ECC Report 127

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

THE IMPACT OF RECEIVER STANDARDS ON SPECTRUM MANAGEMENT

Cordoba, October 2008

0 EXECUTIVE SUMMARY

This study was initiated by a decision of the ECC's Krakow meeting in March 2007 to consider the impact of receiver performance on spectrum management.

The document begins by setting out technical and regulatory background to the issues, with some references to their underlying economic relevance.

Some groups within the CEPT and ETSI have been consulted to identify examples of where poor receiver performance, or spectrum planning on the assumption of poor receiver standards, has given rise to frequency management problems. Typically these are lost opportunities to develop new services to their full potential, or at all, or else the constraints to existing services caused by interference. The hypothesis underlying the study is that by applying more demanding requirements for receivers, backed by an appropriate regulatory framework, an overall economic benefit might be obtained. This study is only the first step of a process to test the hypothesis.

The study has revealed several cases where it would have been possible to make a significant difference to an outcome in spectrum management if the treatment of receiver performance, and particularly the application of receiver parameters, had been different. Historically the extent of technical benefit or disadvantage has not been quantified, and so the evidence available to this study is very limited in how it can be used. In particular, there is a lack of available impact analysis to determine whether and to what extent an alternative approach or alternative receiver parameters would have given a net economic benefit.

Improvements in technology allow for opportunities to improve spectrum management. This will be helped at a later stage if standards can play a role in licensing and/or consumer expectation when a service is first launched, in order to manage legacy protection issues at a later stage.

Nevertheless the study has revealed sufficient cases to suggest that the role of receiver parameters in standards and their related consideration in spectrum engineering should receive greater prominence in order to promote more efficient use of the spectrum, including maximising economic and social welfare. Without further study it is difficult to prescribe in detail what regime and approach would be most effective. The depth of study required to evaluate every possible option and all their variations could be out of proportion to the accrued benefits, not least because of the delays to decision making which may be implied by a more complex process. There is also the consideration that such estimates of benefit can be decidedly speculative.

The study makes recommendations of principles which could be introduced, or applied with increased vigour, to how receiver performance is specified and regulated, or information made available to consumers. The recommendations are of necessity very general and further study - itself a recommendation of the report - would be needed to turn these into more precise proposals.

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1 INTRODUCTION

Every radio communication link includes transmitters and receivers. Engineering such communications requires the careful matching of transmitter characteristics with corresponding receiver characteristics. Hence, for frequency planning, the characteristics of receivers as well as transmitters are important and central to the decisions which need to be taken on channellisation, frequency re-use and the planning of systems in adjacent frequency bands. The incorporation of receiver performance specifications in planning and regulation can thus serve to promote more efficient utilization of the spectrum and create opportunities for new and additional use of radio communications.

The general recognition that future spectrum assignments will become even more technology neutral; places even greater emphasis on efficient spectrum management. The use of Reconfigurable Radio Systems (RRS), Cognitive Radio (CR) and SDR (Software Defined Radio) will also become useful spectrum management mechanisms for which attaching due importance to good receiver performance should maximize spectrum utilization. On the other side, recognition of the cost impact of receiver performance specifications is important.

From a technical standpoint, a radio receiver's susceptibility to interference is largely dependent on the interference immunity of the device, particularly with regard to its rejection of undesired radiofrequency (RF) energy and signals. If the receivers used in connection with a radio service are designed to provide a greater immunity or tolerance of undesired RF energy and signals, more efficient and predictable use of the spectrum resource can be achieved. In particular, such receiver improvements could also provide greater opportunities for newcomers to gain access to the spectrum.

Authorities responsible for spectrum management face the problem of allocating frequencies to new services while avoiding potential interference to existing services.

If these existing services rely on poorly performing receivers, which are or may be subject to interference from the new service, then the frequency spectrum cannot be used efficiently. Either the existing service is subject to interference and reduction of its utility, or a new service is subject to technical regulatory restrictions, or denied altogether. Either way, there is a loss of utility. This may or may not exceed the gain of utility which accrues from not regulating receiver standards effectively.

Receiver requirements and receiver parameters in general have been a point for discussion in national and international radio regulatory bodies (see RR articles 3.11 to 3.13)[1]. One of the issues raised in these discussions is the question whether receiver requirements should be mandatory. Not only on a national level but also within the CEPT there has not been any unanimous view on this point. Prior to the implementation of the R&TTE Directive[2], some receiver parameter limits were set as mandatory in type approval regulations in many countries. Within the R&TTE regime, those parameter limits are only present in some Harmonized Standards (e.g. standards for cellular networks), although they are also included in product standards. Under the R&TTE Directive, EMC requirements are also made applicable. For radio receivers, specific EMC standards have been developed for a number of different applications. If not included in a harmonized standard, no legal obligation exists to fulfil any requirements. The underlying assumption behind allowing this situation to arise is that the market itself will try to reach the best receiver quality in order to satisfy the customers. However, this does not preclude the possibility of market failure due to imperfect information being available to, or the information not being understood by the consumers. This effect could be particularly significant where an existing system is either interfered with by a new one, or represents an opportunity cost where protection of an existing system with a poor standard of receivers prevents the deployment of a new system. It is therefore important for manufacturers and users of radio receiving equipment at all times to have at one's disposal the full set of (minimum) reception characteristics that are applicable.

[1] RR Article 3

3.11 Wherever necessary for efficient spectrum use, the receivers used by any service should comply as far as possible with the frequency tolerances of the transmitters of that service, due regard being paid to the Doppler Effect where appropriate.
3.12 Receiving stations should use equipment with technical characteristics appropriate for the class of emission concerned; in particular, selectivity should be appropriate having regard to No. 3.9 on the bandwidths of emissions.

3.13 The performance characteristics of receivers should be adequate to ensure that they do not suffer from interference due to transmitters situated at a reasonable distance and which operate in accordance with these Regulations.

[2] Directive Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity.

There have been three main justifications given previously for receiver requirements being specified at a low or non-existent level for certain types of equipment:

- Increased costs caused by the addition of better filters and related components.
- The impact of reduced battery life due to the increased power consumption of the improved receiver circuitry.
- An unacceptable increase in the physical volume of very small products due to the added circuitry.

Technological improvements have greatly reduced the costs for components designed to improve receiver performance and one can say that there is now no economic penalty for improving receiver performance in new products. A decrease in battery life may still be an issue for cheaper products using older technologies; however improvements are being made in developing components requiring less power. The unacceptable increase in volume due to added components in very small products remains an issue but is limited to a very small range of products.

This document investigates the current situation, taking into account views and inputs from ETSI, CEPT Administrations and WG SE. A questionnaire on current practice was sent out to administrations. The response to this questionnaire has been incorporated in chapter 4. In the context of this study, WG SE has discussed the impact of receiver parameter values on co existence studies and the outcome has been used in this report. A number of conclusions and recommendations are given in chapter 5. Some familiarity is assumed with spectrum management, associated acronyms and relevant regulatory structures used in Europe.

2 HISTORIC PERSPECTIVE

Radio communications in most countries used to be controlled and regulated by the incumbent telecom operator. The equipment to be used was procured by the operator according to specifications that usually included receiver parameter values. The exception was the broadcasting service, for which radio and TV receivers were available in the market. The only specifications for these receivers were laid down in EN 55020 (Electromagnetic immunity of broadcast receivers and associated equipment)

After the privatisation of telecom operators and the increase of competition in that area, Government organisations had set up regulations for the use and putting on the market of radio communications equipment including receivers. ETSI was mainly responsible for developing standards that could be referred to in those regulations. Product (vertical) radio standards were published as well as vertical EMC standards, while also some horizontal EMC standards existed, covering a broad range of products. In an effort to guide the interested parties in how to apply various standards, an ETSI report was published aiming to define what characteristics are to be considered EMC related (ETR 238).

With the coming into force of the R&TTE Directive, Harmonized Standards were developed, giving the presumption of conformity with the essential requirements of the Directive when applied. In general, these Harmonised Standards often do not include receiver parameter limits (other than receiver spurious emissions). In addition, conditions for the use of equipment, as set by individual administrations, should not contain receiver parameter limit values. Previously, the European Commission had consistently resisted regulations on receive-only equipment and pressed for minimising regulatory requirements on receivers and receiver parts of equipment (see also ETSI document OCGRTTE-D #35).

The combined effect of licence free operation in a number of frequency bands, without strict receiver requirements, that was introduced in many countries and the advance of technology has lead to an enormous surge in the use of low cost radio products, with attendant benefits of consumer welfare. However in many cases, the market failures of imperfect consumer information[3] meant that market forces could not compensate for the absence of mandatory receiver requirements in such a way that receiver performance improved[4]. In other words, and in principle, it is possible that, despite the benefits of low cost receivers, overall consumer welfare has not been maximised.

After several years of R&TTE implementation, some administrations observe that they are constrained in new frequency designations due to poor receiver performance in some cases. Other administrations have received complaints caused by poor receiver performance. In recent years, the pre-emptive effect (opportunity cost) of poorly performing receivers has been demonstrated, as licensees seek protection for service predicated on the performance of receivers with little tolerance for other signals. Had the RF environment in which these services would be expected to operate in the future, been defined in some way, then these services could have been developed with receivers that could better tolerate the introduction of newer services on the same or proximate frequencies.

[3] This information can be either provided by the manufacturer in accordance with the article 6.3 of the RTTE Directive, or gathered by the user himself when using the equipment which is possible with some systems but not with other systems.

[4] The alternative consideration is that if interference is allowed into receivers by a transmitting system, this represents an economic ”externality”. Equally, the opportunity cost of protecting a system with poor quality receivers could be considered a sort of externality, in that the purchasers of those ’cheap’ receivers have not paid the opportunity cost of the service which has been denied.

The large installed base of low performance receivers has started to create problems in frequency management.

3 REGULATORY ISSUES

Before the year 2000, type approval of radio equipment was common in Europe. CEPT had developed many Decisions on the adoption of harmonized type approval regulations for radio equipment[5]. Those Decisions usually did refer to ETSI standards that would generally include receiver parameter limit values (see Annex 1 for receiver parameter details).

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Prior to the entry into force of the R&TTE Directive, which changed the approval regulations within the EU, CEPT ERC had discussed the matter of receiver regulations. The ERC expressed the view that in certain cases the receiver requirements can be justified e.g. for safety services, EMC and spectrum efficiency. Also in general, if these requirements are left as voluntary, it would lead to a permanent reduction of spectrum efficiency. It was agreed that where justified, these should be incorporated as “essential requirements” within the relevant ETSI standards on a case by case basis (see Annex 2 for different service categories). The ERC position was considered at preparatory meetings called by the EC in 1998 in its preparation of the RTTE Directive.

Assumed or enforced receiver parameter limits had always been used for planning and interference calculations prior to new allocations of frequency bands. After the coming into force of the R&TTE Directive in April 2000, such requirements were not mandatory any more for equipment to be sold within the EU. Also, in the radio interfaces regulated by national administrations those parameters were no longer part of mandatory regulations. In recognition of these facts, CEPT developed the ECC Recommendation 02(01) which specifies receiver requirements which are not included in harmonized standards either by taking them from some ETSI document or from ECC deliverables. Administrations may use this Recommendation as a basis for their spectrum planning criteria and methods of investigation and resolving interference complaints related to receiver parameters.

The reference receiver performance parameter values were typically quantified in a radio product standard. Administrations were also encouraged to publish the appropriate information on their spectrum planning criteria. In the EFIS system (www.efis.dk), the radio interface section includes a placeholder for those references

EU

In April 1999, the type approval regime in the EU was replaced by the R&TTE Directive (Directive 1999/5/EC). One way to demonstrate conformity of radio and terminal equipment with the essential requirements of this Directive is via compliance with the applicable Harmonized Standard.

These Harmonized Standards are developed by ETSI under mandate from the EC. Harmonized Standards sometimes include receiver parameter limits. The ETSI Guide to the production of Harmonized standards for application under the R&TTE Directive (EG 201 399) did enable the inclusion of reference receiver performance parameters in Harmonized standards under certain circumstances. In addition, some standardization groups in ETSI have made specific decisions for inclusion of certain receiver parameters in some cases.

The definition of harmful interference in Article 2.2 a) the Authorisations Directive (which mainly conforms to the definition in Art. 1.169 ITU RR) is relevant to all apparatus and could therefore be understood to include the protection also of “deficient” receivers. A more reasonable legal interpretation would however be that receivers are protected only if they fulfil reasonable technical requirements. This reasoning should have impact also on the understanding of what are “essential requirements” according to the R&TTE including the application of Article 3.1(b).

Receiver equipment should be allowed to operate without unacceptable degradation of its intended use and it should also have an adequate level of immunity to other radio services as required by Article 3.1(b) of the R&TTE Directive. However, in this context a distinction should be made between the receiver parameters that are specified as reasonable technical requirements for the assessment of harmful interference, and receiver parameters that may be considered as essential requirements if they are incorporated in Harmonised Standards under the R&TTE or EMC Directives. Only in the latter case does the fulfilment of receiver requirements become prerequisites for placing a product on the EU Market.

More generally, higher receiver performances will not only improve the performances of a radio application. In a shared spectrum environment, it will contribute to the avoidance of harmful interference. It can therefore be argued that the

[5] Example: ERC Decision of 1 November 1996 on the adoption of approval regulations for radio equipment to be used in the land mobile service intended for the transmission of data (and speech) and having an antenna connector, based on the European Telecommunications Standard (ETS) 300 113 (ERC/DEC/(96)07).

specification of a receiver parameter as an essential requirement is consistent with the obligation stipulated in Art. 3.2 R&TTE ("radio equipment shall be so constructed that it effectively uses the spectrum […] so as to avoid harmful interference").

In the light of R&TTE it could however be questioned whether receiver parameters should be included in the normative parts of a standard. With regards to Article 3.2 R&TTE, essential requirements are based on the protection from harmful interference. Quality requirements, such as good interworking with other apparatus, are set by the EU Commission in separate decisions.

However, the proportionality of standardization measures has to be taken into account. In certain cases, adopting receiver requirements as prerequisites for placing a product on the EU Market may be seen as non-proportional, as it may be argued that manufacturers should be allowed to produce low-cost "deficient" receivers if the users of such receivers are clearly informed that such equipment may be subject to interference that has to be accepted. Consequently, any proposal to include receiver parameters in Harmonised Standards under the R&TTE or EMC Directives must be assessed in the light of the principle of proportionality, which is a key principle of EU law.

If receiver parameter limits are included in standards, then updating the limit values in those standards may have an impact on equipment design specifications. This is however taken care of by specifying appropriate transition periods when the standards are revised in accordance with normal practice.

ETSI

In December 2000, ETSI ERM/TG18 issued a liaison statement to TCAM #7, with the intent to clarify the role of receiver parameters in ETSI standards and how these could assist the spectrum planning process. In justified cases, receiver parameters (which represent essential requirements) are to be included in harmonized standards. Such examples include receiver requirements derived from essential requirements under R&TTE Directive article 3.3e (safety) or cases where the receiver controls the power of the transmitter.

Another example issued from TCAM 7 is the case where the transmitter performance depends of a listen before talk technique in the receiver.

Where the receiver parameters have not been identified as essential requirements under the R&TTE Directive, it is recognized that receiver parameters are, in any case, necessary as frequency planning assumptions as part of a spectrum management regime. It is therefore suggested that an alternative route could be implemented to manage receiver parameters when they are not considered as essential requirements under the R&TTE Directive.

According to ETSI, a critical issue in the application of such a route is how to inform users, particularly an unskilled user, on whether the equipment which he has bought is afforded a certain protection right or not. It seems practical and legally correct to envisage that such information could be included in the end user manual. It is therefore envisaged that a minimum set of information, in easy-to-understand language has to be offered to the user. The manufacturer should adopt a set of formatted relevant information that can be drafted and agreed as appropriate.

ETSI suggested that receiver parameters specified in some ETSI Standards, possibly supported by a CEPT official document, e.g. an ERC Decision, can be used as a common reference by the European countries in implementing their National Spectrum Regulations.

ETSI recently took up the matter of receiver parameters again and in March 2007 decided to establish a project team, ETSI ERM TGRx. The team concluded that for some applications, the EMC standard and the radio standard did leave a gap in the frequency domain where no requirements were specified. Work will be done on this and output is expected late 2008. The group also indicated that user information on some products does not indicate any quality or interference related aspects. Hence a user is not made aware of potential risks.

Outside Europe

In the USA, the FCC had launched a Notice of inquiry in the matter of Interference Immunity Performance Specifications for Radio Receivers (ET Docket No. 03-65, March 24, 2003). Comments on this issue were invited, but did not urge the FCC to issue general rules. The FCC terminated the Notice of inquiry in May 2007, since the Notice and record in this proceeding had become outdated. Further, to the extent receiver interference immunity performance specifications are desirable they may be addressed in proceedings that are frequency band or service specific.

4 TECHNICAL IMPACT ANALYSIS

4.1 Receiver parameters in regulations and standards

In the current regulatory framework, radio interfaces as declared by national authorities under article 2 and 4.1 of the RTTE Directive combined with harmonized standards describe the technical requirements for radio equipment and the use of it throughout the frequency spectrum. This is in place for most frequency bands and the use in terms of transmitters is well described and can be taken into account when compatibility studies are carried out. This is however not true for receiver characteristics, since those are not always part of a harmonised standard but rather left to the market. It is ETSI TBs' choice whether to set receiver parameters in Harmonized Standards or not. But in all communication links, receiver technology is crucial in frequency planning and compatibility analysis. Hence these may have to be derived from other sources, usually product standards, not part of regulations. If no documented information is available, then values can only be derived from field surveys.

Over the years, receiver specifications in standards have hardly been updated. Moreover, with the coming into force of the R&TTE directive they were mostly removed on the advice of the European Commission, except for specific cases. There is little information on actual receiver performance since manufacturers do not generally disclose that and since it is not part of essential requirements there is no point in performing control measurements in connection with market surveillance.

In the context of the studies for a more flexible spectrum usage it has been noted that the receiver parameters play a fundamental role, as the assumptions taken in order to define the minimum technical characteristics such as power restrictions are a function of the receiver parameters (e.g. sensitivity, protection ratio, blocking, etc…)

Therefore consideration of receiver parameters has even more importance when defining the use of flexible bands (defined in a broad sense) than in frequency bands used in a more traditional way.

4.2 Coexistence considerations

It has been demonstrated that some receiver parameter values are crucial in co existence considerations. A WG SE study on CDMA PAMR 900 MHz vs. GSM-R (ECC Report 038) provides an example of the blocking parameter of receivers being a major constraint. The FDD vs. TDD studies in ITU-R (Report M.2030) is another example demonstrating that in many situations the receiver parameters (e.g. ACS) are the constraining factor in achieving satisfactory, efficient coexistence.

Sharing principles based on LBT (Listen Before Talk), DAA (Detect And Avoid) or DFS and similar techniques require a receiver response that controls the associated transmitter. In such case, essential requirements are extended to the receiver that should comply with minimum requirements. Thus for those receivers, the relevant harmonized standard should contain receiver parameter specifications.

4.3 WG SE compatibility studies

In carrying out compatibility studies, WG SE[6] had identified two problem areas:

1. Real receivers "under-performing" against the standard requirements

This could lead to interference problems if new systems would be introduced that were supposed to be compatible with receivers that comply with the standard. Recent interference cases caused by 5 GHz RLANs to meteorological radar have highlighted serious selectivity/spurious response problems in radar receivers.

An example of Social Alarms in 169.4-169.8 MHz, where an SE study (ECC Report 55) found that these devices had to have some 10-20 dB improvement to the initially assumed receiver selectivity/blocking parameters in order to ensure co-existence with other services[7]. This issue was addressed by the current harmonized standard EN 300 220 making it obligatory for Social Alarm receivers to refer to compliance with Receiver Category I (formerly called Receiver Class 1) not to be confused with R&TTE class 1) requirements (including selectivity, blocking, adjacent channel selectivity and adjacent band selectivity), which is the most stringent category. It is obvious that this had been an economic issue also, since producing receivers which comply with more strict requirements has financial implications.

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[6] Document SE(07)127-Annex 25.

[7] Other services are Meter reading systems, Tracing and asset tracking systems, Social alarms, Aids for hearing-impaired persons, Applications for temporary use or PMR and Paging systems.

A recent study by the WiMAX Forum[8] revealed a potential problem caused by emissions from WiMAX technology into satellite earth station receivers both in-band and out-of-band. Even when the two services operate in separate, dedicated sub-bands (i.e. band segmentation), co-existence may prove difficult if the deployed earth stations use wideband front-end RF amplifiers that do not filter out the emissions from nearby terrestrial WiMAX base stations or terminals.

RTTT Dedicated Short Range Communication (RTTT DSRC) systems receivers have been found too susceptible to the impact from other system in adjacent spectrum (e.g. BFWA, ITS), see e.g. recent Austrian comments to BFWA, ITS reports (ECC Report 068 and 101). This is caused by the enormous receiver bandwidth as compared with the transmitter signal bandwidth.

2. Real receivers “over-performing” against certain elements of the standard requirements

In some cases certain elements of performance are enhanced at the expense of other elements which may therefore become deficient. Particularly, receiver sensitivity could be enhanced at the expense of immunity to interference.

This is in particular critical for systems operating in licensed bands (such as public mobile communications systems as GSM, UMTS, WiMAX, etc). In these systems the receiver sensitivity is often much better in actual receivers than the minimum value specified in the standards. Hence co existence is more problematic than it would be in the case that this parameter value had been closer to the standard.

On the other hand, over performance against blocking requirements would allow for better co existence in many cases.

4.4 Parameter limits

The results of co existence studies performed by WG SE and others clearly indicate the need for realistic receiver parameter values as an input; otherwise their calculations would not be meaningful and no spectrum management decisions could be based on these. In this context, realistic values relate to real life. In some cases even taking values from standards could produce wrong results as equipment in a competitive market often performs better then the standard. It seems that many standards have not been updated and adjusted to the state of the art for a long time so that the products on the market differ considerably from what the standard may indicate. On the other hand, some products for which no receiver standards are applicable perform so badly that proper operation of the device is impossible in cases where transmitters operate in adjacent frequency bands. Since those products can be lawfully placed on the market and used, the possible negative effects of low receiver quality will confront the user unexpectedly.

Especially when a new service is planned in adjacent bands this will be a problem for the authorities who could face complaints from users of existing low quality receiver equipment when a new transmitter becomes operational. Introducing certain receiver parameter limits in the relevant Harmonized Standards could help to solve the problem.

4.5 Real world problems

In order to identify practical problems due to poor receiver performance, a questionnaire was sent to market surveillance authorities within CEPT. 10 administrations responded to this questionnaire. A limited number of interference cases were described (summarized in annex 3). However it was also stated by respondents that poorly performing receivers had not generated many complaints.

4.6 Real world solution

One case of a spectrum management improvement brought about by a change of receiver standards was in the area of compatibility between FM broadcasting transmitters and aeronautical navigation receivers, which use adjacent bands either side of 108 MHz. One of the principal interference mechanisms is the generation of intermodulation products within the receiver. The introduction of improved immunity receiver performance in calculations from the mid nineties onwards greatly improved the opportunities to introduce new FM broadcast services. As with many examples, there is no study which quantifies the extent of this benefit in technical, let alone economic terms, but the UK’s regulator responsible for planning considered that its large expansion of FM services in the 1990’s and early 2000’s would have been constrained rather below the level actually achieved.

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[8] WiMAX Forum 2007: Compatibility of services using WiMAX technology with satellite services in the 2.3 - 2.7 GHz and 3.3 - 3.8 GHz bands.

5 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Historically, the extent of technical benefit or disadvantage has not been quantified.

2. Receiver parameters are a crucial element of co existence calculations and thus in spectrum management.

3. Carefully chosen values for receiver parameters should be available for compatibility studies.

4. Field surveys are necessary in many cases to determine the actual performance of receivers.

5. Significant enhancement of receiver performance in one respect (for example sensitivity) can come at the expense of underperformance in another. Under those circumstances co-existence assumptions can be prejudiced.

6. If it would give a net overall benefit, receiver parameter technical requirements could be included in the relevant Harmonized Standards under the R&TTE Directive[9].

7. If receiver parameters are included in Harmonized Standards, then including new requirements or updating existing limit values in those standards could have an impact on equipment design specifications, such changes would require economic impact assessment. Normally transitional periods are agreed when standards are revised to allow industry adapt to the new requirements.

8. Some interference, especially in short range devices, affects the general public in a manner that they may not be aware of the real cause. An example is car locks in the 433 MHz band, where receiver performance is the cause of the problem. So the weakness of the feedback mechanism to the market can make market forces an unreliable mechanism for maximising consumer welfare. That is to say, there are several points of market failure in markets using radiocommunications. The role and further potential of standards and/or regulation to compensate for these market failures is significant.

9. The role of receiver parameters in standards and their related considerations in spectrum engineering should receive greater prominence in order to promote more efficient use of the spectrum, including maximising economic and social welfare.

10. Appropriate migration paths should be followed where improvements in technology allow for opportunities to improve spectrum management.

Recommendations

1. In general, there is always a case in introducing new services, (and in managing existing ones) to identify what are the appropriate receiver parameter limit values, and to consider the best mechanism.

2. Identify the set of receiver parameters that could be introduced in standards on a case by case basis in Harmonized Standards and/or in regulations

3. Where absolutely necessary for spectrum management purposes, introduce a limited number of receiver parameter minimum values in relevant Harmonized Standards and/or regulations[10].
   Where necessary for spectrum management purposes, the ETSI TB should introduce specific receiver parameter values in relevant Harmonized Standards.

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[9] At present, radio receivers are subject to conformity assessment procedures, and in some cases receiver parameter values are introduced in the conditions for compliance of equipment to fulfil the essential requirements of the R&TTE Directive.

[10] The content of harmonised standards is within the responsibility of the European Commission and ETSI.

4. Receiver parameters included in Harmonized Standards, or other ETSI or ECC (e.g. ECC/REC/(02)01) deliverables should periodically be reviewed and where appropriate updated to bring them in line with the state of the art technology. Legacy and transition issues would need to be appropriately addressed.

5. An impact assessment should be made for each revision of a Harmonized Standard with regard to receiver parameters[11]. The appropriate depth of that assessment may vary from case to case and the form of that assessment should be further studied.

[11] ETSI comment: the impact assessment should always be made when revising an ETSI standard.

ANNEX 1

Receiver Performance Parameters[12]

A radio receiver's immunity to interference is dependent on a number of factors in its technical design and, in addition, the characteristics of the signals it receives. These factors may be closely related and in many cases interdependent, and a receiver's performance in one factor may often affect its performance in others. The factors determining receiver immunity performance generally include **selectivity, sensitivity, blocking, desensitization, spurious response, required protection ratio, co-channel rejection, adjacent band rejection, intermodulation rejection, cross modulation rejection, dynamic range, automatic RF gain control, shielding, modulation method, and signal processing**.

Receiver selectivity is the ability to isolate and acquire the desired signal from all of the undesired signals that may be present on other channels. Selectivity is a central factor in the control of adjacent channel interference[13]. Sensitivity is the measure of a receiver's ability to receive signals of low strength. More sensitivity means a receiver can pick up lower level signals.[14]

The **receiver blocking** characteristics is a measure of the receiver ability to receive a wanted signal at its assigned channel frequency in the presence of an unwanted interferer on frequencies other than those of the adjacent channels. It is caused by gain compression due to overloading from a very strong signal in the receiver front end.

Receiver desensitization occurs when a strong off-channel signal overloads a receiver front end and thus reduces the sensitivity to weaker on-channel signals. This effect is caused by reciprocal mixing, due to phase noise

External spurious responses are signals propagated at frequencies outside of the tuned principal response frequency to which the receiver responds with measurable output power. They reveal frequencies where the receiver is most susceptible to undesired signals.

Internal spurious responses are caused by harmonics and/or mixing products of internal oscillators, which can lead to a sensitivity reduction on certain frequencies. This can lead problems with one design, and not with another – or never, depending on frequency allocations, never lead to a problem at all!

The **co-channel rejection** is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal, both signals being at the nominal frequency of the receiver. It is worth stating if the interfering signal is of the same or a different modulation type – this can have a major effect. Where digital signals using the same modulation type are concerned, the time correlation between wanted and unwanted signals also comes into play, so this definition is a little simplistic.

The **intermodulation response rejection** is a measure of the capability of the receiver to receive a wanted modulated signal, without exceeding a given degradation due to the presence of two or more unwanted signals with a specific frequency relationship to the wanted signal frequency.

Dynamic range is the range of the highest and lowest received signal strength levels over which the receiver can satisfactorily operate. The upper side of a receiver's dynamic range determines how strong a received signal can be before failure due to overloading occurs. Automatic RF gain control allows a receiver to adjust the level of a received signal as it appears at the unit's signal processing and demodulation sections. It can also be used to improve a unit's dynamic range and provide protection against overload. Shielding can consist of metal boxes, foil or other materials that isolate sections of a receiver from undesired RF energy.

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[12] From: ECC Recommendation ECC/REC(02)01, Specification of reference receiver performance parameters and Notice of Inquiry in the matter of Interference Immunity Performance Specifications for Radio Receivers (ET Docket No. 03-65, March 24, 2003).

[13] There are several ways to describe the selectivity of a radio receiver. One way is to simply give the bandwidth of the receiver over which its response level is within 3 dB of its response level at the centre frequency of the desired signal. This measure is often termed the "bandwidth over the -3db points." This bandwidth, however, is not necessarily a good means of determining how well the receiver will reject unwanted frequencies. Consequently, it is common to give the receiver bandwidth at two levels of attenuation; for example, -3dB and -60 dB. The ratio of these two bandwidths is called the shape factor. Ideally, the two bandwidths would be equal and the shape factor would be one. However, this value is very difficult to achieve in a practical circuit.

[14] Greater sensitivity can also result in reception of unwanted signals at low levels that then must be eliminated or attenuated by the selectivity characteristics of the receiver..

Spurious Free Dynamic Range is 2/3 of the difference in dB between the noise floor and the Third Order Intermodulation Intercept Point (TOIP)

Phase Noise Limited Dynamic Range is the measure of the ‘blocking ‘or 'desensitization’

Dynamic range, applicable in receivers using logarithmic amplifiers (such as RSSI, Received Signal Strength Indication) or radar, is the range over which the logarithmic amplifier output meets some requirement on linearity.

Signal processing provides increased ability to isolate a desired signal from other RF energy, including another (undesired) transmitted signal. The degree to which interference immunity can be achieved through signal processing depends on the modulation method used for the transmitted signal. For example, the CDMA digital modulation system allows multiple signals to be transmitted and received simultaneously on the same frequency in the same area without intra-system interference.[15] Also advanced combined antenna technique and signal processing like MIMO, beamforming or Rx Diversity technique have improved the spatial selectivity and the discrimination of particular users hence reducing the interference of undesired transmitted signal. The analogue FM modulation system provides for a “capture effect” from processing gain that allows a receiver to demodulate only the strongest signal present. Finally, in digital systems, trade-offs can be made between signal strength and data rates. In order to receive signals with higher data rates, it is generally necessary to have higher levels of signal-to-interference ratio (S/I ratio).[16] Thus, in the presence of interfering signals the data rate could be adjusted to provide satisfactory reception. The interference immunity provided by signal processing and modulation systems is due to radio system design and signal architecture, rather than specific receiver attributes such as filtering. However, because proper use of these system factors can provide improvements in interference immunity, we are including them in the subjects to be investigated in this proceeding for inclusion in our spectrum policies.

Software Defined Radio

The advent of new technologies like Software Defined Radio using concepts like direct-digital-conversion will also lead to technical implementations where the transmitter performance is directly affected by the receiver performance including the receiver’s exact input levels. This subject may need studies in WGSE in the future.

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[15] In order to make more efficient use of the spectrum, radio system designers have introduced a number of additional new modulation formats. These include continuous phase modulation (CPM), multiple phase shift keying (MPSK), and quadrature amplitude modulation (QAM).

[16] The trade-off between data rate and signal strength is in accordance with Shannon’s Law, a mathematical statement defining the theoretical maximum information rate that can be transmitted over a specific amount of bandwidth in the presence of noise. For digital transmissions, this translates into the maximum number of bits per second that can be transmitted, error free, in a specific amount of bandwidth at any specific ratio of received signal to noise. Error-correction codes can improve the communications performance relative to un-coded digital transmissions, but no practical error correction coding system exists that can achieve the theoretical performance limit given by Shannon's law. However, a new class of forward error correction (FEC) codes known as “turbo codes” has been introduced that can simultaneously improve data throughput and reduce the error rate. It should be noted that turbo codes do have an irreducible error rate, and so require ‘backing up’ with another error correcting method, such as Reed-Solomon.

ANNEX 2

Categories

Given the large number of radiocommunication applications with different equipment requirements, it appears appropriate to consider grouping the service related receivers.

Public safety systems
Public safety communications systems are used by organizations such as police, fire and emergency medical services whose mission often involves safety of life. These organizations need and, indeed, demand that their communications systems provide a very high degree of reliability. Thus, the operating requirements of public safety communications systems would seem to warrant or even necessitate the use of receiver immunity performance guidelines/standards that are tighter than those for general communication services.

Satellite services
Satellite receivers must be very sensitive to low level received signals and therefore can be adversely affected by communications systems in adjacent bands. They can also experience interference from low level ambient noise sources that are below the minimum sensitivity level of receivers used in other types of radio services. Satellite communications systems are currently used for radionavigation, mobile communications, broadcast video and audio services, and fixed services. Each of these types of service has its own operating considerations and some are much more robust with respect to interfering signals than others. For example, fixed satellite systems that operate with geo-stationary orbit (GSO) satellites may use high gain antennas that provide high levels of signal, thus mitigating the relatively low level of the received signal. Fixed receivers used with direct broadcast satellite services also use dish antennas that provide considerable gain. However, mobile satellite receivers and mobile satellite radionavigation receivers use antennas that provide relatively low gain and thus must have very high levels of sensitivity to provide service. In the fixed satellite services, the use of high gain directional antennas provides a form of increased system selectivity because potentially interfering sources not located in the main beam of the antenna are attenuated.

Mobile service
Mobile radio services include a broad range of systems operating on the land, the seas, and in the air. While these systems vary in their sophistication and operating ranges, all mobile receivers typically experience varying signal levels throughout their service area.

Terrestrial Fixed Service
Terrestrial Fixed Service includes point-to-point and point-to-multipoint facilities. Point-to-point operations usually use highly directional transmit and receive antennas in order to minimize the potential for receiving interference and causing interference to others. Such operations are typically used for private or common carrier communications links, often as part of a bi-directional system with a transmitter and receiver at each end of the link. Point-to-multipoint operations sometimes use sectorised antennas that transmit in a broadcast-like mode to receivers used at fixed locations. The fixed receivers use highly directional antennas that are pointed at the transmitting antenna. Point-to-multipoint operations are generally used for one-way distribution of communications, including, for example, data and video programming, but two-way voice and data operation are also being developed and used. Fixed Service are generally exposed to a constant fixed interference environment characterized by the location of specific operations

Broadcast Service
The broadcast AM, FM, and television services operate much like fixed point-to-multipoint services, in that many consumer radios and television sets receive one-way communications from one or more fixed transmitter sites. However, the technical quality of service provided by different models of radio and television receivers varies to some extent, depending on the design of the device. These variations generally reflect manufacturers' perceptions of user demand balanced against cost/pricing factors.

Short range devices
The SRD category of devices is usually addressed at a mass market so widespread use may be expected. If then a radio service is introduced that operates on nearby frequencies, problems can be expected.

ANNEX 3

Non exhaustive list of receiver performance problems encountered in some CEPT countries

- Problems with car alarms in 433 MHz:
  - caused by wireless cash system, wireless headphones or other SRD operating in the same band;
  - caused by radio links or other legal transmitters operating near this band.

- TV analogue reception interferences are caused by CDMA 450 MHz if active antennas are used for reception. The channel selectivity is not used in antenna amplifiers. The same problem might appear with DVB reception. There is no interference cases with DVB reception registered yet.

- Operation of a CDMA transmitter at the frequency 465 MHz (e.r.p. 200W) entirely erased functionality of the safety appliance using a sensor at the frequency 434 MHz in a building 200m far-away.

- The most common interference complaint that is attributable to poor receiver performance is RF overload; desensitization has also been a contributing factor to some problems experienced by users of the radio spectrum, although this has been more difficult to conclusively prove in field conditions.

  - The most common equipment that has been found to suffer from poor receiver performance are SRD's in the UHF spectrum, television reception systems and some microwave applications.

  - SRD's - most commonly 433MHz licence exempt equipment for remote central locking on cars is affected. It has been found that in most cases the source of the interference/desensitization of the receiver has not been a signal on the same frequency, but rather a signal on an adjacent channel. Desensitization of such equipment has also been noted in environments of high RF noise.

  - Television Reception Systems - within the last year, all bar one complaint of interference to television reception were as a result of poor performance of some aspect of the receive system, this includes masthead amplifiers, satellite decoder sets, and in some cases the televisions themselves. It should be noted that in all cases where receive system deficiencies were cited as the cause of the interference, the 'interfering' signal was removed in frequency from the UHF television band, i.e. TETRA, PMR, GSM, UMTS, and wireless broadband user equipment.

  - Microwave applications - Analogue systems operating in the 1 - 4 GHz spectrum have been found to suffer from RF overload/desensitization as a result signals operating in adjacent bands within license conditions. Adjacent channel interference is also becoming more prominent in the higher frequency microwave point-to-point links bands i.e. 13GHz and 18GHz primarily, possibly as a result of the amount of users seeking to operate high capacity wireless links as an integral part of their network backbone.

- MMDS signal receiver has been situated near by WiFi equipment (2,4 GHz), which has had influence on MMDS receiver
- another cases:
- UMTS equipment has had influence on MMDS receiver
- aeronautic radar has had influence on MMDS receiver
- OFDM equipment (450 MHz)has had influence on TV receiver
- radioamateur equipment has had influence on TV and radio receiver

Problems with:

- low cost FM receivers
- alarmclockradios