Annex B – TORNADO-IDS EMC/EMI CASE STUDY

B.1 GENERAL

Before installation of the ASHTECH GPS receiver in the TORNADO-IDS experimental aircraft, some ground tests were performed to investigate EMC/EMI aspects. In fact, due to the need of using an L-band telemetry datalink for the TORNADO flight trails (including safety-critical test points and requiring real-time data analysis at a remote ground station), the EMC/EMI aspects of the GPS and datalink coexisting installations into the aircraft had to be deeply analysed. This was necessary because the GPS and upper datalink antennas, respectively receiving and transmitting in the same spectral band, were relatively close one to the other, and because possible interference problems degrading reception/ reacquisition of GPS signals at the airborne GPS antenna location could seriously affect the validity of the flight trials.

B.2 EXPERIMENTAL SET-UP

The ASHTECH GPS antenna and two telemetry antennas were installed on an aluminium-alloy plate. The telemetry antennas were placed at distances of 70 cm and 27 cm respectively from the GPS antenna, in order to investigate the effect of distance on telemetry-GPS interference. The Spectrum Analyser TEKTRONIX 495P (input impedance = 50 Ω, frequency interval = 100 Hz ÷1.8 GHz, maximum signal level = 30 dBm) was used for the ground tests (Figure B-1).

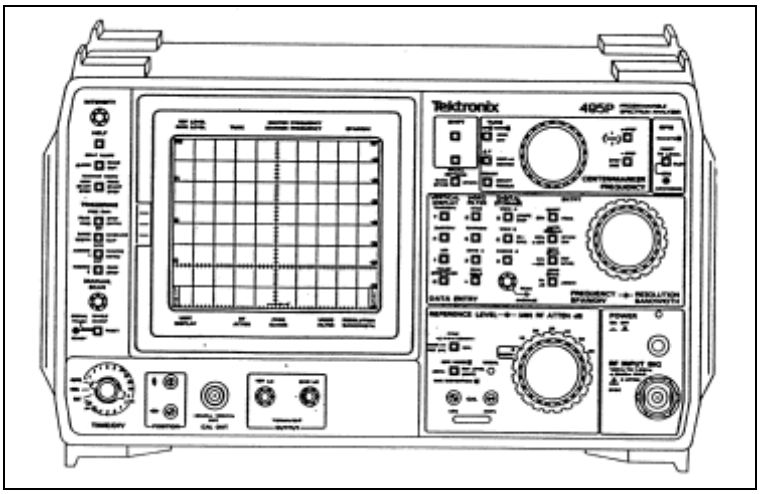

Figure B-1: Spectrum Analyser (TEKTRONIX 495P).

During the tests, two different telemetry transmitters were used:

- MICROCON T-710 model, high quality (very narrow-band) transmitter with carrier frequency of 1460 MHz; and
- SOUTHERN CALIFORNIA MICROWAVE TTX 13L-10A model, medium quality transmitter with carrier frequencies (selectable) in the interval 1435.5 MHz ÷ 1540.5 MHz.

For the ground test, the Spectrum Analyser was connected to the exit of the GPS antenna pre-amplifier. This pre-amplifier has a gain of 48 ± 4 dB, an input voltage of 9.5 ± 2V, and an input current 80 ± 10 mA. The GPS antenna pre-amplifier response to an input signal at –80 dBm is shown in Figure B-2.

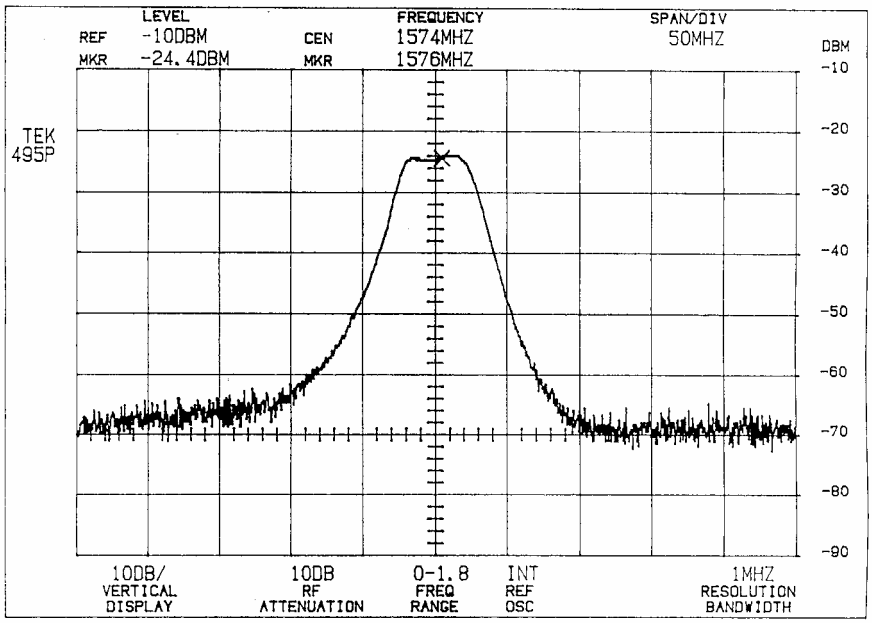

Figure B-2: GPS Antenna Pre-Amplifier Response.

The instrumentation set-up used for the interference measurements is shown in Figure B-3.

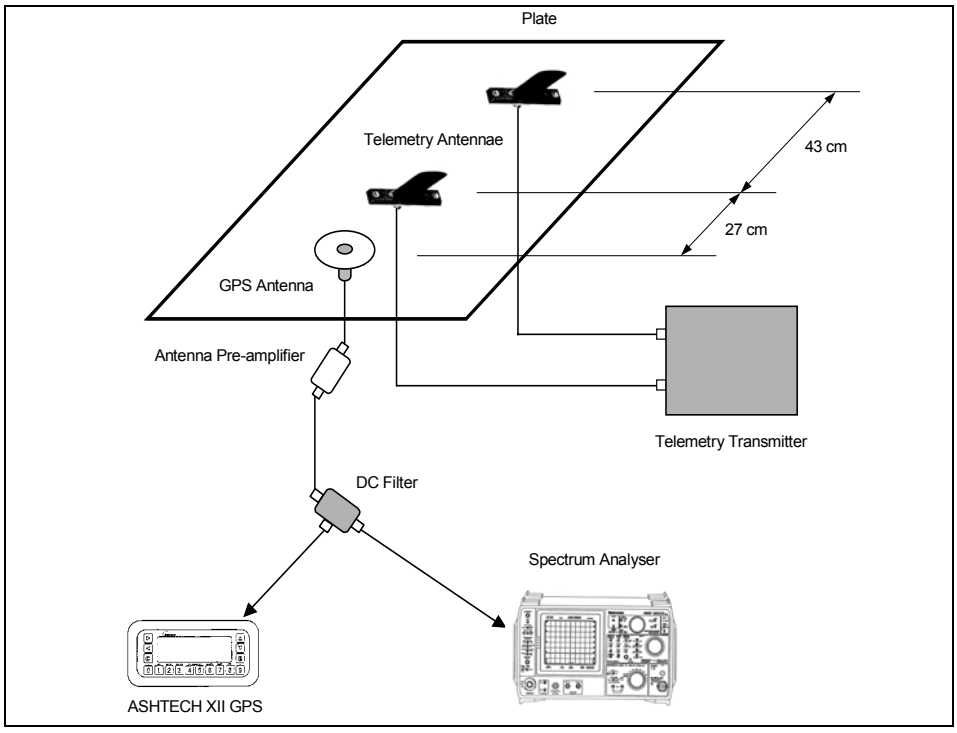

Figure B-3: Interference Measurements Set-up.

With this experimental set-up, the GPS signal power spectrum in the absence of telemetry signal (Telemetry Transmitter off) could be displayed on the Spectrum Analyser (Figure B-4).

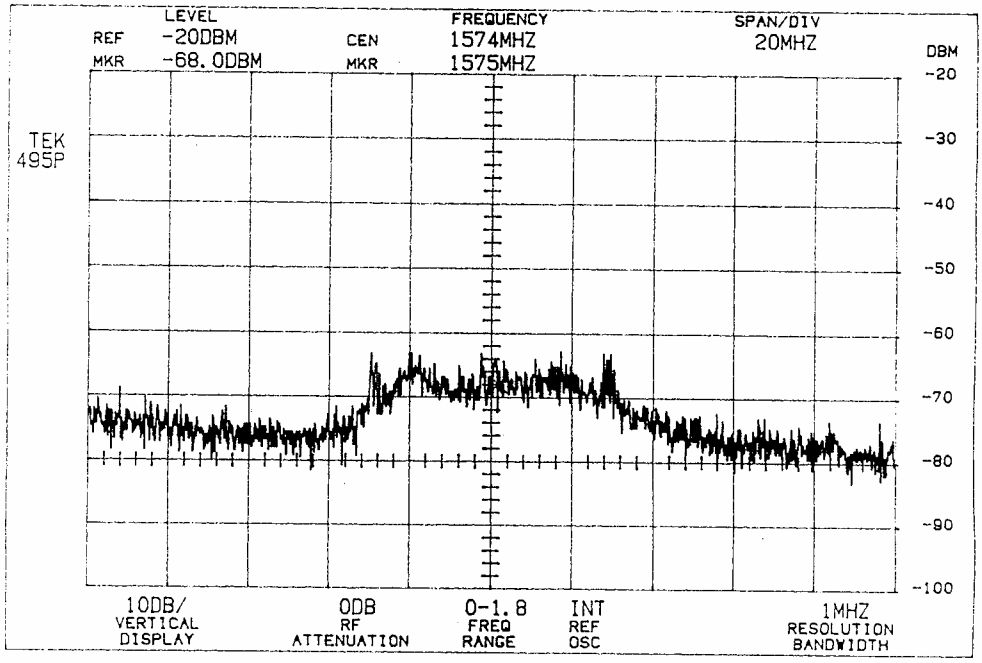

Figure B-4: GPS Signal Power Spectrum.

Successively, the Telemetry Transmitter was turned on. The resulting power spectrum in the GPS signal band is shown in Figure B-5.

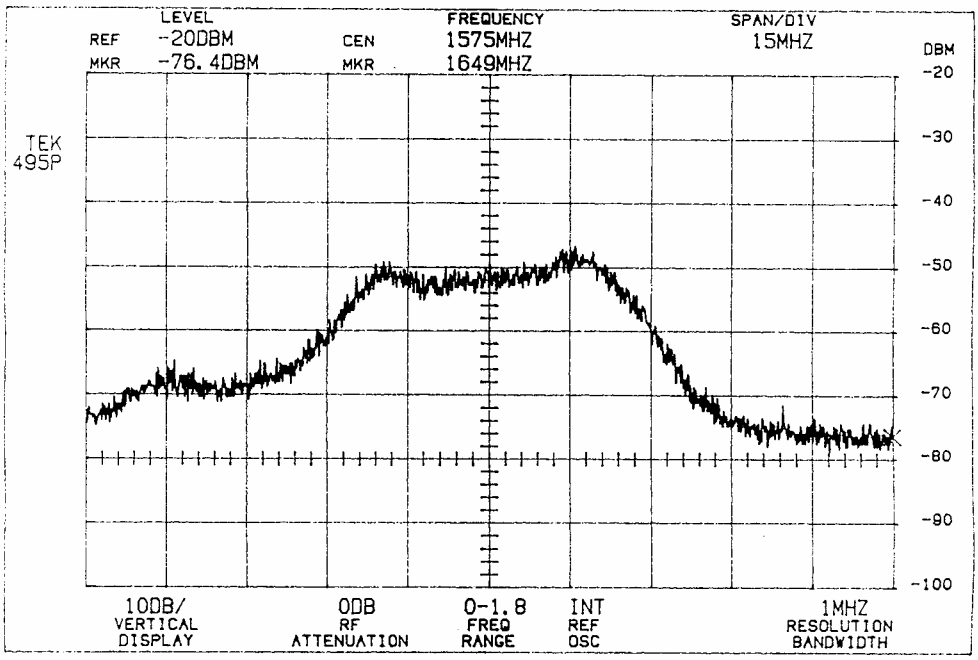

Figure B-5: GPS/Telemetry Power Spectrum in the GPS Signal Band.

The complete spectrogram showing both the GPS signal and the telemetry signal (carrier and spurious signals) is shown in Figure B-6.

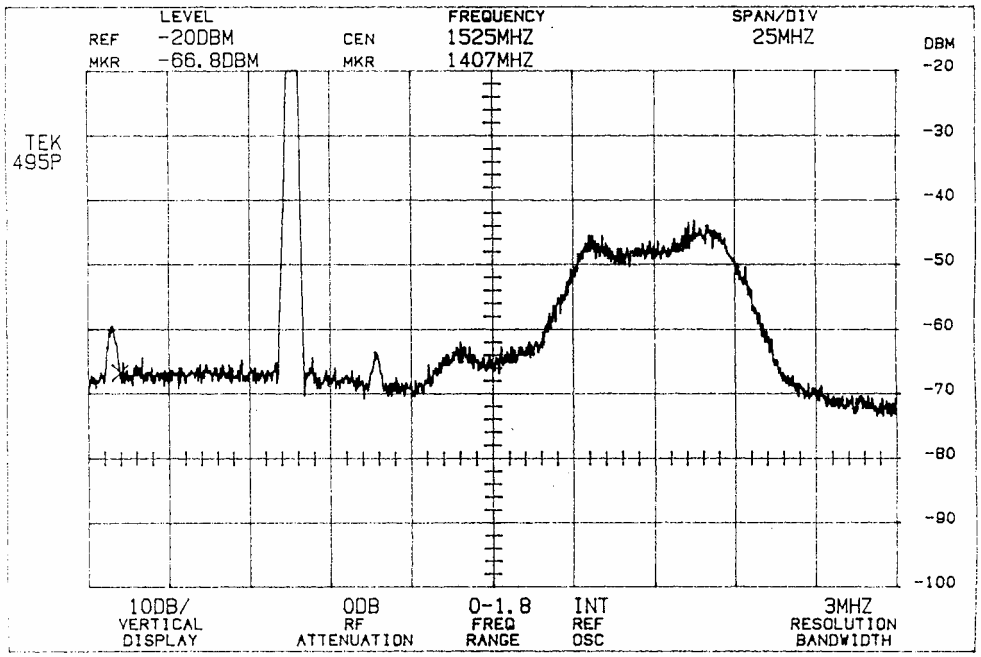

Figure B-6: Overall GPS/Telemetry Signal Power Spectrum.

In order to verify the effects of this significant telemetry interference on the GPS receiver, we looked at one of the ASHTECH XII display menus called "signal-health". This particular menu shows the tracked satellites numbers (**sv**) and some information regarding the signals received from the satellites, like the signal-to-noise ratio (**s/n**) and the satellite tracking parameter (**cnt**). An example is shown in Figure B-7.

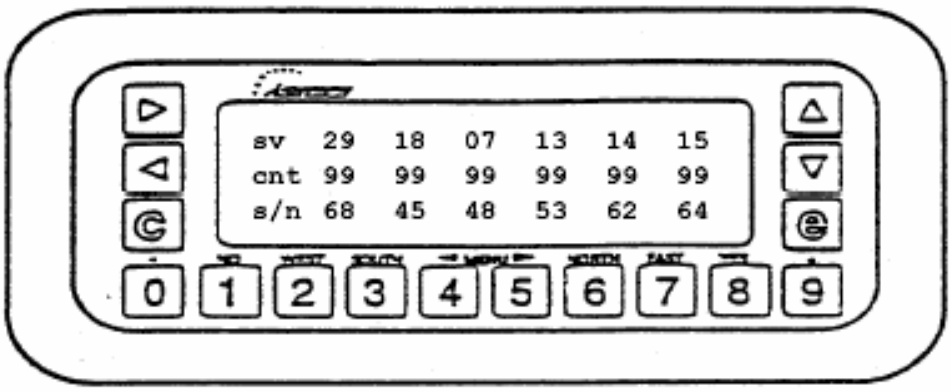

Figure B-7: ASHTECH XII Signal-Health Display Format.

Regarding the signal-to-noise ratio, a "weak" signal has a **s/n** of less than 30 dB, while a "strong" signal has a **s/n** greater than 50 dB. The **cnt** parameter relative to a particular satellite goes to 00 when the receiver lose track to a satellite, and it is normally at a value of 99 when the satellite is being tracked.

Two signal-health formats relative to tracking (a) and lose of tracking (b) of the GPS satellites due to telemetry transmission, are shown in Figure B-8.

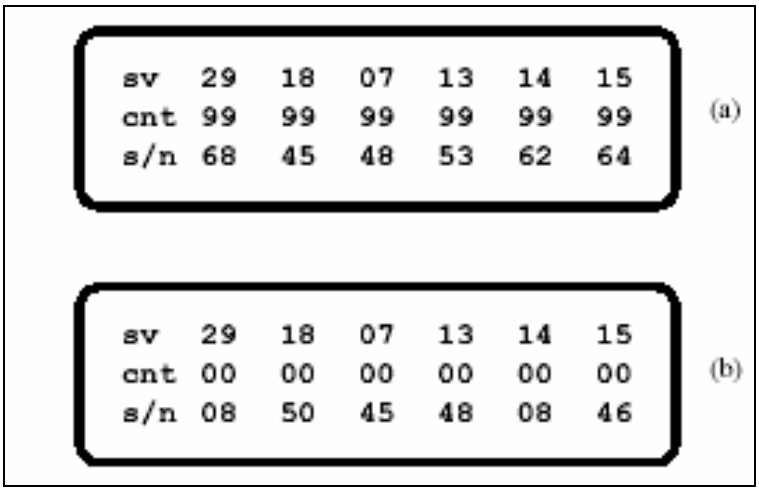

Figure B-8: Signal-Health Display Formats Before and During Interference.

It appears that the **s/n** values immediately decrease down to certain minimum values and then "freeze" when the satellite signals are lost due to telemetry interference. No significant difference in the GPS tracking behaviour (immediate loss-of-lock to the satellites) was observed transmitting at all assigned telemetry frequencies (1442.5 MHz, 1436 MHz, and 1460 MHz), and using alternatively the two telemetry antennae installed on the plate (27 cm and 70 cm from the GPS antenna).

B.3 FILTERING

Since the L-band telemetry transmission caused such a severe interference that prevented the GPS receiver satellite signal tracking, an L-band filter was identified (MU-DEL ELECTRONICS MCP1478-110-9BB model), whose characteristics were deemed suitable for insertion between the Telemetry Transmitter and the antennae. The L-band filter characteristics are listed in Table B-1. The L-band filter transfer function is shown in Figure B-9.

Table B-1: L-Band Filter Characteristics

Characteristics	Lower Rejection Point	Lower 1 dB Point	Centre Frequency	Upper 1 dB Point	Upper Rejection Point
	1239.9	1430	1478	1526	1563.1
Attenuation (spec.)	50 dB	2.0 dB	1.0 dB	2.0 dB	50 dB
Attenuation (meas.)	> 50 dB	< 2.0 dB	< 2.0 dB	< 2.0 dB	> 50 dB
VSWR (spec.)	N/A	< 1.5 : 1	< 1.5 : 1	< 1.5 : 1	N/A
VSWR (meas.)	N/A	< 1.5 : 1	< 1.5 : 1	< 1.5 : 1	N/A

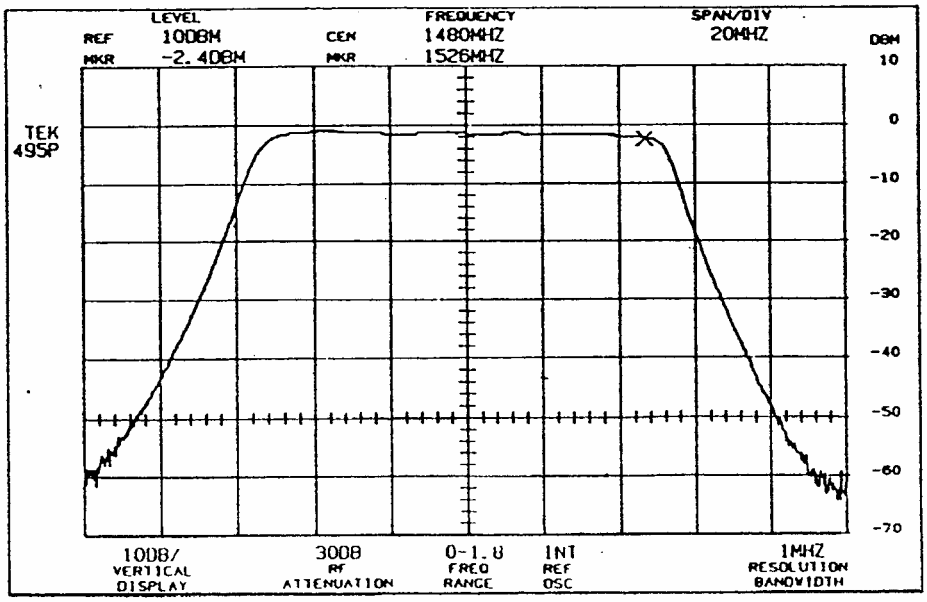

Figure B-9: L-Band Filter Transfer Function.

The L-band filter attenuates the telemetry signal of about – 2 dBm, but it guarantees, based on the specs, an attenuation of 50 dBm at frequencies greater than 1563.1 MHz. Therefore, in principle, that filter could avoid interference at 1575.42 MHz (GPS L1 frequency). After installing the L-band filter between the Telemetry Transmitter and the antennae, further ground tests were performed.

Two GPS receiver signal-health formats recorded before (a) and after (b) activating the telemetry transmitter, are shown in Figure B-10.

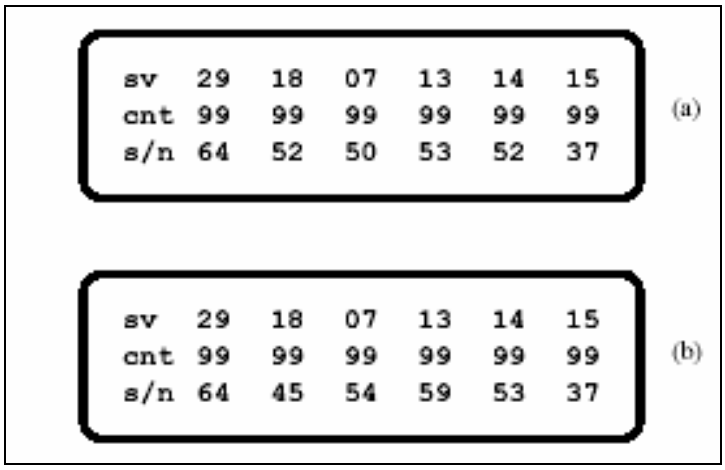

Figure B-10: Signal-Health Display Formats with L-Band Filter.

It is evident that, from a practical point of view, the L-band filter significantly improved the GPS receiver performance, avoiding the interference problems previously found. In order to further investigate the effects of the L-band filter insertion on the L1 GPS signals tracked by the ASHTECH XII receiver, we also measured with the Spectrum Analyser the signal received by the GPS antenna. The results of these measures are shown in Figures B-11 and B-12.

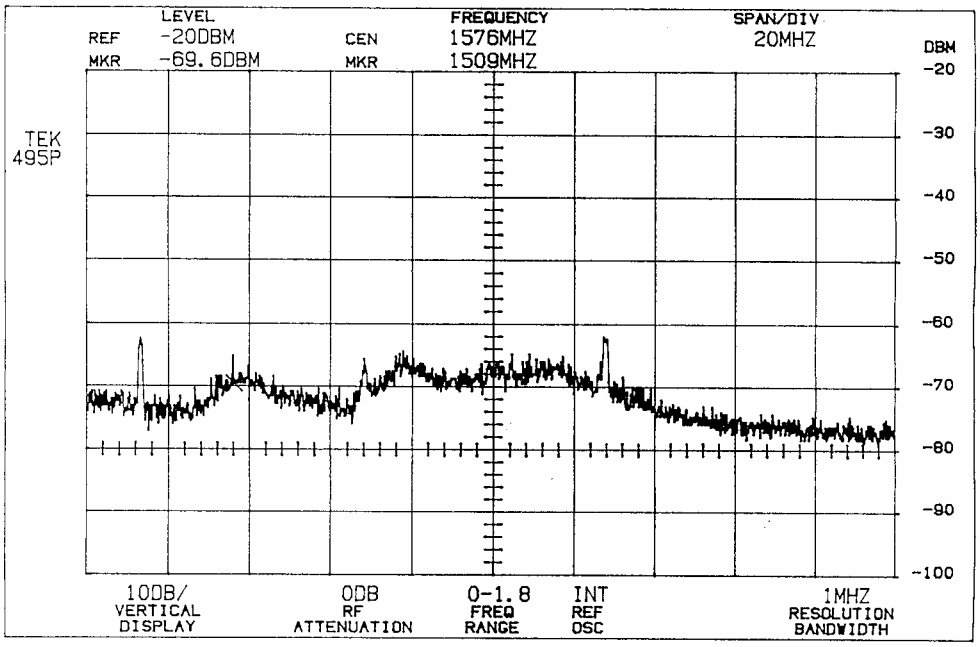

Figure B-11: GPS/Telemetry Signal Spectrum in the GPS Signal Band (with Filter).

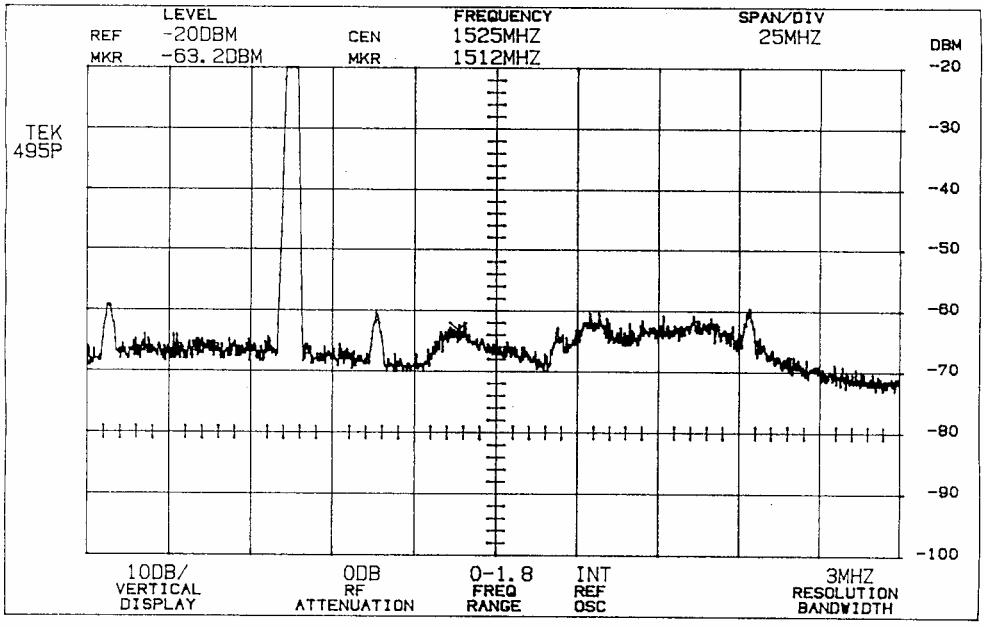

Figure B-12: Overall GPS/Telemetry Signal Spectrum (with Filter).

Both the GPS signal and the telemetry signal received by the GPS antenna did not show significant changes. The irregularity of the spectrum and the presence of picks are probably due to signal distortions, which may be caused, for instance, by the GPS antenna pre-amplifier. Unfortunately, the instrumentation available was not sufficient to test this hypothesis, since the level of the disturbance was comparable to the background noise. The telemetry signal spectrum with the L-band filter is almost unchanged, as shown in Figure B-13 (see Figure 5-9 in Chapter 5 for comparison).

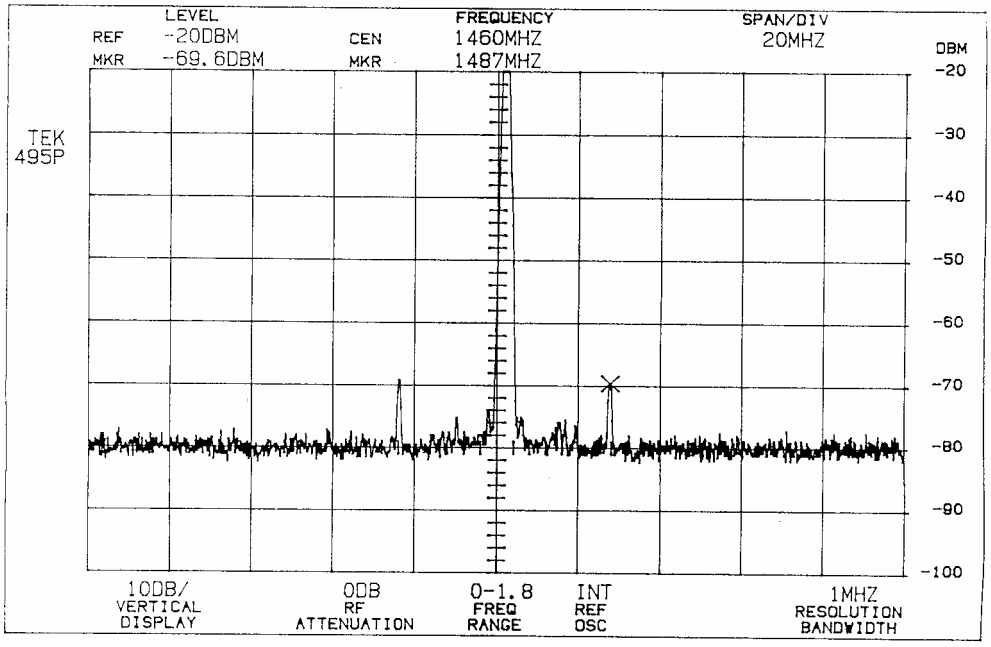

Figure B-13: Telemetry Spectrum with L-Band Filter.

Finally, disconnecting the GPS antenna pre-amplifier and connecting the GPS antenna directly to the Spectrum Analyser, no significant changes were observed between the spectrum of the telemetry signal without the L-band filter (Figure B-14) and with the L-band filter (Figure B-15).

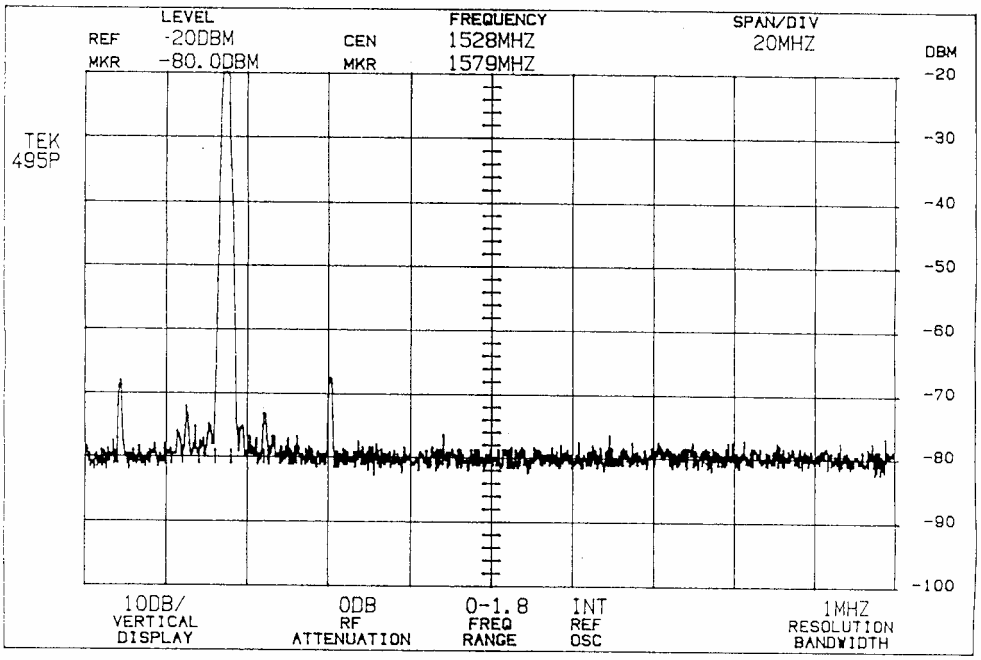

Figure B-14: Telemetry Spectrum without L-Band Filter (No Pre-Amplifier).

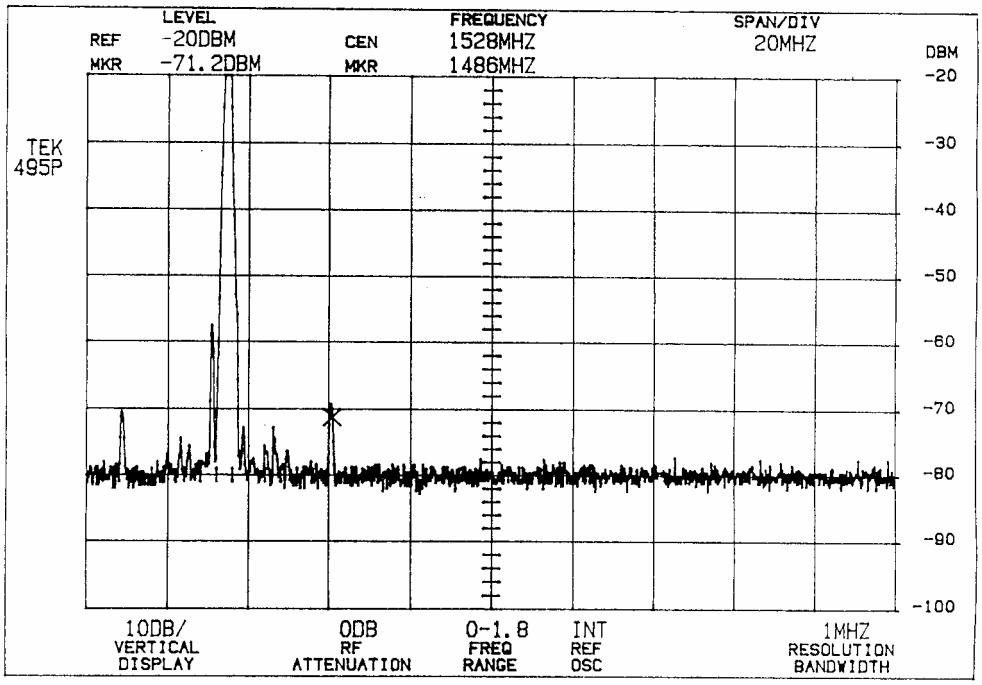

Figure B-15: Telemetry Spectrum with L-Band Filter (No Pre-Amplifier).

Due to the positive results of the ground tests performed with the L-band filter MU-DEL ELECTRONICS mod. MCP1478-110-9BB, this filter was finally selected for installation on the TORNADO-IDS FTI system.