

REPORT 766-2*

FEASIBILITY OF FREQUENCY SHARING BETWEEN THE GPS AND OTHER SERVICES

(Question 83/8)

(1978-1986-1990)

1. Introduction

This Report refers to Question 83/8, DECIDES 4, i.e. "Is the sharing of frequencies with other systems feasible, and if so, what other systems and under what circumstances?". The Question is addressed for the radionavigation-satellite system, global positioning system (GPS), which provides accurate timing and position determination via two satellite-to-Earth transmission channels. This Report addresses the feasibility of this system sharing the 1215-1240 MHz and 1559-1610 MHz bands with terrestrial stations.

A more thorough description of the ———- GPS system and the rationale behind the selection of frequencies is presented in Annex I.

2. Frequency sharing considerations

The frequency band 1215-1240 MHz is presently allocated on a primary co-equal basis to the radiolocation and radionavigation-satellite services in all three regions. Thus the feasibility of sharing with these stations has been given primary emphasis. Detailed consideration has also been given to other allocated services, i.e. fixed, mobile and radionavigation.

3. NAVSTAR GPS sharing with the radiolocation and radionavigation services

The radiodetermination services presently operating in the 1215 to 1240 MHz radiolocation band are almost exclusively P0N and XXX type emissions with duty cycles between 10^{-2} and 10^{-3} .

3.1 Interference to the GPS

The GPS receiver is designed to operate in a pulsed environment. High-speed, rapid-recovery ——— front-end limiters are used to prevent high-energy pulses from damaging the receiver. In addition, intermediate-frequency clipper circuits essentially maintain the peak pulse voltages at the same level as peak noise bursts.

The modulation structure and system logic are such that the system is essentially invulnerable to normal radar signals. The pseudo-random phase-shift signal with a bit rate in excess of 10 MHz is compressed to an information bandwidth of 50 Hz. This provides an extremely large protection ratio against all types of interference of narrower bandwidth than the GPS emissions. Results of various studies have shown that a system of this type, once synchronized, can function satisfactorily in a pulsed environment which has a duty cycle much higher than any operational environment [USA, 1976].

* The Director, CCIR, is requested to bring this Report to the attention of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO).

3.2 Interference from the GPS to the radiolocation and radionavigation services

The signal transmitted from the GPS satellite is of uniform power flux density over the visible portion of the Earth and will appear as a noise-like signal over a band of approximately 20 MHz. The majority of radars operating in the 1215 to 1240 MHz band have IF bandwidths much less than 20 MHz and consequently will receive a noise-like signal with a flat spectral power density over the receiver band pass. The amplitude of this signal will be a function of the radiolocation receiver antenna gain in the direction of the satellite and the impact upon the operation of the radiolocation system will be dependent upon the ratio of this signal amplitude to the receiver noise spectral power density or to the receiver threshold.

The antenna gains and receiver noise figures for the radiolocation equipment operating in the 1215 to 1240 MHz band will vary over a wide range depending upon the system mission. It will be convenient here to utilize the concept of the antenna gain/temperature ratio (G/T) in assessing the impact of the GPS signal upon the radiolocation systems.

3.3 Radar sensitivity

Virtually all radars operate very near their noise level in order to maximize the detectability of the system. There is normally a threshold level established between 5 and 15 dB above the noise level, chosen to optimize the trade-off between suppressing noise peaks and other anomalous responses (false alarms) and detecting the desired signals. Interference power from well below the noise level up to just below the threshold level manifests itself as an increasing number of false alarms. The interference power level at the radar receiver input is given by:

$$(I)_{\text{dB}} = (SPFD)_{\text{dB}} + (A_e)_{\text{dB}} + (B)_{\text{dB}} \quad (1)$$

where

$(I)_{\text{dB}}$ means $10 \log I$,

I : interference power in watts,

$SPFD$: GPS satellite spectral power flux-density at earth surface ($\text{W}/(\text{m}^2 \cdot \text{Hz})$),

A_e : effective antenna aperture of the ground receiving antenna in the direction of the satellite,

B : ground receiver bandwidth in Hz,

$$A_e = \frac{G\lambda^2}{4\pi} \quad (2)$$

where

G : ground receiving antenna power gain,

λ : GPS wavelength = 0.2444 m,

$$(I/N)_{\text{dB}} = (I)_{\text{dB}} - (kTB)_{\text{dB}} \quad (3)$$

where

k : Boltzmann's constant = 1.38×10^{-23} joule K^{-1} ,

T : receiver noise temperature (K),

B : receiver noise bandwidth (Hz),

I/N : interference to receiver noise ratio that would produce noticeable degradation.

From equations (1), (2) and (3) we have:

$$(G/T)_{\text{dB}} = -205.4 + (I/N)_{\text{dB}} - (SPFD)_{\text{dB}} \quad (4)$$

where:

$(G/T)_{\text{dB}}$: maximum ratio of gain of ground antenna to receiver noise temperature for which limiting interference to noise ratio will not be exceeded.

The power flux-density from the satellite L2 signal (see Annex I) in a full capability GPS has been determined to be $-200.0 \text{ dB(W/(m}^2 \cdot \text{Hz))}$. This value includes a margin allowing for satellite ageing, signal fading, etc. Substituting this value into equation (5):

$$(G/T)_{\text{dB}} = (I/N)_{\text{dB}} - 5.4 \quad (5)$$

The value of I/N will vary with the type of radar and some of its basic circuits. For a value $I/N = 0 \text{ dB}$, the false alarm rate for a simple PPI radar with no clutter, jamming or interference suppression circuits would be degraded from 10^{-n} to $10^{-n/2}$ if the G/T in the direction of the GPS satellite exceeded -5.4 dB [Barton, 1965]. The range of acceptable values of I/N might extend from -10 dB for very sensitive systems to values exceeding $+20 \text{ dB}$ for systems with automatic clutter suppression and anti-jamming circuits.

For the remainder of this discussion, a value of 0 dB will be assumed for I/N .

3.4 Variation in G/T

In the band 1215 to 1240 MHz, the antenna sizes range from 1.8 m (6 feet) to 12 m (40 feet) or 15 m (50 feet) for a range of gains 19 dB to 35 dB. Noise figures range from a few dB to $+15 \text{ dB}$. The G/T for the main beam illumination of the satellite is given below for three representative systems:

- a small transportable radar with a 3 metre antenna and a 9 dB noise figure would have a G/T of -10 dB ,
- a large search radar with a 15 metre antenna and a 5 dB noise figure would exhibit a $+10 \text{ dB } G/T$,
- space tracking systems with phased-array antennas of 30 metres and noise figures as low as 1.5 dB have a G/T as high as $+26 \text{ dB}$.

Considering the above examples, it appears that small transportable radars could operate with little or no observable degradation while the larger systems might find compatible co-channel operations difficult.

4. Sharing with the fixed and mobile services and other CW type stations

4.1 Interference from the ~~GPS~~ GPS to the fixed and mobile stations

Power flux-density limitations on the Earth's surface have been specified for space stations operating in the fixed satellite service which share frequencies with the fixed service. These are stated in Recommendation 357 for frequency bands from 1.7 to 23 GHz. Extrapolation of these data to a lower frequency, i.e. 1.2 GHz, would indicate that a power flux-density of $-156 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ would suffice for GPS sharing with the fixed and mobile services. The stated GPS L2 requirement of $-164 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$ should cause no problems. Such services are unlikely to be degraded unless high gain antennas are used, as for tropospheric scatter systems.

4.2 EMC analysis of GPS wideband receiver and terrestrial aeronautical public correspondence

This section addresses interference considerations for a basic wideband GPS receiver utilizing both the precision (P) and coarse/acquisition (C/A) pseudo-random noise (PRN) codes. Interference to a narrow-band GPS receiver utilizing only a C/A code is not considered.

As seen from the table of GPS receiver characteristics contained in Annex I (i.e. for a typical, low-cost, navigation-air receiver), there is not much filtering at 1 593 - 1 594 MHz. Many receivers currently in production have at most 3 dB attenuation due to the filter and, as a consequence, the signal from the aeronautical public correspondence (APC) ground-to-air link appears as an interference source. Further study of the achievable RF filter attenuation is needed, especially insofar as this is a critical factor in the frequency sharing.

The first step in determining the required distance separation between aircraft and APC base is to calculate the APC signal strength at the aircraft GPS receiver input after free space propagation loss, using the following equation:

$$P_R = P_T + G_T + G_R - FDR - L_P \quad (1)$$

where:

P_R	=	received signal power, in dBm
P_T	=	transmitter power output, in dBm
G_T	=	transmitter antenna gain, in dBi
G_R	=	receiver antenna gain, in dBi
FDR	=	frequency-dependent rejection, in dB
L_P	=	propagation path loss, in dB

G_R for the GPS antenna is normally 0 dBi, and FDR is 3 dB. The above equation assumes that there is no shielding from the fuselage, and the receiver is within the line-of-sight of the APC transmitter. The propagation loss, L_P , is given by equation (2) below (for free-space propagation loss only):

$$L_P = 20 \log f + 20 \log D - 27.56 \quad (2)$$

where:

f	=	transmitted frequency, in MHz
D	=	distance, in m

Combining and rearranging Equations 1 and 2 to solve for distance and using 30 dBm as the limiter burnout criterion for received power level results in Equation 3:

$$D = \text{Log}^{-1} \{ (P_T + G_T - 20 \text{ Log } f - 5.44) / 20 \} \quad (3)$$

Assuming a ground based APC transmitter with an EIRP of 46 dBm in the direction of the GPS receiver, the above equation is solved for the distance required to prevent burnout of the high-level clipper. The distance is less than one-tenth meter. Similarly, using -40 dBm as the limiter saturation criterion, the required distance to prevent saturation of the GPS receiver is determined to be 212 m.

If the above minimum required distance separations are met, the GPS receiver will operate without experiencing burnout or saturation; however, the undesired signal strength may still exceed the thresholds for signal acquisition and/or tracking. For normal acquisition by L1 C/A signal, the previously established threshold is -106 dBm. But the APC signal will be