9.   Recommendation G.824

THE CONTROL OF JITTER AND WANDER WITHIN DIGITAL NETWORKS
WHICH ARE BASED ON THE 1544 kbit/s HIERARCHY

        The CCITT,

considering

        (a)   that timing jitter and alignment jitter can arise in digital networks;

        (b)   that, if proper control is not exercised, then under certain circumstances jitter can
accumulate to such an extent that the following impairments can arise;

        i)   an increase in the probability of introducing errors into digital signals at points of signal
regeneration as a result of timing signals being displaced from their optimum position in time;

    ii)   the introduction of uncontrolled slips into digital signals resulting from either data overflow or
            depletion in digital equipment incorporating buffer stores and phase comparators, such as jitter
            reducers and certain digital multiplex equipment;

    iii)   a degradation of digitally encoded analogue information as a result of phase modulation of the
            reconstructed samples in the digital-to-analogue conversion device at the end of the connection,
            which may have significant impact on digitally encoded video signals;

        (c)   that unlike some other network impairments, jitter can be reduced in magnitude by the use of jitter
reducers, and in complex networks, it may be necessary to employ such devices;

        (d)   that wander can arise due to variations in transmission characteristics of the media and equipment,
including disruptions in synchronization reference distribution;

        (e)   that it is necessary to accommodate wander at the input ports of digital equipment if controlled or
uncontrolled slips are to be minimized;

recommends

        that the following guidelines and limits be applied in the planning of networks and in the design of
equipment.

1.   Basic jitter and wander control philosophy

        The goal of the strategy outlined in this Recommendation is to minimize impairments due to jitter and
wander in digital networks. The strategy provides the following elements:

        a)   specification of network limits not to be exceeded at any hierarchical interface;

        b)   a consistent framework for the specification of individual digital equipment;

        c)   information and guidelines to predict and analyze jitter and wander accumulation in any network

configuration, facilitate satisfactory control of the impairments due to this accumulation, and to provide insight into the jitter and wander performance of individual digital equipments;

d) measurement methodology to facilitate accurate and repeatable jitter and wander measurements.

Suggestions for measurement of parameters recommended below can be found in Supplement No. 3.8 of the O-Series (for jitter) and Supplement No. 35 (for wander).

2. Network limits for maximum output at hierarchical interfaces and wander at synchronous network nodes
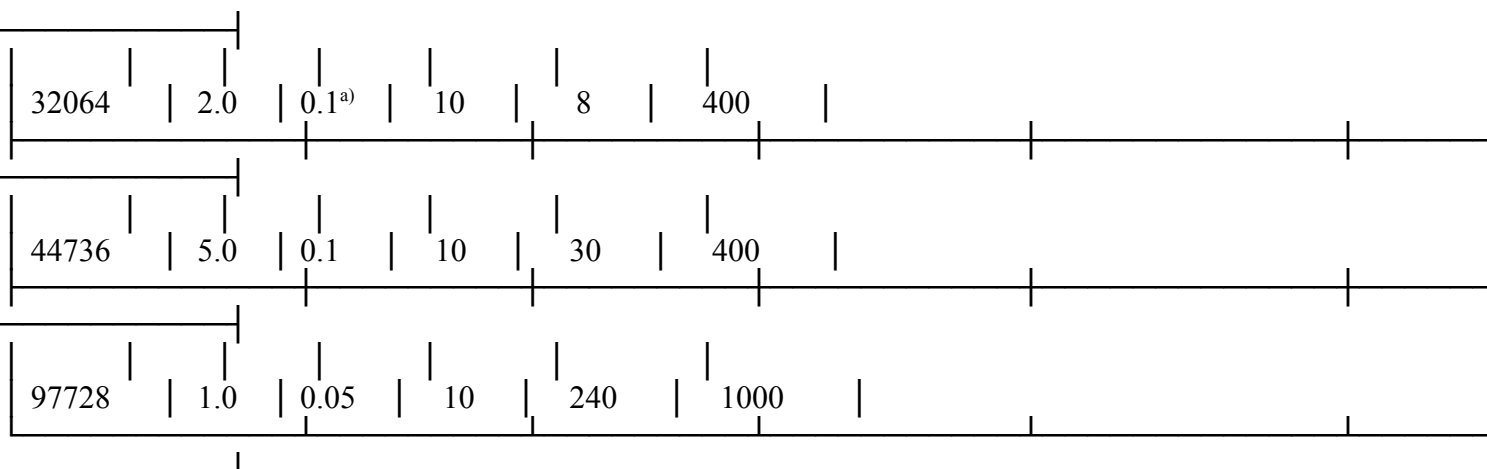
2.1 Network limits for jitter

Specification of maximum permissible values of output jitter at hierarchical network interfaces is necessary to enable the interconnection of digital network components (line section, multiplex equipment, exchanges) to form a digital path or connection. These limits should be met regardless of the number of interconnected network components preceding the interface. The limits are intended to be compatible with the minimum jitter tolerance of all equipment operating at the same hierarchical level.

The limits given in Table 1/G.824 represent maximum permissible output jitter limits at hierarchical interfaces of a digital network. In circumstances where the maximum permissible jitter amplitude occurs at an interface between two countries, it is left to the discretion of national administrations to take the appropriate remedial action. This situation is unlikely to occur very often.

TABLE 1/G.824

Maximum permissible output jitter at hierarchical interfaces					
Network Limit (UI peak-to-peak)			Bandpass filter having a lower cut-off frequency f_1 or f_3 and a minimum upper cut-off frequency f_4		
Digital rate (kbit/s)	B_1	B_2	f_1 (Hz)	f_3 (kHz)	f_4 (kHz)
1544	5.0	0.1 [a)]	10	8	40
6312	3.0	0.1 [a)]	10	3	60

32064	2.0	0.1[a]	10	8	400
44736	5.0	0.1	10	30	400
97728	1.0	0.05	10	240	1000

UI   Unit interval

a)   This value requires further study.

For systems in which the output signal is controlled by an autonomous clock (e.g., quartz oscillator) more stringent output jitter values may be defined in the relevant equipment specifications (e.g., for the muldex in Recommendation G.743, output jitter should not exceed 0.01 UI r.m.s).

The arrangements for measuring output jitter at a digital interface are illustrated in Figure 1/G.824. The specific jitter limits and values of filter cut-off frequencies are given in Table 1/G.824.

FIGURE 1/G.824

Measurement arrangements for output jitter from
a hierarchical interface or an equipment output port

2.2   Network limits for wander

Network output wander specifications at synchronous network nodes are necessary to ensure satisfactory network performance (e.g. slips, error bursts). For network nodes the following limits are specified, based on the assumption of a non-ideal synchronizing signal (containing jitter, wander, frequency departure, and other impairments) on the line delivering timing information. The maximum time interval error (MTIE) (see Recommendation G.811) over a period of $\underline{S}$ seconds shall not exceed the following:

$(10^{-2}\underline{S} + 10,000)$ ns; applicable to values of $\underline{S}$ greater than 10^4.

Note - The resultant overall specification is illustrated in Figure 2/G.824.

3.   Framework for the specification of individual digital equipments

3.1   Basic specification philosophy

Jitter and wander control inherently depends on both network and equipment design. Network considerations are discussed in § 2. The principal parameters of importance when considering the jitter and wander

performance of digital equipment are:

i)   the amount of jitter and wander that can be tolerated at the input;

ii)   the proportion of this input jitter and wander which filters through to the output; and

iii)   the amount of jitter and wander generated by the equipment.

The intention of this section is to provide a foundation for the development of equipment requirements which will ensure that the various network equipments are compatible from the standpoint of jitter and wander performance.

FIGURE 2/G.824

Permissible maximum time interval error (MTIE)
versus observation period S for the output of a network node

Further study is required to quantify the difference in limits for transit and local nodes. In addition, wander accumulation in networks is closely tied to the stability specifications contained in Recommendations G.811, G.81x, Q.511.

3.1.1   Jitter and wander tolerance of input ports

In order to ensure that any equipment will operate satisfactorily when connected to a hierarchical interface within the network, it is necessary that the equipment input ports be capable of accommodating levels of network output jitter up to the maximum network limits specified in Table 1/G.824. Specification of input jitter tolerance in terms of a single Recommendation applicable to all categories of digital equipment ensures that a certain minimum jitter tolerance is satisfied by all network elements. Most specifications of equipment input tolerance are in terms of the amplitude of sinusoidal jitter that can be applied at various frequencies without causing a designated degradation of error performance. The simplicity of this form of specification has great appeal, since it is easily verified with conventional test equipment. However, it is important to recognize that the test condition is not, in itself, intended to be representative of the type of jitter to be found in practice in a network. For some equipment, therefore, it may be necessary to specify supplemental jitter tolerance tests, and reference to the individual equipment Recommendation should always be made.

As a minimum guideline for equipment tolerance, it is recommended that all digital input ports of equipments be able to tolerate the sinusoidal jitter and wander defined by Figure 3/G.824 and Table 2/G.824. The limits are to be met in an operating environment.

In deriving the specifications contained in Table 2/G.824 for frequencies above f_3, the effects of the amount of alignment jitter of the equipment clock decision circuit are considered to be predominant. Measurements carried out to verify compliance with these specifications may provide environment dependent results, hence allowing some ambiguity in their interpretation. Account should be taken of the requirement at the design stage of the equipment; Supplement No. 3.8 (O-Series) provides guidance regarding environment independent measurements.

In deriving these specifications, the wander effects are considered to be predominant at frequencies below f_1, and many transmission equipments, such as digital line systems and asynchronous muldexes using justification techniques, are effectively transparent to these very low frequency changes in phase. However, such phase variation does need to be accommodated at the input of certain equipments (e.g. digital exchanges and synchronous muldexes). The requirement contained in Table 2/G.824 for frequencies below f_1 is not amenable to simple practical evaluation,

but account should be taken of the requirement at the design stage of the equipment.

Equipment wander tolerance must be compatible with network output wander limits specified in Figure 2/G.824. Insufficient wander tolerance at synchronous equipment input ports may result in controlled or uncontrolled slips, depending on the specific slip control strategy employed.

TABLE 2/G.824

Jitter and wander tolerance of input ports
(Provisional values) (Note 1)

Bit Rates (kbit/s)	Jitter amplitude (peak-to-peak)			Frequency					Test Signal
	A_0 (µs)	A_1 (UI)	A_2 (UI)	f_0 (Hz)	f_1 (Hz)	f_2 (Hz)	f_3 (kHz)	f_4 (kHz)	
1544	18 (Note 2)	5.0	0.1 (Note 2)	1.2×10^{-5}	10	120	6	40 (Note 3)	$2^{20}-1$
6312	18 (Note 2)	5.0	0.1	1.2×10^{-5}	10	50	2.5	60 (Note 2)	$2^{20}-1$
32064	18 (Note 2)	2.0	0.1	1.2×10^{-5}	10	400	8	400 (Note 2)	$2^{20}-1$
44736	18 (Note 2)	5.0	0.1 (Note 2)	1.2×10^{-5}	10	600	30	400 (Note 2)	$2^{20}-1$
97728	18 (Note 2)	2.0	0.1	1.2×10^{-5}	10	12 000	240	1 000 (Note 2)	$2^{23}-1$

Note 1 - Reference to individual equipment specifications should always be made to check if supplementary input jitter tolerance requirements are necessary.

Note 2 - This value requires further study.

Note 3 - It is necessary to suppress long zero strings in the test sequence in networks not supporting 64 kbit/s transparency.

Note 4 - The value A_0 (18 us) represents a relative phase deviation between the incoming signal and the internal local timing signal derived from the reference clock.

FIGURE 3/G.824

Mask of peak-to-peak jitter and wander which must be accommodated
at the input of a node in a digital network
(Measurement method - refer to Supplement No. 3.8 (O-Series)
and Supplement No. 35)

3.1.2   Jitter and wander transfer characteristics

Jitter transfer characteristics define the ratio of output jitter to input jitter amplitude versus jitter frequency for a given bit rate. When jitter is present at the digital input port of digital equipment, in many cases some portion of the jitter is transmitted to the corresponding digital output port. Many types of digital equipment inherently attenuate the higher frequency jitter components present at the input. CCITT Recommendations dealing with particular equipment will ultimately define limiting values for its particular jitter transfer characteristics. To control jitter in cascaded homogeneous digital equipment situations, it is important to restrict the value of jitter gain.

Because the bandwidth of phase smoothing circuits in asynchronous digital equipment is generally above 10 Hz, wander on the input signal may appear virtually unattenuated on the output. However, in certain particular digital equipments (e.g. nodal clocks) it is necessary that wander be sufficiently attenuated from input to output. CCITT Recommendations dealing with synchronous equipment will ultimately define limiting values for particular wander transfer characteristics.

3.1.3   Intrinsic jitter and wander generation

Intrinsic jitter and wander generation is defined as output jitter and wander in the absence of input jitter and wander. It is necessary to restrict the amount of intrinsic jitter and wander generated within individual digital equipments to provide control over network jitter and wander accumulation from cascaded network elements. Limits for output jitter and wander for individual digital equipments are defined in the specific CCITT equipment Recommendations. The actual limits applied depend upon the type of equipment.

3.2   Digital line sections

To ensure that the maximum network limit (§ 2.1) is not exceeded within a digital network, it is necessary to control the jitter and wander contributed by transmission systems.

The jitter specifications for digital line sections will ultimately be found in Recommendations G.911 to G.915.

3.3   Digital muldexes

To ensure that the maximum network limit (§ 2.1) is not exceeded within a digital network, it is necessary to control the jitter and wander contributed by transmission systems.

The jitter specifications for digital muldexes using positive justification are found in Recommendations G.743 and G.752.

3.4   Digital exchanges

To ensure that the maximum network limit (to be specified in § 2.2) is not exceeded within a digital network, it is necessary to control jitter and wander transfer and generation, as appropriate, for digital exchanges.

Output wander specifications for primary reference clocks are addressed in Recommendation G.811. The jitter and wander specifications for digital transit exchanges and digital local exchanges are found in Recommendation Q.511.

4. Jitter and wander accumulation in digital networks

The variability of network configurations presents a multitude of connection possibilities. To analyze a particular network configuration, it is necessary to use the information about the jitter characteristics of individual equipments in conjunction with appropriate jitter accumulation models. Supplement No. 36 provides information to aid organizations in carrying out such evaluations.

The term digital section is used in these Recommendations as a general term to include digital line section and digital radio section. This term is defined in Recommendation G.701 (see also Figure 1/G.701 and Figure 2/G.960). Digital sections are defined as component parts of digital links operating at particular bit rates and may be regarded as "black boxes". For digital sections used in digital hierarchy (network) applications the inputs and outputs are recommended in the form of "equipment interfaces" (i.e. in Recommendation G.703 for hierarchical bit rates or in the Recommendation G.931 for non-hierarchical bit rates). For digital sections used for ISDN customer access the "section boundaries" are at the T reference point and the appropriate V reference point. User-network interfaces which may be used at the T reference point are recommended in the I.400-Series of Recommendations and the exchange interfaces which may be used at the V reference points are recommended in the Q.500-Series of Recommendations. Digital section Recommendations contain the common network-related requirements applicable to digital radio, metallic and optical transmission systems. The performance requirements relate to network performance objectives.