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Mixed mode operation in MultiPoint (MP) Time Division Multiple Access (TDMA) Fixed Wireless Access (FWA) systems;
Intersystems co-existence

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Transmission and Multiplexing (TM).

1 Scope

The present document aims at further assessing the rationale (pros/cons) and status of mixed mode operation in MP systems in the context of inter system co-existence (with the specific example of EN 301 213-3 [1] "most stringent mask" requirement in mind), envisaging various situations, producing conclusions and recommendations, (the power amplifier considerations mainly applying to QAM modulations).

In the mean time the present document was issued, some evolution of the concept of the mixed-mode operation was accepted within the TM4 standards, leading to the following principles:

Systems may offer a combination of type A, B, and C on a per terminal station basis, provided that such a system, when operating in mixed mode, complies with:

- the most stringent spectral mask for the types offered when co-ordination between different operators operating on adjacent channels is required;
- with one of the mask type A, B or C, declared by the manufacturer when co-ordination between different operators operating on adjacent channels is not required (i.e. when blocks of channels are assigned with guard bands in between).

With regard to intra system co-existence, there has also been consideration of more stringent masks than those identified in EN 301 213-3 [1] by other ETSI standardization activities for BFWA (e.g. BRAN HIPERACCESS). These have identified requirements to satisfy intra-system RF planning issues in dense deployments including the possibility of operation in the first adjacent channel. These aspects have not been considered as being part of the current version of the present document.

2 References

For the purposes of this Technical Report (TR) the following references apply:

[1] ETSI EN 301 213-3: "Fixed Radio Systems; Point-to-multipoint equipment; Point-to-multipoint digital radio systems in frequency bands in the range 24,25 GHz to 29,5 GHz using different access methods; Part 3: Time Division Multiple Access (TDMA) methods".

[2] CEPT/ERC Report 99: "The analysis of the coexistence of two FWA cells in the 24.5 - 26.5 GHz and 27.5 - 29.5 GHz bands", Edinburgh, October 2000.

[3] IEEE 802.16.2-2001: "IEEE Recommended Practice for Local and Metropolitan Area Networks - Coexistence of Fixed Broadband Wireless Access System 2001".

[4] ITU-R Recommendation P.452: "Prediction procedure for the evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz".

[5] ETSI EN 301 215-2: "Fixed Radio Systems; Point-to-Multipoint Antennas; Antennas for point-to-multipoint fixed radio systems in the 11 GHz to 60 GHz band; Part 2: 24 GHz to 30 GHz".

[6] ITU-R Recommendation P.530: "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[7] 1999 IEEE MTT-S: "International Topical Symposium on Technologies for Wireless Applications" (Cost Effective Operating Power Specification of Ka-Band MMICs for Multimedia Satellite Interactive Terminals) (pp. 247-252).

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

dB	decibel
dBm	decibel relative to 1mW
GHz	GigaHertz
Mbit/s	Megabit per second
MHz	MegaHertz

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

BER	Bit Error Ratio
CDF	Cumulative Distribution Function
CS	Central Station
EB	Excess Bandwidth
TDMA	Time Division Multiple Access
FDD	Frequency Division Duplex
HPA	High Power Amplifier
ITU	International Telecommunication Union
NFD	Net Filter Discrimination
OBO	Output Back Off
P-MP	Point-to-MultiPoint
QAM	Quadrature Amplitude Modulation
RPE	Radiation Pattern Envelope
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TS	Terminal Station

4 General

In a recent amendment to EN 301 213-3 [1], a type C transmitter emissions mask limit has been added. This mask has been proposed as being appropriate for 64 QAM emission limits in the broadband fixed wireless access point-to-multipoint (PMP) operational environment. The specification further requires that when operational systems employ mixed mode transmission features, these being an adaptive transfer between 4/16/64 QAM, that all modulation techniques must be required to meet the most stringent mask requirement (see note 2 in table 1 of EN 301 213-3 [1]).

The Type C emissions mask places noticeably more stringent emission limits within the bandwidth of a 1st adjacent carrier. For emissions within the bandwidth of a 2nd adjacent carrier, the increased emission requirement is more modest, being only 2 dB lower than the Type B mask requirement.

The principal objective of this study report is to examine the requirements that the Type C emissions mask will place on transmission efficiency for the three modulation formats. A further objective is to identify the magnitude of interference improvement that can be expected from the Type C mask in the PMP operational environment, referenced to multiple operators deployed in the same area and operating on adjacent frequency channels.

It is understood that a prime motivation for development of the Type C mask has been the consideration of multiple-operator deployments for 64 QAM that do not assign a frequency guard band between operator frequency assignments.

5 Coexistence system considerations

Inter-System coexistence requires consideration of two primary interference scenarios. The first of these is interference across a boundary that separates the geographical deployments of two operators. This is primarily a co-channel interference situation and adjacent channel impairments are quite secondary.

The second scenario is that of multiple operator deployments in the same geographical area. Here, two operators may deploy in adjacent frequency blocks and may or may not, establish a guard band between their frequencies of operation. This scenario is the focus of the present document.

Establishment of appropriate adjacent channel operational configurations requires making some realistic assumptions as to the C/N threshold performance limits of the three QAM modulation techniques. These are estimated to be 13 dB, 19 dB and 25 dB for the respective 4-QAM, 16-QAM and 64-QAM modulation methods.

Historically, interference objectives have been set so as to not introduce more than a 1 dB impairment to threshold performance. Hence, giving consideration to the combined C/(N+I), the desired C/I limits are increased by 6 dB. Respective C/I objectives are thus 19 dB, 25 dB and 31 dB for the three modulation techniques.

Estimation of interference levels are conveniently expressed in terms of Net Filter Discrimination (NFD), this being the transmission cascade of the out of band emissions and the receiver selectivity. The present document assumes that the receiver selectivity is that provided by a Root-Nyquist filter. As this is the maximum selectivity allowable in a receiver, the values for NFD are thus maximized.

6 Coexistence system studies

Recently, a number of coexistence system studies (see reference [2]) have been published that examine NFD and related guard band requirements for acceptable same-area/adjacent-frequency deployments. Summary descriptions of these system studies may be found in [3]. While each of the studies has employed quite different computational and simulation performance estimation techniques, all of them have reached a similar general conclusion. This conclusion is that multiple operator deployments will require a guard band, or the equivalent, in order to ensure satisfactory limits on the percentage of interference exposures that exceed desired C/I objectives. Typically speaking, the simulation studies assume that an NFD of 50 dB or greater is available. This would require a 2nd adjacent carrier flanking or the equivalent.

While a guard band implies an actual separation between the frequencies of operation, an equivalent can be obtained if the adjacent carrier frequencies employ orthogonal polarizations. Here, the polarization difference will provide an increase of 25 dB to 30 dB for interference suppression. However, if the deployments of the operators are uncoordinated, this may not be possible. Even in the case of coordinated deployments, this may be difficult as each operator will have established an intra-system frequency and polarization re-use plan that may be impaired if polarization assignments are changed.

Monte Carlo simulation can be employed to identify the actual requirements for NFD. Figure A.1 illustrates the simulation model for CS to TS interference estimation that is common to both FDD and TDD. The interference CS is placed in the victim sector at some parameterized separation distance S between the hub centres. Relative angular position of the interference CS is set random for each rotational spin of sector alignments. As the interference CS is always deemed to be within the victim sector, only the sector alignment of the interference CS needs to be varied. Spin increments were set to 5°.

A rain cell of radius R_c = 1,2 km is positioned in the sector at some parameterized distance D_{rc}. The specified radius corresponds to that identified in [4] for ITU rain region K. To ensure that at least some one victim link experiences the full rain attenuation loss, D_{rc} is restricted to be within the range of 1,2 km to 2,4 km. A worst-case value for D_{rc} would tend to be 1,2 km. At this distance, the rain cell just touches the centre of the victim sector, thus maximizing the number of victim TS locations that experience significant rain loss.

For each rotational spin of the interference CS, the angular position of the rain cell is randomized. Angular rotation is restricted to be within ±45°, thus ensuring that the full diameter of the rain cell is always within the victim sector.

Twenty victim subscribers have been selected for each rotational spin. These are randomly distance positioned on roughly an area proportional basis. Hence it would be expected that 50 % of the TS locations are at a distance > 0,75R from the centre of the victim sector/cell centre.

For each spin, the rain loss of the interference and victim vectors is computed, based on the geometry and rain cell intersection experienced by the signal vectors. Victim signal levels are computed based on the transmission parameters, link distance and rain loss. Interference signal levels are similarly computed but with the inclusion of antenna angular discrimination, relative frequency polarization and NFD. A single interference computation accounts for the contribution of each of the four CS sectors and each spin represents 20 independent C/I estimates. Thus a simulation is represented by 1440 C/I estimates. These are sorted and employed to develop a CDF for C/I at given values for S and D_{rc}.

For all of the simulation estimates, the angular antenna RPE rejection provided by the ETSI PMP antenna masks TS1 and CS2 [5] has been employed.

Figure A.2 illustrates the results of a clear sky simulation based on the methodology described above. Here, the available NFD has been parameterized in 10 dB steps ranging from 20 dB to 50 dB. The simulation employs "typical" 26 GHz transmission parameters as reported in [2]. Also, as specified in [2], cell radius has been set at R = 3,6 km. For ITU rain region K, this corresponds to a link availability of 99,995 % at a BER = 10^{-6} for 4-QAM transmission. Based on the rain loss availability procedures given in [6], a fade margin of 25 dB is required.

For this clear sky case, worst C/I performance would be expected to occur when the interference CS is located in close proximity to the CS associated with the victim sector. This geographical configuration tends to minimize the angular antenna discrimination provided by the victim TSs. Other simulations (not reported herein) have confirmed this conclusion. For figure A.1, CS separation distance has been set at S = 0,2 km. Here it is apparent that an NFD of the order of 35 dB would be required in order to satisfy 64-QAM interference coordination objectives.

Figure A.3 illustrates the results for the case when a rain cell is present in the victim sector. As previously noted, a "somewhat worst case" scenario occurs when the rain cell is located close-in to the CS of the victim links as this maximizes the rain attenuation on the victim links. Hence, for this simulation D_{rc} has been set at 1,2 km.

Correspondingly, it would be expected that when the interference CS is located at some significant distance from the victim CS, the rain attenuation experienced by the interference vectors would tend to be minimized. Simulation tests runs indicate that, for some specific separation distance D_{rc} of the rain cell, there is a modest range of variability in C/I performance relative to interference CS separation distance S. For the example simulation, S has been set to a mid range distance of 1,8 km.

The rain attenuation simulation example indicates that there is a significant increase in the NFD requirements in order to meet acceptable C/I exposure limits. For 4-QAM, an NFD of 40 dB would appear to be acceptable (approximately a 2 % exposure conflict for a 1 dB threshold impairment). However this same NFD results in a 9 % exposure conflict for 64-QAM which would clearly be unacceptable. Consequently, one may conclude that the NFD criteria employed in [2] of 50 dB or greater is a reasonable requirement to set for same area/adjacent carrier operation.

7 NFD emission mask estimates

A preliminary estimate of the NFD values to be expected from the emissions masks can be achieved by simply performing a numerical integration of the power allowed in each adjacent carrier bandwidth relative to the power allowed within the bandwidth of the transmitting carrier. There are two components associated with the NFD, the first being just the emission power allowed by the mask and the second being the added improvement provided by the receiver filter selectivity.

Tables 1 to 3 summarize the results of these computations. For each mask, receiver Excess Bandwidths (EB) of 15 %, 25 % and 35 % have been employed. As the spectral shape of the allowed emissions is coloured, particularly within the bandwidth of the 1st adjacent carrier, the NFD improvement provided by filtering increases as excess bandwidth increases. This is a result of the increased "attenuation cut" to the close-in emissions provided by increased excess bandwidth filtering. Specified mask emission limits at a 3rd adjacent carrier location limit are white. Here, the improvement provided by filtering is modest, just being the power adjustment provided by the ratio of the Nyquist bandwidth to the carrier bandwidth.

Table 1: NFD estimates for the ETSI Type A emissions mask

Excess Bandwidth	Type A Mask	1st Adj. Cxr	2nd Adj. Cxr	3rd Adj. Cxr
15 %	Emissions ACI (dB)	19,8	44,2	45
	NFD (dB)	23,6	45,1	45,6
25 %	Emissions ACI (dB)	19,8	44,2	45
	NFD (dB)	25,1	45,6	46,2
35 %	Emissions ACI (dB)	19,8	44,2	45
	NFD (dB)	26,1	46,3	46,9

Table 2: NFD estimates for the ETSI Type B emissions mask

Excess Bandwidth	Type B Mask	1st Adj. Cxr	2nd Adj. Cxr	3rd Adj. Cxr
15 %	Emissions ACI (dB)	20	47,3	50
	NFD (dB)	25	48,4	50,6
25 %	Emissions ACI (dB)	20	47,3	50
	NFD (dB)	27,6	49,2	51,2
35 %	Emissions ACI (dB)	20	47,3	50
	NFD (dB)	29,7	50	51,9

Table 3: NFD estimates for the ETSI Type C emissions mask

Excess Bandwidth	Type C Mask	1st Adj. Cxr	2nd Adj. Cxr	3rd Adj. Cxr
15 %	Emissions ACI (dB)	24,9	50,4	52
	NFD (dB)	29,6	51,4	52,6
25 %	Emissions ACI (dB)	24,9	50,4	52
	NFD (dB)	32	52,1	53,2
35 %	Emissions ACI (dB)	24,9	50,4	52
	NFD (dB)	34	52,9	53,9

Consider an examination of these tables referenced to a mid-range excess bandwidth assignment of 25 %, a current common value. For a 1st adjacent carrier flanking, none of the NFD values approach the NFD requirements necessary for adjacent carrier operation that were identified in clause 2. Further, we may note the NFD differential between the Type B and Type C masks. Here, there is a modest improvement in NFD of 4,4 dB, in spite of the significant tightening of the mask. As the NFD improvement still falls far short of the requirements necessary for 64 QAM, the justification for the increased selectivity of the Type C mask seems questionable.

8 NFD simulation estimates

NFD estimates based on emission masks can be quite misleading as the masks are configured from straight-line segments (on a dB basis). Actual levels of emissions, still falling within the mask, may have a quite different detailed set of emission values that may result in significantly different estimates for NFD. The present clause examines such a possibility by way of an intermodulation simulation referenced to the measured transfer function of a 31 GHz FET HPA [7]. The measured AM/AM and AM/PM transfer function characteristics are illustrated in figure A.4. These are considered to be "typical" for HPA devices employed in the FWA frequency bands of interest.

The simulation methodology employs conventional DFFT techniques that are described in detail in the technical literature. For the simulation examples, output back off (OBO) is referenced to amplifier saturation. Emission masks, signal power and intermodulation power are also referenced to OBO, all being adjusted to the resolution bandwidth of the selected DFFT.

Figures A.5 to A.13 illustrate the inter-modulation results for each of the three QAM modulation techniques, referenced to the three emission masks. All of the simulations assume a carrier bandwidth of 28 MHz however this just simply scales directly to other carrier bandwidths. An excess bandwidth of 25 % has been specified. The frequency scale is normalized to the Nyquist symbol bandwidth f_s which is thus f_s = 28/1,25 = 22,4 MHz.

For the simulations, OBO has been adjusted so that the transmitter out-of-band emissions "just" fall within the specified emissions mask. A given simulation is the result of the averaging of a number of independent random simulation runs. Repeated simulation runs indicate that the computed results, based on different random seeds, are bounded by approximately ±1 dB.

From the simulation results illustrated, the required OBO necessary to meet the emissions mask limits can be identified. Additionally, the expected NFD resulting from the actual emissions, cascaded with the receiver filter may be computed. The impact of the receive filter on the emissions is illustrated in figures A.14 and A.15 for the case of 16 QAM referenced to the Type B emissions mask. Referenced to the signal power, this residual interference energy defines NFD.

Table 4 provides a summary of the simulation results that interrelate the emission mask requirements to OBO and the expected values of NFD. NFD-1 and NFD-2 correspond to respective simulation estimates within the 1st adjacent and 2nd adjacent carrier assignments.

Table 4: NFD and OBO simulation estimate comparisons for an excess modulation bandwidth of 25 %

Mod.	Type A Mask			Type B Mask			Type C Mask		
	NFD-1 (dB)	NFD-2 (dB)	OBO (dB)	NFD-1 (dB)	NFD-2 (dB)	OBO (dB)	NFD-1 (dB)	NFD-2 (dB)	OBO (dB)
4 QAM	37,7	48	6	40	50,7	7	42	51,2	9
16 QAM	37	47	7	39,5	51	8	40	51,6	9
64 QAM	38	49	8	39,4	51,6	9,5	41	56	13,5

A comparison of the NFD mask numerical integration estimates described in clause 3 and the NFD simulation results given in table 4 are of interest. As the simulation emissions must fall within the masks, their NFD values should be greater, a result confirmed by the simulations. For NFD-1, the simulation results are roughly 10 dB to 12 dB better than the integration results and result in an NFD range from 37 dB to 42 dB. For NFD-2, the simulation emission levels are in much closer proximity to the mask limits and consequently there is only a few dB improvement in NFD.

A more interesting comparison occurs when the table 4 NFD simulation estimates vs. modulation and mask type are examined. For NFD-1 and all modulations, there is only a modest change in NFD referenced to the three mask types. Roughly speaking, NFD-1 is about 40 dB. Except possibly for 4-QAM, this value of NFD would be insufficient to maintain interference exposure likelihood at an acceptable percentage.

For NFD-2 and the Type A mask, the simulation estimates are marginal except for 4-QAM. NFD estimates exceed 50 dB for the Type B mask, which would indicate that the mask specifications are suitable for all three-modulation types. Also noteworthy for the Type B mask is that the NFD-2 estimates illustrate a very small dependency on modulation type, the differential being a maximum of 1,6 dB.

Relative to the Type B mask, the NFD-2 estimates for the Type C mask are almost unchanged for both 4/16-QAM. However the Type C mask does impose an increase in OBO for all modulation techniques, which will reduce transmission efficiency and hence cell size.

A much more noticeable requirement for an increase in OBO applies to 64 QAM. Here the increase between the B and C masks is 4 dB that represents a significant reduction in operational range. From the simulation results (compare figures A.10 and A.13), it is evident that the peak-to-RMS levels of 64-QAM require an increase in OBO such that only 3rd order inter-modulation is of significance if the Type C mask is required. However this has done little or nothing of improvement to NFD-1.

9 Conclusion

Coexistence NFD requirements have been examined for same area/adjacent operator CS to TS operational compatibility. It is estimated that an NFD of 50 dB or greater is required, a value consistent with that reported in other system studies. Both numerical mask integration and inter-modulation simulation against measured HPA transfer functions has been employed in order to identify NFD values to be expected referenced to ETSI emission masks.

The computational results indicate that the NFD to be expected from a 1st adjacent carrier flanking falls far short of the requirements for OBO values that limit emissions to within the masks. The results further show that, within this bandwidth, that there is only a modest change in NFD referenced to modulation technique and/or mask type. To meet acceptable NFD levels within the 1st adjacent carrier bandwidth would require either transmitter linearization or significant increases in transmitter OBO. In both cases, all of the current ETSI masks would need reconsideration.

The computational results also indicate that the NFD to be expected from a 2nd adjacent carrier flanking should be satisfactory for emissions that fall within the Type B mask. The computations also indicate that the requirements of the Type C mask offer only a very modest improvement in NFD for both 4-QAM and 16-QAM. However the simulations show that the Type C mask imposes increased values of OBO on these modulation techniques that negatively impacts link transmission distance.

An alarming concern is the impact of the Type C mask on the operation of 64-QAM. Here, it is shown that an OBO increase of 4 dB is required referenced to the Type B and C masks. This could represent a significant reduction in transmission link distance. However the mask provides no significant improvement in NFD to be expected in the 1st adjacent channel bandwidth. Further, while the mask provides a more than adequate NFD for 2nd adjacent carrier operation, the expected levels are inconstant with those to be expected from 4/16-QAM.

Thus, giving consideration to all of the preceding issues, for second adjacent channel working, it is concluded that the Type B mask sets an appropriate emission limit for all three QAM modulation techniques. With OBO levels set to be within the mask requirements, it should provide a relatively uniform set of NFD values for all three techniques. This of course assumes that it is recognized that multiple operator deployments will require one guard band or the equivalent.

Annex A:
The co-existence simulation model and results

A.1 Simulation model

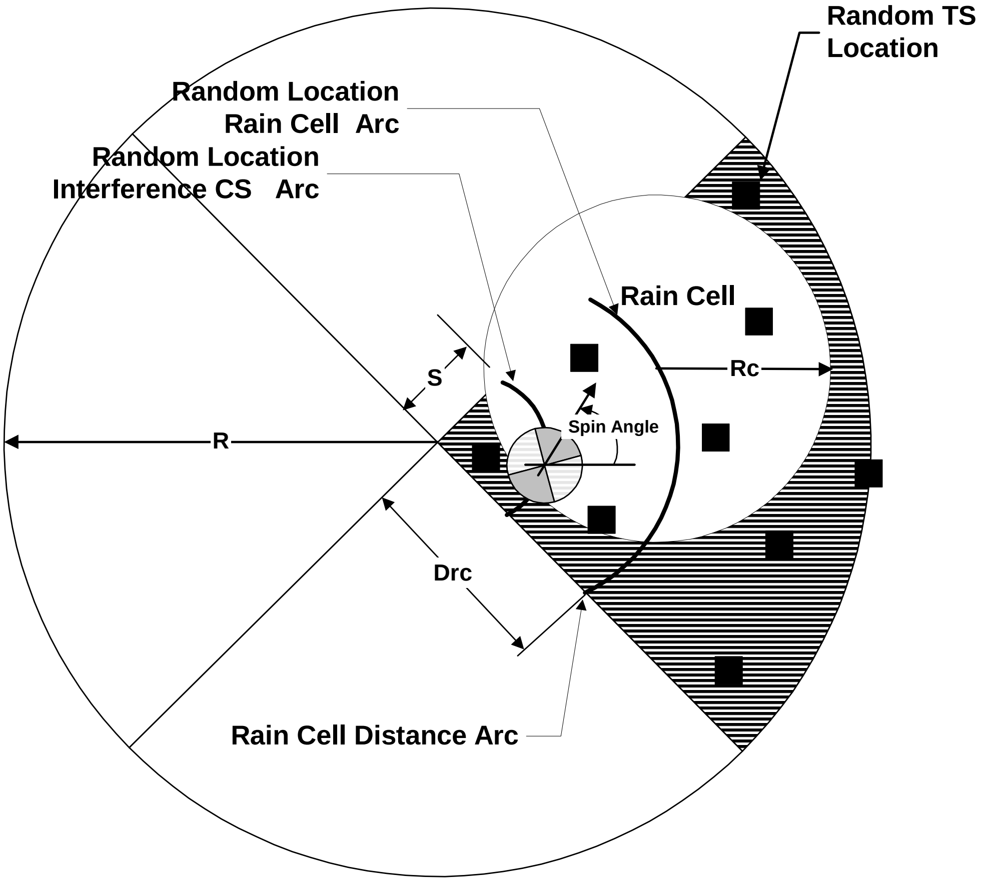

Figure A.1: Coexistence simulation model

A.2 Clear sky/rain cell simulation results

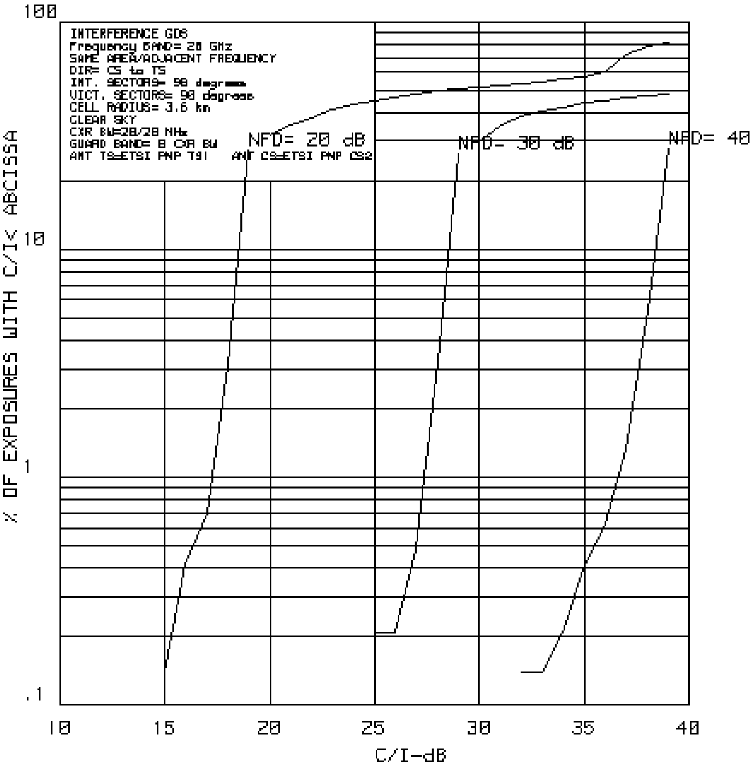

Figure A.2: Clear sky CDF simulation estimate

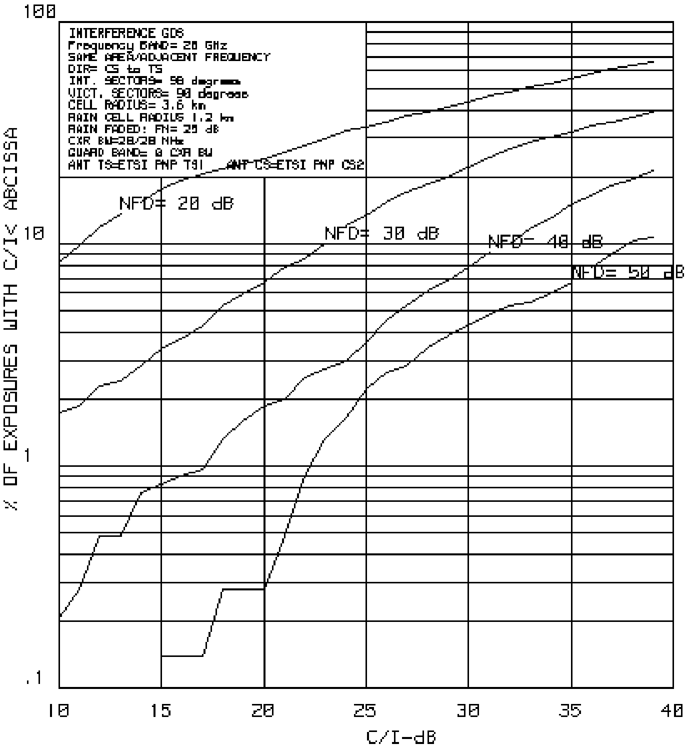

Figure A.3: Rain faded CDF simulation estimate

A.3 AM/AM and AM/PM transfer function characteristics

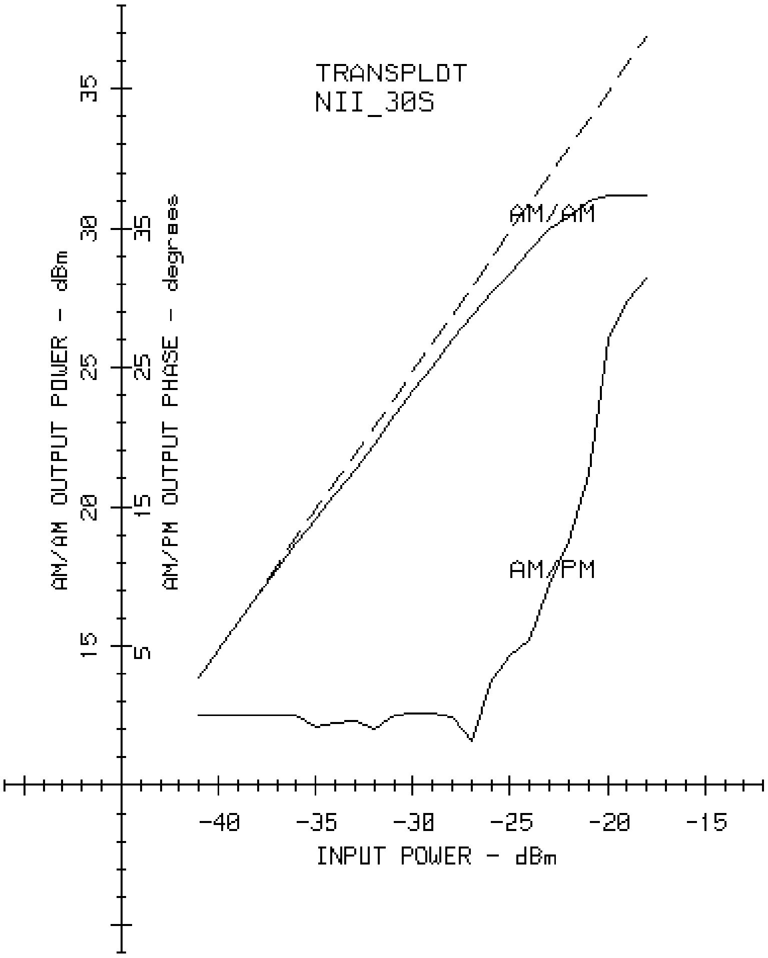

Figure A.4: HPA transfer function

A.4 Intermodulation results for type A mask

A.4.1 4-QAM modulation

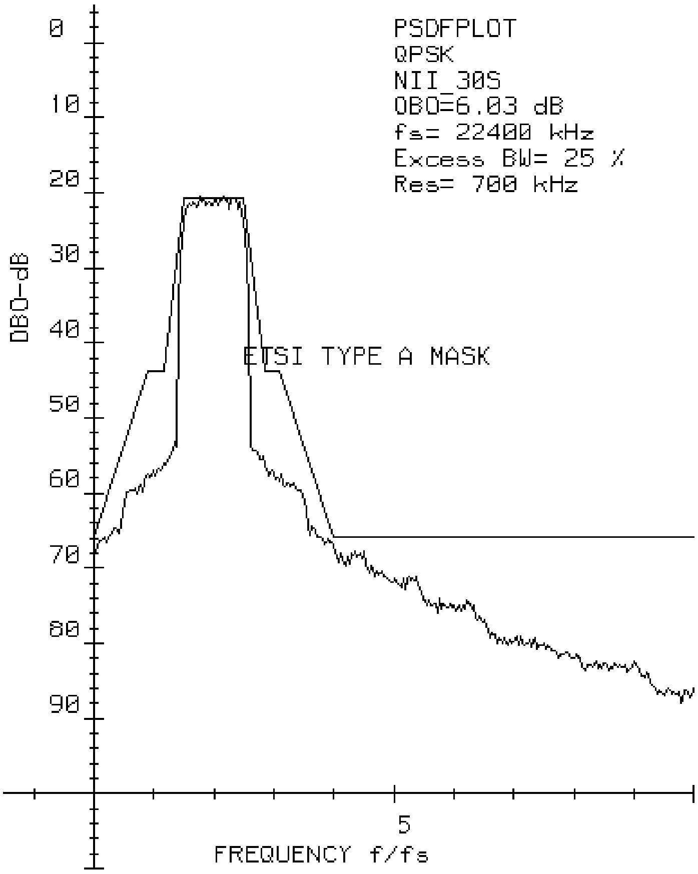

Figure A.5: Intermodulation simulation for 4-QAM referenced to the type A mask

A.4.2 16-QAM modulation

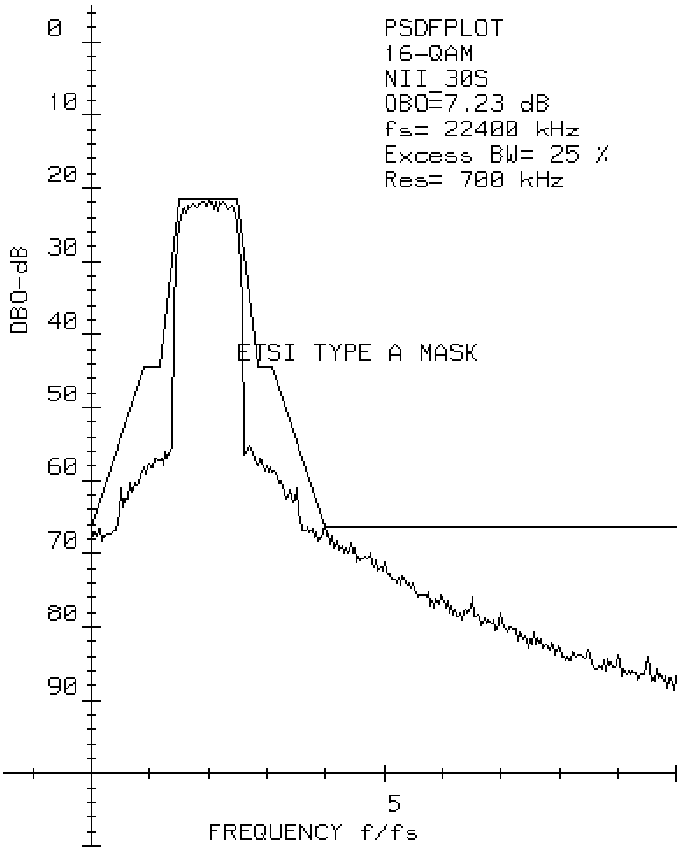

Figure A.6: Intermodulation simulation for 16-QAM Referenced to the type A mask

A.4.3 64-QAM modulation

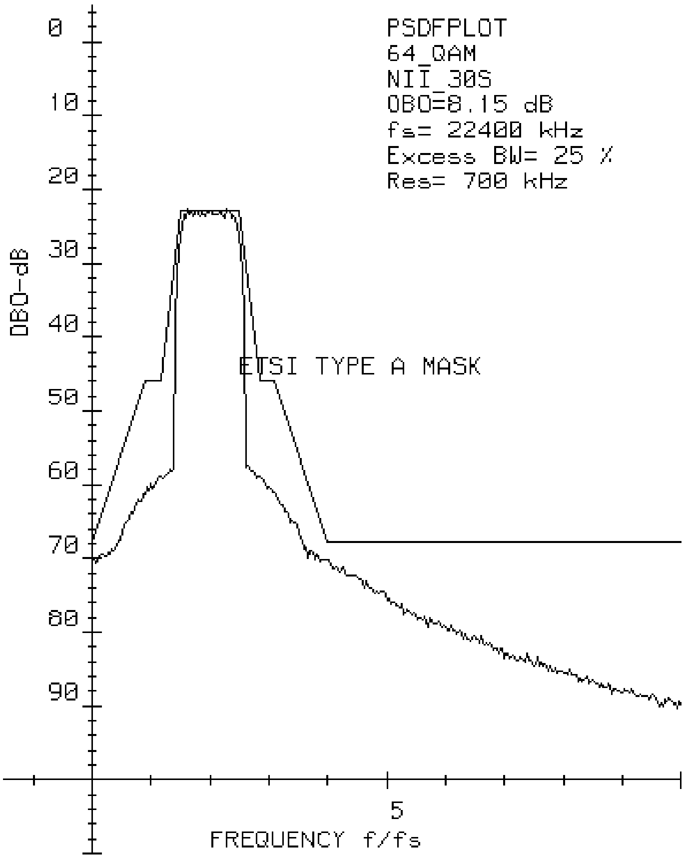

Figure A.7: Intermodulation simulation for 64-QAM referenced to the type A mask

A.5 Intermodulation results for type B mask

A.5.1 4-QAM modulation

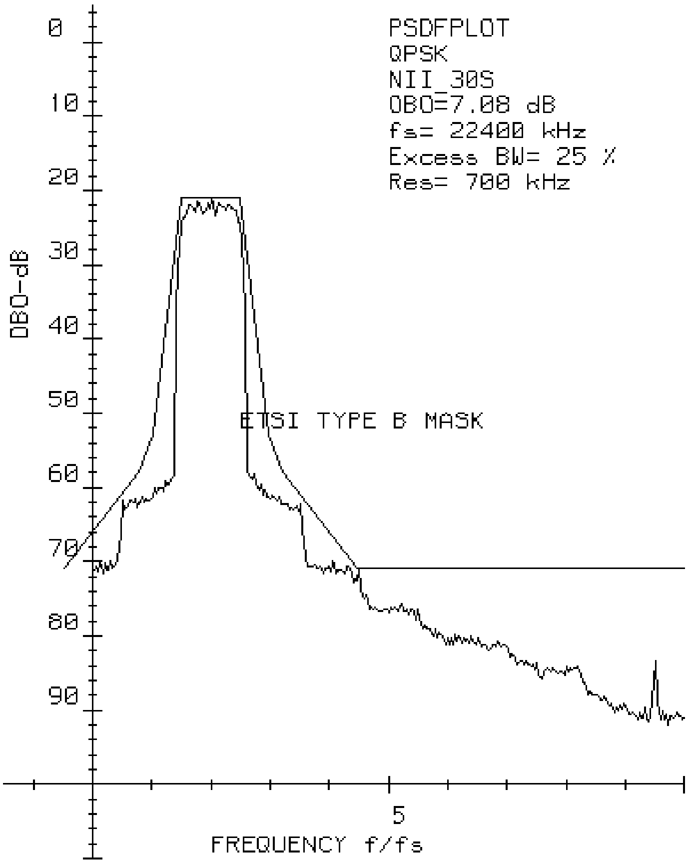

Figure A.8: Intermodulation simulation for 4-QAM referenced to the type B mask

A.5.2 16-QAM modulation

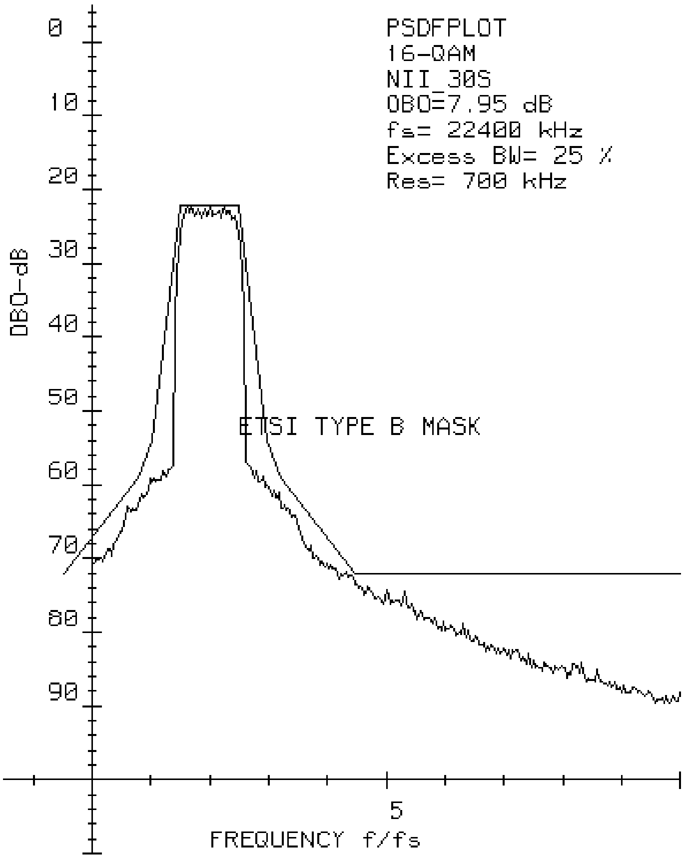

Figure A.9: Intermodulation simulation for 16-QAM referenced to the type B mask

A.5.3 64-QAM modulation

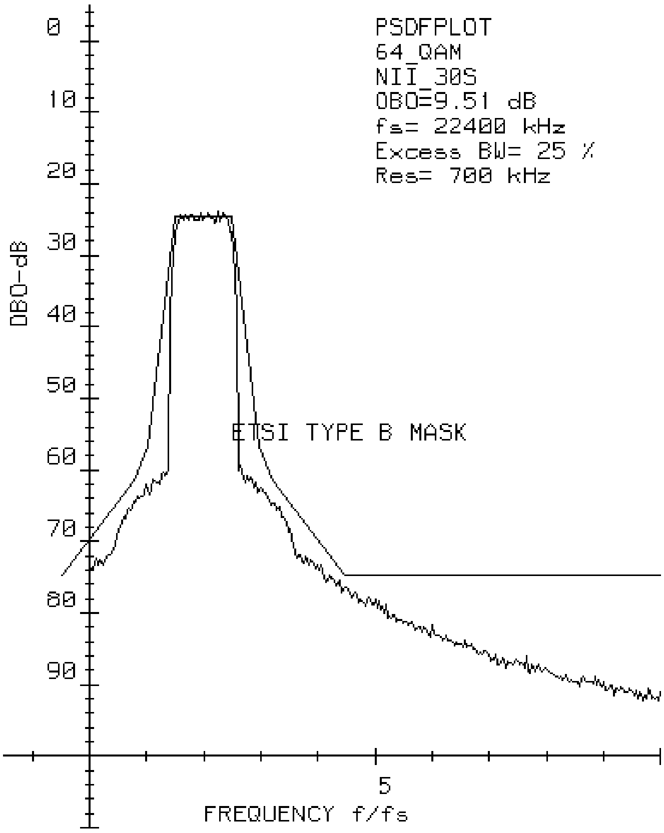

Figure A.10: Intermodulation simulation for 64-QAM referenced to the type B mask

A.6 Intermodulation results for type C mask

A.6.1 4-QAM modulation

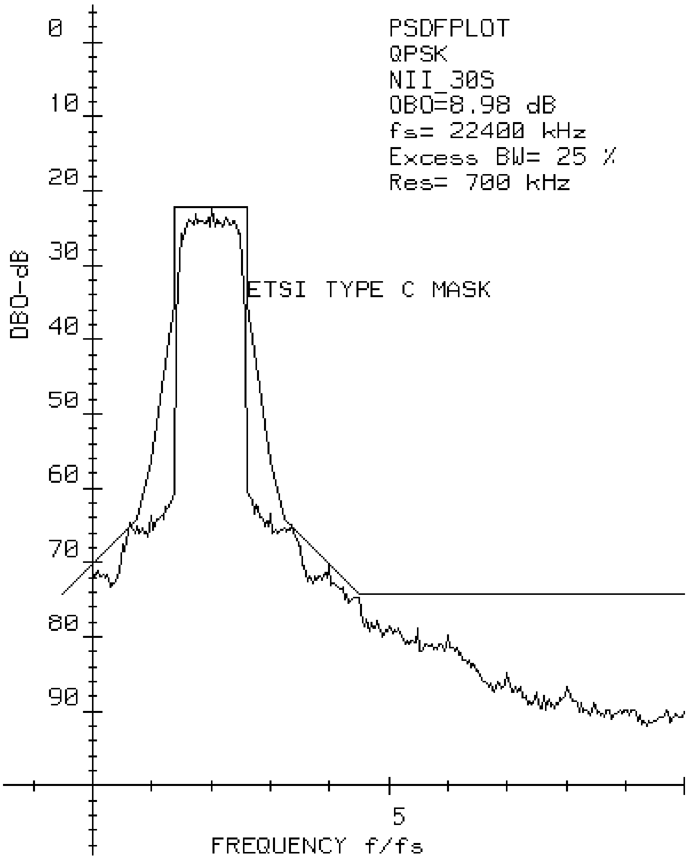

Figure A.11: Intermodulation simulation for 4-QAM referenced to the type C mask

A.6.2 16-QAM modulation

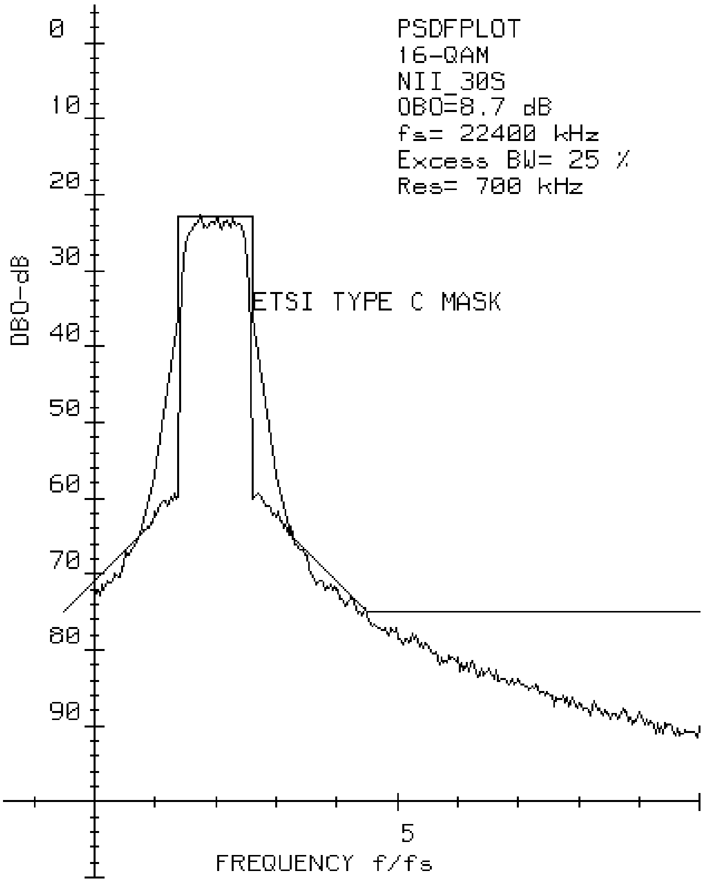

Figure A.12: Intermodulation simulation for 16-QAM referenced to the type C mask

A.6.3 64-QAM modulation

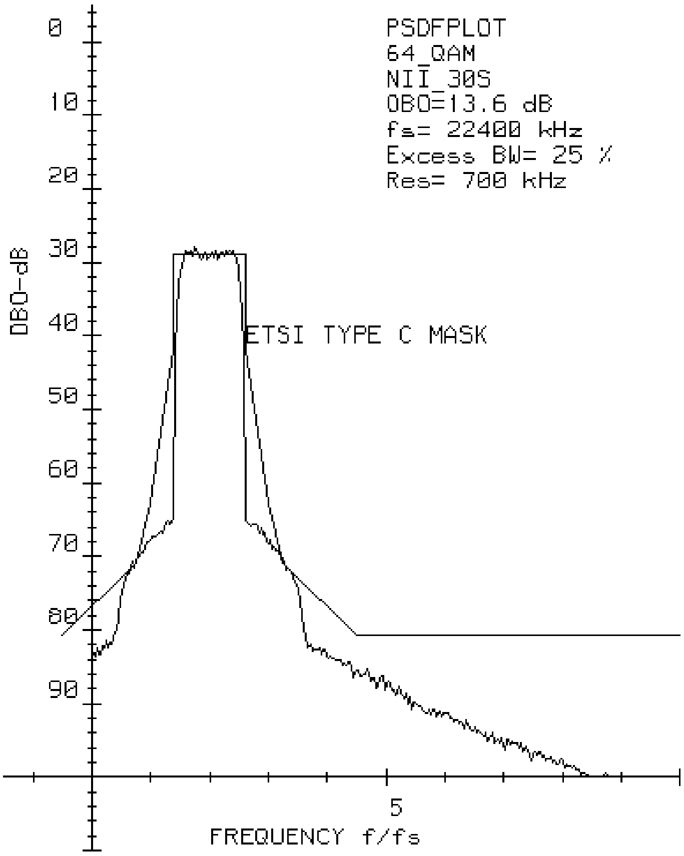

Figure A.13: Intermodulation simulation for 64-QAM referenced to the type C mask

A.7 Receiver filter emission suppression

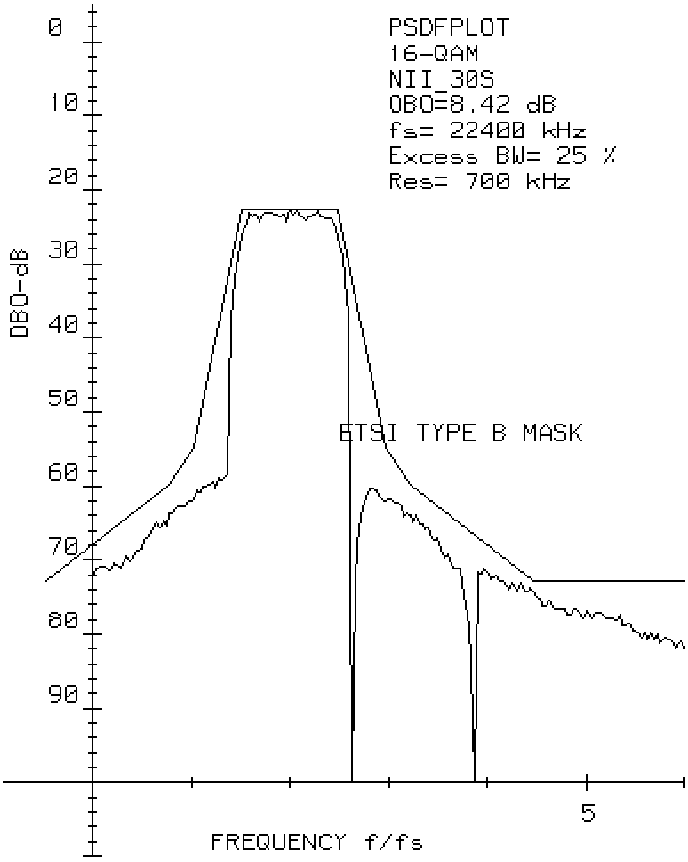

Figure A.14: Receiver filter emission suppression in a 1st adjacent carrier channel

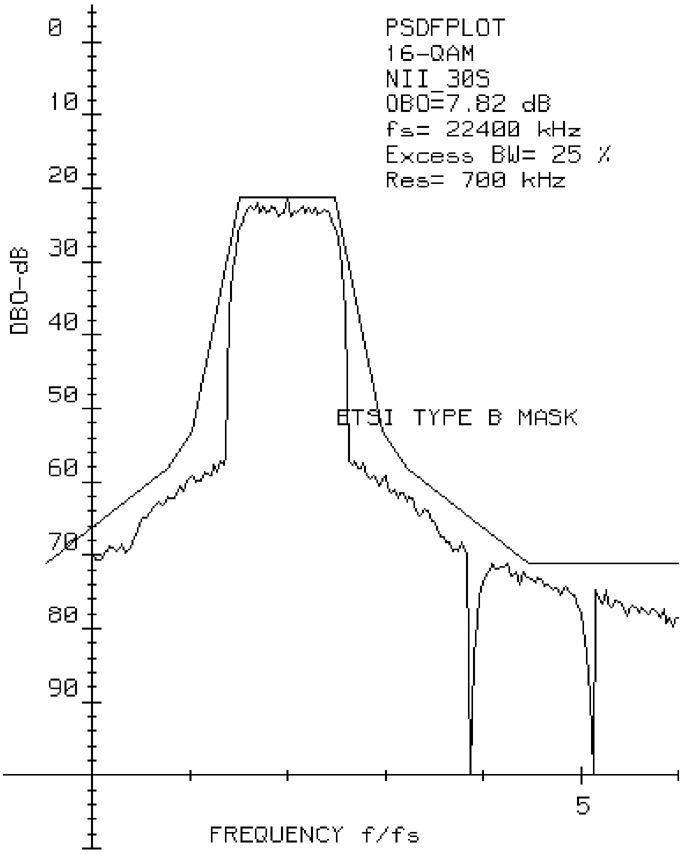

Figure A.15: Receiver filter emission suppression in a 2nd adjacent carrier channel

Annex B: Bibliography

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History

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