An Coimisiún um
Rialáil Cumarsáide
Commission for
Communications Regulation

Interference Susceptibility Measurements – Shannon Airport Radar

A report from Plum Consulting London LLP

Consultant Report

Reference: ComReg 19/124d

Date: 20/12/2019

Shannon IAA radar - interference susceptibility measurements

13 December 2019

Richard Rudd

About Plum

Plum offers strategy, policy and regulatory advice on telecoms, spectrum, online and audio-visual media issues. We draw on economics and engineering, our knowledge of the sector and our clients' understanding and perspective to shape and respond to convergence.

About this study

This study for ComReg investigated the interference susceptibility of the 2.7 GHz aeronautical radar at Shannon through a series of field trials.

Plum Consulting
10 Fitzroy Square
London
W1T 5HP

T +44 20 7047 1919
E info@plumconsulting.co.uk

Contents

Summary

Trials were carried out at the Shannon ATC radar site to determine the susceptibility of the radar to interference from new communication networks in the 2.6 GHz band. These field trials confirmed the assumptions and conclusions of the compatibility analysis undertaken to inform Document 19/59c which were based on the Belgian testing[1] parameters. In particular, additional filtering at the radar front-end will be required to mitigate the possibility of interference from future MFCN services.

The testing confirmed that interference thresholds for two of the three interference mechanisms (intermodulation and spurious emissions) were comparable with those measured on the same model radar in Belgium in 2011, and since used for interference modelling by ComReg. Although an accurate value could not be obtained for the blocking mechanism[2], the interference susceptibility of the radar is determined by the other two values, as these occur at significantly lower interference power levels.

The measurements have also confirmed the elevation gain pattern of the radar antenna, which may be useful in refining existing interference predictions. Those predictions currently make the worst-case assumption that interference enters the radar at the maximum gain of the antenna. In practice, some 9dB of additional discrimination is likely to be available.

Mechanism	Belgian (Liége) measurements	Shannon measurements
Spurious emissions	-108 dBm/MHz	-112 dBm/MHz
Intermodulation	-37.8 dBm	-40.4 dBm
Blocking	-20 dBm	No effects seen at -16.5 dBm

Table 0.1: Summary of measurement results

The trials reported here broadly confirm the assumptions and suggested remediation measures made in previous modelling. These include a combination of:

- implementation of filtering at the impacted radars to address interference due to blocking and intermodulation; and
- Implementation of a pfd limit of -145 dBW/m^2/MHz at the radar receiver antenna location to be satisfied by each operator[3], to address MFCN spurious emissions.
- An additional pfd limit of -83 dBW/m^2 is required if the radar is unfiltered at time of deployment of MFCN base stations to address in-band blocking and intermodulation effects[4,5].

---

[1] The Belgium measurements are described in the report "Study of the Performance Degradation of the Belgian S-band Air Surveillance Radars due to the Interference of Upcoming 4G Technologies", available on the website of the Belgian regulator, BIPT.

[2] The 'blocking' mechanism causes a degradation in the gain of the radar receiver. This degradation will be visible only as a lack of sensitivity, or a reduction in the probability of detection. During the testing no targets presented themselves on the appropriate azimuth to prove the presence of the blocking interference mechanism.

[3] This limit is derived assuming that there are three licensed operators with equal amount of allocated spectrum. If there are a different number of operators and/or a different amount of spectrum allocated to each operator, the corresponding pfd limit can be calculated from [-140 + 10 log10 (Bandwidth(MHz) / 120)].

[4] Following successful installation of filters at the radar receiver, no in-band radiation limit is required as filtering at the radar receiver should address the impact of blocking and intermodulation effects at the radar receiver in the adjacent band.

[5] This limit is derived assuming that there are three licensed operators with equal amount of allocated spectrum. If there are different number of operators and/or different amount of spectrum allocated to each operator, the corresponding pfd limit can be calculated from [-78 + 10 log10 (Bandwidth(MHz) / 120)].

- Implementation of a 1 km co-ordination zone[6] from the radar to provide additional protection from MFCN base stations.

---

[6] For example, in the UK, Ofcom has specified the coordination procedure[6] in a "Notice of coordination procedure required under spectrum access licences in the 2.6 GHz band". https://www.ofcom.org.uk/__data/assets/pdf_file/0028/37396/im2.pdf

1 Introduction

In preparation for the release of spectrum at 2.6 GHz for new mobile services, field trials have been undertaken to assess the impact of near-adjacent-band signals on aeronautical radar systems operating at 2.7 GHz (S-band). The trials involved a series of measurements made at the Shannon air traffic control (ATC) radar

In this report, references are made to a series of tests carried out on the same model of radar at Liége in Belgium in 2011. These are described in the report "*Study of the Performance Degradation of the Belgian S-band Air Surveillance Radars due to the Interference of Upcoming 4G Technologies*" [1], available on the website[7] of the Belgian regulator, BIBP.

In Ireland, there are four sites for S-band civil aeronautical radar; two near Dublin airport, one near Cork airport and one near Shannon airport. All of these sites use the Thales STAR 2000 radar unit with the exception of one of the sites located at Dublin airport. This site operates a Thales TA 10M TD Radar model, understood to be soon decommissioned and replaced by a STAR 2000 with LTE filtering. This radar has been considered separately in the "Update on 2.3 GHz and 2.6 GHz co-existence analysis" reports (Documents 19/59d and 19/59c respectively).

This report details measurement trials conducted on the STAR2000 radar located in Shannon Airport.

Figure 1.1: S-band radar (STAR2000) at Shannon

---

[7] : https://www.bipt.be/en/operators/radio/rights-of-use/terminated-allocation-procedures/study-of-the-performance-degradation-of-the-belgian-s-band-air-surveillance-radars-due-to-the-interference-of-upcoming-4g-technologies

2 Methodology

2.1 Radar system

The Shannon ATC radar is a Thales Star2000 unit, and has the characteristics given below.

Parameter	Value	Notes
Latitude	52° 42’ 5.03”	WGS84
Longitude	8° 56’ 11.74”	WGS84
Site height	5m	Above sea level (Google Earth[8])
Antenna height	17m	Above ground (IAA, verbally)
Antenna maximum gain	33 dBi	Low beam, at 2.°
Radar type	Thales Star2000	
Frequencies	2750 & 2850 MHz	

This monopulse radar operates on two frequencies; for most testing, the upper frequency was locked off to allow assessment of any interference to the lower frequency, as this will be the most susceptible to interference from the 2.6 GHz band.

The radar antenna is illuminated by two feeds, providing beams for ‘high’ and ‘low’ radar coverage. The (receive-only) ‘high’ beam, with a boresight at 6.36°, covers local traffic and has a coaxial feeder. The ‘low’ beam, with a boresight of 2.64° receives returns from more distant targets, is also used in transmit mode, and is fed by waveguide.

The signal at the radar receiver input was measured directly. The figure below shows the STAR2000 receiver rack, with the relevant connector indicated. All measurements in this report were recorded through this port. Measurements were made using the Anritsu MS2724C analyser, via a length of cable with a loss of 1 dB. Measurements were made with the antenna rotating at its normal speed of ~1 revolution in 4 seconds, because it was not a simple matter to stop the radar antenna and align it manually. The ‘max hold’ function on the analyser was therefore used to capture the peak signal level over multiple antenna scans.

---

[8] Shown as 24’ (equivalent to 7.3m) on historic OSI map available online (http://map.geohive.ie/mapviewer.html)

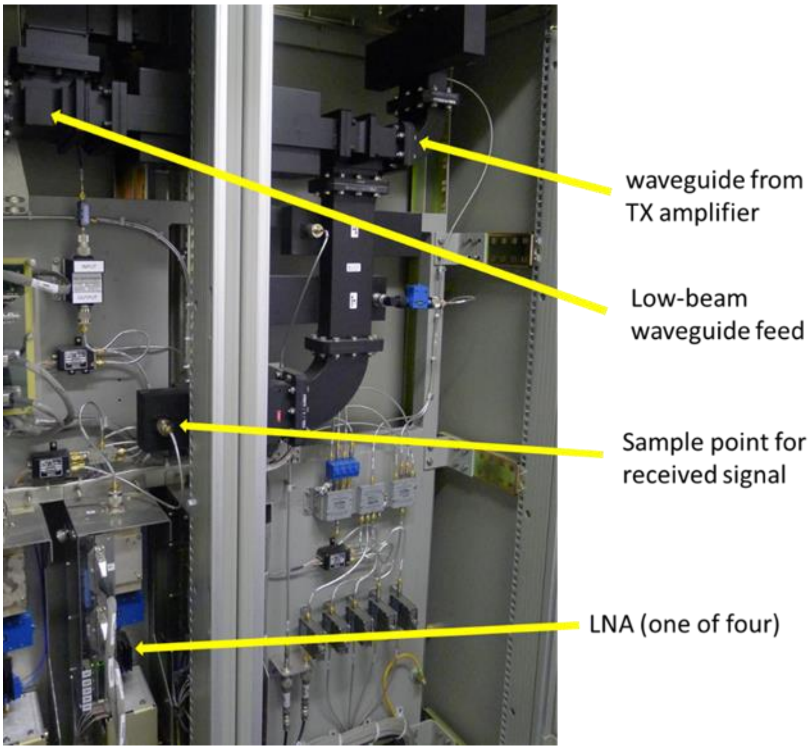


Figure 2.1: Star 2000 radar receiver, showing sampling port

2.2 Test sites

The majority of testing was carried out from a site ('Ridge') that offered an elevation (12m) slightly higher than that of the radar site (5m), at a range of 795m from the radar antenna.

A brief antenna calibration test was also made from a second site located by an airport perimeter gate ('Gate Site'). This site is at 6m elevation and 525m range from the radar.

Both of these sites are marked on the map in Figure 2.1 below:

Figure 2.2: Locations used during October testing

Calibration measurements were also made with the vehicle parked just outside the radar compound, at a range of 55m from the radar antenna.

3 Measurement results

3.1 Radar antenna performance

During the initial configuration of the trials equipment, the opportunity was taken to make measurements of the elevation pattern of the radar antenna.

The resulting data points are plotted below, superimposed on an approximation of the manufacturers pattern data. It can be seen that the measured values are close to those expected, bearing in mind the inevitable measurement uncertainties. The relatively high gain seen at -12° elevation is probably due to scattered multipath, which will limit the isolation possible.

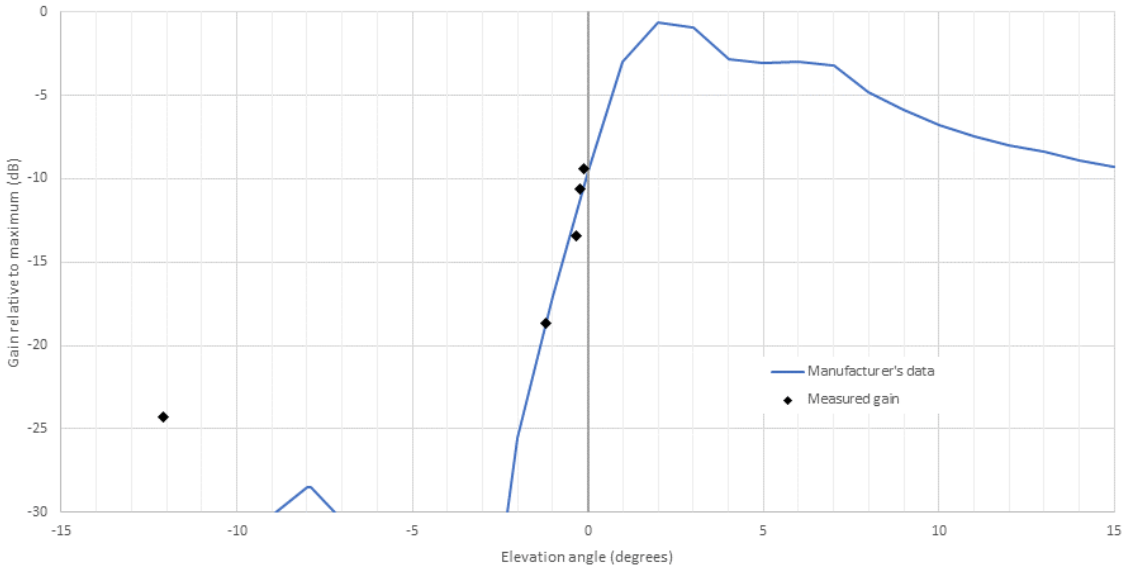


Figure 3.1: Measured radar antenna gain compared with manufacturer's data

This pattern, which was not available at the start of the project, has been coded in the Plum prediction software and used to update the radar susceptibility predictions previously provided.

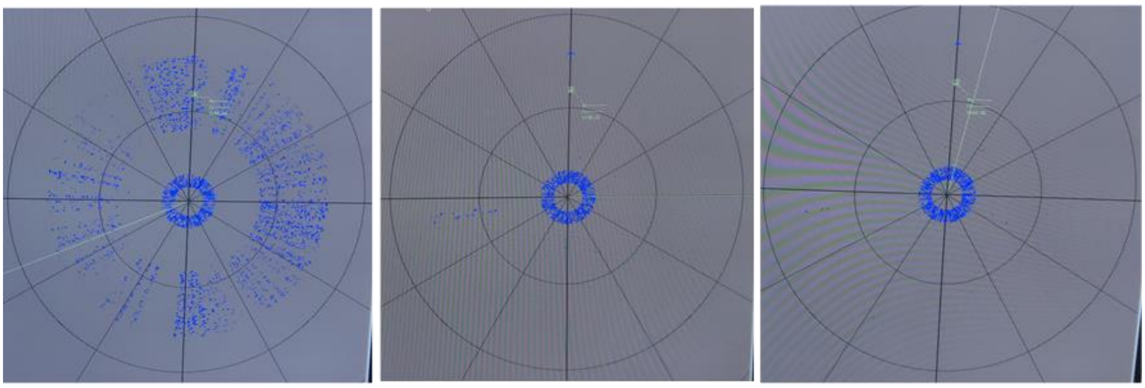
3.2 Spurious emissions (noise in-band to radar)

The first of the measurements were intended to establish the susceptibility of the radar to out-of-band spurious emissions from LTE services, falling within the radar bandwidth. This is, arguably, the most serious interference mechanism, as no mitigating measures can be taken at the radar site itself.

Figure 3.2: Vehicle at 'Ridge' site, test antenna at 5.2m, radar visible in background

The test vehicle was positioned at the 'Ridge' site, and the signal generator (Rohde & Schwartz SMW200A) was configured to generate a noise signal[9] of 20 MHz bandwidth, centred on the lower radar frequency (2750 MHz). The radar was configured to use only the lower frequency and linear (VP) polarisation.

The power radiated from the test site was varied, while the radar's local display was monitored for interference. The figure below shows how this interference (blue dots) varied with the transmitted noise power; at the higher levels, interference is seen on many azimuths, due to reflected energy scattered from the environment. As the power level falls, interference is seen only on the azimuth of the test site. The green line is an azimuth marker that sweeps to indicate the instantaneous position of the radar.



+10 dBm -10 dBm -20 dBm

Figure 3.3: Radar screenshots showing interference for different EIRPs from 'Ridge' site

It was determined that the interference threshold was reached at a transmitted EIRP of -22.0 dBm/20 MHz. This corresponds, at 2750 MHz, to a power at the radar receiver of -99.0 dBm/20 MHz or -112 dBm/MHz.

---

[9] Additive White Gaussian noise (AWGN)

In the Belgian Star2000 tests, a threshold for noise interference of -107.6 dBm/MHz was determined (i.e. -94.6 dBm/20 MHz). In the summary (Table 19), this is rounded to a value of -108dBm/MHz, corresponding to -95 dBm/20 MHz.

The difference of 4dB might imply a somewhat greater sensitivity to interference for the Shannon radar, compared with the Belgian case; the difference, however, is more likely to be the result of the inevitable uncertainties associated with radiated field tests compared to direct injection conducted in Belgium.

3.3 Intermodulation

Because intermodulation can generate products which fall within the radar IF passband, it represents the most severe interference constraint for signals radiated outside the passband.

For these tests, which followed the spurious emission measurements the signal generator was configured to provide two 20 MHz bandwidth LTE signals, at 30 MHz and 60 MHz below the radar frequency. For f1 = 2720 MHz and f2 = 2690 MHz, the third-order product 2f1-f2 falls at 2750 MHz, on the radar centre frequency.

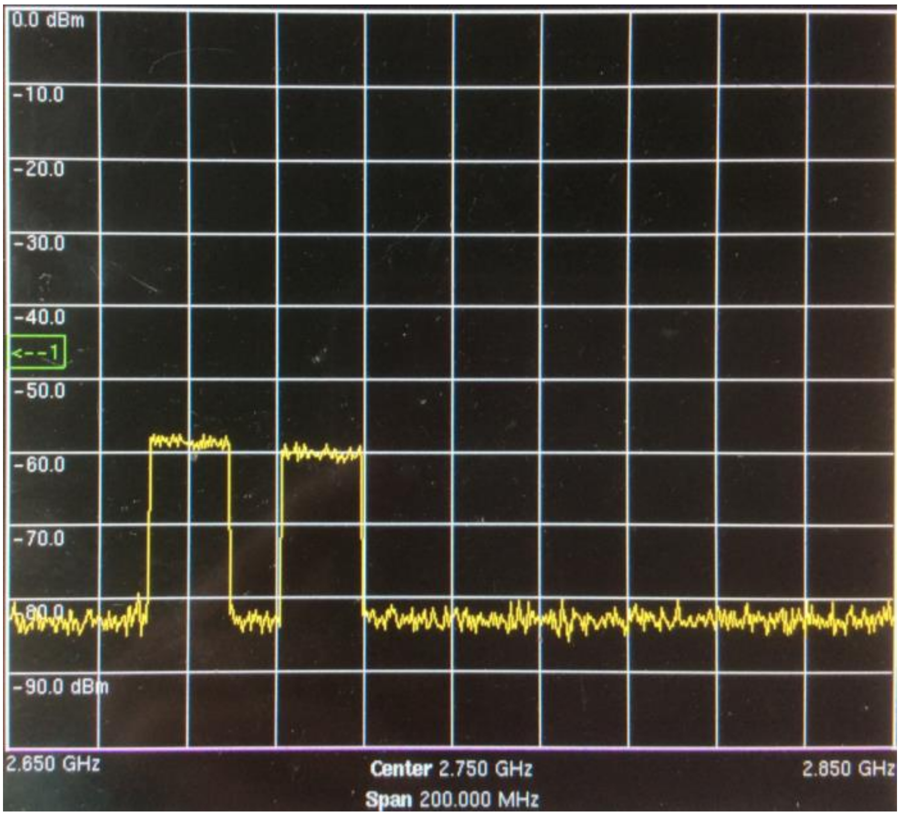


Figure 3.4: Intermodulation test signal

For these tests a 45W amplifier intended for use in COFDM systems requiring high linearity was used (Kuhne Electronic PA 250270-45D). Additional filtering was provided using an interdigital filter purpose-built by Plum. Transmissions were made from the Siretta omnidirectional antenna used for the spurious emission testing, at the same height of 5.2m.

Starting with an EIRP of +20dBm (corresponding to a power at the radar receiver of -59.4dBm), the transmit power was increased until interference was noted. This occurred at an EIRP of +39dBm corresponding to a power at the radar of -40.4 dBm.

In the Belgian Star2000 trials, the intermodulation threshold was found to occur at an interference level of -44 dBm/5 MHz. As two 10 MHz LTE signals were used as interferers, the actual *total* power at the radar front end was -37.8 dBm.

The relationship between overall power, signal bandwidth and impact on the radar is complex in the case of the intermodulation mechanism. The non-linearity giving rise to the generation of IPs is determined by the total power at the radar front-end. If, however, this power is spread over a wide bandwidth, the mixing product will be spread to an even greater bandwidth, lowering the power density within the radar IF. Finally, the probability distribution of the power in the radar bandwidth, itself a function of the joint statistics of the LTE traffic, is likely to have a complex interaction with the radar signal processing.

The conclusion is that a generalised prediction of the exact interference threshold for this mechanism cannot be given without a detailed knowledge of the specific LTE bandwidths, frequencies and traffic profile.

It is, however, clear that the Interference threshold of -40.4 dBm measured at Shannon is broadly consistent with that seen in the Belgian trials at Liège.

3.4 Blocking

A large number of tests were made at received power levels between -32.5 dBm to -16.5 dBm, with both CW and LTE transmissions and with the radar transmitter on and off. Different signal processing options were also configured on the radar by the IAA. No interference was seen in these tests.

This was not unexpected. Whereas the other two interference mechanisms cause signals to fall within the radar passband, where they will be demodulated as visible interference, the 'blocking' mechanism causes a degradation in the gain of the radar receiver.

This degradation in gain will be visible only as a lack of sensitivity, or a reduction in the probability of detection. It had been hoped that 'targets of opportunity' would present themselves on the appropriate azimuth, but air traffic at the time of the testing was minimal and this did not occur. Nevertheless, as the protection requirements of the radar are defined by the more stringent intermodulation mechanism it does not affect the overall conclusion of the testing.

4 Conclusions and recommendations

The testing conducted at the Shannon ATC radar site has confirmed interference thresholds for two of the three interference mechanisms that are of concern in the context of the release of spectrum at 2.6 GHz.

Table 4.1: Summary of measurement results

Mechanism	Belgian (Liége) measurements	Shannon measurements
Spurious emissions	-108 dBm/MHz	-112 dBm/MHz
Intermodulation	-37.8 dBm	-40.4 dBm
Blocking	-20 dBm	No effects seen at -16.5 dBm

Although an accurate value could not be obtained for the blocking mechanism, the interference susceptibility of the radar is determined by the other two values. The Belgian results, which were obtained under more controlled conditions[10], have been used in our earlier modelling for ComReg. As the new results are broadly consistent with the Belgian measurements, we believe that this modelling remains valid[11].

4.1 Recommendations

The trials reported here broadly confirm the assumptions and suggested remediation measures made in previous modelling, detailed in ComReg Document 19/59c. These recommendations are now detailed below:

- to address interference due to blocking and intermodulation and in line with mitigation techniques of the benchmark countries, radar filters should be installed on the Star 2000 Radar sites in Ireland, at Shannon, Cork and Dublin.
- to address the impact of MFCN spurious emissions, a pfd limit of -145 dBW/m^2/MHz at the radar receiver antenna location should be satisfied by each operator[12];
- If MFCNs are deployed before radar filters are fitted, an additional in-band radiation limit is required in the frequency range of 2575-2690 MHz to address the impact of blocking and intermodulation effects at radar receivers in the adjacent band. This restriction is a pfd limit of -83 dBW/m^2 at the radar receiver[13],[14]. Note that the non-linearity of these interference mechanisms means that this limit is expressed in terms of absolute power rather than as a power spectral density, as for the spurious emission limit.

---

[10] Because direct injection of interference to the radar was permitted

[11] The vertical radiation pattern of the radar antenna has been measured directly, and is found to be in good agreement with manufacturers data (see Figure 3.2). Previous interference area predictions by Plum were made using the worst-case assumption that interference would enter the radar with the full (33dBi) antenna gain; a more likely scenario would be that the measured horizon gain of 24 dBi should apply. However for the purposes of this document and considering the safety to life aspect associated with the radars, the modelling should reflect a worst case scenario.

[12] This limit is derived assuming that there are three licensed operators with equal amount of allocated spectrum. If there are a different number of operators and/or a different amount of spectrum allocated to each operator, the corresponding pfd limit can be calculated from [-140 + 10 log10 (Bandwidth(MHz) / 120)].

[13] Following successful installation of filters at the radar receiver, no in-band radiation limit is required as filtering at the radar receiver should address the impact of blocking and intermodulation effects at the radar receiver in the adjacent band.

[14] This limit is derived assuming that there are three licensed operators with equal amount of allocated spectrum. If there are different number of operators and/or different amount of spectrum allocated to each operator, the corresponding pfd limit can be calculated from [-78 + 10 log10 (Bandwidth(MHz) / 120)].

- to ensure protection of radars from MFCN base stations where they are operating in close proximity, a 1 km coordination zone[15] should be applied around the radars in Dublin, Shannon and Cork assuming that radar receivers are fitted with filters[16]:
  - Inside the 1 km coordination zone, MFCN operators would be required to coordinate with the radar operator, regardless of antenna gain value or compliance with pfd limit.
  - Outside the 1 km coordination zone, each potential MFCN operator would be required to comply with the defined pfd limit (-145 dBW/m^2/MHz)[17].

---

[15] as adopted in Belgium

[16] . Following successful installation of filters at the radar receiver, no in-band radiation limit is required as filtering at the radar receiver should address the impact of blocking and intermodulation effects at the radar receiver in the adjacent band.

[17] The compliance with pfd limits could be demonstrated by the MNOs using their own analysis tools as adopted, for example, in France.