transmission and reception of RF signals paraboloid antennes of 3 and 8 m diameter were used. Digital transmission tests were carried out via the OTS-A and OTS-B transponders. Spectra of the transmitted and received signals were measured for different Quadrature Phase Shift Keying modulation and demodulation strategies at bitrates of 4 and 8.448 Mbit/s. Videophone and Single Channel Per Carrier digital telephony demonstrations in satellite loop operation were given. Bit-Error Ratio was measured for Quadrature Phase Shift Keying modulation at bitrates of 4 and 8.448 Mbit/s and 32 kbit/s.

Dijk, J. and A.P. Verlijsdonk, J.C. Arnbak
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List of symbols and abbreviations

BER	: Bit Error Ratio
C	: Carrier Signal Power
CCIR	: Commitee Consultative International de Radio
CQPSK	: Coherent Quadrature Phase Shift Keying
dBc	: Decibell with respect to carrier
DE-QPSK	: Differential Encoded Quadrature Phase Shift Keying
DPCM	: Differential Pulse Code Modulation
DQPSK	: Differential Quadrature Phase Shift Keying
E_o	: Energy per bit
EUT	: Eindhoven University of Technology
EIRP	: Effective Isotropic Radiated Power
G	: Antenna Gain
GHz	: Giga Hertz
H	: Horizontal (Polarisation)
HDPCM	: Hybrid DPCM
Hzn	: Huizen
HPA	: High Power Amplifier
IF	: Intermediate Frequency
IPFDS	: Input Power Flux Density for Saturation
LPF	: Low Pass Filter
MOD	: Modulator
MSL	: Mean Sea Level
N_o	: Noise Power Density
NRZ	: Non Return to Zero
OTS	: Orbital Test Satellite
PCM	: Pulse Code Modulation
PTI	: Philips Telecommunicatie Industrie
QPSK	: Quadrature Phase Shift Keying
SCPC	: Single Channel Per Carrier
SDPCM	: Sequential DPCM
S/P	: Serial to Parallel Converter
SSB	: Single Side Band
T	: System Noise Temperature
TWT	: Travelling Wave Tube
V	: Vertical (Polarisation)
VCO	: Voltage Controled Oscillator

1. Objectives and introduction [1]

The following objectives for transmission experiments via the OTS A and B transponders were formulated by the Telecommunications Division of the Eindhoven University of Technology (EUT).

- development and testing of 11/14 GHz equipment for digital communications at 4 and 8.448 Mbit/s.
- comparison of different QPSK modulation strategies, i.e. direct RF QPSK modulation versus indirect IF QPSK modulation.
- comparison of different QPSK demodulation principles, i.e. QPSK demodulation with coherent detection and QPSK demodulation with differentially coherent detection (DQPSK).
- measurement of bit-error rate (BER) at average weather conditions.
- realisation of a videophone loop transmission experiment at 8.448 Mbit/s, and SCPC telephone experiments at 32 kbit/s.

The intended experiments were prepared and tested via a 11/14 GHz transponder loop and carried out via the OTS A and B transponder. For details of the objectives, see the proposal in Appendix 1.

2. Transmission system - configuration.

2.1. The EUT earth station

The antennas of the Eindhoven earth station have diameters of 8m and 3m; the feeds are of the scalar type. The antenna system is suited for transmitting and receiving circular and linear polarized signals. The antenna tracking is controlled by a micro-processor. Further, a 3m paraboloid antenna was used for the experiments which was situated in Huizen. Huizen is 115 km away from Eindhoven. The transmitter consists of a QPSK data modulator on an IF of 70 MHz, an up-converter and a High Power Amplifier (HPA). In fact, the QPSK modulation can be performed in two different ways:

a) by a hard-switching QPSK modulator directly operating on the RF carrier of 14.4575 GHz (direct QPSK modulator)

b) by a pre-filtered QPSK modulator operating on an IF subcarrier of 70 MHz (indirect QPSK modulator).

Fig. 1 gives an overview of the experimental site of the Radio Laboratory of the Eindhoven University of Technology . Table 1 summarizes the main electrical characteristics.

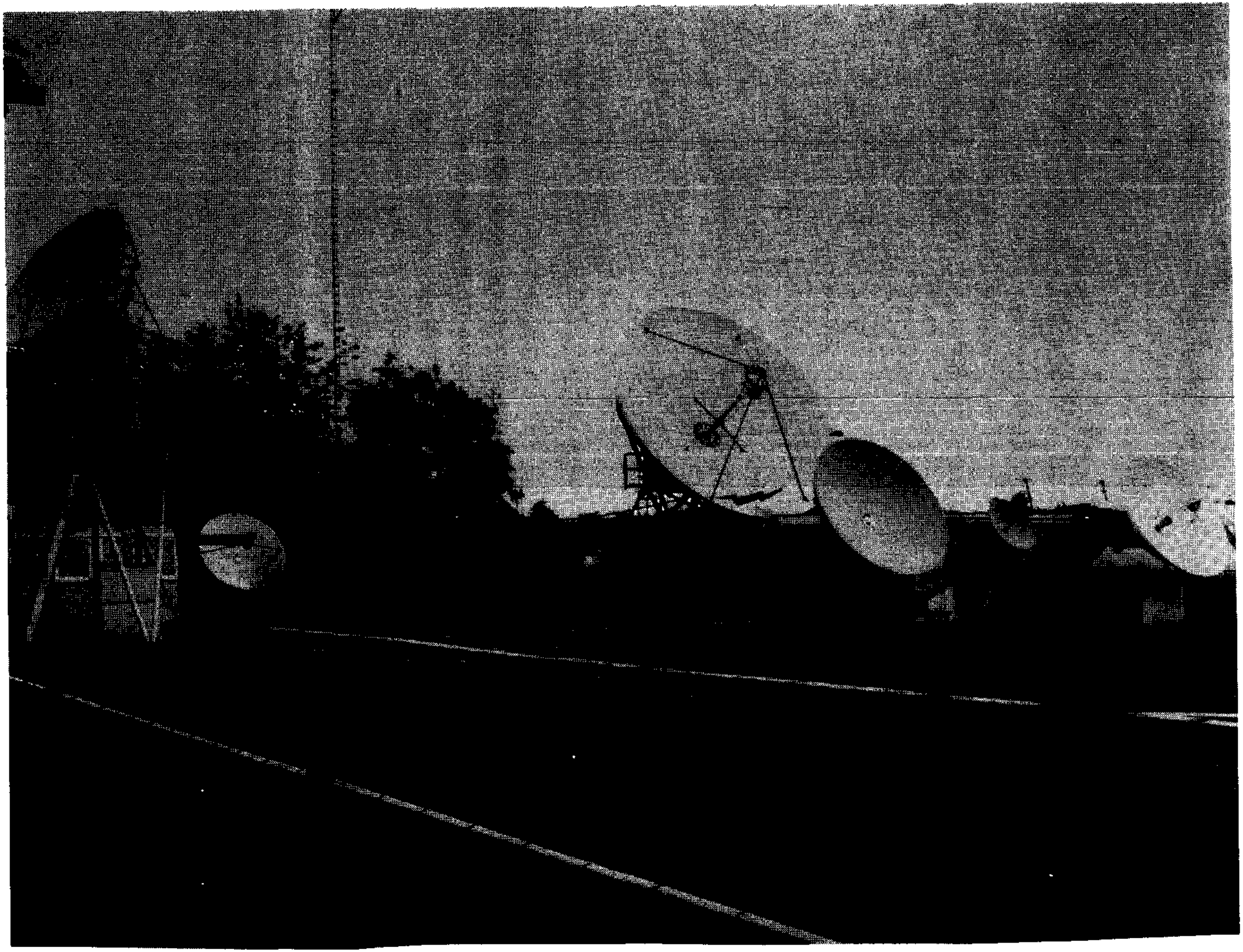


Fig. 1: The experimental site of the Radio Laboratory, Eindhoven University of Technology, seen from SW.
Centre: 8-m 11/14 GHz antenna. Right: cabin I. Left cabin II with radiometer and radar dish.

			8 m dish EUT			3 m dish EUT			3m dish Hzn		
Channel	Freq. (GHz)	Applic.	Gain (dB)	T_{sys}/1K (dB)	G/T (dB)	Gain (dB)	T_{syst}/1K (dB)	G/T (dB)	Gain (dB)	T_{syst}/1K (dB)	G/T (dB)
	11.63	calibrat.	58.6 ± 0.5	x	x	x	x	x		clear	
	14.25	calibrat.	60.4 ± 0.5	x	x	x	x	x		sky	
TM (ECS)	11.45	calibrat.	x	x	x	48.7	28.6	20.1		cond.	
B_o beacon	11.786	propag.	58.71	x	x	x	x	x	x	x	x
B transp.	11.795	commun.	58.71	28.27	30.44	x	x	x	x	x	x
TM	11.575	propag.	58.56	x	x	x	x	x	48.7 ± 0.5	x	x
A2	11.510	commun.	58.51	28.7	29.81	48.75	28.6	20.15	48.7 ± 0.5	25.85	22.85
A4	11.64	commun.	58.60	28.7	29.9	48.84	28.6	20.24	48.7 ± 0.5	25.85	22.85
			Gain (dB)	P_{max} (dBW)	$EIRP_{max}$ (dBW)				Gain (dB)	P_{max} (dBW)	EIRP (dBW)
A2	14.172	commun.	60.35	11.76	72.11				50	13	63
A4	14.302	commun.	60.43	11.76	72.19				50	13	63
B	14.457	commun.	60.52	11.76	72.28				x	x	x

- Measurement accuracy to one decimal
- Calculated values to two decimals

Table 1: Main characteristics of the earth terminals in Eindhoven (EUT) and Huizen (Hzn) used in the OTS experiments.

Fig. 2 gives the block diagram of the measurement set-up. There are three different test loop configurations:

a) the modem loop for testing the indirect modems in back-to-back operation,

b) the translator loop for testing the earth station equipment via the 14/11 GHz translator,

c) the satellite loop for testing the system via the OTS B transponder.

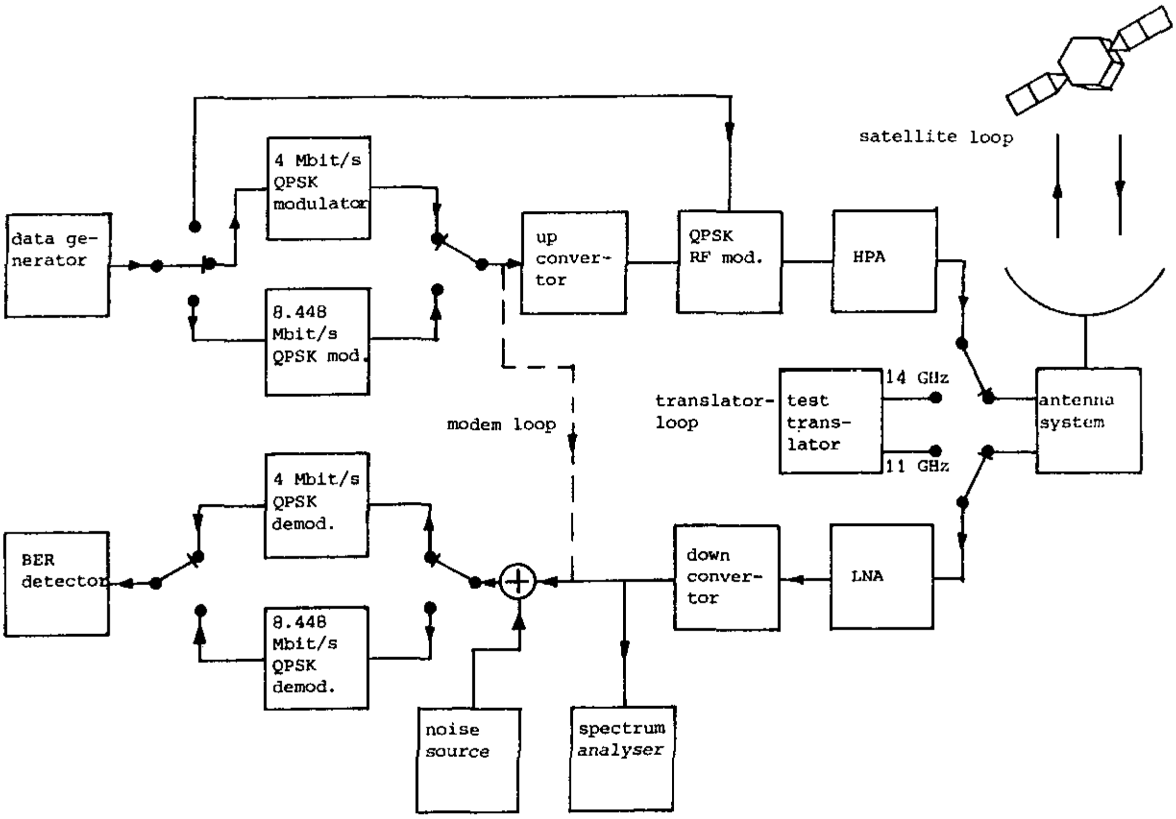


Fig. 2: System measurement set-up for experiments via B-transponder of the OTS.

Figures 3 and 4 show the block diagrams of the earth station equipment in translator loop operation and in satellite loop operation, respectively (via the B-transponder).

Figure 5 shows the block diagram of the EUT earth station for OTS operation via the A-transponder.

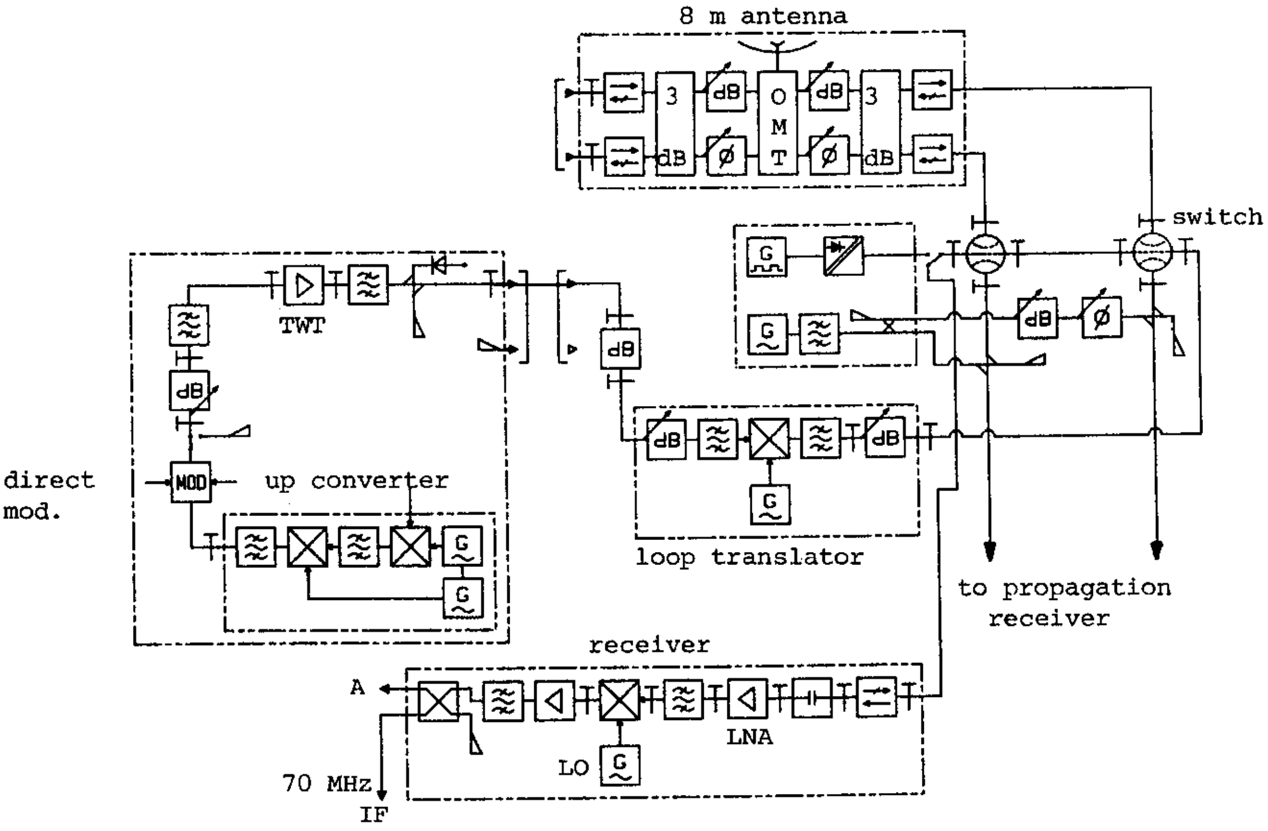


Fig. 3: Block diagram of the earth station in translator loop operation for B-transponder.

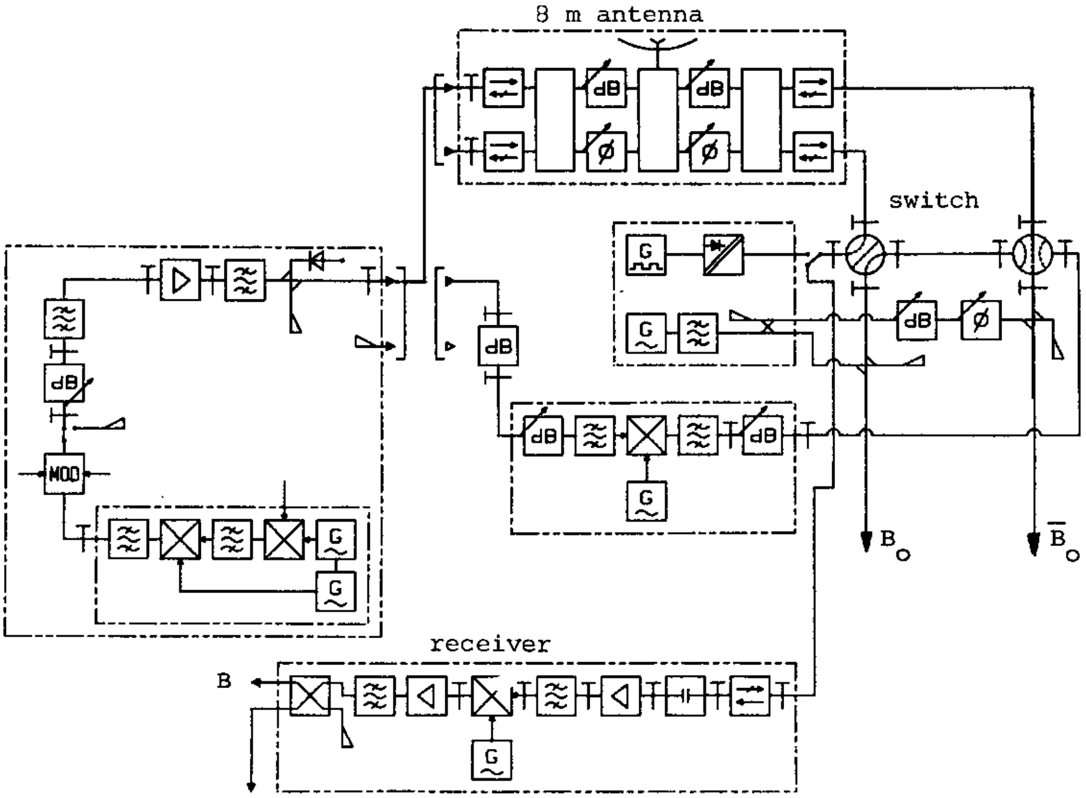


Fig. 4: Block diagram of the earth station in satellite loop operation for B-transponder.

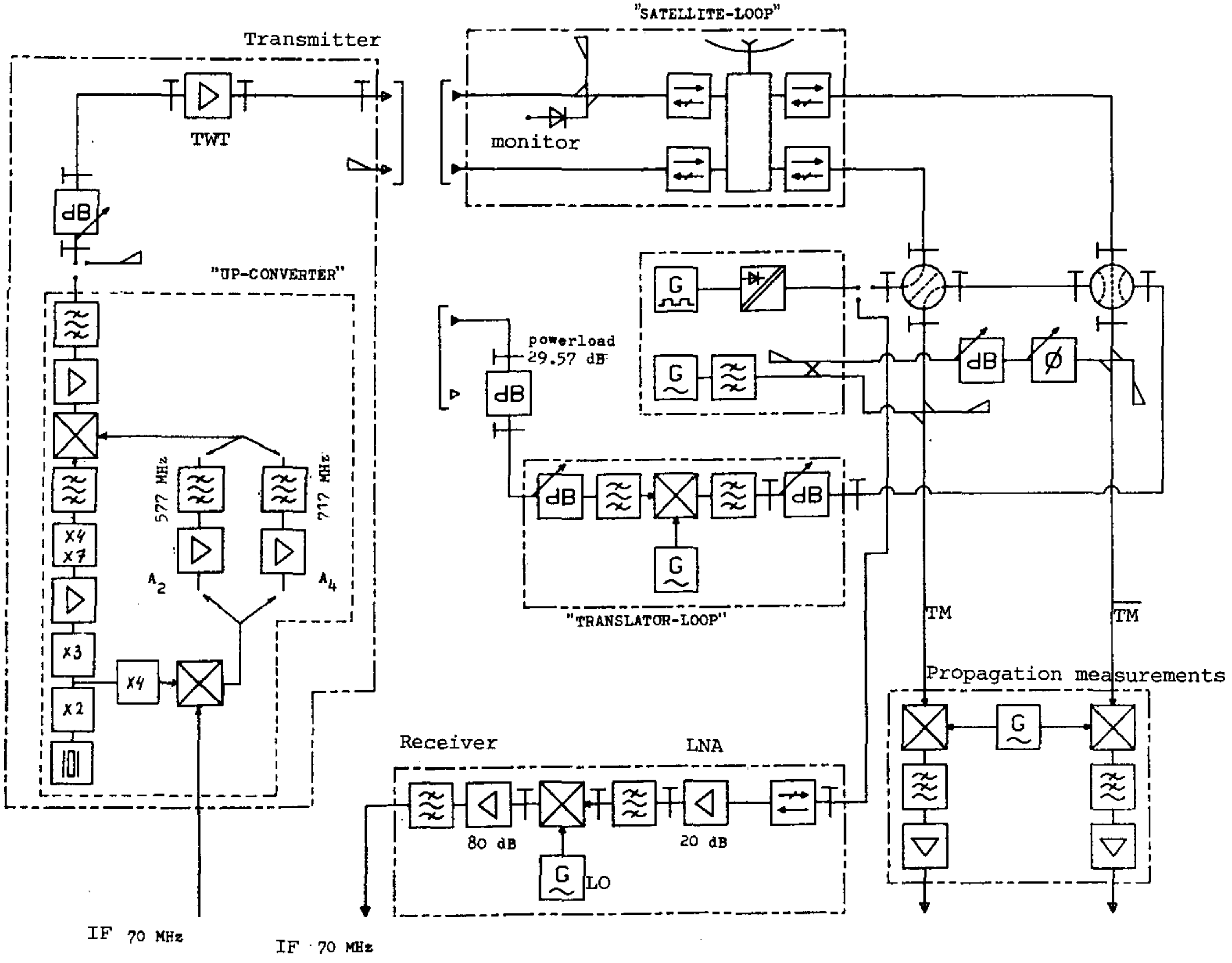


Fig. 5: Block diagram of the earth station of EUT for OTS operation with A transponder (Channel A2, A4).

2.2. Site location and local climate characteristics of EUT.

In table 2 and 3 the main site data and the standard meteorological parameters for EUT earth station are given.

Site location of EUT earth station	
Coordinates	51°27' lat. N, 5°30' long. E.
antenna height	17 m above MSL
range to OTS	38514 km (nominal)
elevation	31°06' (nominal)
azimuth	0°38' (nominal)
rain gauges	two, within 40 m from antenna
antenna horizon	belt of trees under the path
general terrain	flat

Table 2 : Main site data of EUT for OTS experiment
(satellite station 5°00' E.)

Local climate in Eindhoven, the Netherlands	
Rain climatic zone :	E (CCIR 1982)
Mean atmospheric pressure (MSL)	1015.7 mbar
mean surface dry bulb temperature	9.4° C
mean water vapour pressure	10.2 mbar
mean surface refractivity	326.4
dominant wind direction	SW

Table 3 : Standard meteorological parameters
for Eindhoven, the Netherlands
(period of record 1955-1970).

2.3. Propagation model for clear sky and rain attenuation according to CCIR

For the determination of the atmospheric losses, the CCIR propagation model [10] is used.

The calculated attenuation values are given in table 4 and may be used to estimate the margin in signal-to-noise ratio at a certain BER for clear sky conditions and rain conditions for 1, 0.1 and 0.01% of the time.

	B-transp.		A-transp. down		A-transp. up		A-transp. down		A-transp. up	
	down	up	A2	Ā2	A2	Ā2	A4	Ā4	A4	Ā4
%	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
0.01	3.33	5.13	3.05	3.49	4.75	5.31	3.06	3.52	4.76	5.36
0.1	1.39	2.11	1.27	1.44	1.96	2.18	1.29	1.46	1.96	2.20
1.0	0.18	0.24	0.17	0.18	0.23	0.24	0.18	0.18	0.24	0.24
CS	0.15	0.18	0.14	0.14	0.18	0.18	0.14	0.14	0.18	0.18

Table 4: The clear sky and rain attenuations calculated according to CCIR [10].

2.4. OTS characteristics

The following OTS characteristics are used for the calculation of the link budgets [1]:

Parameter		Module B Channel 1r	Module A Channel A2	 Channel A4
EIRP max	dBW	40.5	40.0	46.6
G/T ratio	dB/K	3.1	0.0	0.0
IPFDS	dBW/m^2	not appl.	-79.3	-79.0
aspect angle loss uppath	dB	1.0	0.6	1.0
aspect angle loss downpath	dB	1.0	0.6	0.8
gain step number		6	15	15
gain step relative to 0 dB	dB	-2.57	5.1	4.88
effective IPFDS	dBW/m^2	not appl.	-84.4	-83.88
output back-off	dB	1.7 (measured)	[12]	[12]

Table 5: OTS transponder characteristics [1].

3. Experiment periods and characteristics

3.1. Experimental schedule

The transmission times and various experimental conditions are summarized in Table 6, which shows that a total of 37 hours was used for satellite access by the involved earth terminals.
The Table also shows this involvement and the purpose of the various experiments and demonstrations.

1	2	3	4	5	6	7	8	9	10	11	12	13
Nr.	Date	Time GMT	Hours	Transponder Channel	Gain step	Weather* conditions	Uplink antenna(s)		Downlink antenna(s)		Main experiment	Remarks
						N, R, °C	(m)	(pol.)	(pol.)	(m)		
1	82/9/3	09.30 11.30	2	B:LR	6	0, 0, 8	8	circ.	circ.	8	modem, spectrum	Initial tests
2	82/9/10	12.00 14.00	2	B:LR	6	6, 0, 25	8	"	"	8	modulator testing	Initial tests
3	82/12/14	13.00 16.00	3	B:LR	6	7, 0, 2	8	"	"	8	QPSK 8.448 Mb/s indirect modulation	Initial tests
4	82/12/21	11.00 16.00	5	B:LR	6	7, 0, 5	8	"	"	8	BER QPSK 8.448 group delay, spectra	Measurements
5	83/3/15	10.00 15.00	5	B:LR	6	7, 0, 7	8	"	"	8	modem 4 Mbit/s phase noise	Videophone
6	83/6/16	12.00 15.00	3	A:A2	15	7, 0, 14	8	H	V	8	4 Mbit/s BER videophone phase noise	Videophone
7	83/8/31	11.00 15.00	4	A:A2	15	0, 0, 28	8	H	V	8+3 EUT	SCPC, tf	Demo (with Hzn)
8	83/11/3	11.00 15.00	4	A:A2	15	0, 0, 12	8	H	V	8+3 EUT	BER 4+8 Mbit/s SCPC	Loop tests with 3 m dish
9	83/11/17	11.00 16.00	5	A:A2	15	8, 0, 8	8+3 Hzn	H	V	8+3 EUT 8+3Hzn	BER 4+8 Mbit/s 32 kbit/s	SCPC demo (with Hzn)
10	83/12/20	11.00 15.00	4	A:A4	15	8, 1, 9	8	H	V	8+3Hzn	SCPC, BER Video, puls	Video demo (with Hzn)
total hours			37									

* N cloud layer covering of the sky; R rain intensity mm/hour; Temp. degrees °C at 1.5 m height above ground

Table 6: Eindhoven University transmissions to OTS

3.2. Link budgets for OTS transmission

In Table 7 the uplink Power budget is given for access of module A and B from the 8m dish in Eindhoven and module A channel A 2 from the 3m dish in Huizen.

In Table 8 the downlink Power budget is given for all uplink - downlink combinations employed.

In Table 9 the transmission margin after the demodulation process is calculated.

			Module B	Module A Channel A2		Module A Channel A4
1.	antenna diameter	m	8	8	Hzn 3	8
2.	EIRP max	dBW	72.28	72.11	63	72.19
3.	back-off	dB	1	0.0	13	0.0
4.	filter loss	dB	2.46	1.3	0.0	1.3
5.	pointing loss	dB	0.2	0.2	0.2	0.2
6.	clear sky loss	dB	0.18	0.18	0.18	0.18
7.	spreading loss	dB	162.7	162.7	162.7	162.7
8.	aspect angle loss	dB	1.0	0.6	0.6	1.0
9.	IPFD	dBW/m^2	-95.26	-92.87	-113.68	-93.19
10.	Input Back-off	dB	not appl.	8.47	29.28	9.31
11.	isotr. apert. $(\lambda^2/4\pi)$	$dB.m^2$	-44.65	-44.51	-44.51	-44.56
12.	G/T satellite	dB/K	+3.1	0.0	0.0	0.0
13.	C/T uplink	dBW/K	-136.81	-137.38	-158.19	-137.75
14.	Output Back-off	dB	1.7	3.6	22.88	4.2

Table 7: Uplink budget calculation EUT → OTS

		Module B	Module A							
			Channel A2				Channel A2		Channel A4	
1 uppath antenna	m	8	8				3 Hzn		8	
2 EIRP max. satellite	dBW	40.5	40.0				40.0		46.6	
3 output back-off	dB	1.7	3.6				22.88		4.2	
4 aspect angle loss	dB	1.0	0.6				0.6		0.8	
5 spreading loss	dB.m^2	162.7	162.7				162.7		162.7	
6 clear sky loss	dB	0.15	0.15				0.15		0.15	
7 pointing loss	dB	0.2	0.2				0.2		0.2	
8 isotr. apert. $(\lambda^2/4\pi)$	dB.m^2	-42.89	- 42.69				- 42.69		- 42.77	
9 receiving antenna	m	8	8		3 EUT	3 Hzn	8 EUT	3 Hzn	8 EUT	3 Hzn
10 G/T earth station	dB/K	30.44	29.81		20.15	22.85	29.81	22.85	29.9	22.85
11 C/T down link	- dBW/K	137.70	140.13		149.79	147.09	159.41	166.37	134.32	141.37
12 C/T system	- dBW/K	140.29	141.98		150.03	147.53	161.85	166.98	139.38	142.94
13 Boltzmann's constant	- dB/HzK	228.60	228.60		228.60	228.60	228.60	228.60	228.60	228.60
14 overall C/N_o	dB Hz	88.31	86.62		78.57	81.07	66.75	61.62	89.22	85.66
15 bitrate	Mbit/s	8.448	4	8.448	8.448	8.448	0.032	0.032	8.448	8.448
16 bitrate	dB Hz	69.27	66	69.27	69.27	69.27	45.05	45.05	69.27	69.27
17 E_b/N_o	dB /Hz	19.04	20.62	17.35	9.3	11.80	21.70	16.57	19.95	16.40

Table 8: Downlink budget calculations OTS towards earth stations at EUT and Hzn.

1 System configuration:	modem	CQPSK	DQPSK	DQPSK	DQPSK	DQPSK	DQPSK	DQPSK	Comments
2 satellite channel		B	B	A2	A2	A2	A4	A4	
3 uplink antenna	m	8	8	8	8	3 Hzn	8	8	
4 downlink antenna	m	8	8	8	3EUT	3 Hzn	8	3	
5 bit rate	Mbit/s	8.448	4	8.448	8.448	0.032	8.448	8.448	
6 E_b/N_o	dB	19.04	20.62	17.35	9.3	16.57	19.25	16.40	
7 BER target	dB	40	40	40	40	40	40	40	
8 E_b/N_o theoretical	dB	8.8	10.8	10.8	10.8	10.8	10.8	10.8	
9 modem implementation loss	dB	4.0	2.5	1.8	1.8	2.1	1.8	1.8	see fig.28,29,30,31,32 back to back via loop translator.
10 non-linear channel loss	dB	1.2	0.4	1.3	1.3	0.6	1.3	1.3	
11 interferences	dB	0.0	0.1	0.8	0.8	0.0	0.8	0.8	Transmission via OTS
12 phase noise degradation	dB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	calculated [5] [6] [7]
13 E_b/N_o practical	dB	14.0	13.8	14.7	14.7	13.5	14.7	14.7	
14 margin in clear sky	dB	5.04	6.82	2.75	-5.3	3.07	4.65	1.80	

Table 9: Demodulation performance of digital transmission experiments with OTS.

4. Results with respect to the objectives

The results are given in two categories:

- concerning the developed hardware, (see 4.1)
- concerning the measurement results (see 4.2)

4.1. Specifications of the developed hardware

4.1.1. Modem configurations and specifications

With respect to the data experiments, three modems were developed. Two of them were designed for differential QPSK modulation with differentially coherent detection (DQPSK) at data speeds of 4 Mbit/s (two data inputs and outputs at 2 Mbit/s each) and 8.448 Mbit/s. The other modem was designed for a bit rate of 8.448 Mbit/s and, based on differential QPSK modulation and coherent detection (DE-QPSK).

A. The DQPSK modems for 4 and 8.448 Mbit/s [2, 9]

The block diagrams of the modems are shown in Fig. 6.

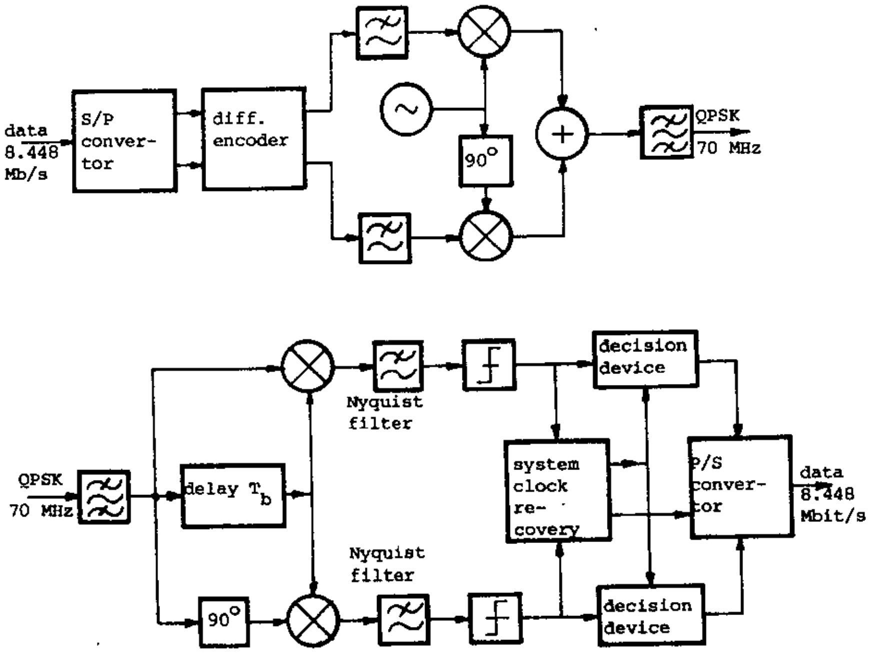


Fig. 6 : Block diagram of the DQPSK modems.

In the 4 Mbit/s modem the Nyquist spectral shaping is performed by the pre-filters in the modulator. These pre-filters were built as binary transversal filters, resulting in a well-determined amplitude characteristic and linear phase characteristic. However, realisation of the Nyquist spectral shaping in the modulator implies that the modulator output filter, the demodulator input filter and the post-detection filters

must be relatively wide, in order not to affect the Nyquist spectral shaping obtained. This causes a relatively large effective noise bandwidth giving a modem degradation of about 2.5 dB at a BER = 10^{-4}.
In the 8.448 Mbit/s DQPSK modem the pre-filters are relatively wide and the Nyquist spectral shaping is performed in the demodulator. This results in a modem degradation of only 1.8 dB at a BER = 10^{-4}.

B. The 8.448 Mbit/s QPSK modem with coherent detection [3]

The block diagrams of the modulator and demodulator are shown in Fig. 7 and Fig. 8, respectively. The pre-filtering in the modulator is not very tight.
The Nyquist spectral shaping is performed in the demodulator which gives a relatively small effective noise bandwidth. The 70 MHz carrier recovery is realised by means of a Costas loop.

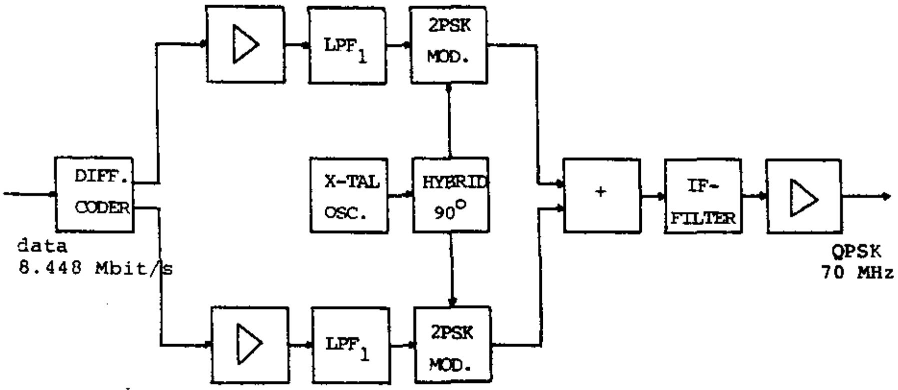


Fig. 7: Block diagram of the 8.448 Mbit/s DE-QPSK modulator.

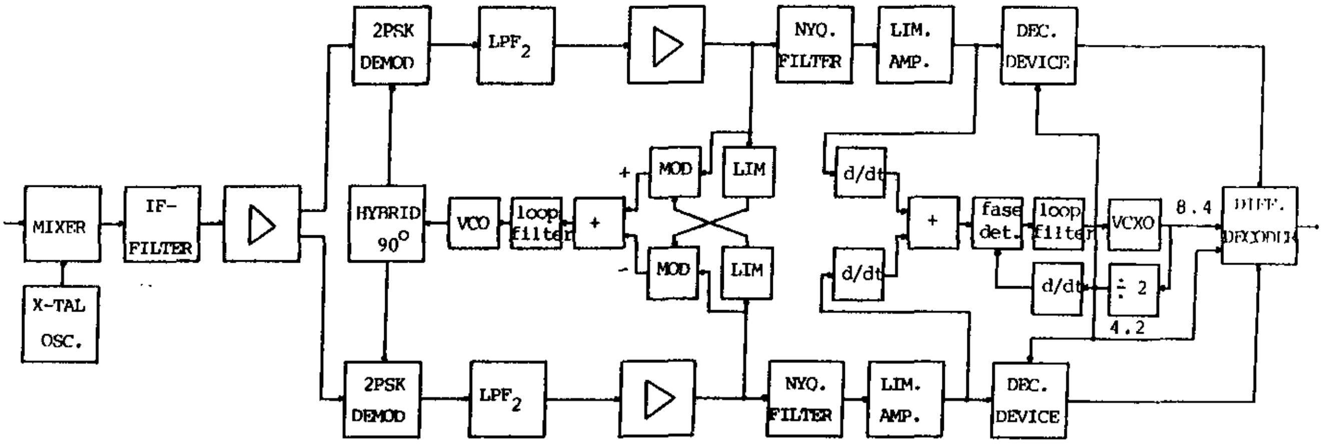


Fig. 8: Block diagram of the 8.448 Mbit/s DE-QPSK demodulator with coherent detection.

The modem specifications are summarized in the following table

Modem	4Mbit/s DQPSK	8.448 Mbit/s DQPSK	8.448 Mbit/s DE-QPSK
IF frequency	70 MHz	70 MHz	70 MHz
IF bandwidth	~3 MHz	~8.5 MHz	~8.5 MHz
IF level	4 dBm	4 dBm	5.2 dBm
output impedance	50 Ω	50 Ω	75 Ω
data input	NRZ signal	NRZ signaal	NRZ signaal
pre-filtering	strict (Nyquist shaping)	moderate	moderate
post-filtering	normal	strict (Nyquist shaping)	strict (Nyquist shaping)
theoretical E_b/N_o at BER = 10^{-4}	10.8 dB	10.8 dB	8.8 dB
experimental E_b/N_o at BER = 10^{-4}	13.8 dB	12.6 dB	12.8 dB
Modem degradation at BER = 10^{-4}	2.5 dB	1.8 dB	4.0 dB

Table 10; Modem specifications

4.1.2. Codec design and specifications

To convert the analogue videophone signal, delivered by the PTI terminal equipment and having a spectrum up to 1.3 MHz (see Sect. 5), into a 8.448 Mbit/s data signal rather efficient source coding had to be performed. For the OTS experiments two codecs have been developed. The first one operates according to the well-known hybrid-DPCM principle [11] and a codec description is given in [13].

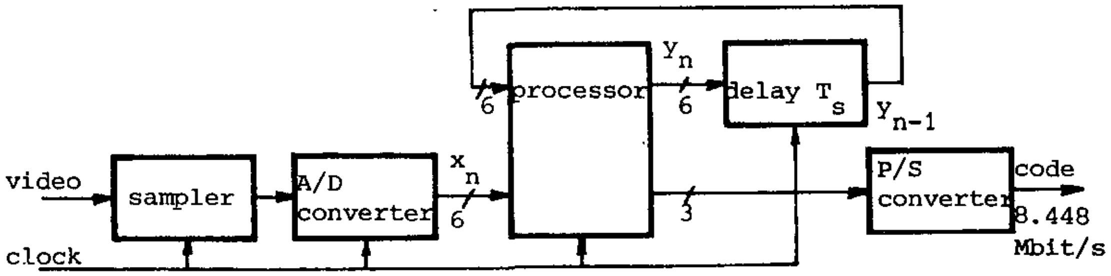
The second codec uses a sequential combination of PCM and DPCM. This is performed by defining 5 proportional levels with spacing S (known as levels A, B, C, D and E), and 7 *sub-levels* around each absolute level. Thus each of 35 quantization levels can be reached from a certain proportional level by means of differential quantization *steps* +Δ, 0, -Δ. As the coding had to be done with 3 bits/pixel, there are only eight possible code words per sample. Five of them are reserved for the proportional levels. With the remaining three code words the differential steps +Δ, 0, -Δ can be coded (see Table 11).

level/step	A	B	C	D	E	+Δ	0	-Δ
code word	000	001	010	011	100	111	101	110

Table 1: Code words for proportional quantization levels and differential quantization steps.

Coding operation

Fig. 2 gives the simplified block diagram of the coder.



$$f_s = \frac{1}{T_s} = 2.816 \text{ MHz}$$

Fig. 9: Simplified block diagram of the coder.

After sampling at $t = nT_s$ and A/D conversion, the processor compares a digitized input sample x_n with the previous reconstructed value y_{n-1}. Depending upon the difference $|x_n - y_{n-1}|$ being greater or smaller than $\frac{1}{2}S$, either a proportional quantization *level* or a differential quantization *step* is chosen to generate the next output code word.

Features of the sequential DPCM codec

1. Unlike a DPCM codec, the sequential DPCM codec shows hardly any slope-overload. Due to the five absolute code levels, fast signal changes can be tracked. However, this gives a rather rough approximation in the event of large discrete changes in the video signal. These great quantisation errors do occur in very small picture areas only. Fortunately, luminance errors in small areas can hardly be perceived.
2. There is no significant error propagation due to transmission bit errors. When a transmission bit error causes a luminance error in

the reconstructed picture, this error will be completely eliminated at the first correctly received code word belonging to any of the proportional levels (A,B,C,D,E).

The sequential DPCM codec is more extensively described in [9].
The following table summarizes the specifications of the two developed codecs.

codec	hybrid-DPCM	sequential DPCM
resolution	270 pixels/line	330 pixels/line
sampling frequency	2.112 MHz	2.816 MHz
bits/pixel	4	3
bitrate	8.448 Mbit/s	8.448 Mbit/s
quantization error	1.5-20% of full scale	2.8-20% of full scale
programmable coding algorithm	no	4 coding algorithms

Table 12 : Codec specifications.

4.1.3. Specification of Up and Down Converter at EUT.

Up and Down Converters were developed at EUT with the specifications summarized in table 13.
For block diagrams see fig. 3 and fig. 5. Details of the Up and Down Converters developed for use in Huizen are available in [8].

Specification	Upconverter	Downconverter
Input frequency (1 dB)	70 ± 4 MHz	A2, A4, B
Input impedance	50 Ω	waveguide
Input return loss	> 21 dB	---
Input level	- 9 dBm	-107 dBm
Noise figure (SSB)	11 dB	7.5 dB
Translating Freq. stab.	< 5 kHz/month	< 15 kHz/month
Output frequency	A2, A4, B	70 MHz ± 4 MHz
Output impedance	waveguide	50 Ω
Output VSWR	1.5	1.1
Output level	- 4 dBm	- 0,2 dBm
Gain variation (ripple)	0.5 dB	0.5 dB
Gain slope	0.01 dB/MHz	0.2 dB/MHz
Output 3 order inter-mod. intercept	+5 dBm	+26 dBm
Phase noise (SSB)	fig.10, fig.11	
Inband spurious *	< -80 dBm	< -59 dBm
Outband spurious *	< -64 dBm	< -15 dBm
Rejection of LO, Imag. *	< -64 dBm	
* with input level -9 dBm		

Table 13: Specification of Up and Down Converter for OTS operation (SCPC operation compatible).

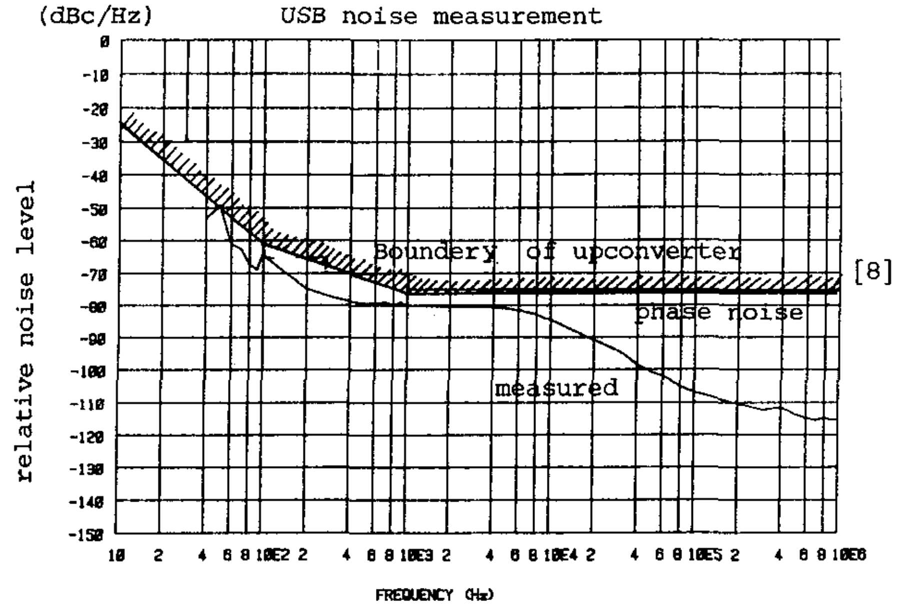


Fig. 10: Measured phase noise spectrum of Hzn up converter.

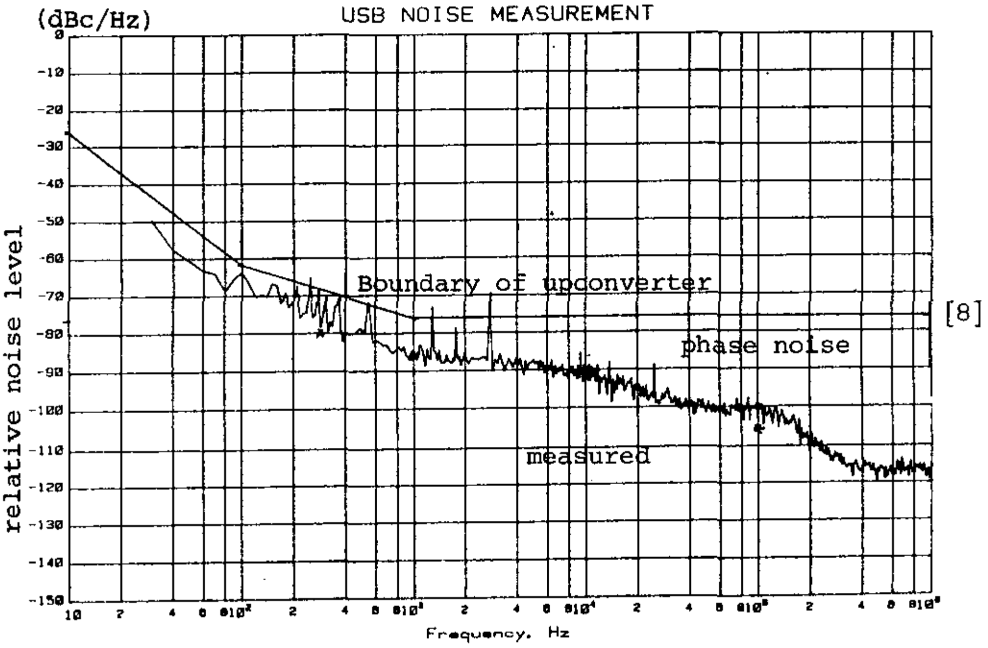


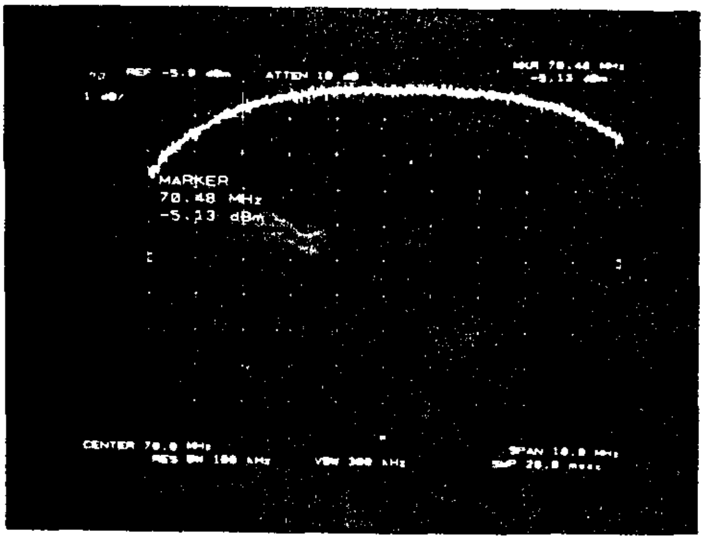
Fig. 11: Measured phase noise spectrum of EUT up converter.

* Spectrum analyser phase noise.

4.2. Measurement results.

4.2.1. Satellite transfer characteristics.

The amplitude characteristic of the translator loop (B transponder) is measured on IF level and displayed in fig. 12.

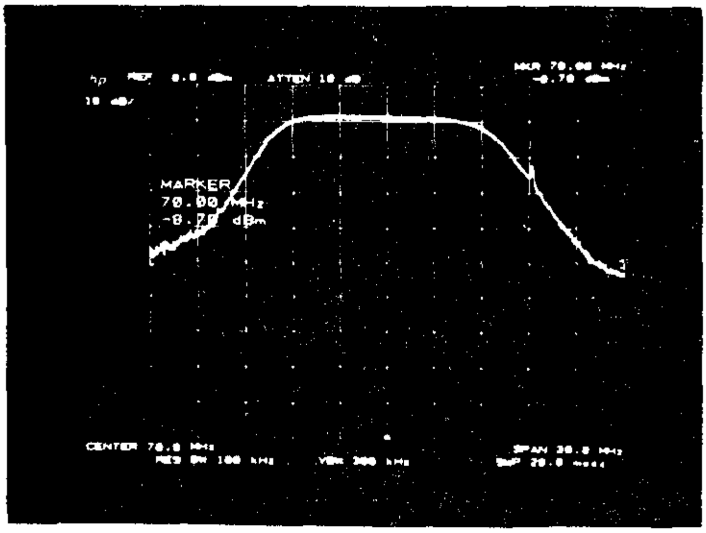


Spectrum Analyser setting:

res. bw.: 100 kHz
vid. bw.: 300 kHz
swp time: 20 msec
function: MAX HOLD
centre freq.: 70 MHz
span: 10 MHz
power level: 1 dB/div.
ref. lev.: -5 dBm
att.: 10 dB

Fig. 12: Amplitude characteristic of the translator loop (module B).

The amplitude characteristic of the satellite loop (B transponder) is displayed in fig. 13. In the band 65.5-74.5 MHz the amplitude variation is smaller than 0.8 dB



spectrum analyser setting:

res. bw.: 100 kHz
vid. bw.: 300 kHz
att.: 10 dB
ref. lev.: 0 dBm
span: 30 MHz
swp time: 20 msec
centre freq.: 70 MHz
power lev.: 10 dB/div.
function: max. HOLD

Fig. 13: Amplitude characteristic of the satellite loop (module B).

The power transfer characteristics of module B (channel 1r), and module A (channel A2) are given in fig. 14 and fig. 15 respectively.

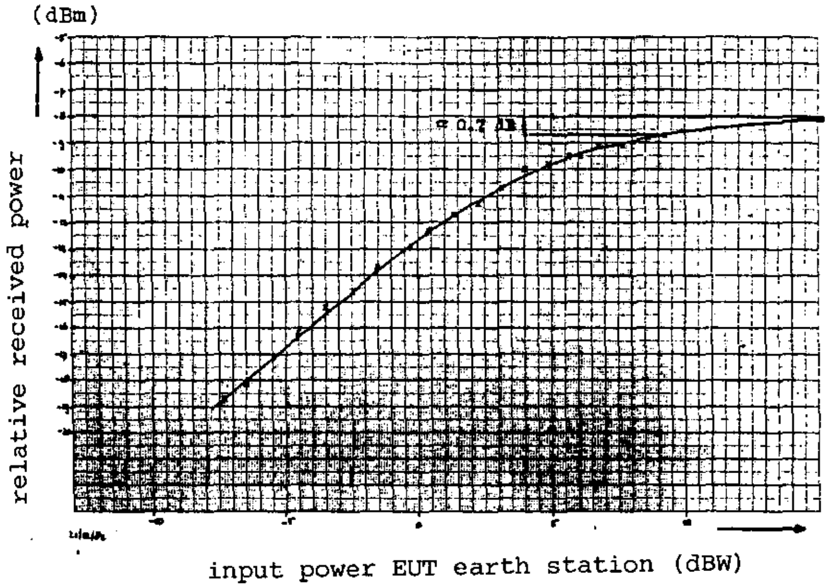


Fig. 14: Satellite power transferfunction (module B channel 1r, gainstep 6).

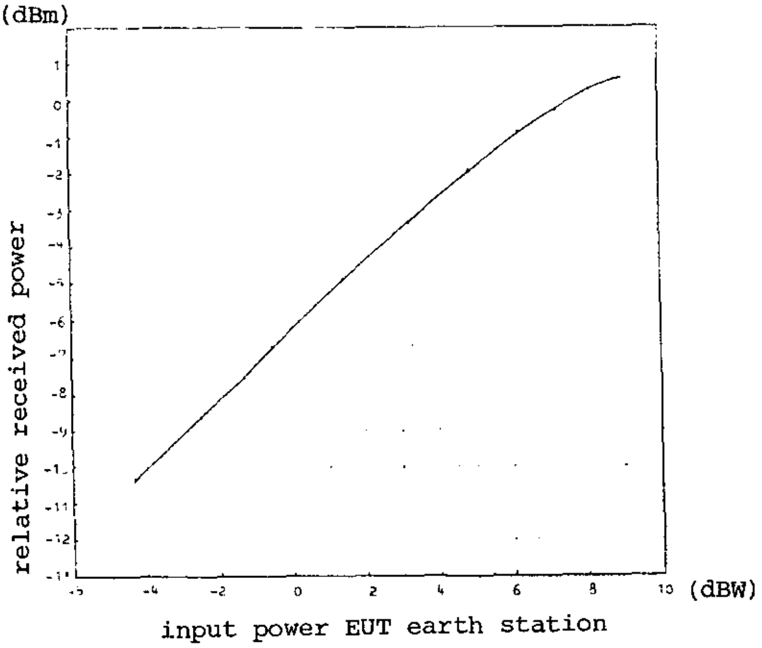


Fig. 15: Satellite power transfer function (module A channel A2, gainstep 15).

4.2.2. Comparison of direct and indirect modulation spectra.

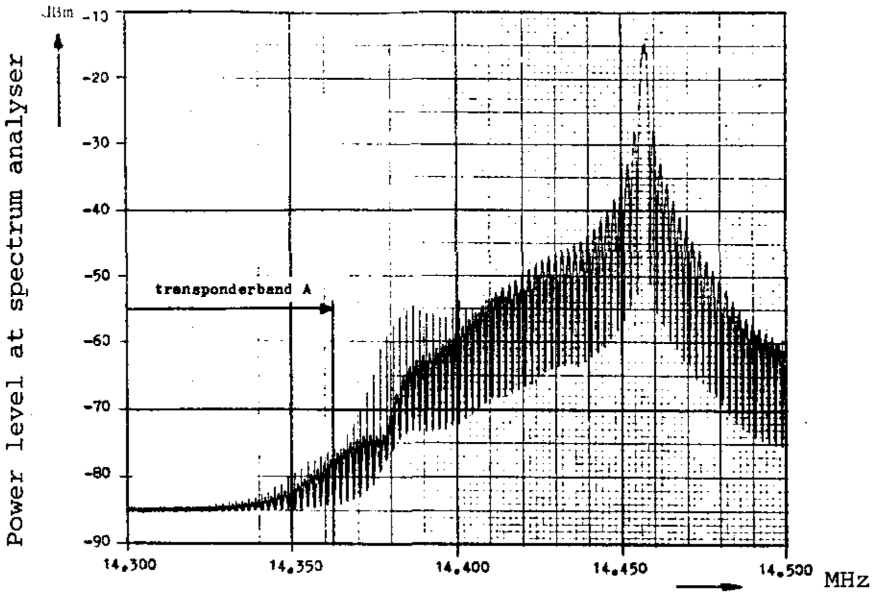


Fig. 16: Transmitted RF signal spectrum of the 4 Mbit/s direct DE-QPSK modulator.

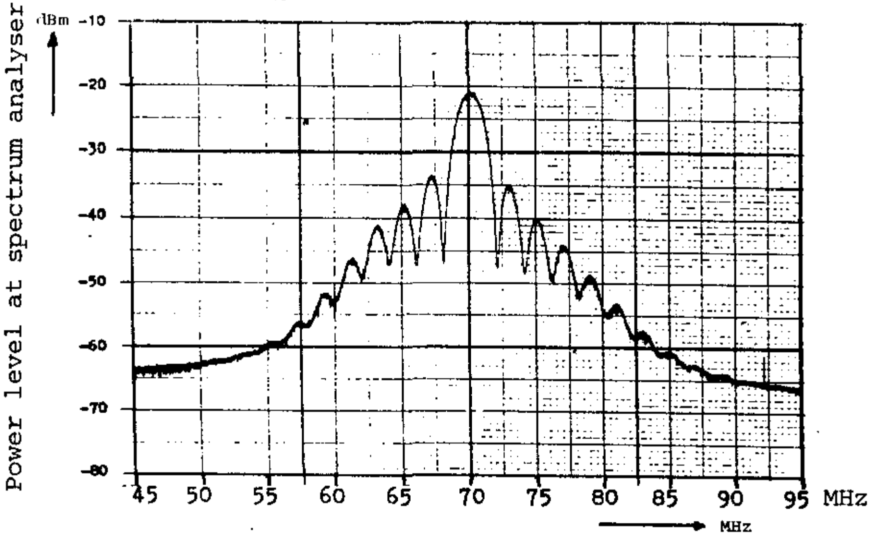


Fig. 17: Signal spectrum of the 4 Mbit/s direct DE-QPSK modulator after transmission via the translator loop.

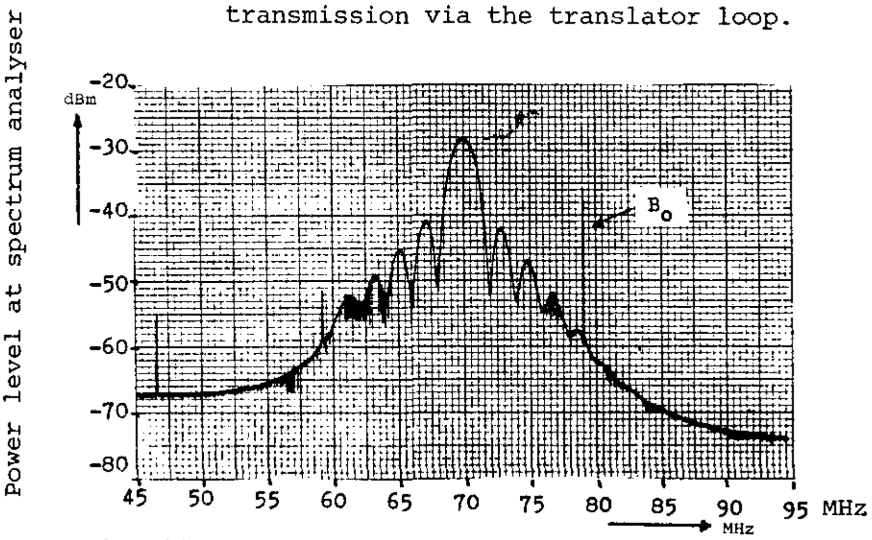


Fig. 18: Signal spectrum of the 4 Mbit/s direct DE-QPSK modulator after transmission via the satellite loop (B transponder).

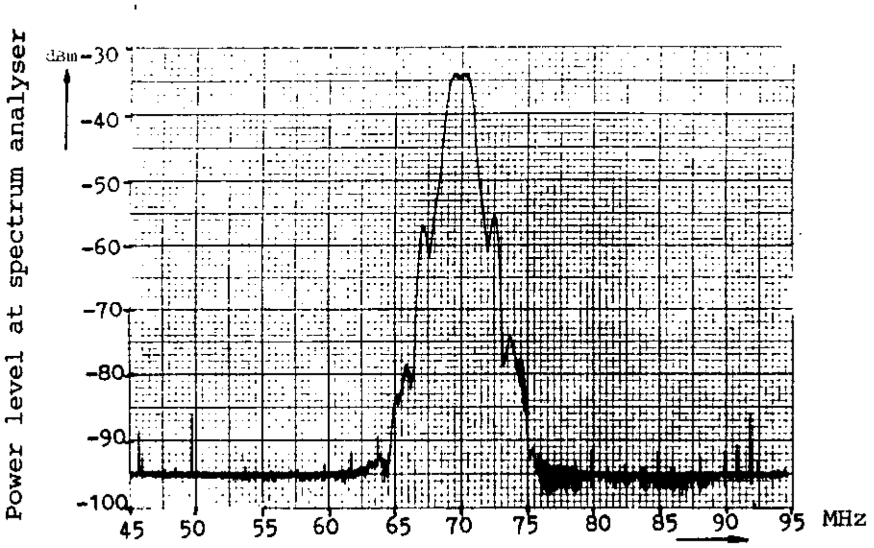


Fig. 19: Signal spectrum at the output of the 4 Mbit/s indirect DQPSK modulator.

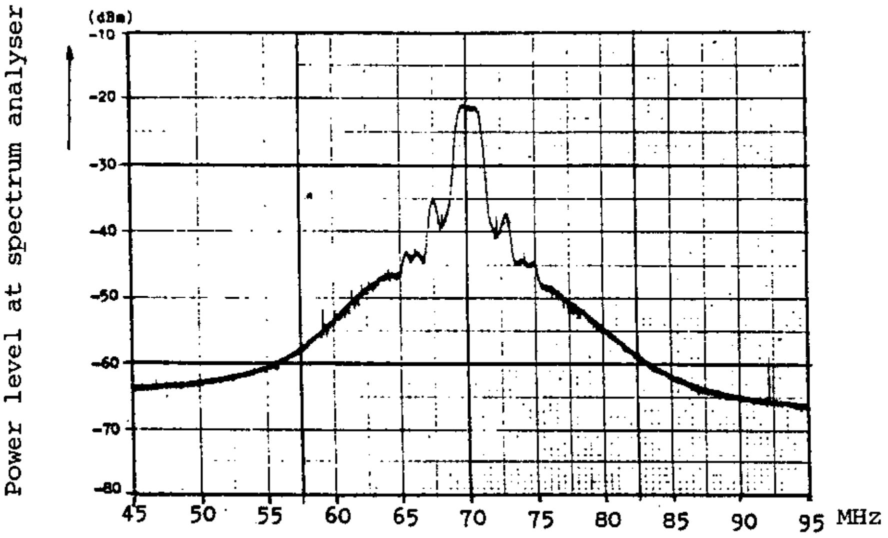


Fig. 20: Signal spectrum of the 4 Mbit/s indirect DQPSK modulator after transmission via the translator loop.

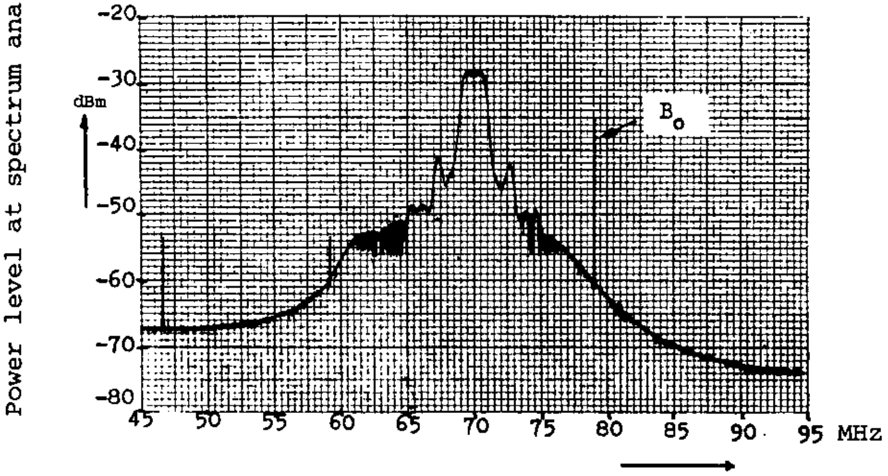


Fig. 21: Signal spectrum of the 4 Mbit/s indirect DQPSK modulator after transmission via the satellite loop (B transponder).

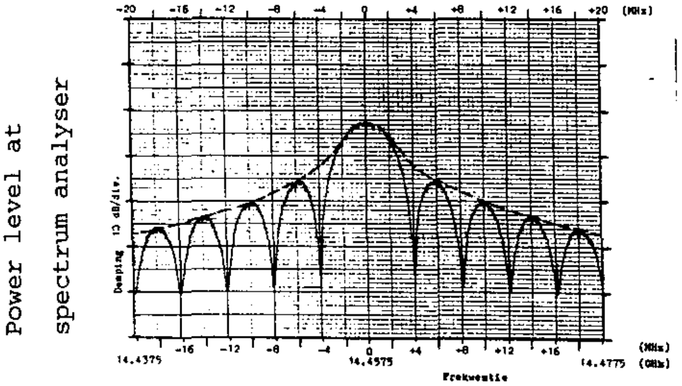


Fig. 22: Signal spectrum of the 8.448 Mbit/s direct DE-QPSK modulator.

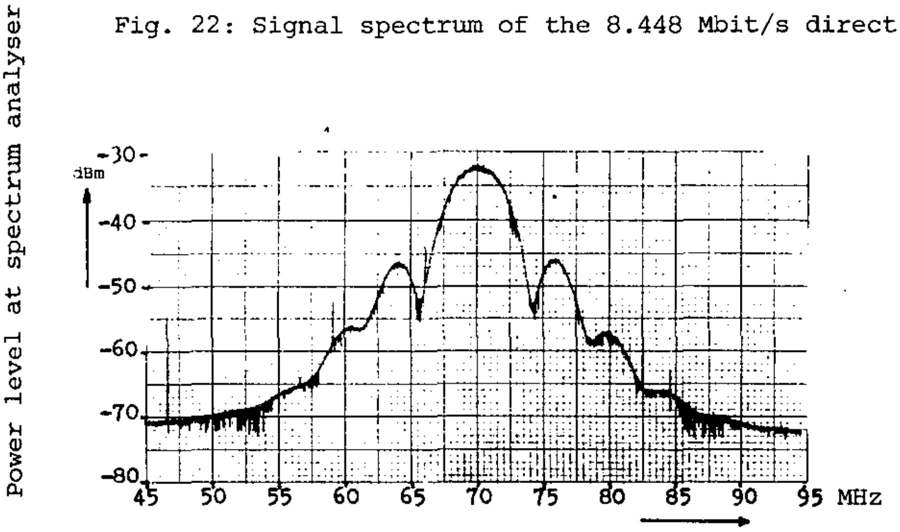


Fig. 23: Signal spectrum of the 8.448 Mbit/s direct DE-QPSK modulator, after transmission via the translator loop.

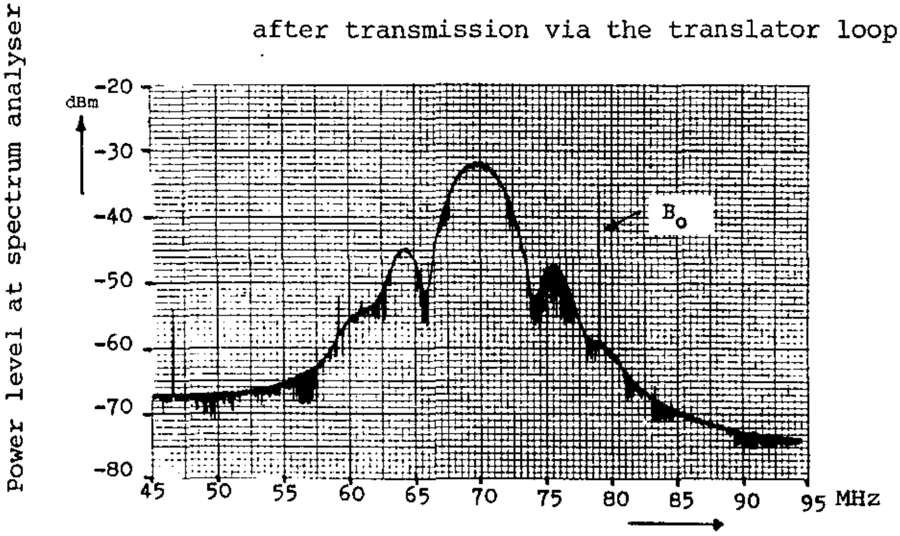
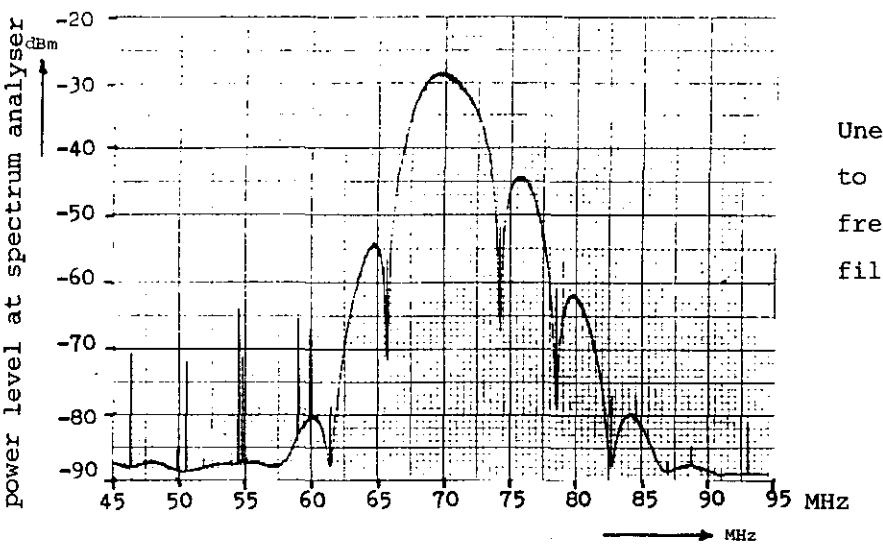
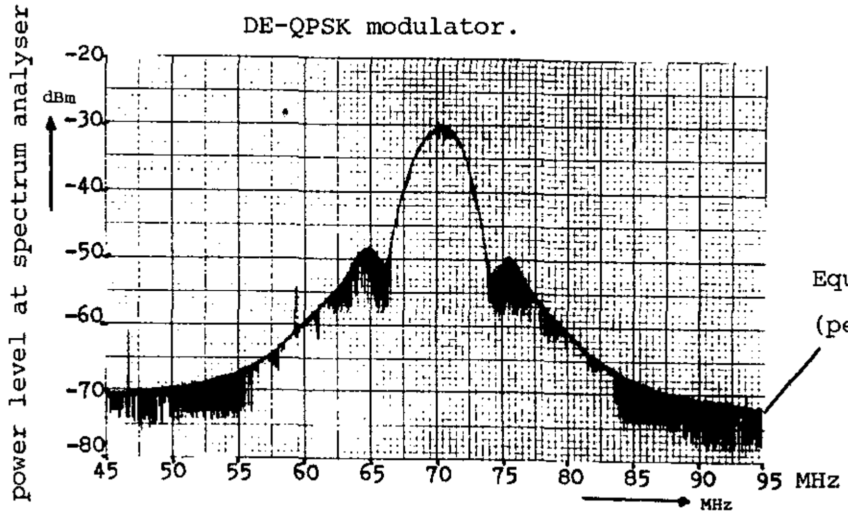


Fig. 24: Signal spectrum of the 8.448 Mbit/s direct DE-QPSK modulator, after transmission via the satellite loop (B transponder).



Unequal side lobes due to offset of center frequency from pre filter.

Fig. 25: Signal spectrum at the output of the 8.448 Mbit/s indirect DE-QPSK modulator.



Equipment failure (pen jitter).

Fig. 26: Signal spectrum of the 8.448 Mbit/s indirect DE-QPSK modulator, after transmission via the translator loop.

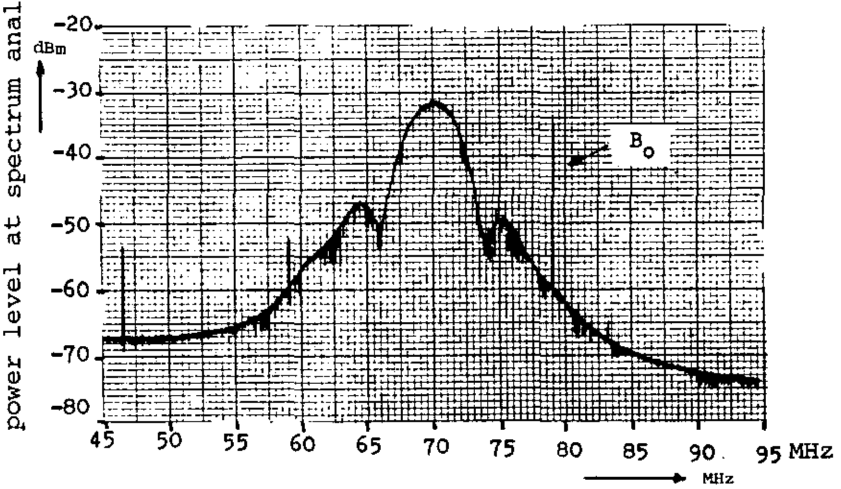


Fig. 27: Signal spectrum of the 8.448 Mbit/s indirect DE-QPSK modulator, after transmission via the satellite loop (B transponder).

4.2.3. BER measurements.

The overall C/N_0-value which was measured after transmission via the B-transponder was C/N_0 = 86.9 dBHz, about 1.4 dBHz worse than to be expected from the link budget calculation (see table 8).
Dividing C/N_0 by the number of bits/s gives an actual E_b/N_0 = 17.6 dB. By adding a controlled amount of white Gaussian noise at the demodulator input (see fig. 2) the E_b/N_0 value could be varied and the corresponding BER measured.
Fig.28 shows the resulting BER versus E_b/N_0 for the 8.448 Mbit/s DE-QPSK (direct and indirect) modulation via the B transponder. The BER curves for the direct DE-QPSK modulation were considerably better then those for the indirect modulation. For the indirect DE-QPSK modulation the modem degradation ranges from about 4 dB at a BER of 10^{-3} up to 4.6 dB at a BER of 10^{-6}. During the BER measurements the HPA of the EUT earth station was adjusted to 1 dB back-off, while the B transponder gain step setting was step 6. The BER curves for the DQPSK modems were measured via the A2 transponder. For the 4 Mbit/s DQPSK modem, the modem degradation ranges from about 2.3 dB at a BER of 10^{-3} up to about 3.2 dB at a BER of 10^{-7} (see fig.29).
In case of loop-back operation via the test translator loop and via the OTS A2 transponder these figures were increased by about 0.4 dB only.
For the 8.448 Mbit/s DQPSK modem, the modem degradation was about 1.5 dB at a BER of 10^{-3} up to about 2.3 dB at a BER of 10^{-7} (see fig.30). For loop-back transmission via the test translator loop, these figures were increased by about 1 to 1.5 dB and loop-back transmission via the A2 transponder yielded a degradation of about 0.8 dB.
Finally, BER curves were measured for the 32 kbit/s DE-QPSK SCPC modem via the A2 transponder. These curves are shown in fig.31
The modem degradation was about 2 dB. Loop-back transmission via the test translator did only give degradation at very low BER values. Transmission via the A4 transponder yielded a degradation of about 0.6 dB.

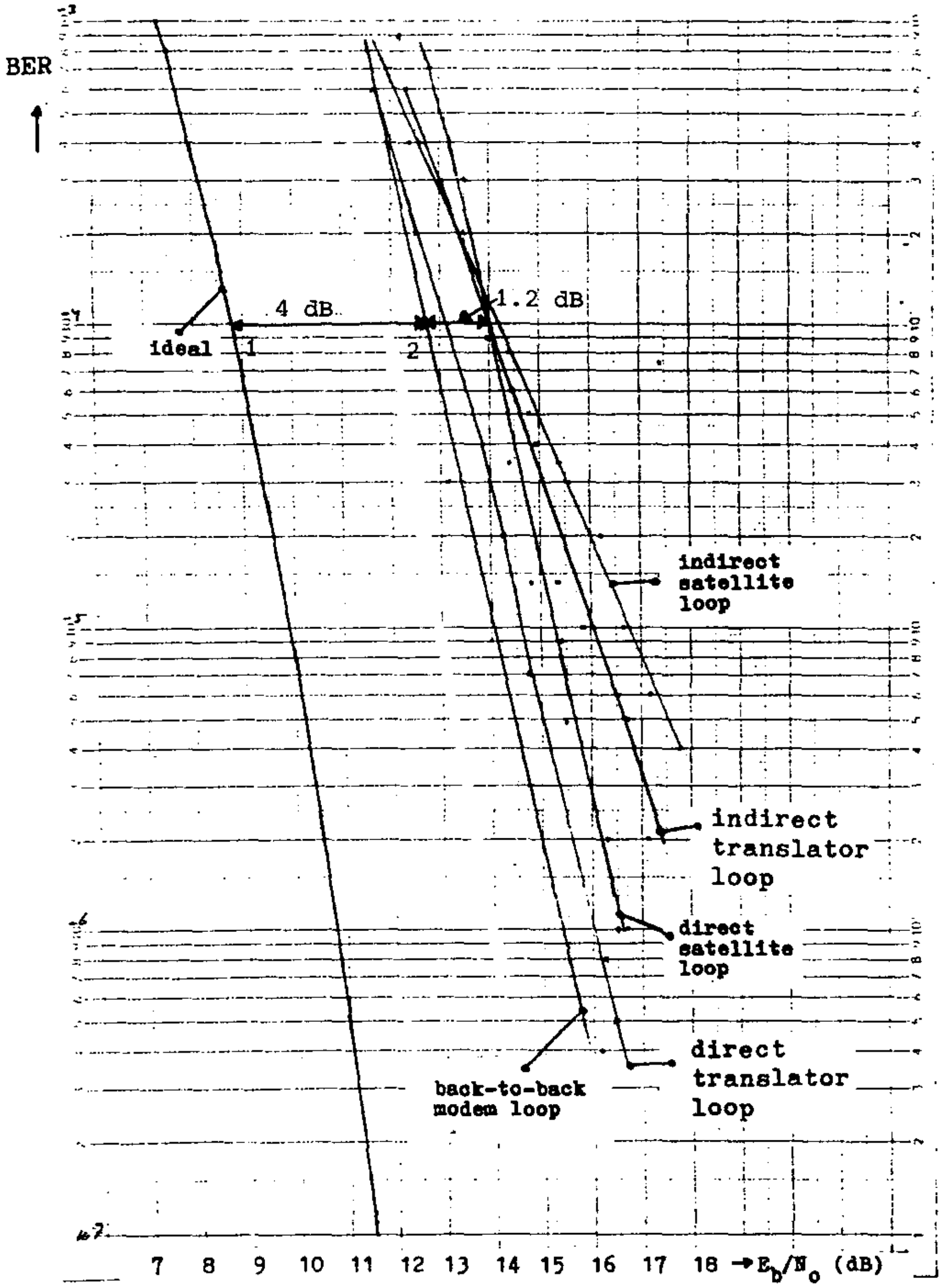


Fig. 28: The BER versus E_b/N_0 for the 8.448 Mbit/s DE-QPSK modulation (direct and indirect) via the B transponder.

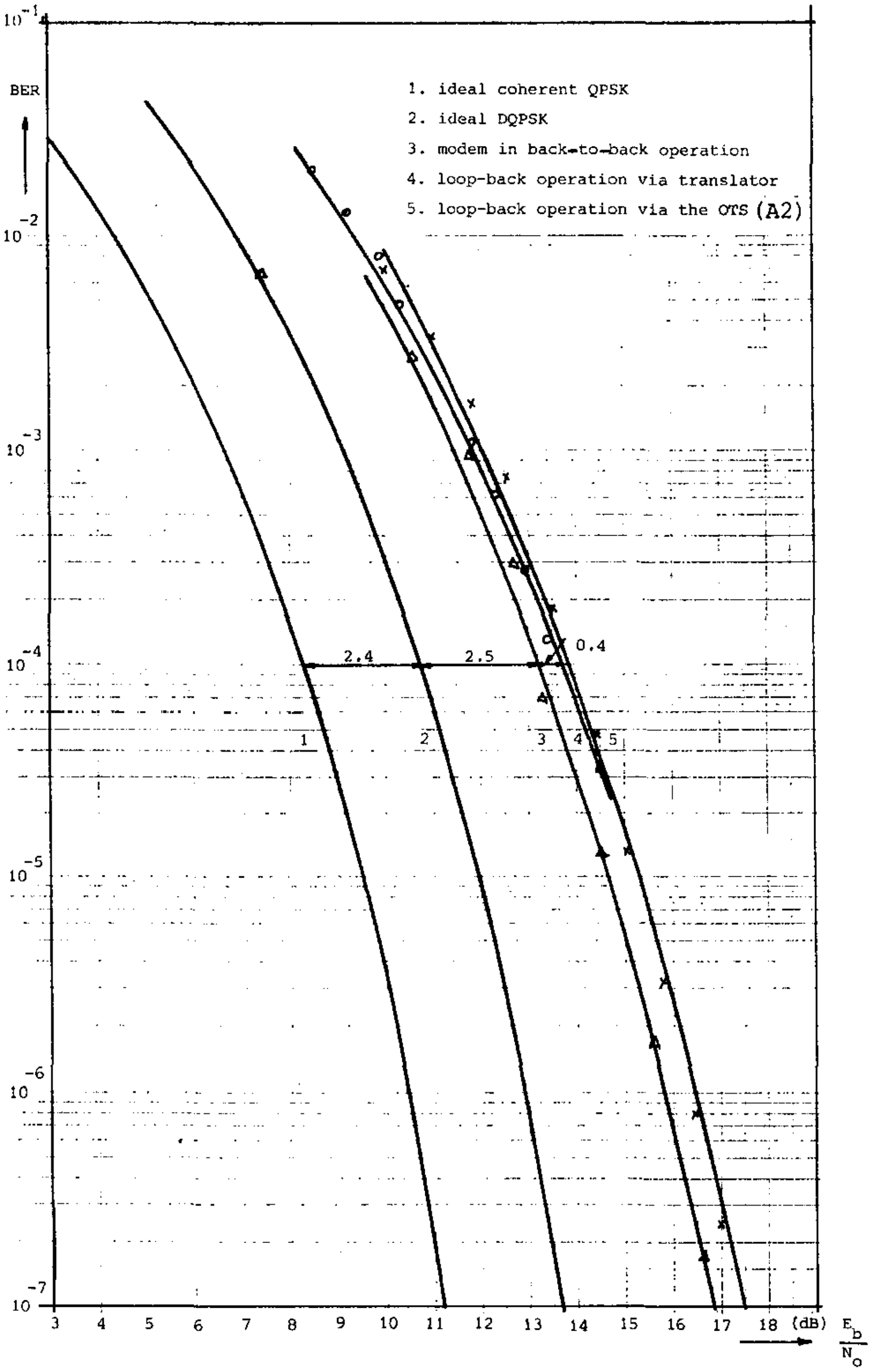


Fig. 29: The BER versus E_b/N_0 for the 4 Mbit/S DQPSK modem via the A2 transponder.

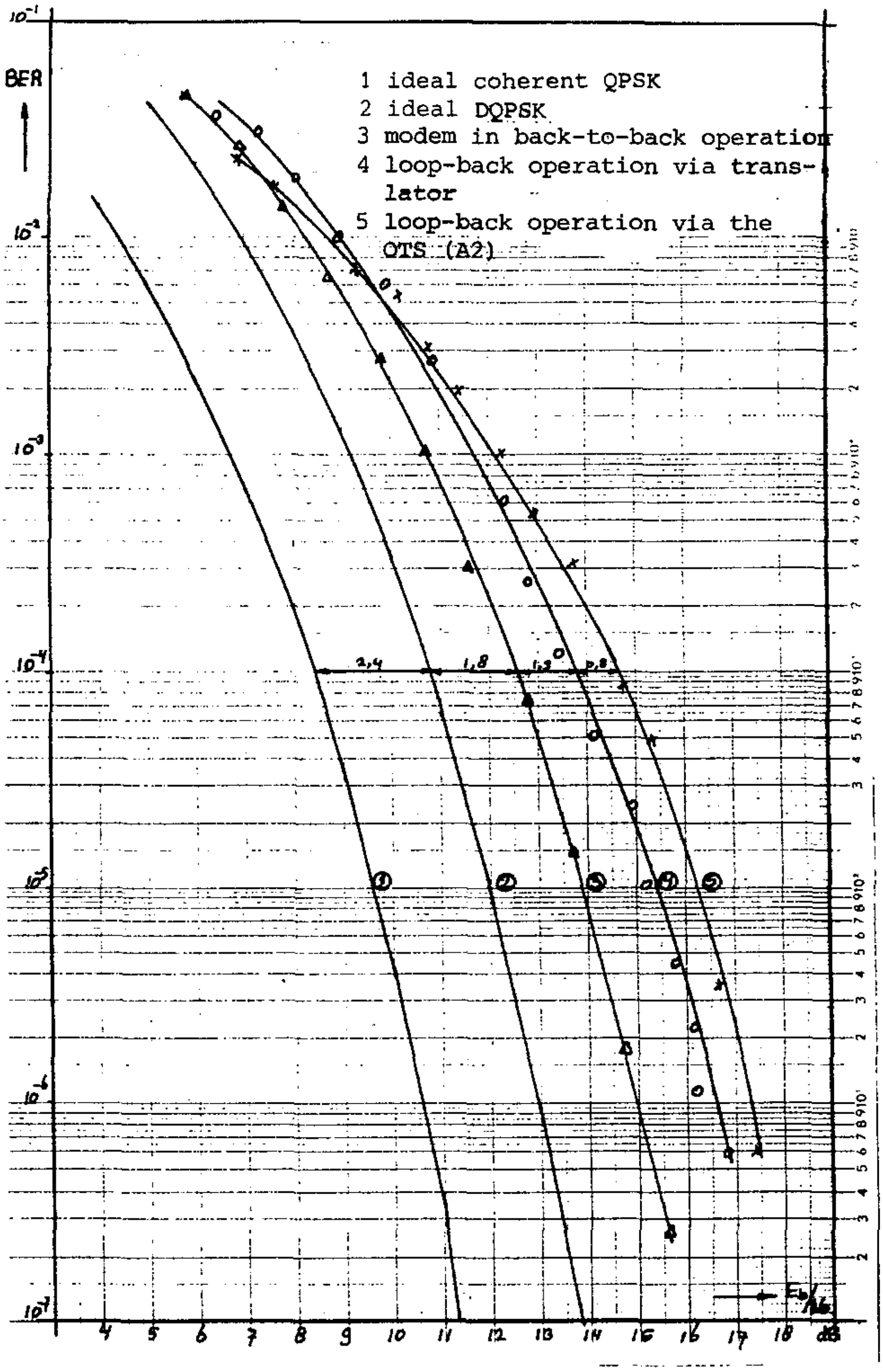


Fig. 30: The BER versus E_b/N_0 for the 8.448 Mbit/s DQPSK modem via the A2 transponder.

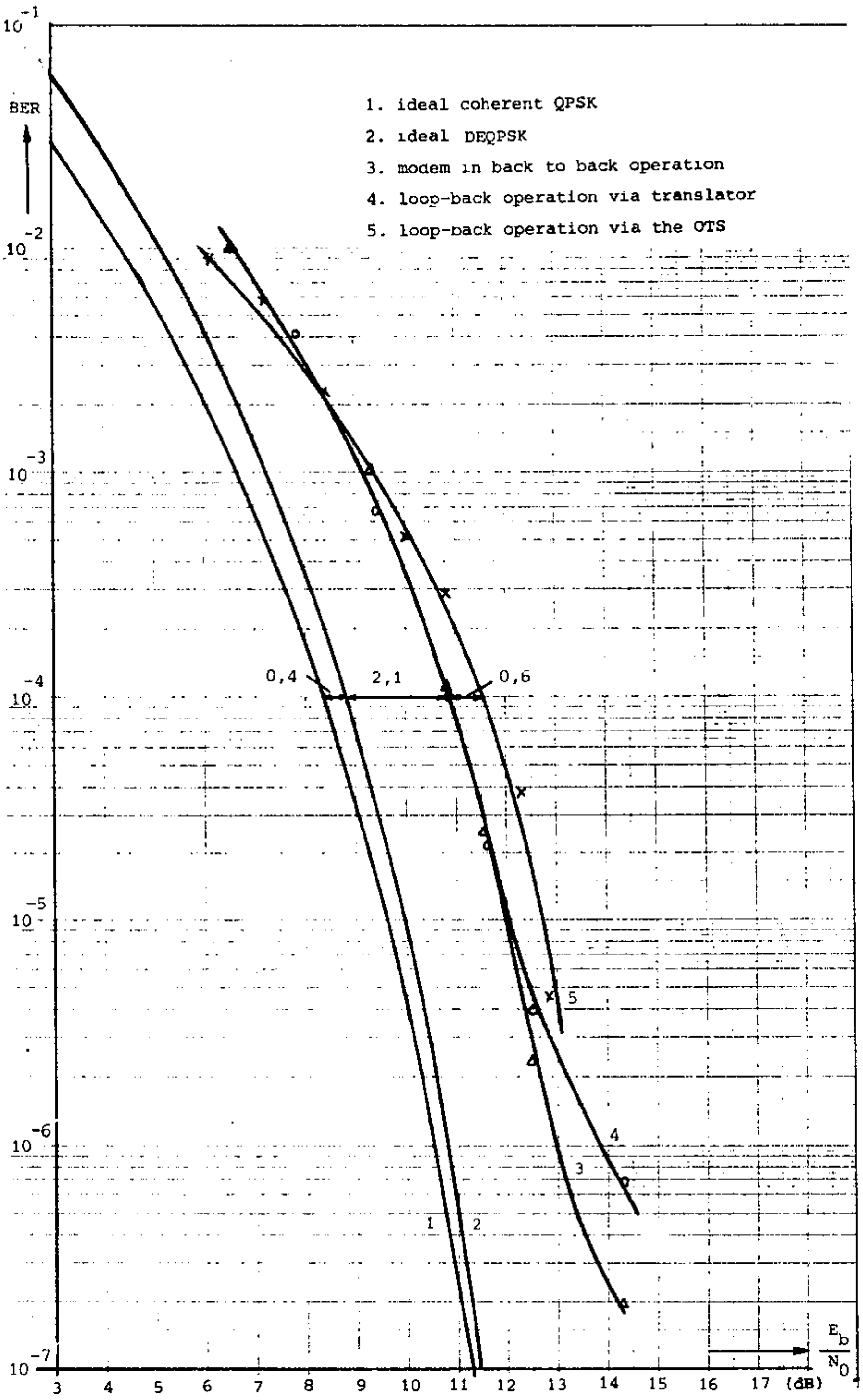


Fig. 31: The BER versus E_b/N_0 for the 32 kbit/s DE-QPSK modem via the A4 transponder.

4.2.4. Intermodulation measurement via channel A2.

To measure the third order system intermodulation, two equal amplitude carriers of approximately 70 MHz with a frequency spacing of 13.5 kHz were fed into the upconverter. The received signal via channel A2 with different power levels is displayed in fig. 32a, b, c and d.

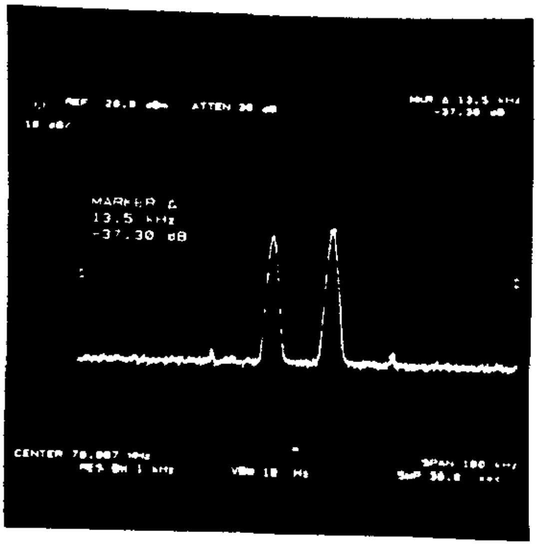


Fig. 32a: Input power 24.1 dBm

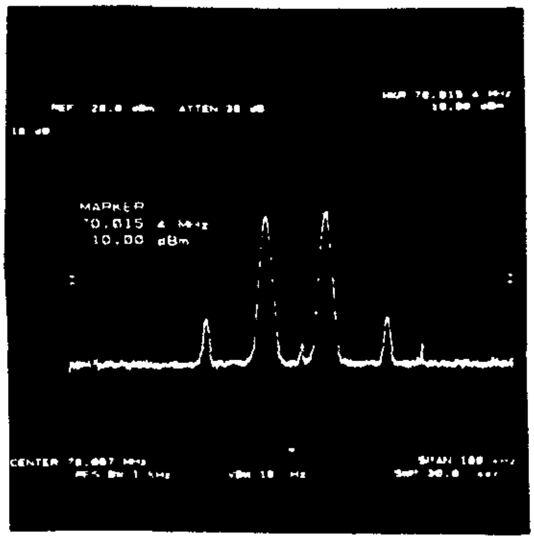


Fig. 32b: Input power 29.5 dBm

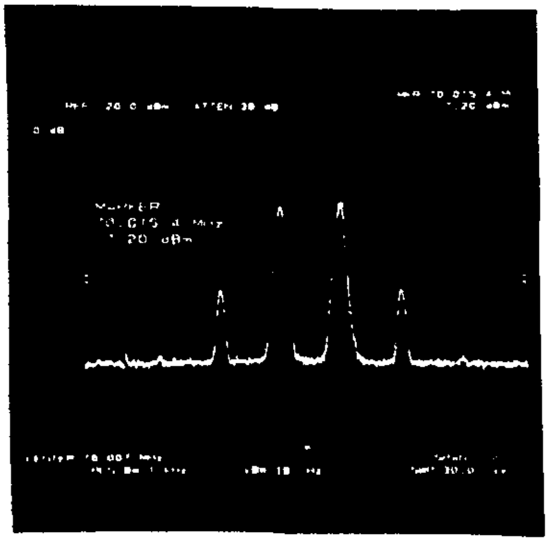


Fig. 32c: Input power 32.5 dBm

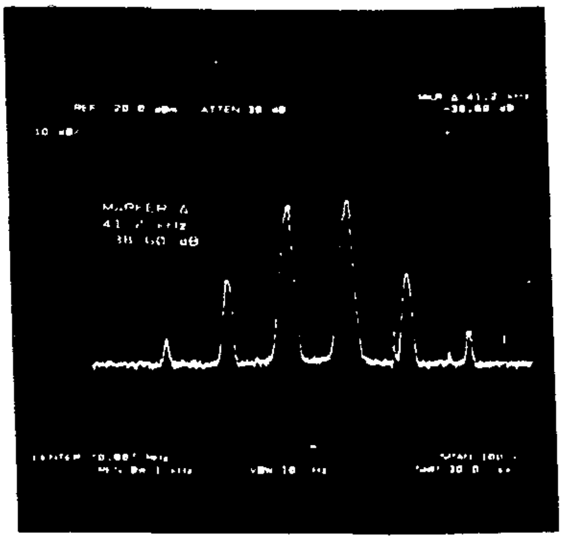


Fig. 32d: Input power 35.05 dBm

Received signal via module A channel A2 of OTS in response to two equal carriers at~70 MHz frequency, as a function of the antenna input power level. The third- and fifth-order intermodulation signals are clearly displayed in fig. 32c and d.

In fig. 33 the received (relative) signal power of one carrier and the third-order intermodulation relative signal power of one component is shown as function of the antenna input power with transmission via the OTS channel A2.

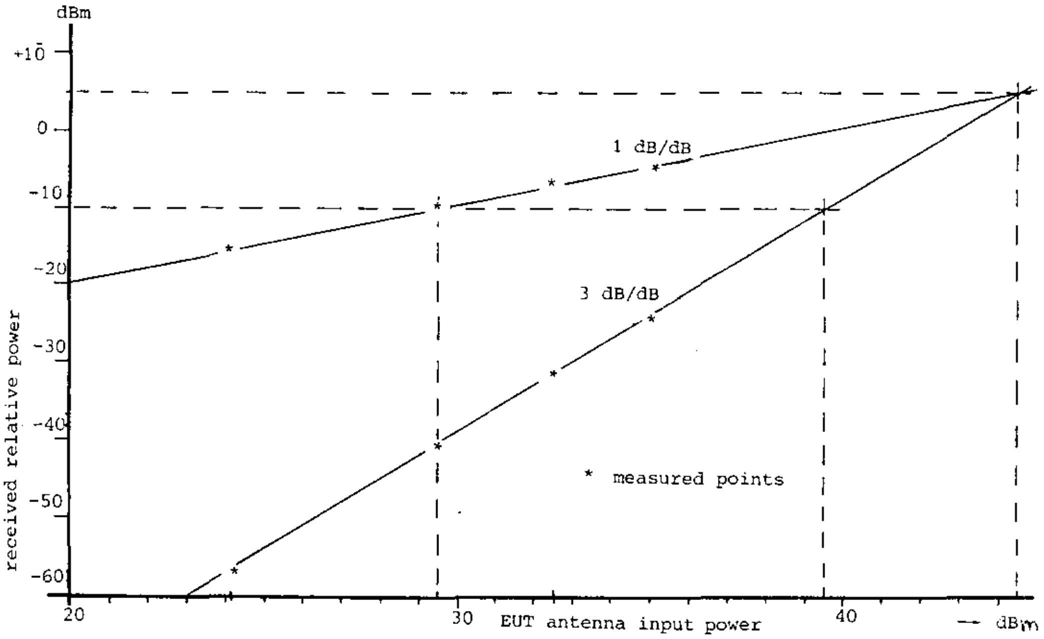


Fig. 33: Third-order intermodulation discrimination with OTS channel A2 transmission via EUT earth station (8m dish).

5. System demonstrations.

5.1. Videophone experiments.

Videophone experiments were performed via the B, A2 and A4 transponders making use of digital transmission at 8.448 Mbit/s. The system set-up is shown in fig. 35. The videophone terminal equipment was provided by Philips Telecommunication Industries. A videophone picture consists of 312 lines. The baseband signal contains analog video information and a digital "sound in sync" signal of 1 Mbit/s. The bandwidth of the baseband signal ranges up to 1.3 MHz. The digital codec developed for this application is described in section 4.1.2.

An impression of the picture quality before and after transmission via the B transponder is given by fig. 34. On the left the original picture is displayed and on the right the picture after transmission. The transmission delay of 0.27 s. is nicely illustrated by the different phases of the metronome (in front) which was adjusted to a beat at 2 Hz. Note that on the left picture the shutter of the camera is open while on the right picture the shutter is still closed.

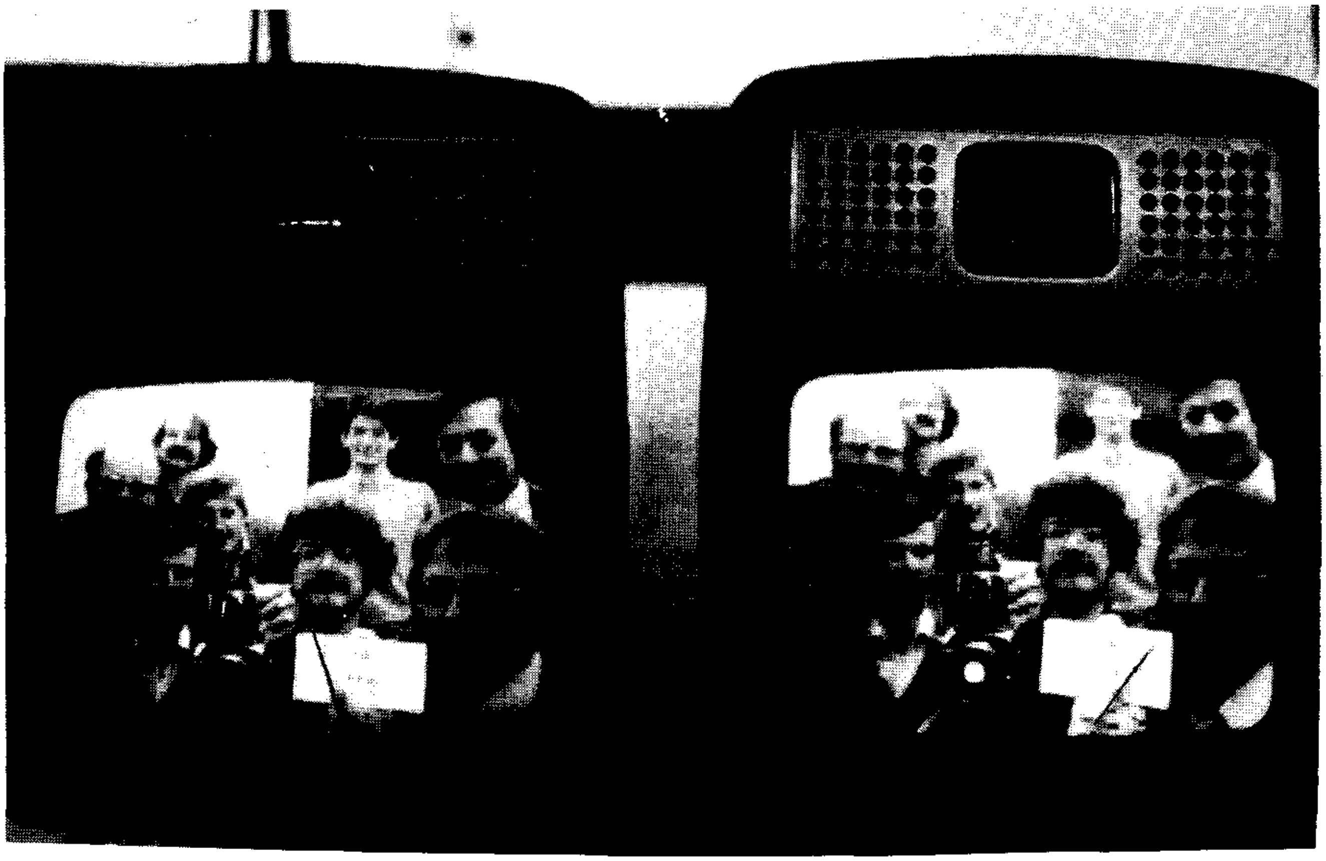


Fig. 34: Videophone demonstration via the B transponder.

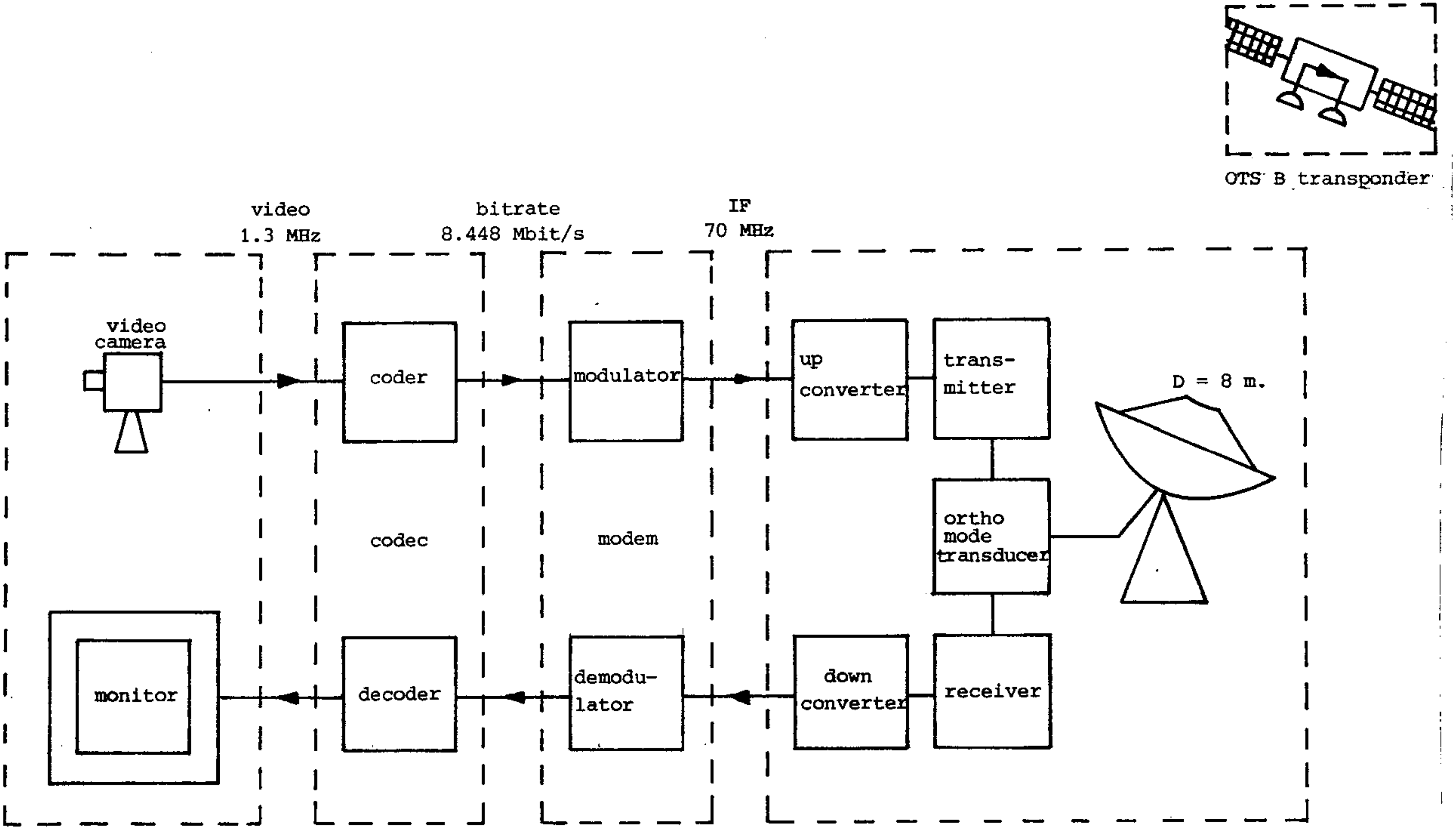


Fig. 35: System set-up for videophone demonstration via OTS at EUT in loop-back operation.

5.2. SCPC experiment.

The blockdiagram of the SCPC experiment is shown in fig. 37. In more detail the modem, codec and multiplexing are shown in fig. 36.
SCPC measurements were made in a configuration with the 8m dish in Eindhoven and the 3m dish in Huizen via channel A2.
The measured C/N_0 was close to the calculated value.
Measurements of the BER were made and are shown in fig. 31.

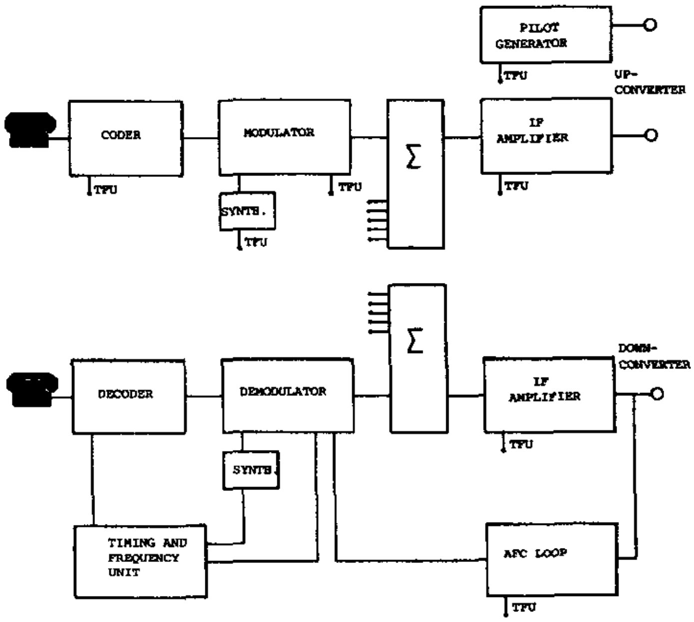


Fig. 36: Block diagram of SCPC unit (Courtesy PTI).

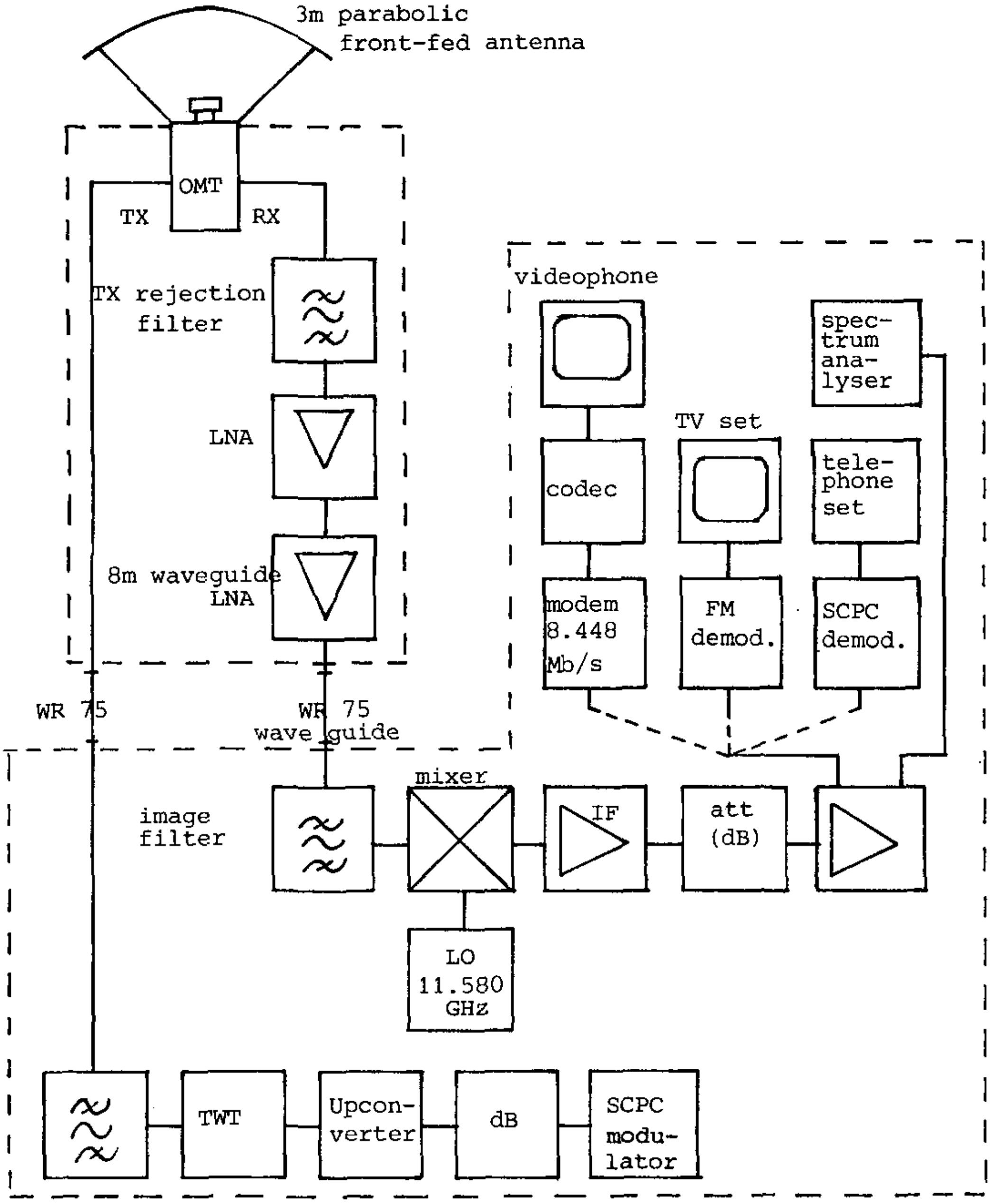


Fig. 37: Earth station at Huizen used for OTS transmission experiments (Dutch data experiments).

6. Conclusions

6.1. With respect to the objectives of the experiment (Appendix 1.1) the general conclusion can be that all the objectives are obtained.

6.2. Three modems were designed and implemented. The test results show that their performance was reasonable. The modem degradation was 1.8 dB and 3.0 dB for the two DQPSK modems at 8.448 and 4 Mbit/s and 4 dB for the DEQPSK modem with coherent detection, at a bit error rate of 10^{-4} in back to back operation at a bitrate of 8.448 Mbit/sec.

6.3. Two video codecs at a bit rate of 8.448 Mbit/s were implemented. One codec is designed according to the hybrid DPCM principle and the second one is using a sequential combination of PCM and DCPM. The last one according a new principle (sequential DPCM) which seems to be suited for video applications with cheap codecs.

6.4. An up and down converter, a low-noise amplifier and a translator loop were implemented and applied.

6.5. Digital transmission experiments were carried out at bitrates of 32 kbit/s, 4 Mbit/s and 8.448 Mbit/s, via the B transponder, A2 and A4 transponder.
The measured BER curves are near the expected values.

6.6. The digital tranmission experiments proved that the non-linear satellite channel has little effect on the BER.

6.7. A comparison was made between the direct and the indirect modulator. Although the direct modulator showed a good performance, the adjacent channel interference is still a problem for bitrates lower than approximately 8 Mbit/s.

6.8. The impact of phase noise on digital transmission was studied; especially for low bit rates the necessity of tight phase noise specifications has been experienced.

6.9. A system demonstration was given with 32 kbit/s telephony SCPC.

6.10. A system demonstration was given with 8.448 Mbit/s videophone-equipment.

7. Acknowledgement

A very valuable spin-off from the experiments reported here was the fact that in total 16 graduate students gained direct experience in satellite communications.
The staff and students in the Telecommunications Division of the Eindhoven University of Technology (EUT) are very grateful for the outstanding opportunity renderedby EUTELSAT and the Netherlands PTT administration to perform digital transmission experiments via the Orbital Test Satellite (OTS).
They would also like to thank Philips Telecommunication Industries (PTI) for their advisory support and for providing some necessary microwave and video equipment.
Finally, the authors of this document would like to acknowledge Messrs. Holleboom, Manders, Stal, Swijghuisen, van der Vorst and Wijdemans and Mrs. Kroontje and Pellegrino, whose technical and administrative support made it possible to carry out and report on this programme.

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Appendix 1: Proposal for Dutch data experiment with OTS submitted to and approved by EUTELSAT.

Experimenters would like to submit the following application for using OTS transponders A2 and A4.

1. Objectives:
   - development and testing of 12/14 GHz equipment for digital communications for special services (up to 8 Mbit/s).
   - measurement of BER as function of bits/s during average weather conditions.
   - comparison of some modulation equipment (IF modulator plus up converter/switched RF modulator).
   - system demonstration with 4 and 8 Mbit/s DPSK and with 32 kbit/s telephony.

   It is the intention to demonstrate a videosystem operating at 8 Mbit/s and a SCPC telephony system at 32 kbit/s.
2. Experimenters: Telecommunications Division, Department of Electrical Engineering, Eindhoven University of Technology, the Netherlands.
3. Administration submitting: Netherlands PTT.
4. Countries involved: The Netherlands only.
5. Signals to be transmitted:
   - 5.1. Swept carrier for channel characterisation (differential gain and phase)
   - 5.2. QPSK signal 2 Mbit/s, 4 Mbit/s, QPSK 32 kbit/s DCDM
   - 5.3. QPSK signal 8 Mbit/s
   - 5.4. FM modulated telephony signal (only for comparison).
6. Repeater: Module A, channels A2 and A4 (exclusive use).
7. Period of implementation: 1 May 1983 to 1 Jan. 1984.
8. Total time: Approximately 30 hours in total (subject to confirmation) (20 hours A2, 10 hours A4).
9. Daily time: Between one and three hours during working day.
10. Earth stations:
    - 10.1. Receive/transmit antenna diameter 8 m, noise figure 5 dB, maximum transmit power 10 W (Eindhoven).
    - 10.2. Receive/transmit antenna diameter 3 m, noise figure 4 dB, maximum transmit power 1 W (Eindhoven).
    - 10.3. Receive/transmit antenna diameter 3 m, noise figure 3 dB, transmit power 1 W. For digital TV-signals up to 8 Mbit/s receive-only operation and receive/transmit operation for 1 channel SCPC 32 kbit/s.

      Subject to approval by the Netherlands PTT this station may be placed in Huizen (NL) where a student from EUT (Eindhoven University of Technology) will be persuing his M.Sc. degree at Philips Telecommunications Industries.
11. Organization responsible: Telecommunications Division, Department of Electrical Engineering, Eindhoven University of Technology, Postbox 513, 5600 MB Eindhoven, The Netherlands.
    Phone 040-479111, twx 51163 thehvnl.
12. Points of contact principle: prof.dr. J.C. Arnbak, phone 040-473451.
13. Points of contact routine: J. Dijk or A.P. Verlijsdonk, phone 040-473417 or 473445.
14. Comments:

    Chief purpose of experiment is educational, and research and development in the field of digital satellite communications for special services.

Eindhoven, 6 May 1983.

Appendix 2

Specification of videophone equipment of Philips Telecommunication Industry.

Subscriber viewing distance	100 cm
camera height to desk top	40 cm
display tube	19 x 14 cm^2
lines per picture	313
field frequency	50 Hz
interlacing	2 : 1
aspect ratio	4 : 3
bandwidth	1.3 MHz
digital audio in sync.	
digital sync. burst	
synchronizing code word	

Appendix 3

Specification of SCPC equipment of Philips Telecommunication Industry.

BB (Hz)	300 - 3400
Encoding	DE-QPSK
Modulation	Digitally controlled delta modulation (DCDM)
Data rate (kbit/s)	32
IF band (MHz)	52 - 80
Channel spacing (kHz)	22.5
Demodulation	Coh. PSK double Costas loop

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