The impact of LTE-TDD transmissions on VSAT DVB-S reception in C-band

A report for Huawei

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Executive Summary

This report summarises testing that was carried out in the Rome area in August and December 2016 as a joint exercise between the CNCER (Centro Nazionale Controllo delle Emissioni Radioelettriche) within Italy Ministry of Economic Development (MISE), the Fondazione Ugo Bordoni (FUB) and Huawei, to determine the impact of an LTE-TDD Radio base station on a domestic VSAT (Very Small Aperture) satellite system operating at 3600 - 3800 MHz.

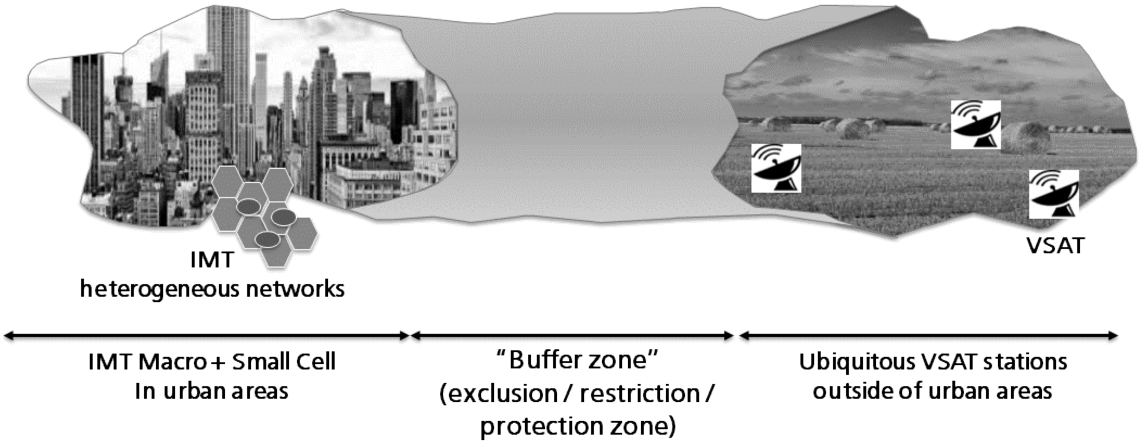
Measurements were performed for a specific set of environments and under a specific set of conditions; therefore, results may not be generalized and may not apply to all environments and conditions. The fieldwork has been supplemented by a series of laboratory measurements jointly attended by MISE, FUB and Huawei to characterise the selectivity and overload characteristics of representative domestic receiving equipment.

While noting that field testing results relate to the specific conditions that were tested and may not apply under all possible conditions, the field trials have provided some confirmation of the predictions made in [5], showing as they do that co-frequency sharing may be possible in realistic scenarios for separation distances between 1.2km and 3.8km.

A significant improvement in compatibility was confirmed for the adjacent channel case, with an additional 20dB protection available for a frequency offset of 28 MHz between LTE and VSAT channel centres.

The laboratory measurements of receiver selectivity were also in agreement with the results measured in the field, and suggest that there may be relatively little variation in selectivity between different receivers. The overload characteristics of satellite receivers were confirmed, and the data gathered will allow reliable modelling of inter-service sharing.

The results summarized above support the scenario in which IMT networks could be rolled out in urban areas while ubiquitous VSAT stations could still be able to operate on the same frequency channels just outside those urban areas.



Even if the test campaign was carried out for a specific set of conditions, the combination of the detailed receiver characterisation (given in Section 4) with a reliable propagation model, will allow the modelling of arbitrary sharing situations. Such modelling could be carried out within a Monte Carlo framework to provide estimates of the probability of interference in specific or generalised scenarios.

In February 2017 ITU-R Study Group 5 WP 5D adopted a new Recommendation[1], "*Modelling and simulation of IMT networks and systems for use in sharing and compatibility studies*". This document describes methods for aggregating interference power due to IMT networks. Such modelling is necessary as field trials will generally be unable to replicate interference from many base stations, but a necessary precursor is to ensure that single-entry interference can be adequately modelled. The results described in this report are intended to provide the data necessary for such modelling.

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[1] Recommendation ITU-R M.2101-0

1 Introduction

With the growth in interest in the use of the 3.6-3.8 GHz band for mobile services, attention has focussed on the need for sharing with satellite systems incumbent in this band. One class of satellite terminal, quite prevalent in Africa, Asia and Latin America, is the Very Small Aperture Terminal (VSAT) used to receive broadcast television. C-band is popular for this application in equatorial and tropical areas as the losses associated with heavy rain can cause severe disruption to satellite broadcasting operating at higher frequencies. In these circumstances, the significant penalty of the large antenna dish that is necessary at C-band is worth paying.

To gauge the impact of LTE services on TV Receive-Only (TVRO) VSAT installations, Huawei, MISE (CNCER) and FUB have recently conducted a number of field trials near Rome (CNCER[2]), supported by laboratory testing in Milan (Huawei laboratories).

The essential purpose of the trials reported here was to verify, from field experience, under what circumstances an LTE base station might transmit on the same channel used for VSAT reception in the local area, and to investigate the impact of adjacent channel operation. These tests are reported in Section 3 below.

Given the limited number of trials possible, and the great variation of propagation paths and potential scenarios, field testing results relate to the specific conditions that were tested and may not apply under all possible conditions.

To allow the robust modelling of arbitrary deployment and sharing scenarios, laboratory tests have therefore been carried out to determine relevant technical parameters of typical consumer VSAT equipment. The results of the laboratory testing are described in Section 4.

[2] Centro Nazionale di Controllo Emissioni Radioelettriche

2 Background

A potential constraint on the use of the 3600 – 3800 MHz band for LTE services is the present use of this band for satellite downlinks operating in the Fixed Satellite Service (FSS). Although little used in Europe, where the use of higher frequencies by the FSS is more convenient, C-band is widely used in Africa, Asia and Latin America due to the better performance in rainy climates.

While co-ordination contours can be defined around large Earth station sites at known locations, such approach may not be applied 'Very Small Aperture Terminal' or VSAT whose location may not be known and that represents an important class of FSS terminal. Although there is no formal definition of what constitutes a VSAT, such equipment will generally have an antenna of 1.8-2.4 m diameter at C-band, and may be a receive-only system for TV reception, or include a transmitter to allow full internet or private network access. VSAT stations are exempted from individual licensing. This signifies that there is no information available, either on the geographical location or the frequencies at which these devices operate. VSATs are typically not protected from possible interference from other systems.

Although interference from C-band mobile broadband services to satellite Earth station receivers has been considered in documents such as ECC Reports 100, 203 & 254 [1], [2], [3] and ITU-R Recommendation M.2109 [4], these studies have mostly related to terminals used for bi-directional telecommunications, and having antenna diameters of 4.5m to 32m. Typical TVRO dishes have antennas of 2.4m or less.

2.1 Co-channel interference

Generic (rather than TVRO) VSAT reception is considered in [1], deriving separation distances of up to 60km for co-channel operation on the basis of an interference criterion of I/N <-10dB for 20% time. If modelling is to progress beyond the use of such conservative criteria, it will be necessary to characterise the satellite system in more detail, taking account of, e.g., the particular characteristics of DVB-S receivers.

In work [5] previously undertaken for the GSM Association (GSMA) by Transfinite Systems Ltd, predictions were made of the areas around VSAT terminals that would be subject to interference from LTE base stations operating on the same frequency. Examples in Bogota, Johannesburg, Kuala Lumpur and Hanoi were given. The GSMA studies initially determine separation distances in the order of 5-30km using a traditional I/N criterion but when the modelling takes into account the actual link margin available to the satellite receiver (in other words, considering the carrier to interference and noise ratio, C/(N+I)), the required separation distances are reduced to between 1-5km.

The field trials described in Section 3 would seem to support this modelling, showing as they do that co-frequency sharing may be possible in realistic scenarios for separation distances between 1.2km and 3.8km.

2.2 Adjacent channel interference

Other sections of [1] consider adjacent channel interference, but only with respect to the impact of spurious base station emissions, and overload effects. To improve the accuracy of spectrum sharing models it is also necessary to understand receiver selectivity characteristics, and such measurements are reported in Section 4.2 of this document. In Reference [1] an overload onset of -60dBm is assumed for C-band LNB (Low Noise Block) receivers, which can imply separation distances of up to 11km from macrocell base stations although the present field measurements suggest much smaller distances will be required in practice; The overload characteristics of three contemporary LNBs have been measured and are reported here in section 4.3.

A contribution from the GSMA to an ITU-R Joint Task Group [6] considered the guard-band needed to prevent adjacent-channel interference from urban IMT services into VSAT receivers in the same area. This study convolved standard IMT systems emission masks and an FSS receiver mask taken from a study carried out in Singapore. This study applied an interference criterion of I/N= −20 dB, and derived guard bands necessary (for protection of VSAT receivers within a ubiquitous macrocell network) of up to 26 MHz, for an LTE bandwidth of 10 MHz.

The ITU-R sharing methodology of [6] considers telecommunications-type VSAT terminals with bandwidths of only 154 kHz (although such narrowband systems are unrepresentative of TVRO systems this is of little relevance if the interference criterion is expressed as an I/N requirement). A free-space propagation model is applied, but it is noted that local clutter can provide between 2-33 dB of additional isolation, though this would not be available for the common class of roof-mounted VSAT terminals. This study again applies a criterion of I= N-10dB at 20% time.

While such stringent criteria may be appropriate as a trigger for detailed co-ordination with large, traditional Earth stations, it is, arguably, inappropriate for the VSAT TVRO case, where deployment is ubiquitous and unlicensed.

In this case, what is really required is a robust method to assess the likelihood of interference occurring in practice. As well as being based on realistic, modern, system parameters, such an approach would also acknowledge that a significant link margin is often available at the 'victim' receiver.

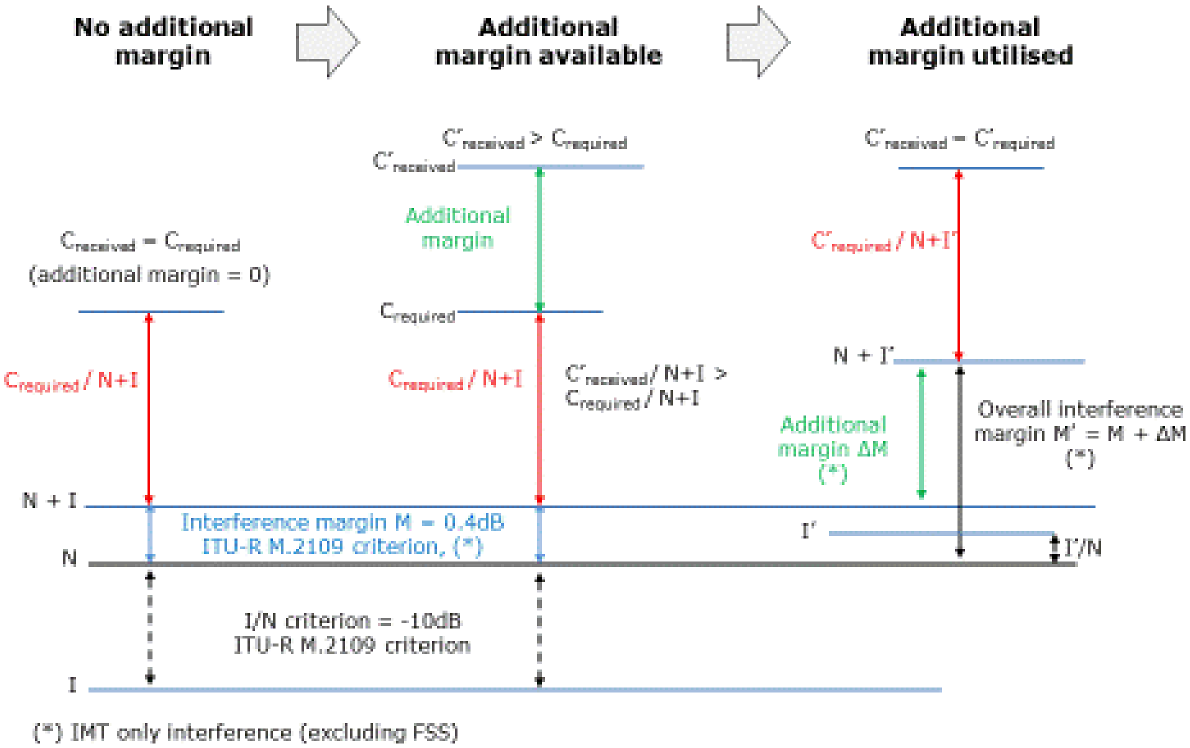

Figure 2-1: Use of available link margin to improve overall spectrum efficiency

The figure above illustrates the conventional planning assumption on the left; here the received carrier at the VSAT terminal is just sufficient to support the link in the presence of interference that raises the thermal noise floor by 0.4dB.

The situation more generally found in practice is illustrated in the middle, where the actual received carrier level provides several dB of additional margin. If this margin is well defined, some of it can be used to allow more efficient use of the spectrum by other services, raising the overall 'noise + interference' floor of the satellite receiver, but leaving adequate headroom[3] for satisfactory reception of signals.

The penalty for this increased spectrum efficiency is that it demands a better understanding or real-world system performance; the trials reported in this paper aim to provide this information.

[3] It may be noted that satellite systems will require a much smaller fade margin than is necessary in fixed link systems operating in the same band, which may need to allow for multipath fades of over 40dB.

3 Field tests

The impact of LTE signals on satellite reception was assessed by using a transportable eNodeB to radiate LTE-TDD signals at different distances from a satellite receiver, configured to demodulate a commercial DVB-S television signal.

Interference was assessed at a range of distances and azimuths, at each of which the power of the LTE transmitter was varied while observing the received DVB-S Bit Error Rate (BER) and other parameters.

3.1 Technical parameters

3.1.1 LTE terminal ('interferer')

An LTE eNodeB, provided by Huawei, was installed in a CNCER[4] mobile laboratory, with the parameters given in the table below

Table 3-1: LTE parameters

Antenna	Huawei ATD4516R7 (gain = 15.5dBi)
Feeder	Cellflex SCF 12-50J (10.3 metres, 2.2dB loss)
TX power	20—40 dBm (into each of two MIMO antenna ports)
EIRP	33.3 – 53.3 dBm
Antenna height	9.5 m agl
Frequency	3730 MHz
Bandwidth	20 MHz
PCI	01
Traffic	Generally 70% (also varied 30% - 100% in some testing)

The transmitter van is shown in the figure below.

4

Figure 3-1: MISE van used for LTE transmission (at 'eNodB1' location)

3.1.2 VSAT terminal ('victim')

A receiver system intended for domestic reception of digital satellite TV services in C-band was procured. This consisted of a 1.8m dish antenna, a low-noise amplifier and block converter (LNA/LNB) and a receiver/demodulator unit for the DVB-S standard. In the event, the receiver/demodulator unit was not used for the field tests; a test demodulator provided by MISE was substituted.

Details of the equipment used are given below:

Table 3-2: VSAT characteristics

Location	41° 59' 12.53" N, 12°34' 25.65" E, altitude: 73m asl
Antenna	1.8m prime focus parabola
LNA/LNB	WS International 741U universal C/Ku band LNA/LNB
Noise temperature	13 K
Frequency band (input)	3400 – 4200 MHz
LNA/LNB gain	65 dB
Local oscillator frequency	5150 MHz
IF output	950 -1750 MHz
Receiver/demodulator	Sefram TV analyser model number 7876

The satellite receiver was configured to demodulate a transmission from a Eutelsat satellite in an (geostationary) orbital position of 5°W. The signal parameters are given in the table below.

Table 3-3: Satellite transmission parameters

Satellite	Eutelsat 5W
Azimuth	205.3°
Elevation	38.5°
System	DVB-S
Station name	TVE INT Africa
Frequency	3727 MHz
Polarisation	Vertical
Code rate	7/8
Symbol rate	29952 kbaud
Modulation	QPSK
Channel bandwidth	42 MHz

The satellite receiver was located in the grounds of the CNCER, on the Via di Tor San Giovanni, Rome. The Ministry also provided a van to allow measurements to be made of the incident field strength from the LTE interferer.

3.1.3 Measurement receiver

To verify the power incident at the VSAT receiver from the LTE transmitter, a Rohde & Schwarz TSMW 'Universal Radio Network Analyser' (TSMW Analyser hereafter) measuring receiver[5] was used with a calibrated antenna.

The gain of the antenna was 27dBi, with a cable loss of 7.8dB. A preamplifier with 25.5dB gain could be switched in, but was not used for the present tests.

The TSMW reports two received powers:

- The 'S-sync' value relates to power received in a 1 MHz bandwidth, and a correction of $10*LOG_{10}(20) = 13$dB should therefore be applied to determine the power in the entire 20 MHz LTE bandwidth.
- The 'RSRP' relates to a single resource block (RB). There are 1200 RB in the 20 MHz channel, so a correction of $10*LOG_{10}$ (1200) = 30.8 dB should be applied.

A further correction is necessary if the loading is less than 100%. For most tests, the load was 70%, so the correction required is 10*LOG10(1/0.7) = 1.6 dB.

[5] The TSMW reports an RSRP power value that relates to a single reference symbol averaged over 72 subcarriers. The reported value is therefore corrected by a factor (30.85 dB) representing the total number of subcarriers in the channel. A further factor was used to allow for the specific traffic level used for a test; for 70%, this factor is 1.55 dB.

Figure 3-2: VSAT receiver dish, with MISE van used for field-strength measurement

3.2 Test locations & calibration

In the course of the VSAT compatibility field trials, four transmitter locations were used for the transportable eNodeB. The first two points were aligned with the azimuth pointing of the VSAT antenna, in a direction largely unobstructed by local obstacles and at ranges of 1.2 and 3.8 km. Points 3 and 4 were behind the VSAT antenna dish (off-axis angles of 107° and 150°) with the paths partly obscured by a line of trees some 10 metres from the VSAT antenna.

Figure 3-3: Transmitter locations

Path profiles and propagation predictions are shown below for all paths. In all cases the LTE transmitter is on the left-hand side.

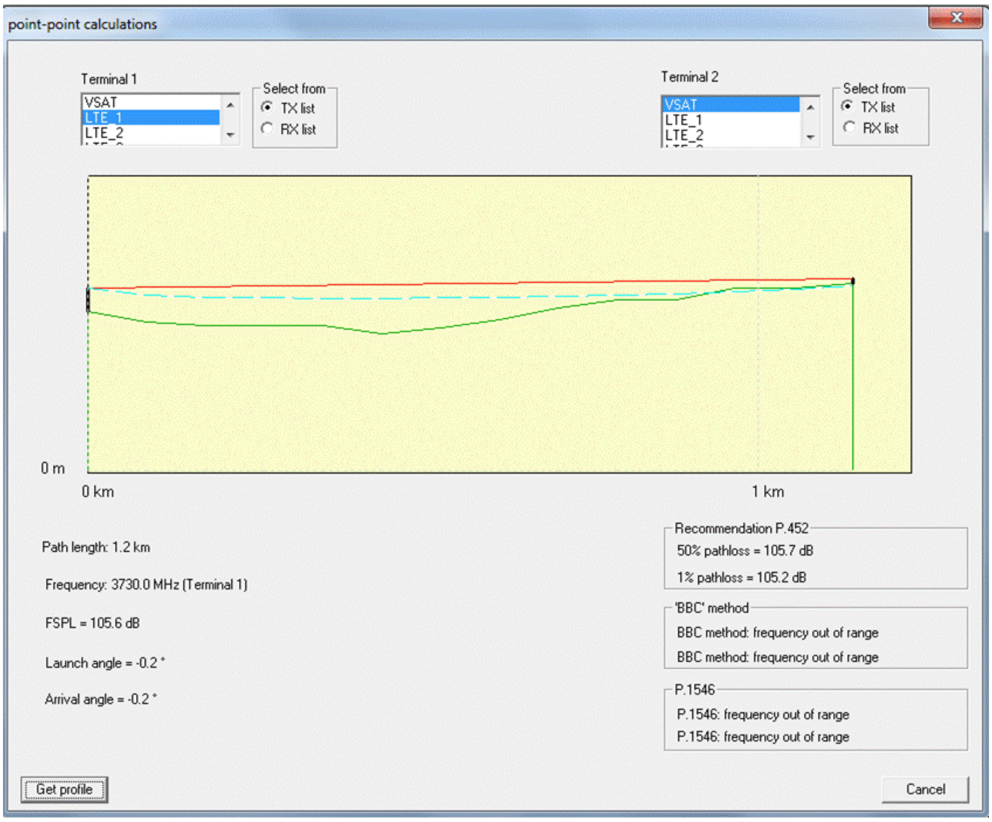

Figure 3-4: Path profile from LTE site 1

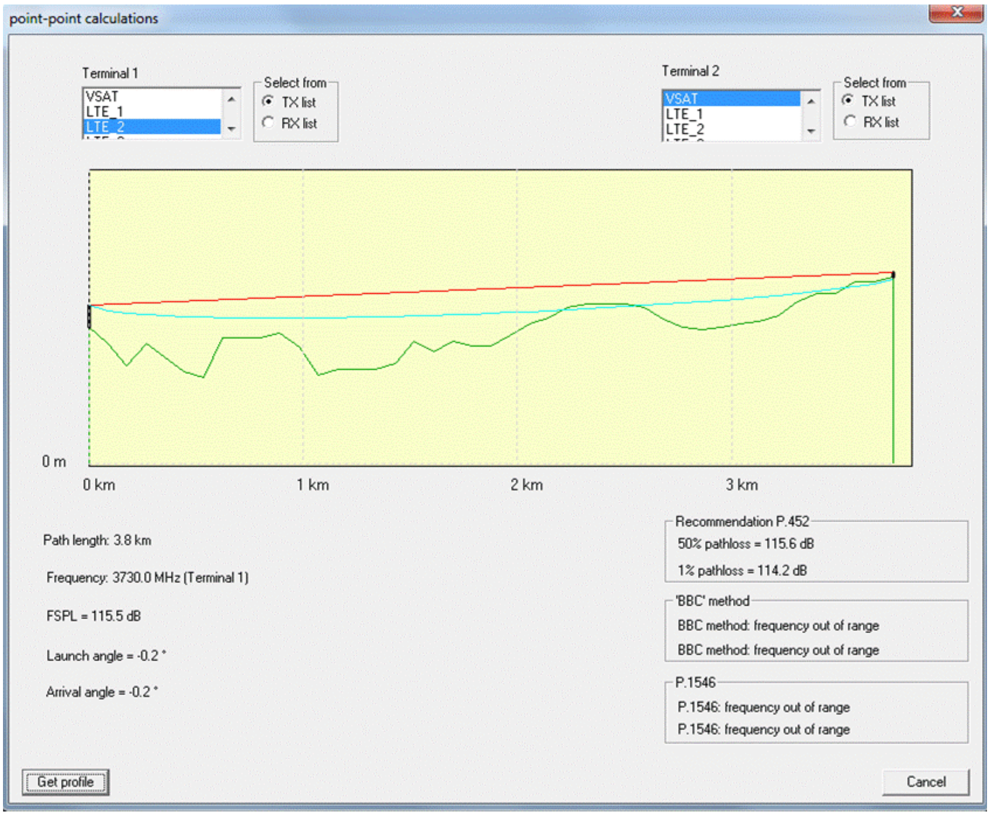

Figure 3-5: Path profile from LTE site 2

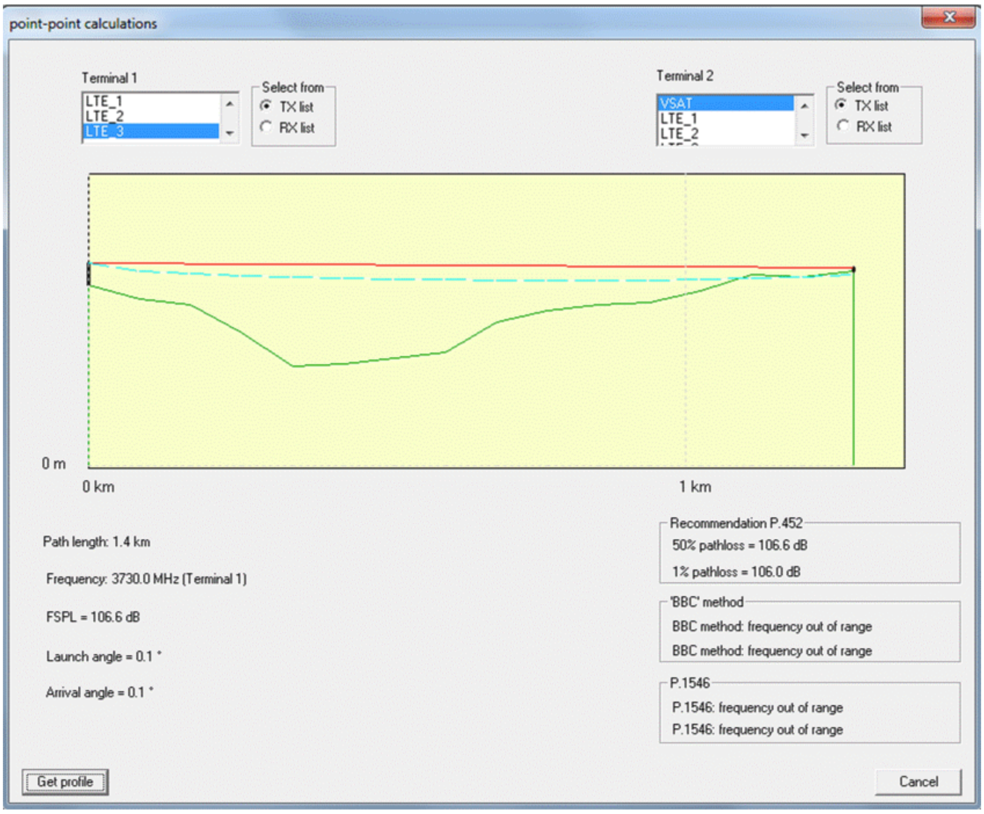

Figure 3-6: Path profile from LTE site 3

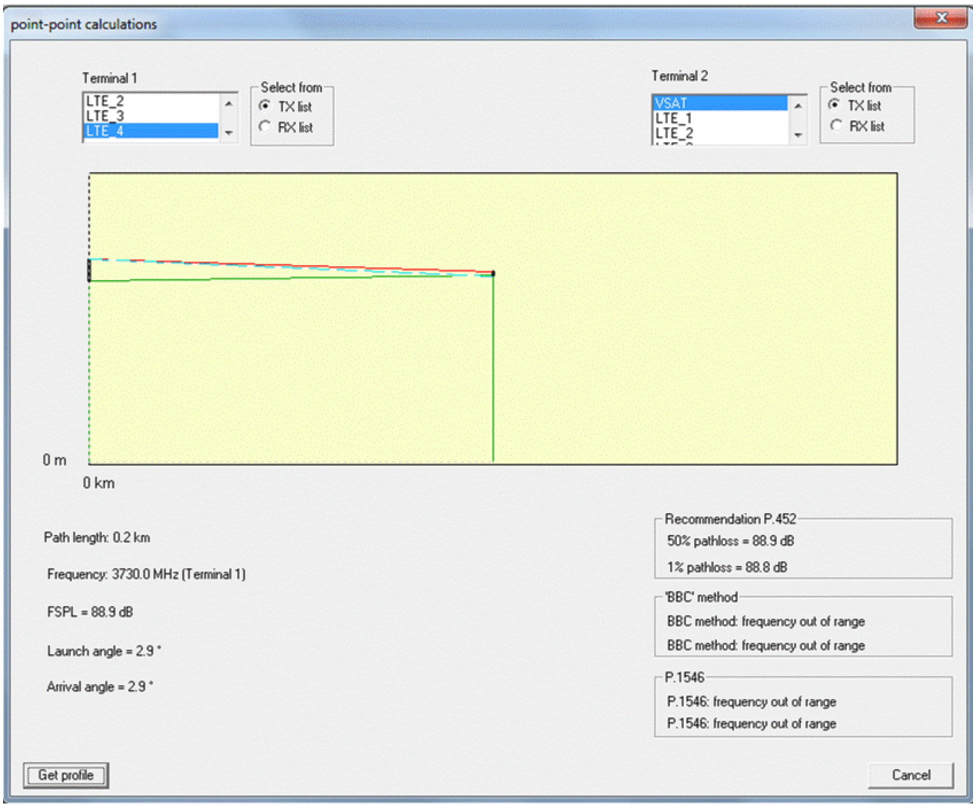

Figure 3-7: Path profile from LTE site 4

3.3 Predicted and measured path losses

For each of these paths, the predicted free-space field strength was determined, and compared with the actual received power as measured on the TSMW measurement receiver. The difference between the prediction and the measured results should represent the additional propagation loss on each path (due to diffraction over terrain and obstacles, and absorption in vegetation).

Table 3-4: Predicted and measured path losses

LTE base station location	**LTE site 1**	**LTE Site 2**	**LTE Site 3**	**LTE Site 4**
Latitude / Longitude	41°58'36.10"N 12°34'4.20"E	41°57'22.81"N 12°33'6.85"E	41°59'41,58" N 12°33'40,66" E	41°59'15.73"N 12°34'32.09"E
Height (above sea level)	53 m	47 m	67 m	66 m
Path length	1.22 km	3.84 km	1.37 km	0.18 km
Off-axis angle WRT satellite	1°	3°	107°	150°
EIRP (max)	53.3 dBm	53.3 dBm	53.3 dBm	53.3 dBm
Free-space path loss (3.73 GHz)	105.6 dB	115.5 dB	106.6 dB	88.9 dB
Receive antenna system gain	19.2 dBi	19.2 dBi	19.2 dBi	19.2 dBi
Predicted free-space received power	-33.1 dBm	-43.0 dBm	-34.1 dBm	-16.4 dBm
A: Measured LTE (20 MHz, 100%) ***(S-sync*** *+ 13 + 1.6 dB)*	*-71.4 dBm*	*-90.4 dBm **	*-51.4 dBm*	*-48.4 dBm*
B: Measured LTE (20 MHz, 100%) ***(RSRP*** *+ 30.8 + 1.6 dB)*	*-73.6 dBm*	*-93.6 dBm **	*-54.6 dBm*	*-51.6 dBm*
Delta A – F/S	***-38.3 dB***	***-47.4 dB***	***-17.3 dB***	***-32.0 dB***

* Measured in August tests (others measured in December)

The last line of the table, showing the additional propagation losses in excess of free space, indicate the substantial isolation that can be provided between terminals in real world situations. In any comprehensive sharing analysis, it is therefore necessary to ensure that a statistically-reliable propagation model is used, based on measurements corresponding to the scenario under investigation.

3.4 Antenna calibration

To confirm the system calibration, further detailed measurements of the antennas were undertaken by CNCER and Huawei on 22nd February, 2017, at the CNCER site (Via di Tor San Giovanni, Rome).

In these trials, the transmit antenna was installed on the telescopic vehicle mast as shown in Figure 3-1, and fed with a CW signal at 3600 MHz from an Agilent E4428C signal generator.

The receiver was located at a range of 116 metres, with a clear line-of-sight path, and two antennas were used; the directional, 27dBi van-mounted antenna used in the field trials (seen in Figure 3-2**Error! Reference source not found.**) and an omnidirectional antenna with a nominal 4dBi gain, mounted on a car roof.

In both cases, the received power, measured on an Anritsu MS2720T spectrum analyser, was within 3dB of the predicted free-space value. This is within the error limits expected for such field measurements, and provides good confirmation that the receive and transmit antennas used in the tests were operating as expected[6].

Figure 3-8: Location of line-of-sight tests (February 2017)

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3.5 Co- channel results

To test the impact of co-channel interference, the LTE transmitter was set of 3730 MHz, so that all the LTE power fell within the nominal bandwidth of the DVB-S receiver, as sketched below.

[6] It should be noted that the antenna calibration measurements in February 2017 did not include the LTE eNodeB transmitter or the TSMW test receiver

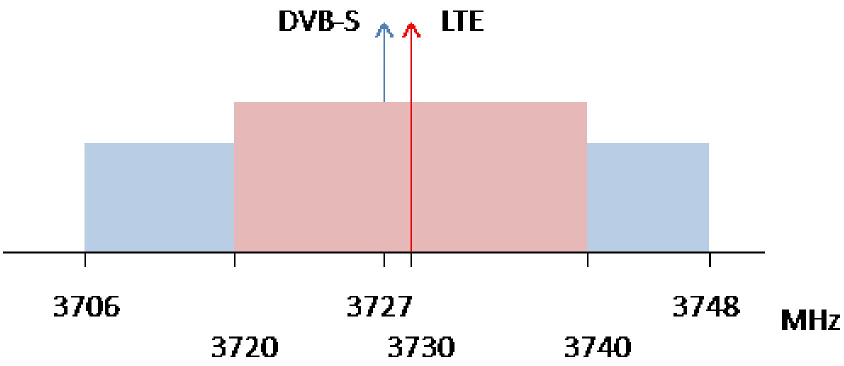

Figure 3-9: Frequency relationships for co-channel case

With the LTE transmitter positioned at each of the test locations 1-4, correct operation of the satellite receiver was confirmed with the eNodeB switched off. The eNodeB was then switched on at full power (EIRP of 40+40 dBm), and the parameters of the received satellite signal recorded. The transmit power was then reduced incrementally to the minimum value of 20dBm + 20dBm.

In all cases, the LTE traffic was set at 70%:

- For LTE site 1 (1.2km from VSAT) satellite reception was impossible except with the LTE transmitter on the lowest power (20dBm + 20dBm) during the August measurements, when the demodulator could just obtain sufficient MER (9.2 dB) for decoding (at -97.0 dBm at the TMSW). In the December measurements, the same nominal power at this location gave a TMSW received power of -93.0 dBm, and no decoding was possible. This 4dB difference is consistent with the location variability that might be expected at 3.6 GHz (the eNodeB antenna is unlikely to have been in precisely the same location, and vegetation will have changed between August and December).
- For LTE site 2 (3.8 km from VSAT) reception was possible at all powers (up to -92.0 dBm at the TSMW).
- For LTE Site 3 (1.4 km from VSAT) reception was impossible at any LTE power (down to -73 dBm at the TSMW). If the LTE traffic was lowered to 30% (giving a TMSW power of -76.6dBm), the DVB-S2 demodulator was able to synchronise, but with insufficient MER (8 dB) to allow decoding.
- For LTE site 4 (0.2 km from VSAT) reception was impossible at any LTE power (down to -70.0 dBm at the TSMW)

Although these results, summarised in the table below, may seem slightly inconsistent, it must be borne in mind that the TMSW and the VSAT receiver are separated by several metres (as shown in Figure 3-2), and the LTE fields received at the two locations will not necessarily track each other. The fact that decoding was possible with the eNodeB at LTE site 2, (despite the TMSW recording a higher LTE power than the -93dBm that caused failure from LTE-site 1) may simply be because the VSAT antenna was more screened by vegetation than the TMSW antenna.

Table 3-5: VSAT reception status for different received LTE power levels

Power at TMSW measurement receiver	DVB-S reception	Notes
-70.0 dBm	Failed	LTE site 4, 150° off-axis, December
-73.0 dBm	Failed	LTE site 3, 107° off-axis, December
-76.6 dBm	Sync, no decoding	LTE site 3, 107° off-axis, December
-92.0 dBm	Decoding	LTE site 2, On-axis, August
-93.0 dBm	Failed	LTE site 1, On-axis, December
-97.0 dBm	Decoding	LTE site 1, On-axis, August

3.6 Adjacent-channel results

For the adjacent-channel measurements, the LTE transit frequency was generally set to 3755 MHz, so that the majority of the LTE energy fell outside the *nominal* bandwidth of the DVB-S signal. [7].

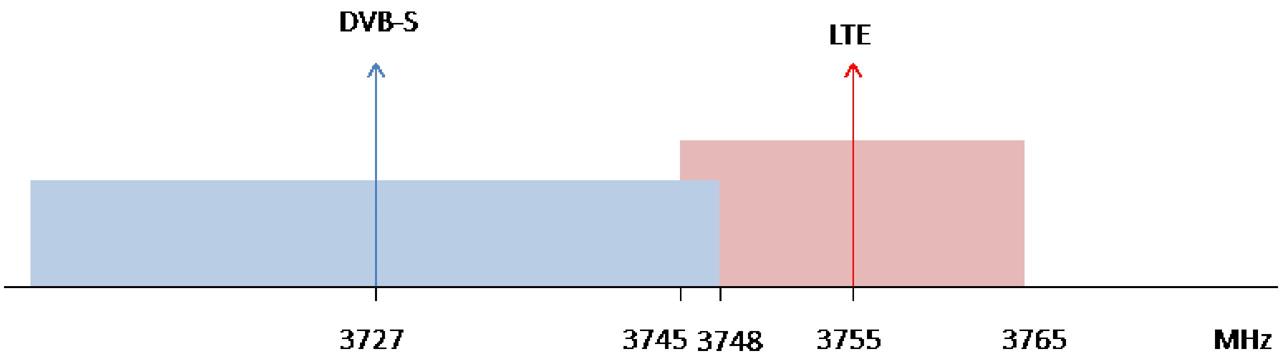

Figure 3-10: Frequency relationships for adjacent-channel case

That this was the case can be seen from the screenshot of the Sefran satellite installation meter shown below (the displayed spectrum is reversed due to the mixing relationship in the LNB).

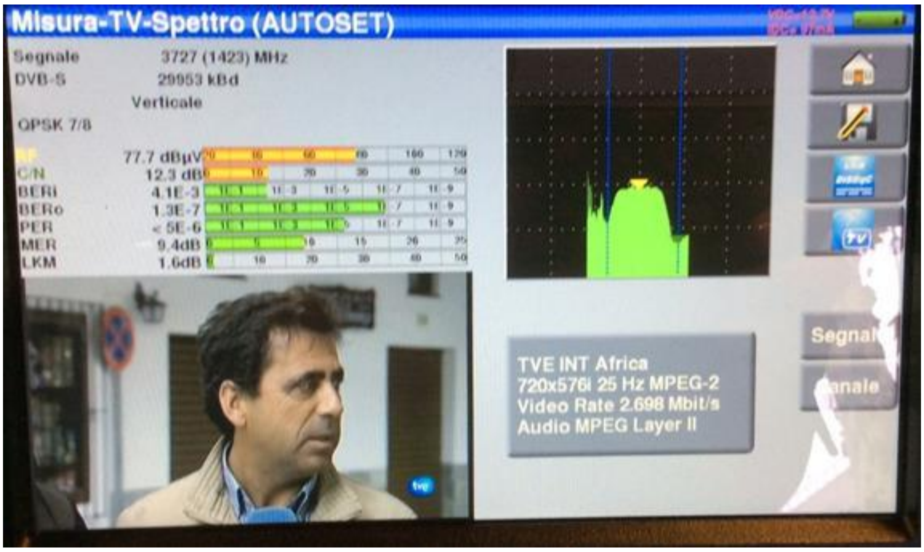

Figure 3-11: Satellite meter showing adjacent-channel interference

The precise characteristics of the satellite receiver selectivity are examined in the laboratory measurements reported in Section 4.

Adjacent channel measurements were made at points 1, 3 and 4.

- For LTE site 1 (1.2km from VSAT), the co-channel failure point was not established in the December tests as decoding was not possible at any LTE power. With an LTE centre frequency of 3750 (i.e. with a 2 MHz overlap with the nominal DVB-S bandwidth), the failure point was established to be at around an LTE power of 22dBm. Increasing the separation by a further 5MHz (LTE frequency = 3755 MHz) allowed DVB-S decoding at the full LTE power of 40dBm, implying an additional discrimination of at least 20dB.
- For LTE site 3 (1.4 km from VSAT), DVB-S decoding just failed at 20dBm LTE power in the co-channel case. Moving to an LTE frequency of 3755 MHz allowed marginal decoding of the satellite signal at 40dBm LTE power, implying an improvement in discrimination of around 20dB.
- For LTE site 4 (0.2 km from VSAT), the co-channel failure point was not established as no decoding or synchronisation was possible even at the lowest LTE power of 20dBm. For an LTE frequency of 3755 MHz, the failure point of the DVB-S demodulator was determined to correspond to an LTE power of between 31 - 34 dBm, implying an additional discrimination of at least 14 dB.

While noting that the evidence for adjacent channel selectivity is necessarily limited to the specific testing environment, it appears that moving from the co-channel case to a centre-frequency offset of 28 MHz affords an additional protection of some 20 dB. The results are summarised in the table below.

Table 3-6: Co- and adjacent-channel results (December0

LTE location	Distance	Maximum LTE transmitter power for DVB-S decoding	
		Co channel case	Adjacent channel case
Site 1	1.2 km	<20dbm	~22 dBm at +23 MHz ≥ 40dBm at +28 MHz
Site 3	1.4 km	~ 20 dBm	≥ 40dBm at +28 MHz
Site 4	0.2 km	<20 dBm	31-34dBm at + 28 MHz

3.7 Satellite antenna performance

A 1.8m dish antenna would be expected to have a gain of around 35dBi at a frequency in the region of 3730 MHz. ITU-R Recommendation S.465 gives expressions for reference radiation patterns to be used in sharing studies; that applicable to a 1.8m C-band antenna is plotted below.

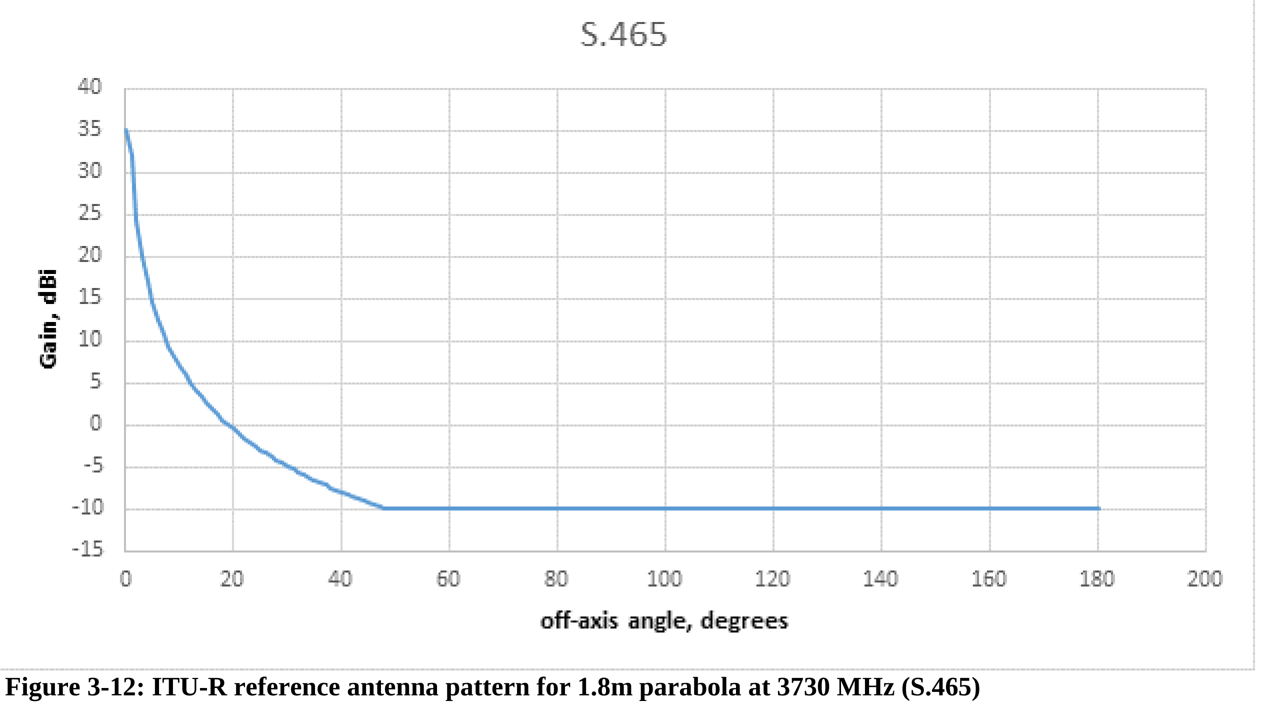

Figure 3-12: ITU-R reference antenna pattern for 1.8m parabola at 3730 MHz (S.465)

As the VSAT antenna in the trials was configured with an elevation angle of 38.5°, the ITU-R pattern would imply that the antenna gain should be almost constant in azimuth at -10dBi for signals arriving horizontally. A small increase in gain to around -8dBi is predicted when the terrestrial signal is aligned in azimuth with the dish boresight.

As it will not be straightforward to make formal measurements of the sample VSAT antenna, some very simple observations of antenna performance were made.

With a CW source radiated from the LTE transmitter antenna, with the van located at 70m range across the CNCER forecourt, the VSAT antenna was swing in azimuth, first for the test elevation of 38.5°, and then with the boresight aligned horizontally (elevation ~ 0°). The power output at the LNB IF was observed on the Safran installation meter.

.At 38.5° elevation, no significant pattern in azimuth was observed, with the received signal fluctuating by about +/-6dB due to the significant amount of multipath energy present on the site from trees, buildings and vehicles.

At 0° elevation, the peak signal, seen for boresight alignment was around 32 dB greater than the median at 38.5° elevation, falling to a constant value (at around 40° azimuth offset from boresight) similar to the 38.5° median.

These results would tend to confirm that the antenna is operating broadly in line with expectations; although the predicted peak gain of 45dB with respect to the sidelobe level was not observed, this would be challenging with the simple observational method used, as alignment to within about 1° would be necessary.

3.8 Field tests - conclusion

While noting that field testing results relate to the specific conditions that were tested and may not apply under all possible conditions, the field trials have provided some confirmation of the predictions made in [5], showing as they do that co-frequency sharing may be possible in realistic scenarios for separation distances between 1.2km and 3.8km.

A significant improvement in compatibility was confirmed for the adjacent channel case, with an additional 20dB protection available for a frequency offset of 28 MHz between LTE and VSAT channel centres.

The performance of the VSAT antenna used in the trial was found to be comparable to that predicted by the relevant ITU-R reference pattern.

4 Laboratory tests

4.1 Introduction

Laboratory tests have[7] been carried out in the Huawei premises in Segrate to derive robust data on the selectivity and overload characteristics of domestic-grade satellite receivers and LNBs.

Information on these parameters is currently rather limited. In ITU-R Report S.2368 [8], a value of -50dBm is given as the 1dB compression point for typical satellite LNBs, but no source or further details are quoted. The same Report reproduces a selectivity curve for a satellite TV receiver that originated in a study made in Singapore[8]. Unfortunately, it has not been possible to trace a copy of the original paper, but the selectivity curve is reproduced below from the ITU document.

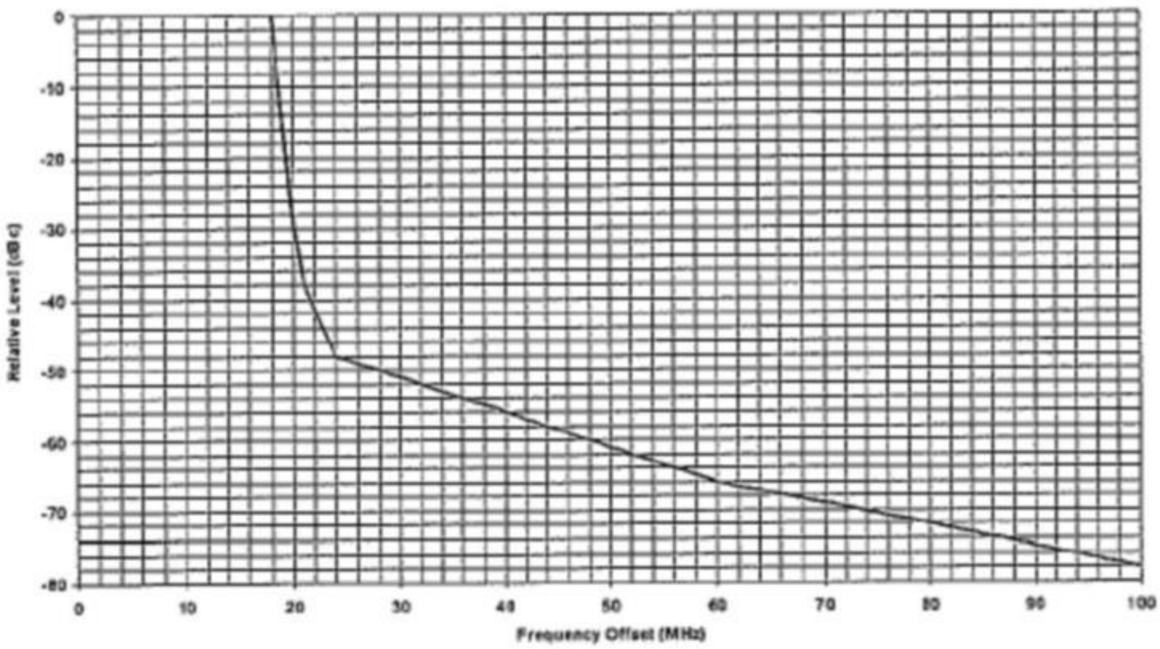

Figure 4-1: Satellite receiver selectivity curve (from [8]).

4.2 Selectivity measurement

To allow interference predictions to be made for arbitrary scenarios, it is necessary to understand the impact of receiver filtering on the protection ratios required at different frequency offsets between the wanted and unwanted signals.

[7] 19-20 December, 2016

[8] Foo Sek Joon and Chng Jhuning, "Test report of potential interference of WBA on FSS in Singapore", R-J6375-TR002 ISSUE B

4.2.1 Method

These measurements were made using Keysight signal generators to synthesise appropriate DVB-S and LTE signals, as shown in the sketch below.

As the LNB has an essentially flat frequency response over the band 3.4 to 4.2 GHz, it will contribute nothing to the overall receiver selectivity. It is therefore sufficient to make measurements at the IF input to the satellite receiver.

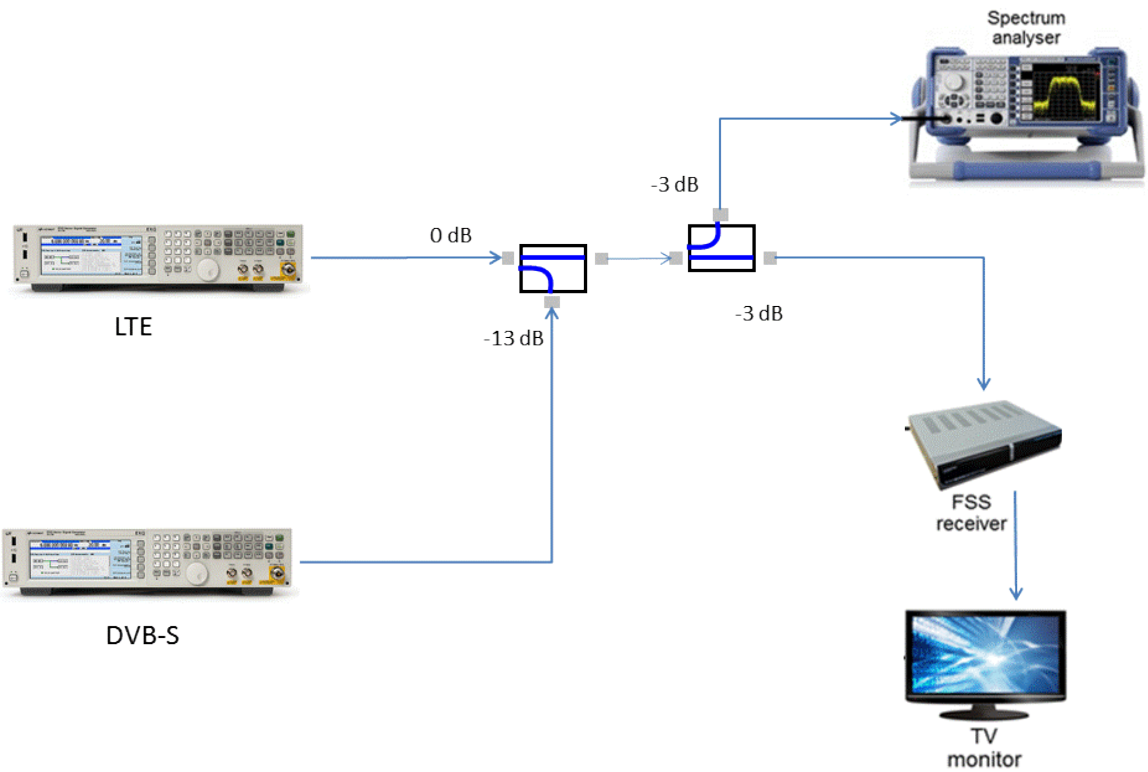

Figure 4-2: Arrangement for selectivity testing

The first signal generator was configured to produce a DVB-S signal with the same parameters as the satellite transmission used for the field testing, as set out in Table 3-3 (29.9MSymbols/S, QPSK, FEC=7/8).

The second generator was used to generate a FDD LTE signal of 20 MHz bandwidth, fully loaded with traffic (all resource blocks in use). Although the field trials were undertaken with TDD transmissions, the purpose here is simply to understand the filter characteristics of the satellite demodulators and the FDD transmission provides an appropriate stable signal.

The DVB-S generator was set to 1420 MHz, representing a satellite signal at 3730 MHz, and to a fixed power of -48dBm at the satellite receiver input; this is a power sufficient to give solid reception, but not so high as to require very high levels of LTE signal to trigger interference at large offsets (as this would give rise to non-linearities in the receiver and high out-of-band emissions from the LTE generator).

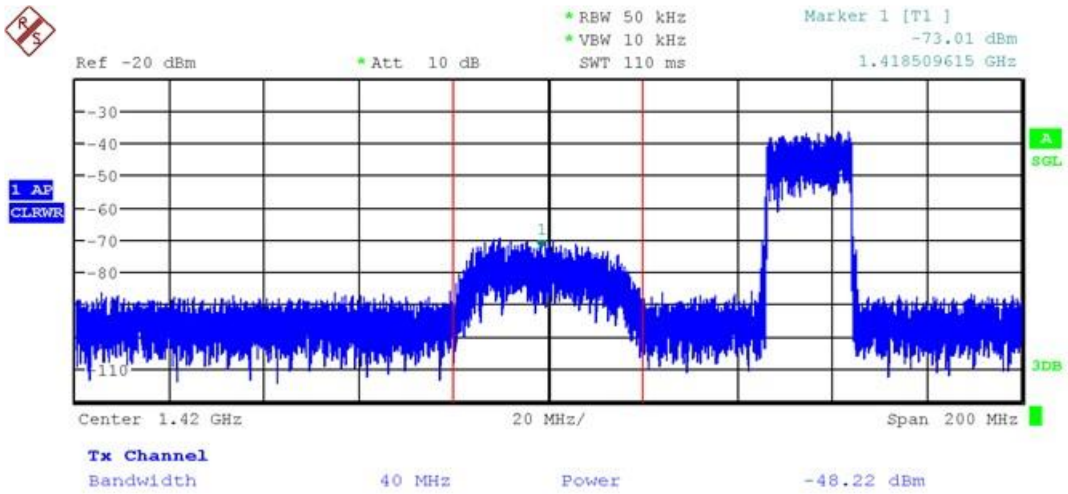

Figure 4-3: DVB-S and LTE signals in laboratory test setup

The disposition of the two signals is shown in the spectrum analyser screenshot above, in which the LTE signal is at an offset of 55 MHz.

4.2.2 Devices under test

Three satellite demodulators were tested; two domestic receivers and the professional test meter used in the tests at CNCER. This selection represents the broad range of available satellite receivers.

Figure 4-4: Edision ‘Proton’ consumer satellite receiver

The Edision ‘Proton’ receiver is a very small unit, retailing for around €32.

Figure 4-5: Technomate TM-5402 HD Mk3 consumer satellite receiver.

This high-end consumer receiver/recorder retails at around €130

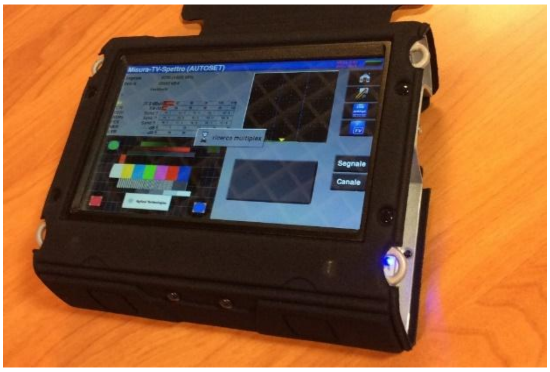

Figure 4-6: Sefram 7876 installer meter.

This professional installation meter and demodulator was used for the testing reported in Section 3, and retails at over €10,000.

4.2.3 Results

The plot of protection ratio[9] for 20 MHz LTE into a 29 MSymbol/S, QPSK DVB-S service is given in Figure 4-7.

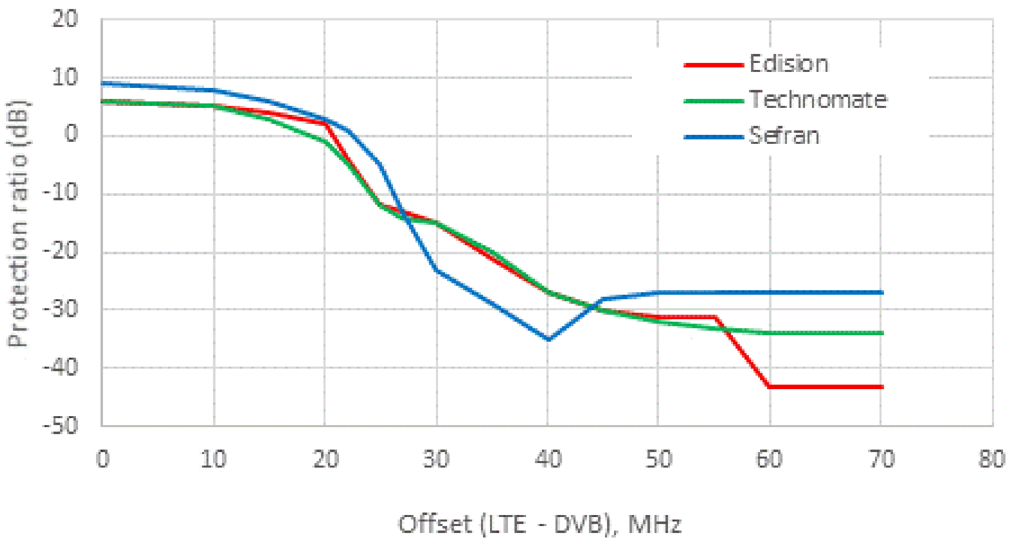

Figure 4-7: DVB-S protection ratio for LTE interferer

The LTE power falls wholly outside the occupied bandwidth of the DVB-S signal at an offset of 30 MHz, at which point the steeper filter characteristic of the professional Sefran receiver gives it a 10dB advantage.

There is a significant difference in the susceptibility of the three receivers to LTE power that is well outside the DVB-S bandwidth; surprisingly, the cheapest receiver offers the best performance and the most expensive the worst.

[9] The minimum ratio of total DVB power to total LTE power at the receiver required to allow decoding of the DVB-S signal.

The apparently anomalous behaviour of the Sefran receiver at 40 MHz offset is due to the receiver dynamically adjusting attenuation (and possibly filtering) in an attempt to optimise reception. This intelligence leads to a non-monotonic response with frequency offset.

Testing selectivity in the presence of a 20 MHz-wide interferer is representative of real-world situations, but does not reveal the selectivity characteristic of the receiver in isolation. In an attempt to characterise this (as, for example, in the plot given in Figure 4-1), the measurements were repeated with a CW interferer for the two consumer receivers.

Figure 4-8: DVB-S protection ratio for LTE interferer

The interference potential of a CW signal within the DVB-S bandwidth is much less than that of LTE, and the Technomate receiver shows the expected sharp transition as the CW interferer moves outside the DVB-S signal bandwidth at ~22 MHz.

The behaviour of the Edision unit is very confused however, although it was found to be repeatable in tests. The oscillation of the protection ratio by over 20dB as it passes outside the DVB-S bandwidth is, perhaps, an artefact of signal processing in a zero-IF architecture receiver chip. Issues with the unexpected behaviour of receiver DSP in DVB-T demodulators led to some interference problems from LTE at 800 MHz; If the precise characteristics of VSAT receiver interference susceptibility seem likely to be of interest, it would be worthwhile investigating receiver architecture in more detail.

4.3 LNB performance tests

Three consumer-grade low-noise block (LNB) downconverters were tested.

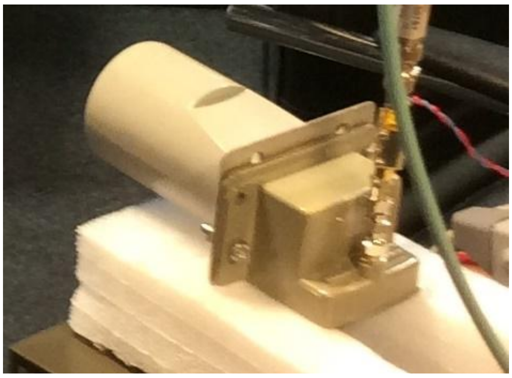

Figure 4-9: Primesat PR1000 C-band LNB with waveguide flange

This unit has a waveguide flange designed to fit a dual-polarity feedhorn, and is targeted at semi-professional or enthusiast users.

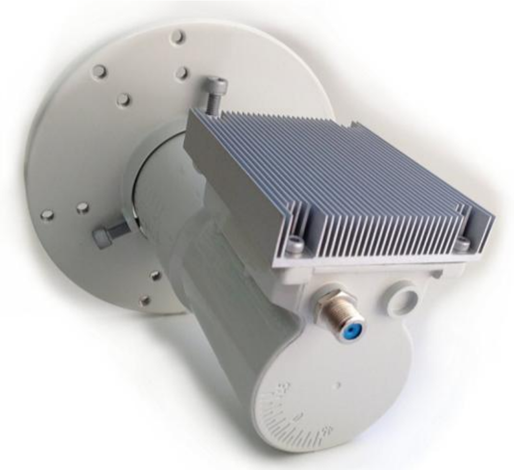

Figure 4-10: Titanium C1W PLL dual polarisation C-band LNB

This LNB uses voltage-switching to select polarisation, and has a phase-locked loop local oscillator for improved frequency stability.

Figure 4-11: WS International 741U C/Ku-band LNB

This dual-band LNB is widely available under a variety of brand names, and combines a a Ku band LNB with a dual-polarity (voltage-switched) C-band unit.

The laboratory test of LNB performance investigated the susceptibility of the three sample LNBs to overload by strong incident field strength. The experimental setup was as shown in the figure below.

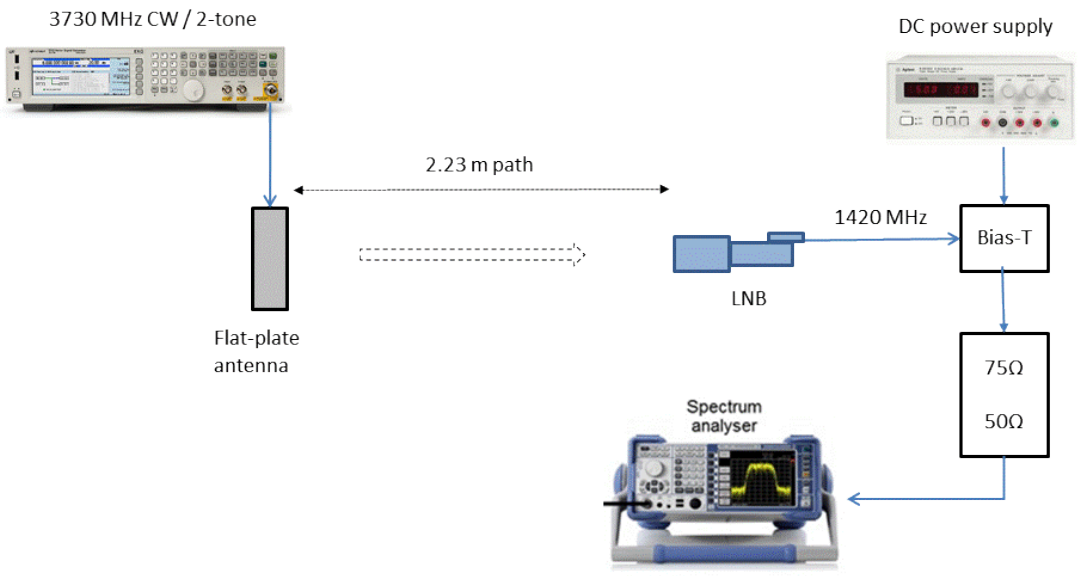

Figure 4-12: Test setup for LNB overload

As most LNBs have no facility for direct coupling to their amplifier input, a radiated test methods was used. A signal generator feeding a flat-plate antenna was used to establish a known field strength at the LNB feed aperture. From the physical dimensions of the feed, the gain was estimated as 7 dBi, allowing the power at the low-noise amplifier input to be determined.

The LNB under test was powered from a variable DC power supply, allowing polarisation switching to be activated as necessary, and the IF output taken to a spectrum analyser via a 75-50 ohm impedance transformer.

4.3.1 1dB compression point

The 1dB compression point is a common metric for amplifier overload performance A perfect amplifier will exhibit a linear relationship between the input and output power; when the input signal becomes too large, the amplifier output will no longer be able to track the input, and 'compression' will occur. The 1dB compression point is defined as the input power that gives rise to an output that is 1dB lower than it would be for a perfectly linear transfer characteristic. The onset of compression is important mainly for the fact that such non-linear operation will give rise to spurious frequency products and other signal distortions.

The 1dB compression point was determined simply by increasing the power of the signal generator until the non-linear portion of the transfer characteristic of each amplifier was reached. Plotting this response allows the 1dB compression point to be determined, as shown below.

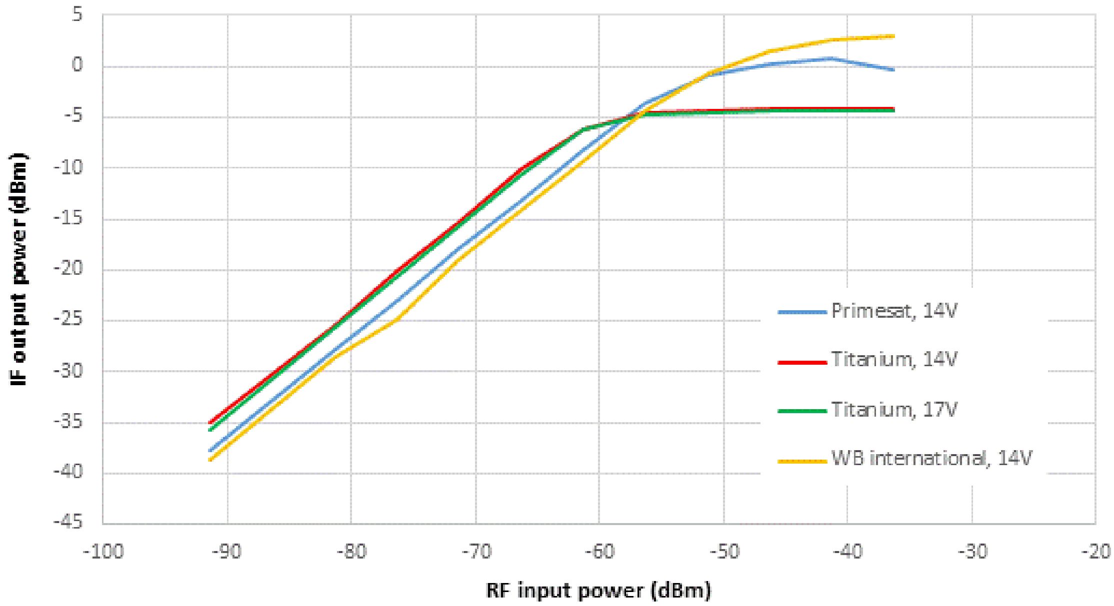

Figure 4-13: LNB transfer characteristic (CW input at 3730 MHz)

From an examination of the 'knee' of each curve, the compression points can be determined, and the results are given in Table 4-1.

4.3.2 Third-order intercept point

An alternative measure of the strong-signal performance of amplifiers is the third-order intercept point (TOIP). When overloaded, non-linear mixing products will appear at the output of the amplifier in addition to the frequencies seen at the input and will increase in amplitude. These products increase in amplitude much more rapidly with input power, and the TOIP relates to the hypothetical[10] point at which the linear and third-order transfer characteristics intersect.

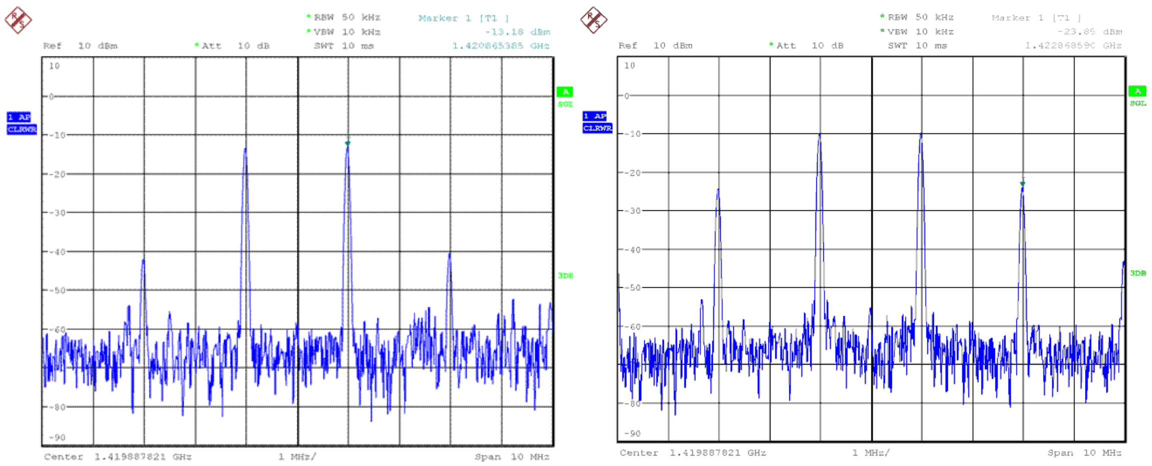

Figure 4-14: Two-tone testing – 5dB increase in input gives 15dB increase in 3rd-order products

[10] Hypothetical, because compression will ensure these powers cannot be reached.

The signal generator used in the measurements has a mode in which it will generate a two-tone test signal; this was configured to create a pair of carriers separated by 10 MHz, centred on 3730 MHz. As the LNB was driven into non-linearity, spurious products at 10 MHz above and below these tones appeared in the IF output, and the amplitude of these was recorded as the generator input power was varied.

The results are shown in the figure below, which also plots the ideal linear and third-order characteristics for the Primesat LNB, to indicate the derivation of the metric.

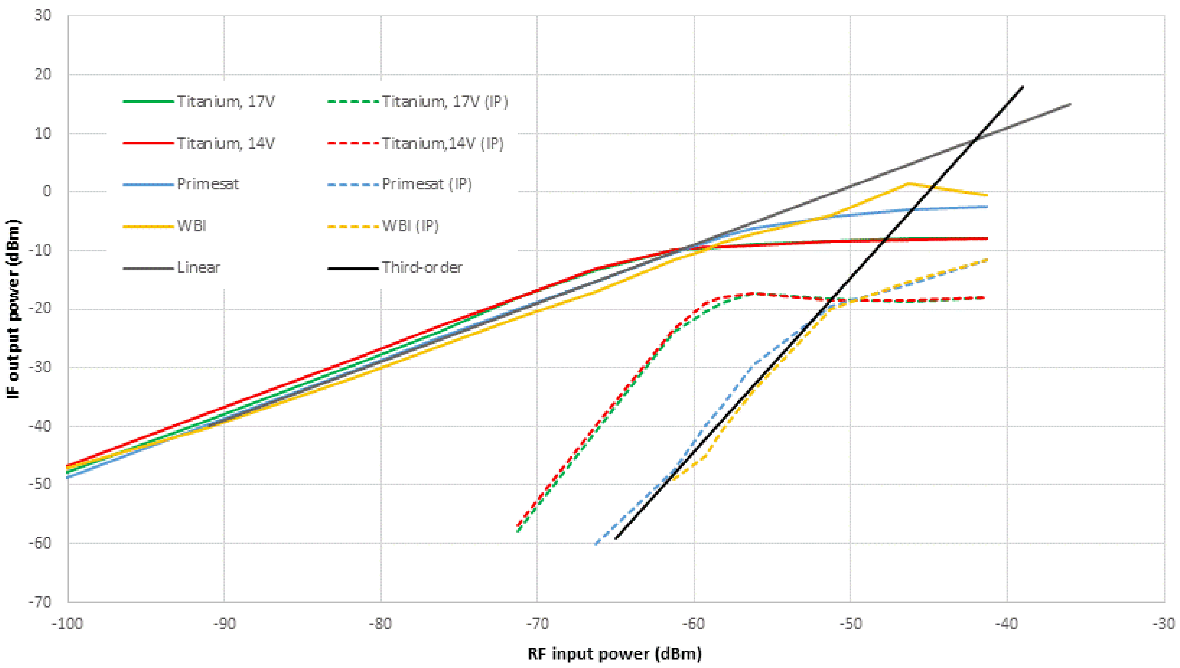

Figure 4-15: Two-tone testing of LNBs

4.3.3 Laboratory tests - Conclusions

The results for both tests are tabulated below.

Table 4-1: Measured LNB characteristics

LNB	1dB compression	TOIP	Note
Primesat	-56 dBm	-42 dBm	C & Ku
Titanium	-62 dBm	-56 dBm	C-band, dual-pol, PLL
WB international	-54 dBm	-41 dBm	C-band, dual-pol

These results suggest that the ITU-R assumption of a 50dBm value for the 1dB compression point is broadly appropriate, although the Titanium unit has a significantly worse performance.

The laboratory measurements of receiver selectivity were also in agreement with the results measured in the field, and suggest that there may be relatively little variation in selectivity between different receivers.

5 Conclusions

5.1 Co-channel interference

In work previously undertaken [5] for the GSM Association (GSMA) by Transfinite Systems Ltd, predictions were made of the areas around VSAT terminals that would be subject to interference from LTE base stations operating on the same frequency. Examples in Bogota, Johannesburg, Kuala Lumpur and Hanoi were given.

Applying the assumptions recommended for sharing studies by the (then-active) WRC-15 Joint Task Group 4-5-6-9 of the ITU-R resulted in required separation distances for co-channel operation of between 30-40 km. These assumptions apply a sharing criterion where the interference from the LTE base station must lie 20dB below the satellite receiver noise floor (I/N of -20dB), and assume flat terrain.

Applying the same I/N criterion in realistic terrain gave much reduced separation distances in the order of 5-30km. When the modelling took into account the actual link margin[11] available to the satellite receiver (in other words, considering the carrier to interference and noise ratio, C/(N+I)), the required separation distances were reduced to between 1-5km.

While noting that field testing results relate to the specific conditions that were tested and may not apply under all possible conditions, the field trials have provided some confirmation of the earlier modelling, showing as they do that co-frequency sharing may be possible in realistic scenarios for separation distances between 1.2km and 3.8km.

5.2 Adjacent-channel interference

The GSMA study [6] that considered a VSAT terminal located within a ubiquitous network of IMT macro cells, determined that a *guard band* of 26 MHz was required to avoid interference for the case of a 10 MHz IMT carrier and a 36 MHz FSS bandwidth. The required *centre frequency separation* is, therefore 49 MHz.

A direct comparison with the present field trials is not possible, as the centre frequency separation was never sufficient to place the LTE power wholly outside the VSAT bandwidth. The field trials did, however, demonstrate a Net Filter Discrimination (NFD) in the order of 20dB for a centre frequency separation of 28 MHz, which is comparable with the values predicted in [6].

The laboratory measurements of receiver selectivity were also in agreement with the results measured in the field, and suggest that there may be relatively little variation in selectivity between different receivers.

[11] In the same manner as suggested in ITU-R Document 4-5-6-7/519 "*Sharing study report between IMT and FSS systems in the 3400-4200 MHz frequency range* " (UMTS Forum , February 2014)

5.3 Laboratory measurements and future work

Given the limited number of trials possible, and the great variation of propagation paths and potential scenarios, field testing can only offer such anecdotal support. The detailed receiver characterisation given in Section 4, however, if combined with a reliable propagation model, will allow the modelling of arbitrary sharing situations. Such modelling could be carried out within a Monte Carlo framework to provide estimates of the probability of interference in specific or generalised scenarios.

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6 References

[1] "*Compatibility studies in the band 3400-3800 MHz between Broadband Wireless access (BWA) systems and other services*", **ECC Report 100**, Bern, February 2007.

[2] "*Least Restrictive Technical Conditions suitable for Mobile/Fixed Communication Networks (MFCN), including IMT, in the frequency bands 3400-3600 MHz and 3600-3800 MHz*", **ECC Report 203**, November 2013.

[3] "*Operational guidelines for spectrum sharing to support the implementation of the current ECC framework in the 3600-3800 MHz range"*, ECC Report 254, November 2016

[4] "*Sharing studies between IMT-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 and 4 500-4 800 MHz frequency bands*", **ITU-R Report M.2109,** ITU-R, Geneva, 2007

[5] Studies for GSMA by Transfinite Systems Ltd, Feb 2013 to Jan 2015. Not publicly available.

[6] "*Study into adjacent channel compatibility/sharing between IMT and ubiquitous FSS Earth Stations in 3.4 – 4.2 GHz*" GSMA contribution to ITU-R Joint Task Group 4-5-6-7, **Document 4-5-6-7/355**, 14 October 2013.

[7] "*Sharing methodology between fixed wireless access systems in the fixed service and very small aperture terminals in the fixed-satellite service in the 3 400-3 700 MHz band*", **ITU-R Recommendation SF.1486**, Geneva, 2000.

[8] "*Sharing studies between International Mobile Telecommunication-Advanced systems and geostationary satellite networks in the fixed-satellite service in the 3 400-4 200 MHz and 4 500-4 800 MHz frequency bands in the WRC study cycle leading to WRC-15*", **ITU-R Report S.2368-0**, Geneva, 2015.

[9] DVB-S bandwidth calculator available at:

http://www.satbroadcasts.com/DVB-S_Bitrate_and_Bandwidth_Calculator.html

7 Acronyms

BER	Bit Error Rate
CNCER	Centro Nazionale Controllo Emissioni Radioelettriche
DVB-S	Digital Video Broadcasting - Satellite
EIRP	Effective Isotropic Radiated Power
FEC	Forward Error Correction
FSS	Fixed Satellite Service
FUB	Fondazione Ugo Bordoni
GSMA	GSM Association
IF	Intermediate Frequency
IMT	International Mobile Telecommunications
LNB	Low Noise Block
LTE	Lont Term Evolution
MISE	Ministry of Economic Development
QPSK	Quadrature Phase-Shift Keying
RSRP	Reference Signal Received Power
TDD	Time Division Duplex
TSMW	Rohde & Schwarz Universal Radio Network Analyser
TVRO	TeleVision Receive-Only
VSAT	Very Small Aperture Terminals