RECOMMENDATION ITU-R S.1522

Impact of loss of synchronization and timing recovery on availability in hypothetical reference digital paths

(Question ITU-R 73/4)

(2001)

The ITU Radiocommunication Assembly,

considering

a) that the unavailability of a hypothetical reference digital path (HRDP) is determined by the combined effects of equipment and link availability;

b) that in some instances equipment unavailability is not due to equipment failure;

c) that Recommendation ITU-R S.521 specifies that HRDPs can include functions such as: demodulation/modulation, error correction, buffer and processing which may be implemented in customer terminal or earth station equipment;

d) that HRDPs may support such applications, as MPEG-2, which contain sequentially layered coding schemes that may include among other things: address security, data compression, and error correction;

e) that HRDPs may also include digital applications employing other modulation and coding techniques such as quadrature phase shift keying (QPSK), octaphase shift keying (8-PSK), quadrature amplitude modulation (QAM), 1/2, 3/4 rate forward error correction (FEC), Reed-Solomon (RS), turbo coding etc.;

f) that such applications, after loss of signal, may take a significant time to recover after signal restoration;

g) that Recommendation ITU-R S.579 indicates that a link is considered to be unavailable when the received digital signal timing alignment (or synchronization) is lost for 10 consecutive seconds or more. Those 10 s are considered to be unavailable time and that period continues until timing alignment (or synchronization) is restored for 10 consecutive seconds;

h) that Recommendation ITU-R S.579 defines availability and unavailability of an HRDP (which may include elements of *considering* c) above);

j) that synchronization in the satellite HRDP may also affect the loss of synchronization and recovery time of higher protocol layers in the hypothetical reference connection (HRX);

k) that freeze frame degradation to MPEG-2 receivers occur when error blocks appear in the video image and can be considered as unavailability, *recommends*

1 that recovery times should be taken into account when determining availability requirements for digital decoders with complex synchronization schemes which are susceptible to short periods of signal degradation due to propagation or interference (see Annex 2);

2 that sensitive digital decoders, that are configured as in *recommends* 1, should be used in links which have been designed to ensure that statistical sources of interference will not cause additional equivalent link noise temperature increases resulting in loss of synchronization;

3 that the $C/(N+I)$ levels given in Table 1 should be used when considering the loss of synchronization for typical digital demodulator/decoders employing various modulation and coding techniques for systems with data rates of 34 Mbit/s or less;

4 that in cases where the minimum performance objectives are below the values indicated in *recommends* 3, the threshold for loss of synchronization is assumed to be 1 dB below the degraded performance objective;

5 that for digital demodulator/decoders, recovery times given in Table 2 should be used when determining the unavailability due to loss of synchronization in an HRDP employing such digital demodulator/decoders;

6 that for applications using MPEG-2 receivers, error blocks will occur in the video image at threshold level higher than the level for synchronization shown in Table 1 by 0.3 dB for QPSK 1/2-RS rate coding and 0.6 dB for QPSK 3/4-RS and 7/8-RS rate coding (see Annex 1).

NOTE 1 – The time duration and frequency of occurrence of interfering signals can contribute to the determination of the allowable maximum interference level. It is observed that multiple short interference events can result in periods of unavailability of longer duration than those periods caused by fewer long events (see Annex 3). This effect and the results of short duration (< 1 s) interference events are subjects of further study.

NOTE 2 – The impact of the loss of synchronization in the satellite HRDP on the higher layer protocol levels in an HRX is a subject of further study.

NOTE 3 – Table 2 is derived from the latest available, limited set of data as given in Annex 4 and is provisional pending further studies.

TABLE 1

Typical $C/(N+I)$ levels when considering the loss of synchronization*

Modulation and coding	**$C/(N+I)$ (dB)**
QPSK rate 1/2	3.5
QPSK rate 3/4	5.3
QPSK rate 7/8	6.0
8-PSK	8.1
16-QAM	11.0

* Taking into account the measured data in Annex 4.

TABLE 2 (see Note 3)

Maximum of measured recovery times

Modulation and coding	**Carrier bit rate**	**Recovery time (s)**
QPSK rate 1/2 FEC	64 kbit/s	40
	2 Mbit/s	4.5
QPSK rate 3/4 FEC	64 kbit/s	19.8
	2 Mbit/s	6
	8 Mbit/s	9.3
	34 Mbit/s	2.3
8-PSK rate 2/3 FEC with (201,219) RS coding	2 Mbit/s	3.1
	8 Mbit/s	9.1
	34 Mbit/s	4.0

ANNEX 1

Considerations for HRDPs when implemented for providing services whose availability are sensitive to synchronization timing recovery

1 Introduction and purpose

The synchronization behaviour of several different classes of receivers were examined based on measurements performed or information supplied by earth station receiver manufacturers. The objectives of the investigation were to determine the interference duration and the power level required to cause the receiver to lose synchronization. For each receiver investigated, the degradation level and length of time necessary to cause loss of synchronization were determined. Additionally, the amount of time to reacquire synchronization for each receiver was determined. The results were then quantified so as to determine the synchronization loss criteria that could be applicable for all geostationary-satellite orbit (GSO) fixed-satellite service (FSS) earth station receivers.

2 Digital video and audio receivers

A typical MPEG-2 digital video and audio receiver is described in Annex 2 along with its performance and discussion of the test results. The test results indicate that a satellite channel of the type tested above and implemented, using QPSK concatenated 1/2 RS or 7/8 RS convolutional coding and operating at a 1×10^{-10} bit error ratio (BER) would lose synchronization if the noise is increased 2.2 dB for a period of 1 to 2 s. Assuming nominal $C/(N + I)$ levels were restored after loss of synchronization, the equipment would require an additional 4 to 8 s to return to normal operation.

It was noted that error blocks occur in the received image at a threshold level higher than the synchronization loss level. MPEG-2 video is considered to be unavailable when error blocks are seen in the video image. For the QPSK 1/2 rate coded MPEG-2 signal, error blocks occurred at a threshold *C*/*N* that was 0.3 dB above the threshold for loss of synchronization. For the QPSK 7/8 rate coded MPEG-2 signal, error blocks occurred at a threshold *C*/*N* that was 0.6 dB above the threshold for loss of synchronization.

3 Data receivers

Performance results for digital receivers operating at various data rates show that the margin for loss of synchronization is of the same order as discussed in § 2.1. When the E_b/N_0 falls below threshold and remains below it for a period of 1 to 2 s, it loses lock both frequency and data synchronization. The time duration to reacquire depends on the particular algorithm used, and on the bandwidth that it must sweep in order to reacquire synchronization. Generally this is a function of the data rate, modulation method (binary PSK (BPSK), QPSK, etc.), coding/decoding method and the coding rate used. The total time to reacquire frequency and data synchronization varies for moderate and high bit rates up to the Mbit/s range, test results illustrating the range of recovery times are given in Table 8.

4 Packet services

Packet data service may be affected for much longer periods even when a system abnormality lasts for a short duration.

ITU-T considers a system to be unavailable after a service is unavailable for 10 s or more. The routing information for the packet service is updated every 30 s, and up to two cycles of such updating may be affected by a short abnormality and its after-effects. Thus, it may be concluded that although the receiver loses synchronization for only 1 to 15 s, the overall effect including the time for service restoration may be to make the service unavailable for much longer period.

5 On-board processing satellite networks

With the advent of on-board processing satellites, consideration of loss of synchronization on the uplink of such networks must also be taken into account when evaluating the effects of interference from non-GSO and other interference sources into GSO FSS systems. Further analysis will be necessary to determine the durations and levels of interference necessary to cause loss of synchronization at satellite receivers employing on-board processing.

6 Summary and conclusions

Test results of performance and interference susceptibility for several types of receiver-demodulators operating or planning to operate in the 30/20 GHz and 14/11 GHz bands have been completed. Additional information on other configurations and improvements in the state of the art is required.

Tests performed on typical receivers used for digital video, digital audio, and data service and voice applications indicate that noise or interference levels exceeding C/N thresholds in Table 1 for short periods of time will cause the receiver to lose synchronization. The tests demonstrate that when signals are returned to nominal $C/(N+I)$ levels, after loss of synchronization, the recovery times of the receiver are a function of modulation, coding and bit rate as shown in Table 2. Further study on the time duration and frequency of occurrence of interference sources is required in order to fully quantify their effects on services with imbedded synchronization implementations.

For the systems tested it is apparent that service restoration time is an important factor that must be taken into consideration when determining the performance requirements of the service. Several factors affect the total time for which service restoration is required including: demodulator and bit synchronization, frame synchronization, error correction decoding, security synchronization, restoration of connection for voice circuits and re-initiation of transmission protocols for data circuits.

ANNEX 2

Loss of synchronization due to short-term interference in an MPEG-2 digital video and audio receiver

1 Introduction

In this Annex, the synchronization behaviour of a digital video receiver is examined that is commonly used for satellite news gathering (SNG) and for video distribution by broadcasters. Similar complex receivers are also used for direct to home and broadcasting-satellite service (BSS) applications, data distribution, file transfer, broadcast of data, etc. This class of receiver was chosen for testing and evaluation because the video data is heavily coded and compressed where the loss of synchronization could cause long-term outages. Other receivers designed for different types of service will perform similarly with different outage times.

2 Objective and approach

The objectives of the investigation were to determine the interference duration and the power level required that cause the receiver to lose synchronization and also to characterize the receiver outage time. For these measurements the interference is modelled as Gaussian noise. This is consistent with accepted test procedures that treat interference from digital sources. Measurements were obtained by raising the noise level to simulate the interference source. Initial tests were designed to characterize the BER performance of the receiver and were compared to the manufacturer's specifications in order to ensure that the system under test was performing properly. Additional tests were performed to determine the mean time to loss of synchronization, and the time for reacquisition. Tests were also conducted to determine the impact of noise bursts on receiver performance.

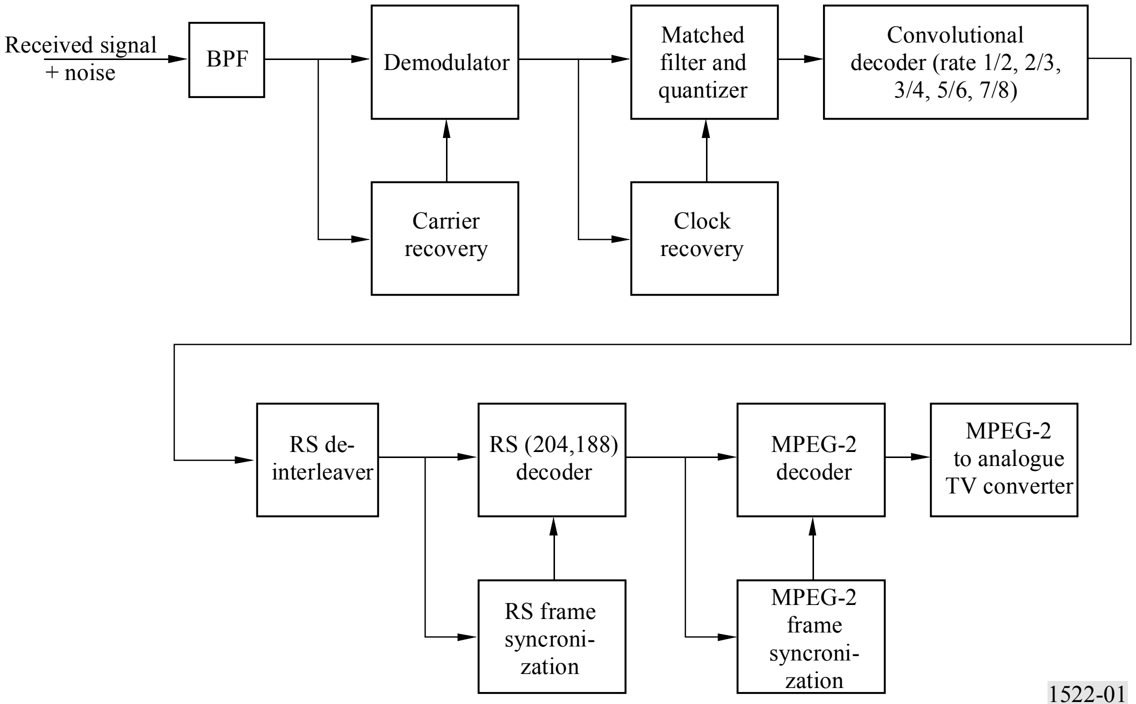
3 Receiver description

The digital video receiver under test integrates MPEG-2 digital video and MPEG-2 digital audio decoders into a single channel per carrier. That configuration allows direct reception of digitized video, audio, and data from satellite network transmissions. For this implementation the received signal was set as QPSK modulated where the receiver can handle data rates from 2.5 Mbit/s to 15 Mbit/s.

Figure 1 is a block diagram showing the receiver processing chain. The received signal is demodulated, matched filtered and the detected symbols are quantized. The quantized symbols are convolutionally (Viterbi) decoded. The system can be set-up for rate 1/2, 2/3, 3/4, 5/6, and 7/8 codes. The symbols then enter an RS decoder, and a de-interleaver that protects the RS decoder from burst errors generated by the Viterbi decoder. The RS decoder outputs MPEG-2 frames. These frames are decoded, demultiplexed and the MPEG-2 signal is converted to analogue TV format.

FIGURE 1

Digital video receiver block diagram



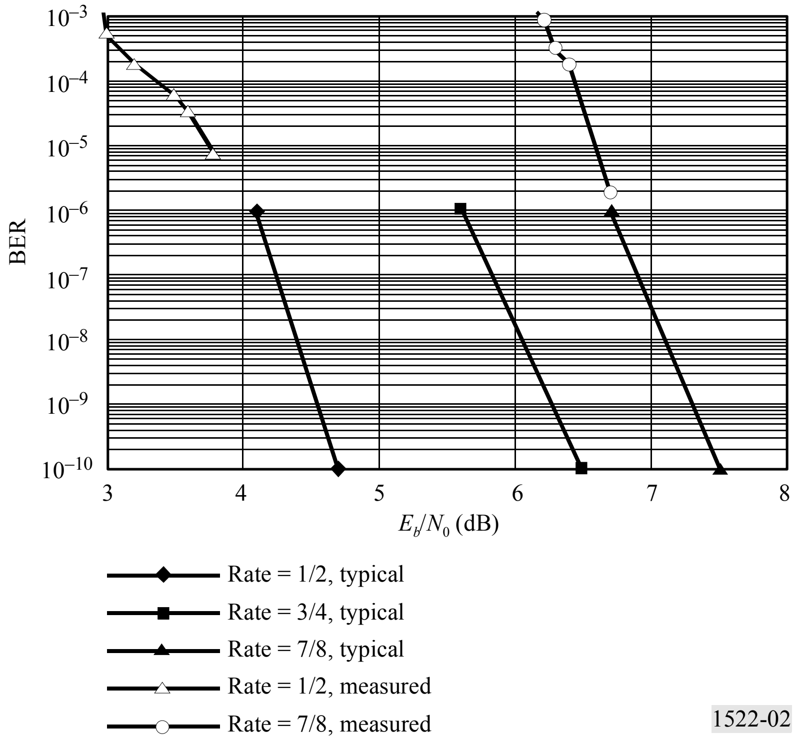
BPF: band pass filter

As seen in Fig. 1, the receiver has many levels of synchronization from initial carrier recovery to MPEG-2 frame synchronization preceding conversion to analogue TV. In general, higher level synchronization functions are more susceptible to loss of synchronization than the lower level functions. Therefore, frame and code synchronization will be lost before carrier synchronization. Loss of synchronization and reacquisition are primarily software functions. Thus the behaviour of the receiver can depend on the specific software implementation.

Figure 2 shows typical performance curves for the RS decoder for several different convolutional code rates. The clear sky performance threshold is usually set to the BER = 1 × 10^{-10}. This corresponds to an E_b/N_0 = 4.7 dB dB for a rate 1/2 code and an E_b/N_0 = 7.5 dB for a rate 7/8 code.

FIGURE 2

BER after the RS/Viterbi decoding



Fade thresholds are defined here as the minimum operating point for the receiver. Fade thresholds in satellite networks are often set for the BER = 1 × 10^{-10}. Table 3 presents E_b/N_0 fade thresholds for different convolutional code rates.

TABLE 3

Fade thresholds for BER = 1 × 10^{-6}

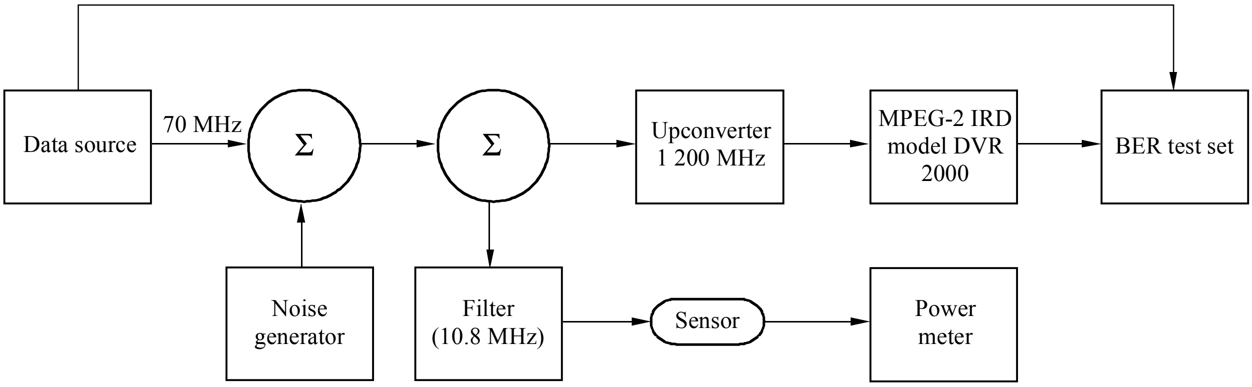
Rate	1/2	2/3	3/4	5/6	7/8
E_b/N_0 (dB)	4.1	4.8	5.6	6.1	6.7

3.1 Receiver performance

Figure 3 shows the BER test set-up that is used to verify the operation of the unit under test. The transmission rate was 3.68 Mbit/s. Two different code rates, 1/2 and 7/8, were tested. The performance of the receiver is included in Fig. 2. Very low BERs were difficult to measure due to the long time needed to perform the measurements. However, the results appear to agree with typical modem performance. The performance of this system was compared to other systems and the results were consistent to within 0.3 dB.

FIGURE 3

BER test set-up



DVR: digital video receiver
IRD: integrated receiver decoder

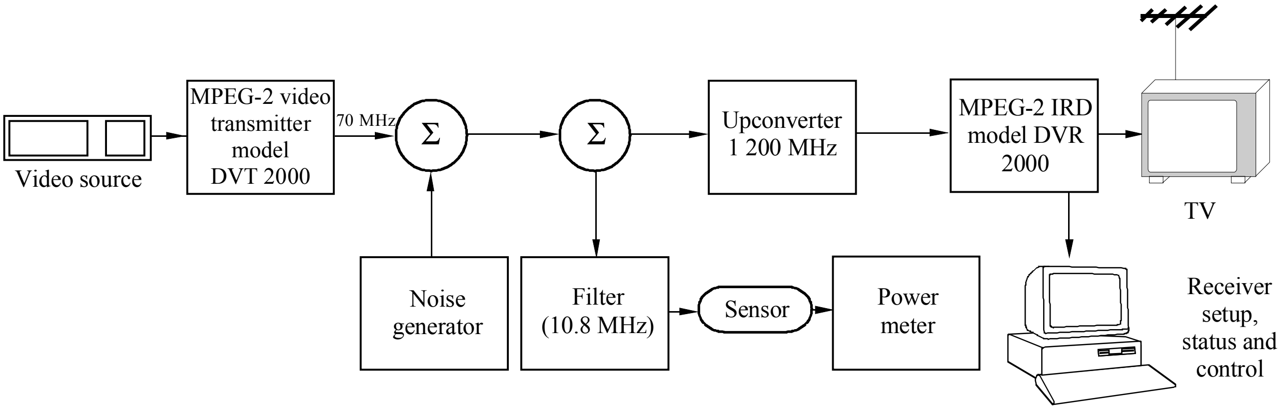
1522-03

4 System test facility

Figure 4 shows the test set-up used to test receiver synchronization behaviour. The video source was programme video of a sporting event. It was determined that the receiver performance was affected by the amount of motion in the video. That source was chosen because of its consistently erratic motion content that constantly stressed the video compression algorithms.

FIGURE 4

Video data test set-up



DVT: digital video transmitter

1522-04

Power meter measurements were made in terms of C/N and converted to E_b/N_0 using the following equation:

$$E_b/N_0 = C/N + 10 \log (B_n/dr) = C/N + 4.68 \tag{1}$$

where:

B_n: noise bandwidth = 10.8 MHz

d_r: data rate = 3.68 Mbit/s.

The test receiver used, provided an external interface that allowed it to be controlled locally by a terminal. Diagnostics also can be made available for display on the terminal which include reports of the number of skipped and repeated frames that are printed every 5 s as well as indications of synchronization status. The test facility also included video displayed on a TV that provided a subjective indication of performance.

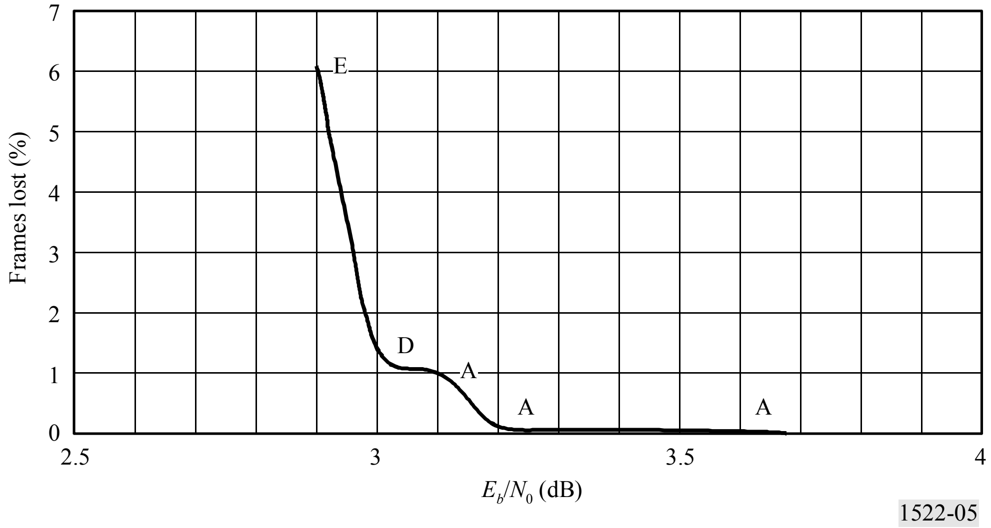
4.1 System test results

4.1.1 Loss of synchronization

Figures 5 and 6 show the number of frames lost as a function of E_b/N_0 for rate 1/2 and 7/8 codes, respectively. For each E_b/N_0 measurement point, results were averaged for 2 min. The steep excursion of the curves reflect the sensitivity of the concatenated convolutional/RS code. Below the E_b/N_0 point where the frame loss rate exceeds approximately 6% the receiver loses synchronization. These correspond to a BER of about 1×10^{-3}.

FIGURE 5

Percentage of video frames lost as a function of E_b/N_0 for the video receiver using rate 1/2 coding

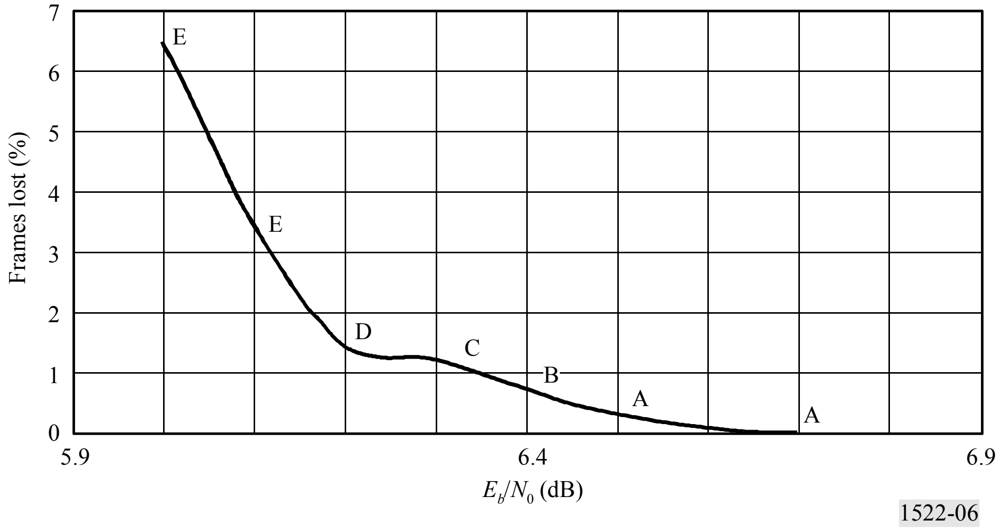


By means of the TV monitor a subjective measurement on viewing quality was made. The subjective measurements are indicated by letters in Figs. 5 and 6. The meaning of these letters is:

A: clear picture
B: occasional jumps or error blocks in the picture
C: frequent jumps or error blocks in the picture
D: the picture is still viewable
E: the picture is unviewable.

FIGURE 6

Percentage of video frames lost as a function of E_b/N_0 for the video receiver using rate 7/8 coding



4.1.2 Mean time to loss of synchronization

The mean time to loss of synchronization was investigated for E_b/N_0 below the 6% frame loss rate. Figures 7 and 8 show the mean time to loss of synchronization for rate 1/2 and 7/8 codes, respectively. These measurements were made by allowing the receiver synchronization up at a high E_b/N_0, then reducing the E_b/N_0 to the test value and recording the time it took to lose synchronization. Time measurements were made by viewing a clock. Ten measurements were averaged for each E_b/N_0.

FIGURE 7

Mean time to loss of lock versus E_b/N_0 for the video receiver using 1/2 rate coding

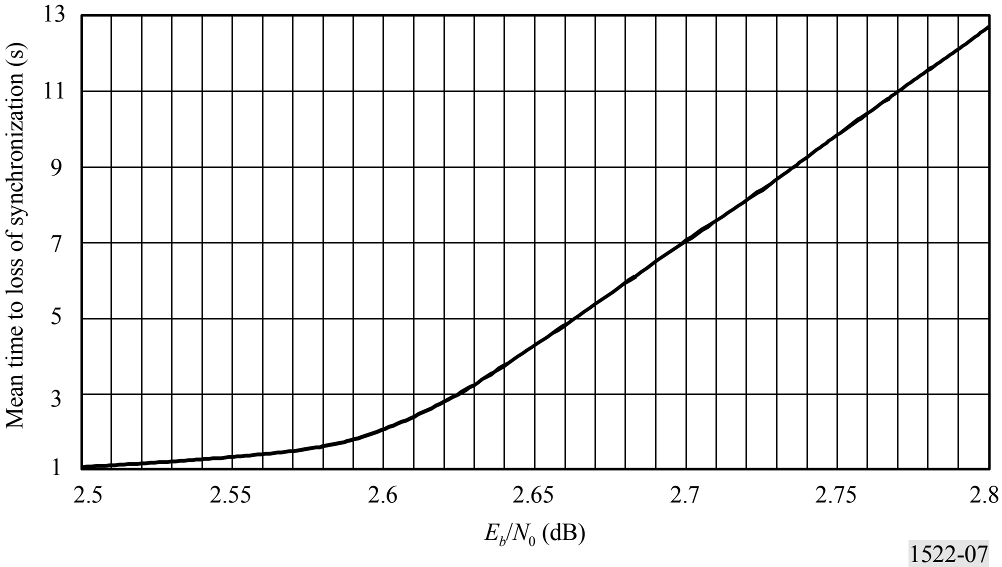
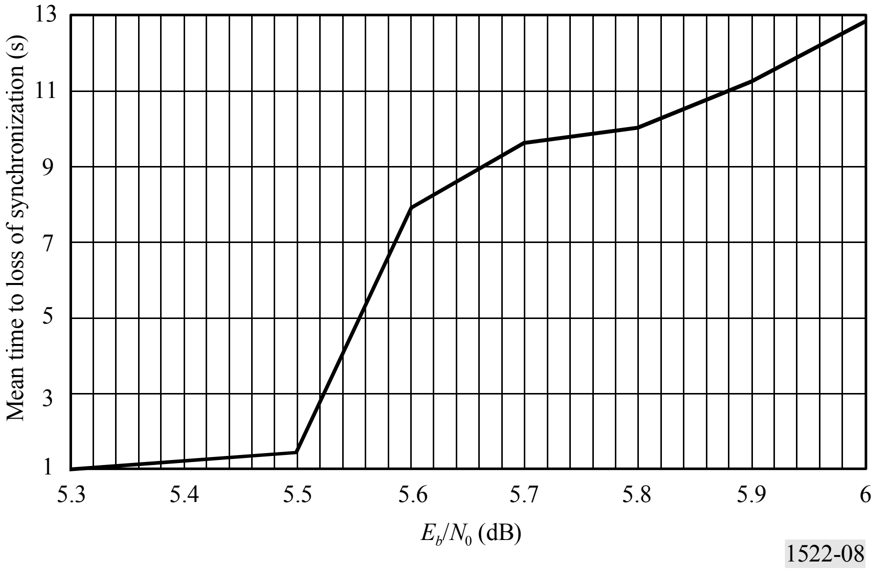


FIGURE 8

Mean time to loss of lock versus E_b/N_0 for the model video receiver using 7/8 rate coding



Below a certain E_b/N_0 the receiver always appears to lose lock in about 1 s. Since the interference from the non-GSO system will occur in short bursts (on the order of seconds) this E_b/N_0 is critical. For the 1/2 rate coded system this E_b/N_0 is 2.5 dB and for the 7/8 coded system this E_b/N_0 is 5.3 dB. Relative to a 1×10^{-10} BER this corresponds to a 2.2 dB margin for both the 1/2 rate and 7/8 rate codes.

4.1.3 Reacquisition

For the receiver under test there are two search ranges for carrier lock. The initial acquisition uses a wide search mode that searches over a range of ±1.5 MHz. Normal reacquisition uses a narrow search mode over a range of ±140 kHz around the frequency it was last synchronized to. The receiver will remain in narrow search mode for approximately 5 min and if the carrier is not acquired it will switch to the wide search mode.

Since it is expected that non-GSO interference will only cause short-term bursts it can be assumed that reacquisition of the carrier is accomplished while in the narrow search mode. Time measurements indicate that reacquisition while in the narrow search mode takes approximately 4 s. Carrier search should only be a portion of this time because the search starts at the frequency where synchronization was lost. Most of the reacquisition time for the receiver involves re-initialization of internal programming.

An upgrade model of the tested digital video receiver promises performance that is slightly better than the tested version. However, this receiver has an additional 4 s delay built in before it starts the reacquisition process.

4.1.4 Recovery from interference bursts

This test is similar to the mean time to loss synchronization test described in § 4.1.2 and better characterizes the impact of a burst of errors. Interference bursts were simulated by operating the receiver without noise and then switching a noise burst into the channel, for a short time. The noise burst was constrained to have an $E_b/N_0 = 2.5$ dB for the 1/2 rate coded channel and an $E_b/N_0 = 5.3$ dB for the 7/8 rate coded channel for a controlled time duration ±0.25 s. The results of this test are shown in Table 4.

TABLE 4

Receiver performance after being hit by a noise burst

Rate	E_b/N_0 transition level (dB)	Interference duration (s)	Loss of synchronization	Lost frames (%)
7/8	5.3	1	No	8.5
7/8	5.3	2	Yes	–
1/2	2.5	0.5	No	4.0
1/2	2.5	1	No	12
1/2	2.5	2	Yes	–

This test indicates that it takes a burst duration of approximately 2 s to cause the receiver to lose synchronization, while, according to § 4.1.2, the mean time to loss of synchronization occurred in just 1 s, for the same E_b/N_0. Apparently a low E_b/N_0 is required for more than 1 s to keep the channel from making a recovery.

5 Conclusions

Performance measurements made on this receiver demonstrate a margin for loss of synchronization, compared to a BER of 1×10^{-10}, of 2.2 dB. An interference burst of approximately 2 s is required to cause loss of synchronization and the receiver reacquires 4 s after the interference ends. Assuming a satellite channel has been implemented with margins that will protect during its availability to a threshold BER of 1×10^{-10}, then a receiver, in the circuit, of the type tested would lose synchronization if that margin was exceeded by 2.2 dB for a period of 1 to 2 s. Assuming operational levels were restored after loss of synchronization, the following receiver functions would reacquire in 4-8 s.

ANNEX 3

The effect of interference events on service availability

1 Introduction and objective

Service availability for a link in a GSO network is affected by a combination of atmospheric, equipment, and interference events in addition to the time to recover from loss of synchronization. This analysis demonstrates that where synchronization recovery time is a consideration, the service availability (defined later) of a GSO network decreases in inverse proportion to the number of propagation, equipment and interference events that cause loss of synchronization, even though the composite total of link unavailable time may remain constant, i.e. many short interference events are more detrimental than fewer long-term events.

2 Definitions

Recommendation ITU-R S.579 defines availability for a hypothetical reference circuit (HRC) and a HRDP in the FSS. *considering* d) and e) of Recommendation ITU-R S.579 state that availability is determined by the combined effects of equipment and propagation availability; and, *recommends* 4 indicates that unavailability should also take into account equipment recovery time. Recommendation ITU-R S.579 defines circuit “availability” and “unavailability” as follows:

$$\text{Availability} = (100 - \text{Unavailability}) \qquad \% \tag{2}$$

where:

$$\text{Unavailability} = (\text{Unavailable time/required time}) \times 100 \qquad \% \tag{3}$$

and “required time” is defined as the period of time during which the user requires the circuit or digital path to be in a condition to perform a required function and the unavailable time is the cumulative time of circuit or digital path interruptions within the required time.

This analysis takes into account the effects of “synchronization recovery time” as a function of individual event duration when assuming that the total of all event times are constant over a year long period. Analysis and the numerical examples are all presented on a “per year” basis. The analysis demonstrates that many events of short duration that cause unavailability generally will have a greater impact, over a longer time period, on performance than a few events of long duration over the same longer time period. More study is required to determine what time periods should be selected for evaluation.

3 Availability and user requirements

Recommendation ITU-R S.579 relates availability to a user requirement for the performance of a function. Those functions such as those that are concerned about loss of synchronization, will require additional time beyond adequate C/N restoration to restore the desired functional capability.

In such links, the restoration of adequate *C*/*N* is followed by reacquisition of restoration of link functionality and resumption of user fonctions.

For the purposes of this analysis it was found to be useful to distinguish between link availability and user service availability as follows:

Link availability = Percentage of time when the receiver/demodulator output is available (4a)

User service availability = Percentage of time bit synchronization and user function is available (4b)

Since user service availability depends on link availability, the former can never be greater than the latter.

It also follows from the above that "Link unavailability" and "User service unavailability" are equal to 100 minus the values indicated in equations (4a) and (4b) respectively.

Some equipment implementations, beyond the receiver/demodulator and bit synchronizer, which are sensitive to loss of synchronization and which will require restoration, are listed below. The time to accomplish these actions will degrade user service availability relative to link availability. These include:

- frame synchronization;
- security synchronization;
- interleaver synchronization;
- error correction decoder synchronization;
- re-initialization of transmission protocols;
- user terminal initialization.

Other user functions that are normally dependent on other links (such as redialling), but which may be affected by the loss of synchronization, are not considered at this time.

4 Analysis

4.1 Event duration and number of events per year

The availability of a link is usually stated in terms of percentages of time during which specific limits may not be exceeded.

Accordingly then if:

p: fraction of time the limit is exceeded; and

$p =$ 1 – 0.01 × percentage of time available; and if

N: number of events per year causing unavailability; and

D: the average duration of each event (s);

then:

$$N \times D = p \times 3.1536 \times 10^7 \text{ unavailable seconds per year} \tag{5}$$

where:

3.1536×10^7: number of seconds in 365 days.

For example availability of 99%, 99.9% and 99.99% are often stated requirements for satellite network links. The choice of those performance requirements is dictated by many factors including cost, frequency bands implemented, technology limits and specific service need. For the three cases being considered:

$$p = 10^{-2},\ 10^{-3} \text{ and } 10^{-4}\text{; and}$$

the unavailable time in seconds per year can be determined from equation (5) as follows:

$N \times D = 315\,360$ unavailable seconds for a 99% available network;

$= 31\,536$ unavailable seconds for a 99% available network; and

$= 3\,153.6$ unavailable seconds for a 99% available network.

Experimental information (see Annex 1) indicates that sufficiently high level interference events of 1 s or longer could cause loss of synchronization of common service functions implemented on satellite links. If it is assumed that the entire unavailability budget is taken up by interference events, and all such events were of 1 s duration, then each link could experience up to:

315 360 interruptions per year for the 99% link;

31 536 interruptions per year for the 99% link; and

3 153.6 interruptions per year for the 99% link.

For each event causing loss of synchronization, a recovery time of R seconds is required for each event, after adequate link C/N margin was restored for S seconds. The systems unavailability for that circuit would be increased by $N(R + S)$ per year: where N equals the number of yearly interruption events causing loss of synchronization, up to the maximums indicated above.

It follows then that:

$$\text{Service unavailability} = \text{Link unavailability} + N(R + S);$$

and

$$\text{Service availability \%} = (100 - (\text{Link unavailability} + N(R + S)) \qquad \%$$

Using the above equations an example calculation was performed on links designed to have an availability of 99%, 99.9% and 99.99%. Tables 5, 6 and 7 illustrate the calculated effects of synchronization recovery time on service availability for the three above link availability examples. In all of these examples it is assumed that:

Recovery time, $R = 10$ s; and

Restoration time, $S = 1$ s.

Figures 9, 10 and 11 provide a graphical illustration of the calculated results.

TABLE 5

Link availability of 99%

Number of loss of synchron-ization events, *N*	Event duration, *D* (s)	*N*(*R* + *S*) recovery time (s)	Service unavailability time (s)	Service availability (%)
10	31 536	110	315 470	98.999
30	10 512	330	315 690	98.998
100	3 153.6	1 100	316 460	98.996
300	1 051.2	3 300	318 860	98.989
1 000	315.36	11 000	326 360	98.965
3 000	105.12	33 000	348 360	98.895
10 000	31.536	110 000	425 360	98.651
30 000	10.512	330 000	645 360	97.954
100 000	3.1536	1 100 000	1 415 360	95.512
300 000	1.0512	3 300 000	3 615 360	88.536

FIGURE 9

Effect of synchronization recovery on 99% link availability

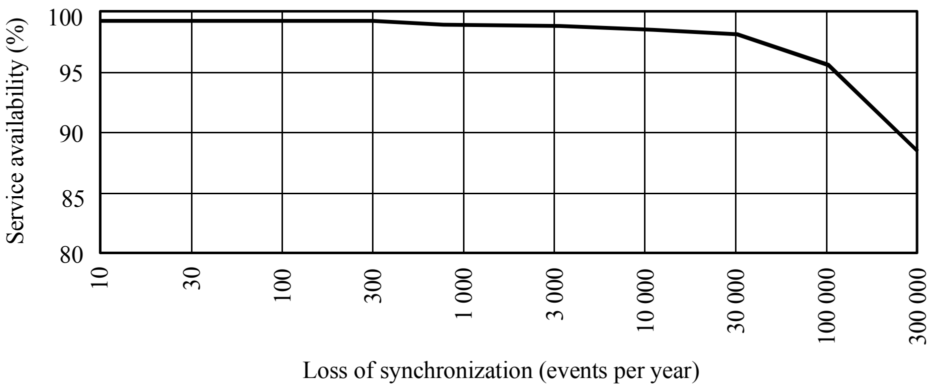


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TABLE 6

Link availability of 99.9%

Number of loss of synchron-ization events, *N*	Event duration, *D* (s)	*N*(*R* + *S*) recovery time (s)	Service unavailability time (s)	Service availability (%)
10	31 536	110	31 464	99.899
30	10 512	330	31 866	99.898
100	3 153.6	1 100	32 636	99.896
300	1 051.2	3 300	34 836	99.889
1 000	315.36	11 000	42 536	99.865
3 000	105.12	33 000	64 536	99.795
10 000	31.536	110 000	141 536	99.551
30 000	10.512	330 000	645 360	97.953

FIGURE 10

Effect of synchronization recovery on 99.9% link availability

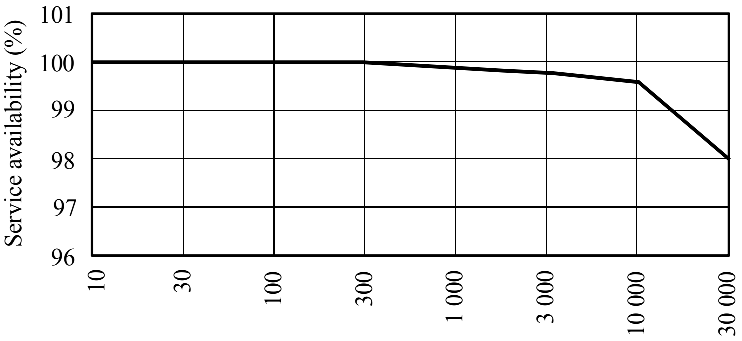

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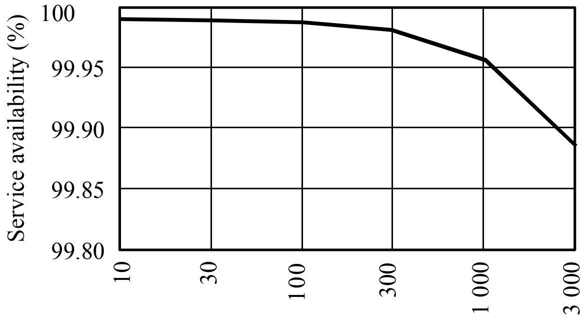
TABLE 7

Link availability of 99.99%

Number of loss of synchronization events, *N*	Event duration, *D* (s)	$N(R+S)$ recovery time (s)	Service unavailability time (s)	Service availability (%)
10	31 536	110	3 263.6	99.989
30	10 512	330	3 483.6	99.986
100	3 153.6	1 100	4 253.6	99.896
300	1 051.2	3 300	6 453.6	99.979
1 000	315.36	11 000	14 153.6	99.955
3 000	105.12	33 000	36 153.6	99.885

FIGURE 11

Effect of synchronization recovery on 99.99% link availability



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5 Discussion

Consideration of Tables 5 to 7 and Figs. 9 to 11 indicate that synchronization recovery affects the availability of service applications in proportion to the frequency of loss of synchronization even when link availability performance is maintained. It is therefore apparent that control of loss of synchronization causation events is important and that further study to characterize those events is warranted. Past impairment studies have generally dealt with propagation anomalies which have been mostly concerned with the total elapsed time of occurrence of transmission impairments and have presented their results in cumulative distribution form. Other interference studies have been generally concerned with causative interference levels of a relatively steady state nature. It is important to note that Article 22 of the Radio Regulations allows provisional equivalent power flux-density limits for non-GSO satellites in certain frequency bands in the FSS. Characterization of interference from non-GSO interference sources should give consideration to the interference environment that will result from the repetitive nature of non-GSO orbits. That such considerations are important can be inferred from the orbital mechanics of a single low altitude non-GSO satellite. It can be shown that a single low altitude satellite can be implemented to operate in an orbit that will pass over the same point on the earth surface in the order of 1 000 times per year. Considering that multiple satellite non-GSO systems will share spectrum with FSS networks there is a concern that the impact of the repetitive nature of those sources of interference are not yet fully understood and must be studied further.

6 Conclusions

The requirements of service recovery times in GSO networks should be taken into account when establishing network reliability during link design. An analysis has demonstrated that the recovery time, after a period of unavailability caused by an event, has an impact on service availability of a GSO circuit. The analysis also shows that given constant link unavailability the service availability of a GSO circuit decreases as the frequency of the loss of synchronization causative events increase. While it is recognized that the distribution of unavailability over a year is important, consideration of the impact of shorter time periods may be the subject of further study.

ANNEX 4

Criteria for determining threshold for synchronization

Loss of synchronization of a digital carrier is related to the $C/(N+I)$ level which is a function of interference, earth station hardware performance, satellite link margin and rain events, and sun interference in some cases.

The values of $C/(N+I)$ given in Table 8 is a summary of several tests which were conducted on digital carriers at various bit rates and with different error coding to determine the values of

$C/(N+I)$ which would cause a demodulator/decoder to lose synchronization and the time to recover from a burst of noise corresponding to an interference which might occur from a non-GSO FSS satellite system.

The values in Table 8 are taken from a limited number of measurement programs (five).

TABLE 8

Results of measurements for thresholds for loss of synchronization and recovery time

Modulation and coding	**Bit rate**	$C/(N+I)$ **(dB)**	**Recovery time (s)**
QPSK rate 1/2 FEC	64 kbit/s	1.7-3.1	9-40
	2 Mbit/s	3.4-3.6	1.7-4.5
QPSK rate 3/4 FEC	64 kbit/s	3.4-4.2	8.6-19.8
	2 Mbit/s	3.1-4.2	1.9-6
	8 Mbit/s	3.9-5.6	4-9.3
	34 Mbit/s	4.1-4.5	1.8-2.3
8-PSK rate 2/3 FEC + TCM	2 Mbit/s	7.9	2.6-3.1
	8 Mbit/s	7.6-7.8	9.1
	34 Mbit/s	7.8-7.9	1.7-4

TCM: trellis coded modulation.

The above $C/(N+I)$ values should be increased by approximately 0.5 dB to take into account the non-linearity contributions of the satellite in an actual satellite link.

Based on the set of measurements in Table 8 for thresholds for loss of synchronization for systems with data rates less than 34 Mbit/s, it is agreed that the $C/(N+I)$ values in Table 9 are representative of thresholds for loss of synchronization for the carriers indicated:

TABLE 9

Modulation and coding	$C/(N+I)$ **(dB)**
QPSK rate 1/2	3.5
QPSK rate 3/4	5.3
QPSK rate 7/8	6.0
8-PSK	8.1
16-QAM	11.0

In all other cases, and in particular when performance objectives are specified with values lower than those assumed above, the threshold for loss of synchronization is assumed to be 1 dB below the degraded performance objective.

Large variation in the recovery times were found in the above test results. For this Recommendation the maximum recovery times are proposed as provisional and further tests should be conducted before lower typical values can be assumed.