

RECOMMENDATION 730

**COMPENSATION OF THE EFFECTS OF SWITCHING DISCONTINUITIES
FOR VOICE BAND DATA AND OF DOPPLER FREQUENCY-SHIFTS
IN THE FIXED-SATELLITE SERVICE**

(Question 7/4)

(1992)

The CCIR,

considering

- a) that circular non-geostationary satellite systems are subject to Doppler frequency-shifts influencing the radio-frequency stability and to differential Doppler frequency-shifts resulting in baseband frequencies "stretch" or "shrinkage", for analogue interconnections and in frame slips for digital interconnections, respectively;
- b) that the orbital perturbations of the geostationary satellites may result in a cyclical variation of the transmission path time delay of less than 3 ms;
- c) that the difference between an audio frequency applied to one end of the circuit and the frequency received at the other end should not exceed 2 Hz according to CCITT Recommendation G.225;
- d) that the maximum allowed frame slip performance of the digital interconnections depends on the network systems connected;
- e) that the hand-over operation of circular non-geostationary satellite systems will cause switching discontinuities due to the different propagation paths via the two satellites,

recommends

- 1. that differential Doppler shift correction is necessary for analogue telephony transmission via a non-geostationary satellite in the fixed-satellite service if the product(s) of the baseband (MHz) times the number of the revolutions per day of the satellite relative to the Earth exceeds 0.666;
- 2. that compensation for switching discontinuities is necessary for time differences greater than 20 ms for analogue telephony transmission and that therefore suitable variable time-delay devices should be implemented for such a compensation;
- 3. that elastic buffer stores should be applied for the differential Doppler-shift correction of digital satellite links on either the receive or transmit side, respectively, where the buffer dimension depends on the orbit parameters, the data rate and the maximum allowed frame slips;
- 4. that for the digital interconnection of national synchronous networks the buffer store should be dimensioned by considerations which allow for the complete removal of the transmission delay variations;
- 5. that the following Notes should be regarded as part of this Recommendation.

Note 1 – The transmission of data and telefax in an analogue telephone channel compensated according to § 1 and thus fulfilling the CCITT Recommendation G.225 requires no further provisions for the compensation of the differential Doppler shift.

Note 2 – Data transmission requiring wider bandwidth than a single telephone channel needs correction of the differential Doppler shift at a smaller value of s as in the case of § 1.

Note 3 – The transmission of analogue television signals in practical systems in the fixed-satellite service is not adversely effected by differential Doppler shift or switching discontinuities due to the propagation path difference and therefore does not require corrections.

Note 4 – For the transmission of data the occurrence of switching discontinuities may be subject to the system's error correction technique.

Note 5 – For the compensation of the differential Doppler shifts as mentioned in § 1, variable time-delay devices as for § 2 may be used. A common device used for both tasks may be applied.

Note 6 – *Recommends* 1 applies for non-geostationary circular satellite orbits only. Other kinds of non-geostationary orbits such as highly inclined elliptical orbits (e.g. MOLNIYA or TUNDRA) need further study to provide for the future use of these systems.

Note 7 – Switching discontinuities of 20 ms as considered in § 2 are expected to be non-critical for present telefax group 3 systems, and cause no unacceptable degradations. However, future Recommendations of the CCITT on the quality of service of telefax transmission may include dedicated information on maximum possible transmission interruptions which may then require further study.

Note 8 – The analysis on which the *recommends* are based, is contained in Annexes 1 and 2.

ANNEX 1

The effects of Doppler frequency-shifts and switching discontinuities in the fixed-satellite service

1. Doppler frequency-shifts (applicable to non-geostationary satellites)

The magnitude of the total Doppler frequency-shift between the terminals of a system in the fixed-satellite service depends upon the wavelengths used and the relative velocities of the satellite with respect to the earth stations. The major component of the effect of the Doppler shift, i.e. the shift of the carrier or a reference-frequency of the transmission, can be removed in the receiver; however, it may be necessary also to compensate for the differential shift across the radio-frequency spectrum of the signal that produces a frequency "stretch" or "shrinkage" of the baseband signal. Depending upon the relative locations of the earth stations and the orbit, the Doppler shifts between transmitting earth station and satellite and also between satellite and receiving earth station can either add or subtract. If 5 000 km is taken as a probable minimum orbital height for a communication satellite, then the "stretch" or "shrinkage" of the baseband signal will not exceed two parts in 10^5 . In most practical cases, the orbital height will be greater and the Doppler shift would be considerably less than this, and in the particular case of the geostationary satellite, there would be no significant Doppler shift.

The maximum value of the Doppler shift, resulting from transmission to, or from, a space station on a satellite in a circular orbit, can be estimated from the relationship:

$$\Delta F \approx \pm 1.54 \times 10^{-6} \times F \times s \quad (1)$$

where:

ΔF : Doppler frequency-shift

F : operating frequency

s : number of revolutions per day (24 hours) of the satellite with respect to a fixed point on the Earth.

This relationship may also be used for calculating the maximum differential Doppler frequency-shift over a frequency band. A few values of s for various circular equatorial orbit altitudes are provided below (Table 1) to facilitate the calculations for individual cases.

TABLE 1

Revolutions per day relative to the Earth, <i>s</i>	Altitude for circular equatorial orbits (km)	Period (h)
0	35 600	24
1	20 240	12
2	13 940	8
3	10 390	6
4	8 080	4.8
5	6 420	4
6	5 170	3.4
7	4 190	3

In a frequency-division multiple-access (FDMA) system, each participating station uses a portion of the frequency band of the satellite repeater. Since the transmissions from each station are independent in time, there is no adverse effect from any relative time-shift. There will, however, be a Doppler frequency-shift in the transmission from each station which varies with time.

For satellites employed to relay signals simultaneously from a number of earth stations, special consideration of Doppler shift may be necessary.

Table 2 shows the maximum possible Doppler frequency-shifts at the satellite at 6 GHz. The figures are based on equatorial orbits and assume that the satellite moves in the same direction as the surface of the Earth.

Because of various perturbing forces, the position of a geostationary satellite varies. If the satellite position is maintained within $\pm 0.1^\circ$ of longitude and latitude, the maximum relative velocity of a satellite with respect to an earth station is less than approximately 3.8 m/s, and the maximum Doppler frequency-shift will not exceed 76 Hz at 6 GHz.

To prevent interference between adjacent radio-frequency channels caused by Doppler frequency-shifts, guard bands can be used. Depending on the location of the stations, the signal transmitted by one station may be shifted upward, while that from a station on an adjacent channel may be shifted downward. Alternatively, the frequency-shifts may be corrected by available techniques.

For example, allowing a guard band equal to the maximum possible Doppler frequency-shift shown in Table 2 for a ten-channel system, the total guard bands would then be 18 times the figures shown (at 6 GHz).

TABLE 2

Maximum Doppler frequency-shift

Period (h)	6	8	12	24
Approximate altitude (km)	11 000	14 000	20 000	36 000
<i>Minimum elevation of antenna: 5°</i>				
Maximum Doppler frequency-shift at 6 GHz (kHz)	27.7	18.5	9.3	0.0

In the time-division multiple-access (TDMA) system, all earth stations transmit on the same nominal carrier frequency. This requires that the transmitter carrier be on only during that interval of the frame assigned to the station. During transmission, the carrier would probably be modulated by phase-shift keying or frequency-shift keying. Because of the Doppler frequency-shift, transmissions will arrive at the satellite and be repeated at frequencies which vary above and below the nominal carrier frequency. To accommodate this shift, the earth-station receivers must be capable of adjusting to the sudden changes in carrier-frequency which will occur. This may impose the requirement for increased interburst guard time and for more time within the burst to be allowed for carrier recovery and burst synchronization for satellites in a non-geostationary orbit.

1.1 Telephony

When frequency-division multiplex telephony is used, it is necessary to limit the bandwidth or the apparent geocentric angular velocity of the satellite to prevent unacceptable differential Doppler frequency-shifts (unless corrections are applied to compensate for the Doppler effects).

According to CCITT Recommendation G.225, the difference between an audio-frequency applied to one end of the circuit and the frequency received at the other end should not exceed 2 Hz. The question of error in reconstituted frequency is still under study in CCITT Study Group XV.

It may be noted that an error of 2 Hz is not exceeded in a single satellite link, if the product(s) of the baseband (MHz) times the number of revolutions per day of the satellite relative to the Earth does not exceed 0.666; however, additional error is likely to be introduced by the multiplex equipment.

Doppler effects will also shift the pilot frequencies used in FDM telephony for satellites with such angular velocities. Possible methods which could be used for correction of these shifts are:

- a suitable variable time-delay device;
- the carrier-frequencies used in the frequency-division multiplex equipment could be automatically controlled to compensate for the effects of Doppler shift and so reduce the overall frequency errors to acceptably small values.

The first of these methods has the advantage of effectively cancelling the errors resulting from the movement of the satellite, in a manner similar to that in which they are introduced (i.e. by change in transmission delay during the pass). This method would, therefore, also eliminate all the effects of Doppler shift on the baseband signals and by suitable arrangements, would avoid switching discontinuities when transferring the information flow from one satellite to the next in the orbital pattern. Control of the variable delay could be performed, either by using predicted orbit information or on a servo basis employing a pilot signal transmitted from the earth station to the satellite and back to the same earth station (loop method). The loop method has the following advantages:

- it would ensure that only the correct frequencies were received at the satellite. This facility could be of particular importance for certain systems, for example, those using closely-spaced channels or blocks of channels with single-sideband modulation in the Earth-to-satellite direction;
- Doppler frequency “stretch” might to some extent be obviated, e.g. by splitting the receiving bandwidth into appropriately separated portions and providing independent compensations for the blocks of circuits arriving from each of the other earth stations.