INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.954

DIGITAL SECTIONS AND DIGITAL LINE SYSTEMS

DIGITAL LINE SYSTEMS BASED ON THE 2048 KBIT/S HIERARCHY ON COAXIAL PAIR CABLES

ITU-T Recommendation G.954

(Extract from the *Blue Book*)

NOTES

1 ITU-T Recommendation G.954 was published in Fascicle III.5 of the *Blue Book*. This file is an extract from the *Blue Book*. While the presentation and layout of the text might be slightly different from the *Blue Book* version, the contents of the file are identical to the *Blue Book* version and copyright conditions remain unchanged (see below).

2 In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Recommendation G.954

DIGITAL LINE SYSTEMS BASED ON THE 2048 kbit/s HIERARCHY ON COAXIAL PAIR CABLES

(Malaga-Torremolinos, 1984; amended at Melbourne, 1988)

1 General

This Recommendation covers digital line systems for the transmission of signals based on the 2048 kbit/s hierarchy on coaxial pair cables and includes systems conveying the following bit rates:

8 448 kbit/s
34 368 kbit/s
139 264 kbit/s
4 × 139 264 kbit/s

In the case of 4 x 139264 kbit/s systems, a digital line muldex equipment combines the functions of multiplexing four digital signals at 139 264 kbit/s and of a line transmission equipment. Details of the digital multiplexing strategy are given in Annex B to this Recommendation.

The requirements for overall performance and interfaces of the corresponding digital line section are given in Recommendation G.921.

2 Transmission media

The systems can be operated on coaxial pairs, as defined in the series G.620 Recommendations, in accordance with Table 1/G.954.

TABLE 1/G.954

Transmission media

System (kbit/s)	Cable Recommendation
8 448	G.621; G.622
34 368	G.621; G.622; G.623
139 264	G.622; G.623
4 × 139 264	G.623

3 Overall design features

3.1 *Availability*

The availability objective of the system should be derived taking into account the availability requirement for the hypothetical reference digital section given in Recommendation G.801.

3.2 *Reliability*

MTBF values should be specified for the line system as a whole taking into account the requirements concerning availability.

3.3 *Repeater noise margin*

Repeater Noise Margin is defined in Annex A together with suggested measurement techniques. The Noise Margin quantifies the performance of digital regenerators for coaxial pairs. This is a function of BER and repeater spacing loss A_0 (at half the line system baud rate).

At a BER = 10^{-7} and over the loss range of the system $A_1 \le A_0 \le A_2$, the Noise Margin should meet the following specifications:

Noise Margin $(M) \ge B + C (A_2 - A_0)$

It has not been possible to recommend specific values for parameters A_1, A_2, B and C.

Note - The degrading effect of timing jitter on Noise Margin should be measured by superimposing appropriate jitter on the test signal.

Examples of the values used by some Administrations are given below:

	A_1 (dB)	A_2 (dB)	B (dB)	C
8 448 kbit/s systems	35	85	9	1
34 368 kbit/s systems	34 56 45	84 82 75	7.5 6 12	0.7 0.5 1
139 264 kbit/s systems	65 60	84 84	5.5 7.5	0.7 0.7 → 1

Note - The values do not include any allowance for the effects of jitter.

3.4 *Error performance*

The design objective for the error ratio of the individual repeater should take into account the network performance objectives given in Recommendation G.821.

4 Specific design features

4.1 *Type of power feeding*

Although CCITT does not recommend the use of a specific remote power-feeding system for these coaxial line systems, in practice only the constant current d.c. feeding via the inner conductors of the two coaxial pairs of system is used.

These coaxial cable systems may be subject to induced voltages and currents caused by lightning, power lines, railways, etc.

Precautions must be taken to protect the staff from any possible danger arising from the normal operating voltages and remote power-feed currents as well as from the induced voltages and currents.

Many national Administrations have issued detailed rules and regulations for the protection of persons. It is obligatory in most cases to meet these rules and regulations. In addition the CCITT Directives [1] give guidance on these problems.

Precautions are also needed for the protection of the equipment against induced voltages and currents. The equipment should therefore be designed in such a way that it passes the tests specified in Recommendation K.17 [2].

4.2 *Nominal repeater spacing*

A specific repeater spacing is not recommended but in practice the nominal values indicated in Table 2 are used by most Administrations:

TABLE 2/G.954

Nominal repeater spacings

System (kbit/s)	Nominal repeater spacing (km) Cable Recommendation a)		
	G.621	G.622	G.623
8 448	4.0	—	—
34 368	2.0	4.0 (Note)	—
139 264	—	2.0	4.5 (Note)
4 × 139 264	—	—	1.5

a) G.621 refers to 0.7/2.9 mm coaxial pairs.
G.622 refers to 1.2/4.4 mm coaxial pairs.
G.623 refers to 2.6/9.5 mm coaxial pairs.

Note - One Administration employs a nominal repeater spacing of 3 km.

4.3 *Maintenance strategy*

4.3.1 *Type of supervision and fault location*

In-service monitoring or out-of-service fault location can be used. For bit rates equal to or above 139 264 kbit/s in-service monitoring is recommended.

4.3.2 *Fault conditions and consequent actions*

The following fault conditions should be detected in addition to those specified in Recommendation G.921 for the relevant digital sections, and the associated consequent actions should be taken:

a) failure of remote power feeding -
a prompt maintenance alarm should be generated, if practicable;

b) low error ratio threshold exceeded -
this threshold is $1 \cdot 10^{-5}$ for systems at 8448 kbit/s
and $1 \cdot 10^{-6}$ for systems at higher bit rates;

a deferred maintenance alarm should be generated to signify that performance is deteriorating.

ANNEX A

(to Recommendation G.954)

Definition and measurement of repeater noise margin

A.1 *Definition*

The noise margin m_n:

$$m_n = SNR/SNR_{ER} \quad \text{(A-1)}$$

where

$$SNR = SNR_{th} \cdot F(t, ER) \quad \text{(A-2)}$$

The product $SNR_{th} \cdot F(t, ER)$ can be considered the actual signal-to-noise ratio SNR being the measure for the regenerator performance.

SNR_{th} is the theoretical signal-to-noise ratio determined by the system parameters such as output pulse, section loss, noise figure of the regenerator input amplifier etc.

$F(t, ER)$ is the reduction factor due to an off-set from the optimum timing instant (including phase jitter) in conjunction with the pulse realized $S(t)$, the intersymbol interference $I(t)$ and any other disturbance which causes a corruption in the information signal (I_c).

Note - The intersymbol interference and other disturbances are fluctuating processes with bounded distributions. The "mean" reduction factor depends on ER, and, for a ternary signal, is given by:

$$F(t, ER) = \frac{S(t)}{S(0)} - 2\left\{\frac{I(t)}{S(0)} - \frac{I_c}{S(0)}\right\} \quad \text{(A-3)}$$

where $S(0)$ is the realized pulse at $t = 0$ giving the maximum amplitude.

SNR_{ER} is the signal-to-noise ratio required for an error ratio to ER. For a ternary signal the relation between ER *and* SNR_{ER} is given by the known Gaussian distribution:

$$ER = \frac{4}{3}P[E] = \frac{4}{3\sqrt{2\pi}} \int_{SNR_{ER}}^{\infty} e^{-x^{1/2}} dx \quad \text{(A - 4)}$$

A.2 *Derived definitions*

The noise margin can be measured by applying an external disturbing signal. For that purpose more practical definitions are derived.

A.2.1 SNR_{ER} (giving an error ratio ER) can be achieved by injecting sufficient white noise into the input of the regenerator:

$$SNR_{ER} = \left\{\frac{N_T}{N_T + N_E}\right\} \cdot SNR \quad \text{(A-5)}$$

where

N_T = thermal noise that appears at the decision point during normal operation.

N_E = mean power of the external noise that appears at the decision point to induce an error rate ER.

Combining (A-2) and (A-5) results in the noise margin M:

$$M = 20 \log m_n = 10 \log \left(1 + \frac{N_E}{N_T}\right) \quad \text{(A-6)}$$

$$N_E = N_0 \int_0^\infty |E(f)|^2 \, df \quad \text{(A-7)}$$

$$N_T = kT \int_0^\infty |E(f)|^2 \, F(f) \, df \quad \text{(A-8)}$$

N_0 = power density of the external noise that is superimposed on the signal

$E(f)$ = transfer function of the regenerator's equalizer

k, T = Boltzmann constant and absolute temperature

$F(f)$ = noise figure of the equalizer amplifier of the regenerator

A.2.2 By injecting a sine wave disturbing signal, a second definition for m_n can be derived.

This disturbance causes a decreasing $F(t, ER)$, which can be defined by:

$$F_d(t, ER) = SNR_{ER}/SNR_{th}$$

Next [in accordance with (A-1) and (A-2)]

$$F(t, ER) = m_n \cdot SNR_{ER}/SNR_{th}$$

Substraction gives:

$$F(t, ER) - F_d(t, ER) = 2 \frac{I_s}{S(0)} - (m_n - 1) \, SNR_{ER}/SNR_{th}$$

where $I_s/S(0)$ is the normalized disturbing signal at the decision point.

Substitution of $SNR_{th} = S(0)/2\sqrt{N_T R_0}$ and some rearrangements results in the noise margin:

$$M = 20 \log 1 \cdot \left(\frac{I_s}{SNR_{ER} \cdot \sqrt{N_T R_0}}\right) \quad \text{(A-9)}$$

$$I_s = S_d \cdot |E(f_d)| \cdot a_c \quad \text{(A-10)}$$

S_d = the magnitude of the disturbing signal at the input of the regenerator

f_d = the frequency of the disturbing signal

a_c = a correction factor taking into account the effect of the disturbance on the peak detector of the automatic equalizer

R_0 = the real part of the characteristic impedance of the cable.

A.3 *Measurements*

Method A is based on the definition directly related to the noise margin (A-6) and therefore, is the reference test method. Methods B and C are alternative test methods.

Method A (Figure A-l/G.954)

The values of N_E *and* N_T are measured directly at the decision point. The value of N_T is measured in the absence of both a signal and an externally applied noise. Under these conditions the automatic gain control (AGC) of the equalizer must be externally controlled to a level appropriate to the corresponding cable attenuation. With the signal restored, the level of the externally applied noise is adjusted to give the desired BER. The noise level $(N_T + N_E)$ is now measured with the signal removed and with the AGC set at the same value as in the measurement of N_T.

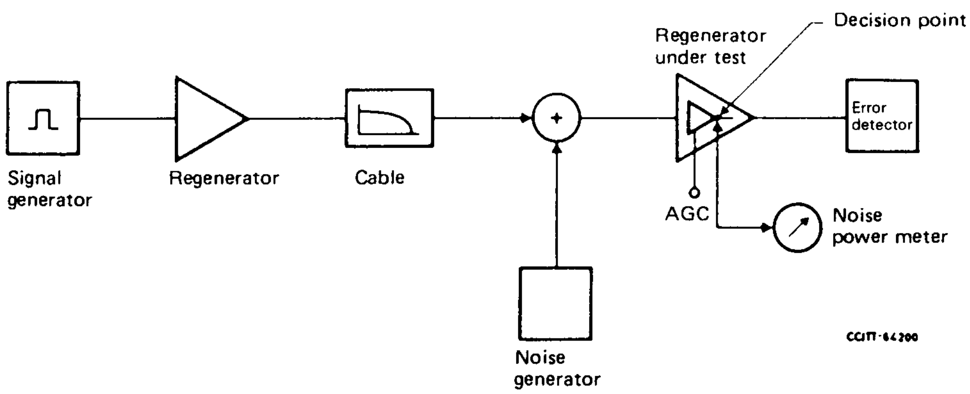


FIGURE A-1/G.954

Measurement of noise margin (Method A)

Method B (Figure A-2/G.954)

This method realizes a measurement without the need to access the decision point. The applied noise at the input, to cause a given BER, is measured directly. The corresponding value at the decision point and also the thermal noise (N_T) are evaluated by means of the transfer function and the noise figure of the amplifier equalizer.

Note - Both the transfer function and the noise figure of the amplifier equalizer need to be calculated and measured on a sample of repeaters before this method can be applied to a particular repeater design.

Method C (Figure A-2/G.954)

This method is similar to the previous method (B) except that in this case the applied disturbance is a sine wave signal. This applied signal at the input, to cause a given error ratio, is likewise measured directly.

The corresponding disturbance at the decision point (I_s) as well as the thermal noise voltage ($\sqrt{N_T R_0}$) are evaluated by means of the transfer function, the noise figure of the equalizer and the correction factor a_c, which have to be determined.

Note 1 - It follows from (A-8) and (A-9):

$$M = 20 \log (1 + S_d \cdot X/SNR_{ER})$$

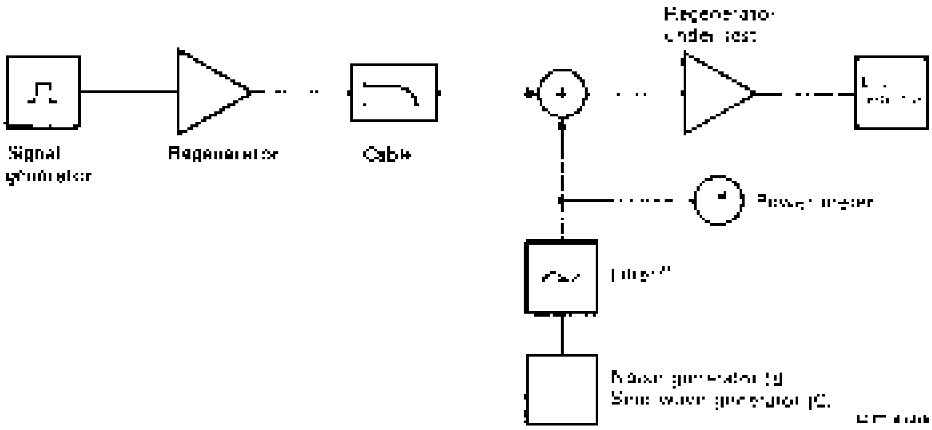
$$\text{where } X = |E(f_d)| \cdot a_c / \sqrt{N_T R_0}$$

being an unknown factor, which has to be determined on the basis of measurements on a sample of prototype regenerators before this method can be applied to a particular regenerator design.

For this purpose, the noise margin of the prototype regenerators needs to be measured in accordance with the reference test method (A).

Note 2 - This method allows the presence of an LBO-network at the regenerator input. In contrast to method B it is not necessary to insert a complementary filter in the injection path.

Note 3 - To obtain the most accurate measurement the disturbing frequency should be around the Nyquist frequency.



[1] Can be deleted in Method C.

ANNEX B

(to Recommendation G.954)

Digital multiplexing strategy for
4 × 139 264 kbit/s systems

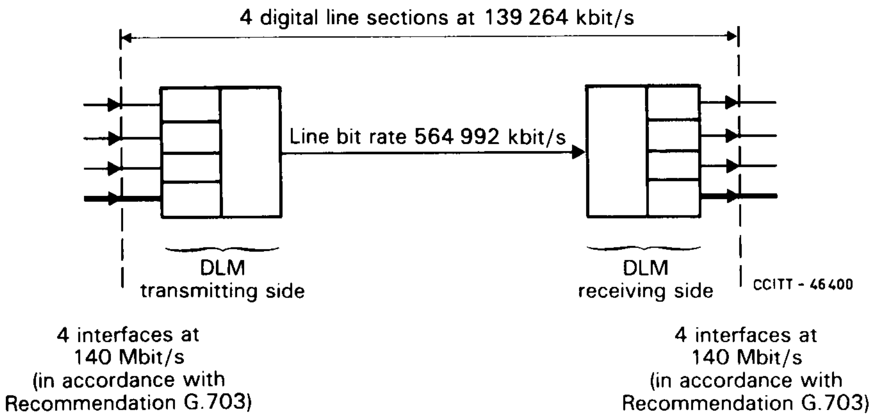


FIGURE B-1/G.954

DLM digital line muldex

B.1 *General*

The digital multiplexing strategy is based on the use of positive justification and combines four 139 264 kbit/s tributaries into one composite signal.

B.2 *Bit rate*

The nominal bit rate should be 564 992 kbit/s. The tolerance on that rate should be ± 15 parts per million (15 ppm).

B.3 *Frame structure*

Table B-l/G.954 gives:

- the tributary bit rate and the number of tributaries,
- the number of bits per frame,
- the bit numbering scheme,
- the bit assignment,
- the bunched frame alignment signal.

Note - Possible alternative frame structures with the characteristics indicated in Appendix II are left for further study.

B.4 *Loss and recovery of frame alignment*

Loss of frame alignment should be assumed to have taken place when four consecutive frame alignment signals have been incorrectly received in their predicted positions.

When frame alignment is assumed to be lost, the frame alignment device should decide that such alignment has effectively been recovered when it detects the presence of three consecutive frame alignment signals.

The frame alignment device, having detected the appearance of a single correct frame alignment signal, should begin a new search for the frame alignment signal when it detects the absence of the frame alignment signal in one of the two following frames.

Note - As it is not strictly necessary to specify the detailed frame alignment strategy, any suitable frame alignment strategy may be used provided the performance achieved is at least as efficient in all respects as that obtained by the above frame alignment strategy.

TABLE B-1/G.954

564 992 kbit/s multiplexing frame structure

Tributary bit rate (kbit/s)	139 264
Number of tributaries	4
Frame structure	Bit number
 Frame alignment signal (binary content under study) bits from tributaries	*Set I* 1 to 12 13 to 384
 Justification service bits C_{jn} (n = 1 to 5) (see Note) Bits from tributaries	*Sets II to VI* 1 to 4 5 to 384
 Remote alarm indication, spare for national use Bits from tributaries available for justification Bits from tributaries	*Set VII* 1 to 4 5 to 8 9 to 384
Frame length Bits per tributary Maximum justification rate per tributary Nominal justification ratio	2688 bits 663 bits 210 190 bit/s 0.4390

Note - C_{jn} indicates the n^{th} justification service bit of the j^{th} tributary.

B.5 *Multiplexing method*

Cyclic bit interleaving in the tributary numbering order and positive justification is recommended. The justification control signal should be distributed and use the C_{jn} bits (n = 1, 2, 3, 4, 5), see Table B-1/G.954. Positive justification should be indicated by the signal 11111, no justification by the signal 00000. Majority decision is recommended.

Table B-1/G.954 gives the maximum justification rate per tributary and the nominal justification ratio.

B.6 *Jitter*

B.6.1 Jitter transfer characteristics (under study).

B.6.2 Tributary output jitter (under study).

B.7 *Service digits*

The first four bits in Set VII of the pulse frame are available for service functions. The first of these bits is used to indicate a prompt alarm condition, see Table C-1/G.954.

Note - A possible solution for scrambler and frame alignment signal is given in Appendix I.

APPENDIX I

(to Annex B of Recommendation G.954)

A possible solution for scrambler and frame alignment signals for a digital line system at 4 × 139 264 kbit/s

I.1 *Reset scrambler*

It is proposed to use a "reset scrambler", i.e. one which is reset at the start of each frame. Advantages of such a scrambler [3] as compared to a free-running or "self-synchronizing" scrambler, are:

- no error multiplication, and
- no necessity to provide additional measures to avoid periodic output signals.

If it is accepted that with an all 1 or all 0 input signal (e.g. with AIS on all four tributaries) the output does not precisely correspond to a 2^n - 1 pseudorandom sequence but represents an approximately random sequence, fully adequate for timing recovery on the line, a scrambler may be realized (Figure I-1/G.954) which has additional favourable features:

- The scrambler works at ≈ 141 Mbit/s. Four sequences delayed with respect to each other (A0, A2, A5 and A6) are used to scramble the individual tributaries T1 ... T4; the four scrambled signals (c, d, e, f) are then multiplexed.
- Simple circuitry, hence easy realization at the high speed involved, and low power consumption.
- After resetting, the scrambler generates the frame alignment signal.

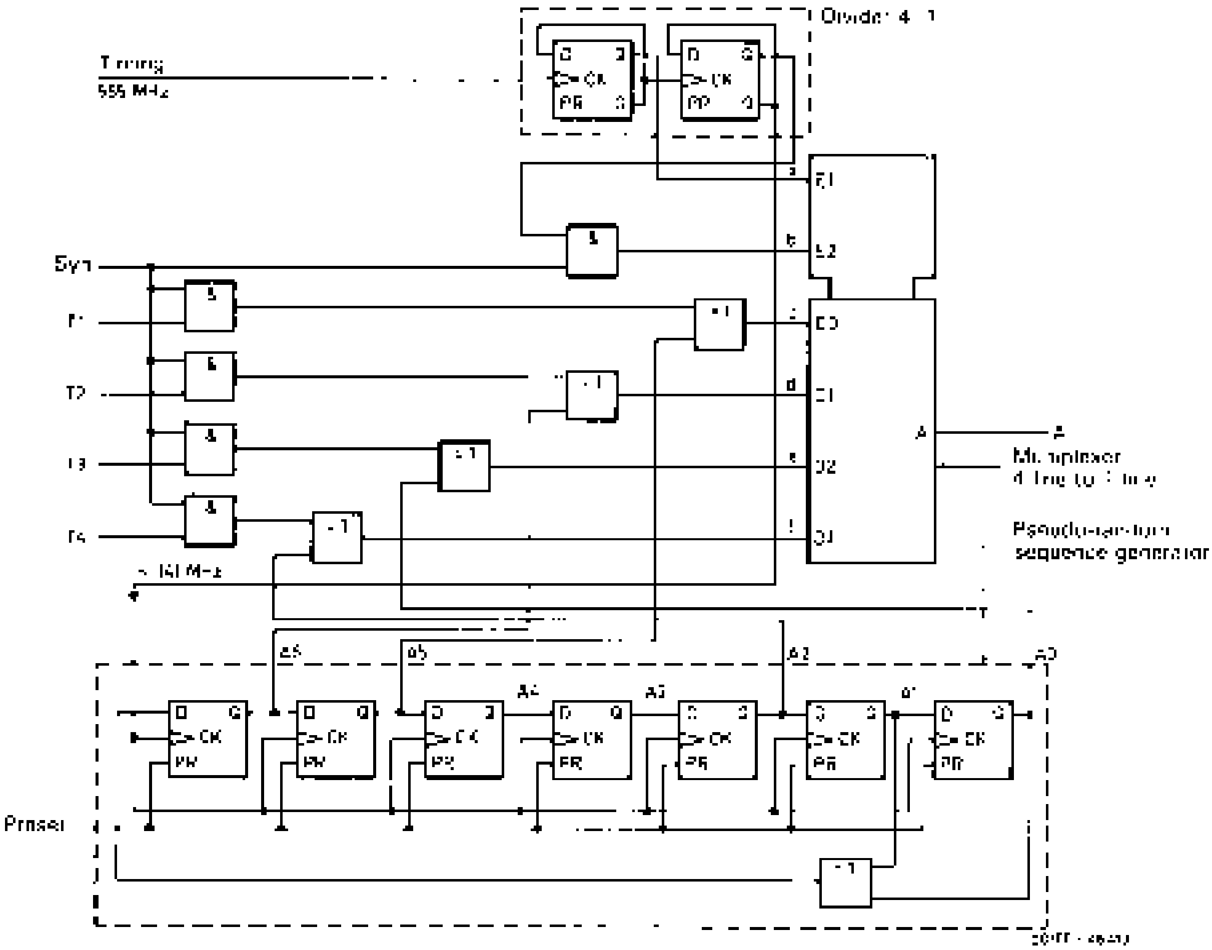
I.2 *Frame alignment signal*

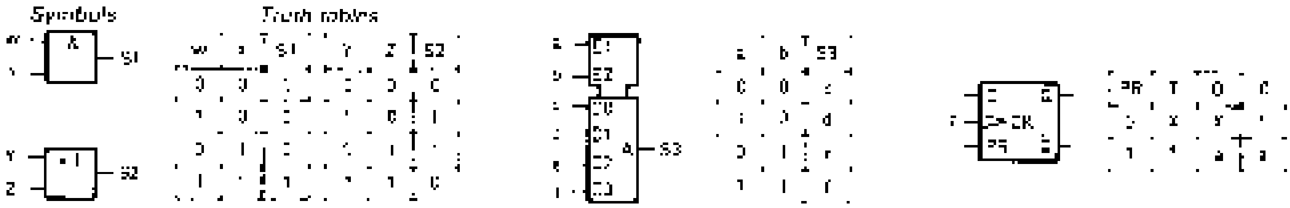
The frame alignment signal, generated at the start of each pulse frame, is

111110100000

and is thus identical to that of the 139 Mbit/s signal according to Recommendation G.751.

The frame alignment signal will not be imitated by all 0 or all 1 signals even if these occur in any combination in the four tributaries.





Note — T represents the timing signal. The positive-going transition is the active transition.

Time	A6	A5	A4	A3	A2	A1	A0	Preset	Syn	Multiplexed scrambler output signal				A				
0	1	1	1	1	1	1	1	0	0	A5	A6	A5	A6	1	1	1	1	Frame alignment word
1	0	1	1	1	1	1	1	1	0	A5	A6	A5	A6	1	0	1	0	
2	0	0	1	1	1	1	1	1	0	A5	A6	A5	A6	0	0	0	0	
3	0	0	0	1	1	1	1	1	1	A5	A6	A0	A2	T1	T2	T3	T4	Scrambled
4	0	0	0	0	1	1	1	1	1	A5	A6	A0	A2	T1	T2	T3	T4	
5	0	0	0	0	0	1	1	1	1	A5	A6	A0	A2	T1	T2	T3	T4	
6	0	0	0	0	0	0	1	1	1	A5	A6	A0	A2	T1	T2	T3	T4	
7	1	0	0	0	0	0	0	1	1	A5	A6	A0	A2	T1	T2	T3	T4	
8	0	1	0	0	0	0	0	1	1	A5	A6	A0	A2	T1	T2	T3	T4	

FIGURE I-1/G.954

Reset scrambler and multiplexer

APPENDIX II

(to Annex B of Recommendation G.954)

Possible alternative multiplex frame structures

Other multiplex frame structures at 564 992 kbit/s are possible which still retain the same per tributary frame structure as implied by the multiplex frame structure given in Figure I-1/G.954.

These alternative multiplex frame structures are based on the cyclic interleaving of groups of bits from tributaries and such methods of multiplexing can have implementation advantages when alphabetic line codes such as 6B4T are used. Integration of the multiplex and the line code conversion functions can reduce the speed requirements of the associated circuitry.

Equipments based on these alternative multiplex frame structures, provided that they adopt the same multiplex frame length, the same number of bits per tributary, the same maximum justifications rate and the same nominal justification ratio, are consistent with the network performance offered by equipments using the multiplexing method described in the body of this Recommendation.

ANNEX C

(to Recommendation G.954)

Fault conditions and consequent actions for digital lines systems at 4 × 139 264 kbit/s

C.1 *Fault conditions*

The digital line system 4 × 139 264 kbit/s should detect the following fault conditions:

C.1.1 Failure of internal power supply.

C.1.2 Failure of power feeding of regenerators.

C.1.3 Error ratio $1 \cdot 10^{-3}$.

Note - The criteria for activating and deactivating of these alarm indications are under study.

C.1.4 Error ratio $1 \cdot 10^{-6}$.

C.1.5 Loss of incoming line signal.

Note - The detection of this fault condition is required only when it does not result in an indication of loss of frame alignment.

C.1.6 Loss of frame alignment.

C.1.7 Loss of line word alignment when alphabetic line codes are used.

Note - The detection of this fault condition is required only when it does not result in an indication "Error ratio $1 \cdot 10^{-3}$".

C.1.8 Loss of incoming signal on a tributary.

C.1.9 Remote alarm indication.

C.2 *Consequent actions*

Further to the detection of a fault condition, appropriate actions should be taken as specified in Table C-1/G.954.

TABLE C-1/G.954

Fault conditions and consequent actions

Equipment	Fault conditions	Maintenance alarms		Alarm indication to the remote line muldex generated	AIS applied see § C.2	
		Prompt	Deferred		to all the tributaries	to the relevant time slot of the composite signal
Muldex	Failure of internal power supply	Yes			Yes, if practicable	
	Failure of power feeding of regenerators	Yes			Yes, if practicable	
Receiving side only of line muldex (See Figure 2/G.901)	Error rate 1×10^{-3}	Yes		Yes	Yes	
	Error rate 1×10^{-6}		Yes			
	Loss of incoming signal	Yes		Yes	Yes	
	Loss of frame alignment	Yes		Yes	Yes	
	Loss of line word alignment when alphabetic line code is used	Yes		Yes	Yes	
	Detection of remote alarm indication					
Transmitting side only of line muldex (See Figure 2/G.901)	Loss of incoming signal on a tributary	Yes				Yes

Note - A *Yes* in the table signifies that a certain action should be taken as a consequence of the relevant fault condition. An *open space* in the table signifies that the relevant action should *not* be taken as a consequence of the relevant fault condition, if this condition is the only one present. If more than one fault condition is simultaneously present the relevant action should be taken if, for at least one of the conditions, a *Yes* is defined in relation to this action.

C.2.1 Prompt maintenance alarm indication generated to signify that performance is below acceptable standards and maintenance attention is required locally.

C.2.2 Deferred maintenance alarm indication generated to signify that performance is deteriorating.

Note - The location and provision of any visual and/or audible alarm activated by the alarm indications given in §§ C.2.1 and C.2.2 above, is left to the discretion of each Administration.

C.2.3 AIS applied to all the tributaries (see Notes 1 and 2 below).

C.2.4 AIS applied to the relevant time slot of the composite signal (see Note 1 below).

C.2.5 Alarm indication to the remote muldex generated.

Note 1 - The equivalent binary content of the Alarm Indication Signal (AIS) is a continuous stream of 1s.

Note 2 - The bit rate of this AIS should be within ± 15 ppm of the nominal bit rate.

References

[1] CCITT Manual *Directives concerning the protection of telecommunication lines against harmful effects from electric power and electrified railway lines*, ITU, Geneva, 1988.

[2] CCITT Recommendation *Tests on power-fed repeaters using solid state devices in order to check the arrangements for protection from external interference*, Vol. IX, Rec. K.17.

[3] MULLER (H), Bit sequence independence through scramblers in digital communication systems, *Nachr. Techn. Z.*, Vol. 27 (1974), pp. 475 to 479.