UMTS900 – GSM-R Interference Measurements

A Report Prepared for Ofcom

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Executive Summary

This document details a measurement study investigating the performance of GSM-R mobile stations (MS) in the presence of strong UMTS900 signals in the immediately adjacent E-GSM band.

The approach adopted has been to:

- Accurately characterise the out of band (OOB) performance of a typical UMTS900 Node B by measuring out of band emissions across the GSM-R band.
- Simulate this performance in the laboratory to the extent possible with standard laboratory signal generators.
- Measure the error rate of a full rate speech call between a GSM-R test set and a GSM-R MS at a constant carrier level as the interfering UMTS test signal is varied in magnitude. The level of interfering signal required to produce a given BER is recorded as a function of GSM-R carrier level.

Measurements have been taken with and without filters designed to improve performance in the presence of interference, and on GSM-R MS from three different vendors. OOB performance of three different types of Node B and two different types of transmit filter combiners have also been assessed.

Observation of the measurement results show that for GSM-R MS under the conditions measured.

- Without any blocking protection filters the dominant interference mechanism under most of the measurement ranges is MS blocking.
- The tests on the passive and active blocking protection filters deployed between the antenna and the GSM-R MS show that both effectively remove UMTS interfering signals. The remaining dominant interference mechanism under most of the measurement ranges is then OOB interference. The difference between the ‘best’ and ‘worst’ performing UMTS node B and transmit filter combiner combination is ~30dB, where ~15dB comes from differences in NodeB performance and ~15dB from suppression of the OOB signals from the transmit filter combiner.
- Both the passive and active filters reduce the sensitivity of the MS. At very low signal levels (in the range -98dBm to -104dBm), the improvement in interference protection from deploying the blocking protection filters is lower than is achieved at higher wanted signal levels.
- The blocking protection filters tested have low (3-5dB) rejection to interferers at 925.2MHz. When blocking protection filters are used interference from an E-GSM signal at 925.2MHz has the most impact on the GSM-R receivers, for a given interference power.
- When no blocking filter is used, E-GSM interference has most effect on the GSM-R receivers tested for lower levels of wanted signal but all GSM-R MS tested are better able to cope with GSM interference than UMTS interference at higher interfering power levels.

The performance of the GSM-R MS from different vendors was slightly different, but the overall conclusion drawn from measurements on different devices is the same. It is relatively difficult to protect a GSM-R MS from interference with a wanted signal of -98dBm (Network Rail's planning limit) under 'absolute worst case' interference conditions because the wanted signal is very close to the sensitivity limit of the GSM-R MS.

The concept of protection separation distance was introduced. This is the distance above which, for a given signal level, a GSM-R MS can maintain a call with RXQUAL=4 or better in the presence of 'worst case' interference from a UMTS NodeB. 'Worst Case' in this context means a signal on full power with the interferer's antenna boresight pointed directly at the antenna of the GSM-R MS.

In the case of the MS receiving a wanted signal of -90dBm, deploying blocking protection in front of the MS improves interference performance and generally reduces the protection separation distance by a factor between 2 and 3. The combination of Combiner_Filter_2 filter combiners, NodeB_type3 (at 932.6MHz) and receiver blocking filters was shown to be particularly effective in reducing the protection separation distance to below 25m.

Vodafone, who in the UK have the lowest allocation of E-GSM spectrum, immediately adjacent to the GSM-R band, cannot use transmit filter combiners that suppress OOB signals at the top of the GSM-R band. Vodafone therefore have the potential to have a greater impact on the GSM-R network than O2, and there may be fewer mitigation options. In the case of the MS receiving a wanted signal of -90dBm, deploying blocking protection in front of the MS reduces the protection separation distance to less than 200m.

The data in this report should be useful to guide Ofcom in any revisions of the interim co-ordination procedure for UMTS deployment in the 900MHz band and also to guide Network Rail in assessing interference mitigation options. A recommendation as to specific remedies is beyond the scope of this document.

Vendors and operators expressed sensitivity to identities of themselves and their suppliers being publicly linked to specific performance results, and so Red-M was requested to produce a redacted version of this report for circulation beyond Ofcom and Network Rail. This version of the document has been redacted.

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Disclaimer

1. Introduction

Red-M has been contracted by Ofcom to perform a measurement study investigating the performance of GSM-R mobile stations (MS) in the presence of strong UMTS900 signals in the immediately adjacent E-GSM band.

The approach adopted has been to

- Accurately characterise the OOB performance of a typical UMTS900 Node B by measuring out of band emissions across the GSM-R band.
- Simulate this performance in the laboratory to the extent possible with standard laboratory signal generators.
- Measure the error rate of a full rate speech call between a GSM-R test set and a GSM-R MS at a constant carrier level as the interfering UMTS test signal is varied in magnitude. The level of interfering signal required to produce a given BER is recorded as a function of GSM-R carrier level.

Measurements have been taken with and without filters designed to improve performance in the presence of interference.

2. Background

The spectrum allocation between 862 and 960MHz is shown in Figure 1.

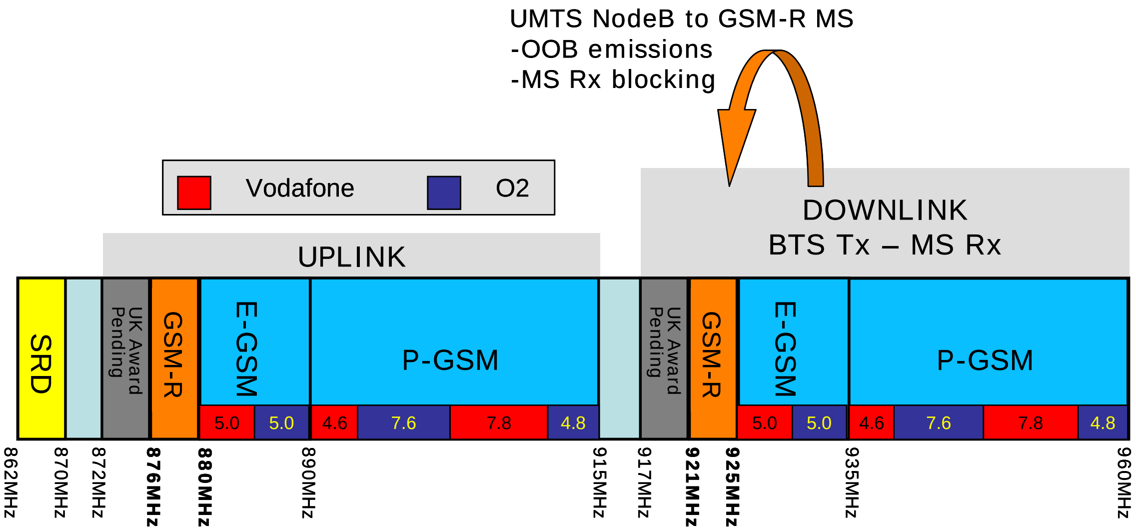

Figure 1: Spectrum Allocation 860 - 960MHz

Ofcom has recently amended the licensing arrangements of Vodafone and O2 to allow them to deploy UMTS carriers in spectrum previously reserved for 2G services in the 900 MHz band. UMTS services need a contiguous allocation of 5MHz of spectrum, and this means that those allocations in the E-GSM band are particularly suited to initial deployments of UMTS at 900MHz.

Network Rail has raised concerns about the potential for interference from UMTS900 equipment to their GSM-R network. As Figure 1 shows, the GSM-R frequencies are immediately adjacent to the E-GSM frequency band. Two potential disruption mechanisms are:

- OOB emissions from a UMTS Node B preventing the GSM-R MS from demodulating a weak GSM-R signal on the same frequency. This mechanism can potentially be mitigated by the deployment of additional filtering at the output of the NodeB.
- Blocking of the GSM-R MS by the UMTS NodeB. This mechanism can potentially be mitigated by the deployment of additional filtering at the front-end of the GSM-R MS.

As a result of the concerns of Network Rail, Ofcom has put in place an interim coordination procedure on Vodafone and O2 requiring them to coordinate the deployment of UMTS900 base stations with Network Rail where signal strengths from UMTS900 base stations are predicted to exceed a set of coordination thresholds specified by Ofcom. These thresholds have been derived from a set of assumptions taken from GSM specifications.

The purpose of this study is to measure the actual performance of real GSM-R MS in the presence of a UMTS900 transmitter with an emissions profile that is representative of the actual performance of UMTS base stations likely to be deployed. The key output of this study is therefore a set of protection criteria that will help Ofcom develop a more realistic set of coordination thresholds. The measurements have been performed to simulate performance of a range of both 'unprotected' NodeBs and GSM-R MSs, as well as a number of measurements where additional filtering has been deployed on either or both the NodeB and the GSM-R MS. Measurements have been focussed on the GSM-R channel at 924.8MHz. This is the channel nearest in frequency to the E-GSM band and is therefore likely to be the worst affected by both the interference and blocking mechanisms listed above.

The interim co-ordination procedure is required only for new UMTS deployments in the 900MHz band. No equivalent co-ordination procedure is in place for GSM900 deployments, even though the same disruption mechanisms may apply. In order to provide a more complete picture, measurements of the effect of GSM interference in the E-GSM band have also been taken. The GSM interfering signal used is characteristic of a BCCH interferer with all timeslots transmitted at full power.

Measurements taken 'off air' in Germany[1] have identified some areas where GSM-R communications are disrupted by GSM transmissions in the E-GSM spectrum. A particular 'worst case' identified concerned interference measured in a station car-park from a shared E-GSM cell site situated on the roof of the local station. The GSM-R signal at this point was provided by a GSM-R BTS at a distant station. Measurements showed that there were two E-GSM BCCH signals at f1, f2 which created a (2f1 – f2) intermodulation product in the GSM-R band which happened to be co-incident with the non-hopping carrier that was used for GSM-R communications in that area. Intermodulation as a mechanism is not studied in this report, which considers only effects from a single dominant interfering source.

The exact situation described is much less likely in the UK because currently, and unlike Germany, neither O2 nor Vodafone routinely use BCCH frequencies in the E-GSM band. Equivalent interference produced by E-GSM traffic channels would be more sporadic and harder to observe, as the channel occupancy would depend on whether there was an active call or not. The situation where all timeslots for an E-GSM traffic channel were used at full power would be extremely rare.

An analogous situation could arise in the UK where there are two UMTS interferers of similar magnitudes –for example in an area where O2 and Vodafone have shared a mast near to a railway and both have deployed

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[1] Presentation by Hendrik Holz, Funkwerk Kolleda, to Network Rail, Ofcom and Red-M on 11th March 2011

UMTS. The nature of UMTS and E-GSM interference and their resulting potential impact on a GSM-R signal are somewhat different.

Table 1: GSM and UMTS interference sources

Interference Type	Magnitude	Interference Power Spectral Density	Interference Bandwidth
E-GSM	non-constant (unsynchronised TCH timeslot, power control) or constant (BCCH)	higher	lower
UMTS	relatively constant (P-CPICH)	lower	higher

Intermodulation products arising from UMTS signals are likely to be less destructive than products arising from GSM signals. As UMTS carriers have relatively constant transmission levels, if there is a potential interference problem at a location it is likely to manifest itself most of the time. As GSM carriers (with the exception of the BCCH) have non-constant transmission levels, interference may manifest itself as an intermittent problem which may be harder to conclusively track down. Where multiple interference sources cause intermodulation issues, the combination of lower power spectral density and higher bandwidth of UMTS interference has the effect of reducing the peak co-channel interference energy whilst increasing the number of GSM-R carriers over which the energy is distributed. The situation is illustrated schematically in Figure 2.

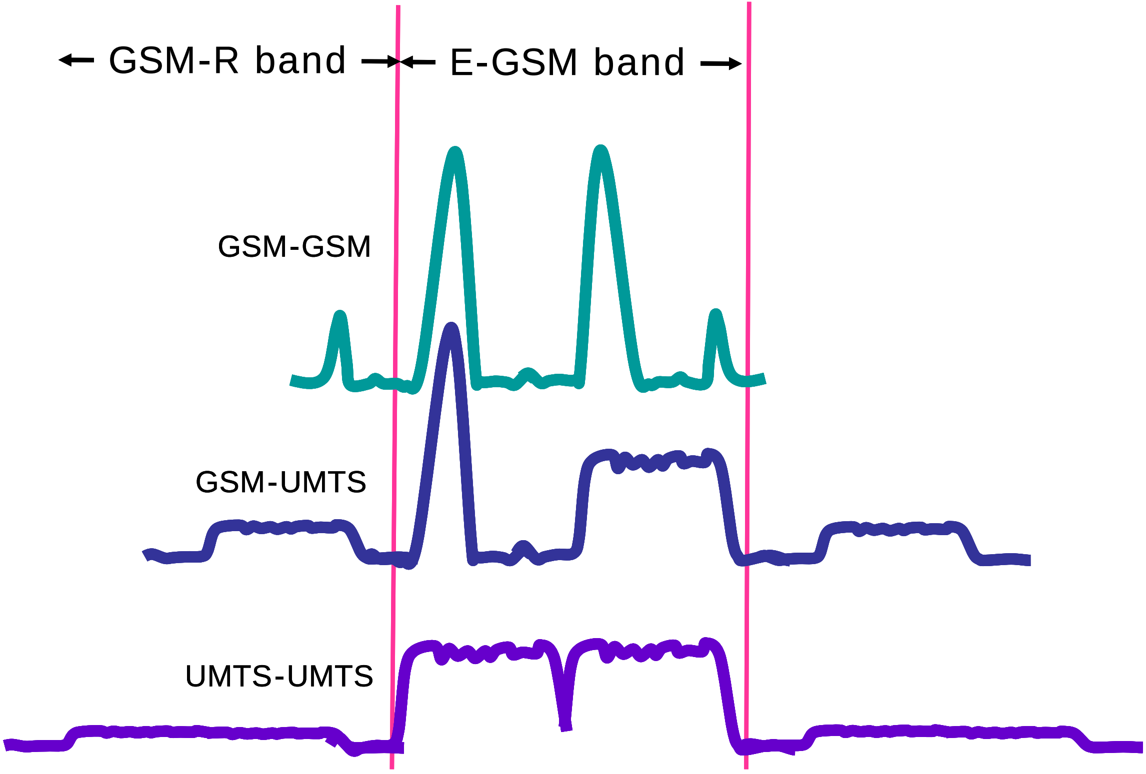

Figure 2: Intermodulation Mechanisms, GSM and UMTS interference

This report contains measurements which do not take into account some other factors that may need to be considered in field-based measurements. In particular

- In the measurements made in the lab, neither the wanted nor interfering signals are subject to Rayleigh fading or log-normal shadowing. Particular allowance for these effects is necessary when interpreting field measurements or performance.
- Some GSM-R MS have a diversity reception feature which can help to mitigate the effects of interference, especially where slow frequency hopping is not implemented. Diversity performance[2] was not investigated in the laboratory measurements.
- The report considers only interference effects on the downlink. The uplink is not considered.

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[2] Diversity at the MS (i.e. on the downlink) is not used on the UK rolling stock, although diversity on the uplink is generally implemented.

3. Measurement Set Up

GSM-R MS provided by Network Rail were tested using the configuration shown in Figure 3.

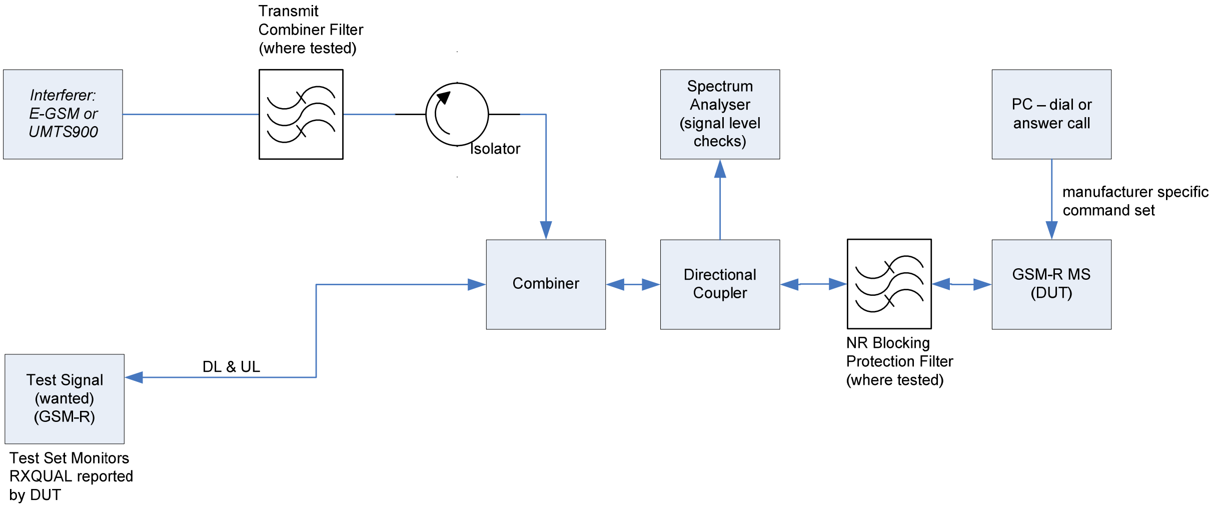
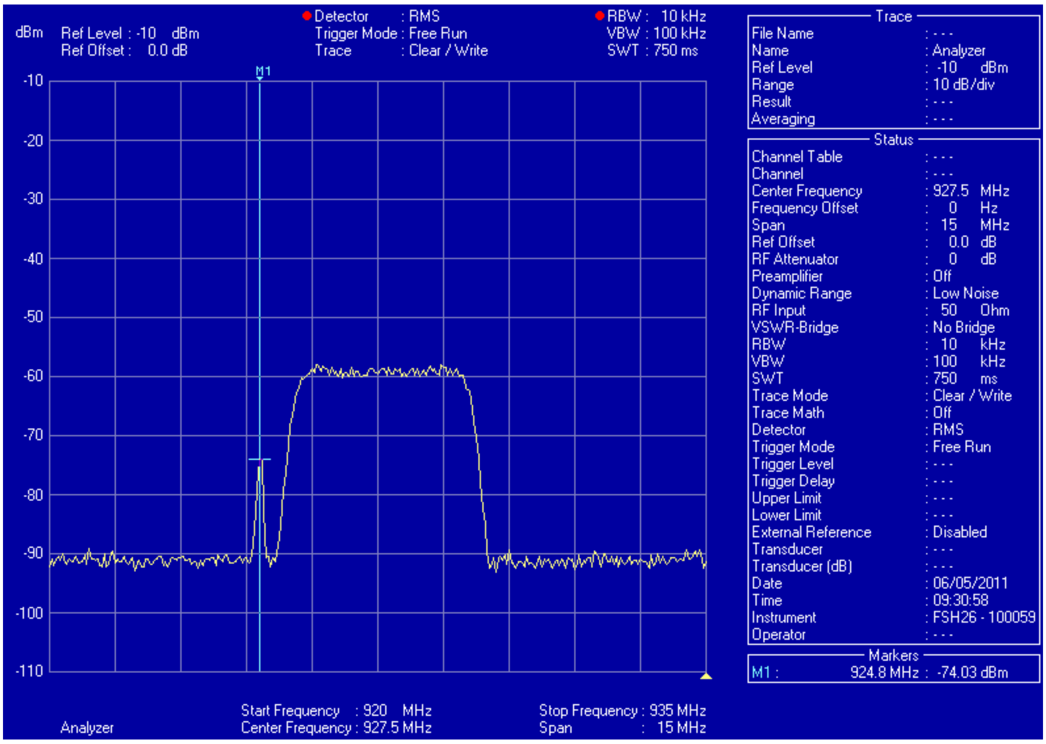


Figure 3: GSM-R Testing

The test setup used the following equipment:

- Aeroflex 4202R GSM-R mobile test set. This unit was used to establish a test speech call with the GSM-R MS, and vary the wanted signal level. The GSM-R MS reports signal level and quality which are relayed back to the test set and displayed on the screen. Interfering signal levels that resulted in the MS reporting RXQUAL=4 were recorded during the tests. The test-set was configured so that the TCH and BCCH used the same frequency, and the call was always set up on timeslot 4.
- Rohde & Schwarz SMIQ03B signal generator. This unit was used to generate both the E-GSM and UMTS900 interfering signals. A more detailed discussion of the required settings on this unit is given in Appendix A.4
- GSM-R mobiles from three manufacturers were housed in a test-rack supplied by Comtest. The test rack has lots of functionality for GSM-R drive test campaigns, but in this instance the sole function of the test-rack was to house the various GSM-R MS and to allow speech calls to be initiated.
- Blocking protection filters provided by Network Rail were added to the test configuration for a subset of the measurements. Two filters were supplied. Appendix B contains the measured characteristics of these filters.
- Transmit combiner filters from two vendors used by O2 were added to the test configuration for a subset of the measurements. Appendix C contains the measured characteristics of these filters.
- An isolator was used at the output of the signal generator for all tests to avoid interfering power reflected by the device under test affecting the purity of the interfering signal produced by the signal generator.

- A directional coupler with a -15dB tap connected to an FSH6 spectrum analyser was used to monitor test signal levels during the tests. The spectrum analyser was used for visual confirmation of signal levels only and was not used to record any measurements. An example of the type of trace observed is shown in Figure 4.



Ref Level : -10 dBm
Ref Offset : 0.0 dB

Detector : RMS
Trigger Mode : Free Run
Trace : Clear / Write

RBW : 10 kHz
VBW : 100 kHz
SWT : 750 ms

Start Frequency : 920 MHz
Center Frequency : 927.5 MHz
Stop Frequency : 935 MHz
Span : 15 MHz

Trace

File Name	: - - -
Name	: Analyzer
Ref Level	: -10 dBm
Range	: 10 dB/div
Result	: - - -
Averaging	: - - -

Status

Channel Table	: - - -
Channel	: - - -
Center Frequency	: 927.5 MHz
Frequency Offset	: 0 Hz
Span	: 15 MHz
Ref Offset	: 0.0 dB
RF Attenuator	: 0 dB
Preamplifier	: Off
Dynamic Range	: Low Noise
RF Input	: 50 Ohm
VSWR-Bridge	: No Bridge
RBW	: 10 kHz
VBW	: 100 kHz
SWT	: 750 ms
Trace Mode	: Clear / Write
Trace Math	: Off
Detector	: RMS
Trigger Mode	: Free Run
Trigger Level	: - - -
Trigger Delay	: - - -
Upper Limit	: - - -
Lower Limit	: - - -
External Reference	: Disabled
Transducer	: - - -
Transducer (dB)	: - - -
Date	: 06/05/2011
Time	: 09:30:58
Instrument	: FSH26 - 100059
Operator	: - - -

Markers

M1 : 924.8 MHz : -74.03 dBm

Figure 4: Example Signal Levels Monitored During Tests (GSM-R wanted signal at 924.8MHz, Interfering UMTS signal with centre frequency 927.6MHz)

4. Results

4.1 GSM-R MS Selection

A number of GSM-R MS were supplied by Network Rail for testing.

- 5 Kapsch MT2
- 5 Sagem MRM
- 4 Selex RMM2300
- 1 TrioRail (Siemens) hand portable, used by Network Rail for network scanning drive tests.

The Kapsch and Sagem MS are used in UK rolling stock, the Selex MS are not used in the UK but are used in continental Europe. Selex MS could conceivably need to operate in the UK in circumstances where foreign trains are running on UK track.

In order to choose a 'representative' MS for complete characterisation, all of the supplied MS were tested for interference using both UMTS and E-GSM interferers. Tests were carried out at wanted signal levels of -104dBm and -98dB. The test configuration of Figure 3 was used for testing without any combiner or blocking protection filters.

The table in Appendix D contains the results from measurements on each of the MS, and indicates which ones were chosen for further characterisation.

4.2 Presentation of Measurement Results

The objective of the measurement campaign was to present a family of response curves similar to Figure 5. For a given GSM-R wanted signal plotted on the x-axis, the level of interfering signal required to degrade the signal quality to the point where the GSM-R MS reports RXQUAL=4[3] is plotted on the y-axis.

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[3] RXQUAL is a measurement of signal quality made by a GSM receiver. RXQUAL=0 is the best level and RXQUAL=7 is the worst level. RXQUAL is a convenient choice of measurement metric as it is reported frequently by the MS on the air interface and displayed on the radio test-set.

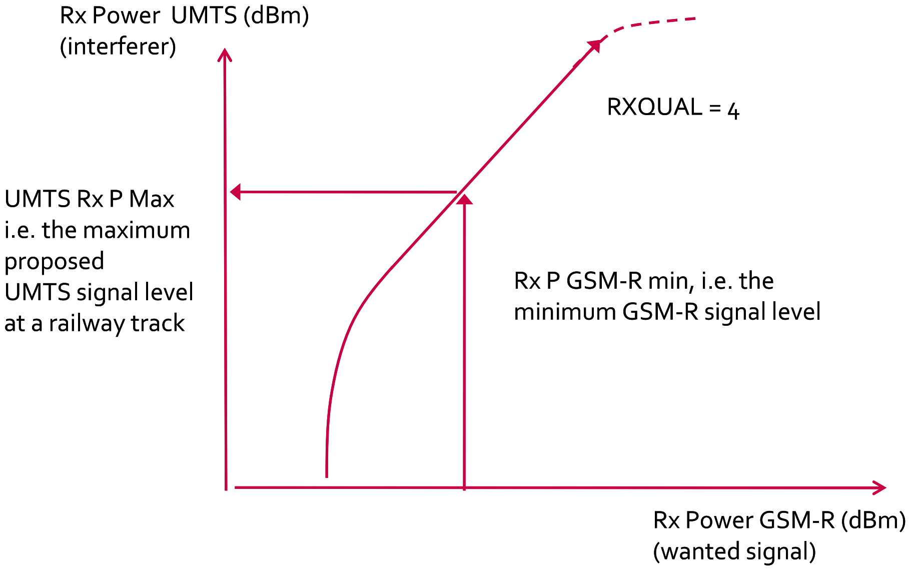

Figure 5: Presentation of Measurement Results

Although there are only 8 possible RXQUAL levels reported, the degradation of the RXQUAL metric with increasing interfering signal level is such that there is only a range of ~1dB of interfering signal level where RXQUAL=4 is reported. In a cabled test environment with no fading, the reported level of RXQUAL does not vary if the wanted and interfering signal levels are kept constant.

In order to reduce the measurement error associated with using RXQUAL=4 (rather than, say, a BER measurement), measurements were always taken by increasing the interfering signal level gradually and the lowest level at which RXQUAL=4 was consistently reported was recorded.

In order to provide a consistent set of results across measurements with and without filters the measurement reference point shown in Figure 6 was adopted. This reference point is intended to closely represent the MS antenna connector in normal operation. Where a measurement is taken with no external filter, the raw signal levels observed on the test instruments are corrected for the insertion loss of the test set (isolator, combiner and directional coupler) and the values plotted therefore represent the actual signal levels incident on the GSM-R MS. When the GSM-R MS is measured with a blocking protection filter the value plotted represents the actual signal levels incident on the antenna port of the filter and the actual level received by the MS will be different due to the insertion gain/loss of the filter (given in Appendix B). When the GSM-R MS is measured with a transmit combiner filter, the actual interfering signal level received by the MS will be slightly lower due to the insertion loss of the filter (<1dB) given in Appendix C. The measurement therefore highlights the change in MS interference response achieved when the filter is inserted but everything else remains the same.

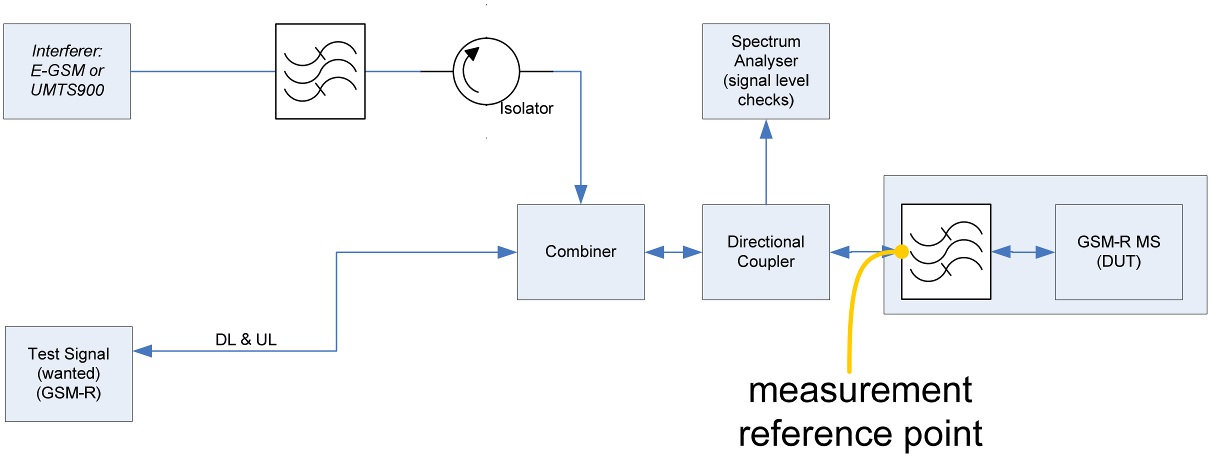

Figure 6: Measurement Reference Point

There are a number of maximum test signal limits which were not exceeded during measurements even if degradation to RXQUAL=4 was not achieved. The limits are shown in Figure 7 with reference to the test-set and signal generator outputs that were controlled during the measurements (i.e. the values given in Figure 7 are not corrected for test-set loss). The limits are:

- -41dBm wanted signal. This is the maximum signal level that the test set can generate[4].
- -1dBm[5] interfering signal for measurements taken with the active blocking protection filter. The filter is specified for operation with signal levels not exceeding 0dB. In order to ensure that this level was never accidentally exceeded, a lower self-imposed limit was used during the measurements. The combination of this limit with the very high rejection of the active filter meant that signal degradation to RXQUAL=4 was not achieved under a wide range of wanted signal levels.
- +5dBm interfering signal for measurements taken using a UMTS interfering signal. This is close to the output limit of the signal generator. Although it was observed that somewhat higher signal levels could be achieved without degradation of the measured out of band characteristic, exceeding +5dBm results in increased IQ signal error vectors and potential clipping of the combined signal. This limit was therefore not exceeded.
- +22dBm interfering signal for measurements taken using the GSM-R interfering signal. This is close to the output limit of the signal generator. In practice it was never necessary to approach this limit during measurements.

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[4] The 4202R test set can generate a signal of -38dBm. It has the facility to pre-compensate the output for test-set loss, and a compensating value of 3dB was used. Setting the instrument to -41dBm output therefore generated a signal of -38dBm which after test-set losses corresponded to approximately -41dBm at the measurement reference point.

[5] Corresponding to approximately -4dBm at the measurement reference point.

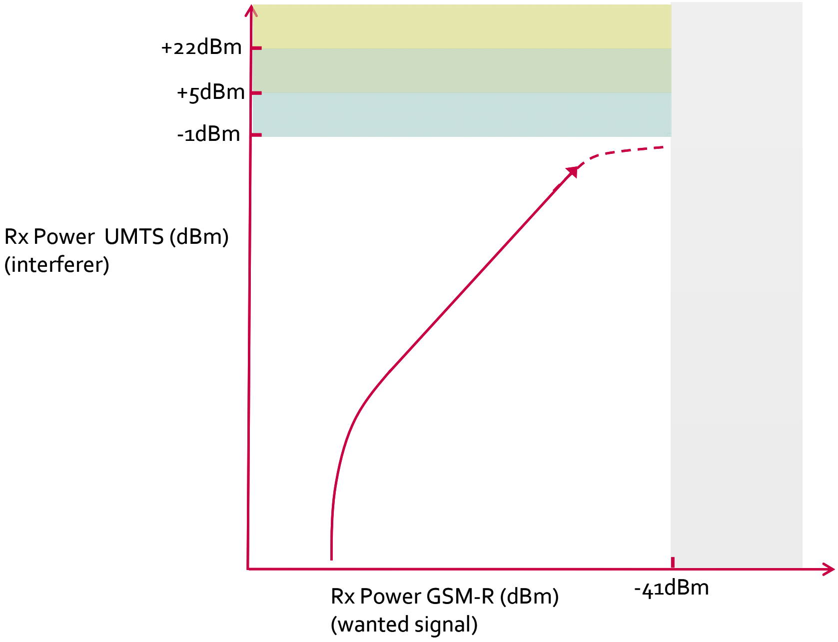

Figure 7: Maximum Test Signal Limits

A series of three sets of result curves for each vendors MS are presented in sections 4.3 and 4.5 below. Each set of curves corresponds to the three receiver conditions

- MS with no blocking protection filter
- MS with passive blocking protection filter
- MS with active blocking protection filter

For each receiver condition a set of 8 curves corresponding to the required interference cases were captured. The interference cases are:

- Vodafone NodeB_type1 UMTS900 interference with a centre frequency of 927.6MHz
- O2 NodeB_type2 UMTS900 interference with a centre frequency of 932.6MHz
- O2 NodeB_type2 UMTS900 interference with a centre frequency of 932.6MHz and a Combiner_Filter_1 transmit filter combiner
- O2 NodeB_type2 UMTS900 interference with a centre frequency of 932.6MHz and an Combiner_Filter_2 transmit filter combiner[6]
- O2 NodeB_type3 UMTS900 interference with a centre frequency of 932.6MHz
- O2 NodeB_type3 UMTS900 interference with a centre frequency of 932.6MHz and a Combiner_Filter_1 transmit filter combiner
- O2 NodeB_type3 UMTS900 interference with a centre frequency of 932.6MHz and an Combiner_Filter_2 transmit filter combiner
- E-GSM BCCH interference with a centre frequency of 925.2MHz (in Vodafone's E-GSM allocation).

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[6] The OOB characterisation measurements determined that this curve is co-incident with the O2 NodeB_type3 response with no transmit filter combiner and so only the latter is visible in the graphs.

Each interference case is simulated by using the R&S signal SMIQ03B signal generator as described in Appendix A.4.
The general characteristics of the result curves are shown in Figure 8, showing transition regions that are observed. At low signal levels performance of the MS is noise limited and as the wanted signal is reduced to below the MS sensitivity limit, RXQUAL=4 is not achieved even in the absence of interference. At high interfering signal levels the wanted signal has to be increased significantly to overcome blocking effects at the receiver. In general between these two regions there is a region where the curve has a slope of 1dB/dB, although this region may not necessarily exist in all scenarios other than as a transition between slope >1 and <1.

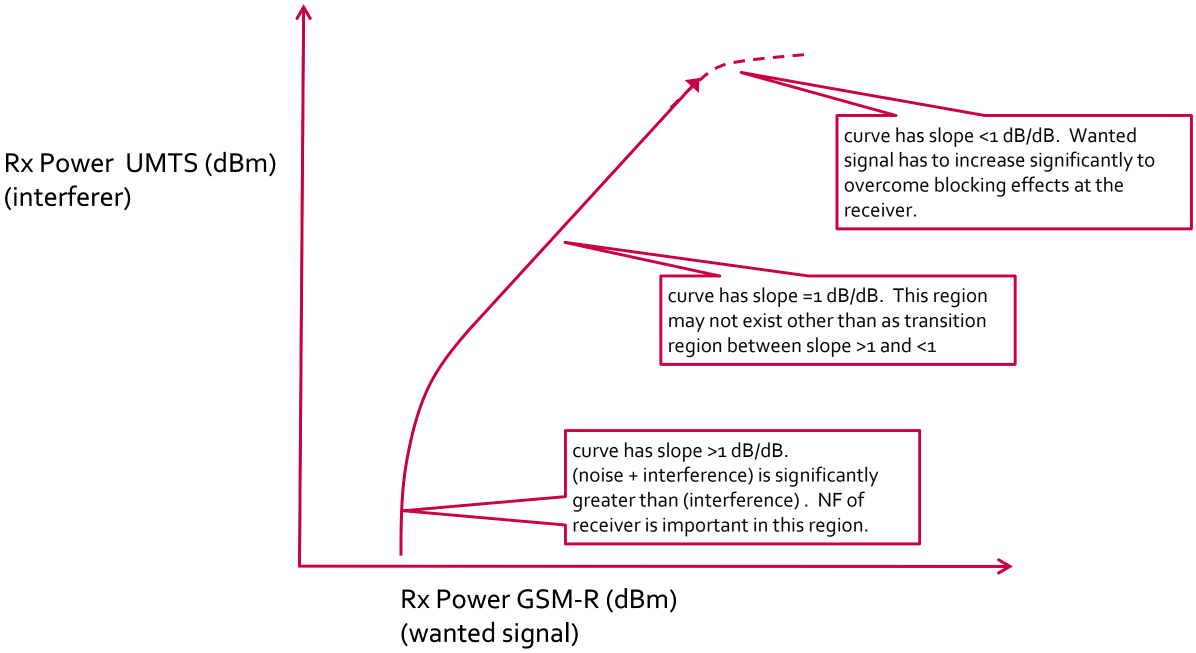

Figure 8: Characteristics of Result Curves

In order to observe the transition between these regions visually, for each set of receiver curves a graph of Δinterferer(dB)/Δwanted(dB) calculated by forward difference is presented. Measurement error is amplified in these curves because the calculation takes the difference of two similar quantities. Grey shading about the unity slope value is therefore used to highlight regions where the slope is '1' within measurement error. The use of the forward difference calculation method also means that an error of 2-3dB in transition between the regions may be exhibited.

4.3 Results for Kapsch GSM-R MS

Figure 9 and Figure 10 show the results for the Kapsch GSM-R MS with no receiver blocking protection filter. Figure 11 and Figure 12 show the results for the Kapsch GSM-R MS with the passive receiver blocking protection filter. Figure 13 and Figure 14 show the results for the Kapsch GSM-R MS with the active receiver blocking protection filter.

The results for the Kapsch GSM-R MS were inspected. The following observations were made:

- Without any blocking protection filters the dominant interference mechanism under most of the measurement ranges is MS blocking.
- Both the passive and active Rx filters effectively remove the UMTS interfering signals. The dominant interference mechanism under most of the measurement ranges is then OOB interference. The difference between the 'best' and 'worst' case UMTS interfering combination is ~30dB, where ~15dB comes from differences in NodeB performance and ~15dB from suppression of the OOB signals from the transmit filter combiner.
- At very low signal levels (the range -98dBm to -104dBm) both the passive and active filters reduce the sensitivity of the MS, so that the improvement in protection from deploying the blocking protection filters is lower than is achieved at higher signal levels. (This result is most easily observed by comparing the relative protected signal levels and separation distances in the case-study analysis in section 4.4).
- The blocking protection filters have low rejection to interferers at 925.2MHz[7]. For a given interference power, when blocking protection filters are used, interference from an E-GSM signal at 925.2MHz has the most impact on the Kapsch GSM-R receiver.
- When no blocking filter is used, E-GSM interference has most effect on the Kapsch GSM-R receiver for lower levels of wanted signal, but the receiver seems better able to cope with GSM interference than UMTS interference at higher interfering power levels.

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[7] The blocking protection filters only provide 3-5dB interference rejection at 925.2MHz.

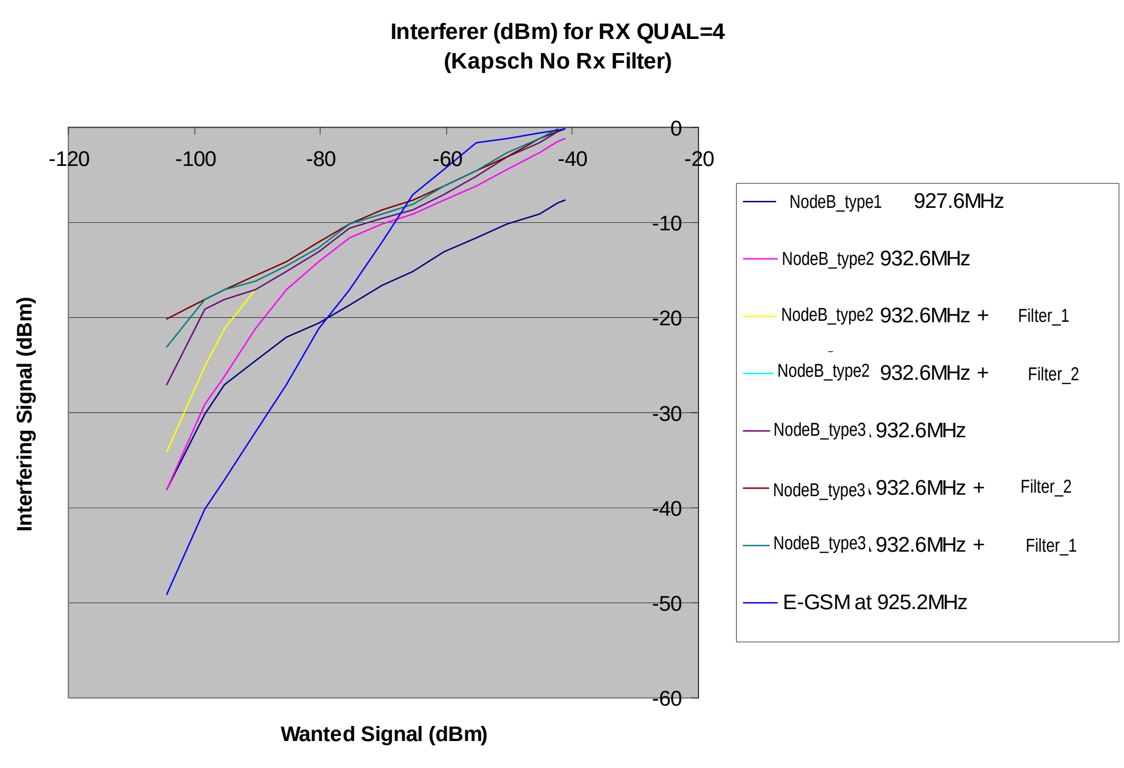

Figure 9: Interference Level for Kapsch MS with no receiver blocking protection filter.

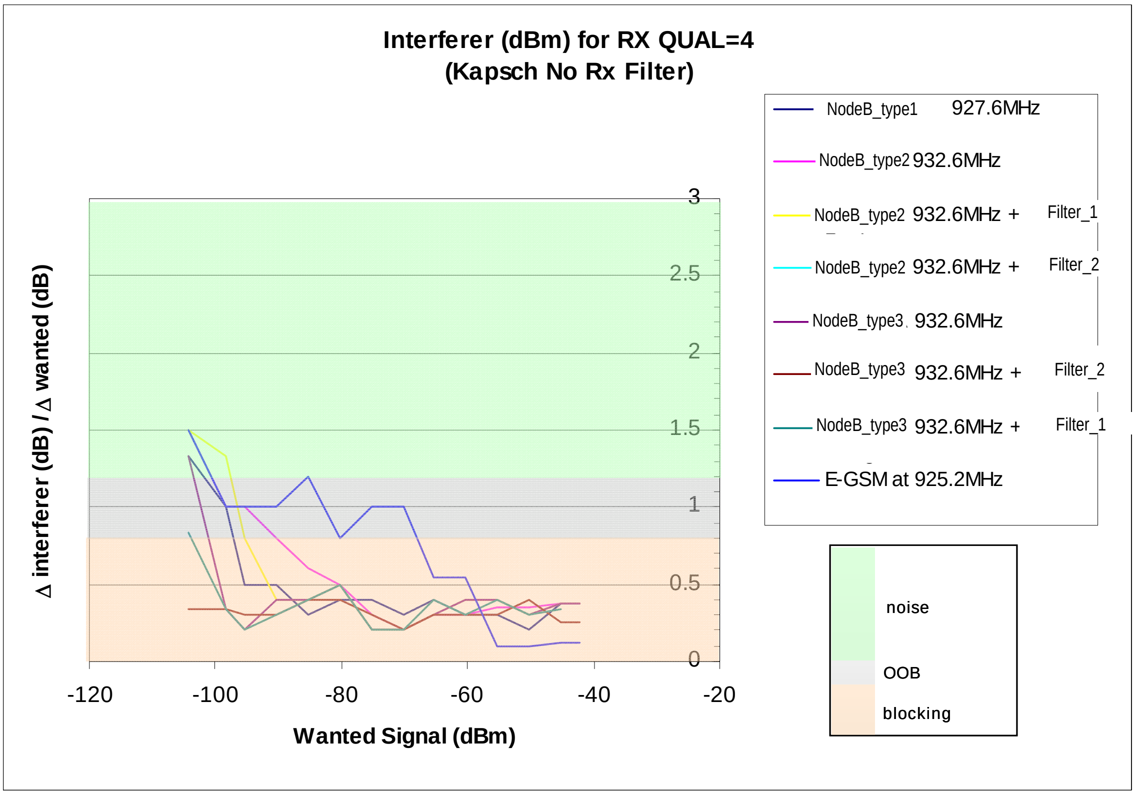

Figure 10: Interference slope for Kapsch MS with no receiver blocking protection filter.

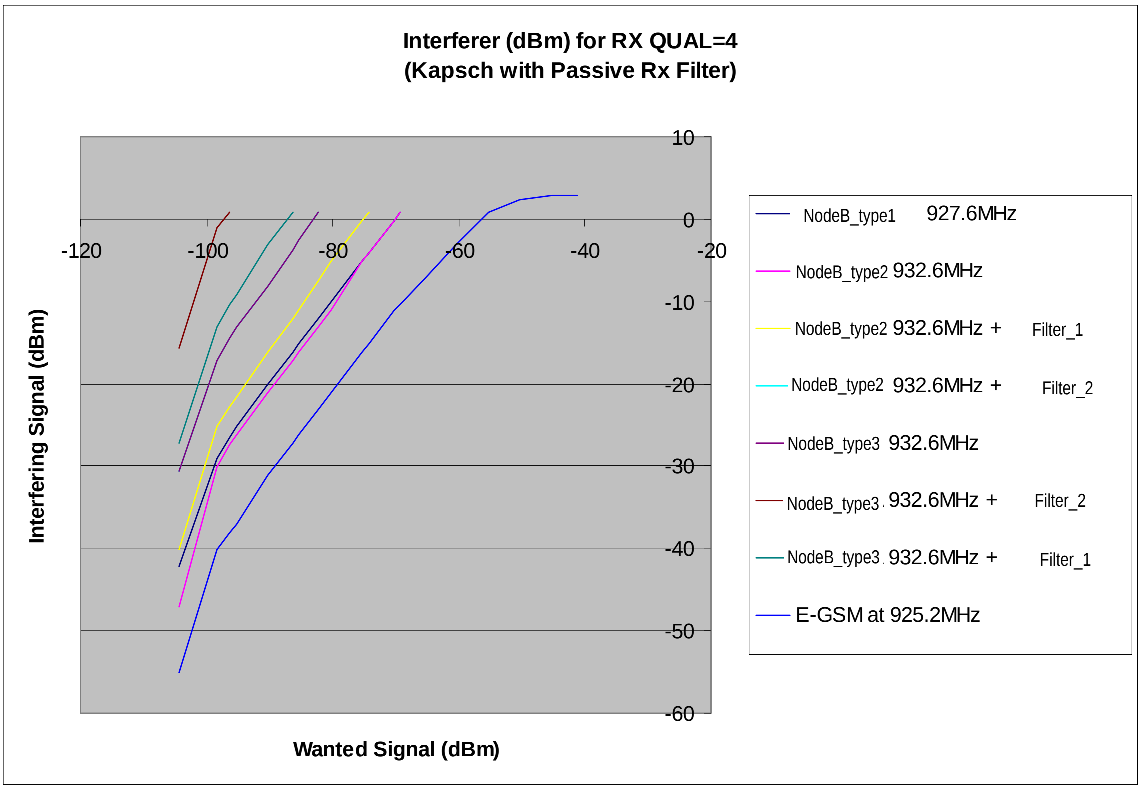

Figure 11: Interference Level for Kapsch MS with passive receiver blocking protection filter.

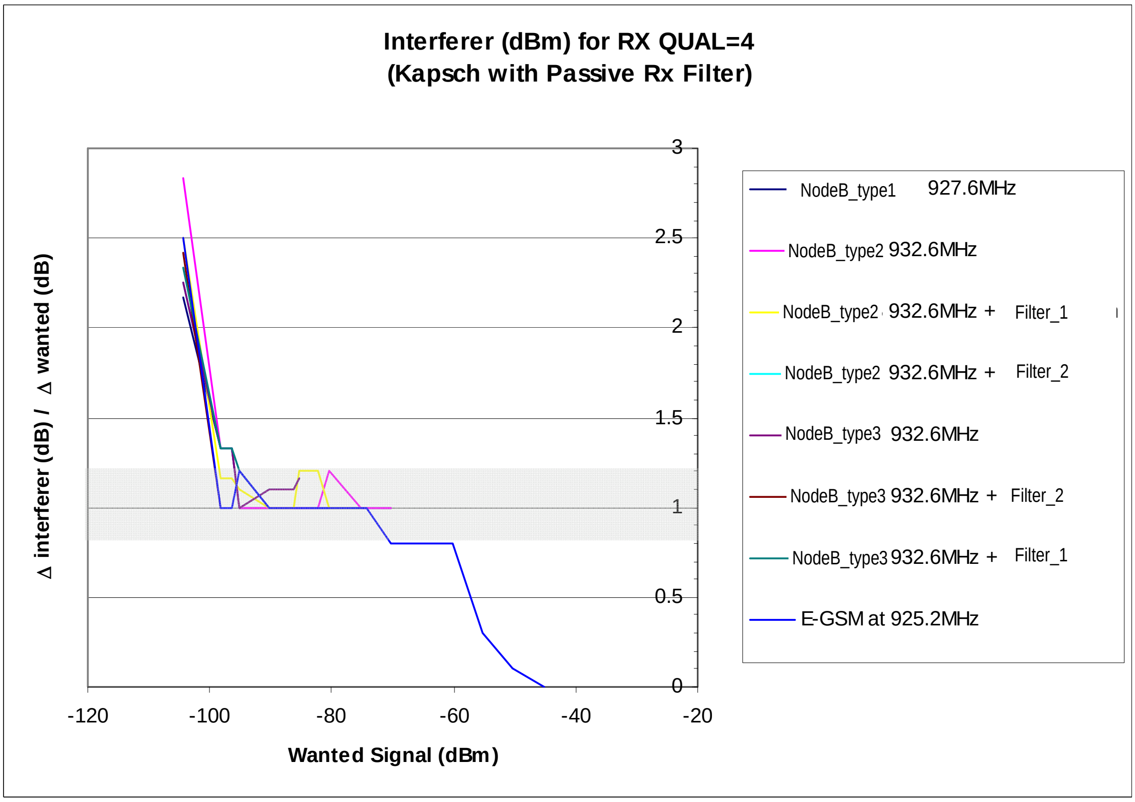

Figure 12: Interference slope for Kapsch MS with passive receiver blocking protection filter.

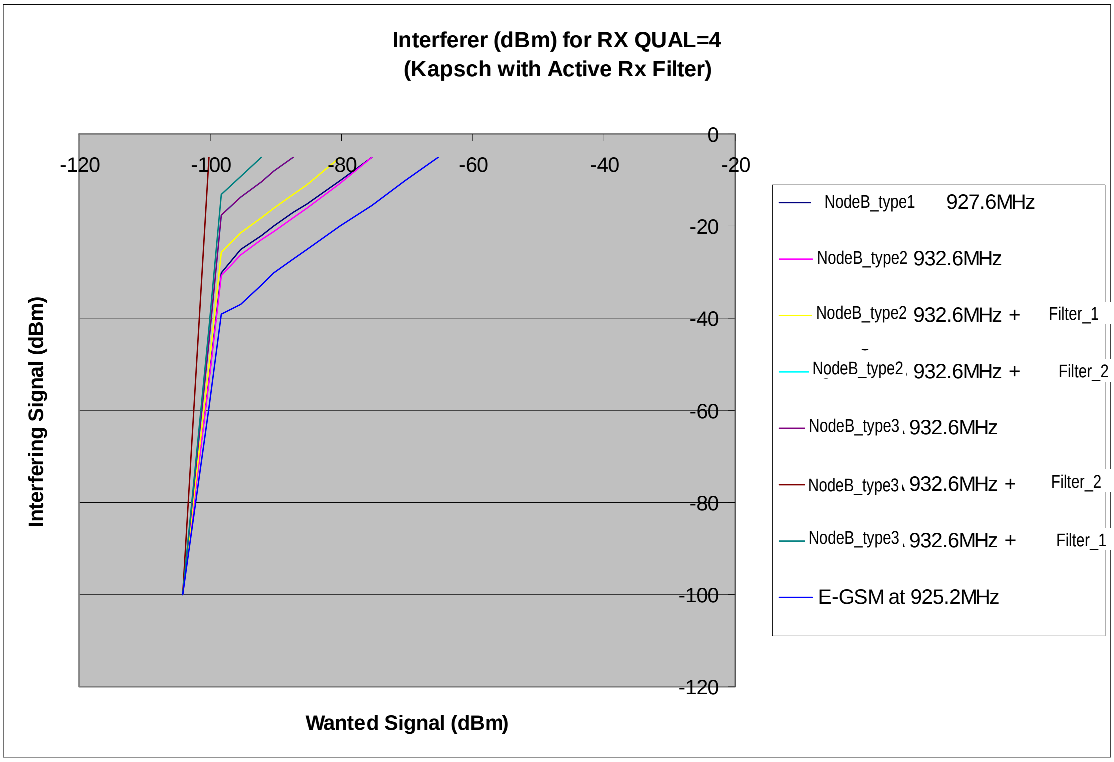

Figure 13: Interference Level for Kapsch MS with active receiver blocking protection filter.

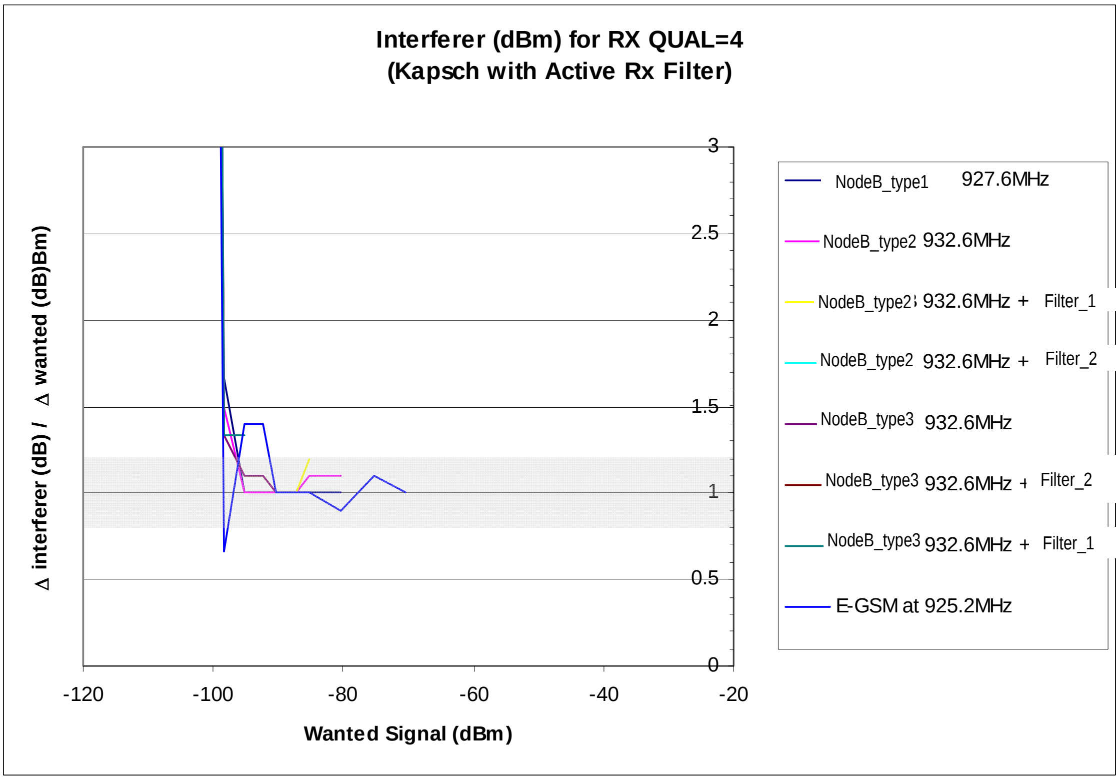

Figure 14: Interference slope for Kapsch MS with active receiver blocking protection filter.

4.4 Analysis of Results of tests on Kapsch MS

A case study was constructed based entirely on interpolation/extrapolation of the curves from section 4.3. Two questions are answered by Table 2.

- If there is a 25m separation between a train mounted GSM-R MS sitting on the bore-sight of the main lobe of the transmission from a UMTS NodeB[8] with the characteristics given (transmit power of +43dBm, 18dBi antenna gain, 3dB feeder loss, MS antenna gain of 2dB), what GSM-R signal level is required to maintain a call with RXQUAL=4 or better?
- If a GSM-R MS receives a wanted signal of -98dBm or-90dBm whilst on the bore-sight of a main lobe of a UMTS NodeB with the characteristics given, what is the protection separation distance required[9] such that the MS can maintain a call with RXQUAL=4 or better?

Each of these two questions is answered using the result curves from section 4.3 for the cases where the GSM-R MS is used both with and without blocking protection filters.

In the case of the 25m separation from the UMTS interferer, the interfering signal is large, and the blocking protection filters provide 35 to 60dB of improvement. The improvement depends on the OOB performance of the Node B providing the interfering signal.

In the case of the MS receiving a wanted signal of -98dBm, the improvement by deploying blocking protection filters is generally much lower because the MS is closer to its sensitivity limit.

In the case of the MS receiving a wanted signal of -90dBm, deploying blocking protection in front of the MS improves interference performance and generally reduces the protection separation distance by a factor of 2 to 3. The measured combination of Combiner_Filter_2 filter combiners, NodeB_type3 on O2's frequency and receiver blocking filters is seen to be particularly effective in reducing the protection distance to below 25m. In presenting the protection separation distance between a Vodafone NodeB at 927.6MHz and the GSM-R MS, the tolerated interferer has been increased by 3.7dB where blocking protection filters are used to account for the error in OOB emissions from the SMIQ03 compared to those measured from the NodeB_type1 in the laboratory (noted in Appendix A.4 Table 4). It is appropriate to apply this correction only if it is clearly demonstrated that OOB performance of the interferer and not blocking of the MS is dominating at the relevant signal levels. That this is the case is confirmed by inspection of Figure 12 and Figure 14.

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[8] This is a worst case assumption. Antenna height and a small 3dB elevation beam-width normally combine to ensure that you cannot be on bore-sight very close to an interfering source

[9] The protection separation distance is defined as the distance above which, for a given signal level, a GSM-R MS can maintain a call with RXQUAL=4 or better in the presence of 'worst case' interference from a UMTS NodeB.

Table 2: Case Study for Interference to Kapsch GSM-R MS

		KAPSCH		
Label	Item	Value	Unit	Note
A	Tx Signal	43	dBm	UK operator deployment
B	Tx Ant Gain	18	dBi	ECC REP096 Table 3-2
C	Feeder Loss	3	dB	ECC REP096 Table 3-2
D	Rx Ant Gain	2	dBi	ECC REP096 Table 3-2
E	Free Space Separation Distance	25	m	
F	Free Space Loss	59.7	dB	
G=A+B-C+D-F	Interference Signal Received	0.3	dBm	
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (No Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	-20	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz	-37	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-40	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-40	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz	-40	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-41	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-40	dBm	based on extrapolated values
	EGSM transmitter at 925.2 MHz	-38	dBm	based on extrapolated values
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (Passive Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	-70	dBm	
	O2 NodeB_type2 at 932.6 MHz	-70	dBm	
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-75	dBm	
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-83	dBm	
	O2 NodeB_type3 at 932.6 MHz	-83	dBm	
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-87	dBm	
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-97	dBm	
	EGSM transmitter at 925.2 MHz	-56	dBm	
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (Active Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	-70	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz	-70	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-75	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-82	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz	-82	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-87	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-100	dBm	based on extrapolated values

EGSM transmitter at 925.2 MHz	-60	dBm		based on extrapolated values

Measurement Results - Protected Separation Distance for Protected Wanted Signal (No Rx Filter)

Wanted Signal Level Protected -98 dBm

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-30	dBm	804	m
O2 NodeB_type2 at 932.6 MHz	-29	dBm	717	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-25	dBm	447	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-19	dBm	232	m
O2 NodeB_type3 at 932.6 MHz	-19	dBm	232	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-18	dBm	207	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-18	dBm	207	m
EGSM transmitter at 925.2 MHz	-40	dBm	2544[10]	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Passive Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-29	dBm	709	m
O2 NodeB_type2 at 932.6 MHz	-30	dBm	795	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-25	dBm	450	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-17	dBm	178	m
O2 NodeB_type3 at 932.6 MHz	-17	dBm	178	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-13	dBm	112	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-1	dBm	29	m
EGSM transmitter at 925.2 MHz	-40[11]	dBm	2544	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Active Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-29	dBm	786	m
O2 NodeB_type2 at 932.6 MHz	-30	dBm	838	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-25	dBm	474	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-17	dBm	189	m
O2 NodeB_type3 at 932.6 MHz	-17	dBm	189	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-13	dBm	112	m
O2 NodeB_type3 at 932.6 MHz plus	-1	dBm	36	m

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[10] The use of a free-space approximation with separation distances of >400m is a worst-case assumption. Significant additional propagation loss would normally be observed.

[11] The result is the same as the result with no blocking filter. The blocking filter provides low rejection to the interfering signal at 925.2MHz but as it has a small insertion loss at 924.8MHz it reduces the sensitivity of the receiver relative to the measurement reference point.

Combiner_Filter_2				
EGSM transmitter at 925.2 MHz	-40	dBm	2293	m
Measurement Results - Protected Separation Distance for Protected Wanted Signal (No Rx Filter)				
Wanted Signal Level Protected	-90	dBm		ECC REP118 Paragraph 6.1 (with -Gi+Pcon=-2dB)
Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-24	dBm	434	m
O2 NodeB_type2 at 932.6 MHz	-21	dBm	287	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-17	dBm	184	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-17	dBm	184	m
O2 NodeB_type3 at 932.6 MHz	-17	dBm	184	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-16	dBm	164	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-16	dBm	155	m
EGSM transmitter at 925.2 MHz	-32	dBm	1013	m
Measurement Results - Protected Separation Distance for Protected Wanted Signal (Passive Rx Filter)				
Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
				m (corrected for 3.7dB measured offset shown in Table 4 of Appendix A)
VF NodeB_type1 at 927.6 MHz	-16	dBm	166	
O2 NodeB_type2 at 932.6 MHz	-21	dBm	285	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-16	dBm	160	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-3	dBm	36	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	7	dBm	11	m
EGSM transmitter at 925.2 MHz	-31	dBm	902	m
Measurement Results - Protected Separation Distance for Protected Wanted Signal (Active Rx Filter)				
Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
				m (corrected for 3.7dB measured offset shown in Table 4 of Appendix A)
VF NodeB_type1 at 927.6 MHz	-16	dBm	166	
O2 NodeB_type2 at 932.6 MHz	-21	dBm	285	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-16	dBm	160	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-3	dBm	36	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	5	dBm	14	m
EGSM transmitter at 925.2 MHz	-30	dBm	804	m

4.5 Results for Sagem GSM-R MS

Figure 15 and Figure 16 show the results for the Sagem GSM-R MS with no receiver blocking protection filter. Figure 17 and Figure 18 show the results for the Sagem GSM-R MS with the passive receiver blocking protection filter. Figure 19 and Figure 20 show the results for the Sagem GSM-R MS with the active receiver blocking protection filter.

The results for the Sagem GSM-R MS were inspected. Comparison of the results to those of the Kapsch MS under the same conditions indicates that the Sagem MS behaves similarly to the Kapsch MS, although it is generally a little more susceptible to interference. The observations made were identical to those made with the Kapsch MS. Those observations are:

- Without any blocking protection filters the dominant interference mechanism under most of the measurement ranges is MS blocking
- Both the passive and active Rx filters effectively remove the UMTS interfering signals. The dominant interference mechanism under most of the measurement ranges is then OOB interference. The difference between the 'best' and 'worst' case UMTS interfering combination is ~30dB, where ~15dB comes from differences in NodeB performance and ~15dB from suppression of the OOB signals from the transmit filter combiner
- At very low signal levels (the range -98dBm to -104dBm) both the passive and active filters reduce the sensitivity of the MS, so that the improvement in protection from deploying the blocking protection filters is lower than is achieved at higher signal levels. (This result is most easily observed by comparing the relative protected signal levels and separation distances in the case-study analysis in section 4.6).
- The blocking protection filters have low rejection to interferers at 925.2MHz[12]. For a given interference power, when blocking protection filters are used interference from an E-GSM signal at 925.2MHz has the most impact on the Sagem GSM-R receiver.
- When no blocking filter is used, E-GSM interference has most effect on the Sagem GSM-R receiver for lower levels of wanted signal, but the receiver seems better able to cope with GSM interference than UMTS interference at higher interfering power levels.

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[12] The blocking protection filters only provide 3-5dB interference rejection at 925.2MHz.

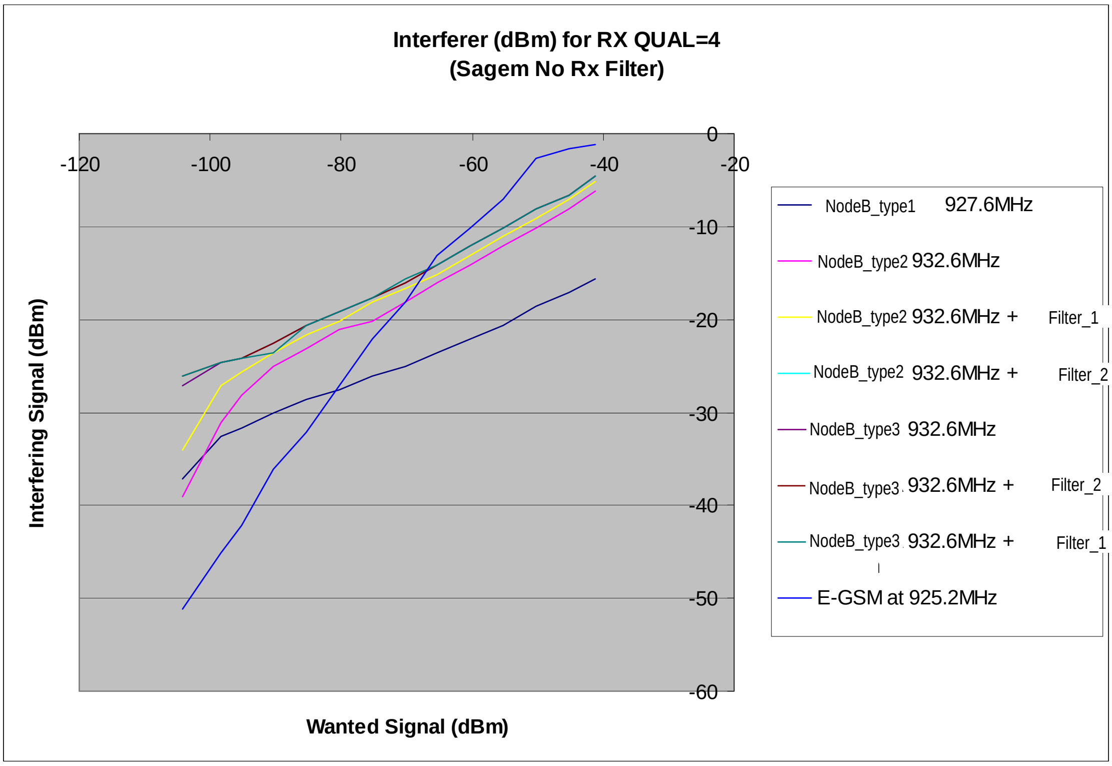

Figure 15: Interference Level for Sagem MS with no receiver blocking protection filter.

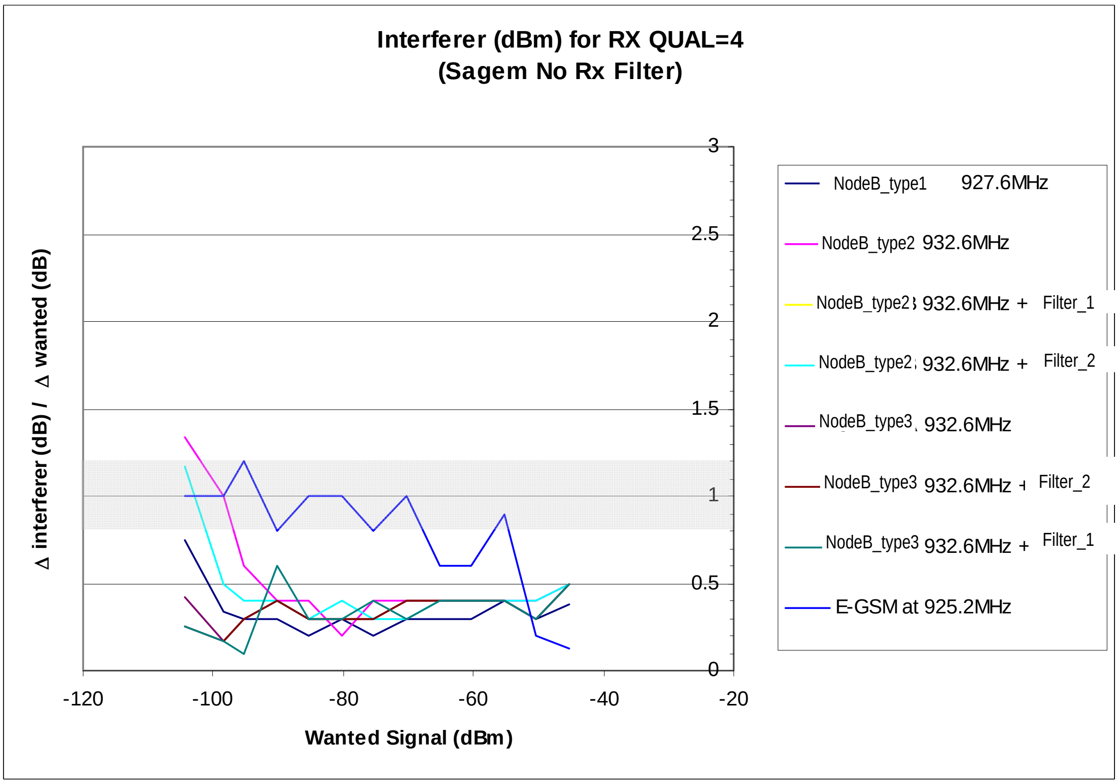

Figure 16: Interference slope for Sagem MS with no receiver blocking protection filter.

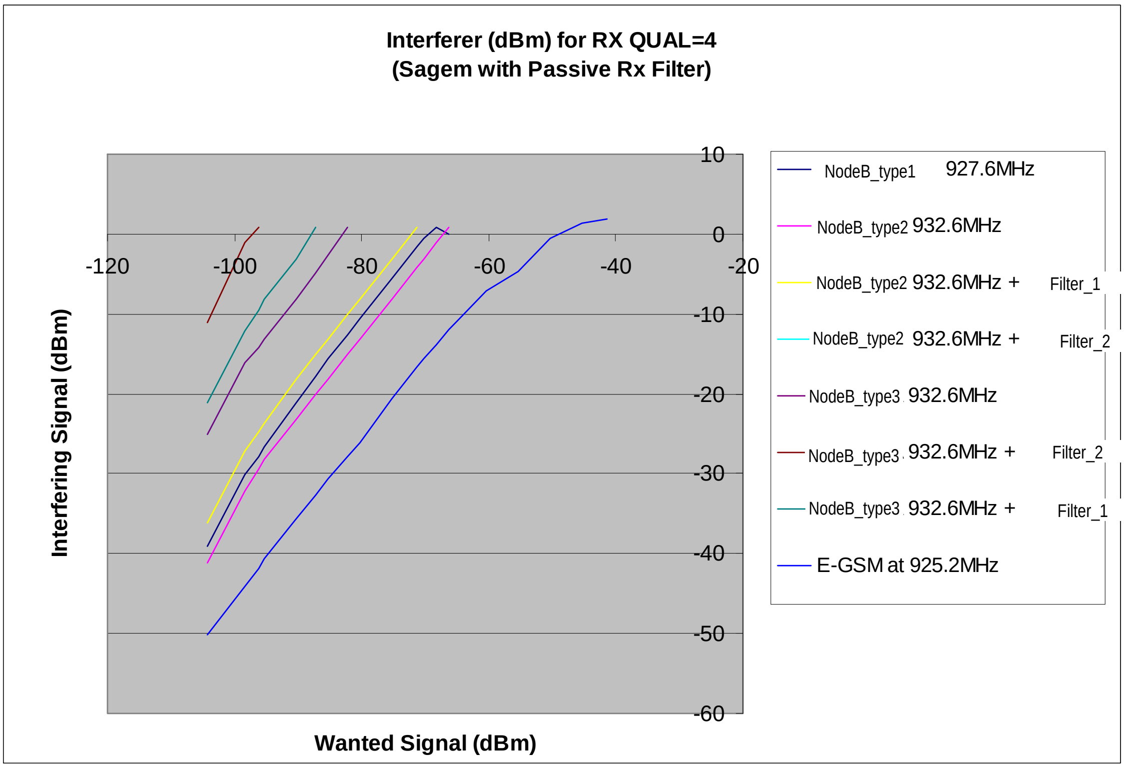

Figure 17: Interference Level for Sagem MS with passive receiver blocking protection filter.

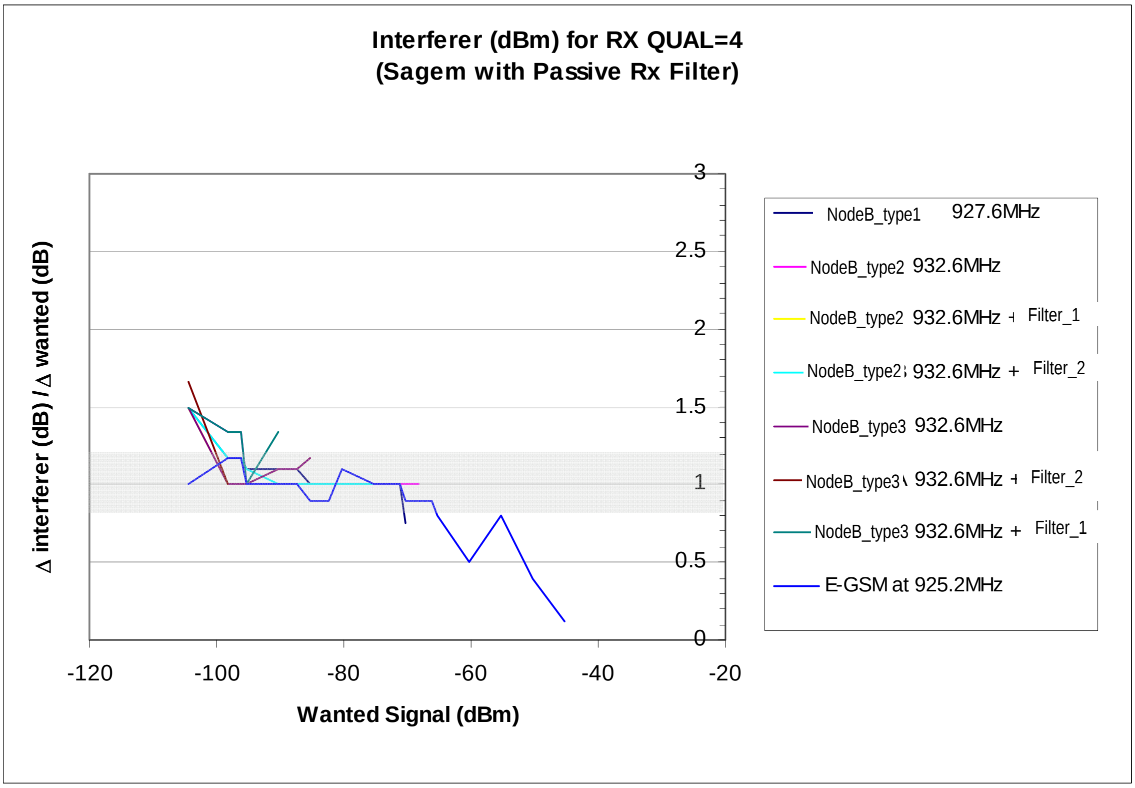

Figure 18: Interference slope for Sagem MS with passive receiver blocking protection filter.

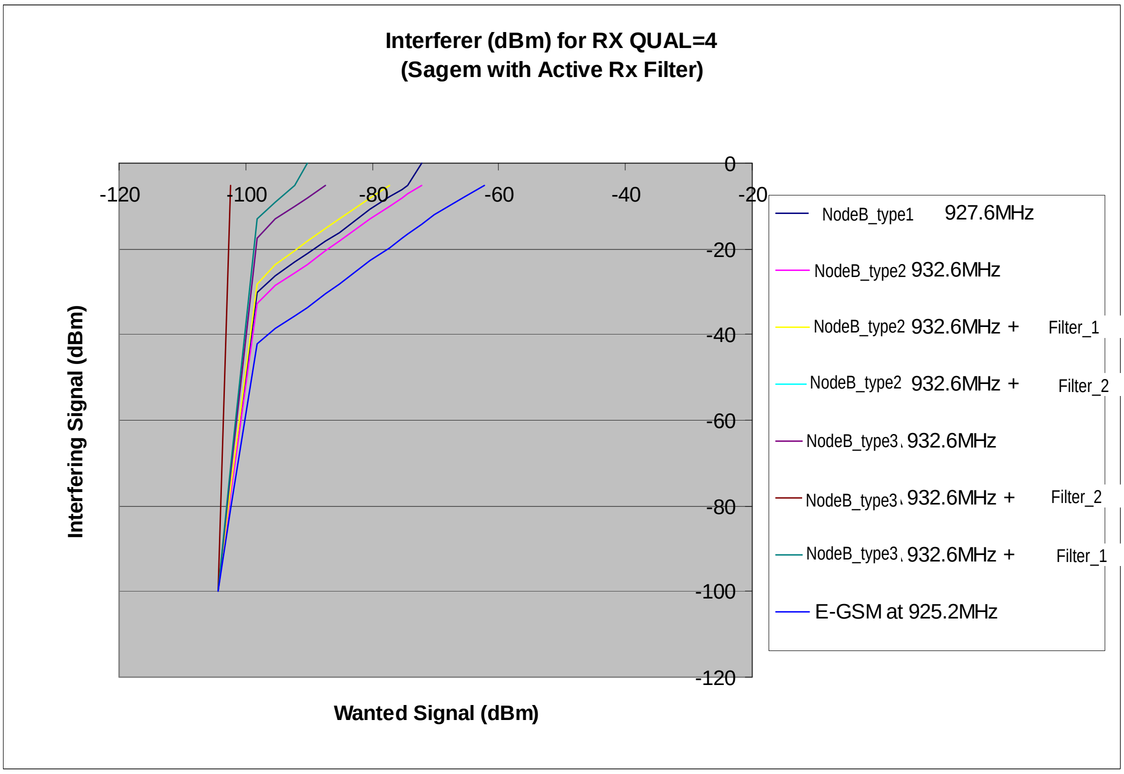

Figure 19: Interference Level for Sagem MS with active receiver blocking protection filter.

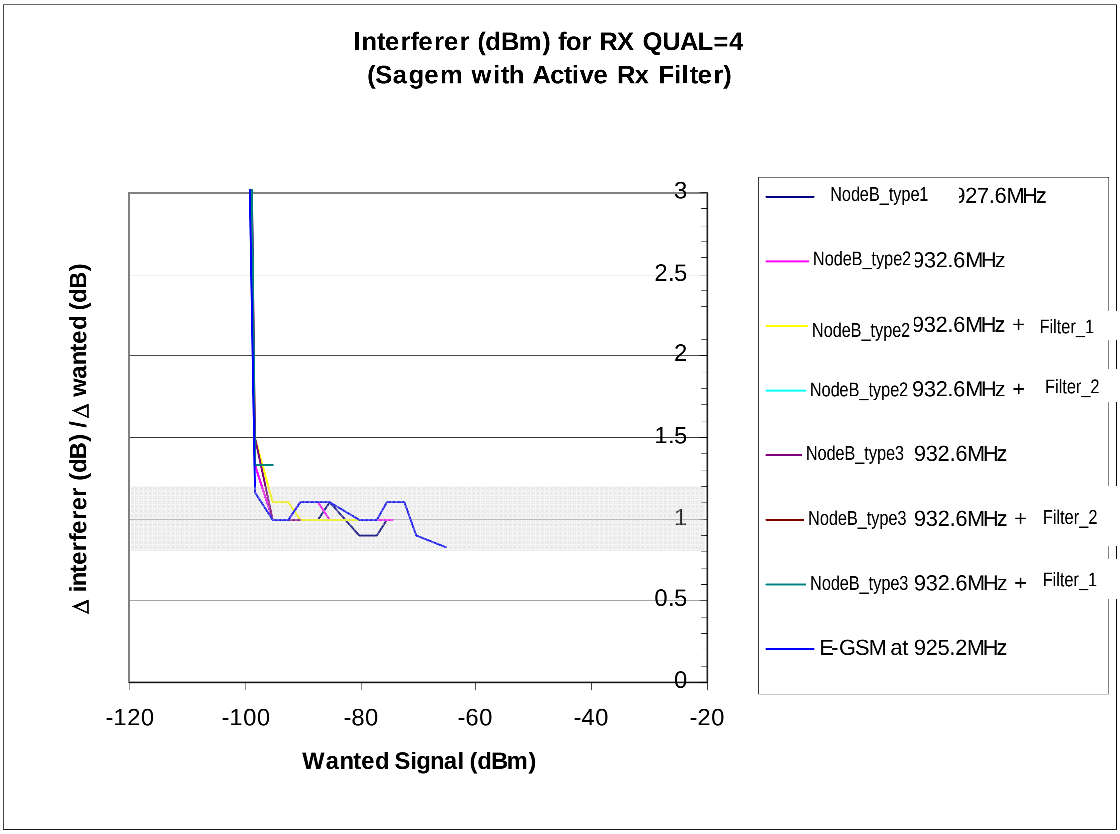

Figure 20: Interference slope for Sagem MS with active receiver blocking protection filter.

4.6 Analysis of results of tests on Sagem MS

A case study was constructed for the Sagem MS. This case study is identical to the one described in section 4.4 for the Kapsch MS. The same two questions answered by Table 2 for the Kapsch MS are therefore also answered by Table 3 for the Sagem MS.

- If there is a 25m separation between a train mounted GSM-R MS sitting on the bore-sight of a main lobe of a UMTS node B with the characteristics given (transmit power of +43dBm, 18dBi antenna gain, 3dB feeder loss, MS antenna gain of 2dB), what GSM-R signal level is required to maintain a call with RXQUAL=4 or better?
- If a GSM-R MS receives a signal of -98dBm/-90dBm whilst on the bore-sight of a main lobe of a UMTS NodeB with the characteristics given, what is the protection separation distance required such that the MS can maintain a call with RXQUAL=4 or better?

Each of these two questions is answered using the result curves from section 0 for the cases where the GSM-R MS is used both with and without blocking protection filters.

In the case of the 25m separation from UMTS interferers, the interfering signal is large, and the blocking protection filters provide 40-70dB of improvement. The improvement gain depends on the OOB performance of the Node B providing the interfering signal.

In the case of the MS receiving a wanted signal of -98dBm, the improvement by deploying blocking protection filters is generally much lower because the MS is closer to its sensitivity limit.

In the case of the MS receiving a wanted signal of -90dBm, deploying blocking protection in front of the MS improves interference performance and generally reduces the protection separation distance by a factor of 2 to 3. The combination of Combiner_Filter_2 filter combiners, NodeB_type3 on O2's frequency and receiver blocking filters is particularly effective in reducing the protection distance to below 25m. In presenting the protection separation distance between a Vodafone NodeB at 927.6MHz and the GSM-R MS, the tolerated interferer has been increased by 3.7dB where blocking protection filters are used to account for the error in OOB emissions from the SMIQ03 compared to those measured from the NodeB_type1 in the laboratory (noted in Appendix A.4 Table 4). It is appropriate to apply this correction only if it is clearly demonstrated that OOB performance of the interferer and not blocking of the MS is dominating at the relevant signal levels. That this is the case is confirmed by inspection of Figure 18 and Figure 20.

Table 3: Case Study for Interference to Sagem GSM-R MS

		SAGEM		
Label	Item	Value	Unit	Note
A	Tx Signal	43	dBm	UK operator deployment
B	Tx Ant Gain	18	dBi	ECC REP096 Table 3-2
C	Feeder Loss	3	dB	ECC REP096 Table 3-2
D	Rx Ant Gain	2	dBi	ECC REP096 Table 3-2
E	Free Space Separation Distance	25	m	
F	Free Space Loss	59.7	dB	
G=A+B-C+D-F	Interference Signal Received	0.3	dBm	
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (No Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	1	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz	-28	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-30	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-31	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz	-31	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-31	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-31	dBm	based on extrapolated values
	EGSM transmitter at 925.2 MHz	-30	dBm	based on extrapolated values
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (Passive Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	-69	dBm	
	O2 NodeB_type2 at 932.6 MHz	-67	dBm	
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-72	dBm	
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-83	dBm	
	O2 NodeB_type3 at 932.6 MHz	-83	dBm	
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-88	dBm	
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-97	dBm	
	EGSM transmitter at 925.2 MHz	-48	dBm	
Measurement Results - Minimum Wanted Signal Protected for Interference Signal 'G' (Active Rx Filter)				
	Radio	Protected Signal Level		signal level required to maintain call with RXQUAL=4 or better
	VF NodeB_type1 at 927.6 MHz	-69	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz	-67	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-72	dBm	based on extrapolated values
	O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-82	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz	-82	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-87	dBm	based on extrapolated values
	O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-97	dBm	based on extrapolated values
	EGSM transmitter at 925.2 MHz	-57	dBm	based on extrapolated values

Measurement Results - Protected Separation Distance for Protected Wanted Signal (No Rx Filter)

Wanted Signal Level Protected -98 dBm

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-33	dBm	1097	m
O2 NodeB_type2 at 932.6 MHz	-31	dBm	902	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-27	dBm	579	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-25	dBm	439	m
O2 NodeB_type3 at 932.6 MHz	-25	dBm	439	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-25	dBm	439	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-25	dBm	439	m
EGSM transmitter at 925.2 MHz	-45	dBm	4523	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Passive Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-30	dBm	800	m
O2 NodeB_type2 at 932.6 MHz	-32	dBm	1001	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-27	dBm	566	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-16	dBm	160	m
O2 NodeB_type3 at 932.6 MHz	-16	dBm	160	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-12	dBm	100	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-1	dBm	29	m
EGSM transmitter at 925.2 MHz	-44	dBm	4008	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Active Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-30	dBm	795	m
O2 NodeB_type2 at 932.6 MHz	-32	dBm	1061	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-28	dBm	628	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-17	dBm	188	m
O2 NodeB_type3 at 932.6 MHz	-17	dBm	188	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-13	dBm	112	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-1	dBm	29	m
EGSM transmitter at 925.2 MHz	-42	dBm	3184	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (No Rx Filter)

Wanted Signal Level Protected	-90	dBm		ECC REP118 Paragraph 6.1 (with -Gi+Pcon=-2dB)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-30	dBm	824	m
O2 NodeB_type2 at 932.6 MHz	-25	dBm	462	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-24	dBm	388	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-23	dBm	346	m
O2 NodeB_type3 at 932.6 MHz	-23	dBm	346	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-23	dBm	386	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	-23	dBm	346	m
EGSM transmitter at 925.2 MHz	-36	dBm	1616	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Passive Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-17	dBm	186	m (corrected for 3.7dB measured offset shown in Table 4 of Appendix A)
O2 NodeB_type2 at 932.6 MHz	-23	dBm	359	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-18	dBm	202	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-3	dBm	36	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	7	dBm	11	m
EGSM transmitter at 925.2 MHz	-35	dBm	1515	m

Measurement Results - Protected Separation Distance for Protected Wanted Signal (Active Rx Filter)

Radio	Tolerated Interferer		Protection Separation Distance	(based on free space on boresight)
VF NodeB_type1 at 927.6 MHz	-17	dBm	186	m (corrected for 3.7dB measured offset shown in Table 4 of Appendix A)
O2 NodeB_type2 at 932.6 MHz	-23	dBm	379	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_1	-18	dBm	202	m
O2 NodeB_type2 at 932.6 MHz plus Combiner_Filter_2	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz	-8	dBm	64	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_1	-3	dBm	36	m
O2 NodeB_type3 at 932.6 MHz plus Combiner_Filter_2	7	dBm	11	m
EGSM transmitter at 925.2 MHz	-33	dBm	1199	m

4.7 Results for Selex GSM-R MS

Following MODEM grading tests the Selex GSM-R MS were removed and not returned so measurements could not be completed.

4.8 Conclusions

The performance of the Kapsch and Sagem MS is slightly different, but the overall conclusion drawn from measurements on both devices is the same (paragraphs 4.3 and 4.5 above). It is relatively difficult to protect a GSM-R MS from interference with a wanted signal of -98dBm under 'absolute worst case' interference conditions because the wanted signal is very close to the sensitivity limit.

Other conclusions are:

- Vodafone, who in the UK have the allocation of E-GSM spectrum immediately adjacent to the GSM-R band, cannot use transmit filter combiners that suppress OOB signals at the top of the GSM-R band. Vodafone therefore have the potential to have greater impact on the GSM-R network than O2 and there may be fewer mitigation options.
- The blocking protection filters only provide 3-5dB interference rejection at 925.2MHz, but more than 35dB at frequencies of 927.6MHz and above. For a given interference power, when blocking protection filters are used interference from an E-GSM signal at 925.2MHz has the most impact on the GSM-R receiver.
- When no blocking filter is used, E-GSM interference has most effect on the GSM-R receiver for lower levels of wanted signal, but the receiver seems better able to cope with GSM interference than UMTS interference at higher interfering power levels.
- The nature of E-GSM interference (see section 4.2) is such that it might not be observed in practice, despite the results of the measurements in this report.
- The data in this report should be useful to guide Ofcom in any revisions of the interim co-ordination procedure for UMTS deployment in the 900MHz band and to guide Network Rail in assessing interference mitigation options. A recommendation as to specific remedies is beyond the scope of this document.

Appendix A Measuring OOB Emissions

A.1 Introduction

A key requirement of Ofcom for this piece of work was to ensure that care was taken to characterise OOB emissions from real NodeBs, and to ensure that these OOB emissions were realistically represented during the measurement process.

Certain precautions need to be observed to measure OOB emissions from a WCDMA carrier with a spectrum analyser. OOB emissions are small signals associated with a large carrier. During direct measurements of the output of a Node B, the large carrier is incident on the first mixer stage of the spectrum analyser. The level of this large carrier must be maintained at a level below the IP3 (third order intercept) of the first mixer[13], or third and fifth order intermodulation products generated in the instrument itself will appear at the same frequencies as the OOB emissions to be characterised. These intermodulation products may therefore prevent measurement of the OOB emissions. From a measurement perspective, it is relatively easy to determine whether the ‘out of band’ signals viewed on the screen are generated inside the measuring instrument. If they are they will appear to increase in relative magnitude as the signal power is increased.

When the output of the NodeB is attenuated sufficiently to ensure that the carrier does not push the spectrum analyser into a non-linear operating mode, OOB emissions are also attenuated and may be pushed below the noise floor of the instrument.

Figure 21 shows an example of a direct carrier measurement made on O2’s UMTS carrier frequency (932.6MHz) with a R&S FSH6 spectrum analyser. The levels in both of these measurements have been adjusted to roughly maximise the useful dynamic range of the analyser by adjusting the signal level with an external attenuator. Attenuation was increased in 10dB steps until the intermodulation products generated inside the instrument disappeared. Comparison of the signal measured from the real NodeB with that of the signal from the (undistorted) signal generator shows that OOB emissions can be detected just above the noise floor of the analyser within a 5MHz window between 2.5MHz and 7.5MHz from the carrier. At the GSM-R frequency of interest (924.8MHz), the OOB emissions are below the displayed average noise level (DANL) of the analyser. As the OOB emissions are wideband in nature, reducing the RBW of the analyser to reduce the DANL reduces the measured OOB emission by the same amount.

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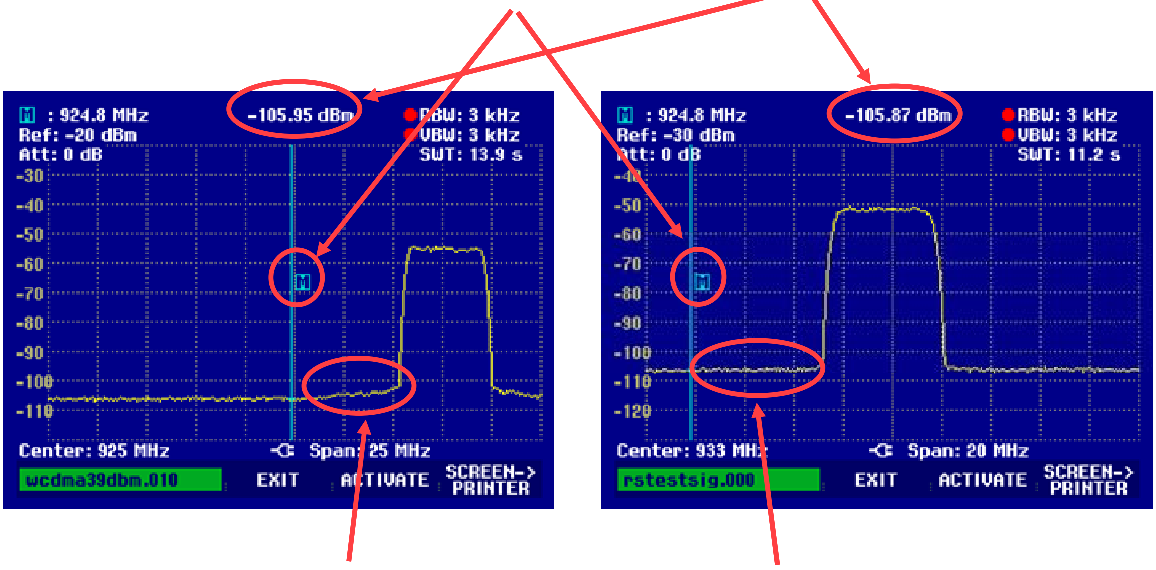
[13] The input referred IP3 of spectrum analysers is normally in the range +10 to +13dBm. The FSH6 has a IP3 of about +10dBm under these operation conditions.



marker on 924.8MHz (GSM-R)

DANL of analyser at this setting

NodeB: region where OOB emissions can be seen above noise (but not accurately measured)

Ideal Sig Gen: OOB emissions cannot be seen above noise

Figure 21: Comparison of WCDMA Carrier from NodeB and Signal Generator

The analyser is not therefore capable of making direct measurements of OOB signals to the accuracy required. Figure 22 illustrates that the analyser ***is*** capable of accurately determining that the signal complies with the 3GPP TS125.104 OOB specification since at 924.8MHz the spectrum mask referred to the 30kHz measurement bandwidth is about 10dB above the DANL of the analyser. It is also evident from Figure 22 that the performance of the Node B is significantly better than specification limit.

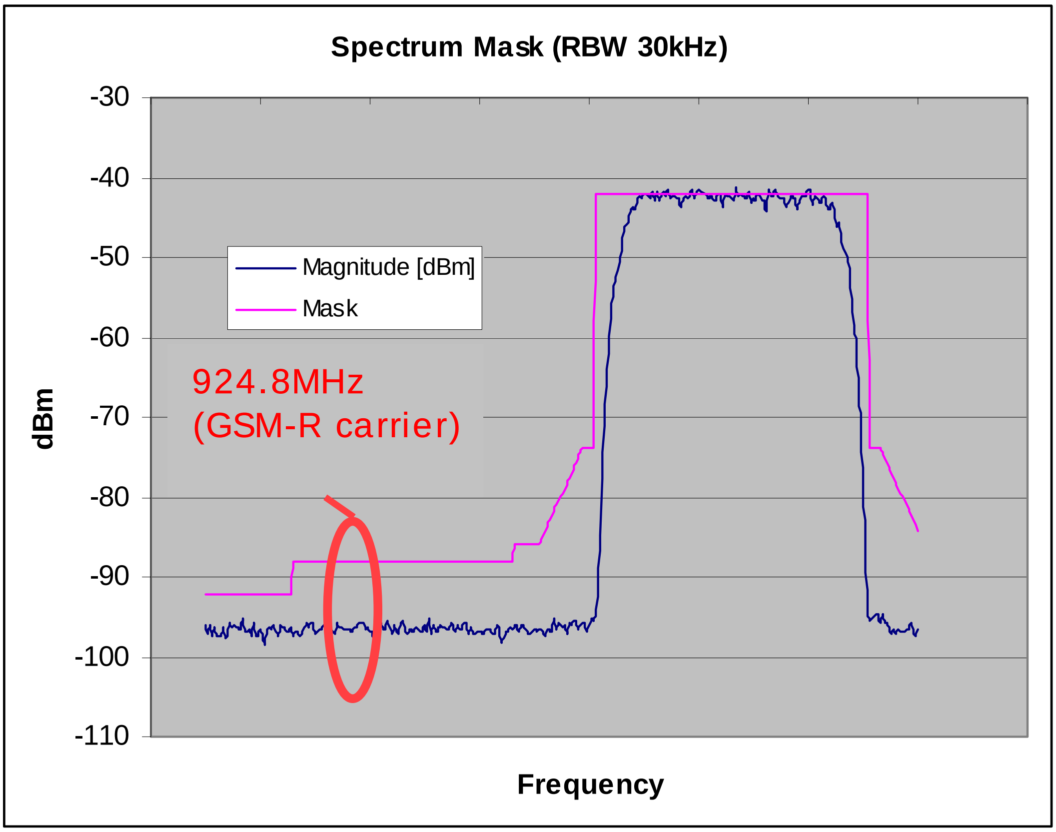


Figure 22: WCDMA Signal (Signal Generator) and OOB Emissions Mask[14]

In order to characterise the OOB emissions using the FSH6 spectrum analyser it is necessary to suppress the carrier by filtering so that the attenuator between the NodeB and the spectrum analyser can be reduced without overloading the analyser.

An ideal solution to filtering the carrier is to use a tuneable notch filter[15]. A number of suppliers were contacted during the early phases of the project, but due to the specialist nature of the filter all manufacturers build to order. The filters would not therefore be available in the relatively short time-frame required by the project.

Network rail have supplied two filters that suppress the unwanted UMTS carrier frequency, an 'active' and a 'passive' filter. These filters are characterised in Appendix B. The better performing filter in terms of UMTS carrier suppression is the 'active' filter that should suppress the UMTS carrier

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[14] 3GPP TS125 104 defines a spectrum mask measured with a resolution bandwidth (RBW) of 1MHz at frequency offsets of 4MHz or greater from the carrier centre frequency and a RBW of 30kHz at offsets of less than 4MHz. Measurements taken with a smaller RBW at large offsets should be integrated to determine mask compliance. As we are principally interested in OOB emissions at 925.8MHz, Figure 22 presents the WCDMA signal measured with a RBW of 30kHz across the frequency band and compares it with a mask lowered by $10\log_{10}(30e3/1e6)$ at frequency offsets of 4MHz and greater.

[15] E.g. Lorch Microwave 5NF-890/960-X1-S

by ~70dB. As the active filter is designed to be placed between an antenna and a receiver, the downlink signal handling capability is insufficient for it to be placed directly on the output of a NodeB. The filter can be used behind the passive filter to increase rejection of UMTS carriers.

The resulting measurement set-up is shown in Figure 23. Both filters reflect incident power outside their pass-band, so isolators are required as shown.

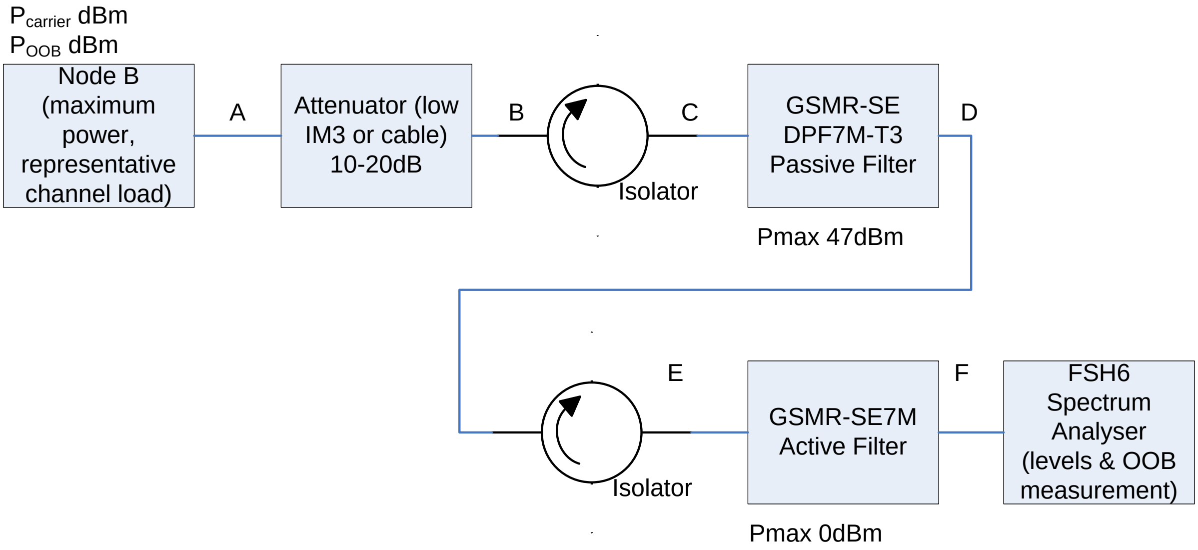

Figure 23: Measurement of OOB using GSM-R Passband Filters

The passive filter provides at least 30dB suppression of the UMTS carrier. It has a maximum input power rating of 50W, and as it reflects out of band power is suitable to be placed on the output of a NodeB[16] as long as an isolator with sufficient return loss is used to prevent the reflected power affecting the power amplifier in the NodeB .

Initial indicators from NodeB vendors indicate that the OOB emissions performance at 924.8MHz can be expected to be about 30dB better than specification. In order to ensure that measured OOB signals are representative of the output of the NodeB, it is necessary to ensure that any signal impairments introduced by the measurement system do not affect the result. In particular, there are strict linearity requirements on the first attenuator[17] in Figure 23, and the isolators used[18] were also chosen for good intermodulation performance.

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[16] Confirmed by email from Matthias Riechmann of ComSYS.
[17] An attenuator with IP3 > +115dBm is recommended.
[18] MCS Microwave P-3615-01 N-type female coaxial circulator.

Test Point	**Pcarrier**	**POOB**	
A	43	X	dBm
Attenuator Loss	10	10	dBm
B	33	X-10	dBm
C	32.75	X-10.25	dBm
D	-3.25	X-11.75	dBm
E	-3.5	X-12	dBm
F	-73.25	X-13.5	dBm
X		-53.3	dBm expected in 200kHz @ 924.8MHz
F		-75.0	dBm expected in 30kHz @ 924.8MHz
DANL FSH6		-96	dBm in 30kHz (better than)

Isolator Insertion Loss	0.25	dB typ
GSMR-SE DPF7M Passband	1.5	dB meas @ 924.8MHz
GSMR-SE DPF7M Stopband	36	dB meas @ 932.6MHz
GSMR-SE7M-T3 Passband	-0.95	dB meas @ 924.8MHz
GSMR-SE7M-T3 Stopband	70	dB spec @ 932.6MHz

Figure 24: Expected Out of Band Signal Levels (O2)

Test Point	Pcarrier	POOB	
A	43	X	dBm
Attenuator Loss	10	10	dBm
B	33	X-10	dBm
C	32.75	X-10.25	dBm
D	-5.25	X-11.75	dBm
E	-5.5	X-12	dBm
F	-75.25	X-13.5	dBm
X		-53.3	dBm expected in 200kHz @ 924.8MHz
F		-75.0	dBm expected in 30kHz @ 924.8MHz
DANL FSH6		-96	dBm in 30kHz (better than)

Isolator Insertion Loss	0.25	dB Typ
GSMR-SE DPF7M Passband	1.5	dB meas @ 924.8MHz
GSMR-SE DPF7M Stopband	38	dB meas @ 927.6MHz
GSMR-SE7M-T3 Passband	-0.95	dB meas @ 924.8MHz
GSMR-SE7M-T3 Stopband	70	dB spec @ 927.6MHz

Figure 25: Expected Out of Band Signal Levels (Vodafone)

The calculations in Figure 24 and Figure 25 use the ‘test point’ reference letter convention shown in Figure 23. The calculations predict that it should be possible to characterise the OOB performance using the combination of both the active and the passive filter to suppress the carrier. The expected OOB signal level[19] should be at least 20dB above the DANL of the spectrum analyser.

The passive filter reflects approximately +33dBm back into the isolator and the input signal to the active filter is approximately -3.5dBm. The input band-pass section of the active filter provides further suppression of the UMTS carrier of about 35dB, so that the incident carrier power on the active

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[19] Expected level supplied by vendors based on their own measurements

stages will be around -40dBm. This is well below the level at which the automatic level control circuitry (described briefly in Appendix B) comes into operation.

The linearity specifications for the active filter should ensure that third order products generated by the active filter will be below the DANL of the spectrum analyser.

A.2 OOB Characterisation – O2

Figure 26 shows the OOB measurements taken in O2’s test facility. A composite curve is presented from two sets of measurements using the spectrum analyser with a RBW (resolution bandwidth) of 100kHz. O2 have deployed UMTS900 using two NodeB types. These two NodeB types are known as ‘NodeB_type2’ and ‘NodeB_type3’. The NodeB_type3 is the more modern type that O2 will increasingly deploy.

A transmitter power measurement was made by connecting the spectrum analyser to the output of the Node B though a known attenuation. The NodeB was configured by O2 to provide a ‘representative’ test signal by choosing high levels of a number of downlink signalling channels. The following signalling channels were used: CPICH, P-SCH, S-SCH, P-CCPCH, PICH, AICH, S-CCPCH

The OOB measurement was taken using the test configuration shown in Figure 23. OOB test results have been corrected using the measured insertion loss of the characterisation system in its pass-band and the results were referred to 200kHz by averaging the three nearest power measurements from the spectrum analyser (with RBW = 100kHz) and applying the appropriate scaling factor of 2/3.

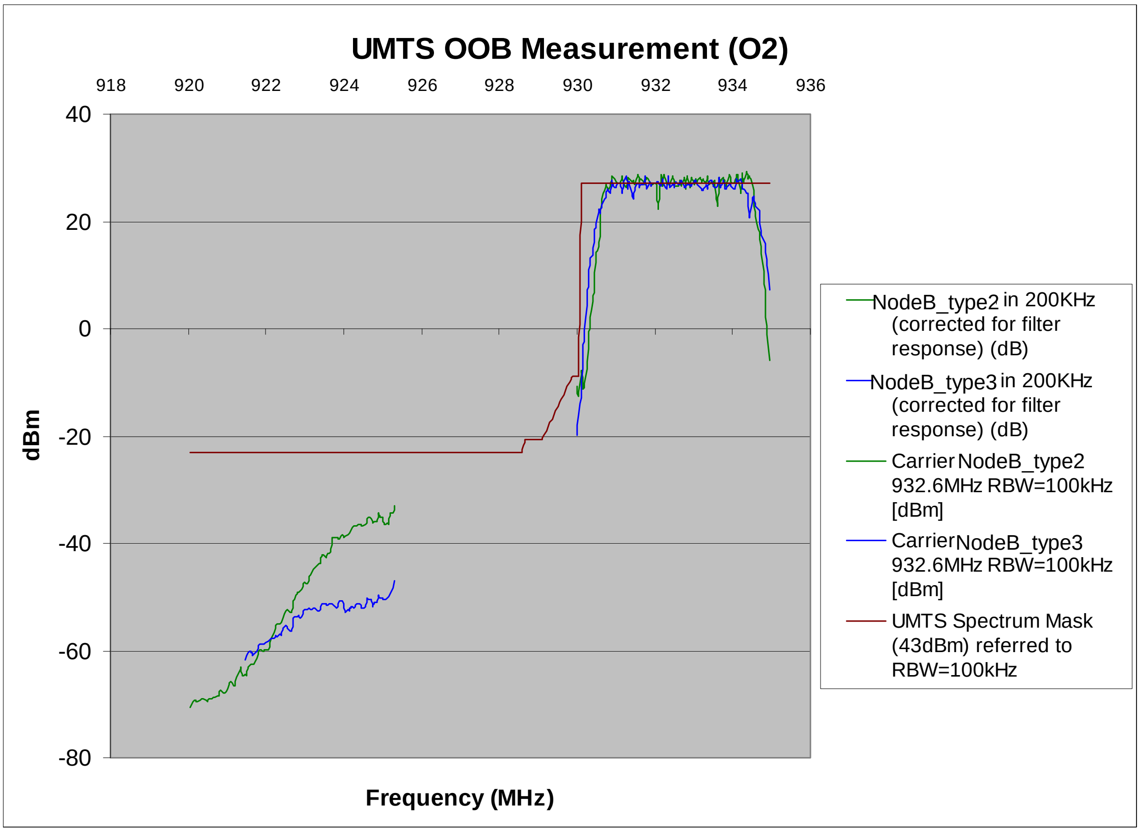

Figure 26: OOB Measured on Sample NodeB_type2 and NodeB_type3 Transmitters

Measurements showed that there was a significant difference between the two transmitters, with the newer NodeB_type3 having approximately 15dB lower emissions than the older NodeB_type2 at the GSM-R frequency of interest.

It was observed that the NodeB_type2 and the NodeB_type3 OOB emissions were not flat, despite the key measurement frequency of 924.8MHz being offset by 7.8MHz from the carrier centre frequency at 932.6MHz. This may be due to band filtering in the transmit chain as the measurement frequency is outside the NodeB transmit band.

In order to confirm that the measurement was of a real signal and was not an artefact of the measurement system caused by measurement system non-linearity, the signal was observed at point ‘D’ in Figure 23 as the Node B went through its shut-down sequence. At point ‘D’, the measurements of Figure 27 were observed. A residual carrier is visible, with the characteristic flat-top replaced by a slope caused by increasing attenuation of the passive filter throughout its stop-band. The OOB signal below 924.8MHz is not attenuated. Over a period of several seconds, the carrier signal reduces in distinct steps. The OOB signal did not reduce, demonstrating that it was not an artefact of the measurement system generated by the presence of a high power carrier.

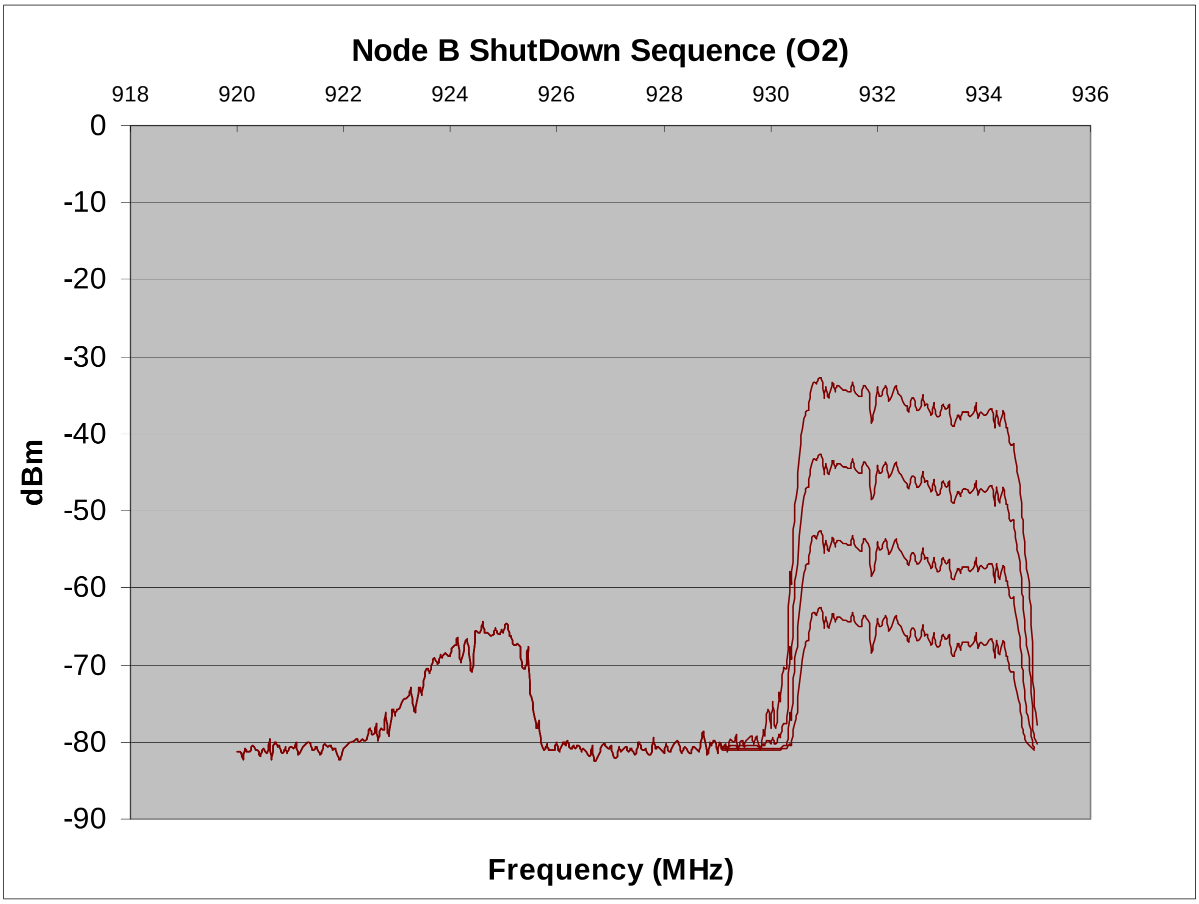

Figure 27: Observed NodeB_type2 shutdown Sequence (not corrected for measurement system losses)

Following observation of the results in Figure 27 there was some concern that if the shut-down sequence was typical of the NodeB in lower power modes, then these lower power modes would generate relatively higher OOB power levels. Confirmatory measurements were made with a NodeB output power of +33dBm and it was confirmed that as the NodeB output power is reduced the OOB signal *does* reduce in proportion. Overall the observations were consistent with the dominant OOB source being transmitter noise (shaped by a band filter), which is not affected by a shut-down sequence driven by reducing the magnitude of the baseband I-Q signals.

A.3 OOB Characterisation – Vodafone

Figure 28 shows the OOB measurements taken in Vodafone's test facility. A composite curve is presented from two measurements using the spectrum analyser with a RBW (resolution bandwidth) of 100kHz. Vodafone have deployed UMTS900 using a NodeB_type1.

A transmitter power measurement was made by connecting the spectrum analyser to the output of the Node B though a known attenuation. The NodeB was configured by Vodafone to provide a +43dBm test signal measured as +45dBm). Vodafone's NodeB has a 60W PA. Vodafone deploy this as 1x20W, with capacity to expand to 2x20W in the future. For the purposes of these tests, the PA was set to 60W power output and the CPICH was set to 33.3%.

The OOB measurement was taken using the test configuration shown in Figure 23. OOB test results have been corrected using the measured insertion loss of the characterisation system in its pass-band and the results were referred to 200kHz by averaging the three nearest power measurements from the spectrum analyser (with RBW = 100kHz) and applying the appropriate scaling factor of 2/3.

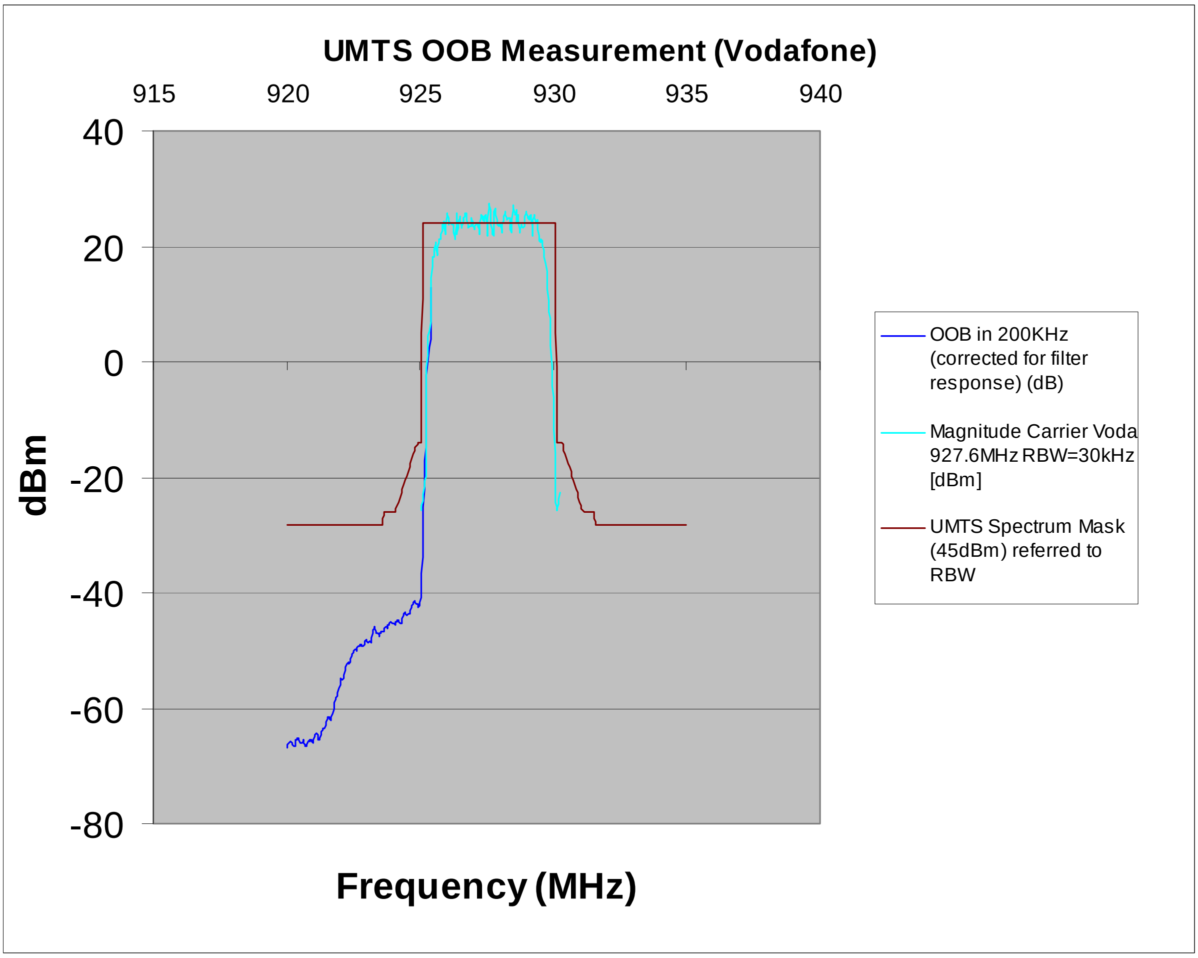

Figure 28: OOB Measured on a sample NodeB_type1 Transmitter

A.4 OOB Characterisation - R&S SMIQ03B Test Signals

The Rohde & Schwarz SMIQ03B used for the measurement campaign is an I-Q vector signal generator capable of producing complex test signals. It can generate both a GSM and a UMTS900 test signal using a range of test profiles defined by ETSI 3GPP.

The GSM test signal had all timeslots active at full power simulating the ‘worst case’ of a BCCH interferer.

The UMTS test signal used a standard test profile available on the instrument as a base – this simulates a UMTS signal with P-CPICH (approximately 15% of power), P-SCH, S-SCH, P-CCPCH, S-CCPCH, and 10 DPCH

In order to match measured OOB performance of the O2 and Vodafone NodeB's empirically it was originally planned to use an IQ simulator, as shown in Figure 29. R&S Win IQSIM allows noise and distortion profiles to be loaded into the signal generator in order to modify the base test signal.

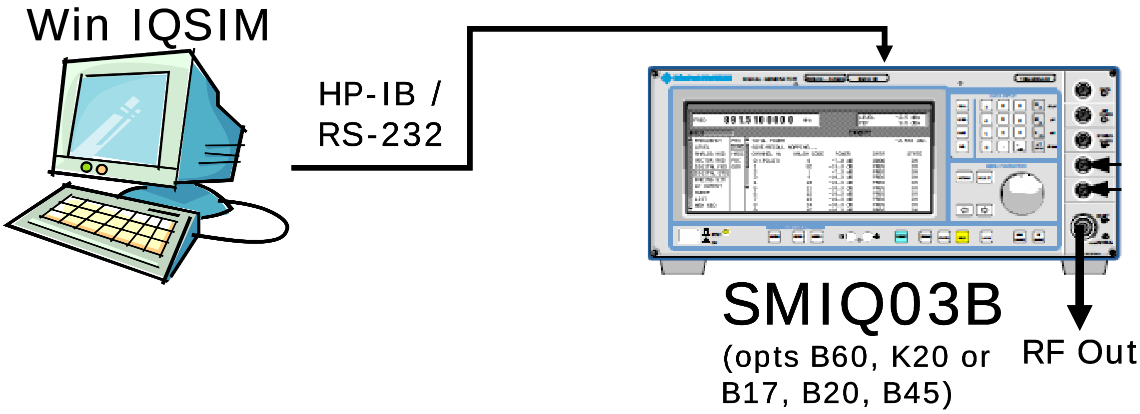

Figure 29: Simulating Measured OOB Performance with a Signal Generator

Figure 30 shows how the OOB spectrum can be modified using an I-Q simulator. There are four curves in Figure 30, labelled 'clean', '3rd Order', '5th Order' and 'Phase Noise'. They are as follows:

- Clean – this is the signal with the lowest OOB signals that we can produce with the SMIQ03B given IQ DAC and output stage performance
- '3rd Order' – This shows an (exaggerated) amount of 3rd order distortion. The dominant effect on OOB emissions is to raise them in adjacent channels
- '5th Order' – This shows an (exaggerated) amount of 5th order distortion. The dominant effect on OOB emissions is to raise them in 1st & 2nd adjacent channels
- 'Phase Noise' – This shows an (exaggerated) amount of wide band phase noise. The dominant effect on OOB emissions is to raise them consistently across band of interest

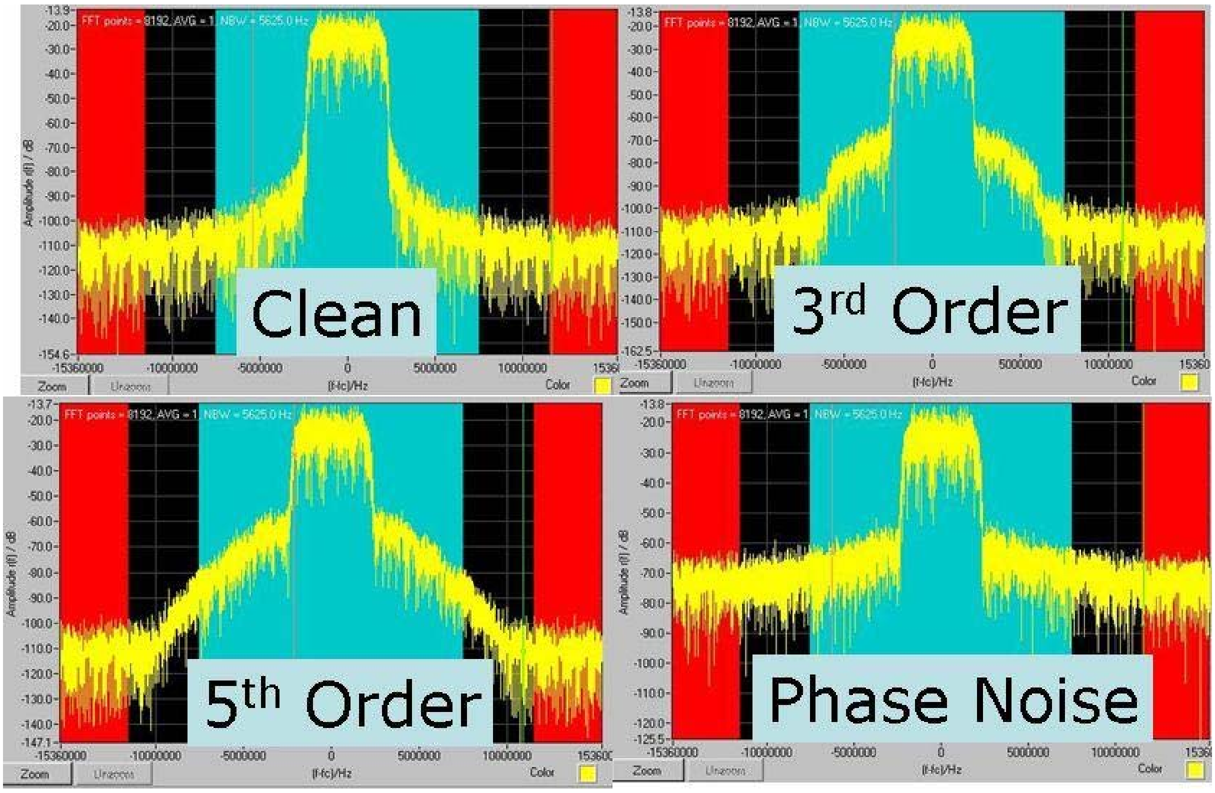

Figure 30: Controlling Degradation Empirically

In theory at least, it was originally thought that the combination of all three effects should be able to match the general characteristics of the NodeB's reasonably well. This proved not to be the case however, as the measured OOB performance of all measured NodeB's was significantly better than the minimum specified in 3GPP TS25.104 and the SMIQ03 was not able to use signal degradation to match both the magnitude and shape of the OOB emissions from the NodeBs. The performance of the real NodeB equipment is also improved by band-filtering which is not present in the SMIQ03B. The SMIQ03B has a flat OOB response in the frequency ranges of interest, as shown in Figure 31.

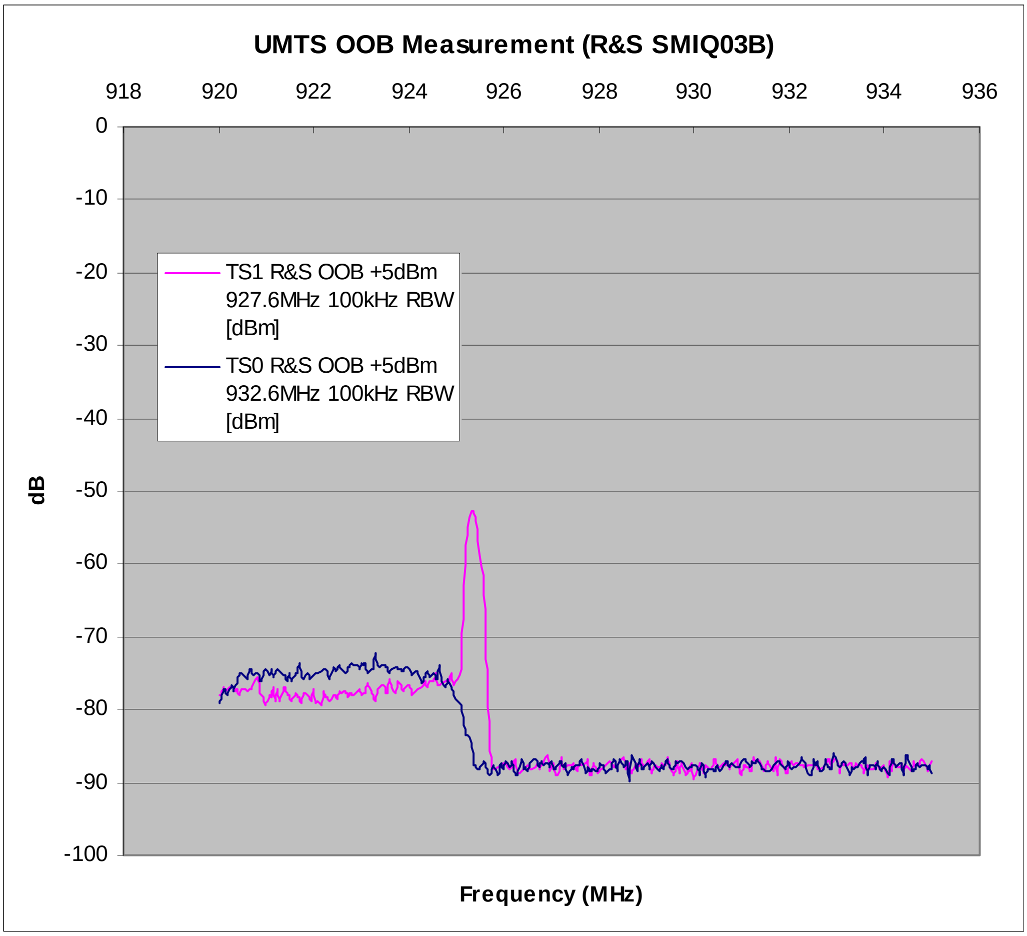

Figure 31: OOB Measured on a +5dBm UMTS Test Signal using defined test sequences TS0 (O2) and TS1 (Vodafone)

It was therefore decided to use the SMIQ03 to match the measured levels of OOB emissions at 924.8MHz, this being the centre frequency of the GSM-R test signals. Even this proved to be difficult using the SMIQ03B alone, as the dynamic range of the signal generator was insufficient to match the highest performing NodeB. Additional filtering was therefore used where possible and necessary to reduce the OOB signal from the SMIQ without affecting the carrier signal.

Table 4 shows the compromises that were adopted as the best empirical match to the measured OOB signals that were achieved.

Table 4: Comparison of Measured and Simulated OOB Performance

Node B to Simulate	SMIQ03B Test Sequence	External Filtering	OOB Error[20]
NodeB_type2 @ 932.6MHz	TS0	None	-0.4dB
NodeB_type3 @ 932.6MHz	TS0	1 Combiner_Filter_2 filter stage	+1.2dB
NodeB_type1 @ 927.6MHz	TS1	None	+3.7dB

The worst match between the SMIQ03B and the measured NodeB is for the Vodafone signal from the NodeB_type1, where the signal generator produces relatively 3.7dB more OOB signal than the NodeB. The match between the measured and observed levels for the NodeB_type2 and NodeB_type3 is good.

If it was necessary, Vodafone interference measurements taken in the region where OOB interference dominates over blocking effects could be adjusted by ~4dB to take account of this discrepancy.

A.5 R&S SMIQ03B Test Signal Settings

Table 5 documents the settings on the R&S SMIQ03B used during the tests.

Table 5: UMTS Test Signal Setttngs on SMIQ03B

Test Sequence 0 (TS0)			Test Sequence 1 (TS1)	
			(showing differences to Test Sequence 0 only)	
Test Model	Test1_32			
3GPP Version	4.1.0			
Chip Rate	3.84Mcps			
Link Direction	Down/Forward			
Sequence Length	1 frame			
Clipping Level	100%		Clipping Level	50%
Filter	WCDMA 0.22			
	Filter Mode	Low_EVM	Filter Mode	Low_ACP
	Chip Rate Variation	3.84Mcps		
Para.Predef Setting				
	Channels for Sync of Mobile	On		
	S-CCPCH	60 ksps		
	Number of DPCH	10		

---

[20] This is the difference between the simulated OOB signal and the measured level at 924.8MHz. A negative value in this cell indicates that the signal simulated by the SMIQ03 has a lower OOB signal than measured, and a positive value indicates that the simulated signal has a higher value.

Test Sequence 0 (TS0)			Test Sequence 1 (TS1)	
	Symbol Rate	30ksps		
	Crest	Average		
Enhanced Channels				
BS1/MS1	Off			
Add OCNS	Off			
Trigger Mode	Retrig			
Trigger	Int			
Clock	Int			
Total IQ Power	0dB			
Number of BS	1			
BS1 State	On			
Scrambling Code State	On			
Scrambling Code	0000H			
TFCI State	Off			
TFCI	1			
2nd Search Code Group	0			
TPC Pattern/Dlist Read Out Mode	Continuous			
Misuse TPC for Output Power Ctrl	Off			
Power Step TCP	0dB			
Transmit Diversity	Off			
Number of Page Indicators Per Frame	36			
Channel List				
Type	Pow/Db			
P-CPICH	-8.23			
P-SCH	[-8.23]			
S-SCH	[-8.23]			
P-CCPCH	-11.50			
S-CCPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
DPCH	-11.50			
%CPICH	15%			
Signal Peak to Mean	12.5dB		Signal Peak to Mean	9.4dB

Appendix B Network Rail MS Filter Measurements

B.1 ComSYS GSMR-SE DPF7M-T3 Passive Filter

The magnitude of S21 for this filter was measured using the FSH6 spectrum analyser (with tracking generator). The filter has two ports. 'Port 1' is intended to be connected to the train antenna and 'Port 2' to the GSM-R MS. The device is not labelled so it was not possible to determine which is Port 1 or Port 2 as installed in a train, although as the device is symmetrical and as S21 = S12 there is no significant difference in performance whichever way round the device is connected. Measurements showed that it exceeded its specification for 30dB rejection across the E-GSM band providing 36dB loss at 932.6MHz and 38dB loss at 926.7MHz.

The device adds 1.5dB loss at 924.8MHz, so it would decrease the effective sensitivity of the GSM-R MS by this amount at the top of the band.

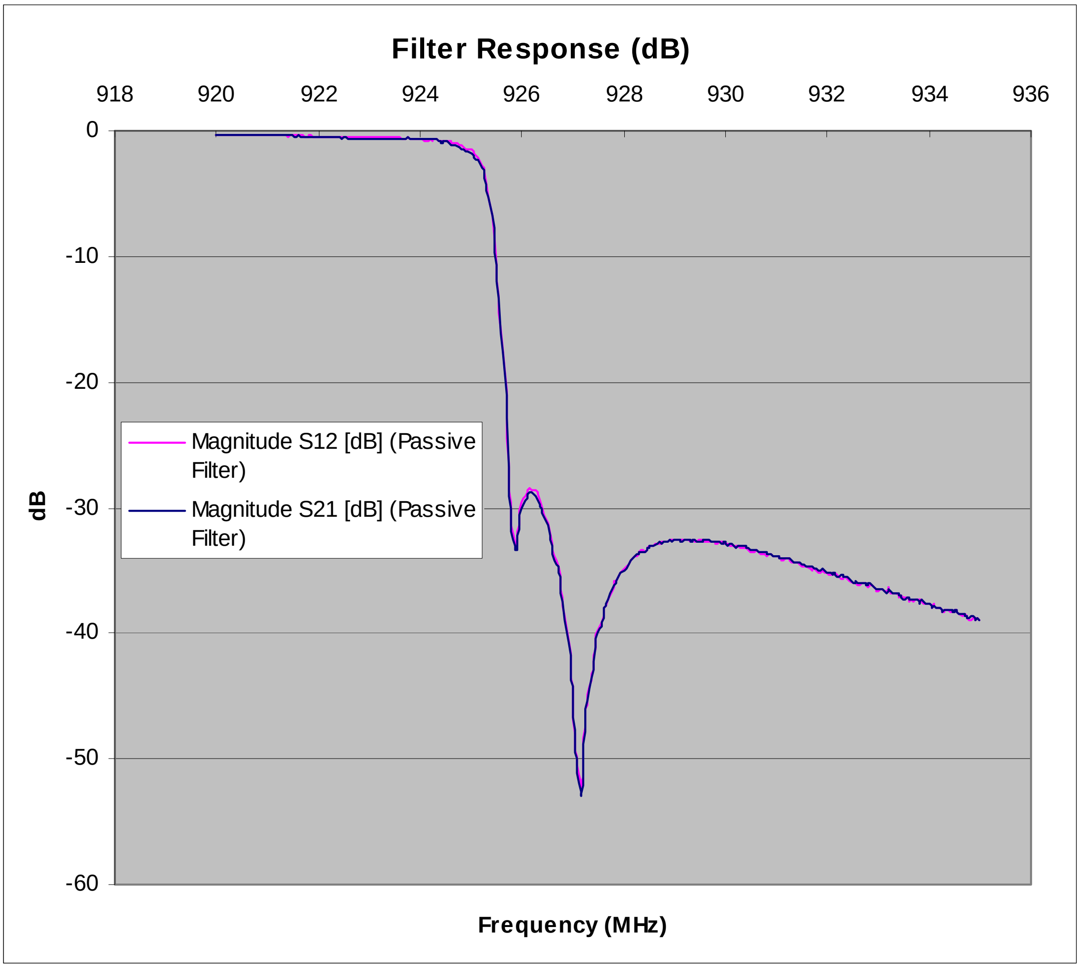

Figure 32: S12 / S21 ComSys GSMR-SE DPF7M-T3 Passive Filter (Measured)

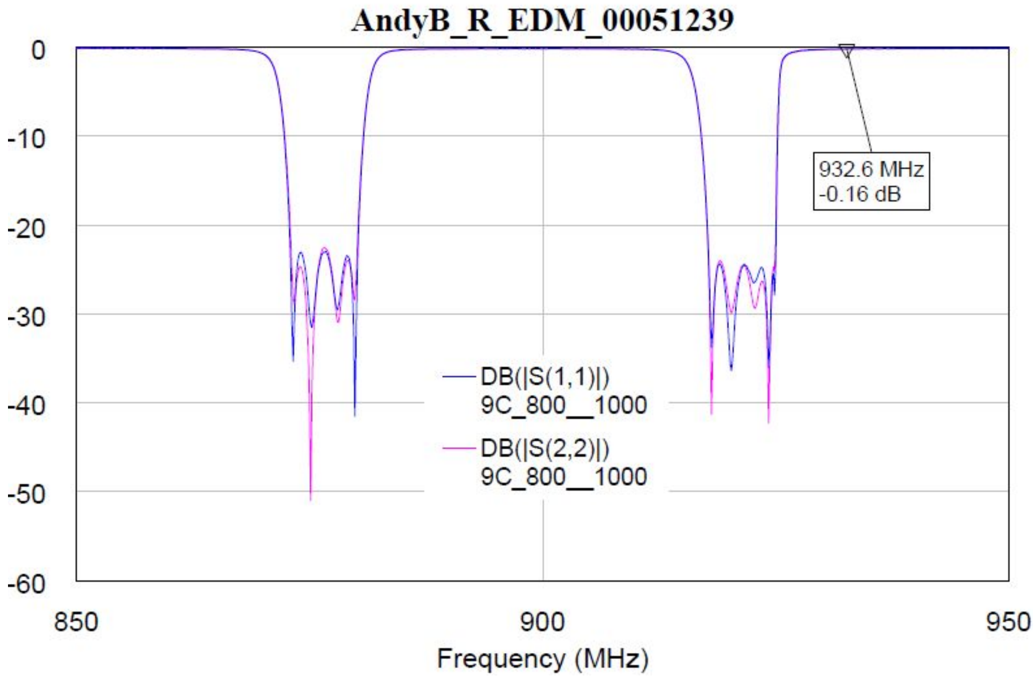

Figure 33: Typical S11 / S22 ComSys GSMR-SE DPF7M-T3 Passive Filter (Measured by ComSYS)

B.2 ComSYS GSMR-SE7M-T3 Active Filter

The magnitude of S21 for this filter was measured using the FSH6 spectrum analyser (with tracking generator). The filter has two ports. 'Port 1' is intended to be connected to the train antenna and 'Port 2' to the GSM-R MS. Unlike the passive filter, it is important to respect the orientation of the filter in actual use. Measurements using the FSH tracking generator (fixed output -10dBm) showed the operation of the automatic power control circuitry that operates when the filter receives large in-band received signals. The filter settles with an output of around -20dBm. Measurement of the filter using a reduced input signal (-30dBm) showed that the filter behaved as expected (Table 6).

Table 6: Active Filter Specification and Measurement

Downlink	Spec (dB)	Meas (dB)	Meas Exceeds Spec?
Operation S21 Insertion Loss 918.0 - 918.2MHz	<1.5	-0.23	Yes
Operation S21 Insertion Loss 918.2 - 924.8MHz	<0.5	-0.57	Yes
Operation S21 Insertion Loss 924.8 - 925MHz	<1.5	0.63	Yes
Operation S21 Isolation 925.6 - 925.8MHz	>37	39.4	Yes

Measurements showed that the device added ~1dB of gain at 924.8MHz. The noise figure of the active filter in its pass band was not determined. No direct conclusions were therefore drawn as to the effect of the filter on the effective sensitivity of the GSM-R MS at 924.8MHz, although measurements with the test set showed that the use of the active filter was more detrimental to the ultimate sensitivity of the MS than that of the passive filter.

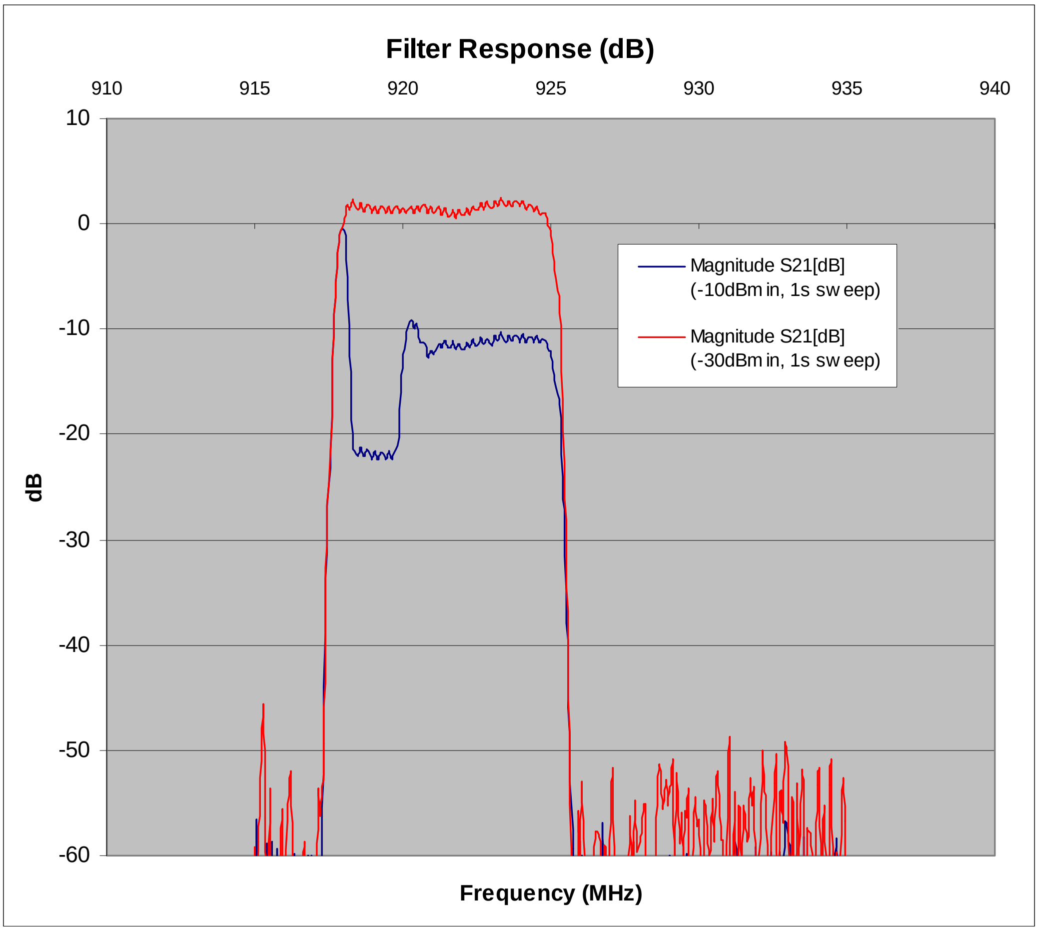

Figure 34: S21 ComSys GSMR-SE7M-T3 Active Filter (Measured)

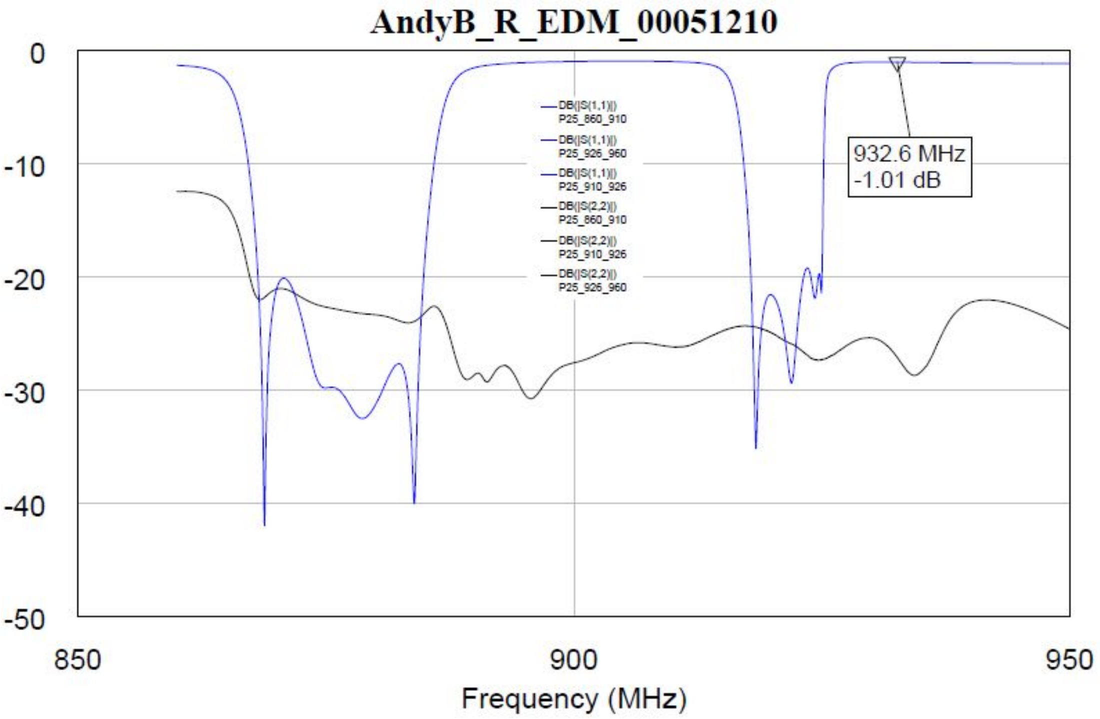

Figure 35: Typical S11 / S22 ComSys GSMR-SE7M-T3 Active Filter (Measured by ComSYS)

Appendix C Operator Combiner Filter Measurements

C.1 O2 Combiner Filters

O2 supplied an example of a combiner filter from one of each of two suppliers that they use. The combiner filters are designed to allow a UMTS NodeB to be co-located with an existing GSM900 BTS and share the same mast, feeder cables and antenna element.

Measurements on these filter combiners are shown in Figure 36. At 924.8MHz the Combiner_Filter_2 filter combiner provides 14.3dB suppression of NodeB OOB signals, whilst the Combiner_Filter_1 provides only 4.2dB. It should be noted that the suppression of OOB signals is not the primary aim of introducing filter combiners into the network, and neither manufacturer would have optimised the performance of the combiner for this task.

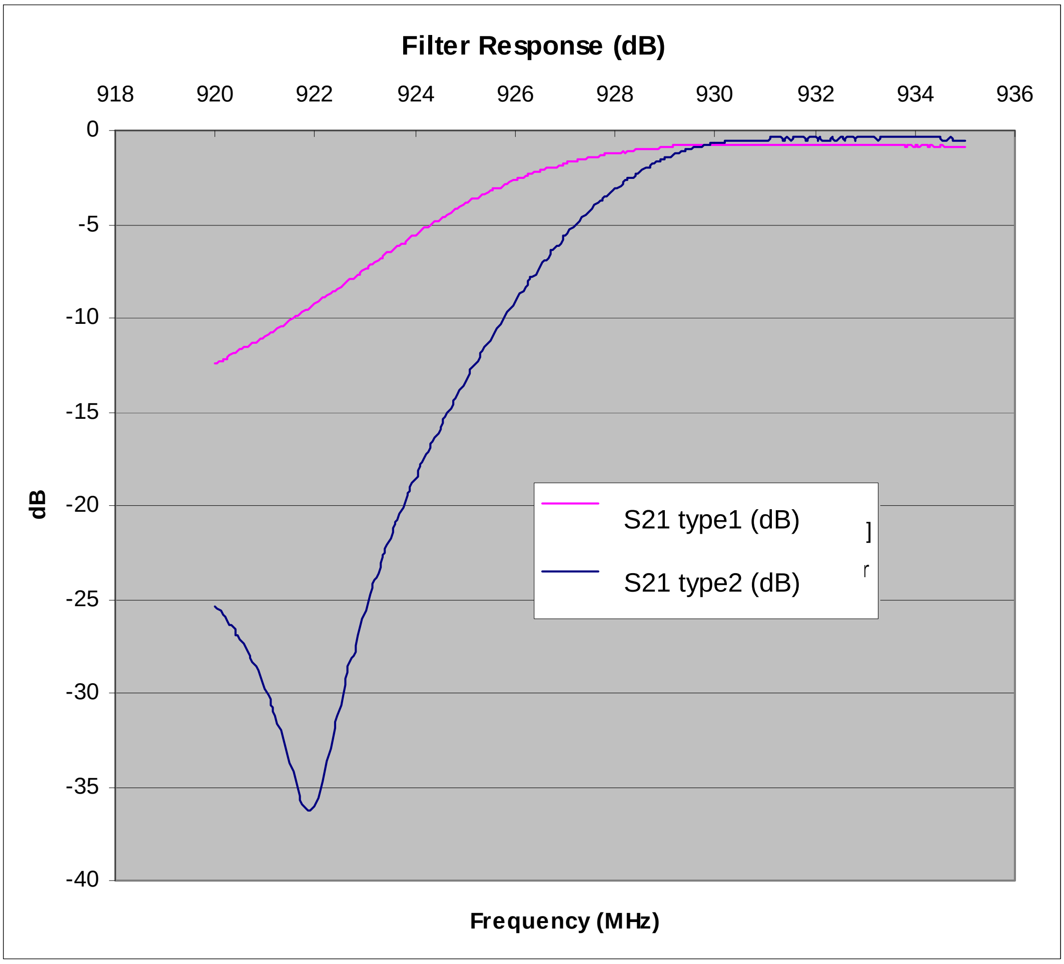

Figure 36: S21 O2 Filter Combiners (measured)

C.2 Vodafone Combiner Filters

Vodafone do not use combiner filters in their UK network. Even if they did, the proximity of Vodafone's UMTS frequency to the GSM-R frequency band would mean that any suppression of OOB signals would not be significant.

Appendix D MODEM Grading Tests

A number of GSM-R MS were supplied by Network Rail for testing.

- 5 Kapsch MT2
- 5 Sagem MRM
- 4 Selex RMM2300
- 1 TrioRail (Siemens) hand portable, used by Network Rail for network scanning drive tests.

The Kapsch and Sagem MS are used in UK rolling stock, the Selex MS are not used in the UK but are used in continental Europe. Selex MS could conceivably need to operate in the UK in circumstances where foreign trains are running on UK track.

In order to choose a 'representative' MS for complete characterisation, all MS were tested for interference using both UMTS and E-GSM interferers. Tests were carried out at wanted signal levels of -104dBm and -98dB. The test configuration of Figure 3 was used for testing without any combiner or blocking protection filters.

The results of the grading exercise are shown in Table 7. All 5 of the Kapsch MT2 MS tested gave repeatable results. The results of the 5 SAGEM MRMs were a bit more variable especially for the tests with an E-GSM interferer on the second adjacent channel to the wanted signal. The SAGEM MRM MS tested had a ~3dB lower tolerance to interference than the Kapsch mobiles at the higher signal level measured, irrespective of interferer type. The results of the four Selex RMM2300 tested were the most variable, with one MS reporting RXLEV ~9dB lower than the test-set signal (MS presumed faulty) and two further MS achieving RXQUAL=4 with a wanted signal at -104dBm only when the interfering signal was removed completely. The results are consistent with the Selex RMM2300s measured having lower sensitivity than the Kapsch and Sagem MS. It should be stressed that as the MS tested represented a small and random sample supplied by Network Rail, no conclusions should be drawn as to the relative performance of the MS from different manufacturers in general.

Table 7: GSM-R Modem Grading Tests

Manufacturer	GSM-R MS Number	Wanted Level (dBm)	Interfering Level for RXQUAL4 (dBm)	Interferer Type	Comments
Kapsch MT2	1	-104	-40	UMTS @ 927.6MHz	
Kapsch MT2	1	-98	-30	UMTS @ 927.6MHz	
Kapsch MT2	1	-104	-48	E-GSM @ 925.2MHz	
Kapsch MT2	1	-98	-41	E-GSM @ 925.2MHz	
Kapsch MT2	2	-104	-40	UMTS @ 927.6MHz	
Kapsch MT2	2	-98	-30	UMTS @ 927.6MHz	
Kapsch MT2	2	-104	-51	E-GSM @ 925.2MHz	
Kapsch MT2	2	-98	-41	E-GSM @ 925.2MHz	
Kapsch MT2	3	-104	-39	UMTS @ 927.6MHz	

Manufacturer	GSM-R MS Number	Wanted Level (dBm)	Interfering Level for RXQUAL4 (dBm)	Interferer Type	Comments
Kapsch MT2	3	-98	-30	UMTS @ 927.6MHz	
Kapsch MT2	3	-104	-50	E-GSM @ 925.2MHz	
Kapsch MT2	3	-98	-42	E-GSM @ 925.2MHz	
Kapsch MT2	4	-104	-39	UMTS @ 927.6MHz	
Kapsch MT2	4	-98	-30	UMTS @ 927.6MHz	
Kapsch MT2	4	-104	-50	E-GSM @ 925.2MHz	
Kapsch MT2	4	-98	-41	E-GSM @ 925.2MHz	
Kapsch MT2	5	-104	-39	UMTS @ 927.6MHz	Mobile chosen for further characterisation
Kapsch MT2	5	-98	-31	UMTS @ 927.6MHz	Mobile chosen for further characterisation
Kapsch MT2	5	-104	-50	E-GSM @ 925.2MHz	Mobile chosen for further characterisation
Kapsch MT2	5	-98	-41	E-GSM @ 925.2MHz	Mobile chosen for further characterisation
SAGEM MRM	1	-104	-39	UMTS @ 927.6MHz	
SAGEM MRM	1	-98	-34	UMTS @ 927.6MHz	
SAGEM MRM	1	-104	-49	E-GSM @ 925.2MHz	
SAGEM MRM	1	-98	-43	E-GSM @ 925.2MHz	
SAGEM MRM	2	-104	-39	UMTS @ 927.6MHz	
SAGEM MRM	2	-98	-34	UMTS @ 927.6MHz	
SAGEM MRM	2	-104	-49	E-GSM @ 925.2MHz	
SAGEM MRM	2	-98	-43	E-GSM @ 925.2MHz	
SAGEM MRM	3	-104	-39	UMTS @ 927.6MHz	Mobile chosen for further characterisation
SAGEM MRM	3	-98	-35	UMTS @ 927.6MHz	Mobile chosen for further characterisation
SAGEM MRM	3	-104	-53	E-GSM @ 925.2MHz	Mobile chosen for further characterisation
SAGEM MRM	3	-98	-47	E-GSM @ 925.2MHz	Mobile chosen for further characterisation
SAGEM MRM	4	-104	-39	UMTS @ 927.6MHz	
SAGEM MRM	4	-98	-34	UMTS @ 927.6MHz	
SAGEM MRM	4	-104	-50	E-GSM @ 925.2MHz	
SAGEM MRM	4	-98	-43	E-GSM @ 925.2MHz	
SAGEM MRM	5	-104	-39	UMTS @ 927.6MHz	
SAGEM MRM	5	-98	-34	UMTS @ 927.6MHz	
SAGEM MRM	5	-104	-50	E-GSM @ 925.2MHz	
SAGEM MRM	5	-98	-43	E-GSM @ 925.2MHz	
Selex RMM2300	1	-104	no interferer	UMTS @ 927.6MHz	RXQUAL = 4 at -104dBm wanted signal with no interferer
Selex RMM2300	1	-98	-33	UMTS @ 927.6MHz	
Selex RMM2300	1	-104	no interferer	E-GSM @ 925.2MHz	RXQUAL = 4 at -104dBm wanted signal with no interferer
Selex RMM2300	1	-98	-42	E-GSM @ 925.2MHz	
Selex RMM2300	2	-104	no interferer	UMTS @ 927.6MHz	RXQUAL = 4 at -104dBm wanted signal with no interferer
Selex RMM2300	2	-98	-35	UMTS @ 927.6MHz	
Selex RMM2300	2	-104	no interferer	E-GSM @ 925.2MHz	RXQUAL = 4 at -104dBm wanted signal with no interferer
Selex RMM2300	2	-98	-40	E-GSM @ 925.2MHz	
Selex RMM2300	3	-104	no interferer	UMTS @ 927.6MHz	Mobile reports signal ~9dB lower than test set
Selex RMM2300	3	-98	no interferer	UMTS @ 927.6MHz	Mobile reports signal ~9dB lower than test set
Selex RMM2300	3	-104	no interferer	E-GSM @ 925.2MHz	Mobile reports signal ~9dB lower than test set
Selex RMM2300	3	-98	no interferer	E-GSM @ 925.2MHz	Mobile reports signal ~9dB lower than test set
Selex RMM2300	4	-104	-43	UMTS @ 927.6MHz	RXQUAL = 3 at -104dBm wanted signal with no interferer. Mobile chosen for further characterisation.
Selex RMM2300	4	-98	-34	UMTS @ 927.6MHz	Mobile chosen for further characterisation.

Manufacturer	GSM-R MS Number	Wanted Level (dBm)	Interfering Level for RXQUAL4 (dBm)	Interferer Type	Comments
Selex RMM2300	4	-104	-49	E-GSM @ 925.2MHz	RXQUAL = 3 at -104dBm wanted signal with no interferer. Mobile chosen for further characterisation.
Selex RMM2300	4	-98	-40	E-GSM @ 925.2MHz	Mobile chosen for further characterisation.
TrioRail		-104	-39	UMTS @ 927.6MHz	
TrioRail		-98	-34	UMTS @ 927.6MHz	
TrioRail		-104	-48	E-GSM @ 925.2MHz	
TrioRail		-98	-40	E-GSM @ 925.2MHz	