



INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

V.90

(09/98)

SERIES V: DATA COMMUNICATION OVER THE
TELEPHONE NETWORK

Simultaneous transmission of data and other signals

**A digital modem and analogue modem pair
for use on the Public Switched Telephone
Network (PSTN) at data signalling rates of
up to 56 000 bit/s downstream and up to
33 600 bit/s upstream**

ITU-T Recommendation V.90

(Previously CCITT Recommendation)

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DATA COMMUNICATION OVER THE TELEPHONE NETWORK

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Printed in Switzerland
Geneva, 1999

ITU-T RECOMMENDATION V.90

A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN) AT DATA SIGNALLING RATES OF UP TO 56 000 bit/s DOWNSTREAM AND UP TO 33 600 bit/s UPSTREAM

Summary

This Recommendation specifies the operation of a digital modem and analogue modem pair for use on the Public Switched Telephone Network (PSTN) at data signalling rates of up to 56 000 bit/s in the downstream direction and up to 33 600 bit/s in the upstream direction. The two modems are specified herein in terms of coding, start-up signals and sequences, operating procedures and DTE-DCE interface functionalities. The network interface of the digital modem and the signalling rate that is used to connect the digital modem locally to a digital switched network are considered to be national matters and are hence not specified herein.

Source

ITU-T Recommendation V.90 was prepared by ITU-T Study Group 16 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on the 25th of September 1998.

FOREWORD

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**A DIGITAL MODEM AND ANALOGUE MODEM PAIR FOR USE
ON THE PUBLIC SWITCHED TELEPHONE NETWORK (PSTN)
AT DATA SIGNALLING RATES OF UP TO 56 000 bit/s
DOWNSTREAM AND UP TO 33 600 bit/s UPSTREAM**

(Geneva, 1998)

1 Scope

This Recommendation specifies the operation between two different modems, one a digital modem and the other an analogue modem, both as defined in clause 3. The two modems are specified herein in terms of coding, start-up signals and sequences, operating procedures and DTE-DCE interface functionalities. The network interface of the digital modem and the signalling rate that is used to connect the digital modem locally to a digital switched network are considered to be national matters and are hence not specified herein. The principal characteristics of these modems are as follows:

- a) duplex mode of operation on the PSTN;
- b) channel separation by echo cancellation techniques;
- c) PCM modulation in the downstream direction at a symbol rate of 8000;
- d) synchronous channel data signalling rates in the downstream direction from 28 000 bit/s to 56 000 bit/s in increments of 8000/6 bit/s;
- e) V.34 modulation in the upstream direction;
- f) synchronous channel data signalling rates in the upstream direction from 4800 bit/s to 28 800 bit/s in increments of 2400 bit/s, with optional support for 31 200 bit/s and 33 600 bit/s;
- g) adaptive techniques that enable the modems to achieve close to the maximum data signalling rates the channel can support on each connection;
- h) negotiate full duplex V.34 operation if a connection will not support V.90 operation;
- i) exchange of rate sequences during start-up to establish the data signalling rate;
- j) automodging to V-series modems supported by V.32 *bis* automode procedures and group 3 facsimile machines;
- k) use of V.8, and optionally V.8 *bis*, procedures during modem start-up or selection.

2 References

The following Recommendations contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent editions of the Recommendations listed below. A list of currently valid ITU-T Recommendations is regularly published.

- CCITT Recommendation G.711 (1988), *Pulse Code Modulation (PCM) of voice frequencies*.
- ITU-T Recommendation T.30 (1996), *Procedures for document facsimile transmission in the general switched telephone network*.
- ITU-T Recommendation V.8 (1998), *Procedures for starting sessions of data transmission over the public switched telephone network*.
- ITU-T Recommendation V.8 *bis* (1996), *Procedures for the identification and selection of common modes of operation between Data Circuit-terminating Equipments (DCEs) and between Data Terminal Equipments (DTEs) over the public switched telephone network and on leased point-to-point telephone-type circuits*.

- ITU-T Recommendation V.14 (1993), *Transmission of start-stop characters over synchronous bearer channels.*
- ITU-T Recommendation V.24 (1998), *List of definitions for interchange circuits between Data Terminal Equipment (DTE) and Data Circuit-terminating Equipment (DCE).*
- ITU-T Recommendation V.25 (1996), *Automatic answering equipment and general procedures for automatic calling equipment on the general switched telephone network including procedures for disabling of echo control devices for both manually and automatically established calls.*
- CCITT Recommendation V.32 bis (1991), *A duplex modem operating at data signalling rates of up to 14 400 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*
- ITU-T Recommendation V.34 (1998), *A modem operating at data signalling rates of up to 33 600 bit/s for use on the general switched telephone network and on leased point-to-point 2-wire telephone-type circuits.*
- ITU-T Recommendation V.42 (1996), *Error-correcting procedures for DCEs using asynchronous-to-synchronous conversion.*
- ITU-T Recommendation V.43 (1998), *Data flow control.*
- ITU-T Recommendation V.80 (1996), *In-band DCE control and synchronous data modes for asynchronous DTE.*

3 Definitions

This Recommendation defines the following terms:

3.1 analogue modem: The analogue modem is the modem of the pair that, when in data mode, generates V.34 signals and receives G.711 signals that have been passed through a G.711 decoder. The modem is typically connected to a PSTN.

3.2 digital modem: The digital modem is the modem of the pair that, when in data mode, generates G.711 signals and receives V.34 signals that have been passed through a G.711 encoder. The modem is connected to a digital switched network through a digital interface, e.g. a Basic Rate Interface (BRI) or a Primary Rate Interface (PRI).

3.3 downstream: Transmission in the direction from the digital modem towards the analogue modem.

3.4 nominal transmit power: Reference transmit power that is configured by the user.

3.5 Uchord: Ucodes are grouped into eight Uchords. Uchord₁ contains Ucodes 0 to 15; Uchord₂ contains Ucodes 16 to 31; ...; and Uchord₈ contains Ucodes 112 to 127.

3.6 Ucode: The universal code used to describe both a μ -law and an A-law PCM codeword. All universal codes are given in decimal notation in Table 1. The μ -law and A-law codewords are the octets to be passed to the digital interface by the digital modem and are given in hexadecimal notation. All modifications defined in Recommendation G.711 have already been made. The MSB in the μ -law PCM and A-law PCM columns in Table 1 corresponds to the polarity bit of the G.711 character signals. A linear representation of each PCM codeword is also given.

3.7 upstream: Transmission in the direction from the analogue modem towards the digital modem.

Table 1/V.90 – The universal set of PCM codewords

Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear	Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear
0	FF	0	D5	8	64	BF	1980	95	2112
1	FE	8	D4	24	65	BE	2108	94	2240
2	FD	16	D7	40	66	BD	2236	97	2368
3	FC	24	D6	56	67	BC	2364	96	2496
4	FB	32	D1	72	68	BB	2492	91	2624
5	FA	40	D0	88	69	BA	2620	90	2752
6	F9	48	D3	104	70	B9	2748	93	2880
7	F8	56	D2	120	71	B8	2876	92	3008
8	F7	64	DD	136	72	B7	3004	9D	3136
9	F6	72	DC	152	73	B6	3132	9C	3264
10	F5	80	DF	168	74	B5	3260	9F	3392
11	F4	88	DE	184	75	B4	3388	9E	3520
12	F3	96	D9	200	76	B3	3516	99	3648
13	F2	104	D8	216	77	B2	3644	98	3776
14	F1	112	DB	232	78	B1	3772	9B	3904
15	F0	120	DA	248	79	B0	3900	9A	4032
16	EF	132	C5	264	80	AF	4092	85	4224
17	EE	148	C4	280	81	AE	4348	84	4480
18	ED	164	C7	296	82	AD	4604	87	4736
19	EC	180	C6	312	83	AC	4860	86	4992
20	EB	196	C1	328	84	AB	5116	81	5248
21	EA	212	C0	344	85	AA	5372	80	5504
22	E9	228	C3	360	86	A9	5628	83	5760
23	E8	244	C2	376	87	A8	5884	82	6016
24	E7	260	CD	392	88	A7	6140	8D	6272
25	E6	276	CC	408	89	A6	6396	8C	6528
26	E5	292	CF	424	90	A5	6652	8F	6784
27	E4	308	CE	440	91	A4	6908	8E	7040
28	E3	324	C9	456	92	A3	7164	89	7296
29	E2	340	C8	472	93	A2	7420	88	7552
30	E1	356	CB	488	94	A1	7676	8B	7808
31	E0	372	CA	504	95	A0	7932	8A	8064
32	DF	396	F5	528	96	9F	8316	B5	8448
33	DE	428	F4	560	97	9E	8828	B4	8960
34	DD	460	F7	592	98	9D	9340	B7	9472
35	DC	492	F6	624	99	9C	9852	B6	9984
36	DB	524	F1	656	100	9B	10364	B1	10496
37	DA	556	F0	688	101	9A	10876	B0	11008
38	D9	588	F3	720	102	99	11388	B3	11520
39	D8	620	F2	752	103	98	11900	B2	12032

Table 1/V.90 – The universal set of PCM codewords (concluded)

Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear	Ucode	μ -law PCM	μ -law linear	A-law PCM	A-law linear
40	D7	652	FD	784	104	97	12412	BD	12544
41	D6	684	FC	816	105	96	12924	BC	13056
42	D5	716	FF	848	106	95	13436	BF	13568
43	D4	748	FE	880	107	94	13948	BE	14080
44	D3	780	F9	912	108	93	14460	B9	14592
45	D2	812	F8	944	109	92	14972	B8	15104
46	D1	844	FB	976	110	91	15484	BB	15616
47	D0	876	FA	1008	111	90	15996	BA	16128
48	CF	924	E5	1056	112	8F	16764	A5	16896
49	CE	988	E4	1120	113	8E	17788	A4	17920
50	CD	1052	E7	1184	114	8D	18812	A7	18944
51	CC	1116	E6	1248	115	8C	19836	A6	19968
52	CB	1180	E1	1312	116	8B	20860	A1	20992
53	CA	1244	E0	1376	117	8A	21884	A0	22016
54	C9	1308	E3	1440	118	89	22908	A3	23040
55	C8	1372	E2	1504	119	88	23932	A2	24064
56	C7	1436	ED	1568	120	87	24956	AD	25088
57	C6	1500	EC	1632	121	86	25980	AC	26112
58	C5	1564	EF	1696	122	85	27004	AF	27136
59	C4	1628	EE	1760	123	84	28028	AE	28160
60	C3	1692	E9	1824	124	83	29052	A9	29184
61	C2	1756	E8	1888	125	82	30076	A8	30208
62	C1	1820	EB	1952	126	81	31100	AB	31232
63	C0	1884	EA	2016	127	80	32124	AA	32256

4 Abbreviations

This Recommendation uses the following abbreviations:

BRI	Basic Rate Interface
DCE	Data Circuit-terminating Equipment
DIL	Digital Impairment Learning sequence
DTE	Data Terminal Equipment
PRI	Primary Rate Interface
PSTN	Public Switched Telephone Network
RMS	Root Mean Square
RTDEa	Round-Trip Delay Estimate – Analogue modem
RTDEd	Round-Trip Delay Estimate – Digital modem
U _{INFO}	The Ucode given by bits 25:31 of INFO _{1a}

5 Digital modem

5.1 Data signalling rates

Synchronous channel data signalling rates from 28 000 bit/s to 56 000 bit/s in increments of 8000/6 bit/s shall be supported. The data signalling rate shall be determined during Phase 4 of modem start-up according to the procedures described in 9.4.

5.2 Symbol rate

The downstream symbol rate shall be 8000 established by timing from the digital network interface. The digital modem shall support the upstream symbol rates 3000 and 3200. It may also support the optional upstream symbol rate 3429 as defined in Recommendation V.34.

5.3 Scrambler

The digital modem shall include a self-synchronizing scrambler as specified in clause 7/V.34, using the generating polynomial, GPC, in equation 7-1/V.34.

5.4 Encoder

The block diagram in Figure 1 is an overview of the encoder and represents one data frame. Data frames in the digital modem have a six-symbol structure. Each symbol position within the data frame is called a data frame interval and is indicated by a time index, $i = 0, \dots, 5$, where $i = 0$ is the first in time. Frame synchronization between the digital modem transmitter and analogue modem receiver is established during training procedures.

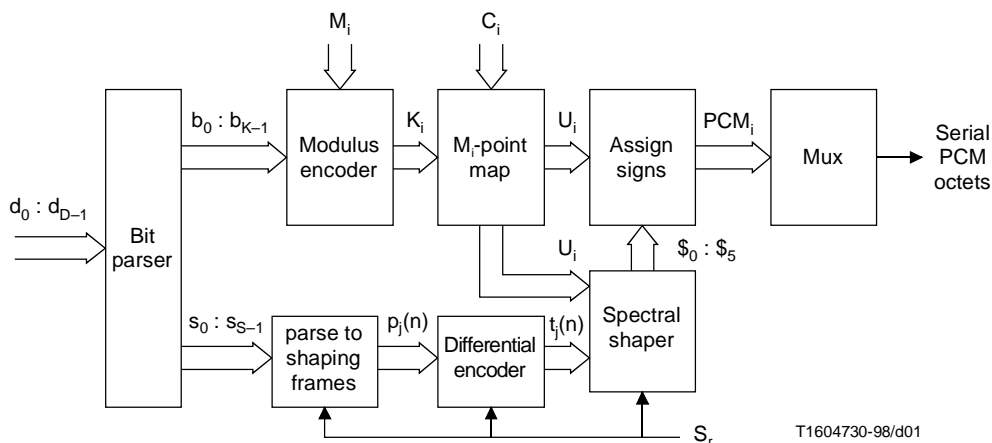


Figure 1/V.90 – Digital modem encoder block diagram

5.4.1 Mapping parameters

Mapping parameters, established during training or rate renegotiation procedures, are:

- six PCM code sets, one for each data frame interval 0 to 5, where data frame interval i has M_i members;
- K , the number of modulus encoder input data bits per data frame;
- S_r , the number of PCM code sign bits per data frame used as redundancy for spectral shaping; and
- S , the number of spectral shaper input data bits per data frame, where $S + S_r = 6$.

Table 2 shows the data signalling rates achieved by the valid combinations of K and S during data mode. Table 17 shows the valid combinations of K and S used during Phase 4 and rate renegotiation procedures.

Table 2/V.90 – Data signalling rates for different K and S

K, bits entering modulus encoder	S, sign bits used for user data		Data Signalling Rate, kbit/s	
	From	To	From	To
15	6	6	28	28
16	5	6	28	29 1/3
17	4	6	28	30 2/3
18	3	6	28	32
19	3	6	29 1/3	33 1/3
20	3	6	30 2/3	34 2/3
21	3	6	32	36
22	3	6	33 1/3	37 1/3
23	3	6	34 2/3	38 2/3
24	3	6	36	40
25	3	6	37 1/3	41 1/3
26	3	6	38 2/3	42 2/3
27	3	6	40	44
28	3	6	41 1/3	45 1/3
29	3	6	42 2/3	46 2/3
30	3	6	44	48
31	3	6	45 1/3	49 1/3
32	3	6	46 2/3	50 2/3
33	3	6	48	52
34	3	6	49 1/3	53 1/3
35	3	6	50 2/3	54 2/3
36	3	6	52	56
37	3	5	53 1/3	56
38	3	4	54 2/3	56
39	3	3	56	56

5.4.2 Input bit parsing

D (equal to S + K) serial input data bits, d_0 to d_{D-1} where d_0 is first in time, are parsed into S sign input bits and K modulus encoder bits. d_0 to d_{S-1} form s_0 to s_{S-1} and d_S to d_{D-1} form b_0 to b_{K-1} .

The K modulus encoder bits and the S sign bits are used as specified in 5.4.3 and 5.4.5 respectively.

5.4.3 Modulus encoder

K bits enter the modulus encoder. The data signalling rates associated with each value of K are tabulated in Table 2. There are six independent mapping moduli, M_0 to M_5 , which are the number of members in the PCM code sets defined for data frame interval 0 to data frame interval 5, respectively. M_i is equal to the number of positive levels in the constellation to be used in data frame interval i as signalled by the analogue modem using the CP sequences defined in 8.5.2.

The values of M_i and K shall satisfy the inequality $2^K \leq \prod_{i=0}^5 M_i$

The modulus encoder converts K bits into six numbers, K_0 to K_5 , using the following algorithm.

NOTE – Other implementations are possible but the mapping function must be identical to that given in the algorithm described below.

- 1) Represent the incoming K bits as an integer, R_0 :

$$R_0 = b_0 + b_1 * 2^1 + b_2 * 2^2 + \dots + b_{K-1} * 2^{K-1}$$

- 2) Divide R_0 by M_0 . The remainder of this division gives K_0 , the quotient becomes R_1 for use in the calculation for the next data frame interval. Continue for the remaining five data frame intervals. This gives K_0 to K_5 as:

$$K_i = R_i \text{ modulo } M_i, \text{ where } 0 \leq K_i < M_i; R_{i+1} = (R_i - K_i) / M_i$$

- 3) The numbers K_0, \dots, K_5 are the output of the modulus encoder, where K_0 corresponds to data frame interval 0 and K_5 corresponds to data frame interval 5.

5.4.4 Mapper

There are six independent mappers associated with the six data frame intervals. Each mapper uses a tabulation of M_i PCM codes that make up the positive constellation points of data frame interval i denoted C_i . The PCM codes to be used in each data frame interval are specified by the analogue modem during training procedures. The PCM code that is denoted by the largest (smallest) Ucode is herein called the largest (smallest) PCM code. The members of C_i shall be labelled in descending order so that label 0 corresponds to the largest PCM code in C_i , label $M_i - 1$ corresponds to the smallest PCM code in C_i . Each mapper takes K_i and forms U_i by choosing the constellation point in C_i labelled by K_i .

5.4.5 Spectral shaping

The digital modem output line signal spectrum shall be shaped, if spectral shaping is enabled. Spectral shaping only affects the sign bits of transmitted PCM symbols. In every data frame of 6 symbol intervals, S_r sign bits are used as redundancy for spectral shaping while the remaining S sign bits carry user information. The redundancy, S_r , is specified by the analogue modem during training procedures and can be 0, 1, 2 or 3. When $S_r = 0$, spectral shaping is disabled.

NOTE – The initial state of the spectral shaper does not affect the performance of the analogue modem and is therefore left to the implementor.

5.4.5.1 $S_r = 0, S = 6$

The PCM code sign bits, $\$0$ to $\$5$ shall be assigned using input sign bits s_0 to s_5 and a differential coding rule:

$$\$0 = s_0 \oplus (\$5 \text{ of the previous data frame}); \text{ and}$$

$$\$i = s_i \oplus \$_{i-1} \text{ for } i = 1, \dots, 5$$

where " \oplus " stands for modulus-2 addition.

5.4.5.2 $S_r = 1, S = 5$

Sign bits s_0 to s_4 shall be parsed to one six-bit shaping frame per data frame according to Table 3.

The odd bits shall be differentially encoded to produce the output p'_j according to Table 4.

Table 3/V.90 – Parsing input sign bits to shaping frames

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$
0	$p_j(0) = 0$	$p_j(0) = 0$	$p_j(0) = 0$
1	$p_j(1) = s_0$	$p_j(1) = s_0$	$p_j(1) = s_0$
2	$p_j(2) = s_1$	$p_j(2) = s_1$	$p_{j+1}(0) = 0$
3	$p_j(3) = s_2$	$p_{j+1}(0) = 0$	$p_{j+1}(1) = s_1$
4	$p_j(4) = s_3$	$p_{j+1}(1) = s_2$	$p_{j+2}(0) = 0$
5	$p_j(5) = s_4$	$p_{j+1}(2) = s_3$	$p_{j+2}(1) = s_2$

Table 4/V.90 – Odd bit differential coding

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$
0	$p'_j(0) = 0$	$p'_j(0) = 0$	$p'_j(0) = 0$
1	$p'_j(1) = p_j(1) \oplus p'_{j-1}(5)$	$p'_j(1) = p_j(1) \oplus p'_{j-1}(1)$	$p'_j(1) = p_j(1) \oplus p'_{j-1}(1)$
2	$p'_j(2) = p_j(2)$	$p'_j(2) = p_j(2)$	$p'_{j+1}(0) = 0$
3	$p'_j(3) = p_j(3) \oplus p'_j(1)$	$p'_{j+1}(0) = 0$	$p'_{j+1}(1) = p_{j+1}(1) \oplus p'_j(1)$
4	$p'_j(4) = p_j(4)$	$p'_{j+1}(1) = p_{j+1}(1) \oplus p'_j(1)$	$p'_{j+2}(0) = 0$
5	$p'_j(5) = p_j(5) \oplus p'_j(3)$	$p'_{j+1}(2) = p_{j+1}(2)$	$p'_{j+2}(1) = p_{j+2}(1) \oplus p'_{j+1}(1)$

Finally, a second differential encoding shall be performed to produce the initial shaping sign bit assignment, $t_j(0)$ to $t_j(5)$ using the rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

The spectral shaper converts each bit $t_j(k)$, to a PCM code sign bit $\$k$ as described in 5.4.5.5.

5.4.5.3 $S_r = 2, S = 4$

Sign bits s_0 to s_3 shall be parsed to two three-bit shaping frames per data frame as shown in Table 3.

The odd bit in each shaping frame shall be differentially encoded to produce differentially encoded outputs p'_j and p'_{j+1} according to Table 4.

Finally, a second differential encoding shall be performed on each shaping frame to produce the initial shaping sign bit assignments $t_j(0)$ to $t_j(2)$ and $t_{j+1}(0)$ to $t_{j+1}(2)$ using the differential encoding rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

$$t_{j+1}(k) = p'_{j+1}(k) \oplus t_j(k)$$

The spectral shaper converts each bit $t_j(k)$, to PCM code sign bit $\$k$ and each bit $t_{j+1}(k)$, to PCM code sign bit $\$_{k+3}$ as described in 5.4.5.5.

5.4.5.4 $S_r = 3, S = 3$

Sign bits s_0 to s_2 shall be parsed to three two-bit shaping frames per data frame as shown in Table 3.

The odd bit in each shaping frame shall be differentially encoded to produce differentially encoded outputs p'_j , p'_{j+1} , and p'_{j+2} as shown in Table 4.

Finally, a second differential encoding shall be performed on each shaping frame to produce the initial shaping sign bit assignments $t_j(0)$ to $t_j(1)$, $t_{j+1}(0)$ to $t_{j+1}(1)$, and $t_{j+2}(0)$ to $t_{j+2}(1)$ using the differential encoding rule:

$$t_j(k) = p'_j(k) \oplus t_{j-1}(k)$$

$$t_{j+1}(k) = p'_{j+1}(k) \oplus t_j(k)$$

$$t_{j+2}(k) = p'_{j+2}(k) \oplus t_{j+1}(k)$$

The spectral shaper converts each bit $t_j(k)$, to PCM code sign bit $\$k$, each bit $t_{j+1}(k)$, to PCM code sign bit $\$(k+2)$, and each bit $t_{j+2}(k)$, to PCM code sign bit $\$(k+4)$ as described in 5.4.5.5.

5.4.5.5 Spectral shaper

The spectral shaper operates on a spectral shaper frame basis. For the cases $S_r = 2$ and $S_r = 3$, there are multiple shaper frames per six-symbol data frame. Spectral shaper operation for each shaper frame within a data frame (called shaping frame j in this subclause) is identical except that they affect different data frame PCM sign bits as shown in Table 5.

Table 5/V.90 – Shaping frame to data frame sign relationship

Data frame interval	$S_r = 1, S = 5$	$S_r = 2, S = 4$	$S_r = 3, S = 3$	Data frame PCM sign bit
0	$t_j(0)$	$t_j(0)$	$t_j(0)$	$\$0$
1	$t_j(1)$	$t_j(1)$	$t_j(1)$	$\$1$
2	$t_j(2)$	$t_j(2)$	$t_{j+1}(0)$	$\$2$
3	$t_j(3)$	$t_{j+1}(0)$	$t_{j+1}(1)$	$\$3$
4	$t_j(4)$	$t_{j+1}(1)$	$t_{j+2}(0)$	$\$4$
5	$t_j(5)$	$t_{j+1}(2)$	$t_{j+2}(1)$	$\$5$

The spectral shaper shall modify the initial sign bits $[t_j(0), t_j(1), \dots]$ to corresponding PCM code sign bits $(\$0, \$1 \dots)$ without violating the constraint described below, so as to optimize a spectral metric.

The constraint of the spectral shaper is described using the 2-state trellis diagram shown in Figure 2.

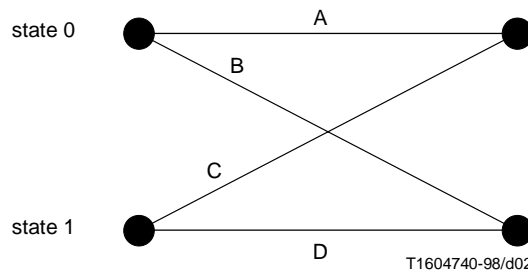


Figure 2/V.90 – Trellis diagram used to constrain the spectral shaper

In a given spectral shaping frame j , the spectral shaper shall modify the initial sign sequence, $t_j(k)$, according to one of the following four sign inversion rules:

- Rule A: Do nothing;
- Rule B: Invert all sign bits in spectral shaping frame j ;
- Rule C: Invert even-numbered $[t_j(0), t_j(2), \text{etc.}]$ sign bits in spectral shaping frame j ;
- Rule D: Invert odd-numbered $[t_j(1), t_j(3), \text{etc.}]$ sign bits in spectral shaping frame j .

The trellis diagram describes the sequence of sign inversion rules that are allowable. For example, when the spectral shaper is in state $Q_j = 0$ at the beginning of frame j , only rules A and B are allowable in frame j . The current state Q_j together with the sign inversion rule selected for frame j determine the next state Q_{j+1} according to the trellis diagram.

The look-ahead depth parameter, l_d , is an integer between 0 and 3 selected by the analogue modem during training procedures. l_d of 0 and 1 are mandatory in the digital modem. l_d of 2 and 3 are optional.

To select the sign inversion rule for the j^{th} spectral shaping frame, the spectral shaper shall use the PCM symbol magnitudes produced by the mapper for spectral shaping frames $j, j+1, \dots, j+l_d$. It shall compute the spectral metric that would result if each of the allowable sequences of sign inversion rules for frames j through $j+l_d$, starting from the current state Q_j in frame j , were to be used. The shaper shall select the sign inversion rule for frame j that minimizes the spectral metric, $w[n]$, defined in 5.4.5.6 up to and including the final symbol of spectral shaping frame $j+l_d$. The selection determines the next state Q_{j+1} .

The shaper shall then set PCM code signs S_i for shaping frame j according to the selected sign inversion rule for shaper frame j .

5.4.5.6 Spectral shape filter

The analogue modem determines the spectral shape filter function used in the digital modem by selecting parameters of the following transfer function:

$$T(z) = \frac{(1-a_1z^{-1})(1-a_2z^{-1})}{(1-b_1z^{-1})(1-b_2z^{-1})}$$

where a_1, a_2, b_1 and b_2 are parameters having absolute values less than or equal to 1. The parameters, a_1, a_2, b_1 and b_2 , are specified by the analogue modem during training procedures and are represented in the 8-bit two's-complement format with 6 bits after the binary point. The digital modem shall perform the spectral shaping according to the spectral shaping metric, $w[n]$, characterised by the filter:

$$F(z) = \frac{1}{T(z)} = \frac{(1-b_1z^{-1})(1-b_2z^{-1})}{(1-a_1z^{-1})(1-a_2z^{-1})}$$

The filter input, $x[n]$, shall be a signed signal proportional to the linear value corresponding to PCM codes being transmitted. The relationship between PCM codes and corresponding linear values is given in Table 1. $w[n]$ shall be computed as:

- 1) $y[n] = x[n] - b_1x[n-1] + a_1y[n-1]$
- 2) $v[n] = y[n] - b_2y[n-1] + a_2v[n-1]$
- 3) $w[n] = v^2[n] + w[n-1]$

5.4.6 Sign assignment

Six sign bits, generated by 5.4.5, are attached to the six unsigned mapper outputs $U_0 - U_5$ to complete the mapping of the data frame intervals. A sign bit of 0 means the transmitted PCM codeword will represent a negative voltage and a sign bit of 1 means it will represent a positive voltage.

5.4.7 Mux

The signed PCM codewords, PCM_i , are transmitted from the digital modem sequentially with PCM_0 being first in time.

6 Analogue modem

The characteristics of the analogue modem described herein apply when in V.90 mode. After fallback to V.34 mode, the analogue modem shall have characteristics as defined in Recommendation V.34.

6.1 Data signalling rates

The modem shall support synchronous data signalling rates of 4800 bit/s to 28 800 bit/s in increments of 2400 bit/s, with optional support for 31 200 bit/s and 33 600 bit/s. The 200 bit/s V.34 auxiliary channel is not supported. The data signalling rate shall be determined during Phase 4 of modem start-up according to the procedures described in 9.4.

6.2 Symbol rates

The analogue modem shall support the symbol rate 3200. It may also support 3000 and the optional symbol rate 3429 as defined in Recommendation V.34. The other V.34 symbol rates, 2400, 2743 and 2800, shall not be supported. The symbol rate shall be selected by the analogue modem during Phase 2 of modem start-up according to the procedures described in 9.2.

6.3 Carrier frequencies

The analogue modem shall support the carrier frequencies specified in 5.3/V.34 for the appropriate symbol rate. The carrier frequency shall be determined during Phase 2 of modem start-up according to the procedures specified in 9.2.

6.4 Pre-emphasis

The analogue modem shall support the pre-emphasis filter characteristics specified in 5.4/V.34. The filter selection shall be provided by the digital modem during Phase 2 of modem start-up according to the procedures specified in 9.2.

6.5 Scrambler

The analogue modem shall include a self-synchronizing scrambler as specified in clause 7/V.34, using the generating polynomial, GPA, in equation 7-2/V.34.

6.6 Framing

The analogue modem shall use the framing method specified for the V.34 primary channel in clause 8/V.34.

6.7 Encoder

The analogue modem shall use the encoder specified for the V.34 primary channel in clause 9/V.34.

7 Interchange circuits

The requirements of this clause apply to both modems.

7.1 List of interchange circuits

References in this Recommendation to V.24 interchange circuit numbers are intended to refer to the functional equivalent of such circuits and are not intended to imply the physical implementation of such circuits. For example, references to circuit 103 should be understood to refer to the functional equivalent of circuit 103 (see Table 6).

7.2 Asynchronous character-mode interfacing

The modem may include an asynchronous-to-synchronous converter interfacing to the DTE in an asynchronous (or start-stop character) mode. The protocol for the conversion shall be in accordance with Recommendation(s) V.14, V.42 or V.80. Data compression may also be employed.

8 Start-up signals and sequences

All PCM codewords transferred in training sequences are described using the universal codes as specified in Table 1.

Table 6/V.90 – Interchange circuits

Interchange circuit		Notes
No.	Description	
102	Signal ground or common return	
103	Transmitted data	
104	Received data	
105	Request to send	
106	Ready for sending	
107	Data set ready	
108/1 or	Connect data set to line	
108/2	Data terminal ready	
109	Data channel received line signal detector	
125	Calling indicator	2
133	Ready for receiving	
NOTE 1 – Thresholds and response times are not applicable because a line signal detector cannot be expected to distinguish received signals from talker echoes.		
NOTE 2 – Operation of circuit 133 shall be in accordance with 4.2.1.1/V.43.		

8.1 Phase 1

Recommendation V.8, and optionally Recommendation V.8 *bis*, is used in Phase 1. All signals in 9.1 are defined in either Recommendation V.25 or Recommendation V.8 and shall be transmitted at the nominal transmit power level.

8.2 Phase 2

During Phase 2, all signals except L1 shall be transmitted at the nominal transmit power level. If a recovery mechanism returns the modem to Phase 2 from a later phase, the transmit level shall revert to the nominal transmit power from the previously negotiated transmit power level.

8.2.1 A

As defined in 10.1.2.1/V.34.

8.2.2 B

As defined in 10.1.2.2/V.34.

8.2.3 INFO sequences

INFO sequences are used to exchange modem capabilities, results of line probing, and data mode modulation parameters.

8.2.3.1 Modulation

All INFO sequences are transmitted using binary DPSK modulation at 600 bit/s \pm 0.01%. The transmit point is rotated 180 degrees from the previous point if the transmit bit is a 1, and the transmit point is rotated 0 degrees from the previous point if the transmit bit is a 0. Each INFO sequence is preceded by a point at an arbitrary carrier phase. When multiple INFO sequences are transmitted as a group, only the first sequence is preceded by a point at an arbitrary carrier phase.

INFO sequences are transmitted by the analogue modem with a carrier frequency of 2400 Hz \pm 0.01%, at 1 dB below the nominal transmit power, plus an 1800 Hz \pm 0.01% guard tone 7 dB below the nominal transmit power. INFO sequences are transmitted by the digital modem with a carrier frequency of 1200 Hz \pm 0.01% at the nominal transmit power.

The transmitted line signal shall have a magnitude spectrum within the limits shown in Figure 13/V.34.

NOTE – It is highly desirable to design linear phase transmitter channel separation and shaping filters since there are no provisions for adaptive equaliser training.

8.2.3.2 INFO information bits

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 7 defines the bits in the INFO_{0d} sequence. Bit 0 is transmitted first in time.

Table 7/V.90 – Definition of bits in INFO_{0d}

INFO _{0d} bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting in V.34 mode
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an INFO _{0d} sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664 point signal constellations
26:27	Reserved for the ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
28	Set to 1 to acknowledge correct reception of an INFO _{0a} frame during error recovery
29:32	Digital modem nominal transmit power for Phase 2. This is represented in –1 dBm0 steps where 0 represents –6 dBm0 and 15 represents –21 dBm0
33:37	Maximum digital modem transmit power. This is represented in –0.5 dBm0 steps where 0 represents –0.5 dBm0 and 31 represents –16 dBm0
38	Set to 1 indicates the digital modem’s power shall be measured at the output of the codec. Otherwise the digital modem’s power shall be measured at its terminals
39	PCM coding in use by digital modem: 0 = μ -law, 1 = A-law
40	Set to 1 indicates ability to operate V.90 with an upstream symbol rate of 3429
41	Reserved for the ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
42:57	CRC
58:61	Fill bits: 1111

NOTE 1 – Bits 12, 13, 14 and 40 are used to indicate the modem’s capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem’s transmitter.

NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in Recommendation V.8 to determine the optimum parameters for the signal convertors and error-control functions in the analogue and digital modem and any intervening CME.

Table 8 defines the bits in the INFO_{0a} sequence. Bit 0 is transmitted first in time.

Table 8/V.90 – Definition of bits in INFO_{0a}

INFO_{0a} bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12	Set to 1 indicates symbol rate 2743 is supported in V.34 mode
13	Set to 1 indicates symbol rate 2800 is supported in V.34 mode
14	Set to 1 indicates symbol rate 3429 is supported in V.34 mode
15	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3000
16	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3000
17	Set to 1 indicates the ability to transmit at the low carrier frequency with a symbol rate of 3200
18	Set to 1 indicates the ability to transmit at the high carrier frequency with a symbol rate of 3200
19	Set to 0 indicates that transmission with a symbol rate of 3429 is disallowed
20	Set to 1 indicates the ability to reduce transmit power to a value lower than the nominal setting
21:23	Maximum allowed difference in symbol rates in the transmit and receive directions in V.34 mode. With the symbol rates labelled in increasing order, where 0 represents 2400 and 5 represents 3429, an integer between 0 and 5 indicates the difference allowed in number of symbol rate steps
24	Set to 1 in an INFO _{0a} sequence transmitted from a CME modem
25	Set to 1 indicates the ability to support up to 1664 point signal constellations
26:27	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
28	Set to 1 to acknowledge correct reception of an INFO _{0d} frame during error recovery
29:44	CRC
45:48	Fill bits: 1111
<p>NOTE 1 – Bits 12 to 14 are used to indicate the modem's capabilities and/or configuration. The values of bits 15 to 20 depend upon regulatory requirements and apply only to the modem's transmitter.</p> <p>NOTE 2 – Bit 24 may be used in conjunction with the PSTN access category octet defined in Recommendation V.8 to determine the optimum parameters for the signal convertors and error-control functions in the analogue and digital modem and any intervening CME.</p>	

Table 9 defines the bits in the INFO_{1d} sequence. The bit definitions are identical to those of INFO_{1c} in Recommendation V.34 and are given here for convenience. Bit 0 is transmitted first in time.

Table 9/V.90 – Definition of bits in INFO_{1d}

INFO_{1d} bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:14	Minimum power reduction to be implemented by the analogue modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if INFO _{0a} indicated that the analogue modem transmitter cannot reduce its power
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the digital modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if INFO _{0a} indicated that the analogue modem transmitter cannot reduce its power
18:24	Length of MD to be transmitted by the digital modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400
26:29	Pre-emphasis filter to be used in transmitting from the analogue modem to the digital modem for a symbol rate of 2400. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3/V.34 and 4/V.34)
30:33	Projected maximum data rate for a symbol rate of 2400. These bits form an integer between 0 and 14 which gives the projected data rate as a multiple of 2400 bits/s. A 0 indicates the symbol rate cannot be used
34:42	Probing results pertaining to a final symbol rate selection of 2743 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
43:51	Probing results pertaining to a final symbol rate selection of 2800 symbols per second. The coding of these 9 bits is identical to that for bits 25-33
52:60	Probing results pertaining to a final symbol rate selection of 3000 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in INFO _{0a}
61:69	Probing results pertaining to a final symbol rate selection of 3200 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in INFO _{0a}
70:78	Probing results pertaining to a final symbol rate selection of 3429 symbols per second. The coding of these 9 bits is identical to that for bits 25-33. Information in this field shall be consistent with the analogue modem capabilities indicated in INFO _{0a}
79:88	Frequency offset of the probing tones as measured by the digital modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, $f(\text{received}) - f(\text{transmitted})$. A two's complement signed integer between -511 and 511 gives the measured offset in 0.02 Hz increments. Bit 88 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to -512 indicating that this field is to be ignored
89:104	CRC
105:108	Fill bits: 1111
NOTE 1 – Projected maximum data rates greater than 12 in bits 30:33 shall only be indicated when the analogue modem supports up to 1664 point signal constellations.	
NOTE 2 – The analogue modem may be able to achieve a higher downstream data signalling rate in V.90 mode if the digital modem indicates that the analogue modem may transmit at a lower power in bits 15:17.	

Table 10 defines the bits in the INFO_{1a} sequence that an analogue modem uses to request Phase 3 of this Recommendation. Bits 37:39 represent the integer 6, indicating that V.90 operation is desired. Bit 0 is transmitted first in time.

Table 10/V.90 – Definition of bits in INFO_{1a} when V.90 is selected

INFO_{1a} bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:17	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25:31	U _{INFO} : Ucode of the PCM codeword to be used by the digital modem for the 2 point train. The power of this point shall not exceed the maximum digital modem transmit power. U _{INFO} shall be greater than 66
32:33	Reserved for the ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
34:36	Symbol rate to be used in transmitting from the analogue modem to the digital modem. An integer between 3 and 5 gives the symbol rate, where 3 represents 3000 and 5 represents 3429. The symbol rate selected shall be consistent with information in INFO _{1d} . The carrier frequency and pre-emphasis filter to be used are those already indicated for this symbol rate in INFO _{1d}
37:39	Symbol rate of 8000 to be used by the digital modem: The integer 6
40:49	Frequency offset of the probing tones as measured by the analogue modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, f(received) – f(transmitted). A two's complement signed integer between –511 and 511 gives the measured offset in 0.02 Hz increments. Bit 9 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to –512 indicating that this field is to be ignored
50:65	CRC
66:69	Fill bits: 1111

Table 11 defines the bits in the INFO_{1a} sequence that an analogue modem uses to request Phase 3 of Recommendation V.34. The bit definitions are identical to those of INFO_{1a} in Recommendation V.34 and are given here for convenience. Bits 37:39 represent an integer between 0 and 5, indicating that V.34 operation is desired. Bit 0 is transmitted first in time.

8.2.3.3 INFOMARKS

INFOMARKS_d is created by the digital modem applying binary ones to the DPSK modulator described in 8.2.3.1.

INFOMARKS_a is created by the analogue modem applying binary ones to the DPSK modulator described in 8.2.3.1.

8.2.4 Line probing signals

As defined in 10.1.2.4/V.34.

8.3 Phase 3 signals for the analogue modem

The analogue modem shall use the polynomial, GPA, in equation 7-2/V.34 when generating signals J_a, TRN and SCR.

Table 11/V.90 – Definition of bits in INFO_{1a} when V.34 is selected

INFO_{1a} bits LSB:MSB	Definition
0:3	Fill bits: 1111
4:11	Frame sync: 01110010, where the left-most bit is first in time
12:14	Minimum power reduction to be implemented by the digital modem transmitter. An integer between 0 and 7 gives the recommended power reduction in dB. These bits shall indicate 0 if INFO _{0d} indicated that the digital modem transmitter cannot reduce its power
15:17	Additional power reduction, below that indicated by bits 12:14, which can be tolerated by the analogue modem receiver. An integer between 0 and 7 gives the additional power reduction in dB. These bits shall indicate 0 if INFO _{0d} indicated that the digital modem transmitter cannot reduce its power
18:24	Length of MD to be transmitted by the analogue modem during Phase 3. An integer between 0 and 127 gives the length of this sequence in 35 ms increments
25	Set to 1 indicates that the high carrier frequency is to be used in transmitting from the digital modem to the analogue modem. This shall be consistent with the capabilities of the digital modem indicated in INFO _{0d}
26:29	Pre-emphasis filter to be used in transmitting from the digital modem to the analogue modem. These bits form an integer between 0 and 10 which represents the pre-emphasis filter index (see Tables 3/V.34 and 4/V.34)
30:33	Projected maximum data rate for the selected symbol rate from the digital modem to the analogue modem. These bits form an integer between 0 and 14 which gives the projected data rate as a multiple of 2400 bits/s
34:36	Symbol rate to be used in transmitting from the analogue modem to the digital modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with information in INFO _{1d} and consistent with the symbol rate asymmetry allowed as indicated in INFO _{0a} and INFO _{0d} . The carrier frequency and pre-emphasis filter to be used are those already indicated for this symbol rate in INFO _{1d}
37:39	Symbol rate to be used in transmitting from the digital modem to the analogue modem. An integer between 0 and 5 gives the symbol rate, where 0 represents 2400 and a 5 represents 3429. The symbol rate selected shall be consistent with the capabilities indicated in INFO _{0a} and consistent with the symbol rate asymmetry allowed as indicated in INFO _{0a} and INFO _{0d}
40:49	Frequency offset of the probing tones as measured by the analogue modem receiver. The frequency offset number shall be the difference between the nominal 1050 Hz line probing signal tone received and the 1050 Hz tone transmitted, $f(\text{received}) - f(\text{transmitted})$. A two's complement signed integer between -511 and 511 gives the measured offset in 0.02 Hz increments. Bit 49 is the sign bit of this integer. The frequency offset measurement shall be accurate to 0.25 Hz. Under conditions where this accuracy cannot be achieved, the integer shall be set to -512 indicating that this field is to be ignored
50:65	CRC
66:69	Fill bits: 1111
NOTE – Projected maximum data rates greater than 12 in bits 30:33 shall only be indicated when the digital modem supports up to 1664 point signal constellations.	

8.3.1 J_a

Sequence J_a consists of repetitions of the DIL descriptor detailed below. The modulation used for transmitting J_a is as defined in 10.1.3.3/V.34. Transmission of sequence J_a may be terminated without completing the final DIL descriptor.

The DIL descriptor tells the digital modem what parameters to use when transmitting DIL. The bit fields in the DIL descriptor are given in Table 12. Definitions and interpretation of the parameters are given in 8.4.1. Due to the variability in the length of the sequences SP and TP the bit numbers are given using $\alpha = \lceil (L_{SP}/16) \rceil * 17$ and $\beta = \alpha + \lceil (L_{TP}/16) \rceil * 17$, where $\lceil x \rceil$ is the smallest integer higher than or equal to x . When L_{SP} is not a multiple of 16, zeroes shall be used to pad SP to the next multiple of 16 bits so that the format of the J_a sequence is preserved. Similarly, when L_{TP} is not a multiple of 16, zeroes shall be used to pad TP to the next multiple of 16 bits. $L_{SP} - 1 = L_{TP} - 1 = 0$ when $N = 0$. The values for SP and TP have no significance when $N = 0$.

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 12/V.90 – Definition of bits in the DIL descriptor

LSB:MSB	Definition
0:16	Frame sync: 1111111111111111
17	Start bit: 0
18:25	N
26:33	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
34	Start bit: 0
35:41	$L_{SP} - 1$
42	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
43:49	$L_{TP} - 1$
50	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
51	Start bit: 0
52:67	SP
68	Start bit: 0
	Possible continuation of SP with a start bit (0) every 16 bits
$51+\alpha$	Start bit: 0
$52+\alpha:67+\alpha$	TP
$68+\alpha$	Start bit: 0
	Possible continuation of TP with a start bit (0) every 16 bits
$51+\beta$	Start bit: 0
$52+\beta:58+\beta$	H_1
$59+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$60+\beta:66+\beta$	H_2
$67+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$68+\beta$	Start bit: 0
$69+\beta:75+\beta$	H_3
$76+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$77+\beta:83+\beta$	H_4
$84+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$85+\beta$	Start bit: 0
$86+\beta:92+\beta$	H_5
$93+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$94+\beta:100+\beta$	H_6
$101+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
$102+\beta$	Start bit: 0
$103+\beta:109+\beta$	H_7
$110+\beta$	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem

Table 12/V.90 – Definition of bits in the DIL descriptor (concluded)

LSB:MSB	Definition
111+β:117+β	H ₈
118+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
119+β	Start bit: 0
120+β:126+β	REF ₁
127+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
128+β:134+β	REF ₂
135+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
136+β	Start bit: 0
137+β:143+β	REF ₃
144+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
145+β:151+β	REF ₄
152+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
153+β	Start bit: 0
154+β:160+β	REF ₅
161+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
162+β:168+β	REF ₆
169+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
170+β	Start bit: 0
171+β:177+β	REF ₇
178+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
179+β:185+β	REF ₈
186+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
187+β	Start bit: 0
188+β:194+β	The Ucode of the training symbol used for the 1 st DIL segment
195+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
196+β:202+β	The Ucode of the training symbol used for the 2 nd DIL segment
203+β	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
204+β	Start bit: 0
	Remaining Ucodes of training symbols with a start bit (0) every 16 bits and appropriate reserved bits including 9 reserved bits to fill the final 16 bits if N is odd
187+β+⌈N/2⌉*17	Start bit: 0
188+β+⌈N/2⌉*17: 203+β+⌈N/2⌉*17	CRC
204+β+⌈N/2⌉*17	Fill bit: 0
205+β+⌈N/2⌉*17	Fill bit: 0 may be necessary to ensure that the descriptor has an even number of bits.

NOTE – It is highly desirable that the analogue modem requests a DIL that does not allow echo control devices in the switched digital network to re-enable. The analogue modem may also continuously transmit SCR during the reception of DIL to maintain line energy.

8.3.2 MD

As defined in 10.1.3.5/V.34.

8.3.3 PP

As defined in 10.1.3.6/V.34.

8.3.4 S

As defined in 10.1.3.7/V.34.

8.3.5 SCR

Signal SCR is defined as binary ones modulated according to 10.1.3.9/V.34 except that neither the scrambler nor the differential encoder need be initialized at the beginning of its transmission. During Phase 3 and Phase 4 start-up procedures the constellation size depends on bit 47 of J_d . During rate renegotiation procedures the constellation size depends on bit 48 of J_d .

8.3.6 TRN

As defined in 10.1.3.8/V.34 using a 4-point 2D constellation.

8.4 Phase 3 signals for the digital modem

The digital modem shall use the polynomial, GPC, in equation 7-1/V.34 when generating signals J_d , J'_d and TRN_{1d} . Signals transmitted by the digital modem during Phase 3 are not spectrally shaped.

8.4.1 DIL

The parameters necessary for the digital modem to form the DIL are sent to it by the analogue modem using the DIL descriptor defined in 8.3.1.

The DIL consists of N DIL-segments of length L_c where:

$$0 \leq N \leq 255;$$

$$1 \leq c \leq 8; \text{ and}$$

$$L_c = (H_c + 1) * 6 \text{ symbols.}$$

Eight H_c values are used to calculate the length of the DIL-segments containing training symbols from each Uchord. H_1 shall be used to calculate the length of the DIL-segments containing training symbols from Uchord₁, H_8 shall be used to calculate the length of the DIL-segments containing training symbols from Uchord₈.

Eight Ucodes, REF_c , define the PCM codeword used as a reference symbol in DIL-segments containing training symbols from each Uchord. The PCM codeword given by the Ucode REF_1 shall be used as a reference symbol in DIL-segments containing training symbols from Uchord₁, the PCM codeword given by the Ucode REF_8 shall be used as a reference symbol in DIL-segments containing training symbols from Uchord₈.

A single Sign Pattern (SP) and Training Pattern (TP) is used for the entire DIL. An SP bit determines the sign of a transmitted symbol. 0 shall represent negative and 1 shall represent positive. A TP bit determines whether the reference symbol (REF_c) or a training symbol is transmitted. 0 shall represent REF_c and 1 shall represent a training symbol. The LSB of each pattern applies to the first symbol of a DIL-segment. The lengths of these patterns are:

$$1 \leq L_{SP} \leq 128; \text{ and}$$

$$1 \leq L_{TP} \leq 128.$$

The patterns are restarted at the beginning of each DIL-segment. The patterns are repeated independently within DIL-segments whose lengths exceed that of L_{SP} or L_{TP} .

The entire sequence, not just the last DIL-segment, is repeated until either the analogue modem causes it to be terminated or a timeout occurs. The sequence shall be terminated on a DIL-segment boundary.

A set of N Ucodes determine the training symbol that is assigned to each DIL-segment. The first of the N Ucodes specifies the training symbol assigned to the first DIL-segment and so on.

When $N = 0$, DIL is not transmitted.

8.4.2 J_d

Sequence J_d consists of a whole number of repetitions of the bit pattern given in Table 13. Bit 0 is transmitted first. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO} . A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted TRN_{1d} .

The CRC generator used is described in 10.1.2.3.2/V.34.

Table 13/V.90 – Definition of bits in J_d

J_d bits LSB:MSB	Definition
0:16	Frame Sync: 1111111111111111
17	Start bit: 0
18:33	Data signalling rate capability mask. Bit 18:28 000; bit 19:29 333; bit 20:30 666; ...; bit 33:48 000. Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
34	Start bit: 0
35:46	Data signalling rate capability mask (contd.). Bit 35:49 333; bit 36:50 666; ...; bit 39:54 666; bit 40:56 000; bits 41 to 46: Reserved for ITU. (These bits are set to 0 by the digital modem and are not interpreted by the analogue modem.) Bits set to 1 indicate data signalling rates supported and enabled in the transmitter of the digital modem
47	Size of constellation used to transmit CP, E and SCR during training sequences: 0 = 4-point constellation; 1 = 16-point constellation
48	Size of constellation used to transmit CP, E and SCR during rate renegotiation procedures: 0 = 4-point constellation; 1 = 16-point constellation
49:50	A number between 1 and 3 indicating the digital modem's maximum lookahead for spectral shaping
51	Start bit: 0
52:67	CRC
68:71	Fill bits: 0000

8.4.3 J'_d

J'_d is used to terminate J_d . J'_d consists of 12 binary zeroes. The bits are scrambled and differentially encoded and then transmitted as the sign of the PCM codeword whose Ucode is U_{INFO} . A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The differential encoder shall be initialized with the final symbol of the transmitted J_d .

8.4.4 S_d

S_d consists of 64 repetitions of the sequence $\{+W, +0, +W, -W, -0, -W\}$ where W is defined to be the PCM codeword whose Ucode is $16 + U_{INFO}$ and 0 is the PCM codeword with Ucode 0. $\overline{S_d}$ consists of 8 repetitions of the sequence $\{-W, -0, -W, +W, +0, +W\}$.

The first symbol of S_d is defined to be transmitted in data frame interval 0. The digital modem shall keep data frame alignment from this point on.

8.4.5 TRN_{1d}

Signal TRN_{1d} is a sequence of the PCM codeword whose Ucode is U_{INFO} with signs generated by applying binary ones to the input of the scrambler described in 5.3. A sign of 0 represents a negative voltage, a sign of 1 represents a positive voltage. The scrambler is initialized to zero prior to the transmission of TRN_{1d}. TRN_{1d} shall be an integer multiple of 6 symbols long.

8.5 Phase 4 signals for the analogue modem

8.5.1 B1

As defined in 10.1.3.1/V.34.

8.5.2 CP

CP sequences consist of symbols chosen from a 4- or 16-point 2D constellation. During Phase 4 start-up procedures the constellation size depends on bit 47 of J_d. During rate renegotiation procedures the constellation size depends on bit 48 of J_d. CP is used by the analogue modem to pass constellation parameters to the digital modem. A CP_t sequence is sent to pass the parameters used by the digital modem in Phase 4 training. A CP sequence with the acknowledge bit set to 1 is denoted by CP'. A CP sequence with the request for silence bit set is denoted CP_s. Due to the nature of the procedures that use CP_s, the constellation parameters contained in CP_s are not used. The average power of the constellations that the analogue modem requests the digital modem to use during data mode shall not be greater than 3 dB above the average power of the constellations it requests the digital modem to use during Phase 4.

CP sequences are modulated according to 10.1.3.9/V.34. The scrambler and differential encoder are initialized to zero prior to the transmission of the first CP_t sequence. Bit fields for CP sequences are defined in Table 14. Bit 0 is transmitted first.

The CRC generator used is described in 10.1.2.3.2/V.34.

CP sequences are defined to be of variable length. A constellation mask consists of 128 bits where a bit set to 1 indicates that the constellation includes the PCM code represented by the corresponding Ucode. Only the number of different constellations need to be sent. The constellations that are sent are indexed from 0 (in bits 136:271) to a maximum of 5 (in bits 816:951). If the constellations at the digital modem's transmitter differ from those at the output to the codec's D/A convertor, then bit 128 shall be set and the constellation at the output to the codec's D/A convertor corresponding to each transmit constellation shall be sent. Due to the variability in the number of constellations, a parameter γ is defined to be 136* (the maximum constellation index given in bits 103:127) and a parameter δ is defined to be $(2*\gamma)+136$ if bit 128 is set and γ if bit 128 is clear.

When multiple CP and CP' sequences are transmitted as a group, they shall all contain identical modulation and spectral shaping parameter information.

Table 14/V.90 – Definition of bits in CP

CP bits LSB:MSB	Definition
0:16	Frame Sync: 1111111111111111
17	Start bit: 0
18	Reserved for ITU: This bit is set to 0 by the analogue modem and is not interpreted by the digital modem
19	0 indicates CP _i ; 1 indicates CP
20:24	Selected digital modem to analogue modem data signalling rate, an integer, drn, between 0 and 22. drn = 0 indicates clear-down. Data signalling rate = (drn+20)*8000/6 in CP and (drn+8)*8000/6 in CP _i .
25:29	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
30	Set to 1 indicates a silent period is requested. This may be used during rate renegotiation (see 9.6)
31:32	S _i : The number of sign bits used as redundancy for spectral shaping
33	Acknowledge bit: 0 = modem has not received MP from far end; 1 = received MP from far end
34	Start bit: 0
35	Codec type: 0 = μ -law; 1 = A-law
36:48	Analogue modem to digital modem data signalling rate capability mask: Bit 36:4800; ...; bit 47:31 200; bit 48:33 600. Bits set to 1 indicate data signalling rates supported and enabled in analogue modem transmitter
49:50	ld: Number of look-ahead frames requested during spectral shaping. This shall be consistent with the capabilities of the digital modem indicated in J _d
51	Start bit: 0
52:67	The RMS value of TRN _{ld} at the transmitter output divided by the RMS value of TRN _{ld} at the output to the codec's D/A convertor expressed in unsigned Q3.13 format (xxx.xxxxxxxxxxxx)
68	Start bit: 0
69:76	Parameter a ₁ of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
77:84	Parameter a ₂ of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
85	Start bit: 0
86:93	Parameter b ₁ of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
94:101	Parameter b ₂ of the spectral shaping filter in signed Q1.6 format (sx.xxxxxx)
102	Start bit: 0
103:106	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 0
107:110	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 1
111:114	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 2
115:118	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 3
119	Start bit: 0
120:123	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 4
124:127	An integer between 0 and 5 denoting the index of the constellation to be used in data frame interval 5
128	Set to 1 if the constellations at the transmitter differ from those at the output to the codec's D/A convertor

Table 14/V.90 – Definition of bits in CP (concluded)

CP bits LSB:MSB	Definition
129:135	Reserved for ITU: These bits are set to 0 by the analogue modem and are not interpreted by the digital modem
136	Start bit: 0
137:152	Constellation mask for Uchord ₁ (bit 137 corresponds to Ucode 0)
153	Start bit: 0
154:169	Constellation mask for Uchord ₂ (bit 154 corresponds to Ucode 16)
170	Start bit: 0
171:186	Constellation mask for Uchord ₃ (bit 171 corresponds to Ucode 32)
187	Start bit: 0
188:203	Constellation mask for Uchord ₄ (bit 188 corresponds to Ucode 48)
204	Start bit: 0
205:220	Constellation mask for Uchord ₅ (bit 205 corresponds to Ucode 64)
221	Start bit: 0
222:237	Constellation mask for Uchord ₆ (bit 222 corresponds to Ucode 80)
238	Start bit: 0
239:254	Constellation mask for Uchord ₇ (bit 239 corresponds to Ucode 96)
255	Start bit: 0
256:271	Constellation mask for Uchord ₈ (bit 256 corresponds to Ucode 112)
272:271+γ	Possibly more constellations in same format as bits 136:271
272+γ:271+δ	Corresponding codec constellations in same format as bits 136:271
272+δ	Start bit: 0
273+δ:288+δ	CRC
289+δ:291+δ	Fill bits: 000

The analogue modem shall design constellations such that their average power, when calculated using the formula below, does not exceed the limit given in Table 15 corresponding to the maximum digital modem transmit power specified in INFO_{0d}, assuming the calculation is performed using infinite precision arithmetic.

$$\text{Average power of constellation set} = \frac{\sum_{i=0}^5 \sum_{j=0}^{M_i-1} p_{i,j} \cdot n_{i,j}}{6 \cdot 2^K}$$

where K is defined in 5.4.1;

M_i is defined in 5.4.3;

p_{i,j} is the square of the linear value in Table 1 corresponding to the level labelled j in the ith constellation at the measurement point specified by bit 38 of INFO_{0d}; and

$$\begin{aligned} n_{i,j} &= A_i(R_{i+1} + 1) && \text{if } j < K_i \\ n_{i,j} &= 2^K - A_i(R_i - R_{i+1}) && \text{if } j = K_i \\ n_{i,j} &= A_i(R_{i+1}) && \text{if } j > K_i \end{aligned}$$

where A₀ = 1; A_{i+1} = A_iM_i; and R_i and K_i are the outputs of the modulus encoder when R₀ = 2^K – 1 in 5.4.3.

Table 15/V.90 – Limits for the average power calculation

Maximum digital modem transmit power, dBm0	Limit of average power calculation
-0.5	(15124) ²
-1	(14276) ²
-1.5	(13480) ²
-2	(12724) ²
-2.5	(12012) ²
-3	(11340) ²
-3.5	(10708) ²
-4	(10108) ²
-4.5	(9544) ²
-5	(9008) ²
-5.5	(8504) ²
-6	(8028) ²
-6.5	(7580) ²
-7	(7156) ²
-7.5	(6756) ²
-8	(6380) ²
-8.5	(6020) ²
-9	(5684) ²
-9.5	(5368) ²
-10	(5068) ²
-10.5	(4784) ²
-11	(4516) ²
-11.5	(4264) ²
-12	(4024) ²
-12.5	(3800) ²
-13	(3588) ²
-13.5	(3388) ²
-14	(3196) ²
-14.5	(3020) ²
-15	(2852) ²
-15.5	(2692) ²
-16	(2540) ²

NOTE – Since modems use finite precision arithmetic, the digital modem should ensure that its calculations give results greater than or equal to the results that would be calculated using infinite precision arithmetic. Similarly, the analogue modem should ensure that its calculations give results less than or equal to the results that would be calculated using infinite precision arithmetic. The actions that a digital modem takes when a constellation set is found to have an average power above the appropriate limit are a national matter and are beyond the scope of this Recommendation.

8.5.3 E

As defined in 10.1.3.2/V.34.

8.6 Phase 4 signals for the digital modem

Signals transmitted by the digital modem during Phase 4 may be spectrally shaped. During initial train or retrain, signals TRN_{2d}, MP and E_d use the spectral shaping parameters defined by CP_t. During rate renegotiation, TRN_{2d}, MP and E_d use the spectral shaping parameters as used in the preceding data mode along with the K previously derived from CP_t. B1_d and the following data mode signals shall use the spectral shaping parameters defined by CP.

8.6.1 B_{1d}

B_{1d} consists of 48 data frames of scrambled ones transmitted at the end of start-up using the selected data mode constellation parameters. The scrambler, differential encoder and spectral shape filter memory are initialized to zero prior to transmitting B_{1d}. The symbols in the first data frame of B_{1d} shall have the magnitudes resulting from mapping the first D scrambled ones after initializing the scrambler to zero, and shall be identical for all values of ld. Permitted values of K and S are given in Table 2.

8.6.2 E_d

E_d consists of 2 data frames of scrambled binary zeroes used to signal the end of MP. It is mapped using the same constellation parameters used to send TRN_{2d}.

8.6.3 MP

Modulation parameters for the analogue modem are sent in an MP sequence. MP is transmitted using the constellation parameters used to send TRN_{2d}. An MP with the acknowledge bit set is denoted MP'. Bit fields for MP sequences are defined in Table 16. Bit 0 is transmitted first.

Two types of MP sequences are used. Type 1 is the same as Type 0 with the addition of precoding coefficients. The CRC generator used is described in 10.1.2.3.2/V.34.

When multiple MP and MP' sequences are transmitted as a group, they shall all contain identical modulation parameter information.

Table 16/V.90 – Definition of bits in MP

MP bits LSB:MSB	Definition
0:16	Frame Sync: 1111111111111111
17	Start bit: 0
18	MP Type bit: 0 = Type 0 without precoder coefficients; 1 = Type 1 with precoder coefficients
19:23	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
24:27	Maximum analogue modem to digital modem data signalling rate, drn. Data rate = drn*2400 where drn is an integer between 2 and 14. drn = 0 indicates cleardown
28	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
29:30	Trellis encoder select bits in analogue modem to digital modem direction: 0 = 16 state; 1 = 32 state; 2 = 64 state; 3 = reserved The digital modem receiver requires the analogue modem transmitter to use the selected trellis encoder
31	Nonlinear encoder parameter select bit for the analogue modem transmitter. 0: $\Theta = 0$; 1: $\Theta = 0.3125$
32	Constellation shaping select bit for the analogue modem transmitter. 0: minimum; 1: expanded (see Table 10/V.34)
33	Acknowledge bit: 0 = modem has not received CP from far end; 1 = received CP from far end
34	Start bit: 0
35	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
36:49	Analogue modem to digital modem data signalling rate capability mask: Bit 36:4800; ...; bit 47:31 200; bit 48:33 600; 49: Reserved for ITU. (This bit is set to 0 by the digital modem and is not interpreted by the analogue modem.) Bits set to 1 indicate data signalling rates supported and enabled in digital modem
50	Reserved for ITU: This bit is set to 0 by the digital modem and is not interpreted by the analogue modem
51	Start bit: 0

Table 16/V.90 – Definition of bits in MP (concluded)

MP bits LSB:MSB	Definition
Continuation for MP Type 0 (without precoder coefficients)	
52:67	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
68	Start bit: 0
69:84	CRC
85	Fill bit: 0
86:...	Fill bits: 0s to extend the MP sequence length to the next multiple of 6 symbols
Continuation for MP Type 1 (with precoder coefficients)	
52:67	Precoding coefficient h(1) real
68	Start bit: 0
69:84	Precoding coefficient h(1) imaginary
85	Start bit: 0
86:101	Precoding coefficient h(2) real
102	Start bit: 0
103:118	Precoding coefficient h(2) imaginary
119	Start bit: 0
120:135	Precoding coefficient h(3) real
136	Start bit: 0
137:152	Precoding coefficient h(3) imaginary
153	Start bit: 0
154:169	Reserved for ITU: These bits are set to 0 by the digital modem and are not interpreted by the analogue modem
170	Start bit: 0
171:186	CRC
187	Fill bit: 0
188:...	Fill bits: 0s to extend the MP sequence length to the next multiple of 6 symbols

8.6.4 R

Signal R is transmitted by repeating the 6 symbol sequence containing PCM codewords with the sign pattern + + + - - - where the left-most sign is transmitted first. \bar{R} consists of 4 repetitions of the 6-symbol sequence containing the same PCM codewords with the sign pattern - - - + + + where the left-most sign is transmitted first.

NOTE – Neither R nor \bar{R} are differentially encoded. This imposes a requirement on the receiver to be able to detect these sequences regardless of their polarity.

R_d denotes signal R using the highest power PCM codeword from the data mode constellation of each data frame interval as passed in CP.

R_i denotes signal R using the single PCM codeword whose Ucode is U_{INFO} for all data frame intervals.

R_t denotes signal R using the highest power PCM codeword from the training constellation of each data frame interval as passed in CP_t .

8.6.5 TRN_{2d}

TRN_{2d} is generated by applying scrambled binary ones to the encoder of 5.4. The constellation set to be used is passed in CP_t. The scrambler, differential encoder and spectral shape filter memory shall be initialized to zero prior to transmitting TRN_{2d}. The symbols in the first data frame of TRN_{2d} shall have the magnitudes resulting from mapping the first D scrambled ones after initializing the scrambler to zero, and shall be identical for all values of ld. Permitted values of K and S are given in Table 17. TRN_{2d} shall be an integer multiple of 6 symbols long.

Table 17/V.90 – Phase 4 signalling rate for different K and S

K, bits entering modulus encoder	S, sign bits used for Phase 4 data		Data Signalling Rate, kbit/s	
	From	To	From	To
6	3	6	12	16
7	3	6	13 1/3	17 1/3
8	3	6	14 2/3	18 2/3
9	3	6	16	20
10	3	6	17 1/3	21 1/3
11	3	6	18 2/3	22 2/3
12	3	6	20	24
13	3	6	21 1/3	25 1/3
14	3	6	22 2/3	26 2/3
15	3	6	24	28
16	3	6	25 1/3	29 1/3
17	3	6	26 2/3	30 2/3
18	3	6	28	32
19	3	6	29 1/3	33 1/3
20	3	6	30 2/3	34 2/3
21	3	6	32	36
22	3	6	33 1/3	37 1/3
23	3	6	34 2/3	38 2/3
24	3	6	36	40

9 Operating procedures

The start-up procedure carried out after establishing a dialled connection between the two modems consists of four distinct phases:

- Phase 1: Network interaction;
- Phase 2: Channel probing and ranging;
- Phase 3: Equaliser and echo canceller training and digital impairment learning;
- Phase 4: Final training.

9.1 Phase 1 – Network interaction

9.1.1 Use of bits in Recommendation V.8

Bit b5 in the "modn0" octet of Recommendation V.8 shall be set to indicate that a modem is capable of V.90 operation. This also indicates that at least one bit shall be set in the V.90 availability category. A modem that indicates V.90 capability shall indicate its PSTN access type using a bit in the PSTN access category. The operation defined in this Recommendation is only possible when two V.90 capable modems are connected and one or both of the modems is

accessing the PSTN digitally. If both modems are accessing the PSTN over analogue connections they shall proceed in accordance with Recommendation V.8 as if V.90 capability had not been indicated. Similarly, if the information in the V.90 availability category does not indicate the presence of an analogue and digital modem pair, the modems shall proceed in accordance with Recommendation V.8 as if V.90 capability had not been indicated. In the case where both modems are digitally connected to the PSTN and both modems indicate the ability to be an analogue and a digital modem, the call modem shall become the analogue modem and the answer modem shall become the digital modem.

9.1.2 Call modem

9.1.2.1 Initially, the call modem shall condition its receiver to detect either signal ANS or ANSam as defined in Recommendation V.8, and the modem shall either transmit CI, CT, CNG or no signal as defined in Recommendation V.8. If signal ANSam is detected, the modem shall transmit silence for the period T_e as specified in Recommendation V.8. The modem shall then condition its receiver to detect JM and shall send CM with the appropriate bits set to indicate that V.90 operation is desired. When a minimum of two identical JM sequences have been received, the modem shall complete the current CM octet and send CJ. After sending CJ, the modem shall transmit silence for 75 ± 5 ms and proceed with Phase 2. This procedure is shown in Figure 3.

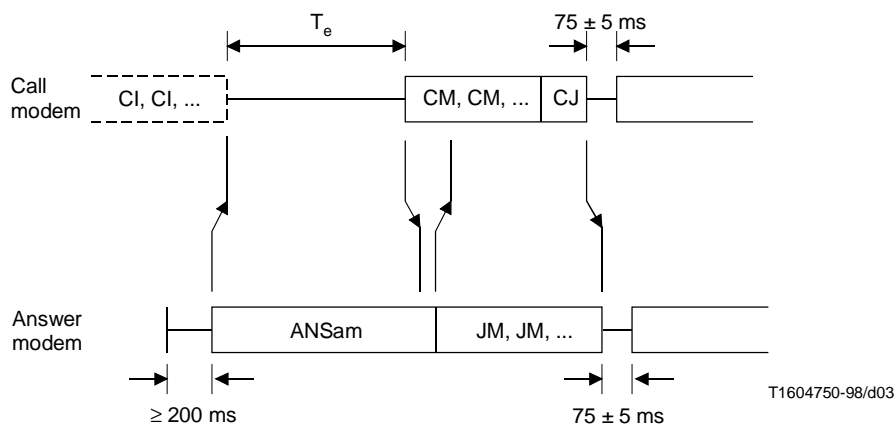


Figure 3/V.90 – Phase 1 – Network interaction

9.1.2.2 If signal ANS (rather than ANSam) is detected, the modem shall proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendations.

9.1.3 Answer modem

9.1.3.1 Upon connection to line, the modem shall initially remain silent for a minimum of 200 ms and then transmit signal ANSam according to the procedure specified in Recommendation V.8. This signal shall include phase reversals as specified in Recommendation V.8. The modem shall condition its receiver to detect CM and, possibly, calling modem responses specified in other appropriate Recommendations.

9.1.3.2 If a minimum of 2 identical CM sequences are received and the appropriate bits are set to indicate V.90 operation, the modem shall send JM and condition its receiver to detect CJ. After receiving all 3 octets of CJ, the modem shall transmit silence for 75 ± 5 ms, and proceed with Phase 2 of start-up. This procedure is shown in Figure 3.

9.1.3.3 If a call modem response specified in some other appropriate Recommendation is detected, the modem shall proceed in accordance with the appropriate Recommendation.

9.1.3.4 If neither CM nor a suitable call modem response is detected for the allowed ANSam transmission period as specified in Recommendation V.8, the modem shall transmit silence for 75 ± 5 ms, and then proceed in accordance with Annex A/V.32 *bis*, Recommendation T.30, or other appropriate Recommendations.

9.2 Phase 2 – Probing/ranging

Channel probing and ranging are performed in Phase 2 of the start-up procedure. The description below details both the error-free and recovery procedures in the digital and analogue modems. Capabilities information and modulation parameters are sent in the INFO sequences detailed in 8.2.3.

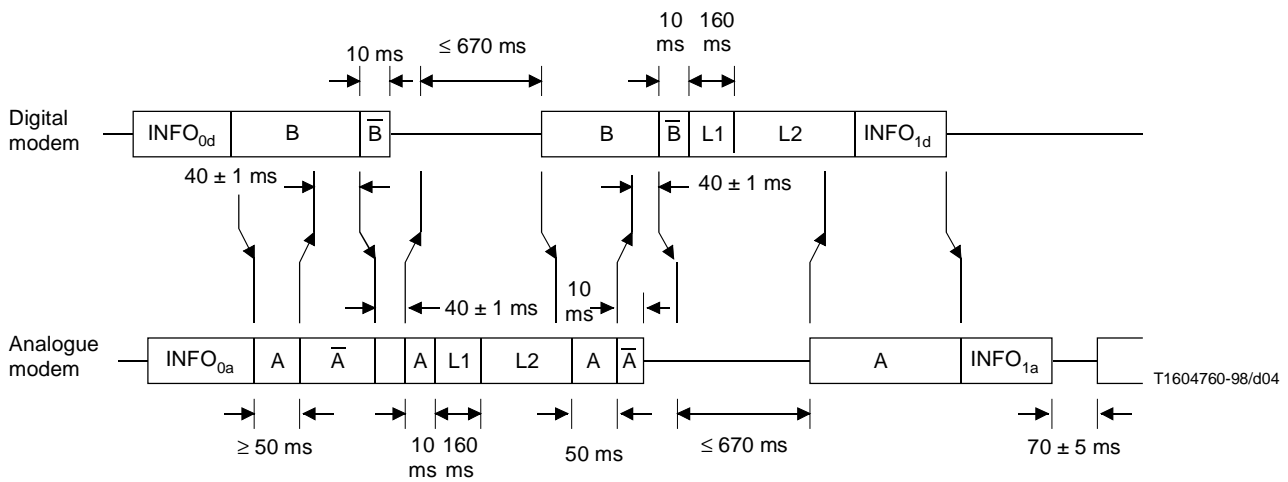


Figure 4/V.90 – Phase 2 – Probing/ranging

9.2.1 Digital modem

9.2.1.1 Error-free procedures

9.2.1.1.1 During the 75 ± 5 ms silent period ending Phase 1, the digital modem shall condition its receiver to receive INFO_{0a} and detect Tone A. After the 75 ± 5 ms silent period, the digital modem shall send INFO_{0d} with bit 28 set to 0, followed by Tone B.

9.2.1.1.2 After receiving INFO_{0a}, the digital modem shall condition its receiver to detect Tone A, receive INFO_{0a} (see 9.2.1.2 Recovery procedures) and detect the subsequent Tone A phase reversal.

9.2.1.1.3 After detecting the Tone A phase reversal, the digital modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for another 10 ms after the phase reversal. The digital modem shall then transmit silence and condition its receiver to detect a second Tone A phase reversal.

9.2.1.1.4 After detecting the second Tone A phase reversal, the digital modem has the information required to calculate the round-trip delay. The round-trip delay estimate, RTDEd, is the time interval between the appearance of the Tone B phase reversal at the digital modem line terminals and receiving the second Tone A phase reversal at the line terminals minus 40 ms. The modem shall then condition its receiver to receive the probing signals L1 and L2.

9.2.1.1.5 The digital modem shall receive signal L1 for its 160 ms duration. The digital modem may then receive signal L2 for a period of time not to exceed 500 ms. The digital modem shall then transmit Tone B and condition its receiver to detect Tone A and the subsequent Tone A phase reversal.

9.2.1.1.6 After detecting Tone A and the subsequent Tone A phase reversal, the digital modem shall transmit a Tone B phase reversal. The Tone B phase reversal shall be delayed so that the time duration between receiving the Tone A phase reversal at the line terminals and the appearance of the Tone B phase reversal at the line terminals is 40 ± 1 ms. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2 and condition its receiver to detect Tone A.

9.2.1.1.7 After the digital modem detects Tone A and has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the digital modem shall send INFO_{1d}.

9.2.1.1.8 After sending INFO_{1d}, the digital modem shall transmit silence and condition its receiver to receive INFO_{1a}. After receiving INFO_{1a}, the digital modem shall proceed to Phase 3 of the start-up procedure if bits 37:39 of INFO_{1a} indicate the integer 6. If bits 37:39 of INFO_{1a} indicate an integer between 0 and 5, the digital modem shall proceed in accordance with 11.3.1.1/V.34 assuming the role of a call modem. Any subsequent retrains shall use Phase 2 of V.90 regardless of the analogue modem's choice of operating mode.

9.2.1.2 Recovery procedures

9.2.1.2.1 If, in 9.2.1.1.2 or 9.2.1.1.3, the digital modem detects Tone A before receiving INFO_{0a}, or if it receives repeated INFO_{0a} sequences, the digital modem shall repeatedly send INFO_{0d} sequences. The digital modem shall set bit 28 of the INFO_{0d} sequence to 1 after correctly receiving INFO_{0a}. If the digital modem receives INFO_{0a} with bit 28 set to 1, it shall condition its receiver to detect Tone A and the subsequent Tone A phase reversal, complete sending the current INFO_{0d} sequence, and then transmit Tone B. Alternatively, if the digital modem detects Tone A and has received INFO_{0a}, it shall condition its receiver to detect a Tone A phase reversal, complete sending the current INFO_{0d} sequence, and transmit Tone B. In both cases, the digital modem shall then proceed according to 9.2.1.1.3.

9.2.1.2.2 If, in 9.2.1.1.3, the digital modem does not detect the Tone A phase reversal, the digital modem shall continue transmitting Tone B until it does detect a Tone A phase reversal.

9.2.1.2.3 If, in 9.2.1.1.4, the digital modem does not detect a Tone A phase reversal within 2000 ms from the phase reversal detected during the procedure in 9.2.1.1.3, the digital modem shall transmit silence and condition its receiver to detect Tone A. After detecting Tone A, the digital modem shall transmit Tone B and condition its receiver to detect a Tone A phase reversal and proceed in accordance with 9.2.1.1.3.

9.2.1.2.4 If, in 9.2.1.1.6, the digital modem does not detect the Tone A phase reversal within 900 ms plus a round-trip delay from the phase reversal detected during the procedure defined in 9.2.1.1.4, the modem waits 40 ms, then transmits a Tone B phase reversal. Tone B shall be transmitted for an additional 10 ms after the phase reversal. The modem shall then transmit signal L1 followed by signal L2, condition its receiver to detect Tone A, and proceed in accordance with 9.2.1.1.7.

9.2.1.2.5 If, in 9.2.1.1.7, the digital modem does not detect Tone A within 650 ms plus a round-trip delay from the beginning of L2, the digital modem shall initiate a retrain according to 9.5.1.1.

9.2.1.2.6 If, in 9.2.1.1.8, the digital modem does not receive INFO_{1a} within 700 ms plus a round-trip delay from the end of INFO_{1d} transmission, the digital modem shall condition its receiver to detect either Tone A or INFOMARKS_a. Upon detection of INFOMARKS_a, the digital modem shall either initiate a retrain according to 9.5.1.1 or send INFO_{1d} and proceed in accordance with 9.2.1.1.8. Upon detection of Tone A, the digital modem shall respond to a retrain and proceed according to 9.5.1.2.

9.2.2 Analogue modem

9.2.2.1 Error-free procedures

9.2.2.1.1 During the 75 ± 5 ms silent period ending Phase 1, the analogue modem shall condition its receiver to receive INFO_{0d} and detect Tone B. After the 75 ± 5 ms silent period, the analogue modem shall send INFO_{0a} with bit 28 set to 0, followed by Tone A.

9.2.2.1.2 After receiving INFO_{0d}, the analogue modem shall condition its receiver to detect Tone B and receive INFO_{0d} (see 9.2.2.2 Recovery procedures).

9.2.2.1.3 After Tone B is detected and Tone A has been transmitted for at least 50 ms, the analogue modem shall transmit a Tone A phase reversal, and condition its receiver to detect a Tone B phase reversal.

9.2.2.1.4 After detecting the Tone B phase reversal, the analogue modem has the information required to calculate the round-trip delay. The round-trip delay estimate, RTDE_a, is the time interval between sending the Tone A phase reversal at the line terminals and receiving the Tone B phase reversal at the line terminals minus 40 ms.

9.2.2.1.5 The analogue modem shall then transmit a Tone A phase reversal. The Tone A phase reversal shall be delayed so that the time duration between receiving the Tone B phase reversal at the line terminals and the appearance of the Tone A phase reversal at the line terminals is 40 ± 1 ms. Tone A shall be transmitted for 10 ms after the phase reversal. Then the analogue modem shall transmit signal L1 followed by signal L2 and condition its receiver to detect Tone B.

9.2.2.1.6 When Tone B is detected and the analogue modem has received the local echo of L2 for a period of time not to exceed 550 ms plus a round-trip delay, the analogue modem shall transmit Tone A for 50 ms followed by a Tone A phase reversal. Tone A shall be transmitted for an additional 10 ms after the phase reversal. Then the analogue modem shall transmit silence and condition its receiver to detect a Tone B phase reversal.

9.2.2.1.7 After detecting the Tone B phase reversal, the analogue modem shall condition its receiver to receive the probing signals L1 and L2.

9.2.2.1.8 The analogue modem shall receive signal L1 for its 160 ms duration. The analogue modem may then receive signal L2 for a period of time not to exceed 500 ms. The analogue modem shall then transmit Tone A and condition its receiver to receive INFO_{1d}.

9.2.2.1.9 After receiving INFO_{1d}, the analogue modem shall send INFO_{1a} using bits 37:39 to indicate its choice of V.90 mode or V.34 mode. After sending INFO_{1a}, the analogue modem shall proceed to either Phase 3 of the start-up procedure or 11.3.1.2/V.34 assuming the role of an answer modem. Any subsequent retrains shall use Phase 2 of V.90 regardless of the analogue modem's choice of operating mode.

9.2.2.2 Recovery procedures

9.2.2.2.1 If, in 9.2.2.1.2, 9.2.2.1.3, or 9.2.2.1.4, the analogue modem detects Tone B before correctly receiving INFO_{0d}, or if it receives repeated INFO_{0d} sequences, the analogue modem shall repeatedly send INFO_{0a}. The analogue modem shall set bit 28 of the INFO_{0a} sequence to 1 after correctly receiving INFO_{0d}. If the analogue modem receives INFO_{0d} with bit 28 set to 1, it shall condition its receiver to detect Tone B, complete the current INFO_{0a}, and then transmit Tone A. Alternatively, if the analogue modem detects Tone B and has received INFO_{0d}, it shall complete the current INFO_{0a}, and transmit Tone A. In both cases, the analogue modem shall then proceed according to 9.2.2.1.3.

9.2.2.2.2 If, in 9.2.2.1.4, the analogue modem does not detect the Tone B phase reversal within 2000 ms, the analogue modem shall condition its receiver to detect Tone B and then proceed according to 9.2.2.1.3.

9.2.2.2.3 If, in 9.2.2.1.6, the analogue modem does not detect Tone B within 600 ms plus a round-trip delay from the beginning of L2, it shall condition its receiver to detect Tone B and transmit Tone A. It shall then proceed according to 9.2.2.1.3.

9.2.2.2.4 If, in 9.2.2.1.9, the analogue modem does not receive INFO_{1d} within 2000 ms plus two round-trip delays from the detection of Tone B during the procedure defined in 9.2.2.1.6, the modem shall either initiate a retrain according to 9.5.2.1 or send INFOMARKS_a until it receives INFO_{1d} or detects Tone B. If Tone B is detected, the analogue modem shall proceed according to 9.2.2.1.3. If INFO_{1d} is received, the analogue modem shall then proceed according to 9.2.2.1.9.

9.3 Phase 3 – Equaliser and echo canceller training and digital impairment learning

Equaliser and echo canceller training and digital impairment learning are performed in Phase 3 of the start-up procedure. The description below (see Figures 5 and 6) details the procedures in the digital and analogue modems.

9.3.1 Digital modem

The digital modem may initiate a retrain during Phase 3 according to 9.5.1.1. If Tone A is detected during Phase 3, the digital modem shall respond to retrain according to 9.5.1.2.

9.3.1.1 The digital modem shall be initially silent and condition its receiver to detect S and the subsequent \bar{S} . If the duration of signal MD indicated by INFO_{1a} is zero, the digital modem shall proceed according to 9.3.1.2. Otherwise, after detecting the S-to- \bar{S} transition, the digital modem shall wait for the duration of signal MD as indicated by INFO_{1a} and then shall condition its receiver to receive signal S and the S-to- \bar{S} transition.

9.3.1.2 After detecting signal S and the S-to- \bar{S} transition, the digital modem shall condition its receiver to begin training its equaliser using signal PP. After receiving signal PP, the digital modem may further refine its equaliser using the first 512T of signal TRN.

9.3.1.3 After receiving the first 512T of signal TRN, the digital modem shall condition its receiver to receive sequence J_a . After receiving J_a , the digital modem may wait for up to 500 ms and shall then transmit signal S_d for 384T and signal \bar{S}_d for 48T.

9.3.1.4 The digital modem shall then transmit TRN_{1d} for a minimum of 2040T. Within 4000 ms of starting to transmit TRN_{1d} the digital modem shall transmit J_d and condition its receiver to detect signal S and the S-to- \bar{S} transition.

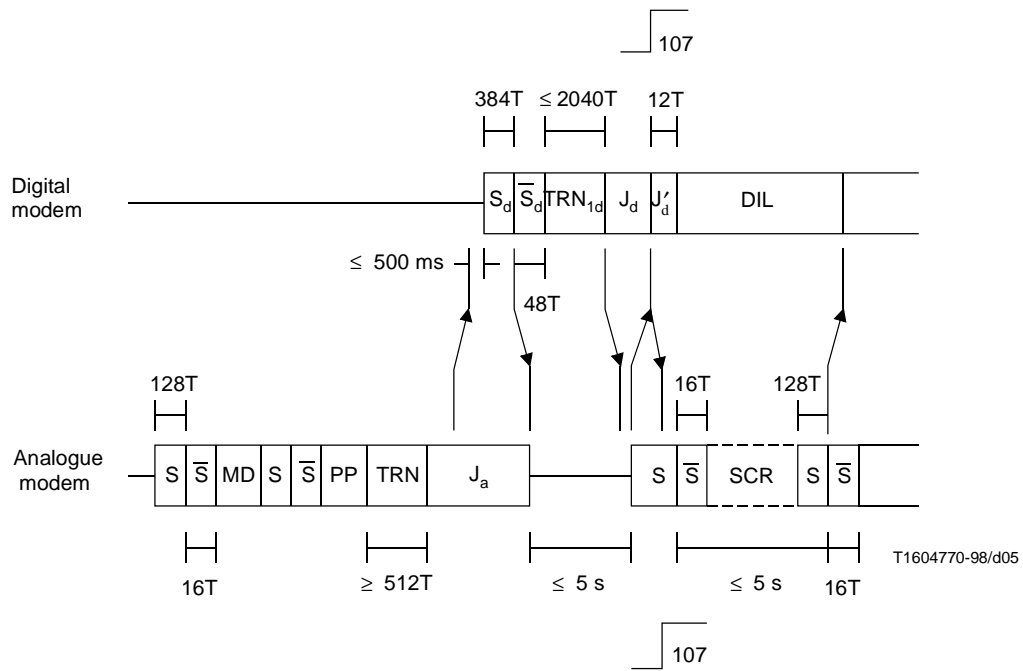


Figure 5/V.90 – Phase 3 – Equaliser and echo canceller training and digital impairment learning

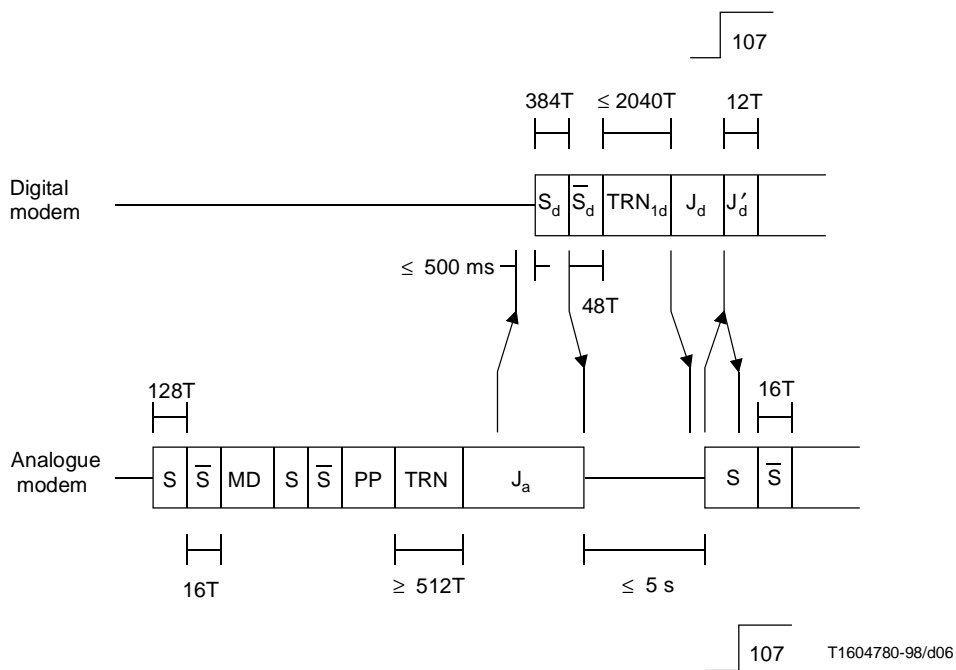


Figure 6/V.90 – Phase 3 – Equaliser and echo canceller training when no DIL has been requested

9.3.1.5 The digital modem shall continue to repeat the J_d sequence until it detects S . It shall then complete the current J_d sequence and then transmit J'_d . If the digital modem does not detect S within 5100 ms plus a round-trip delay from the start of TRN_{1d} , it shall initiate a retrain according to 9.5.1.1. If the analogue modem has requested a DIL of length zero, the digital modem shall proceed to Phase 4 of the start-up procedure. Otherwise, the digital modem shall proceed according to 9.3.1.6.

9.3.1.6 The digital modem shall send the DIL requested by the analogue modem. After receiving a subsequent S -to- \bar{S} transition, the digital modem shall complete sending the current segment of the DIL and proceed to Phase 4 of the start-up procedure.

NOTE – Since this Recommendation does not specify the turnaround time in the analogue modem from the J_d to J'_d transition to the S -to- \bar{S} transition, failure by the digital modem to detect both S -to- \bar{S} transitions may result in the premature termination of DIL.

9.3.2 Analogue modem

The analogue modem may initiate a retrain during Phase 3 according to 9.5.2.1. If Tone B is detected during Phase 3, the analogue modem shall respond to retrain according to 9.5.2.2.

9.3.2.1 After sending sequence $INFO_{1a}$, the analogue modem shall transmit silence for 70 ± 5 ms, signal S for 128T and signal \bar{S} for 16T. If the duration of the analogue modem's MD signal, as indicated in the $INFO_{1a}$, is zero, the modem shall proceed according to 9.3.2.2. Otherwise, the modem shall transmit signal MD for the duration indicated in $INFO_{1a}$, signal S for 128T, and signal \bar{S} for 16T.

9.3.2.2 The analogue modem shall then transmit signal PP.

9.3.2.3 After transmitting signal PP, the modem shall transmit signal TRN. Signal TRN consists of four constellation points and shall be transmitted for at least 512T. The total time from the beginning of transmission of signal MD to the end of signal TRN shall not exceed one round-trip delay plus 4000 ms.

9.3.2.4 After transmitting signal TRN, the modem shall send sequence J_a and condition its receiver to detect signal S_d and the S_d -to- \bar{S}_d transition. After detecting the S_d -to- \bar{S}_d transition, the modem shall terminate J_a and transmit silence. If the analogue modem does not detect the S_d -to- \bar{S}_d transition within 1500 ms from the start of J_a , the analogue modem shall initiate a retrain according to 9.5.2.1.

9.3.2.5 The modem shall condition its receiver to begin its equaliser training using signal the first 2040T of signal TRN_{1d} .

9.3.2.6 After receiving the first 2040T of signal TRN_{1d} , the modem shall condition its receiver to receive sequence J_d .

9.3.2.7 After receiving J_d , the analogue modem may wait for up to 5000 ms from having begun to transmit silence as required in the procedure in 9.3.2.4 and shall then begin transmitting signal S and condition its receiver to detect J'_d . If the analogue modem does not receive J_d within 4500 ms from the end of J_a , the analogue modem shall initiate a retrain according to 9.5.2.1.

9.3.2.8 After detecting J'_d , the analogue modem shall transmit \bar{S} for 16T. If the analogue modem requested a DIL of zero length it shall proceed with Phase 4 of the start-up procedure. Otherwise it shall proceed in accordance with 9.3.2.9.

9.3.2.9 The analogue modem shall receive the DIL sequence it requested in J_a . During the reception of DIL the analogue modem shall transmit either silence or SCR at its discretion.

9.3.2.10 Within 5000 ms of transmitting \bar{S} in 9.3.2.8 the analogue modem shall again transmit signal S for 128T followed by \bar{S} for 16T. This indicates to the digital modem that the analogue modem has received enough of the DIL sequence. The analogue modem shall then proceed to Phase 4 of the start-up procedure.

9.4 Phase 4 – Final training

See Figure 7.

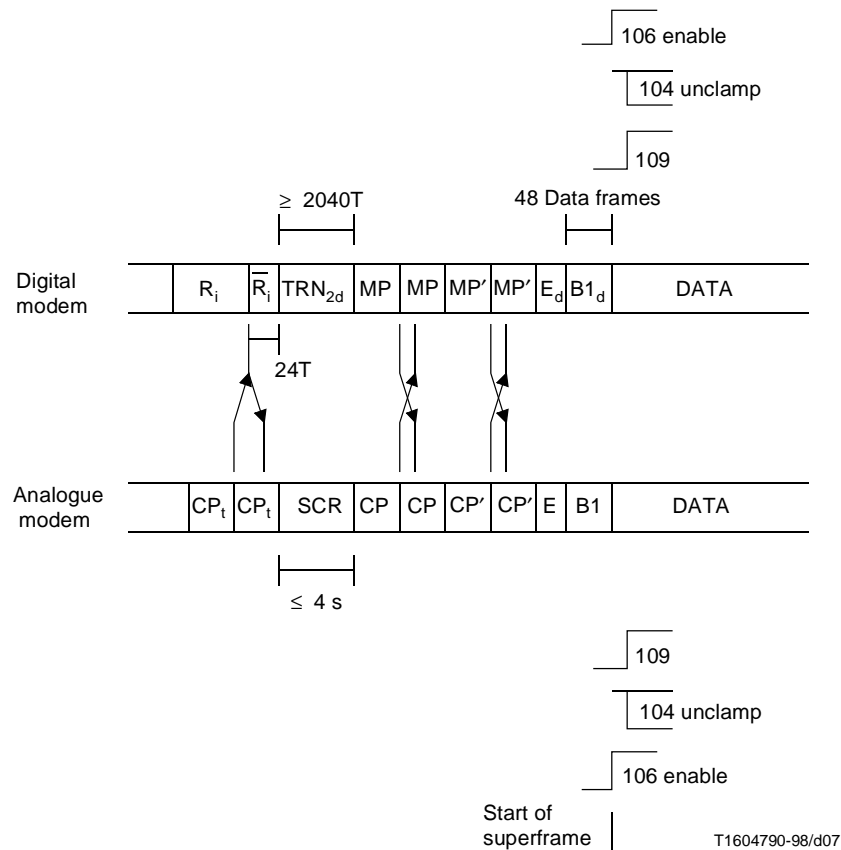


Figure 7/V.90 – Phase 4 – Final training

9.4.1 Digital modem

The digital modem shall initiate a retrain during Phase 4 according to 9.5.1.1 if it does not receive B1 within 15 s plus 5 round-trip delays after receiving INFO_{1a} in 9.2.1.1.8. The digital modem may initiate a retrain at any time during Phase 4 according to 9.5.1.1. If Tone A is detected during Phase 4, the digital modem shall respond to retrain according to 9.5.1.2.

9.4.1.1 The digital modem shall send signal R_i for a minimum of 192T and condition its receiver to receive a CP_t sequence.

9.4.1.2 After receiving a CP_t sequence, the digital modem shall send signal R̄_i for 24T followed by TRN_{2d} for a minimum of 2040T.

9.4.1.3 Within 2000 ms of beginning to transmit TRN_{2d}, the digital modem shall send MP sequences. After receiving the analogue modem's CP sequence, the digital modem shall complete sending the current MP sequence, and then send MP' sequences (MP sequences with the acknowledge bit set).

9.4.1.4 The digital modem shall continue sending MP sequences until it has sent an MP' sequence and received a CP' or a 20-bit E from the analogue modem. The digital modem shall then complete the current MP' sequence and send a single E_d sequence.

9.4.1.5 After sending the E_d sequence, the digital modem shall send B1_d at the negotiated data signalling rate using the data mode constellation parameters it received in CP. The modem shall then enable circuit 106 to respond to the condition of circuit 105 and begin data transmission using the modulation procedures of 5.4.

9.4.1.6 After receiving a 20-bit E sequence, the digital modem shall condition its receiver to receive B1. After receiving B1, the digital modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.4.2 Analogue modem

The analogue modem shall initiate a retrain during Phase 4 according to 9.5.2.1 if it does not receive $B1_d$ within 15 s plus 5 round-trip delays after sending $INFO_{1a}$ in 9.2.2.1.9. The analogue modem may initiate a retrain at any time during Phase 4 according to 9.5.2.1. If Tone B is detected during Phase 4, the analogue modem shall respond to retrain according to 9.5.2.2.

9.4.2.1 The analogue modem shall send CP_t sequences containing the constellation parameters that the digital modem shall use during Phase 4 training and rate renegotiations. The analogue modem shall also condition its receiver to detect an R_i -to- $\overline{R_i}$ transition.

9.4.2.2 After detecting an R_i -to- $\overline{R_i}$ transition, the analogue modem completes the current CP_t sequence and optionally transmits SCR for no more than 4000 ms.

9.4.2.3 The analogue modem shall send CP sequences containing the constellation parameters that the digital modem shall use during data mode. After receiving the digital modem's MP sequence, the analogue modem shall complete sending the current CP sequence, and then send CP' sequences (CP sequences with the acknowledge bit set).

9.4.2.4 The analogue modem shall continue sending CP sequences until it has sent a CP' sequence and received an MP' or E_d from the digital modem. The analogue modem shall then complete the current CP' sequence and send the 20-bit E sequence. The analogue modem shall condition its transmitter to transmit at a data signalling rate that is the maximum rate enabled in both modems that is less than or equal to the maximum analogue to digital modem data signalling rate specified in the MP sequence.

9.4.2.5 After sending the 20-bit E sequence, the analogue modem shall send B1 at the negotiated data signalling rate using the data mode modulation parameters. The analogue modem shall then enable circuit 106 to respond to the condition of circuit 105, start a new superframe, and begin data transmission using the modulation procedures of clause 6.

9.4.2.6 After receiving an E_d sequence, the analogue modem conditions its receiver to receive $B1_d$. After receiving $B1_d$, the analogue modem shall unclamp circuit 104, turn on circuit 109, and begin demodulating data.

9.5 Retrains

9.5.1 Digital modem

9.5.1.1 Initiating retrain

To initiate a retrain, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B and condition its receiver to detect Tone A. After detecting Tone A, the digital modem shall condition its receiver to detect a Tone A phase reversal and proceed in accordance with 9.2.1.1.3.

9.5.1.2 Responding to retrain

After detecting Tone A for more than 50 ms, the digital modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The digital modem shall then transmit Tone B, condition its receiver to detect a Tone A phase reversal, and proceed in accordance with 9.2.1.1.3.

9.5.2 Analogue modem

9.5.2.1 Initiating retrain

To initiate a retrain, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and condition its receiver to detect Tone B. After detecting Tone B and when Tone A has been transmitted for at least 50 ms, the analogue modem shall transmit a Tone A phase reversal, condition its receiver to detect a Tone B phase reversal and proceed according to 9.2.2.1.4.

9.5.2.2 Responding to retrain

After detecting Tone B for more than 50 ms, the analogue modem shall turn OFF circuit 106, clamp circuit 104 to binary one and transmit silence for 70 ± 5 ms. The analogue modem shall then transmit Tone A and proceed in accordance with 9.2.2.1.3.

9.6 Rate renegotiation

The rate renegotiation procedure can be initiated at any time during data mode. Data signalling rate and spectral shaping parameters may change as a result of rate renegotiation. This procedure can also be used to retrain the analogue modem's echo canceller without going through a complete retrain. Only the analogue modem can request this second procedure.

The digital modem's transmitter and the analogue modem's receiver shall maintain data frame synchronization during rate renegotiation. Rate renegotiation shall be initiated by the digital modem's transmitter only on the boundary of a data frame. Similarly, a digital modem's transmitter shall only respond to a rate renegotiation on the boundary of a data frame.

9.6.1 Digital modem

The digital modem shall initiate a retrain according to 9.5.1.1 if it does not receive an E sequence within 5000 ms plus 2 round-trip delays after transmitting the R_d - to - \overline{R}_d transition. The digital modem may initiate a retrain at any time during a rate renegotiation according to 9.5.1.1. If Tone A is detected during a rate renegotiation, the digital modem shall respond to retrain according to 9.5.1.2 (see Figure 8).

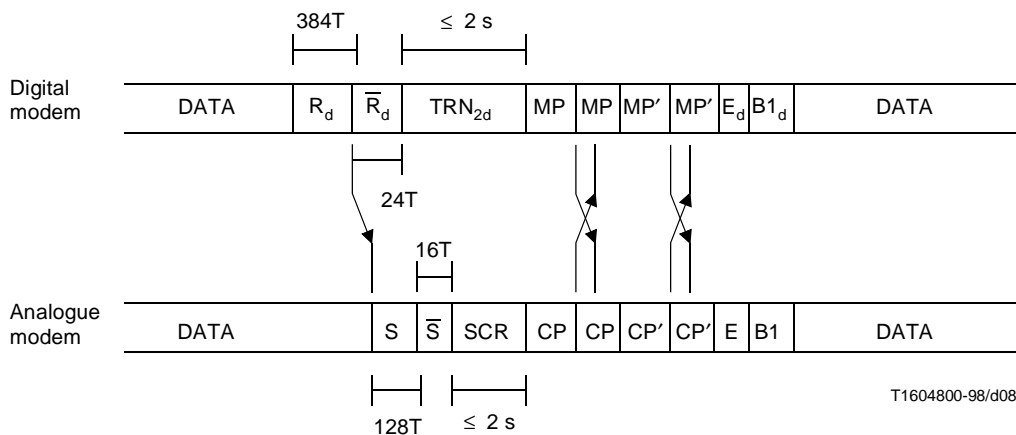


Figure 8/V.90 – Rate renegotiation procedure initiated by the digital modem

9.6.1.1 Initiating a rate renegotiation

9.6.1.1.1 The digital modem shall turn OFF circuit 106, condition its receiver to detect S , \overline{S} , and CP , and transmit signal R_d for 384T and \overline{R}_d for 24T. The signal R_d shall begin on the boundary of a data frame. After transmitting \overline{R}_d , the digital modem shall optionally transmit TRN_{2d} for no more than 2000 ms followed by MP sequences and shall condition its receiver to receive CP sequences. The digital modem shall then proceed in accordance with 9.6.1.2.3.

9.6.1.2 Responding to a rate renegotiation

9.6.1.2.1 After detecting S , the digital modem shall clamp circuit 104 to binary one and condition its receiver to detect the S -to- \overline{S} transition.

9.6.1.2.2 After detecting the S-to- \bar{S} transition, the digital modem shall transmit signal R_d for 384T and \bar{R}_d , for 24T and condition its receiver to receive CP. The signal R_d shall begin on the boundary of a data frame. After transmitting \bar{R}_d , the digital modem shall optionally transmit TRN_{2d} for no more than 2000 ms followed by MP sequences.

9.6.1.2.3 After receiving a CP sequence, the digital modem shall send MP' sequences and proceed in accordance with 9.4.1.4, unless bit 30 of the CP sequence is set (a CP_s sequence), in which case it proceeds in accordance with 9.6.1.2.4.

9.6.1.2.4 The digital modem shall transmit MP' sequences until it receives a CP'_s sequence.

9.6.1.2.5 After receiving a CP'_s sequence, the digital modem shall complete sending the current MP' and transmit E_d followed by silence. The digital modem shall generate silence by sending PCM codewords with magnitudes represented by Ucode 0. It shall retain data frame alignment during this period of silence.

9.6.1.2.6 After receiving a CP sequence with bit 30 clear, the digital modem shall transmit signal R_t for 384T and \bar{R}_t for 24T. The signal R_t shall begin on the boundary of a data frame. The digital modem shall then start sending MP sequences and proceed in accordance with 9.4.1.4.

9.6.2 Analogue modem

The analogue modem shall initiate a retrain according to 9.5.2.1 if it does not receive E_d within 5000 ms plus 2 round-trip delays after sending the S-to- \bar{S} transition. The analogue modem may initiate a retrain at any time during a rate renegotiation according to 9.5.2.1. If Tone B is detected during a rate renegotiation, the analogue modem shall respond to retrain according to 9.5.2.2 (see Figure 9).

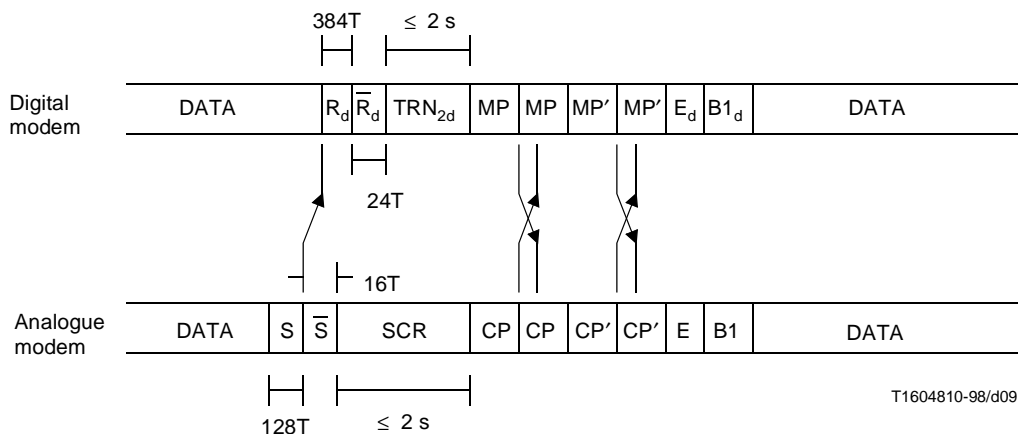


Figure 9/V.90 – Rate renegotiation initiated by the analogue modem

9.6.2.1 Initiating a rate renegotiation

9.6.2.1.1 The analogue modem shall turn OFF circuit 106, transmit signal S for 128T and condition its receiver to detect signal R_d and the R_d - to - \bar{R}_d transition.

9.6.2.1.2 The analogue modem shall transmit signal \bar{S} for 16T followed by an optional signal SCR for no more than 2000 ms.

9.6.2.1.3 The analogue modem shall then send CP sequences. If the analogue modem wishes to recondition its echo canceller, it shall send CP_s sequences.

9.6.2.1.4 After detecting the R_d - to - \bar{R}_d transition, the analogue modem shall condition its receiver to receive MP sequences, continue transmitting CP and proceed in accordance with 9.4.2.3, unless it is sending a CP_s sequence, in which case it shall proceed in accordance with 9.6.2.1.5.

9.6.2.1.5 After receiving the digital modem's MP sequence, the analogue modem shall complete sending the current CP_s sequence, and then send CP'_s sequences (CP_s sequences with the acknowledge bit set).

9.6.2.1.6 After detecting E_d, the analogue modem shall complete sending the current CP'_s and send signal SCR until it has reconditioned its echo canceller, but for no more than 1000 ms.

9.6.2.1.7 The analogue modem shall send CP sequences with bit 30 clear and condition its receiver to detect signal R_t and the R_t - to - $\overline{R_t}$ transition.

9.6.2.1.8 After detecting the R_t - to - $\overline{R_t}$ transition, the analogue modem shall condition its receiver to receive MP sequences, continue transmitting CP and proceed in accordance with 9.4.2.3. (See Figure 10).

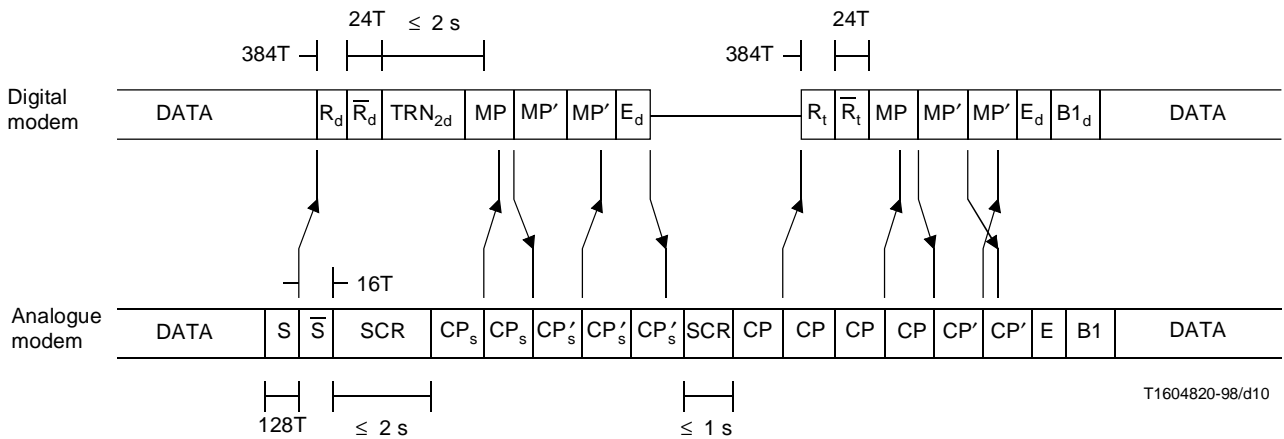


Figure 10/V.90 – Rate renegotiation initiated by the analogue modem with silence requested

9.6.2.2 Responding to a rate renegotiation

9.6.2.2.1 After receiving R_d, the analogue modem shall clamp circuit 104 to binary one and shall condition its receiver to detect the R_d - to - $\overline{R_d}$ transition.

9.6.2.2.2 After receiving the R_d - to - $\overline{R_d}$ transition, the analogue modem shall condition its receiver to receive MP, and transmit S for 128T.

9.6.2.2.3 The analogue modem shall then transmit \overline{S} for 16T followed by an optional signal SCR for no more than 2000 ms.

9.6.2.2.4 The analogue modem shall then proceed in accordance with 9.6.2.1.3.

9.7 Cleardown

The cleardown procedure shall be used to terminate a connection. Cleardown is indicated by setting drn to 0 in either CP by the analogue modem or MP by the digital modem. This may be signalled at any time that a modem sends a rate sequence. To cleardown from data mode, a modem shall initiate a rate renegotiation according to 9.6 in order to send a rate sequence with drn = 0.

NOTE – The transmit and receive constellation fields of a CP sequence with drn = 0 should be ignored in the digital modem.

10 Testing facilities

Testing facilities as specified in other V-series modem Recommendations cannot be used for this Recommendation. Appropriate testing facilities are for further study.

11 Glossary

s_i	Sign bits output from the spectral shaper
$\alpha, \beta, \gamma, \delta$	Variables used to define bit positions in J_a and CP
a_1, a_2	Parameters in the spectral shape filter
A_i	A parameter used to calculate $n_{i,j}$
b_0 - b_{K-1}	The bits input to the modulus encoder
b_1, b_2	Parameters in the spectral shape filter
c	An index to each G.711 A-law or μ -law code segment
C_i	M_i PCM codes that make up the positive constellation points of data frame interval I
D	Total number of input data bits ($K + S$)
d_0 - d_{D-1}	The input data bits
drn	A parameter used in determining the downstream data signalling rate
$F(z)$	The characteristic of the spectral shape filter
$h()$	A precoding coefficient
H_c	A parameter used in determining the length of a DIL-segment
i	The time index of the data frame interval, from 0 to 5
j	An index to a spectral shaping frame
j	A general index
K	The number of modulus encoder input data bits per data frame
k	A general index
K_i	The output of the modulus encoder used in data frame interval i
L_c	The length of a DIL-segment
ld	The look-ahead depth
L_{SP}	The length of SP
L_{TP}	The length of TP
M_i	Number of members of the PCM code set used in data frame interval i
n	A general index
N	The number of DIL-segments
$n_{i,j}$	A parameter related to the number of occurrences of a particular PCM code
$p'_j(k)$	A differentially encoded intermediate bit in the spectral shaper
PCM_i	A signed PCM codeword
$p_i(k)$	An input bit to the spectral shaper
$p_{i,j}$	A parameter related to the power of a particular PCM code
Q_j	The state of the trellis used in the spectral shaper
R_0	The integer formed for input to the modulus encoder
REF_c	A reference PCM codeword
R_{i+1}	Quotients Remainders generated during modulus encoding

S	The number of spectral shaper input data bits per data frame
s_0 - s_{S-1}	The bits input to the spectral shaper
SP	A sign pattern
S_r	The number of PCM code sign bits per data frame used as redundancy for spectral shaping
$T(z)$	The transfer function of the spectral shape filter
$t_j(k)$	An intermediate bit in the spectral shaper
TP	A training pattern
U_i	The constellation point labelled by K_i
$v[n]$	The output of the spectral shape filter
W	A PCM codeword used in signal S_d
$w[n]$	The spectral shaping metric
$x[n]$	The spectral shape filter input
$y[n]$	An intermediate value in the spectral shaping metric calculation
z	A general index

Appendix I

Overview

Unlike previous modem Recommendations, this Recommendation defines a method for signalling between a modem connected to an analogue loop (the analogue modem) and a modem connected to a digital trunk (the digital modem). Although analogue modem Recommendations, such as V.34, have been implemented in this fashion for many years, this Recommendation takes advantage of this particular arrangement to increase the data signalling rate from the digital modem towards the analogue modem. The signalling method in this direction is a newly defined baseband scheme that utilizes the frequency band from 0 to 4 kHz. This Recommendation allows for spectral shaping to be employed to help the analogue modem combat the effects of the transformers and filters used in the digital-to-analogue conversion. Since this is for the benefit of the analogue modem, it is the analogue modem that requests the spectral shaping parameters to be used and so the optimum spectral shape is implementation dependent. In the direction from the analogue modem towards the digital modem, standard V.34 techniques are employed with the usual transmit and receive level considerations. An example network configuration is shown in Figure I.1.

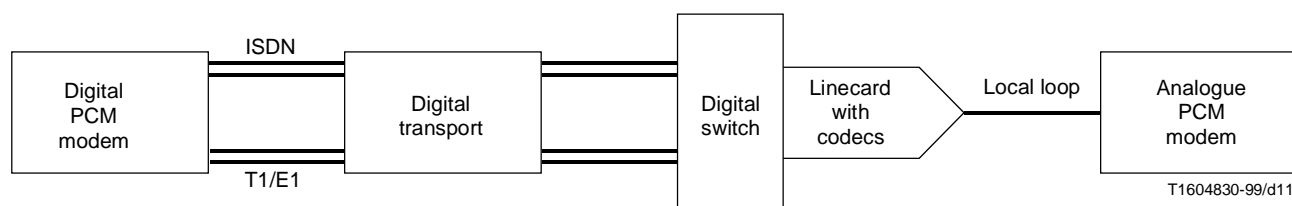


Figure I.1/V.90 – Example network configuration

