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Potential interference between the ICAO standard microwave landing system (MLS) operating above 5 030 MHz and radionavigation-satellite service (RNSS) systems in the band 5 000-5 030 MHz

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R M.2262

Potential interference between the ICAO standard microwave landing system (MLS) operating above 5 030 MHz and radionavigation-satellite service (RNSS) systems in the band 5 000-5 030 MHz

(Questions ITU-R 217-2/4 and ITU-R 288/4)

Summary

A number of administrations plan to develop RNSS systems in the 5 000-5 010 MHz and/or 5 010-5 030 MHz bands. In order to facilitate such plans, studies of potential interference were performed to determine the technical and/or operational RNSS system features required to protect the International Civil Aviation Organization (ICAO) standard microwave landing system (MLS) in the band 5 030-5 091 MHz from harmful interference, and also the separations needed to protect the RNSS systems from MLS transmissions. This Report documents the findings of the analysis on the compatibility of the GPS feeder links and GPS and Galileo service links with the MLS. The findings in this Report are based on ICAO Standards for the MLS, and RNSS parameters of systems that are currently under development. The analysis resulted in separation distances between RNSS and MLS sites that would preclude interference to each system from the other. This Report may need to be updated in the future as those systems mature.

1 Background

In addition to addressing the RNSS system features that would be required to ensure continued safe operation of the MLS, the impact of MLS out-of-band (OoB) emissions into the RNSS band were studied to determine the impact on RNSS systems and networks. The study also considered the effect of MLS in-band emissions on RNSS receivers that have selectivity that overlaps the MLS band. RNSS receivers also share the bands 5 000-5 010 MHz and 5 010-5 030 MHz with other primary systems and proposed primary systems:

– In the 5 000-5 010 MHz band, the RNSS feeder uplink shares this band on a primary basis with ARNS and AMS(R)S. Recommendation ITU-R M.1906 recommends that the allowance for total aggregate interference to RNSS receivers operating in this band from other (i.e. non-RNSS) primary in-band services should not exceed 6% of the RNSS receiver noise. Since there are two primary services besides RNSS in this band, the allowance for aggregate interference to RNSS systems from any one of the two other primary services is assumed to not exceed 3% of the RNSS receiver system noise (i.e. an equal apportionment among services is assumed).

– In the 5 010-5 030 MHz band, the RNSS feeder downlink and service link share this band on a primary basis with ARNS and AMS(R)S. The characteristics as well as the protection criteria for the RNSS receiving earth stations are given in Tables 2-1 and 2-2.

2 RNSS characteristics

For this study, the RNSS characteristics used were for the Global Positioning System (GPS) and Galileo systems as reported in Recommendation ITU-R M.1906. The characteristics as well as the protection criteria for the RNSS receiving earth stations are given in Tables 2-1 and 2-2.

Table 2-1 provides protection criteria for Galileo receiving earth stations operating in the band 5 010-5 030 MHz. Table 2-2 provides the assumed link budget and signal characteristics for a GPS feeder downlink, service downlink, and feeder uplink.

TABLE 2-1

Protection criteria for Galileo receiving earth stations operating in the band 5 010-5 030 MHz

Parameter (units)	RNSS parameter description
Signal frequency range (MHz)	5 010-5 030
Maximum receiver antenna gain (dBi)	4
RF filter 3 dB bandwidth (MHz)	20
Pre-correlation filter 3 dB bandwidth (MHz)	20
Receiver system noise temperature (K)	530
Tracking mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	–157.1
Acquisition mode threshold power level of aggregate narrow-band interference at the passive antenna output (dBW)	–160.1
Tracking mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–147.1
Acquisition mode threshold power density level of aggregate wideband interference at the passive antenna output (dB(W/MHz))	–150.1

TABLE 2-2

GPS parameters

Characteristics	Feeder downlink	Service downlink	Feeder uplink
TRANSMIT			
Carrier frequency (assumed) (MHz)	5 013.63	5 019.861	5 000.605
Transmit power (dBW)	7.00	13.50	20.00
Antenna gain (dBi)	27.60 (0.75 m centre-fed circular parabolic dish, 4.0 dB efficiency loss; 0.31 dB polarization mismatch loss; RHCP)	13.20	46.61 (5.00 m centre-fed circular parabolic dish, 1.5 dB efficiency loss; 0.26 dB polarization mismatch loss; RHCP)
e.i.r.p. (dBW)	34.60	26.70	66.61
Path loss (dB) (20 200 km SV altitude)	–194.50 (at 5° elevation)	–194.32 (at 10° elevation)	–194.47 (at 5° elevation)
Propagation losses (dB)	–5	–5	–5
Other signal losses (dB)	0	–2	0
Total loss (dB)	–199.50	–201.32	–199.47
Transmit filter rejection at 5 031 MHz (dB)	0 (Note 1)/–60/ –80	–9.7	0 (Note 1)/–60/ –80

TABLE 2-2 (*end*)

Characteristics	Feeder downlink	Service downlink	Feeder uplink
RECEIVE			
Received isotropic power (dBW)	–164.90	–174.62	–132.87
Total pointing loss, Tx+Rx (dB)	0.9 (0.1 Tx + 0.8 Rx)		0.9 (0.8 Tx + 0.1 Rx)
Antenna gain (dBi)	46.63 (5.00 m centre-fed circular parabolic dish; 1.5 dB efficiency loss; 0.26 dB polarization mismatch loss; RHCP)	3.0 (all angles for handhelds; 0.03 antenna diameter; 1.0 dB efficiency and polarization mismatch loss; RHCP)	13.60 (0.150 m centre-fed circular parabolic dish, 4.0 dB efficiency loss; 0.31 polarization mismatch loss; RHCP)
Received power C (dBW)	–119.18	–171.62	–120.17
Receiver noise density (dBW/Hz)	–207.14 (G/T = 25.17 dB/K)	–201.61 (G/T = –23.99 dB/K)	–200. 89 (G/T= –14.14 dB/K)
Received C/N_0 (dB-Hz)	87.96	N/A	N/A
Required E_b/N_0 (dB-Hz) (includes receiver implementation losses and channel coding gains)	9.00	N/A	N/A
Required C/N_0 (dB-Hz)	77.20 (6.6 Mbit/s data)	N/A	N/A
C/N_0 margin (dB)	10.77	N/A	N/A
Receiver RF filter 3 dB bandwidth (Note 2) (MHz)	6.6	20.0	1.1
Receiver pre-correlation 3 dB bandwidth (Note 3) (MHz)	6.6	20 and 18	1.1
Receiver pre-correlation filter OoB roll-off (Note 4) (–70 dB max) (dB/MHz)	–6 to –10	–6 to –10	–6 to –10

NOTE 1 – Every 5 GHz GPS transmitter will include filtering. The 0 dB filter case is included here to show the importance of the use of transmit filtering to reduce the interference, allowing smaller separation distance between systems operating in the adjacent frequency bands.

NOTE 2 – Receiver RF filter 3 dB bandwidth is the bandwidth between the 3 dB down points of the receiver's front-end RF bandpass filter.

NOTE 3 – Receiver pre-correlation 3 dB bandwidth is the bandwidth between the 3 dB down points of the receiver's IF bandpass filter (just prior to the correlator). For currently fielded RNSS receivers, the receiver pre-correlation 3 dB bandwidth varies. For this reason, both 20 MHz and 18 MHz values are considered.

NOTE 4 – Receiver pre-correlation filter out-of-band (OoB) roll-off includes the combined effect of the RF and IF receiver filter stages. For currently fielded RNSS service links, achievable receiver OoB rejection ranges from –4 to –6 dB/MHz.

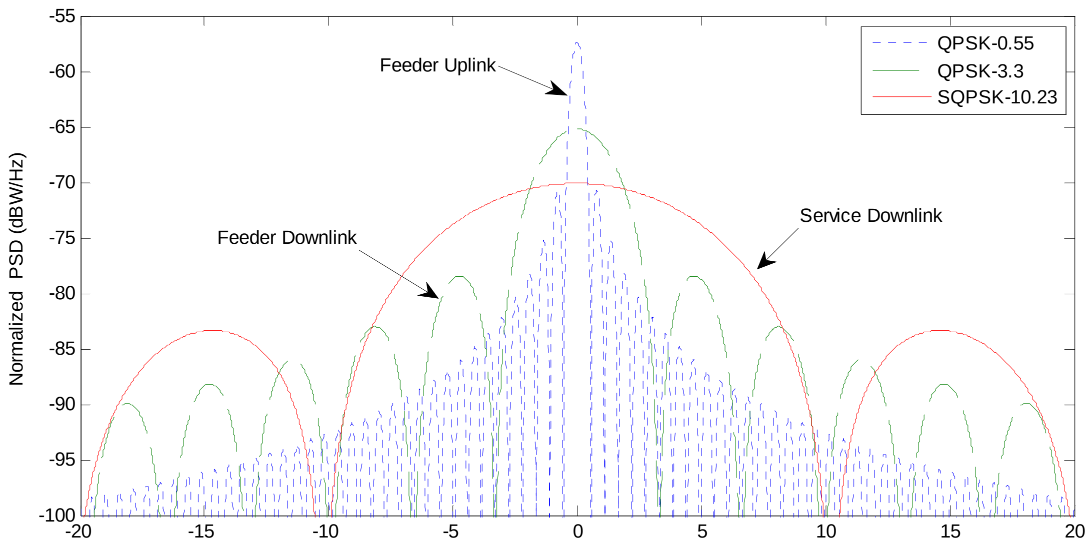
We assume that the RNSS transmit signals' power spectral densities are consistent with those using rectangular pulse modulations. The expression of the unfiltered power spectral density (psd) normalized to 1 W over infinite bandwidth is given by:

$$S(f) = \frac{1}{f_c}\left(\frac{\sin\left(\frac{\pi f}{f_c}\right)}{\frac{\pi f}{f_c}}\right)^2$$

where f_c is the pulse modulation rate. It is equal to the per channel data rate for the RNSS feeder links ($f_c = 0.55$ MHz for feeder uplink and 3.3 MHz for feeder downlink) and the PRN chip-rate of the RNSS service downlink ($f_c = 10.23$ MHz). The unfiltered baseband normalized power spectral densities, given by the equation above, for the feeder uplink signal, the feeder downlink signal, and the service downlink signal are plotted in Fig. 2-1.

FIGURE 2-1

Normalized RNSS links – Baseband power spectral densities



Frequency (MHz)

The off-boresight antenna gain pattern of a parabolic dish antenna is given as:

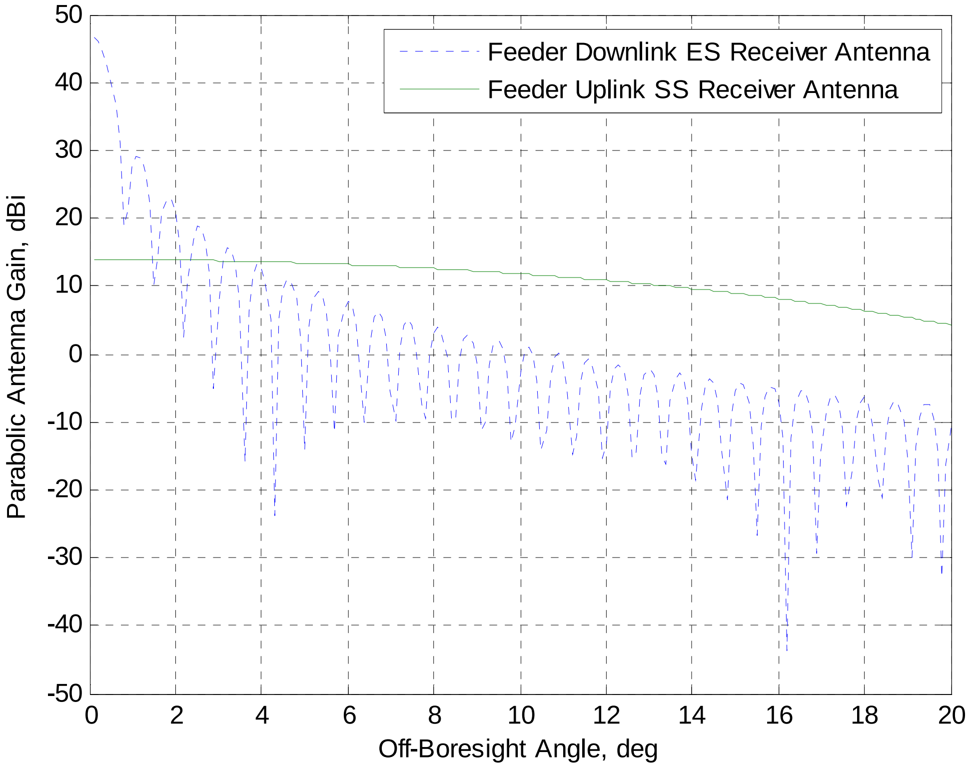
$$G(\theta) = G_{\max}\left[\frac{2J_1\left(\pi\frac{D}{\lambda}sin\theta\right)}{\pi\frac{D}{\lambda}sin\theta}\right]^2$$

where J_1 = first-order Bessel function of the first kind, D = antenna diameter in metres, λ = wavelength at the carrier frequency in metrer, θ = off-boresight angle, G_{max} = $\eta(\pi D/\lambda)^2$ = antenna peak gain, and η = antenna efficiency.

The gain patterns of a feeder downlink earth station (ES) receiver antenna and a feeder uplink space station (SS) receiver antenna are shown in Fig. 2-2.

FIGURE 2-2

Off-boresight antenna patterns for RNSS feeder links



3 MLS characteristics

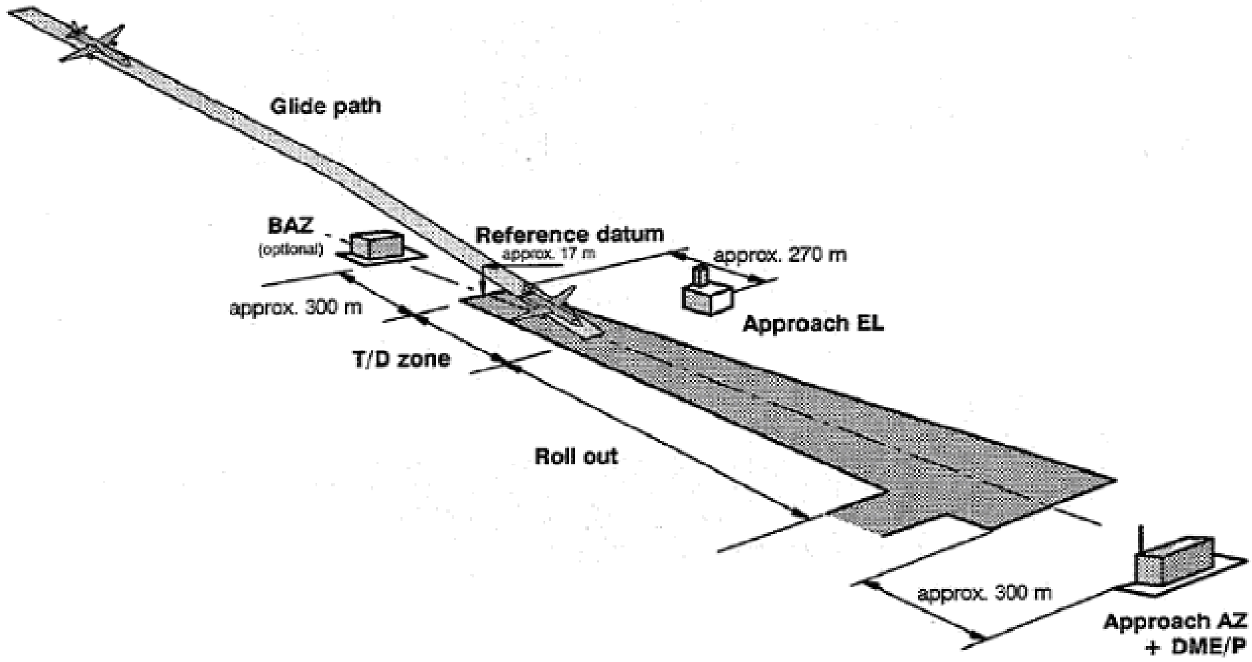
MLS is standardized by ICAO, Standards and Recommended Practices (SARPs) for MLS (MLS SARPs) defining the characteristics of the system in Volume 1 of Annex 10 to the Convention on International Civil Aviation (denoted hereafter as “ICAO Annex 10”).

3.1 MLS ground system components and signals

The minimal configuration of an MLS ground system typically consists of separate approach azimuth and elevation transmitters, one for each direction of use of an airport runway, each with its own antenna, as shown in Fig. 3-1. Back azimuth, a number of OCI (out-of-coverage indication) signals and flare (not shown) may be provided optionally.

FIGURE 3-1

MLS system arrangement in azimuth and elevation facilities



All MLS signals generated by MLS ground-components are transmitted on the same MLS-frequency channel in a specified time division multiplex mode. The sequence of transmission is shown in Fig. 3-2.

Azimuth and elevation signals provide coverage within an azimuth of +40° to −40° TRD (true runway direction) (+60° to –60° for low rate azimuth) and an elevation of 0.9° to 15°. The transmission of azimuth, back azimuth (if installed, denoted BAZ in Fig. 3-2) and elevation signals is preceded by the transmission of a preamble, a combination of continuous wave (CW) followed by DPSK (differential phase shift keying) modulations. It is then followed by a CW signal that is scanned once to and from, between +40° and −40° TRD for the azimuth signal and between 0.9° and 15° for the elevation signal. In addition there are out-of-coverage indications transmitted as CW outside the azimuth, elevation, and back azimuth coverage. These signals are seen by a receiver as CW pulses. The antenna used for these OCI transmissions can also radiate DPSK data signals with 360° azimuthal coverage for applications other than approach and landing aids, such as RNAV (area navigation) and 5 GHz data link. However, no ICAO contracting State is known to be planning implementation of such DPSK data transmission via the OCI antennas.

There are two types of OCI antennas: wide beam and high gain OCI antennas. The high gain OCI antenna is used to suppress strong multi-path occurrences outside the proportional guidance sector. This scenario can occur if specular reflection occurs very close to the MLS ground stations. The high gain OCI antenna is not used to transmit DPSK data over 360° azimuth coverage.

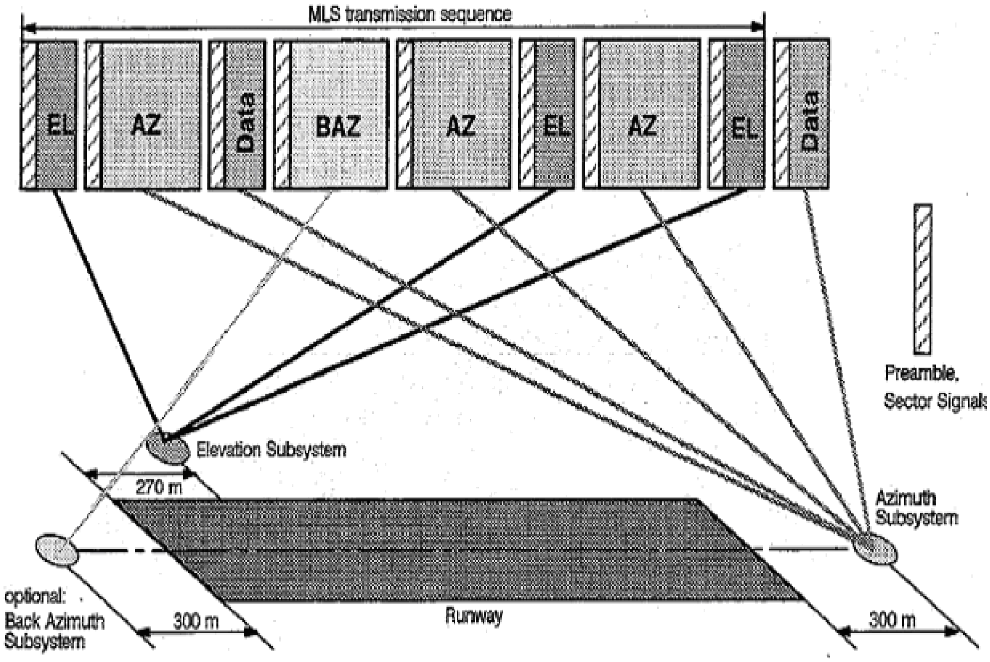
The wide-beam OCI antennas are used to suppress moderate multi-path occurrences outside the proportional guidance sector. This is the more common multi-path scenario.

The wide-beam OCI antennas may also be used to transmit DPSK data words in order to achieve 360° data coverage. However, the e.i.r.p. achieved with these antennas when used simultaneously is smaller than that achieved with the dedicated DPSK antenna that has a horizontal beam width of 120° because the same RF amplifier is used to feed the antennas.

OCI pulses consist only of CW with a level at the maximum 4 dB higher than the scanning beam signals. The duration of the OCI pulses is about 200 microseconds with a repetition rate of 100 per second. These CW pulses can occur anywhere outside the proportional guidance coverage.

FIGURE 3-2

Elements and structure of the MLS-information sequence

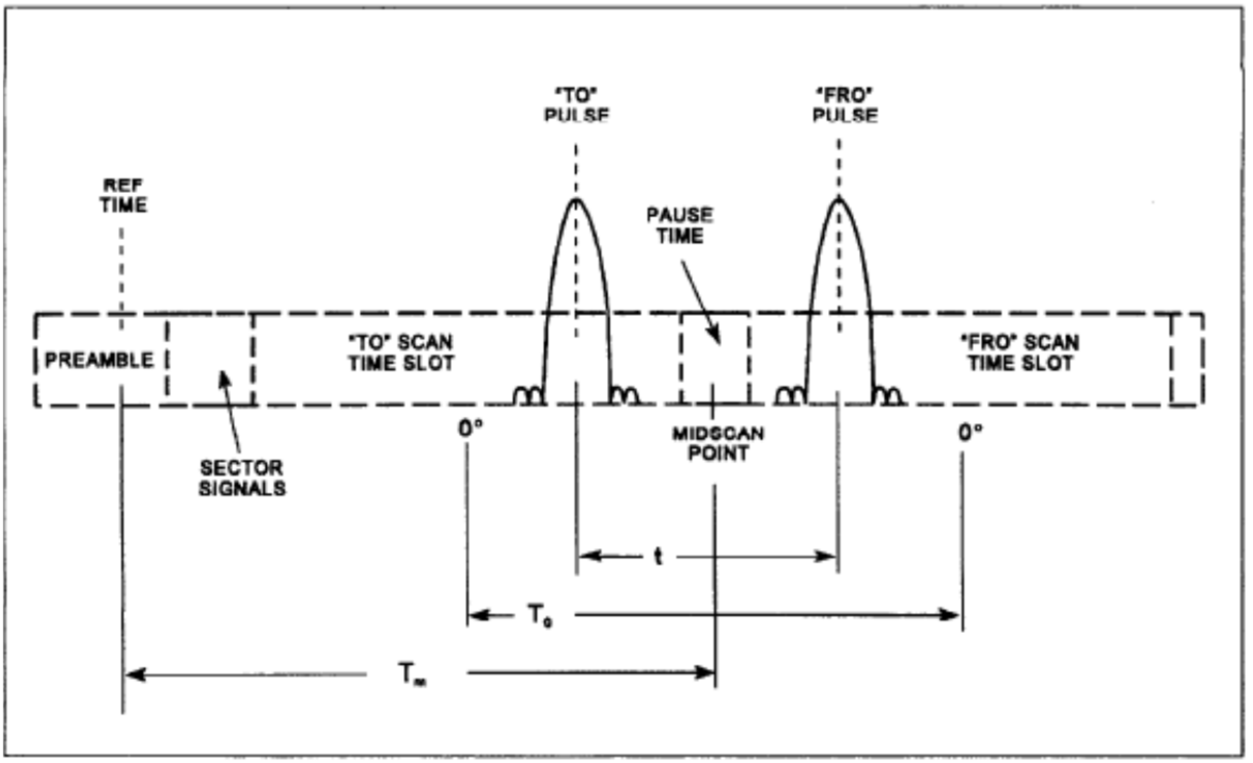


NOTE – The preamble "info" (depicted as the {narrow, striped} time-slots) is transmitted using a combination of CW followed by DPSK modulations prior to both azimuth and elevation angle CW signals, alternatively by both the azimuth, back azimuth, and elevation transmitting stations, or prior to the data transmissions alternately by both the azimuth and the back azimuth transmitting stations.

Figure 3-3 shown below, extracted from ICAO Annex 10, Vol. 1, § 3.11, illustrates the CW angle scanning taking place after data DPSK transmission in a typical MLS sequence. More details on MLS implementation are available in Attachment G to ICAO Annex 10, Vol. 1. MLS operates with a 300 kHz channel spacing with each MLS channel paired with other ICAO navigation aids, i.e. ILS/VOR and DME as defined in the Table A of ICAO Annex 10, § 3.11. Therein the first and closest channel to the band 5 010-5 030 MHz is indicated as centred on 5 031 MHz.

FIGURE 3-3

Angle scan timing parameters



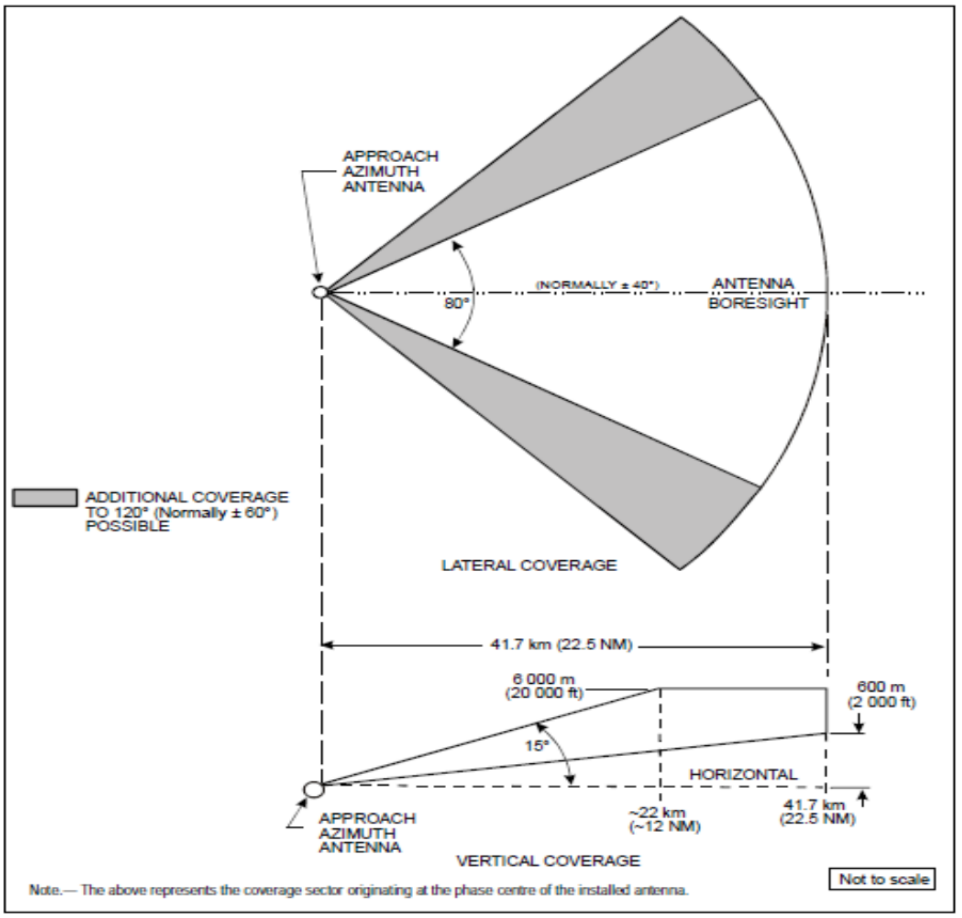
Angle guidance (azimuth, elevation and flare) and data information, serving a particular runway, are transmitted by TDM on a single radio-frequency channel and are time-synchronized to assure interference-free operations on a common channel. The preamble codes, basic data, and auxiliary data are transmitted by differential phase shift keying (DPSK) modulation.

Approach azimuth guidance information is summarized below:

– Each CW transmission of a guidance angle consists of a clockwise TO-scan, followed by a counter-clockwise FRO-scan as viewed from above the antenna.
– Carrier acquisition: the preamble begins with a period of CW transmission.
– Scanning beam shape: a fan-shaped beam which is narrow ($\leq 4^{o}$) in the horizontal plane, broad in the vertical plane, and scans horizontally between the limits of the proportional guidance sector. The minus 10 dB points on the beam envelope are displaced from the beam centre by at least 0.76 beamwidth, but not more than 0.96 beamwidth, as modelled in Fig. 3-7.
– Angle scanning rate of 50 µs/deg.
– Approach azimuth region coverage, as shown in Fig. 3-4 (Fig. G-5A of Attachment G, ICAO Annex 10, Volume 1), with a 0.825° lower elevation angle.

FIGURE 3-4

Approach azimuth region coverage



Approach elevation guidance information is summarized below:

− Each CW transmission of a guidance angle consists of a TO-scan in the direction of increasing angle values, followed by a FRO-scan in the direction of decreasing angle values. Zero-elevation angle coincides with a horizontal plane through the antenna phase centre.

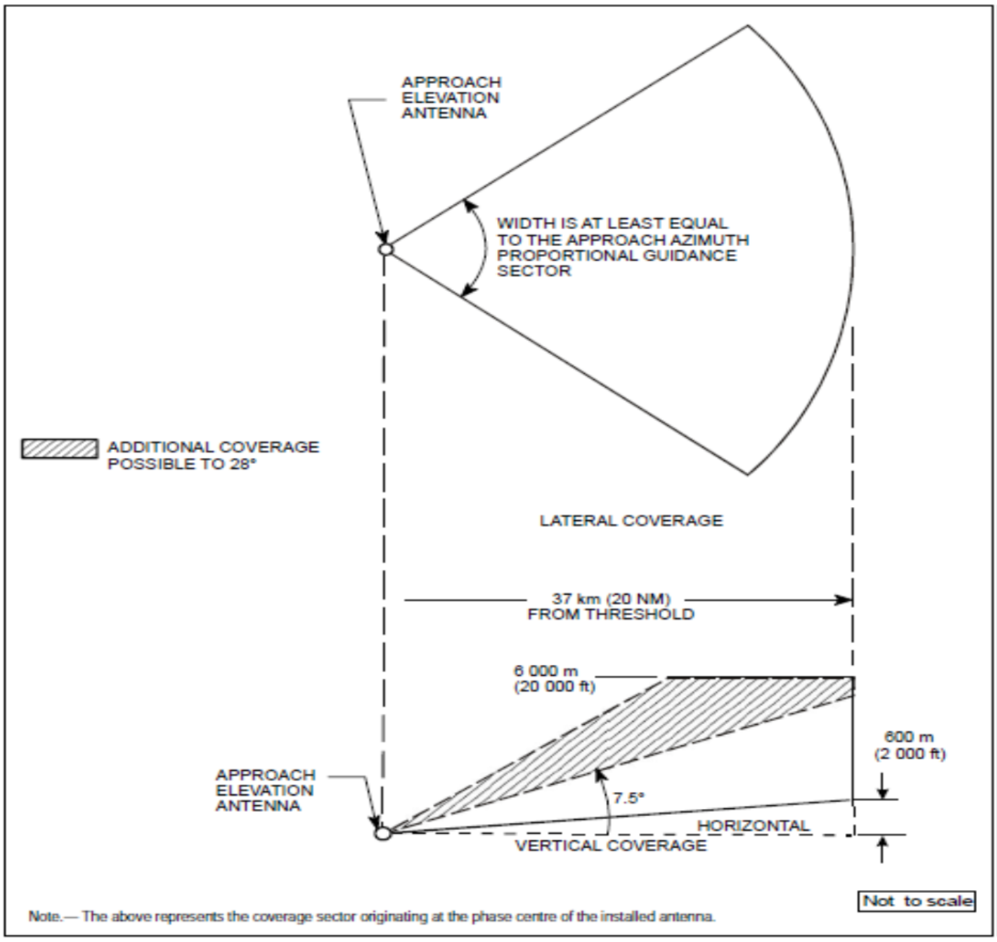
− Carrier acquisition: the preamble begins with a period of CW transmission − Scanning beam shape: a fan-shaped beam which is narrow ($\leq 2.5^{o}$) in the vertical plane, broad in the horizontal plane, and scans vertically between the limits of the proportional guidance sector. The minus 10 dB points on the beam envelope are displaced from the beam centre by at least 0.76 beamwidth, but not more than 0.96 beamwidth, as modelled in Fig. 3-7.

− Angle scanning rate of 50 µs/deg.

− Approach elevation region coverage, as shown in Fig. 3-5 (Fig. G-10A of Attachment G, ICAO Annex 10, Volume 1), with a 0.93° lower elevation angle.

FIGURE 3-5

Approach elevation region coverage



3.2 MLS essential characteristics pertaining to its unwanted emissions in the band 5 010-5 030 MHz

MLS receiver operation in the band 5 030-5 091 MHz, as well as actual transmit spectra measurements, have shown that CW transmissions used for both angle scans and OCI functions do not interfere with the DPSK data and angle scan signals received on an adjacent MLS channel. Accordingly, only DPSK signal transmissions account for out-of-band emissions likely to interfere with desired MLS channels in the band 5 030-5 091 MHz and beyond, and with non-aviation systems in adjacent bands, such as the 5 000-5 030 MHz addressed by this report. However, for the interference assessment between the MLS and the planned and operating RNSS systems in the band 5 000-5 030 MHz, the effects of both the MLS CW signal and the MLS DPSK signal will be used to do the interference assessment since these MLS signals can come through the skirts of the RNSS receiver filters, as no practical filter can perfectly reject 100% of the adjacent band energy.

Furthermore, measured spectra on operating facilities have shown that:

a) MLS unwanted emissions are mainly due to out-of-band emissions with no noticeable spurious emissions (parasitic emissions, intermodulation and frequency conversion products);

b) the MLS data modulation at the data rate f_d = 15 625 baud results in a DPSK data transmitted power spectral density (psd) which closely fits that of the theoretical model of the psd of a DPSK modulated signal of power P:

$$psd(f) = \frac{P}{f_d} \cdot \left[\frac{\sin\left(\pi \cdot \frac{f}{f_d}\right)}{\pi \cdot \frac{f}{f_d}} \right]^2$$

The power level of out-of-band emissions falling into the bandwidth, *Bw*, relative to the considered channel transmit level, can then be modelled as a spectrum attenuation in dBc equal to $10\log\left(\frac{1}{2\pi^2}\frac{f_d \cdot Bw}{f^2}\right) + 0.5$ (dB), with f, equal to the frequency offset from the centre frequency of the considered MLS channel, as long as *Bw* is much greater than f_d. *Bw* is taken to be either 150 kHz, representing a worst-case MLS receiver bandwidth, or 1 MHz (the usual reference bandwidth for transmit spectrum attenuation values in the 5 GHz spectrum region).

The MLS DPSK data signals are radiated via low gain, broad beam antenna patterns of the azimuth and elevation facilities, since they are designed to cover the MLS ±62° required coverage in azimuth and 0° to 15° in elevation. They are transmitted with a peak antenna gain of approximately 8 dBi within the signals' respective required coverage volumes. Figure 3-6 below illustrates the vertical pattern requirement for the azimuth scan and DPSK data functions, within the MLS required coverage volumes, which shows that in a worst case situation this pattern is reduced by only 6 dB with respect to the peak gain.

FIGURE 3-6

Azimuth antenna vertical pattern at boresight

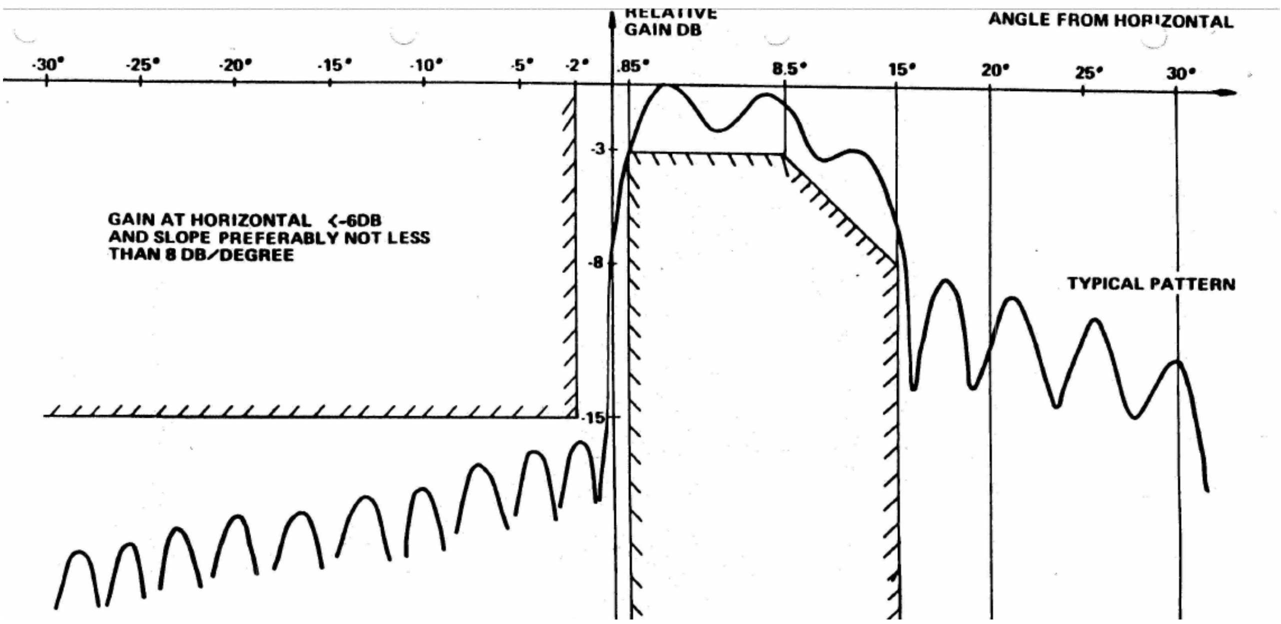


Table 3-1 lists the MLS essential characteristics relevant to the unwanted emissions assessment in the adjacent band 5 010-5 030 MHz, starting with the band edge frequency 5 030 MHz, assuming an MLS channel assignment at 5 031 MHz. The theoretical analyses below assume that DPSK data is transmitted via the dedicated DPSK pattern of the azimuth and elevation scanning antennas.

TABLE 3-1

MLS essential characteristics relevant to unwanted emissions assessment

Item/MLS transmission	Unit	DPSK data	Az. and El. scans and OCI	Comments
MLS transmit power	dBm	43	43	
MLS transmit antenna gain		2 to 8 dB in coverage, 0 dBi outside	Narrow beamwidth, high gain (Az and El) Wide beam (OCI) Note 8	Note 1
Modulation		DPSK	CW	
Longest continuous DPSK data sequence	ms	9.3-15	N/A	Note 2
Polarization		Vertical	Vertical	
Spectrum attenuation variation with freq. Offset "f"		Proportional to f^2	N/A	Note 3
Spectrum attenuation variation with bandwidth BW		Inversely proportional to BW	N/A	Note 3
Duty cycle		25%	N/A	Note 4
a): Max. unwanted emissions pfd in 150 kHz at 840 kHz offset	dBW/m²	−94.5	N/A	Note 5
b): Additional attenuation at 1 MHz offset	dB	1.5	N/A	Note 6
c): Increase due to change of reference Bw from 150 kHz to 1 MHz	dB	8.2	N/A	Self-explanatory
d): MLS DPSK antenna gain drop at 0° elevation within Az and El required coverage volume	dB	6.0	N/A	Min. 6 dB gain drop per Fig. 3-4
e): Max. unwanted emissions pfd at 5 030 MHz within Az and El required coverage volume	dBW/($m^2 \cdot$ MHz)	−93.8	N/A	e = a − b + c − d; at ground level and 2.32 km away
Max. unwanted emissions pfd at 5 030 MHz outside MLS required Az and El coverages	dBW/($m^2 \cdot$ MHz)	−95.8	N/A	Note 7

NOTE 1 – The 2 to 8 dBi pattern applies within the required MLS coverages of ±62° in azimuth and 0° to 15° in elevation for DPSK data and CW OCI signals; 0 dBi is assumed outside these coverages. As for the angle scans functions, using the narrow beam patterns on both azimuth and elevation transmit facilities, the minimum antenna gains vary from 18 to 23 dBi at specified half-beamwidths ranging from 3° to 1°.

NOTE 2 – 9.3 ms corresponds to 3 basic MLS words, 15 ms is the worst case associated with 1 basic + 2 auxiliary words transmission. In absence of MLS data word, the longest sequence is 1.8 ms for data preamble associated with angle scan functions, azimuth and elevations.

NOTE 3 – Attenuation is modelled as (f_d.Bw/$2\pi^2 f^2$), with f_d = 15 625 Hz.

Notes to Table 3-1 (end)

NOTE 4 – A typical MLS frame time duration as shown in Fig. 3-2 is about 615 ms. The total duration of DPSK transmissions within that frame is 153.5 ms. This results in a duty cycle of (153.5/615) × 100% = 24.9%. In the remainder of the time, there are successively quiescent periods followed by CW transmissions on either the high gain scanning antenna or the low gain patterns for OCI.

NOTE 5 – This is an MLS SARPs-specified limit to be met under either one of two conditions, as referenced in § 3.11.4.1.4 "*Radio frequency signal spectrum*":

i. at a height of 600 metres above the ground station (i.e. at an elevation of 15 degrees) corresponding to a minimum slant distance of 2.320 km and DPSK highest antenna gain of 8 dBi;

ii. on ground at a minimum distance of 4.8 km within MLS required coverage.

NOTE 6 – In order to reach the adjacent channel band edge at 5 030 MHz from the MLS first channel assignment (i.e. 5 031 MHz), the lowest assignable frequency as defined in Table A of the MLS SARPS.

NOTE 7 – Outside the azimuth and elevation required coverage areas the unwanted emission power flux-density (pfd) is 2 dB lower on account of the antenna pattern dropping another 2 dB, in line with the 0 dBi antenna pattern assumption (due to an 8 dB drop versus 6 dB).

NOTE 8 – Two or three OCI wide beam antennas would be used to cover up to 270 degrees azimuth.

3.3 Recent MLS developments

– In 2005, MLS SARPS were updated (Amendment 81), as a result of developing and achieving certification for airborne equipment with CAT II/III approach and landing capabilities.

– More recently, at the end of 2006 and in order to support preparation for ITU WRC-07 on the specific Agenda items 1.5 and 1.6 affecting the 5 GHz ARNS band, ICAO requested the European states to verify and confirm their requirements for MLS. This resulted in the identification of 433 requirements, for which frequency planning needs to be done. This number is down considerably on the 800 requirements originally identified in the ICAO ILS/MLS transition plan established at the end of the 1980s. These are intended for use at major airports, open to civil aviation. There are other government usages which have not been accounted for in that number.

– In March 2009, a significant MLS development milestone was achieved with airworthiness authorities in Europe granting certification and operations approval for CAT II/III MLS operations at the London/Heathrow airport in UK. And this for the use under routine commercial conditions of certified air-transport aircraft of the Airbus A320 family, suitably equipped with MLS airborne multi-mode receiver capable of ILS and MLS operations.

– One airline has recently made public a plan to equip 90 aircraft for operations in Europe in the next few years.

3.4 Details on MLS system and signal-in-space for interference analysis

MLS has 200 channels, 300 kHz channel separation and is operated in the 5 031-5 090.7 MHz frequency band. The MLS signal is based on time-division multiplex (TDM), where each angle function and data function are transmitted in sequence, all on the same radio frequency with vertical polarization. Table 3-2 lists the detailed timing and emission type information for the following MLS angle and data functions: approach azimuth, high rate approach azimuth, back azimuth, approach elevation, flare elevation, basic data, and auxiliary data.

TABLE 3-2

MLS angle and data functions – Timing and emission type

Approach azimuth timing (in µs) – 15.9 ms (1.216 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • Morse code + antenna select: 1 600-2 048 (DPSK) • OCI: 2 048-2 432 (CW) • TO AZ test: 2 432-2 560 (SCW) • TO AZ scan: 2 560-8 760 (SCW) • *Pause: 8 760-9 060 (X)* • *Mid-scan point: 9 060-9 360 (X)* • FRO AZ scan: 9 360-15 560 (SCW) • FRO AZ test: 15 560-15 688 (SCW) • End time: 15 688-15 900 (X)	**High rate approach azimuth and back azimuth timing** (in µs) – 11.9 ms (1.216 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • Morse code + antenna select: 1 600-2 048 (DPSK) • OCI: 2 048-2 432 (CW) • TO AZ test: 2 432-2 560 (SCW) • TO AZ scan: 2 560-6 760 (SCW) • *Pause: 6 760-7 060 (X)* • *Mid-scan point: 7 060-7 360 (X)* • FRO AZ scan: 7 360-11 560 (SCW) • FRO AZ test: 11 560-11 688 (SCW) • End time: 11 688-11 900 (X)
Approach elevation timing (in µs) – 5.6 ms (0.768 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • *Processor pause: 1 600-1 728 (X)* • OCI: 1 728-1 856 (CW) • TO EL scan: 1 856-3 406 (SCW) • *Pause: 3 406-3 606 (X)* • *Mid-scan point: 3 606-3 806 (X)* • FRO EL scan: 3 806-5 356 (SCW) • End time: 5 356-5 600 (X)	**Flare elevation timing** (in µs) – 5.3 ms (0.768 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • *Processor pause: 1 600-1 856 (X)* • TO scan: 1 856-3 056 (SCW) • *Pause: 3 056-3 456 (X)* • *Mid-scan point: 3 456-3 856 (X)* • FRO scan: 3 856-5 056 (SCW) • End time: 5 056-5 300 (X)
Basic data timing (in µs) – 3.1 ms (2.048 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • Data and parity: 1 600-2 880 (DPSK) • End time: 2 880-3 100 (X)	**Auxiliary data timing** (in µs) – 5.9 ms (4.864 ms DPSK) • Carrier acquisition: 0-832 (CW) • Preamble data: 832-1 600 (DPSK) • Data, address and parity: 1 600-5 696 (DPSK) • End time: 5 696-5 900 (X)

NOTES:

- CW – Tone interference emission from a fixed data antenna.
- DPSK – Data word RF emission from a fixed data antenna.
- SCW – Tone interference emission from scanning antenna (approach azimuth, high-rate approach azimuth, approach elevation, flare).
- X – No emission.
- Azimuth or back azimuth scanning beam can be up to 4 degrees at –3 dB. The beam can be as wide as 7.68 degrees at –10 dB per MLS specs (2×0.96×4). The beam can be as wide as 10 degrees (2×1.25×4) at –40 dB down. Hence, the exposed time to the scanning beam can be as long as 500 µs (50 µs/deg scan rate) per TO-scan or FRO-scan.
- Elevation scanning beam can be up to 2.5 degrees at –3 dB. The beam can be as wide as 4.8 degrees at –10 dB per MLS specs (2×0.96×2.5). The beam can be as wide as 6.25 degrees (2×1.25×2.5) at –40 dB down. Hence, the exposed time to the scanning beam can be as long as 312 µs (50 µs/deg scan rate) per TO-scan or FRO-scan.

Notes to Table 3-2 (end):

- Flare scanning beam can be up to 2.5 degrees at –3 dB. The beam can be as wide as 4.8 degrees at –10 dB per MLS specs (2×0.96×2.5). The beam can be as wide as 6.25 degrees (2×1.25×2.5) at –40 dB down. Hence, the exposed time to the scanning beam can be as long as 625 µs (100 µs/deg scan rate) per TO-scan or FRO-scan.

A format of a complete MLS multiplex transmission cycle of 615 ms, for all MLS angle guidance functions, shown in Table 3-3, includes the orders of sequences 1 (S1s), sequences 2 (S2s), and open time periods for data words. Table 3-3 also shows the time-slot orders of angle and data functions for MLS transmission sequence 1 (S1) and MLS transmission sequence (S2).

TABLE 3-3

MLS complete multiplex transmission cycle for all MLS angle guidance functions

Transmission sequence #1 (S1) (in ms): 66.7 ms • Approach elevation: 5.6 ms (0.768 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK) • Approach azimuth: 15.9 ms (1.216 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK) • Basic data word: 3.1 ms (2.048 ms DPSK) • Back azimuth: 11.9 ms (1.216 ms DPSK) • Basic data word: 3.1 ms (2.048 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK) **Transmission sequence #2 (S2)** (in ms): 66.8 ms • Approach elevation: 5.6 ms (0.768 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK) • Approach azimuth: 15.9 ms (1.216 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK) • Growth: 18.2 ms (2 aux + 1 basic, 11.776 ms DPSK max) • Approach elevation: 5.6 ms (0.768 ms DPSK) • Flare: 5.3 ms (0.768 ms DPSK)	**Complete multiplex transmission cycle**: 615 ms • S1 • 1 ms (no data word) • S2 • 13 ms (2 data words – 1 basic + 1 aux or 2 basic or 2 aux) • S1 • 19 ms (3 data words – 1 basic + 2 aux, max) • S2 • 2 ms (no data word) • S1 • 20 ms (3 data words – 1 basic + 2 aux, max) • S2 • 6 ms (1 data word – 1 basic or 1 auxiliary word) • S1 • S2 • 18 ms (3 data words – 1 basic + 2 aux, max)

A format of a complete MLS multiplex transmission cycle of 615 ms, for MLS high rate angle guidance functions, shown in Table 3-4, includes the orders of sequences 1 (S1s), sequences 2 (S2s), and open time periods for data words. Table 3-4 also shows the time-slot orders of angle and data functions for MLS high rate transmission sequence 1 (S1) and MLS high rate transmission sequence (S2).

TABLE 3-4

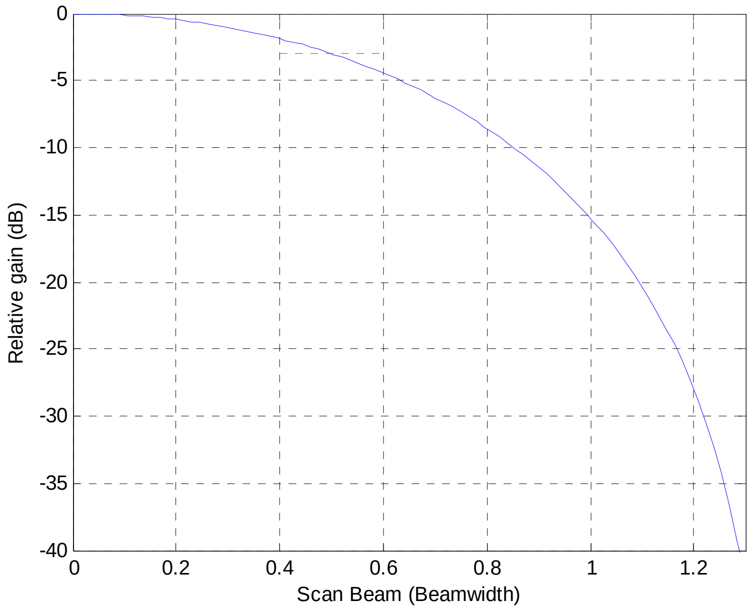
MLS complete multiplex transmission cycle for MLS high rate angle guidance functions

Transmission sequence #1 (S1) (in ms): 64.9 ms • Approach elevation: 5.6 ms (0.768 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Data word: 12.4 ms (8.192 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK)	**Complete multiplex transmission cycle**: 615 ms • S1 • 1 ms (no data word) • S2 • 13 ms (2 data words – 1 basic + 1 aux or 2 basic or 2 aux) • S1 • 19 ms (3 data words – 1 basic + 2 aux, max) • S2 • 2 ms (no data word) • S1 • 20 ms (3 data words – 1 basic + 2 aux, max) • S2 • 6 ms (1 data word – 1 basic or 1 auxiliary word) • S1 • S2 • 18 ms (3 data words – 1 basic + 2 aux, max)
Transmission sequence #2 (S2) (in ms): 67.5 ms • Approach elevation: 5.6 ms (0.768 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Basic data word 2: 3.1 ms (2.048 ms DPSK) • Back azimuth: 11.9 ms (1.216 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK) • High rate approach azimuth: 11.9 ms (1.216 ms DPSK) • Approach elevation: 5.6 ms (0.768 ms DPSK)	

A scanning beam shape model to meet MLS specifications of 3 dB down at 0.5 beamwidth and 10 dB down at 0.86 beamwidth (midpoint between 0.76 and 0.96, specs), is as shown in Fig. 3-7. Azimuth scan beamwidth varies from 0.5° to 4°. Elevation scan beamwidth varies from 0.5° to 2.5°.

FIGURE 3-7

Modelled scanning beam shape



Based on a complete MLS multiplex transmission cycle (615 ms) overlaid by a 10 ms RNSS symbol duration, MLS interference must be computed for all possible combinations of signal overlaps. An example MLS multiplex transmission waveform as seen by an RNSS receiver in an MLS coverage zone is shown in Fig. 3-8. In this figure the product of transmit power (P_t) and transmit antenna gain (G_t) is plotted as a function of time for the first 140 ms. The highest peaks are the times when the scanning beams sweep by the RNSS receiver, while other peaks belong to DPSK, OCI, and other transmissions.

The effective MLS signal duty cycle is easily computed and is shown in Fig. 3-9. It is evident from this plot that there are times when the duty cycle is very high (close to 1) while there are times when the duty cycle is low. Figure 3-10 shows the cumulative density function for the duty cycle values. It illustrates that the duty cycle is greater than 0.8 a little more than 10% of the time. Hence, the worst case analysis considered in this study considers this small percentage in time.

FIGURE 3-8

An example of MLS multiplex transmit sequence showing PtGt for the first 140 ms

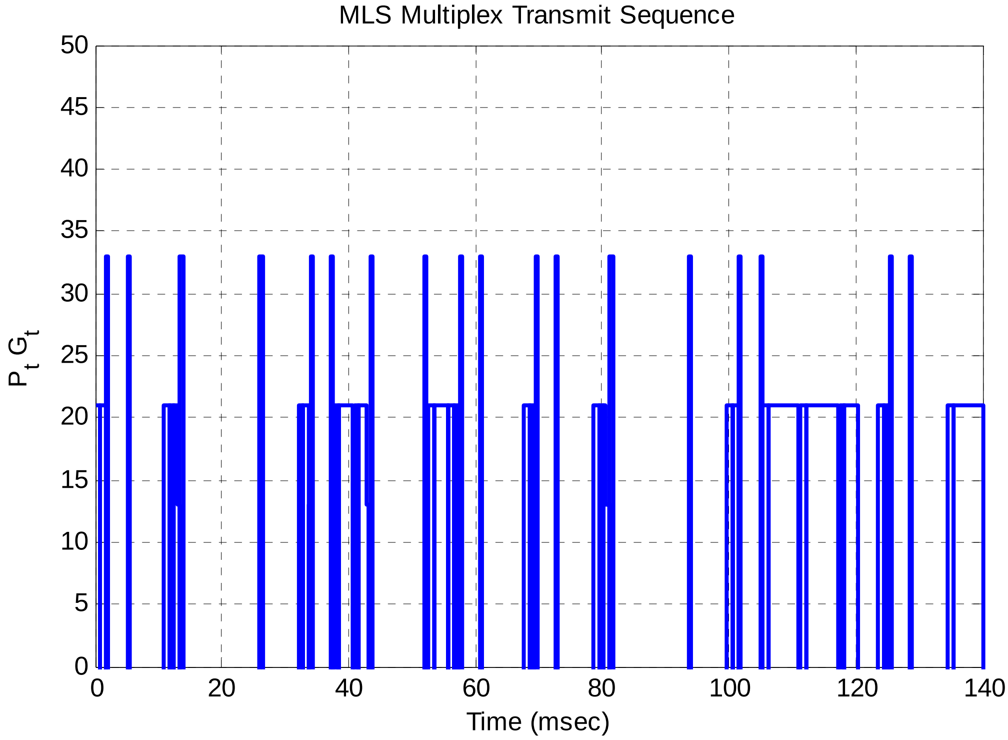


FIGURE 3-9

Estimated MLS signal duty cycle over 615 ms multiplex transmission

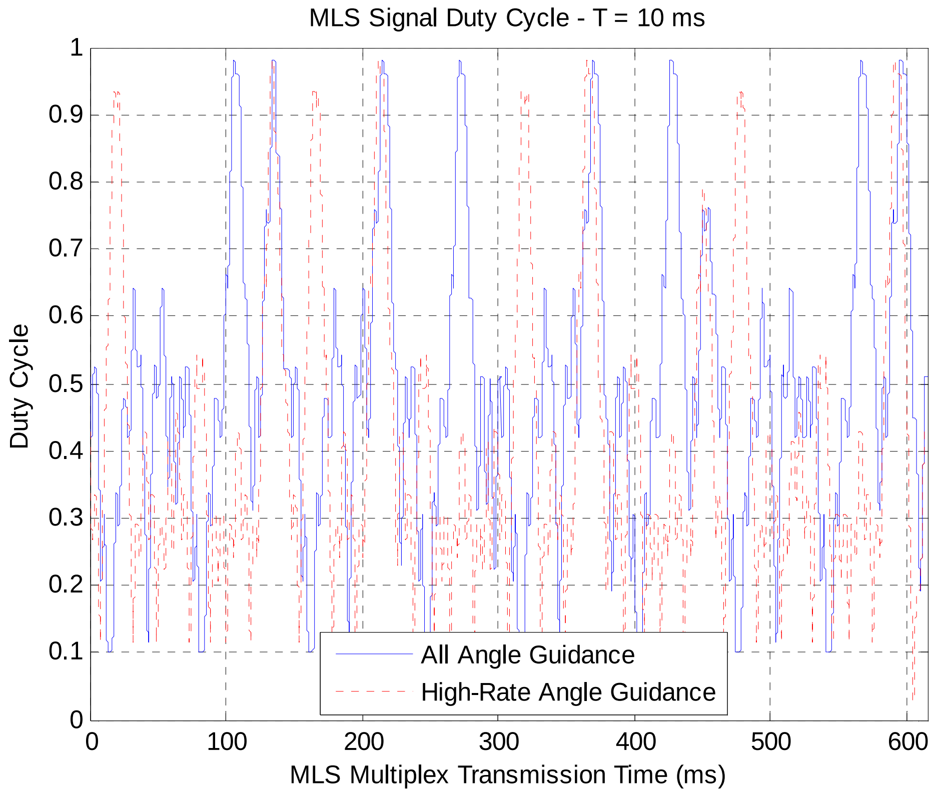


FIGURE 3-10

Cumulative density function of MLS effective duty cycle

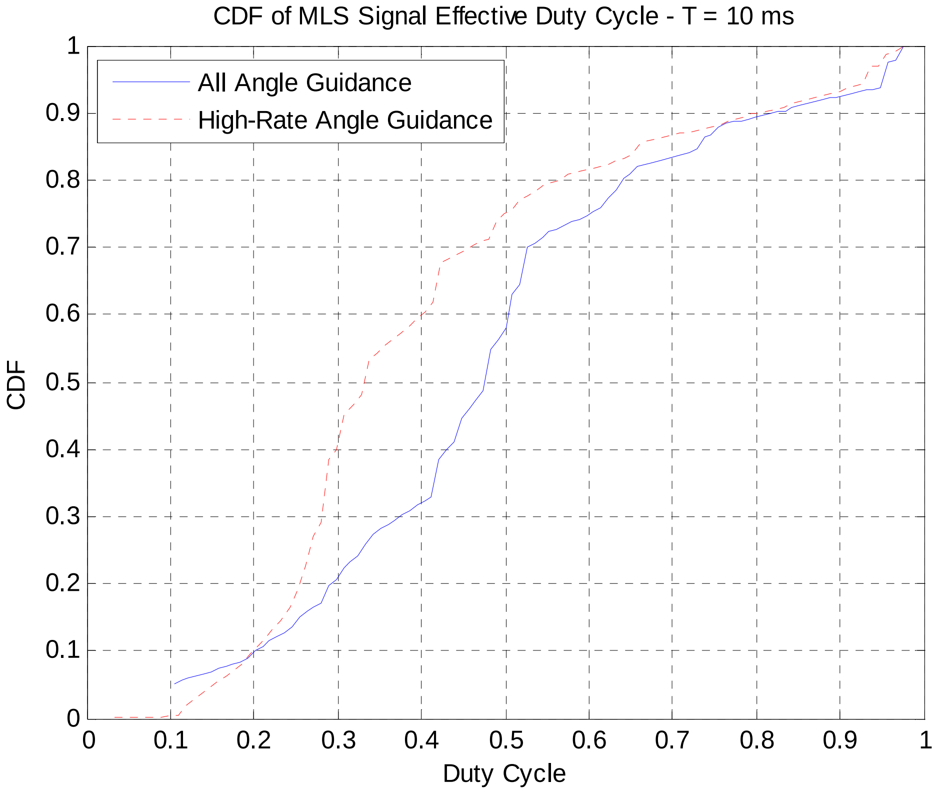
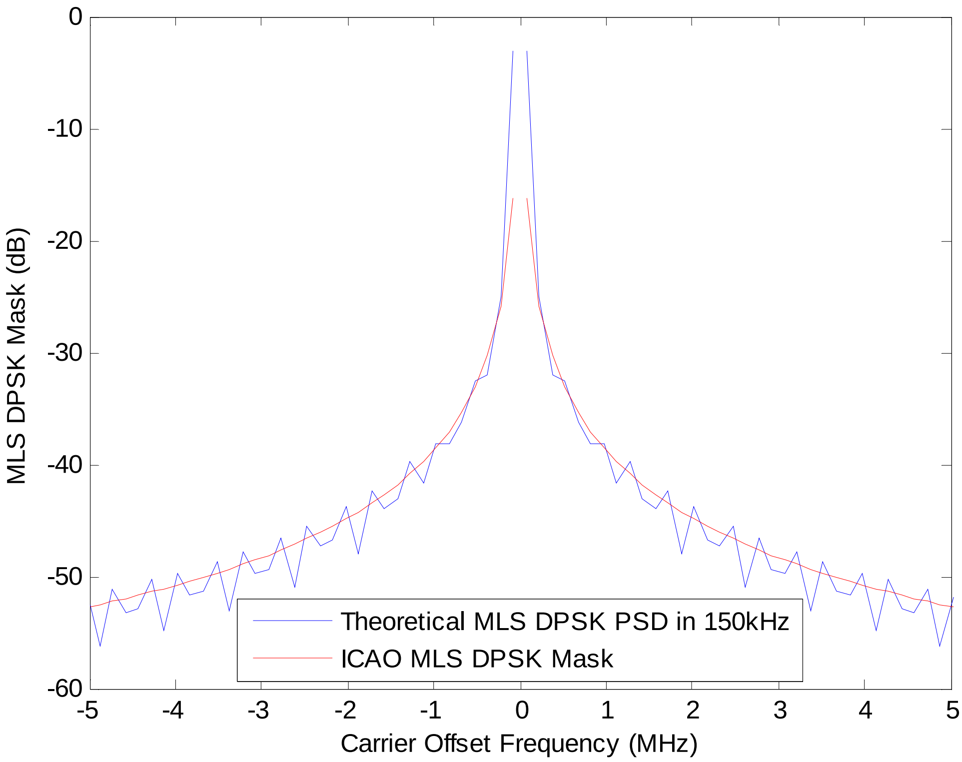


Figure 3-11 shows the ICAO-modelled MLS DPSK emission level, $10\log\left(\frac{1}{2\pi^2}\frac{f_d \cdot Bw}{f^2}\right) + 0.5\,(\text{dB})$, vs. a theoretical MLS DPSK emission level, in a 150 kHz bandwidth, relative to the considered channel transmit level.

FIGURE 3-11

ICAO-Modelled MLS DPSK Emission



4 Interference analysis

Radio-frequency interference is the unwanted radio-frequency signals that impact the receiver performance of victim systems. Most systems/receivers can tolerate weak interference below their system noise level. For strong interference above their system noise level, the interference impact depends on the receiver design, mitigation techniques, and types of interference. In general, interference can be categorized into two types – pulsed and continuous in time:

– Pulsed interference is characterized by the pulse duration and duty cycle. Pulse duration is the pulse time-width of an individual pulse. Pulse duty cycle is the percentage of time that the pulses are on. For a particular system, pulsed interference refers to individual interference pulse durations that are small compared to the receiver's integration time, normally a data/symbol duration time. Strong interference pulses can saturate the receiver RF front-end or will be clipped in amplitude.

– Continuous or continuous wave (CW) interference includes wideband, narrowband, and tone interference. All of these waveforms are continuous in time, but have different spectral characteristics.

The four cases identified in Table 4-1 were analysed. Analysis approaches and results are presented in § 4.1 for MLS interference to RNSS receivers and in § 4.2 for RNSS interference to MLS receivers. Table 4-1 categorizes and summarizes the potential interference cases investigated as well as the interference criteria for each case.

This analysis considers the worst case where the MLS transmitter carrier frequency is assumed to be 5 031 MHz, which is one of 200 MLS channels that could be implemented at any given airport. The results of this analysis, therefore, only apply to RNSS receivers in the vicinity of those airports assigned this one MLS channel and do not apply to all airports operating MLS systems. It is prudent to use 5 031 MHz in the analyses, because any airport can use this frequency at some point in time, based on aviation needs (e.g. installation of a new MLS station or interference mitigation). RNSS operators should be mindful of such potential MLS frequency changes that could result in expensive adjustments such as relocation of the RNSS earth station site and/or steeper RNSS transmit filter requirements. Furthermore, this also applies to the design of the RNSS service link receivers with respect to interference from MLS.

TABLE 4-1

Cases investigated

Category	Case	Interferer	Victim	Interference Criterion
Compatibility of MLS and GPS/Galileo links	1	MLS Tx	GPS feeder downlink ES Rx	Maximum allowable I_0 based on assumed RNSS I/N criteria
	2	MLS Tx	GPS/Galileo service downlink Rx	Maximum allowable I_0 based on assumed max aggregate non-RNSS wideband interference threshold
	3	MLS Tx	GPS feeder uplink SS Rx	Maximum allowable I_0 based on assumed RNSS I/N criteria
	4	GPS feeder downlink SS Tx + GPS service downlink SS Tx + GPS feeder uplink ES Tx	MLS Rx	–124.5 dB(W/m^2/150 kHz) aggregate (Note)

NOTE – Reference RR No. **5.443B**.

4.1 MLS interference to RNSS receivers

For the Case 1 of MLS interference to GPS feeder downlink ES receiver, the analysis is based on the following assumptions:

− MLS at 5 031 MHz;

− GPS feeder downlink at 5 013.63 MHz;

− 5-degree off boresight receiver antenna gain aligns with near-horizon beam gain of the MLS;

− Due to the very short bit duration, 303 ns per bit (3.3 Mbit/s for each I and Q channel), MLS DPSK interference is considered as continuous interference into the receiver.

For the Case 2 of MLS interference to GPS service downlink receiver, based on a complete MLS multiplex transmission cycle (615 ms) overlaid by a 10 ms GPS service-downlink symbol duration, MLS interference must be computed for all possible combinations of signal overlaps. MLS interference can occur under one of the 6 scenarios listed below (limited to 10 ms duration):

− Scenario 1 from 2 auxiliary words: 832 CW + 4864 DPSK + 204 X + 832 CW + 3 268 DPSK in μs.

− Scenario 2 from 1 basic word + 2 auxiliary words: 832 CW + 2 048 DPSK + 220 X + 832 CW + 4864 DPSK + 204 X + 832 CW + 168 DPSK in µs.

− With Flare system:

- Scenario 3 from approach elevation system + flare system: 832 CW + 768 DPSK + 128 X + 128 CW + 312 SCW + 1 238 X + 400 X + 1 238 X + 312 SCW + 244 X + 832 CW + 768 DPSK + 256 X + 575 X + 625 SCW + 800 X + 544 SCW in µs.
- Scenario 4 from approach elevation system + basic word + back azimuth (or basic word if back azimuth not installed): 832 CW + 768 DPSK + 128 X + 128 CW + 312 SCW + 1 238 X + 400 X + 1 238 X + 312 SCW + 244 X + 832 CW + 2 048 DPSK + 220 X + 832 CW + 468 DPSK in µs.

− Without Flare system (substitute with basic data word):

- Scenario 5 from approach azimuth system: 832 CW + 768 DPSK + 448 DPSK + 384 CW + 5 828 X + 500 SCW + 600 X + 500 SCW + 140 X in µs.
- Scenario 6 from approach elevation system + basic word + back azimuth (or basic word if back azimuth not installed): 832 CW + 768 DPSK + 128 X + 128 CW + 312 SCW + 1 238 X + 400 X + 1 238 X + 312 SCW + 244 X + 832 CW + 2 048 DPSK + 220 X + 832 CW + 468 DPSK in µs.

MLS systems are likely not to install the flare system and to use data words in place of the "growth" time-slot. Hence, Scenarios 1, 2, 5, and 6 are more likely and the worst-case is Scenario 1. The analysis is based on the following assumptions:

− MLS at 5 031-5 040 MHz.

− GPS service downlink at 5 019.861 MHz.

− Main beam GPS receiver antenna gain aligns with near-horizon beam gain of the MLS.

− Use a combination of MLS DPSK and CW interference from Scenario 1 as the MLS interference into the receiver. For this interference scenario, since the duration of the MLS interference is longer than a symbol period, the MLS interference is considered as continuous interference to the service link receiver.

For the Case 3 of MLS interference to GPS feeder uplink SS receiver, the analysis is based on the following assumptions:

− MLS at 5 031 MHz.

− GPS feeder uplink at 5 000.605 MHz.

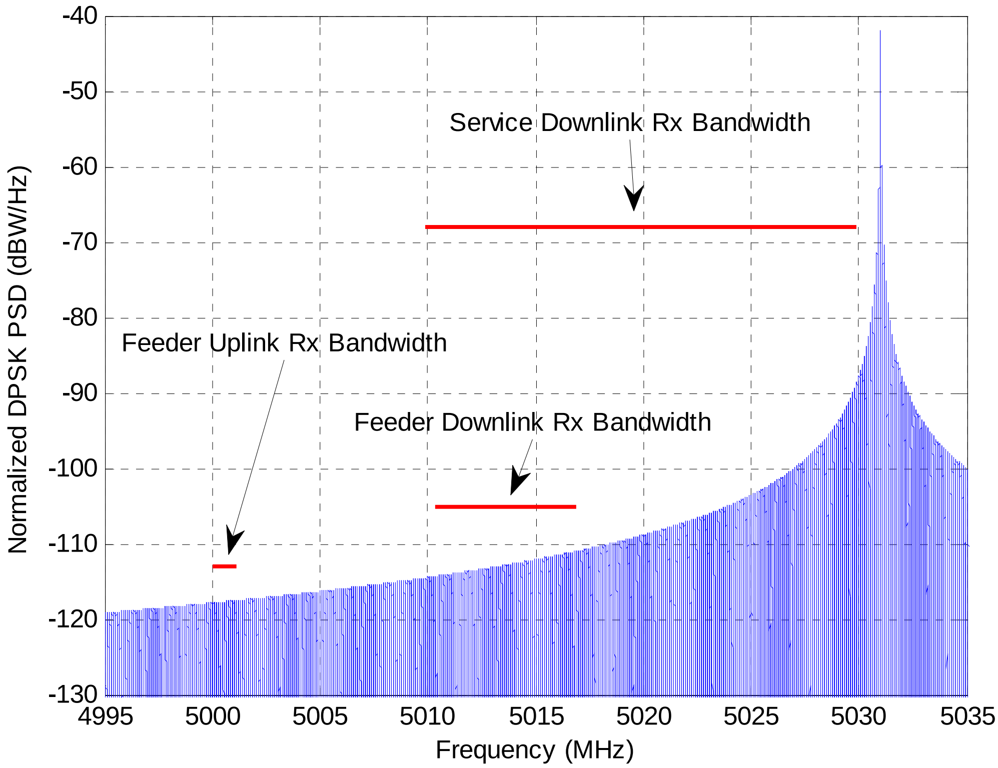
− Main beam SS receiver antenna gain aligns with main beams of the MLS.

− Due to the very short bit duration, 909 ns per bit (1.1 Mbit/s for each I and Q channel), the MLS DPSK interference is considered as continuous interference by the receiver.

Figure 4-1 shows the MLS DPSK psd spectrum in relation to the bandwidths of GPS feeder downlink receiver, feeder uplink receiver, and service downlink receiver.

FIGURE 4-1

Normalized MLS DPSK psd spectrum and GPS receiver bandwidths



GPS feeder downlink data is transmitted in QPSK-modulation and the transmitted data rate is 6.6 Mbit/s with a 9 dB-Hz E_b/N_0. GPS feeder uplink data is also transmitted in QPSK-modulation and the transmitted data rate is 1.1 Mbit/s with a 9 dB-Hz E_b/N_0.

For these feeder-link signals, current interference criteria require the MLS interference density, I, in dBW/Hz to be less than the acceptable interference threshold, associated with each uplink and downlink signal.

The following method was used to analyse the MLS interference to the GPS feeder uplink receiver and feeder downlink receiver:

– This method computes the frequency-dependent rejection (FDR) in dB, based on Recommendation ITU-R SM.337-6. The interference rejection density (dB/Hz) is computed, dividing FDR by the 3-dB receiver two-sided bandwidth.

$$FDR(\Delta f) = 10 \log \frac{\int_{-\infty}^{\infty} P(f)|H(f+\Delta f)|^2 df}{\int_{-\infty}^{\infty} P(f) df}$$

where:

FDR: frequency-dependent rejection defined by the ratio between the MLS power transmitted in the GPS receiver bandwidth centred at the GPS centre frequency, f_c, and the total MLS power transmitted

$P(f)$: MLS power spectral density

$H(f)$: frequency response of the receiver

Δf: frequency offset between the transmitting centre frequency and the victim centre frequency.

As for the interference from the MLS to the RNSS service link receiver, the interference rejection density (IRD) in dB/Hz is calculated using the following equation:

$$IRD(\Delta f) = 10\log\left[\int_{-\infty}^{+\infty} P_{MLS}(f) \cdot P_{RNSS}(f) \cdot |H(f+\Delta f)|^2 \, df\right]$$

where:

- $P_{MLS}(f)$: MLS power spectral density normalized to a total power of 1
- $P_{RNSS}(f)$: RNSS power spectral density normalized to a total power of 1
- $H(f)$: frequency response of the RNSS receiver
- Δf: frequency offset between the transmitting centre frequency and the victim centre frequency.

The results on the MLS interference to GPS receivers are summarized in Table 4-2 for cases 1, 2 and 3. In this table, the case 2 result only considers an MLS channel at 5 031 MHz, the worst case, when the MLS is operating very close to the GPS service downlink band. In this case, the required separation distances are 20.6 km and 14.1 km, respectively, for –223.6 dBW/Hz interference criteria when using a 20 MHz passband RF/IF filter with a –6 dB/MHz and a –10 dB/MHz OoB roll-off.

TABLE 4-2

MLS interference to RNSS receivers

	GPS **Feeder downlink ES receiver** **(f_c = 5 013.63 MHz)**	**GPS** **Feeder uplink SS receiver** **(f_c = 5 000.605 MHz)**	**GPS/Galileo** **Service downlink receiver, acquisition** **(f_c = 5 019.861 MHz)**
MLS interference type to RNSS	DPSK	DPSK	DPSK AND CW (Scenario 1)
MLS transmit power (dBW)	13	13	13
MLS transmit DPSK antenna gain (dBi)	2 (near horizon gain, 6 dB lower)	8	2 (near horizon gain, 6 dB lower)
MLS aggregate (dB)	0	20	0
Interference rejection density (dB/Hz) + RF/IF filtering (–6/ –10 dB/MHz)	–115.1/–115.6 (Note 10)	–118.6/–120.2 (Note 10)	–101.3/–104.9 (DPSK) (Note 3) –98.8/–103.4 (CW) (Note 4)
RNSS receiver antenna gain (dBi)	10.0 (horizon gain)	13.8	3 (GPS) 4 (Galileo)
Polarization loss (MLS vertical in RNSS RHCP) (dB)	–3	–3	–3
Received MLS interference density (dBW/Hz)	–93.1/–93.6	–66.8/–68.4	–85.8/–89.7 (GPS) –84.8/–88.7 (Galileo) (Note 5)
Max I_0 aggregate non-RNSS wideband interference threshold (dBW/Hz)			–207.6 (GPS) –210.1 (Galileo) (Note 9)
Receiver noise density, N_0 (dBW/Hz)	–207.15	–200.89	
Interference apportionment Factor (dB)	–20.0 (Note 1)	–20.0 (Note 1)	–16.0 (Note 6)

TABLE 4-2 (*end*)

	GPS Feeder downlink ES receiver (f_c = 5 013.63 MHz)	**GPS Feeder uplink SS receiver (f_c = 5 000.605 MHz)**	**GPS/Galileo Service downlink receiver, acquisition (f_c = 5 019.861 MHz)**
Acceptable I_0 density (dB(W/Hz))	–227.15	–220.89	–223.6 (GPS) –226.1 (Galileo)
Required path loss (dB)	134.1/133.5	154.1/152.5	137.8/133.9 (GPS) 141.3/137.4 (Galileo)
Required separation distance (km) (Note 2)	14.3/13.5 (Note 7)	241.8/201.1 (Note 8)	20.6/14.1 (GPS) 29.3/20.0 (Galileo) (Note 7)

NOTE 1 – Recommendation ITU-R S.1432 recommends a $\Delta T/T$ = 1% (–20 dB) for all other interference from non-primary sources (in this case, mainly due to unwanted emissions). The separation distance is computed, based on the assumption that all 1% of the interference comes from a single MLS. The separation distance will change if a different MLS interference apportionment level is used.

NOTE 2 – Required separation distance is limited to the transmit/receive radio line-of-sight (LoS), using 4/3 earth radius propagation model.

NOTE 3 – Calculated interference rejection density between filtered MLS DPSK at 5031 MHz and RNSS 20.46 MHz spreading code at 5019.861 MHz, when using a 20 MHz passband RF/IF filter with –6 dB/MHz and –10 dB/MHz OoB roll-off.

NOTE 4 – Calculated interference rejection density between filtered MLS CW at 5031 MHz and RNSS 20.46 MHz spreading code at 5019.861 MHz, when using a 20 MHz passband RF/IF filter with –6 dB/MHz and –10 dB/MHz OoB roll-off.

NOTE 5 – Combination of received MLS DPSK density and received MLS CW density, using 0.8132 (8 132/10 000) and 0.1664 (1 664/10 000) scaling factors per scenario 1, respectively.

NOTE 6 – The –16 dB factor is based on the following two presumptions: 1) apportionment factor of –10 dB for aggregate interference due to all OoB sources; and 2) MLS allotted 25% (–6 dB) of this apportionment value.

NOTE 7 – Based on the radio LoS between the transmit MLS's antenna height and the RNSS feeder downlink/service downlink receivers' antenna height, it is determined that the airport propagation model (ground-to-ground) is more accurate for calculating the required separation distance (short distances). The model is accurate for short distances. Different (more complex) propagation model is required to calculate the longer separation distances. Airport propagation model used in this study is as follow: path loss, PL = $-(99.8 + 10\,n\,\log10(d/d_0))$, in dB; where n = 2.3 and d_0 = 462 m.

NOTE 8 – Free-space propagation model is used to calculate the required separation distance. In this scenario, the victim receiver is in a spacecraft in orbit, thus separation distance shown here is typically achieved by default.

NOTE 9 – Maximum aggregate non-RNSS wideband interference threshold in the RNSS allocated band for GPS is –147.6 dB(W/MHz) or –207.6 dB(W/Hz) and for Galileo is –150.1 dB(W/MHz) or –210.1 dB(W/Hz).

NOTE 10 – FDR method is used.

Figure 4-2 plots the separation distance as a function of MLS frequency, varying from 5 031 to 5 040 MHz, to be implemented by the operator of a GPS service link receiver with a 20 MHz passband RF/IF filter (assuming –6 dB/MHz and –10 dB/MHz OoB receiver filter roll-offs).

FIGURE 4-2

Separation distance as a function of MLS frequency for a 20 MHz passband GPS receiver

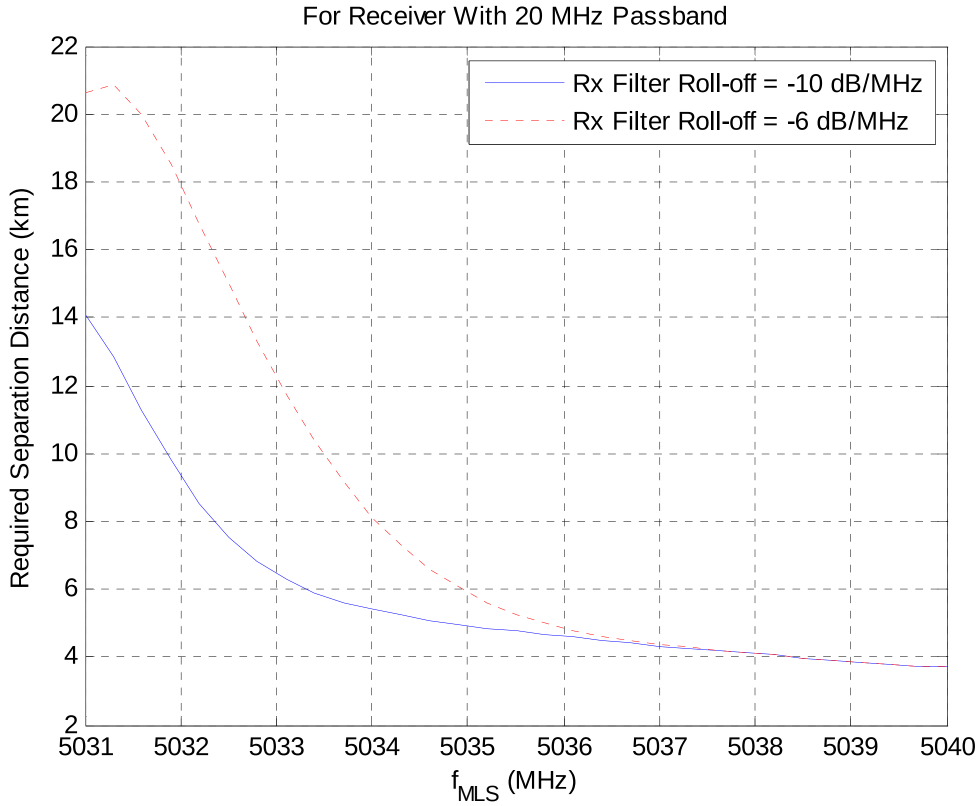
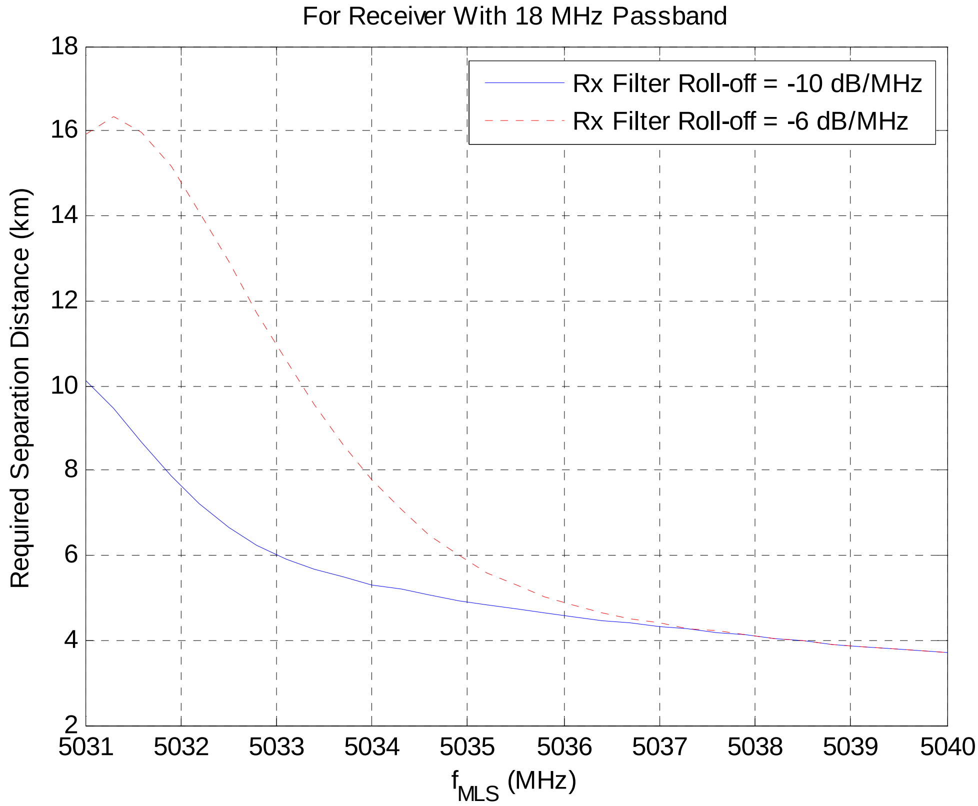


Figure 4-3 plots the separation distance as a function of MLS frequency, varying from 5 031 to 5 040 MHz, to be implemented by the operator of a GPS service link receiver with a 18 MHz passband RF/IF filter (assuming –6 dB/MHz and −10 dB/MHz OoB receiver filter roll-offs).

FIGURE 4-3

Separation distance as a function of MLS frequency for an 18 MHz GPS passband receiver

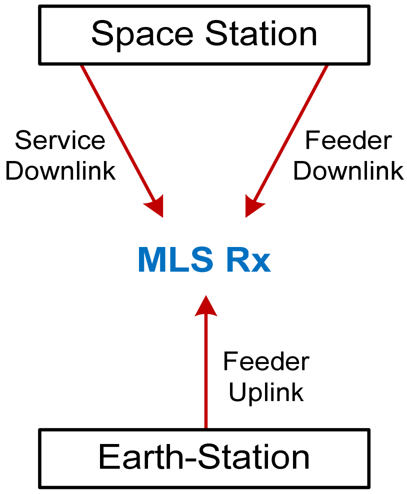


4.2 RNSS interference to MLS receiver

Radio-frequency interference to an MLS receiver from a single RNSS space station and a single RNSS earth station includes RF emissions from the SS service downlink, the SS feeder downlink, and the ES feeder uplink as shown in Fig. 4-4. The RF interference analysis must take into account the interference effects from multiple in-view space-stations and at least a single earth station. The total combined, aggregate power flux-density (pfd) of these three RNSS links from multiple visible space stations and at least a single earth station is required to be less than –124.5 dBW/m^2/150 kHz.

FIGURE 4-4

Single RNSS system interference to MLS receiver



Interference analysis assumptions

– **Feeder downlink**: a) Use main beam feeder-downlink signal interference in the MLS coverage volume; b) Use continuous wideband interference analysis.

– **Service downlink**: a) Use main beam service-downlink signal interference in the MLS coverage volume; b) Use continuous wideband interference analysis.

– **Feeder uplink**: a) Use main beam feeder-uplink signal interference in the MLS coverage volume; b) Use continuous wideband interference analysis.

– **Interference criteria**: Total aggregate power flux density of the combined three interfering links from all satellites in view and at least one earth station is required to be less than –124.5 dBW/m^2/150 kHz.

Interference analysis

Table 4-3 shows the detailed interference analysis for each of the 3 GPS links as well as the overall interference effects on a MLS receiver from all in-view space stations and at least one earth station. In order for the RNSS links to avoid interfering with a MLS receiver, the uplink earth station needs to be at least 332.5 km/2.808 km/ 0.281 km away from the MLS receiver with the use of 0/–60/ –80 dB transmit filter rejection, respectively. The line of sight (LoS) radio horizon limit for an assumed 10 m height ES transmit antenna and a 6 km height MLS coverage volume is 332.5 km, using 4/3 earth radius radio-propagation model. For the 0 dB transmit filter rejection case (see Note 6 below), the separation distance is several thousand kilometres, which is replaced with the LoS radio horizon limit.

TABLE 4-3

GPS interference to MLS receiver

	Feeder downlink (f_c = 5013.63 MHz)	**Service downlink (f_c = 5019.861 MHz)**	**Feeder uplink (f_c = 5000.605 MHz)**
Transmit power (dBW)	7.00	13.50	20.00
Transmit antenna gain (dBi) (not include antenna pointing loss)	27.60	13.20	46.61
e.i.r.p. (dBW)	34.60	26.70	66.61
Path loss (Note 1) (dB/m^2)	–157.1 (R=20 200 km – 6 km)	–157.1 (R=20 200 km – 6 km)	N/A
Required path loss (dB/m^2) to meet the required feeder uplink pfd	N/A	N/A	–139.96/–79.96/–59.96 (0 (Note 6)/–60/–80 dB transmit filter rejection)
G_{AGG} (dB)	0	12	0
Frequency dependent rejection (Note 2) (dB)	–38.22 @ 5 031.6 MHz	–35.39 @ 5 031.0 MHz (Note 3)	–51.15 @ 5 032.2 MHz
Transmit filter rejection (dB)	0 (Note 6)/–60/–80 @ 5 031 MHz	–9.7 @ 5 031 MHz	0 (Note 6)/–60/–80 @ 5 031 MHz
Power flux-density (dB(W/m^2/150 kHz))	–160.7/–220.7/–233.7	–163.5	–124.501/–124.50/ –124.50 (required) (Note 4)
Required pfd (dB(W/m^2/150 kHz))	–124.50		
GPS interference to MLS receiver	No harmful interference (Note 5)	No harmful interference (Note 5)	No harmful interference (Note 5) assuming separation distance is maintained as follows: * *R > 332.5 km (Note 6) /2.808 km/0.281 km respectively away from the MLS receiver with RNSS use of 0 (Note 6)/ –60/–80 dB transmit filter rejection.*
Total power flux-density (dBW/m^2/150 kHz)	–124.50 (Note 5)		
Total GPS interference to MLS receiver	No harmful interference (Note 5)		

NOTE 1 – Path loss (or spreading loss) in dB/m^2 is defined as $10*\log(1/4\pi R^2)$.

NOTE 2 – Frequency-dependent rejection (FDR) is defined here as the integral of the RNSS signal psd over a 150 kHz MLS receiver's passband centred at the MLS channel frequency. Figure 4-5 shows the frequency dependent rejection for the feeder downlink signal (3.3 MHz, QPSK), the service downlink signal (10.23 MHz, staggered QPSK (SQPSK)), and the uplink signal (0.55 MHz, QPSK).

NOTE 3 – For service downlink, use –35.39 dB @ 5 031 MHz instead of –31.6 dB @ 5 033.7 MHz, when accounted for the transmit filter effects (see Fig. 4-5, sign reversion to show the effects of the rejection).

Notes to Table 4-3 (end)

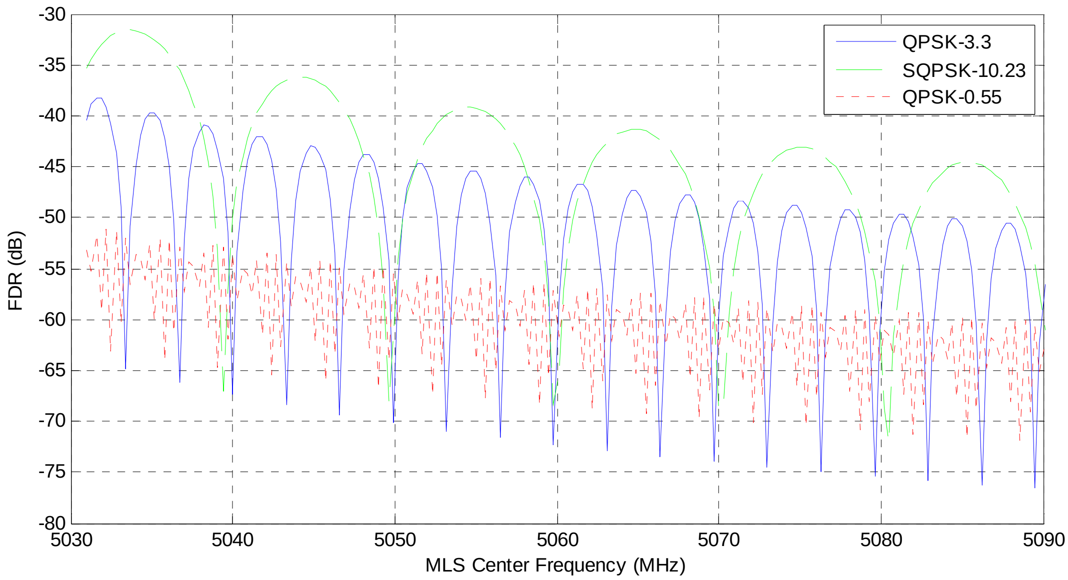
NOTE 4 – The required power flux-density for the feeder uplink is computed by subtracting the feeder downlink pfd and the service downlink pfd from the required pfd of –124.5 dB(W/m2/150 kHz).

NOTE 5 – In order for the RNSS links not to interfere with MLS receivers, the combined power flux-densities of the 3 RNSS links shall be less than –124.5 dB(W/m^2/150 kHz). This results in a required path loss for the RNSS feeder uplink, which in turn, results in the required separation distance between the feeder uplink transmit antenna and the MLS receiver. The required separation distances are at least 332.5 km (in place of 2 808 km due to radio horizon limit)/2.808 km/0.281 km with the use of 0/ –60/ –80 dB transmit filter rejection, respectively. The LoS radio horizon limit for a 10 m height ES transmit antenna and a 6 000 m height MLS coverage volume is 332.5 km, using 4/3 earth radius propagation model.

NOTE 6 – Note that GPS transmitters will not operate with 0 dB filter rejection. Such operation would not be consistent with the Radio Regulations which require an attenuation at the band edge of either 60 dB or 43 + 10log10 (*P*) (dB), where *P* is the power in watts, whichever is smaller attenuation (ITU Radio Regulations, Appendix 3). This theoretical, unrealistic case is only included to illustrate the importance of implementing rejection filters on RNSS transmitters.

FIGURE 4-5

Frequency dependent rejection (FDR) for GPS link signals as a function of MLS centre frequency



5 Summary of compatibility between feeder links, service link, and MLS

Table 5-1 summarizes the key findings of this preliminary analysis of the compatibility of the GPS feeder links and GPS and Galileo service links with MLS. For the cases of MLS interference to the RNSS, these findings are dependent upon the assumptions regarding the interference protection criteria used in this study. For the GPS and Galileo service downlinks, these findings provide an indication of the separation distances that a GPS receiver and Galileo receiver, depending on its filtering, must maintain in order to protect its operations from incumbent in-band MLS transmissions centred at 5 031 MHz. Similarly, as shown in Table 5-1, MLS receivers operating on the worst-case channel at 5 031 MHz will be protected from GPS transmissions when the three calculated separation distances, depending on the three different transmit filter assumptions, are applied to the GPS feeder uplink earth stations. Note that these calculations include the interference effect from GPS feeder downlink and GPS service link signals which do not individually cause harmful interference to the MLS receiver. Insufficient data is currently available to allow definitive conclusions to be drawn or to perform similar analyses of other RNSS systems.

TABLE 5-1

Summary of MLS/RNSS findings when MLS operates on the worst-case channel at 5 031 MHz

Category	Case	Interferer	Victim	Finding
Compatibility of MLS and GPS/Galileo links	1	MLS Tx	GPS feeder downlink ES Rx	No harmful interference when the separation distance is met as shown in Table 4-2
	2	MLS Tx	GPS/Galileo service downlink Rx	No harmful interference when the separation distance is met as shown in Table 4-2
	3	MLS Tx	GPS feeder uplink SS Rx	No harmful interference
	4	GPS feeder downlink SS Tx	MLS Rx	No harmful interference
		GPS service downlink SS Tx	MLS Rx	No harmful interference
		GPS feeder uplink ES Tx	MLS Rx	No harmful interference (Note 1) when the required separation distance (Note 2) between a GPS ES Tx and an MLS Rx is 332.5 km (Note 3)/2.808 km/0.281 km depending on the GPS transmit filter assumptions (0 (Note 3)/–60/–80 dB).

NOTE 1 – No harmful interference when meeting the required separation distances in Table 5-1, which take into account the total aggregate interference from the 3 GPS links.

NOTE 2 – Since the MLS receiver is only protected in the MLS coverage volume centred at the MLS ground transmit antenna, the required separation distance can be referenced from the MLS transmit antenna by adding a MLS coverage range of 41.7 km to the values listed in Table 5-1.

NOTE 3 – Note that GPS transmitters will not operate with 0 dB filter rejection. Such operation would not be consistent with the Radio Regulations which require an attenuation at the band edge of either 60 dB or 43 + 10log (P) (dB), where *P* is the power in watts, whichever is smaller attenuation (ITU Radio Regulations Appendix 3). This theoretical, unrealistic case is only included to illustrate the importance of implementing rejection filters on RNSS transmitters. These required separation distances are based on the GPS interference to the MLS operating at 5 031 MHz.

MLS is a precision approach and landing guidance system which provides position information and various ground-to-air data. The position information is provided in a wide coverage sector and is determined by an azimuth angle coverage, an elevation angle coverage, and a range (distance) coverage as follows:

– Approach azimuth: lateral coverage of –60° to +60°, vertical coverage of 0.9° to 15° (up to 6 000 m above the ground level), and coverage range of 41.7 km from the approach azimuth antenna (see ICAO Annex 10 Fig. G-5A).

– Back azimuth: lateral coverage of –20° to +20° (can be up to –42° to +42°), vertical coverage of 0.9° to 15° (up to 3 000 m above the ground level), and coverage range of 18.5 km from touchdown point of a runway (see ICAO Annex 10 Fig. G-6).

– Approach elevation: vertical coverage of 0.9° to 28° (up to 6 000 m above the ground level), lateral coverage of at least equal to the approach azimuth proportional guidance sector, and coverage range of 37 km from threshold (see ICAO Annex 10 Fig. G-10A).

The MLS coverage volume for a single MLS can occupy a 120° lateral coverage, a radius of 41.7 km, and a height of 6 000 m. In the case where a back-azimuth is implemented the lateral coverage will increase to 240 degrees. In between those coverage volumes DPSK data can be transmitted using the OCI antenna, however the transmit antenna gain, and hence the coverage volume, is reduced. In cases where there are two MLS systems at an airport, the second MLS channel is at least three channels removed in frequency from the first channel (assumed to be at 5 031 MHz for the worst case), less interference is expected from this second system. It is important to note however that any RNSS siting analysis must preserve the capability for frequency managers to change MLS operating channels.

Therefore, since the MLS receiver is only protected in the MLS coverage volume centred at the MLS ground transmit antenna, the required separation distance between an RNSS earth station and an MLS transmit antenna shall be at least 41.981 km from the MLS ground transmit antenna, depending on the RNSS filter assumption (–80 dB).

In order to protect any and all MLS equipped aircraft within the frequency protected service volume, whenever there is a required separation distance between a transmitter (in this case the RNSS earth station), the distance separation is referenced to the fixed ground transmitter, which is the centre of a circle whose radius is the coverage range, i.e. 41.7 km.