CHAPTER

SPECTRUM AND RF CHARACTERISTICS

22

Spectrum flexibility is, as mentioned in Chapter 3, a key feature of LTE radio access and is set out in the LTE design targets [6]. It consists of several components, including deployment in different-sized spectrum allocations and deployment in diverse frequency ranges, both in paired and unpaired frequency bands. There are a number of frequency bands identified for mobile use and specifically for IMT today. These are presented in detail in Chapter 2. The use of OFDM in LTE gives flexibility both in terms of the size of the spectrum allocation needed and in the instantaneous transmission bandwidth used. The OFDM physical layer also enables frequency-domain scheduling, as briefly discussed in Chapter 3. Beyond the physical-layer implications described in Chapters 6 and 7, these properties also impact the RF implementation in terms of filters, amplifiers, and all other RF components that are used to transmit and receive the signal. This means that the RF requirements for the receiver and transmitter will have to be expressed with flexibility in mind.

22.1 FLEXIBLE SPECTRUM USE

Most of the frequency bands identified above for deployment of LTE are existing IMT-2000 bands and some bands also have legacy systems deployed, including WCDMA/HSPA and GSM. Bands are also in some regions defined in a “technology neutral” manner, which means that coexistence between different technologies is a necessity.

The fundamental LTE requirement to operate in different frequency bands [40] does not, in itself, impose any specific requirements on the radio-interface design. There are, however, implications for the RF requirements and how those are defined, in order to support the following:

- *Coexistence between operators in the same geographic area in the band*. Coexistence may be required with other operators that deploy LTE or other IMT-2000 technologies, such as UMTS/HSPA or GSM/EDGE. There may also be non-IMT-2000 technologies deployed. Such coexistence requirements are to a large extent developed within 3GPP, but there may also be regional requirements defined by regulatory bodies in some frequency bands.
- *Colocation of base station equipment between operators*. There are in many cases limitations to where base-station (BS) equipment can be deployed. Often, sites must be

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shared between operators or an operator will deploy multiple technologies in one site. This puts additional requirements on both BS receivers and transmitters.

- *Coexistence with services in adjacent frequency bands and across country borders*. The use of the RF spectrum is regulated through complex international agreements, involving many interests. There will therefore be requirements for coordination between operators in different countries and for coexistence with services in adjacent frequency bands. Most of these are defined in different regulatory bodies. Sometimes the regulators request that 3GPP includes such coexistence limits in the 3GPP specifications.
- *Coexistence between operators of TDD systems* in the same band is provided by inter-operator synchronization, in order to avoid interference between downlink and uplink transmissions of different operators. This means that all operators need to have the same downlink/uplink configurations and frame synchronization, not in itself an RF requirement, but it is implicitly assumed in the 3GPP specifications. RF requirements for unsynchronized systems become much stricter.
- *Release-independent frequency-band principles*. Frequency bands are defined regionally and new bands are added continuously. This means that every new release of 3GPP specifications will have new bands added. Through the "release independence" principle, it is possible to design terminals based on an early release of 3GPP specifications that support a frequency band added in a later release.
- *Aggregation of spectrum allocations*. Operators of LTE systems have quite diverse spectrum allocations, which in many cases do not consist of a block that easily fits exactly one LTE carrier. The allocation may even be noncontiguous, consisting of multiple blocks spread out in a band. Many operators also have allocations in multiple bands to use for LTE deployment. For these scenarios, the LTE specifications support *carrier aggregation* (CA), where multiple carriers in contiguous or noncontiguous blocks within a band, or in multiple bands, can be combined to create larger transmission bandwidths.

22.2 FLEXIBLE CHANNEL BANDWIDTH OPERATION

The frequency allocations for LTE (see Chapter 2) are up to 2×75 MHz, but the spectrum available for a single operator may be from 2×20 MHz down to 2×5 MHz for FDD and down to 1×5 MHz for TDD. Furthermore, the migration to LTE in frequency bands currently used for other radio-access technologies (RATs) must often take place gradually to ensure that a sufficient amount of spectrum remains to support the existing users. Thus, the amount of spectrum that can initially be migrated to LTE can be relatively small, but may then gradually increase, as shown in Figure 22.1. The variation of possible spectrum scenarios implies a requirement for spectrum flexibility for LTE in terms of the transmission bandwidths supported.

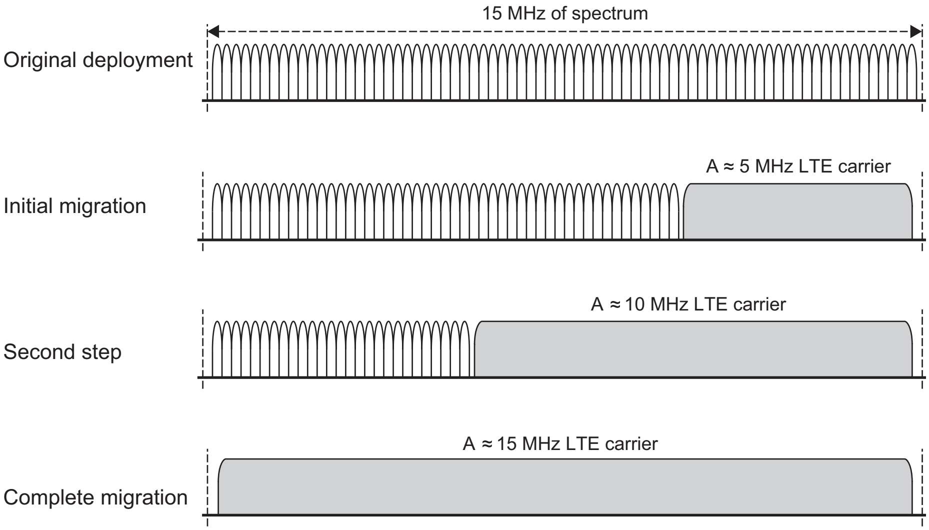

FIGURE 22.1

Example of how LTE can be migrated step by step into a spectrum allocation with an original GSM deployment.

The spectrum flexibility requirement points out the need for LTE to be scalable in the frequency domain. This flexibility requirement is stated in [6] as a list of LTE spectrum allocations from 1.25 to 20 MHz. Note that the final channel bandwidths selected differ slightly from this initial assumption.

As shown in Chapter 5, the frequency-domain structure of LTE is based on resource blocks consisting of 12 subcarriers with a total bandwidth of 12×15 kHz $=$ 180 kHz. The basic radio-access specification including the physical-layer and protocol specifications enables *transmission bandwidth configurations* from 6 up to 110 resource blocks on one LTE RF carrier. This allows for channel bandwidths ranging from 1.4 MHz up to beyond 20 MHz in steps of 180 kHz and is fundamental to providing the required spectrum flexibility.

In order to limit implementation complexity, only a limited set of bandwidths are defined in the RF specifications. Based on the frequency bands available for LTE deployment today and in the future, as described in the preceding paragraphs, and considering the known migration and deployment scenarios in those bands, a limited set of six channel bandwidths is specified. The RF requirements for the BS and terminal are defined only for those six channel bandwidths. The channel bandwidths range from 1.4 to 20 MHz, as shown in Table 22.1. The lower bandwidths, 1.4 and 3 MHz, are chosen specifically to ease migration to LTE in spectrum where CDMA2000 is operated, and also to facilitate migration of GSM and TD-SCDMA to LTE. The specified bandwidths target relevant scenarios in different frequency bands. For this reason, the set of bandwidths available for a specific band is not necessarily the same as in other bands. At a later stage, if new frequency bands are made available that have

Table 22.1 Channel Bandwidths Specified in LTE

Channel Bandwidth ($BW_{channel}$)	Number of Resource Blocks (N_{RB})
1.4 MHz	6
3 MHz	15
5 MHz	25
10 MHz	50
15 MHz	75
20 MHz	100

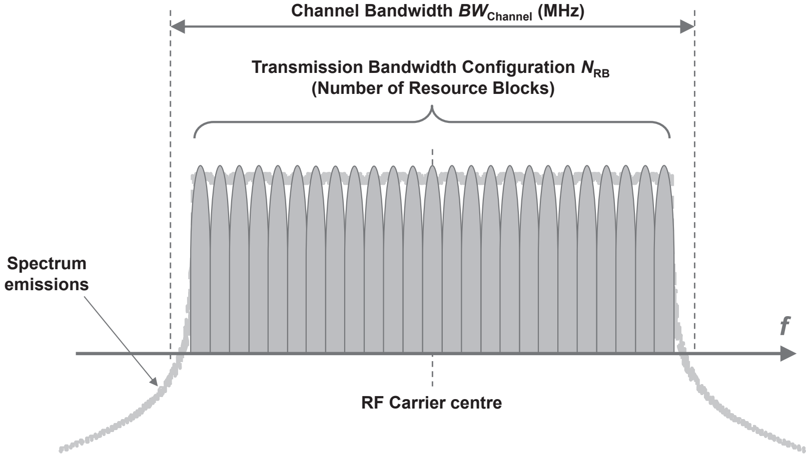

FIGURE 22.2

The channel bandwidth for one RF carrier and the corresponding transmission bandwidth configuration.

other spectrum scenarios requiring additional channel bandwidths, the corresponding RF parameters and requirements could be added in the RF specifications, without actually having to update the physical-layer specifications. The process of adding new channel bandwidths would in this way be similar to adding new frequency bands.

Figure 22.2 illustrates in principle the relationship between the channel bandwidth and the number of resource blocks N_{RB} for one RF carrier. Note that for all channel bandwidths except 1.4 MHz, the resource blocks in the transmission bandwidth configuration fill up 90% of the channel bandwidth. The spectrum emissions shown in Figure 22.2 are for a pure OFDM signal, while the actual transmitted emissions will also depend on the transmitter RF chain and other components. The emissions outside the channel bandwidth are called *unwanted emissions* and the requirements for those are discussed later in this chapter.

22.3 CARRIER AGGREGATION FOR LTE

The possibility from 3GPP Release 10 to aggregate two or more component carriers in order to support wider transmission bandwidths has several implications for the RF characteristics. The impacts for the BS and terminal RF characteristics are also quite different. Release 10 had some restrictions on carrier aggregation in the RF specification, compared to what has been specified for physical layer and signaling, while in later releases there is support for carrier aggregation within and between a much larger number of bands and also between more than two bands.

There is, from an RF point of view, a substantial difference between the two types of carrier aggregation defined for LTE (see also Chapter 12 for more details):

- *Intra-band contiguous carrier aggregation* implies that two or more carriers within the same operating band are aggregated (see also the first two examples in Figure 12.1). Since aggregated carriers from an RF perspective have similar RF properties as a corresponding wider carrier being transmitted and received, there are many implications for the RF requirements. This is especially true for the terminal. For the BS, it corresponds in practice to a multi-carrier configuration (nonaggregated) already supported in earlier releases, which also means that the impact is less than that for the terminal.
- *Intra-band noncontiguous carrier aggregation* implies that there is a gap between the aggregated carriers, making the set of carriers noncontiguous. For the UE, this is declared to be the case for any set of aggregated carriers where the spacing between carriers is larger than the nominal spacing. For the BS, carriers are considered to be noncontiguous if there is a need to define special coexistence requirements in the "gap" between aggregated subblocks.
- *Inter-band carrier aggregation* implies that carriers in different operating bands are aggregated (see also the last example in Figure 12.1). Many RF properties within a band can, to a large extent, remain the same as for a single carrier case. There is, however, impact for the terminal, due to the possibility for intermodulation and cross-modulation within the terminal when multiple transmitter and/or receiver chains are operated simultaneously. For the BS it has very little impact, since in practice it corresponds to a BS supporting multiple bands. There is however additional BS impact, if the inter-band carrier aggregation is deployed with a multi-band Base Station, see Section 22.12.

Intra-band contiguous carrier aggregation is in Release 13 for up to three component carriers aggregated within a band in 12 different bands. There is also support for intra-band noncontiguous carrier aggregation in nine bands. Inter-band carrier aggregation is specified for up to four bands, including both paired bands for FDD and unpaired bands for TDD, and also between paired and unpaired bands. Because of the varying impact on the RF properties for the UE, each band combination has to be specified separately.

Close to 150 different band combinations with two, three, or four bands are defined in Release 13 of the 3GPP specifications. The band or set of bands over which carriers are

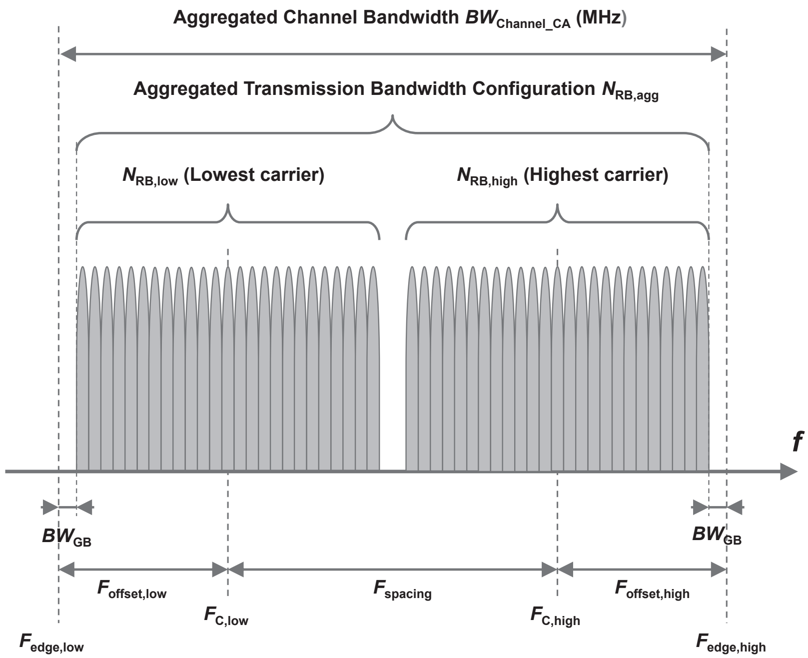

FIGURE 22.3

Definitions for intra-band carrier aggregation RF parameters, example with two aggregated carriers.

aggregated is defined as a UE capability (the term UE, User Equipment, is used in 3GPP specifications instead of terminal). For all band combinations, downlink operation is defined for the terminal. There are only a few bands with uplink operation defined for the terminal. The reason is that transmission in multiple bands from a terminal has large implications in terms of potential intermodulation products created, which creates restrictions in terms of how the UE can operate. This is solved through an allowed reduction of the terminal output power called MPR (*maximum power reduction*), in order to mitigate the intermodulation products. The allowed MPR depends on the number of resource blocks that are transmitted in each of the aggregated component carriers, the modulation format, and the terminals capability in terms of maximum number of resource blocks it can transmit per band (see also the CA bandwidth classes defined in the following).

For intra-band carrier aggregation, the definitions of $BW_{channel}$ and N_{RB} shown in Figure 22.2 still apply for each component carrier, while new definitions are needed for the aggregated channel bandwidth ($BW_{Channel\_CA}$) and the aggregated transmission bandwidth configuration ($N_{RB,agg}$) shown in Figure 22.3. In connection with this, a new capability is defined for the terminal called *CA bandwidth class*. There are six classes in Release 13, where each class corresponds to a range for $N_{RB,agg}$ and a maximum number of component carriers,

Table 22.2 UE Carrier Aggregation Bandwidth Classes (Release 13)

Channel Aggregation Bandwidth Classes	Aggregated Transmission BW Configuration	Number of Component Carriers
A	≤100	1
B	≤100	2
C	101 to 200	2
D	201 to 300	3
E, F	Under study (301 to 500 and 701 to 800)	Under study

as shown in Table 22.2. The classes corresponding to aggregation of more than two component carriers or consisting of more than 300 RBs are under study for later releases.

The terminal capability *E-UTRA CA configuration* [38] is defined as a combination of the operating band (or bands) where the terminal can operate with carrier aggregation, and a bandwidth class. For example, the terminal capability to operate with inter-band carrier aggregation in bands 1 and 5 in bandwidth class A is called CA_1A_5A. For each E-UTRA CA configuration, one or more *bandwidth combination sets* are defined, setting the channel bandwidths that can be used in each band, and what the maximum aggregated bandwidth is. A terminal can declare capability to support multiple bandwidth combination sets.

A fundamental parameter for intra-band carrier aggregation is the channel spacing. A tighter channel spacing than the nominal spacing for any two single carriers could potentially lead to an increase in spectral efficiency, since there would be a smaller unused "gap" between carriers. On the other hand, there is also a requirement for the possibility to support legacy single-carrier terminals of earlier releases. An additional complication is that the component carriers should be on the same 15 kHz subcarrier raster in order to allow reception of multiple adjacent component carriers using a single FFT instead of an FFT per subcarrier.[1] As discussed in Section 5.6, this property, together with the fact that the frequency numbering scheme is on a 100 kHz raster, results in the spacing between two component carriers having to be a multiple of 300 kHz, which is the least common denominator of 15 and 100 kHz.

For the specification, RF requirements are based on a nominal channel spacing that is derived from the channel bandwidth of the two adjacent carriers $BW_{\text{Channel}(1)}$ and $BW_{\text{Channel}(2)}$ as follows[2]:

$$F_{\text{Spacing,Nominal}} = \left\lfloor \frac{BW_{\text{Channel}(1)} + BW_{\text{Channel}(2)} - 0.1\left|BW_{\text{Channel}(1)} - BW_{\text{Channel}(2)}\right|}{2 \cdot 0.3} \right\rfloor 0.3 \qquad (22.1)$$

[1]In case of independent frequency errors between component carriers, multiple FFTs and frequency-tracking functionality may be needed anyway.

[2]$\lfloor \ldots \rfloor$ denotes the "floor" operator, which rounds the number down.

In order to allow for a tighter packing of component carriers, the value of $F_{Spacing}$ can be adjusted to any multiple of 300 kHz that is smaller than the nominal spacing, as long as the subcarriers do not overlap.

RF requirements for LTE are normally defined relative to the channel bandwidth edges. For intra-band carrier aggregation, this is generalized so that requirements are defined relative to the edges of the aggregated channel bandwidth, identified in Figure 22.3 as $F_{edge,low}$ and $F_{edge,high}$. In this way many RF requirements can be reused, but with new reference points in the frequency domain. The aggregated channel bandwidth for both terminal and BS is defined as:

$$BW_{Channel\_CA} = F_{edge,high} - F_{edge,low} \tag{22.2}$$

The location of the edges is defined relative to the carriers at the edges through a new parameter F_{offset} (see Figure 22.3) using the following relation to the carrier center positions F_C of the lowest and highest carriers:

$$F_{edge,low} = F_{C,low} - F_{offset,low} \tag{22.3}$$

$$F_{edge,high} = F_{C,high} + F_{offset,high} \tag{22.4}$$

The value of F_{offset} for the edge carriers and the corresponding location of the edges are, however, not defined in the same way for terminal and BS.

For the BS, there are legacy scenarios where the BS receives and transmits adjacent independent carriers, supporting legacy terminals of earlier releases using single carriers. This scenario will also have to be supported for a configuration of aggregated carriers. In addition, for backward compatibility reasons, a fundamental parameter such as channel bandwidth and the corresponding reference points (the channel edge) for all RF requirements will have to remain the same. The implication is that the channel edges shown in Figure 22.2 for each component carrier will also remain as reference points when the carriers are aggregated. This results in the following BS definition of F_{offset}, for carrier aggregation, which is "inherited" from the single carrier scenario:

$$F_{offset} = \frac{BW_{channel}}{2} \quad \text{(for base station)} \tag{22.5}$$

Unlike the BS, the terminal is not restricted by legacy operation, but rather from the nonlinear properties of the PA and the resulting unwanted emissions mask. At both edges of the aggregated channel bandwidth, a guard band BW_{GB} will be needed, in order for the emissions to reach a level where the out-of-band (OOB) emissions limits in terms of an emission mask are applied. Whether a single wide carrier or multiple aggregated carriers of the same or different sizes are transmitted, the guard band needed will have to be the same at both edges, since the emission mask roll-off is the same. A problem with the backward-compatible BS definition is that the resulting guard BW_{GB} is proportional to the channel BW and would therefore be *different* if carriers of different channel BW are aggregated.

For this reason, a different definition is used for the terminal, based on a "symmetrical" guard band. For the edge carriers (low and high), F_{offset} is half of the transmission bandwidth configuration, plus a symmetrical guard band BW_{GB}:

$$F_{\text{offset}} = \frac{0.18\ \text{MHz} \cdot N_{\text{RB}}}{2} + BW_{\text{GB}} \quad \text{(for terminal uplink)} \tag{22.6}$$

where 0.18 MHz is the bandwidth of one resource block and BW_{GB} is proportional to the channel BW of the largest component carrier. For the CA bandwidth classes defined where the edge carriers have the same channel bandwidth, F_{offset} will in principle be the same for terminals and BSs and $BW_{\text{Channel\_CA}}$ will be the same.

It may look like an anomaly that the definitions may potentially lead to slightly different aggregated channel BW for the terminal and the BS, but this is in fact not a problem. Terminal and BS requirements are defined separately and do not have to cover the same frequency ranges. The aggregated channel BW for both terminal and BS do, however, have to be within an operator's license block in the operating band.

Once the frequency reference point is set, the actual RF requirements are to a large extent the same as for a single carrier configuration. Which requirements are affected is explained for each requirement in the discussion later in this chapter.

22.4 OPERATION IN NONCONTIGUOUS SPECTRUM

Some spectrum allocations used for LTE deployments consist of fragmented parts of spectrum for different reasons. The spectrum may be recycled 2G spectrum, where the original licensed spectrum was "interleaved" between operators. This was quite common for original GSM deployments, for implementation reasons (the original combiner filters used were not easily tuned when spectrum allocations were expanded). In some regions, operators have also purchased spectrum licenses on auctions and have for different reasons ended up with multiple allocations in the same band that are not adjacent.

For deployment of noncontiguous spectrum allocations there are a few implications:

- If the full spectrum allocation in a band is to be operated with a single BS, the BS has to be capable of operation in noncontiguous spectrum.
- If a larger transmission bandwidth is to be used than what is available in each of the spectrum fragments, both the terminal and the BS have to be capable of *intra-band noncontiguous carrier aggregation* in that band.

Note that the capability for the BS to operate in noncontiguous spectrum is not directly coupled to carrier aggregation as such. From an RF point of view, what will be required by the BSs is to receive and transmit carriers over an RF bandwidth that is split in two (or more) separate subblocks, with a subblock gap in-between as shown in Figure 22.4. The spectrum in the subblock gap can be deployed by any other operator, which means that the RF requirements for the BS in the subblock gap will be based on coexistence for

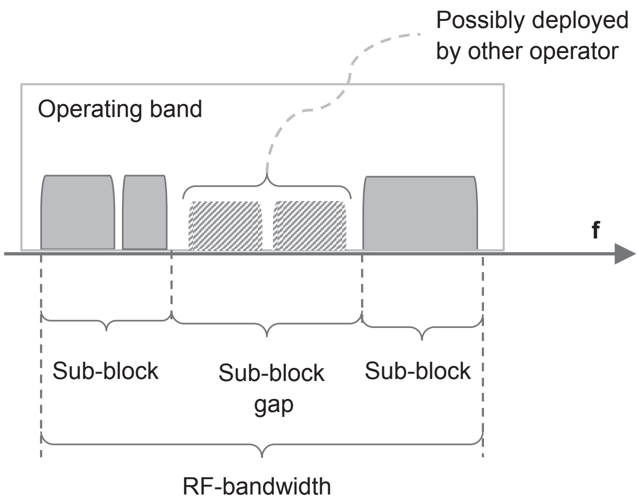

FIGURE 22.4

Example of noncontiguous spectrum operation, illustrating the definitions of *RF bandwidth*, *subclock*, and *subblock gap*.

un-coordinated operation. This has a few implications for some of the BS RF requirements within an operating band.

If the noncontiguous spectrum is operated with carrier aggregation, the RF requirements for the BS will be fundamentally the same as in general for noncontiguous spectrum.

For the terminal, noncontiguous operation is tightly coupled to carrier aggregation, since multi-carrier reception in the downlink or transmission in the uplink within a band does not occur unless carriers are aggregated. This also means that the definition of noncontiguous operation is different for the terminal than for the BS. For the terminal, intra-band noncontiguous carrier aggregation is therefore assumed to occur as soon as the spacing between two carriers is larger than the nominal channel spacing defined in Eq. (22.1).

Compared to the BS, there are also additional implications and limitation to handle the simultaneously received and/or transmitted noncontiguous carriers. There is an allowed maximum power reduction (MPR) already for transmission in a single component carrier, if the resource block allocation is noncontiguous within the carrier. For noncontiguous aggregated carriers, an allowed MPR is defined for subblock gaps of up to 35 MHz between the aggregated carriers. The MPR depends on the number of allocated resource blocks.

22.5 MULTI-STANDARD RADIO BASE STATIONS

Traditionally the RF specifications have been developed separately for the different 3GPP RATs, namely GSM/EDGE, UTRA, and E-UTRA (LTE). The rapid evolution of mobile radio and the need to deploy new technologies alongside the legacy deployments has, however, led to implementation of different RATs at the same sites, often sharing antennas and other parts of the installation. A natural further step is then to also share the BS equipment between multiple RATs. This requires multi-RAT BSs.

The evolution to multi-RAT BSs is also fostered by the evolution of technology. While multiple RATs have traditionally shared parts of the site installation, such as antennas, feeders, backhaul, or power, the advance of both digital baseband and RF technologies enables a much tighter integration. A BS consisting of two separate implementations of both baseband and RF, together with a passive combiner/splitter before the antenna, could in theory be considered a multi-RAT BS. 3GPP has, however, made a narrower, but more forward-looking definition.

In a *multi-standard radio* (MSR) BS, both the receiver and the transmitter are capable of simultaneously processing multiple carriers of different RATs in common *active* RF components. The reason for this stricter definition is that the true potential of multi-RAT BSs, and the challenge in terms of implementation complexity, comes from having a common RF. This principle is illustrated in Figure 22.5 with an example BS capable of both GSM/EDGE and LTE. Much of the GSM/EDGE and LTE baseband functionality may be separate in the BS, but is possibly implemented in the same hardware. The RF must, however, be implemented in the same active components as shown in the figure.

The main advantages of an MSR BS implementation are twofold:

- Migration between RATs in a deployment, for example, from GSM/EDGE to LTE, is possible using the same BS hardware. In the example in Figure 22.5, a migration is performed in three phases using the same MSR BS. In the first phase, the BS is deployed in a network for GSM/EDGE-only operation. In the second phase, the operator migrates

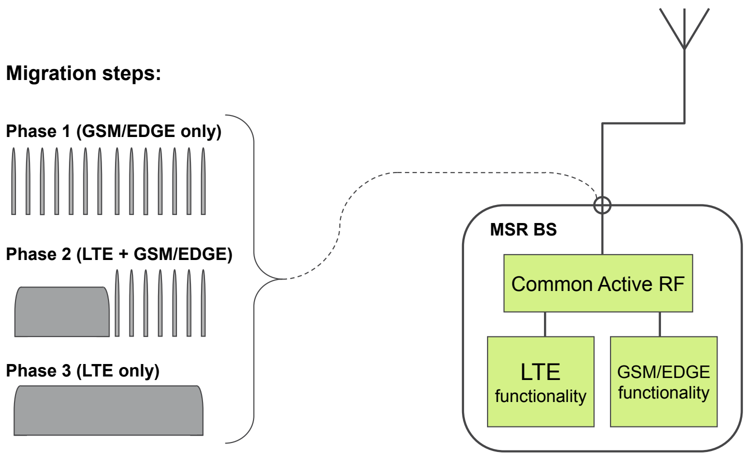

FIGURE 22.5

Example of migration from GSM to LTE using an MSR BS for all migration phases.

part of the spectrum to LTE. The same MSR BS will now operate one LTE carrier, but still supports the legacy GSM/EDGE users in half of the band available. In the third phase, when the GSM/EDGE users have migrated from the band, the operator can configure the MSR BS to LTE-only operation with double the channel bandwidth.
- A single BS designed as an MSR BS can be deployed in various environments for single-RAT operation for each RAT supported, as well as for multi-RAT operation where that is required by the deployment scenario. This is also in line with the recent technology trends seen in the market, with fewer and more generic BS designs. Having fewer varieties of BS is an advantage both for the BS vendor and for the operator, since a single solution can be developed and implemented for a variety of scenarios.

The single-RAT 3GPP radio-access standards, with requirements defined independently per RAT, do not support such migration scenarios with an implementation where common BS RF hardware is shared between multiple access technologies, and hence a separate set of requirements for multi-standard radio equipment is needed.

An implication of a common RF for multiple RATs is that carriers are no longer received and transmitted independently of each other. For this reason, a common RF specification must be used to specify the MSR BS. From 3GPP Release 9 there is a set of MSR BS specifications for the core RF requirements [41] and for test requirements [42]. Those specifications support GSM/EDGE,[3] UTRA, E-UTRA, and all combinations thereof. To support all possible RAT combinations, the MSR specifications have many generic requirements applicable regardless of RAT combination, together with specific single-access-technology-specific requirements to secure the integrity of the systems in single-RAT operation.

The MSR concept has a substantial impact for many requirements, while others remain completely unchanged. A fundamental concept introduced for MSR BSs is *RF bandwidth*, which is defined as the total bandwidth over the set of carriers transmitted and received. Many receiver and transmitter requirements for GSM/EDGE and UTRA are specified relative to the carrier center and for LTE in relation to the channel edges. For an MSR BS, they are instead specified relative to the *RF bandwidth edges*, in a way similar to carrier aggregation in Release 10. In the same way as for carrier aggregation, a parameter F_{offset} is also introduced to define the location of the RF bandwidth edges relative to the edge carriers. For GSM/EDGE carriers, F_{offset} is set to 200 kHz, while it is in general half the channel bandwidth for UTRA and E-UTRA. By introducing the RF bandwidth concept and introducing generic limits, the requirements for MSR shift from being carrier centric toward being frequency block centric, thereby embracing technology neutrality by being independent of the access technology or operational mode.

While E-UTRA and UTRA carriers have quite similar RF properties in terms of bandwidth and power spectral density (PSD), GSM/EDGE carriers are quite different. The

[3]The MSR specifications are not applicable to single-RAT operation of GSM/EDGE.

operating bands for which MSR BSs are defined are therefore divided into three *band categories* (BCs):

- BC1: All paired bands where UTRA FDD and E-UTRA FDD can be deployed.
- BC2: All paired bands where in addition to UTRA FDD and E-UTRA FDD, GSM/EDGE can also be deployed.
- BC3: All unpaired bands where UTRA TDD and E-UTRA TDD can be deployed.

Since the carriers of different RATs are not transmitted and received independently, it is necessary to perform parts of the testing with carriers of multiple RATs being activated. This is done through a set of multi-RAT *test configurations* defined in [42], specifically tailored to stress transmitter and receiver properties. These test configurations are of particular importance for the unwanted emission requirements for the transmitter and for testing of the receiver susceptibility to interfering signals (blocking, and so on). An advantage of the multi-RAT test configurations is that the RF performance of multiple RATs can be tested simultaneously, thereby avoiding repetition of test cases for each RAT. This is of particular importance for the very time-consuming tests of requirements over the complete frequency range outside the operating band.

The requirement with the largest impact from MSR is the spectrum mask, or the so-called *operating band unwanted emissions* requirement. The spectrum mask requirement for MSR BSs is applicable for multi-RAT operation where the carriers at the RF bandwidth edges are either GSM/EDGE, UTRA, or E-UTRA carriers of different channel bandwidths. The mask is generic and applicable to all cases, and covers the complete operating band of the BS. There is an exception for the 150 kHz closest to the RF bandwidth edge, where the mask is aligned with the GSM/EDGE modulation spectrum for the case when a GSM/EDGE carrier or a 1.4/3 MHz E-UTRA carrier is transmitted adjacent to the edge.

An important aspect of MSR is the declaration by the BS vendor of the supported RF bandwidth, power levels, multi-carrier capability, and so on. All testing is based on the capability of the BS through a declaration of the supported *capability set* (CS), which defines all supported single RATs and multi-RAT combinations. There are currently seven CSs, namely CS1 to CS7 defined in the MSR test specification [42], allowing full flexibility for implementing and deploying MSR BS with different capabilities. These CSs are listed in Table 22.3 together with the band categories where the CS is applicable and the RAT configurations that are supported by the BS. Note the difference between the capability of a BS (as declared by the manufacturer) and the configuration in which a BS is operating. CS1 and CS2 define capabilities for BSs that are only single-RAT capable and make it possible to apply the MSR BS specification for such BSs, instead of the corresponding single-RAT UTRA or E-UTRA specifications. There is no CS defined for BSs that are *only* single-RAT GSM capable, since that is a type of BS that is solely covered by the single-RAT GSM/EDGE specifications. In line with the continuing deployments of 3G and 4G systems in the GSM frequency bands (BC2), a new CS, namely *CS7* is introduced in Release 13. It is

Table 22.3 Capability Sets (CSx) Defined for MSR BSs and the Corresponding RAT Configurations

Capability Set CSx Supported by a BS	Applicable Band Categories	Supported RAT Configurations
CS1	BC1, BC2, or BC3	Single-RAT: UTRA
CS2	BC1, BC2, or BC3	Single-RAT: UTRA
CS3	BC1, BC2, or BC3	Single-RAT: UTRA or E-UTRA Multi-RAT: UTRA + E-UTRA
CS4	BC2	Single-RAT: GSM or UTRA Multi-RAT: GSM + UTRA
CS5	BC2	Single-RAT: GSM or E-UTRA Multi-RAT: GSM + E-UTRA
CS6	BC2	Single-RAT: GSM, UTRA, or E-UTRA Multi-RAT: GSM + UTRA, GSM + E-UTRA, UTRA + E-UTRA, or GSM + UTRA + E-UTRA
CS7	BC2	Single-RAT: UTRA or E-UTRA Multi-RAT: GSM + UTRA, GSM + E-UTRA, or UTRA + E-UTRA

used for BS that support all three RATs, but where single-RAT GSM and triple-RAT GSM + UTTRA + E-UTRA operation is not supported.

For a large part of the BS RF requirements, multi-RAT testing is not necessary and the actual test limits are unchanged for the MSR BS. In these cases, both the requirements and the test cases are simply incorporated through direct references to the corresponding single-RAT specifications.

Carrier aggregation as described in Section 22.3 is also applicable to MSR BSs. Since the MSR specification has most of the concepts and definitions in place for defining multi-carrier RF requirements, whether aggregated or not, the differences for the MSR requirements compared to nonaggregated carriers are very minor.

22.6 OVERVIEW OF RF REQUIREMENTS FOR LTE

The RF requirements define the receiver and transmitter RF characteristics of a BS or terminal. The BS is the physical node that transmits and receives RF signals on one or more antenna connectors. Note that a BS is not the same thing as an eNodeB, which is the corresponding logical node in the LTE radio-access network. The terminal is denoted UE in all RF specifications.

The set of RF requirements defined for LTE is fundamentally the same as that defined for UTRA or any other radio system. Some requirements are also based on regulatory requirements and are more concerned with the frequency band of operation and/or the place where the system is deployed, than with the type of system.

What is particular to LTE is the flexible bandwidth and the related multiple channel bandwidths of the system, which make some requirements more complex to define. These properties have special implications for the transmitter requirements on unwanted emissions, where the definition of the limits in international regulation depends on the channel bandwidth. Such limits are harder to define for a system where the BS may operate with multiple channel bandwidths and where the terminal may vary its channel bandwidth of operation. The properties of the flexible OFDM-based physical layer also have implications for specifying the transmitter modulation quality and how to define the receiver selectivity and blocking requirements.

The type of transmitter requirements defined for the terminal is very similar to what is defined for the BS, and the definitions of the requirements are often similar. The output power levels are, however, considerably lower for a terminal, while the restrictions on the terminal implementation are much higher. There is tight pressure on cost and complexity for all telecommunications equipment, but this is much more pronounced for terminals due to the scale of the total market, being close to *two billion* devices per year. In cases where there are differences in how requirements are defined between terminal and BS, they are treated separately in this chapter.

The detailed background of the RF requirements for LTE is described in [43,44], with further details of the additional requirements in Release 10 (for LTE-Advanced) in [45,46]. The RF requirements for the BS are specified in [47] and for the terminal in [38]. The RF requirements are divided into transmitter and receiver characteristics. There are also *performance characteristics* for BS and terminal that define the receiver baseband performance for all physical channels under different propagation conditions. These are not strictly RF requirements, though the performance will also depend on the RF to some extent.

Each RF requirement has a corresponding test defined in the LTE test specifications for the BS [48] and the terminal [36]. These specifications define the test setup, test procedure, test signals, test tolerances, and so on, needed to show compliance with the RF and performance requirements.

22.6.1 TRANSMITTER CHARACTERISTICS

The transmitter characteristics define RF requirements not only for the desirable (wanted) signal transmitted from the terminal and BS, but also for the unavoidable unwanted emissions outside the transmitted carrier(s). The requirements are fundamentally specified in three parts:

- *Output power level* requirements set limits for the maximum allowed transmitted power, for the dynamic variation of the power level, and in some cases, for the transmitter OFF state.

- *Transmitted signal quality* requirements define the "purity" of the transmitted signal and also the relation between multiple transmitter branches.
- *Unwanted emissions* requirements set limits to all emissions outside the transmitted carrier(s) and are tightly coupled to regulatory requirements and coexistence with other systems.

A list of the terminal and BS transmitter characteristics arranged according to the three parts as defined is shown in Table 22.4. A more detailed description of the requirements can be found later in this chapter.

22.6.2 RECEIVER CHARACTERISTICS

The set of receiver requirements for LTE is quite similar to what is defined for other systems such as UTRA, but many of them are defined differently, due to the flexible bandwidth properties. The receiver characteristics are fundamentally specified in three parts:

- *Sensitivity and dynamic range* requirements for receiving the wanted signal.
- *Receiver susceptibility to interfering signals*—defines receivers' susceptibility to different types of interfering signals at different frequency offsets.
- *Unwanted emission* limits are also defined for the receiver.

The terminal and BS receiver characteristics arranged according to the three parts defined in the preceding list are shown in Table 22.5. A more detailed description of each requirement can be found later in this chapter.

Table 22.4 Overview of LTE Transmitter Characteristics

	Base Station Requirement	Terminal Requirement
Output power level	Maximum output power	Transmit power
	Output power dynamics	Output power dynamics
	ON/OFF power (TDD only)	Power control
Transmitted signal quality	Frequency error	Frequency error
	Error-vector magnitude (EVM)	Transmit modulation quality
	Time alignment between transmitter branches	In-band emissions
Unwanted emissions	Operating band unwanted emissions	Spectrum emission mask
	Adjacent channel leakage ratio (ACLR and CACLR)	Adjacent channel leakage ratio (ACLR and CACLR)
	Spurious emissions	Spurious emissions
	Occupied bandwidth	Occupied bandwidth
	Transmitter intermodulation	Transmit intermodulation

Table 22.5 Overview of LTE Receiver Characteristics

	Base Station Requirement	Terminal Requirement
Sensitivity and dynamic range	Reference sensitivity	Reference sensitivity power level
	Dynamic range	Maximum input level
	In-channel selectivity	
Receiver susceptibility to interfering signals	Out-of-band blocking	Out-of-band blocking
		Spurious response
	In-band blocking	In-band blocking
	Narrowband blocking	Narrowband blocking
	Adjacent channel selectivity	Adjacent channel selectivity
	Receiver intermodulation	Intermodulation characteristics
Unwanted emissions from the receiver	Receiver spurious emissions	Receiver spurious emissions

22.6.3 REGIONAL REQUIREMENTS

There are a number of regional variations to the RF requirements and their application. The variations originate from different regional and local regulations of spectrum and its use. The most obvious regional variation is the different frequency bands and their use, as discussed in the preceding section. Many of the regional RF requirements are also tied to specific frequency bands.

When there is a regional requirement on, for example, spurious emissions, this requirement should be reflected in the 3GPP specifications. For the BS it is entered as an optional requirement and is marked as "regional." For the terminal, the same procedure is not possible, since a terminal may roam between different regions and will therefore have to fulfill all regional requirements that are tied to an operating band in the regions where the band is used. For LTE, this becomes more complex than for UTRA, since there is an additional variation in the transmitter (and receiver) bandwidth used, making some regional requirements difficult to meet as a mandatory requirement. The concept of *network signaling* of RF requirements is therefore introduced for LTE, where a terminal can be informed at call setup of whether some specific RF requirements apply when the terminal is connected to a network.

22.6.4 BAND-SPECIFIC TERMINAL REQUIREMENTS THROUGH NETWORK SIGNALING

For the terminal, the channel bandwidths supported are a function of the LTE operating band, and also have a relation to the transmitter and receiver RF requirements. The reason is that some RF requirements may be difficult to meet under conditions with a combination of maximum power and high number of transmitted and/or received resource blocks.

Some additional RF requirements apply for the terminal when a specific network signaling value (NS_x) is signaled to the terminal as part of the cell handover or broadcast message. For implementation reasons, these requirements are associated with restrictions and variations to RF parameters such as terminal output power, maximum channel bandwidth, and number of transmitted resource blocks. The variations of the requirements are defined together with the network signaling value (NS_x) in the terminal RF specification [38], where each value corresponds to a specific condition. The default value for all bands is NS_01. All NS_x values are connected to an allowed power reduction called *additional maximum power reduction* (A-MPR) and apply for transmission using a certain minimum number of resource blocks, depending also on the channel bandwidth. The following are examples of terminal requirements that have a related Network Signaling Value for some bands:

- *NS_03, NS_04, or NS_06* is signaled when specific FCC requirements [49] on terminal unwanted emissions apply for operation in a number of US bands.
- *NS_05* is signaled for protection of the PHS band in Japan when a terminal operates in the 2 GHz band (band 1).

In some bands the NS_x signaling is also applied for testing of receiver sensitivity, since the active transmitted signal can affect the receiver performance.

There are also additional RF requirements and restrictions that may apply in case of LTE carrier aggregation in the uplink. These can be signaled to a terminal configured for carrier aggregation using specific CA network signaling values CA_NS_x and will in this case replace the usual network signaling values NS_x and their related requirements.

22.6.5 BASE-STATION CLASSES

In the BS specifications, there is one set of RF requirements that is generic, applicable to what is called "general-purpose" BSs. This is the original set of LTE requirements developed in 3GPP Release 8. It has no restrictions on BS output power and can be used for any deployment scenario. When the RF requirements were derived, however, the scenarios used were macro scenarios [50]. For this reason, in Release 9 additional BS classes were introduced that were intended for pico-cell and femto-cell scenarios. An additional class for micro-cell scenarios was added in Release 11, together with BS classes applicable also for multi-standard BSs. It is also clarified that the original set of "general-purpose" RF parameters are applicable for macro-cell scenarios. The terms macro, micro, pico, and femto are not used in 3GPP to identify the BS classes, instead the following terminology is used:

- *Wide area BS*. This type of BS is intended for macro-cell scenarios, defined with a minimum coupling loss between BS and terminal of 70 dB.
- *Medium range BS*. This type of BS is intended for micro-cell scenarios, defined with a minimum coupling loss between BS and terminal of 53 dB. Typical deployments are outdoor below-rooftop installations, giving both outdoor hot spot coverage and outdoor-to-indoor coverage through walls.
- *Local area BS*. This type of BS is intended for pico-cell scenarios, defined with a minimum coupling loss between BS and terminal of 45 dB. Typical deployments are indoor offices and indoor/outdoor hotspots, with the BS mounted on walls or ceilings.

- *Home BS*. This type of BS is intended for femto-cell scenarios, which are not explicitly defined. Minimum coupling loss between BS and terminal of 45 dB is also assumed here. Home BSs can be used both for open access and in closed subscriber groups.

The local area, medium range, and home BS classes have modifications to a number of requirements compared to wide area BSs, mainly due to the assumption of a lower minimum coupling loss:

- Maximum BS power is limited to 38 dBm output power for medium range BSs, 24 dBm output power for local area BSs, and to 20 dBm for home BSs. This power is defined per antenna and carrier, except for home BSs, where the power over all antennas (up to four) is counted. There is no maximum BS power defined for wide area BSs.
- Home BSs have an additional requirement for protecting systems operating on adjacent channels. The reason is that a terminal connected to a BS belonging to another operator on the adjacent channel may be in close proximity to the home BS. To avoid an interference situation where the adjacent terminal is blocked, the home BS must make measurements on the adjacent channel to detect adjacent BS operations. If an adjacent BS transmission (UTRA or LTE) is detected under certain conditions, the maximum allowed home BS output power is reduced in proportion to how weak the adjacent BS signal is, in order to avoid interference to the adjacent BS.
- The spectrum mask (operating band unwanted emissions) has lower limits for medium range, local area, and home BSs, in line with the lower maximum power levels.
- Limits for colocation for medium range and local area are relaxed compared to wide area BS, corresponding to the relaxed reference sensitivity for the base station.
- Home BSs do not have limits for colocation, but instead have more stringent unwanted emission limits for protecting home BS operation (from other home BSs), assuming a stricter through-the-wall indoor interference scenario.
- Receiver reference sensitivity limits are higher (more relaxed) for medium range, local area, and home BSs. Receiver dynamic range and in-channel selectivity (ICS) are also adjusted accordingly.
- All medium range, local area, and home BS limits for receiver susceptibility to interfering signals are adjusted to take the higher receiver sensitivity limit and the lower assumed minimum coupling loss (BS-to-terminal) into account.

22.7 OUTPUT POWER LEVEL REQUIREMENTS

22.7.1 BASE-STATION OUTPUT POWER AND DYNAMIC RANGE

There is no general maximum output power requirement for BSs. As mentioned in the discussion of BS classes in the preceding section, there is, however, a maximum output power limit of 38 dBm for medium range BSs, 24 dBm for local area BSs, and of 20 dBm for home BSs. In addition to this, there is a tolerance specified, defining how much the actual maximum power may deviate from the power level declared by the manufacturer.

The BS also has a specification of the total power control dynamic range for a resource element, defining the power range over which it should be possible to configure. There is also a dynamic range requirement for the total BS power.

For TDD operation, a power mask is defined for the BS output power, defining the off power level during the uplink subframes and the maximum time for the *transmitter transient period* between the transmitter on and off states.

22.7.2 TERMINAL OUTPUT POWER AND DYNAMIC RANGE

The terminal output power level is defined in three steps:

- *UE power class* defines a *nominal* maximum output power for QPSK modulation. It may be different in different operating bands, but the main terminal power class is today set at 23 dBm for all bands.
- *Maximum power reduction (MPR)* defines an allowed reduction of maximum power level for certain combinations of modulation used and the number of resource blocks that are assigned.
- *Additional maximum power reduction (A-MPR)* may be applied in some regions and is usually connected to specific transmitter requirements such as regional emission limits and to certain carrier configurations. For each such set of requirement, there is an associated network signaling value NS_x that identifies the allowed A-MPR and the associated conditions, as explained in Section 22.6.4.

The terminal has a definition of the transmitter Off power level, applicable to conditions when the terminal is not allowed to transmit. There is also a general On/Off time mask specified, plus specific time masks for PRACH, SRS, subframe boundary, and PUCCH/PUSCH/SRS.

The terminal transmit power control (TPC) is specified through requirements for the *absolute power tolerance* for the initial power setting, the *relative power tolerance* between two subframes, and the *aggregated power tolerance* for a sequence of power-control commands.

22.8 TRANSMITTED SIGNAL QUALITY

The requirements for transmitted signal quality specify how much the transmitted BS or terminal signal deviates from an "ideal" modulated signal in the signal and the frequency domains. Impairments on the transmitted signal are introduced by the transmitter RF parts, with the nonlinear properties of the power amplifier being a major contributor. The signal quality is assessed for BS and terminal through requirements on *error-vector magnitude* (*EVM*) and *frequency error*. An additional terminal requirement is UE in-band emissions.

22.8.1 EVM AND FREQUENCY ERROR

While the theoretical definitions of the signal quality measures are quite straightforward, the actual assessment is a very elaborate procedure, described in great detail in the 3GPP specification. The reason is that it becomes a multidimensional optimization problem, where the best match for the timing, the frequency, and the signal constellation are found.

The EVM is a measure of the error in the modulated signal constellation, taken as the root mean square of the error vectors over the active subcarriers, considering all symbols of the modulation scheme. It is expressed as a percentage value in relation to the power of the ideal signal. The EVM fundamentally defines the maximum SINR that can be achieved at the receiver, if there are no additional impairments to the signal between transmitter and receiver.

Since a receiver can remove some impairments of the transmitted signal such as time dispersion, the EVM is assessed after cyclic prefix removal and equalization. In this way, the EVM evaluation includes a standardized model of the receiver. The frequency offset resulting from the EVM evaluation is averaged and used as a measure of the *frequency error* of the transmitted signal.

22.8.2 TERMINAL IN-BAND EMISSIONS

In-band emissions are emissions within the channel bandwidth. The requirement limits how much a terminal can transmit into nonallocated resource blocks within the channel bandwidth. Unlike the OOB emissions, the in-band emissions are measured after cyclic prefix removal and FFT, since this is how a terminal transmitter affects a real BS receiver.

22.8.3 BASE-STATION TIME ALIGNMENT

Several LTE features require the BS to transmit from two or more antennas, such as transmitter diversity and MIMO. For carrier aggregation, the carriers may also be transmitted from different antennas. In order for the terminal to properly receive the signals from multiple antennas, the timing relation between any two transmitter branches is specified in terms of a maximum time alignment error between transmitter branches. The maximum allowed error depends on the feature or combination of features in the transmitter branches.

22.9 UNWANTED EMISSIONS REQUIREMENTS

Unwanted emissions from the transmitter are divided into *out-of-band (OOB) emissions* and *spurious emissions* in ITU-R recommendations [51]. OOB emissions are defined as emissions on a frequency close to the RF carrier, which results from the modulation process. Spurious emissions are emissions outside the RF carrier that may be reduced without affecting the corresponding transmission of information. Examples of spurious emissions are harmonic emissions, intermodulation products, and frequency conversion products. The frequency range where OOB emissions are normally defined is called the *out-of-band domain*, whereas spurious emissions limits are normally defined in the *spurious domain*.

ITU-R also defines the boundary between the OOB and spurious domains at a frequency separation from the carrier center of 2.5 times the necessary bandwidth, which corresponds to 2.5 times the channel bandwidth for LTE. This division of the requirements is easily applied for systems that have a fixed channel bandwidth. It does, however, become more difficult for LTE, which is a flexible bandwidth system, implying that the frequency range where requirements apply would then vary with the channel bandwidth. The approach taken for defining the boundary in 3GPP is slightly different for BS and terminal requirements.

With the recommended boundary between OOB emissions and spurious emissions set at 2.5 times the channel bandwidth, third- and fifth-order intermodulation products from the carrier will fall inside the OOB domain, which will cover a frequency range of twice the channel bandwidth on each side of the carrier. For the OOB domain, two overlapping requirements are defined for both BS and terminal: *spectrum emissions mask* (SEM) and *adjacent channel leakage ratio* (ACLR). The details of these are further explained in the following.

22.9.1 IMPLEMENTATION ASPECTS

The spectrum of an OFDM signal decays rather slowly outside of the transmission bandwidth configuration. Since the transmitted signal for LTE occupies 90% of the channel bandwidth, it is not possible to directly meet the unwanted emission limits directly outside the channel bandwidth with a “pure” OFDM signal. The techniques used for achieving the transmitter requirements are, however, not specified or mandated in LTE specifications. Time-domain windowing is one method commonly used in OFDM-based transmission systems to control spectrum emissions. Filtering is always used, both time-domain digital filtering of the baseband signal and analog filtering of the RF signal.

The nonlinear characteristics of the *power amplifier* (PA) used to amplify the RF signal must also be taken into account, since it is the source of intermodulation products outside the channel bandwidth. Power back-off to give a more linear operation of the PA can be used, but at the cost of a lower power efficiency. The power back-off should therefore be kept to a minimum. For this reason, additional linearization schemes can be employed. These are especially important for the BS, where there are fewer restrictions on implementation complexity and use of advanced linearization schemes is an essential part of controlling spectrum emissions. Examples of such techniques are feed-forward, feedback, predistortion, and postdistortion.

22.9.2 SPECTRUM EMISSION MASK

The spectrum emission mask defines the permissible OOB spectrum emissions outside the necessary bandwidth. As explained in the preceding section, how to take the flexible channel bandwidth into account when defining the frequency boundary between OOB emissions and spurious emissions is dealt differently for the LTE BS and terminal. Consequently, the spectrum emission masks are also based on different principles.

22.9.2.1 Base-Station Operating Band Unwanted Emission Limits

For the LTE BS, the problem of the implicit variation of the boundary between OOB and spurious domain with the varying channel bandwidth is handled by not defining an explicit boundary. The solution is a unified concept of *operating band unwanted emissions* (UEM) for the LTE BS instead of the spectrum mask usually defined for OOB emissions. The operating band unwanted emissions requirement applies over the whole BS transmitter operating band, plus an additional 10 MHz on each side, as shown in Figure 22.6. All requirements outside of that range are set by the regulatory spurious emission limits, based on the ITU-R recommendations [51]. As seen in the figure, a large part of the operating band unwanted emissions is defined over a frequency range that for smaller channel bandwidths can be both in spurious and OOB domains. This means that the limits for the frequency ranges that may be in the spurious domain also have to align with the regulatory limits from the ITU-R. The shape of the mask is generic for all channel bandwidth from 5 to 20 MHz, with a mask that consequently has to align with the ITU-R limits starting 10 MHz from the channel edges. Special masks are defined for the smaller 1.4 and 3 MHz channel bandwidths. The operating band unwanted emissions are defined with a 100 kHz measurement bandwidth.

In case of carrier aggregation for a BS, the UEM requirement (as other RF requirements) apply as for any multi-carrier transmission, where the UEM will be defined relative to the carriers on the edges of the RF bandwidth. In case of noncontiguous carrier aggregation, the UEM within a subblock gap is partly calculated as the cumulative sum of contributions from each subblock.

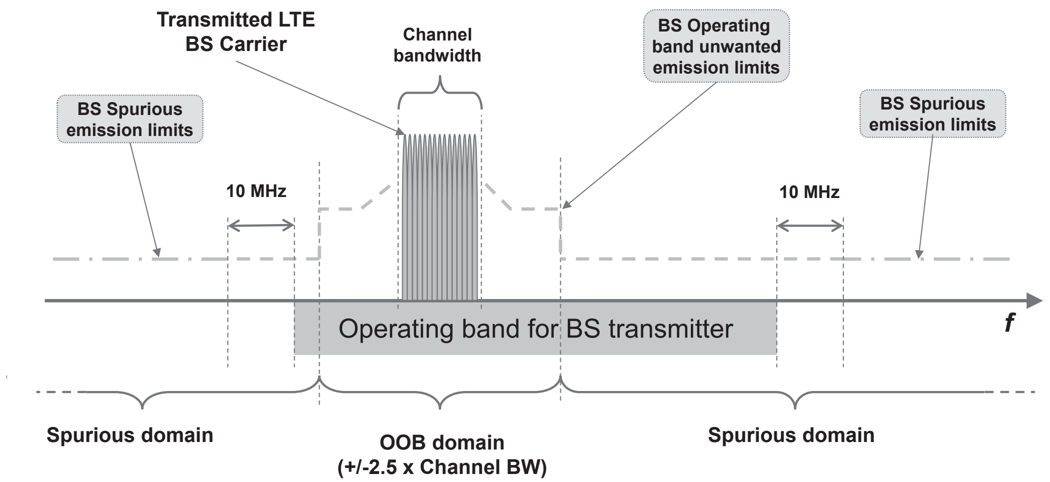

FIGURE 22.6

Frequency ranges for operating band unwanted emissions and spurious emissions applicable to LTE BS.

There are also special limits defined to meet a specific regulation set by the FCC [49] for the operating bands used in the USA and by the ECC for some European bands. These are specified as separate limits in addition to the operating band unwanted emission limits.

22.9.2.2 Terminal Spectrum Emission Mask

For implementation reasons, it is not possible to define a generic terminal spectrum mask that does not vary with the channel bandwidth, so the frequency ranges for OOB limits and spurious emissions limits do not follow the same principle as for the BS. The SEM extends out to a separation Δf_{OOB} from the channel edges, as illustrated in Figure 22.7. For 5 MHz channel bandwidth, this point corresponds to 250% of the necessary bandwidth as recommended by the ITU-R, but for higher channel bandwidths it is set closer than 250%.

The SEM is defined as a general mask and a set of additional masks that can be applied to reflect different regional requirements. Each additional regional mask is associated with a specific network signaling value NS_x.

22.9.3 ADJACENT CHANNEL LEAKAGE RATIO

In addition to a spectrum emissions mask, the OOB emissions are defined by an ACLR requirement. The ACLR concept is very useful for analysis of coexistence between two systems that operate on adjacent frequencies. The ACLR defines the ratio of the power transmitted within the assigned channel bandwidth to the power of the unwanted emissions transmitted on an adjacent channel. There is a corresponding receiver requirement called *adjacent channel selectivity* (ACS), which defines a receiver's ability to suppress a signal on an adjacent channel.

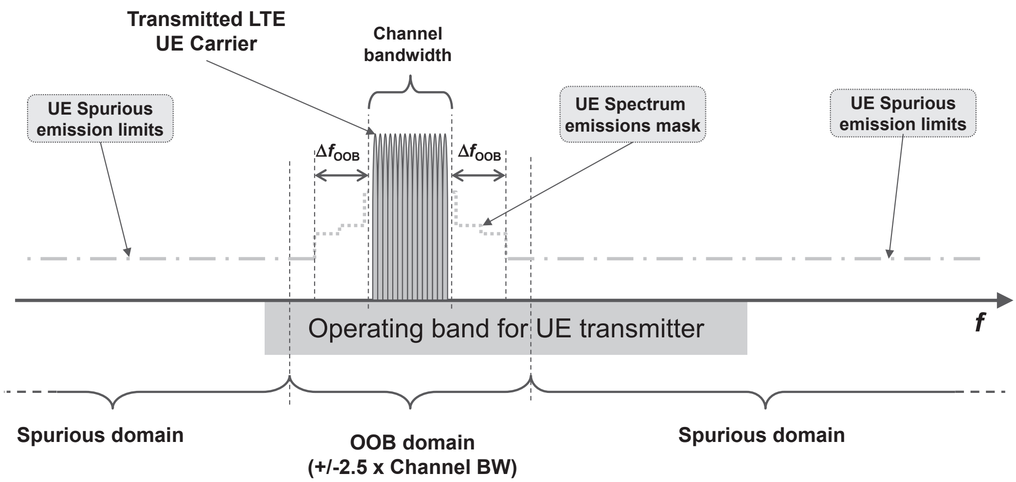

FIGURE 22.7

Frequency ranges for spectrum emission mask and spurious emissions applicable to LTE terminal.

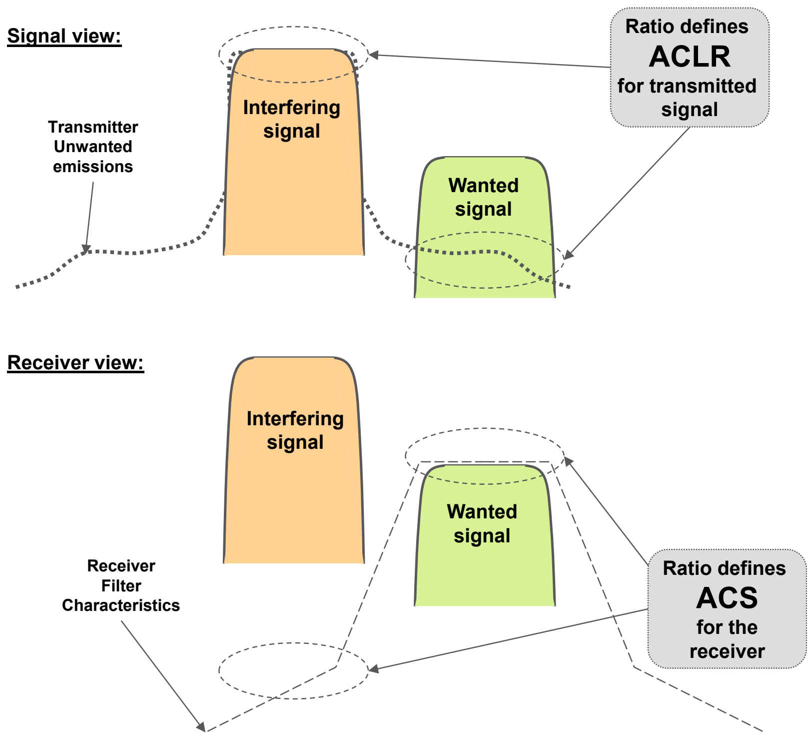

FIGURE 22.8

Illustration of ACLR and ACS, with example characteristics for an "aggressor" interferer and a receiver for a "victim" wanted signal.

The definitions of ACLR and ACS are illustrated in Figure 22.8 for a wanted and an interfering signal received in adjacent channels. The interfering signal's leakage of unwanted emissions at the wanted signal receiver is given by the ACLR and the ability of the receiver of the wanted signal to suppress the interfering signal in the adjacent channel is defined by the ACS. The two parameters when combined define the total leakage between two transmissions on adjacent channels. That ratio is called the *adjacent channel interference ratio* (ACIR) and is defined as the ratio of the power transmitted on one channel to the total interference received by a receiver on the adjacent channel, due to both transmitter (ACLR) and receiver (ACS) imperfections.

This relation between the adjacent channel parameters is [50]:

$$\mathrm{ACIR} = \frac{1}{\frac{1}{\mathrm{ACLR}} + \frac{1}{\mathrm{ACS}}} \tag{22.7}$$

ACLR and ACS can be defined with different channel bandwidths for the two adjacent channels, which is the case for some requirements set for LTE due to the bandwidth flexibility. Eq. (22.7) will also apply for different channel bandwidths, but only if the same two channel bandwidths are used for defining all three parameters ACIR, ACLR, and ACS used in the equation.

The ACLR limits for LTE terminal and BS are derived based on extensive analysis [50] of LTE coexistence with LTE or other systems on adjacent carriers.

The LTE BS requirements on ACLR and operating band unwanted emissions both cover the OOB domain, but the operating band unwanted emission limits are in general set slightly more relaxed compared to the ACLR, since they are defined in a much narrower measurement bandwidth of 100 kHz. This allows for some variations in the unwanted emissions due to intermodulation products from varying power allocation between resource blocks within the channel. For an LTE BS, there are ACLR requirements both for an adjacent channel with a UTRA receiver and with an LTE receiver of the same channel bandwidth. The ACLR requirement for LTE BS is set to 45 dB. This is considerably more strict than the ACS requirement for the UE, which according to Eq. (22.7) implies that in the downlink, the UE receiver performance will be the limiting factor for ACIR and consequently for coexistence between BSs and terminals. From a system point of view, this choice is cost-efficient since it moves implementation complexity to the BS, instead of requiring all terminals to have high-performance RF.

In case of carrier aggregation for a BS, the ACLR (as other RF requirements) apply as for any multi-carrier transmission, where the ACLR requirement will be defined for the carriers on the edges of the RF bandwidth. In case of noncontiguous carrier aggregation where the subblock gap is so small that the ACLR requirements at the edges of the gap will "overlap," a special *cumulative ACLR* requirement (CACLR) is defined for the gap. For CACLR, contributions from carriers on both sides of the subblock gap are accounted for in the CACLR limit. The CACLR limit is the same as the ACLR for the BS at 45 dB.

ACLR limits for the terminal are set both with assumed UTRA and LTE receivers on the adjacent channel. As for the BS, the limits are also set stricter than the corresponding SEM, thereby accounting for variations in the spectrum emissions resulting from variations in resource-block allocations. In case of carrier aggregation, the terminal ACLR requirement applies to the aggregated channel bandwidth instead of per carrier. The ACLR limit for LTE terminals is set to 30 dB. This is considerably relaxed compared to the ACS requirement for the BS, which according to Eq. (22.7) implies that in the uplink, the UE transmitter performance will be the limiting factor for ACIR and consequently for coexistence between base stations and terminals.

22.9.4 SPURIOUS EMISSIONS

The limits for BS spurious emissions are taken from international recommendations [51], but are only defined in the region outside the frequency range of operating band unwanted emissions limits as illustrated in Figure 22.6—that is, at frequencies that are separated from the BS transmitter operating band by at least 10 MHz. There are also additional regional or optional limits for protection of other systems that LTE may coexist with or even be colocated with. Examples of other systems considered in those additional spurious emissions requirements are GSM, UTRA FDD/TDD, CDMA2000, and PHS.

Terminal spurious emission limits are defined for all frequency ranges outside the frequency range covered by the SEM. The limits are generally based on international regulations [51], but there are also additional requirements for coexistence with other bands when the mobile is roaming. The additional spurious emission limits can have an associated network signaling value.

In addition, there are BS and terminal emission limits defined for the receiver. Since receiver emissions are dominated by the transmitted signal, the receiver spurious emission limits are only applicable when the transmitter is Off, and also when the transmitter is On for an LTE FDD BS that has a separate receiver antenna connector.

22.9.5 OCCUPIED BANDWIDTH

Occupied bandwidth is a regulatory requirement that is specified for equipment in some regions, such as Japan and the USA. It is originally defined by the ITU-R as a maximum bandwidth, outside of which emissions do not exceed a certain percentage of the total emissions. The occupied bandwidth is for LTE equal to the channel bandwidth, outside of which a maximum of 1% of the emissions are allowed (0.5% on each side).

In the case of carrier aggregation, the occupied bandwidth is equal to the aggregated channel bandwidth. For noncontiguous carrier aggregation, the occupied bandwidth applies per subblock.

22.9.6 TRANSMITTER INTERMODULATION

An additional implementation aspect of an RF transmitter is the possibility of intermodulation between the transmitted signal and another strong signal transmitted in the proximity of the BS or terminal. For this reason there is a requirement for *transmitter intermodulation*.

For the BS, the requirement is based on a stationary scenario with a colocated other BS transmitter, with its transmitted signal appearing at the antenna connector of the BS being specified, but attenuated by 30 dB. Since it is a stationary scenario, there are no additional unwanted emissions allowed, implying that all unwanted emission limits also have to be met with the interferer present.

For the terminal, there is a similar requirement based on a scenario with another terminal transmitted signal appearing at the antenna connector of the terminal being specified, but attenuated by 40 dB. The requirement specifies the minimum attenuation of the resulting intermodulation product below the transmitted signal.

22.10 SENSITIVITY AND DYNAMIC RANGE

The primary purpose of the *reference sensitivity requirement* is to verify the receiver *noise figure*, which is a measure of how much the receiver's RF signal chain degrades the SNR of the received signal. For this reason, a low-SNR transmission scheme using QPSK is chosen as reference channel for the reference sensitivity test. The reference sensitivity is defined at a receiver input level where the throughput is 95% of the maximum throughput for the reference channel.

For the BS, reference sensitivity could potentially be defined for a single resource block up to a group covering all resource blocks. For reasons of complexity, a maximum granularity of 25 resource blocks has been chosen, which means that for channel bandwidths larger than 5 MHz, sensitivity is verified over multiple adjacent 5 MHz blocks, while it is only defined over the full channel for smaller channel bandwidths.

For the terminal, reference sensitivity is defined for the full channel bandwidth signals and with all resource blocks allocated for the wanted signal. For the higher channel bandwidths (>5 MHz) in some operating bands, the nominal reference sensitivity needs to be met with a minimum number of allocated resource blocks. For larger allocation, a certain relaxation is allowed.

The intention of the *dynamic range requirement* is to ensure that the receiver can also operate at received signal levels considerably higher than the reference sensitivity. The scenario assumed for BS dynamic range is the presence of increased interference and corresponding higher wanted signal levels, thereby testing the effects of different receiver impairments. In order to stress the receiver, a higher SNR transmission scheme using 16QAM is applied for the test. In order to further stress the receiver to higher signal levels, an interfering AWGN signal at a level 20 dB above the assumed noise floor is added to the received signal. The dynamic range requirement for the terminal is specified as a *maximum signal level* at which the throughput requirement is met.

22.11 RECEIVER SUSCEPTIBILITY TO INTERFERING SIGNALS

There is a set of requirements for BS and terminal, defining the receiver's ability to receive a wanted signal in the presence of a stronger interfering signal. The reason for the multiple requirements is that, depending on the frequency offset of the interferer from the wanted signal, the interference scenario may look very different and different types of receiver impairments will affect the performance. The intention of the different combinations of interfering signals is to model as far as possible the range of possible scenarios with interfering signals of different bandwidths that may be encountered inside and outside the BS and terminal receiver operating band.

While the types of requirements are very similar between BS and terminal, the signal levels are different, since the interference scenarios for the BS and terminal are very different. There is also no terminal requirement corresponding to the BS ICS requirement.

The following requirements are defined for LTE BS and terminal, starting from interferers with large frequency separation and going close in (see also Figure 22.9). In all cases where the interfering signal is an LTE signal, it has the same bandwidth as the wanted signal, but at most 5 MHz.

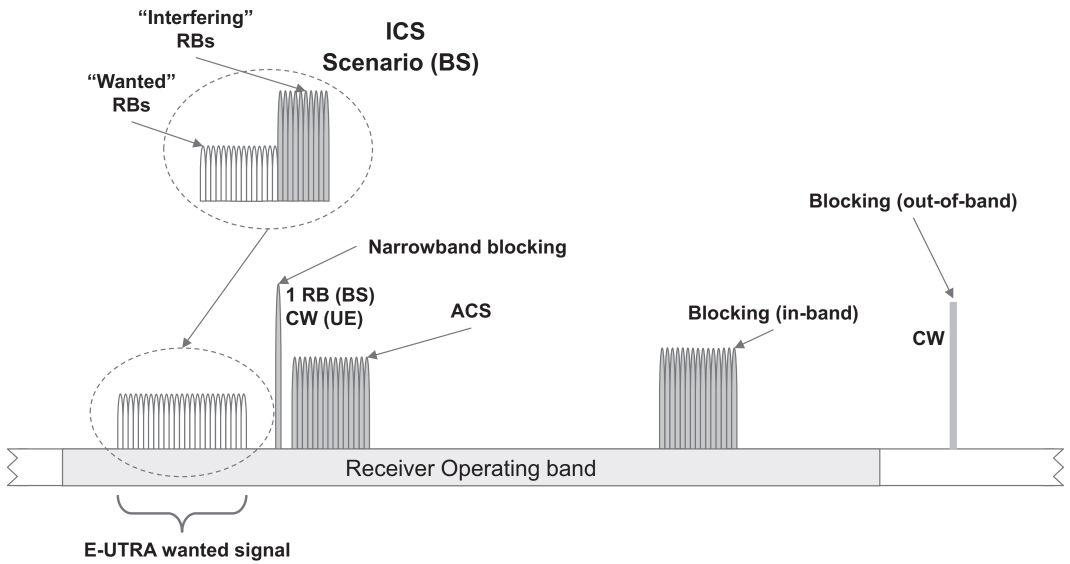

FIGURE 22.9

Base-station and terminal requirements for receiver susceptibility to interfering signals in terms of blocking, ACS, narrowband blocking, and ICS (BS only).

- *Blocking*. This corresponds to the scenario with strong interfering signals received outside the operating band (OOB blocking) or inside the operating band (in-band blocking), but not adjacent to the wanted signal. In-band blocking includes interferers in the first 20 MHz outside the operating band for the BS and the first 15 MHz for the terminal. The scenarios are modeled with a *continuous wave* (CW) signal for the OOB case and an LTE signal for the in-band case. There are additional (optional) BS blocking requirements for the scenario when the BS is colocated with another BS in a different operating band. For the terminal, a fixed number of *exceptions* are allowed from the OOB blocking requirement, for each assigned frequency channel and at the respective *spurious response frequencies*. At those frequencies, the terminal must comply with the more relaxed spurious response requirement.
- *Adjacent channel selectivity*. The ACS scenario is a strong signal in the channel adjacent to the wanted signal and is closely related to the corresponding ACLR requirement (see also the discussion in Section 22.9.3). The adjacent interferer is an LTE signal. For the terminal, the ACS is specified for two cases with a lower and a higher signal level. For MSR BSs, there is no specific ACS requirement defined. It is instead replaced by the narrowband blocking requirement, which covers the adjacent channel properties fully.
- *Narrowband blocking*. The scenario is an adjacent strong narrowband interferer, which in the requirement is modeled as a single resource block LTE signal for the BS and a CW signal for the terminal.

- *In-channel selectivity* (ICS). The scenario is multiple received signals of different received power levels inside the channel bandwidth, where the performance of the weaker "wanted" signal is verified in the presence of the stronger "interfering" signal. ICS is only specified for the BS.
- *Receiver intermodulation*. The scenario is *two* interfering signals near to the wanted signal, where the interferers are one CW and one LTE signal (not shown in Figure 22.9). The purpose of the requirement is to test receiver linearity. The interferers are placed in frequency in such a way that the main intermodulation product falls inside the wanted signal's channel bandwidth. There is also a *narrowband intermodulation* requirement for the BS where the CW signal is very close to the wanted signal and the LTE interferer is a single RB signal.

For all requirements except ICS, the wanted signal uses the same reference channel as in the corresponding reference sensitivity requirement. With the interference added, the same 95% relative throughput is met as for the reference sensitivity, but at a "desensitized" higher wanted signal level.

22.12 MULTIBAND-CAPABLE BASE STATIONS

The 3GPP specifications have been continuously developed to support larger RF bandwidths for transmission and reception through multi-carrier and multi-RAT operation and carrier aggregation over contiguous and noncontiguous spectrum allocations. This has been made possible with the evolution of RF technology supporting larger bandwidths for both transmitters and receivers. The next step in RF technology for BSs is to support simultaneous transmission and/or reception in multiple bands through a common radio. A multi-band BS could cover multiple bands over a frequency range of a few hundred MHz.

One obvious application for multi-band BSs is for inter-band carrier aggregation. It should however be noted that base stations supporting multiple bands have been in existence long before carrier aggregation was introduced in LTE. Already for GSM, dual-band BSs were designed to enable more compact deployments of equipment at BS sites. In some cases these shared also antennas, in other cases there were separate antenna systems for the different bands. These early implementations were really two separate sets of transmitters and receiver for the bands that were integrated in the same equipment cabinet. In the case where a common antenna system is used, the signals are combined and split through passive diplexers. The difference for "true" multi-band capable BSs is that the signals for the bands are transmitted and received in common *active* RF in the BS.

The RF requirements for such multi-band-capable base stations are defined in 3GPP Release 11. The specification supports multi-band operation both with a single RAT and with multiple RATs, also called multi-band multi-standard radio (MB-MSR) BSs. The specifications cover all combinations of RATs, except pure single-RAT GSM operation across the supported bands.

There are several scenarios envisioned for multi-band BS implementation and deployment. The possibilities for the multi-band capability are:

- multi-band transmitter + multi-band receiver;
- multi-band transmitter + single-band receiver;
- single-band transmitter + multi-band receiver.

The first case is demonstrated in Figure 22.10, which shows an example BS with a common RF implementation of both transmitter and receiver for two operating bands X and Y. Through a duplex filter, the transmitter and receiver are connected to a common antenna connector and a common antenna. The example is also a multi-RAT capable MB-MSR BS, with LTE+GSM configured in band X and LTE configured in band Y. Note that the figure has only one diagram showing the frequency range for the two bands, which could either be the receiver or transmitter frequencies.

Figure 22.10 also illustrates some new parameters that are defined for multi-band BS.

- *RF bandwidth* has the same definition as for a multi-standard BS, but is defined individually for each band.
- *Inter-RF-bandwidth gap* is the gap between the RF bandwidths in the two bands. Note that the inter-RF bandwidth gap may span a frequency range where other mobile operators can be deployed in bands X and Y, as well as a frequency range between the two bands that may be used for other services.
- *Total RF bandwidth* is the full bandwidth supported by the BS to cover the multiple carriers in both bands.

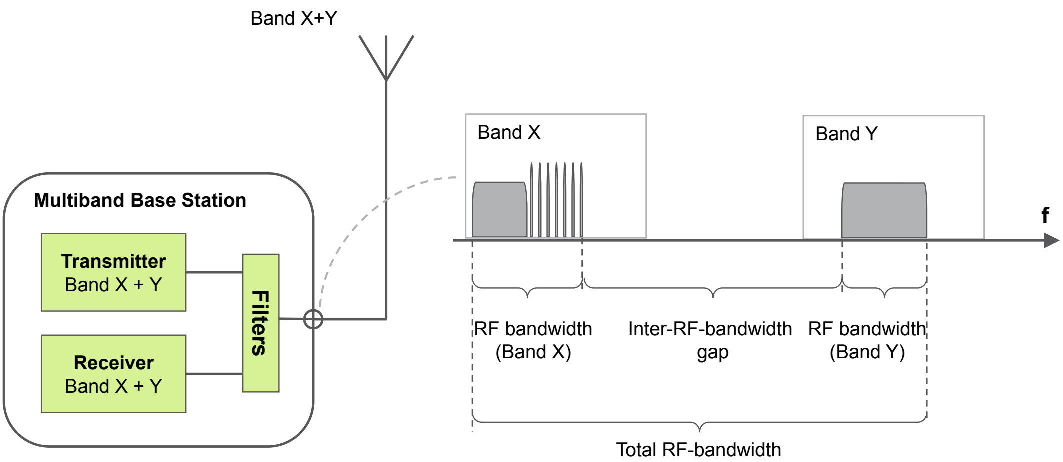

FIGURE 22.10

Example of multi-band BS with multi-band transmitter and receiver for two bands with one common antenna connector.

In principle, a multi-band BS can be capable of operating in more than two bands. The requirements and testing developed for the new type of BSs in 3GPP Release 11 will, however, in general, only cover a two-band capability. Full support for more than two bands is planned to be introduced in the 3GPP specifications in Release 14.

While having only a single antenna connector and a common feeder that connects to a common antenna is desirable to reduce the amount of equipment needed in a site, it is not always possible. It may also be desirable to have separate antenna connectors, feeders, and antennas for each band. An example of a multi-band BS with separate connectors for two operating bands X and Y is shown in Figure 22.11. Note that while the antenna connectors are separate for the two bands, the RF implementation for transmitter and receiver are in this case common for the bands. The RF for the two bands is separated into individual paths for band X and band Y before the antenna connectors through a filter. As for multi-band BSs with a common antenna connector for the bands, it is also possible here to have either the transmitter or receiver to be a single-band implementation, while the other is multi-band.

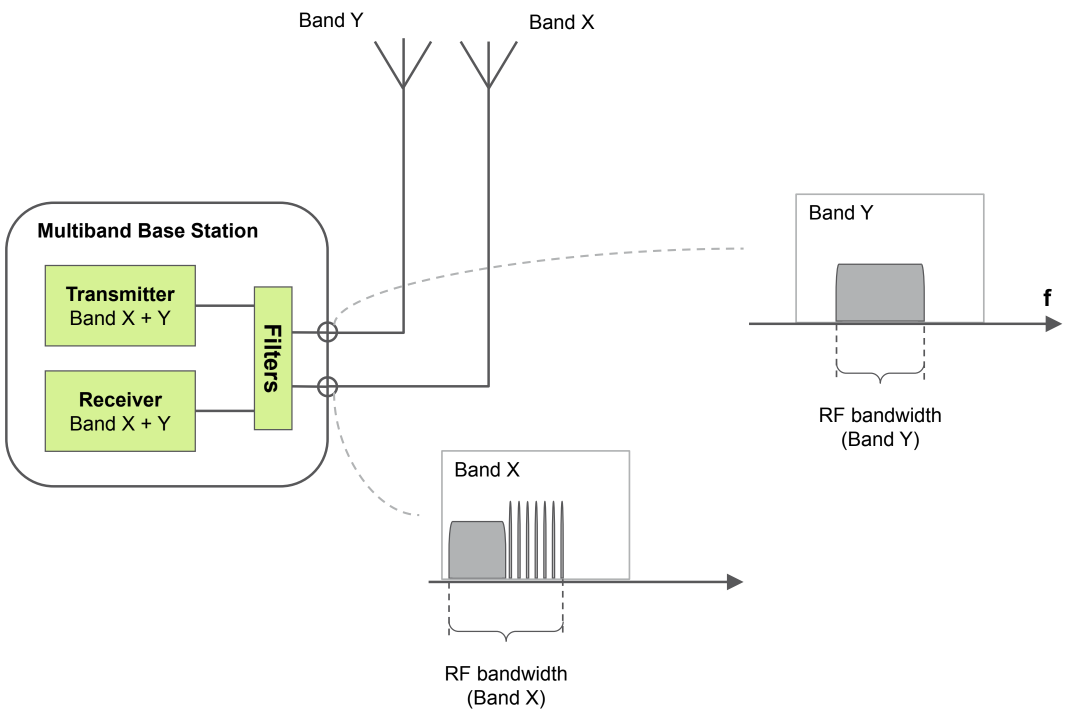

FIGURE 22.11

Multi-band BS with multi-band transmitter and receiver for two bands with separate antenna connectors for each band.

Further possibilities are BS implementations with separate antenna connectors for receiver and transmitter, in order to give better isolation between the receiver and transmitter paths. This may be desirable for a multi-band BS, considering the large total RF bandwidths, which will in fact also overlap between receiver and transmitter.

For a multi-band BS, with a possible capability to operate with multiple RATs and several alternative implementations with common or separate antenna connectors for the bands and/or for the transmitter and receiver, the declaration of the BS capability becomes quite complex. What requirements will apply to such a BS and how they are tested will also depend on these declared capabilities.

Most RF requirements for a multi-band BS remain the same as for a single-band implementation. There are however some notable exceptions:

- *Transmitter spurious emissions*: For LTE BSs, the requirements exclude frequencies in the operating band plus an additional 10 MHz on each side of the operating band, since this frequency range is covered by the UEM limits. For a multi-band BS, the exclusion applies to both operating bands (plus 10 MHz on each side), and only the UEM limits apply in those frequency ranges. This is called "joint exclusion band."
- *Operating band unwanted emissions mask (UEM)*: For multi-band operation, when the inter-RF bandwidth gap is less than 20 MHz, the UEM limit applies as a cumulative limit with contributions counted from both bands, in a way similar to operation in noncontiguous spectrum.
- *ACLR*: For multi-band operation, when the inter-RF bandwidth gap is less than 20 MHz, the CACLR will apply with contributions counted from both bands, in a way similar to operation in noncontiguous spectrum.
- *Transmitter intermodulation*: For a multi-band BS, when the inter-RF bandwidth gap is less than 15 MHz, the requirement only applies for the case when the interfering signals fit within the gap.
- *Blocking requirement*: For multi-band BS, the in-band blocking limits apply for the in-band frequency ranges of *both* operating bands. This can be seen as a "joint exclusion," similar to the one for spurious emissions. The blocking and receiver intermodulation requirements also apply inside the inter-RF bandwidth gap.
- *Receiver spurious emissions*: For a multi-band BS, a "joint exclusion band" similar to the one for transmitter spurious emissions will apply, covering both operating bands plus 10 MHz on each side.

In the case where the two operating bands are mapped on separate antenna connectors as shown in Figure 22.11, the exceptions for transmitter/receiver spurious emissions, UEM, ACLR, and transmitter intermodulation do not apply. Those limits will instead be the same as for single-band operation for each antenna connector. In addition, if such a multiband BSs with separate antenna connectors per band is operated in only one band with the other band (and other antenna connector) inactive, the BS will from a requirement point of view be seen as a single-band BS. In this case all requirements will apply as single-band requirements.

22.13 RF REQUIREMENTS FOR RELAYS

As described in Chapter 18, the LTE specifications support decode-and-forward relays in Release 10. The RF requirements for such relays were introduced in Release 11 and are described in this chapter. The baseline for setting the relay RF requirements has been the existing RF requirements for the BS and the terminal, with the observation that seen from the access link side, a relay would have many similarities with a BS while on the backhaul side, it would have similarities with a terminal. This is illustrated in Figure 22.12.

The RF requirements for LTE relays are defined in a separate specification [55], but many of the requirements are set by direct reference to the terminal specification [38] for backhaul link requirements and BS specification [47] for access link requirements. It is in particular the local area BS requirements that are referenced, since the deployment scenario in that case is similar to a relay. Many RF requirements are however specific for relays, the following in particular:

Output power: Two power classes are defined for relays. Class 1 has a maximum of 24 dBm and Class 2 has a maximum 30 dBm output power for the access link. The maximum for the backhaul link is 24 dBm for both classes. All power levels are counted as the sum over all antennas (up to eight for the access link and four for the backhaul link).

ACLR: In order for the backhaul link to provide proper coexistence properties and not deteriorate the BS uplink, the relay ACLR limits are set equivalent to the ones for a local area BS on both the access and backhaul links.

Operating band unwanted emissions (UEM): New UEM limits for the access and backhaul links are set in relation to the output power levels defined by the relay power class.

Adjacent channel selectivity: The relay backhaul link relative ACS limit is set at a level similar to what is used for a BS, but the requirement is defined at a higher input signal

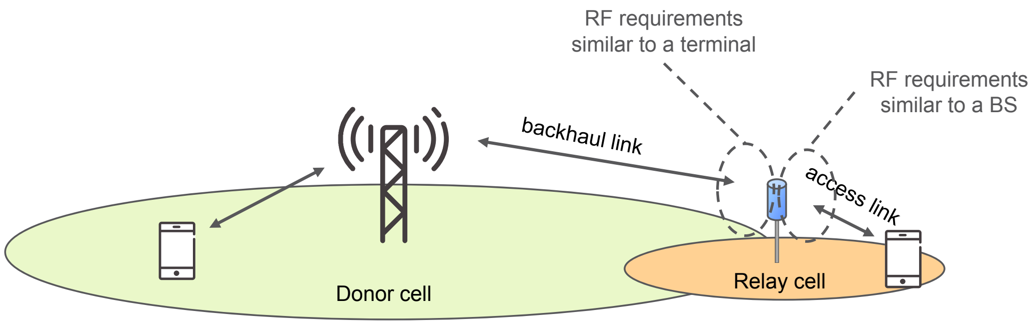

FIGURE 22.12

RF requirements for a relay on the backhaul and access sides.

level corresponding to the maximum downlink signal level at which ACS is defined for a terminal. The ACS requirement for the access link is taken from the local area BS.

Blocking requirements: The in-band blocking levels for the backhaul link are set higher than for a terminal, but are also defined for a correspondingly higher wanted signal level. The blocking requirement for the access link is taken from the local area BS.

22.14 RF REQUIREMENTS FOR LICENSE-ASSISTED ACCESS

Operation in unlicensed spectrum through license-assisted access (LAA) is a new feature in 3GPP Release 13, see Chapter 17 for details. Due to the specific conditions for operating in an unlicensed band with very particular regulation, there is also an impact on the RF requirements, both for terminal and base station.

LAA operation is defined for the 5 GHz unlicensed band as described in Section 17.1. The 5 GHz band is called *Band 46* in 3GPP and covers the frequency range 5150 to 5925 MHz. In the RF specifications, operation in Band 46 is tightly coupled to the use of Frame structure type 3, while TDD operation in other unpaired bands is tied to the use of Frame structure type 2. Band 46 is specified for inter-band carrier aggregation with several other bands, which is a necessity since stand-alone LAA operation in Band 46 is not specified.

22.14.1 REGULATORY REQUIREMENTS FOR THE UNLICENSED 5 GHz BAND

The frequency range 5150−5925 MHz is available in most regions of the world for unlicensed (sometimes called license exempt) operation. The regulation that applies to the band varies from region to region and the type of service that can be used also varies. There are however many similarities in the regulation, while the terminology used for the service differs. There is also an evolution of the use of the band, with the intention of making a larger part of the band available for radio LAN services such as WiFi.

Since LAA operation in Release 13 is defined for downlink only, there are no transmissions from the terminal. This also means that there is no specific regulation that applies to the terminal for band 46 operation. In later releases when uplink operation is added, the regulation will also apply for terminals, but in Release 13 it will thus only apply for base stations.

There is a range of different regional regulatory requirements applicable for operation in the 5 GHz band and they are all applicable to LAA operation. The regulatory requirements can be divided into three different types:

- *Emission limits*: These include limits on maximum transmitter power, peak conducted power, average PSD, directional antenna gain, maximum mean EIRP (effective isotropic radiated power), EIRP density, EIRP elevation angle mask, and OOB emissions.
- *Functional requirements*: These include requirements to have specific TPC, dynamic frequency selection (DFS), and clear-channel assessment such as listen before talk (LBT).

- *Operational requirements*: These requirements restrict operation to indoor use in several frequency ranges.

Most of the regulatory emission limits are related to transmitted power and unwanted emissions, in terms of absolute level, density, or EIRP. There are different types of requirements and limits defined on global level (WRC), plus regional and national regulation for Europe, USA, China, Israel, South Africa, Turkey, USA, Canada, Brazil, Mexico, China, Japan, Korea, India, Taiwan, Singapore, and Australia [57]. There is a substantial variation between regions and countries.

It would not be realistic to cover this whole variation of regional requirements in the BS specifications and covering only a subset could be viewed as discriminatory. The regulation is also continuously updated, making it difficult to maintain an up-to-date specification. It will instead be up to each vendor of equipment supporting LAA that the requirements that are applicable to equipment sold in each region and country are met.

For this reason, the corresponding RF requirements are specified in 3GPP with a single number for each limit of the concerned requirements, such as max BS power and unwanted emissions. The limit is selected to give a broad coverage in terms of regulation. No more specific limits and details are given. Regarding how the regulation is applied, the following can be noted:

- Limits defined based on EIRP cannot be directly applied as an RF requirement in the 3GPP BSs specifications [47]. The reason is that all BS RF requirements are defined as conducted requirements and are specified at the antenna connector. Specification of the antenna, which directly affects the EIRP, is not part of the RF specification. There is however an informative guideline given for assessing such regulatory EIRP-related limits.
- Functional requirements are also specific to regions and have a large variation. The only one fully covered in 3GPP specifications is the clear-channel assessment through LBT.
- Operational requirements are in general not applicable for the RF specifications, since they do not specify a property of the equipment as such, but are more related to how the equipment is deployed and operated.

22.14.2 SPECIFIC BS RF REQUIREMENTS FOR LAA OPERATION

As stated before, Band 46 is available in many parts of the world, but it is not fully available anywhere and the regulation varies between regions and countries. An overview of how the band is assigned is given in Section 17.1. Since LAA operation in Release 13 is defined for downlink only, there are no receiver requirements defined for the BS, except for the functional requirements related to downlink channel access.

In order to reflect this variation of regulation in the specification, Band 46 is divided into four subbands as shown in Table 22.6. The subbands cover the complete band range 5150–5925 MHz, except for the range 5350–5470 MHz, which is presently not available for this kind of service in any region. The situation is the same for the upper part of subband 46D, but is under consideration in several regions.

Table 22.6 Division of Band 46 into Subbands for the BS

Band 46 Subband	Frequency Range
46A	5150–5250 MHz
46B	5250–5350 MHz
46C	5470–5725 MHz
46D	5725–5925 MHz

The division into subbands makes clear which parts of the band are available for operation globally and it can also serve as a reference for base station vendors when designing BSs, in order to describe which parts of Band 46 that are supported and under what conditions. There is no corresponding division into subbands for the terminal.

With regard to LAA-specific RF requirements defined for a BS, the following apply:

- *RF carrier raster*: Normally, LTE carriers may be placed on any carrier position on the predefined 100 kHz carrier raster. For operation of LTE BS, there is however a need to coexist with existing services in the 5 GHz band, including Wi-Fi. For this reason, the possible carrier raster position an LAA BS can use is limited to a set of 32 positions that are aligned with the possible Wi-Fi carrier positions. In order to also allow for LTE carrier aggregation, where the spacing between component LTE carriers should be a multiple of 300 kHz, it is also possible to use the carrier raster positions within ±200 kHz of the 32 aligned ones.
- *BS output power*: There are no specific maximum power limits defined for operation of an LAA BS. The power levels allowed by regulation vary, but fall in general under the local area BS class and in some cases under the Medium Range BS class.
- *Adjacent channel leakage ratio (ACLR)*: The ACLR requirement for LAA BSs is 10 dB lower in the first adjacent channel and 5 dB lower in the second adjacent channel. The reason is that in an interference environment with other unlicensed BS and devices operating, including Wi-Fi equipment, an ACLR requirement at a level of 35–40 dB is sufficient. The CACLR requirement is also 10 dB lower at 35 dB.
- *Base-station operating band unwanted emission limits*: A new spectrum mask is introduced for operation in the 5 GHz band. The mask is defined as on operating band unwanted emission limit across the full band, is based on the regulatory mask applied in Europe [58], and is also similar to the mask defined for Wi-Fi equipment.
- *Downlink channel access*: The LBT mechanism used for downlink channel access is described in Section 17.3.2 and it is a regulatory requirement in many regions for certain bands. It is an assumption that it will be implemented in all BSs. This means that also for downlink-only operation, there will still be a requirement to have a BS receiver, in order to perform clear channel assessment using LBT. A set of parameters is predefined to be used for the LBT mechanism. The set includes an LBT measurement bandwidth, an energy detection threshold, and a maximum channel occupancy time.

22.14.3 SPECIFIC TERMINAL RF REQUIREMENTS FOR LAA OPERATION

The same definitions as related to Band 46 operation are defined for a terminal in LAA operation, except that the full band 5150−5925 MHz is specified for LAA operation, with no subbands or carrier raster restrictions defined. The reason is that terminals should be salable globally and able to roam across countries and regions, in order to get economy-of-scale for the terminal vendors and improve the experience for global users. This also means that terminals will be more future-proof, and can still be used if regulation evolves in terms of what subbands are deployed and what exact RF carrier positions are used.

Since LAA operation in Release 13 is defined for downlink only, there are only requirements defined for the terminal receiver, not the transmitter. The following LAA-specific RF requirements apply for a terminal:

- *RF carrier raster*: The usual 100 kHz LTE carrier raster applies for the terminal without any restrictions, as for other bands.
- *Adjacent channel selectivity*: A modified requirement for carrier aggregation is defined, where the interfering signal is scaled to a larger bandwidth of 20 MHz.
- *In-band blocking*: A modified requirement for carrier aggregation is defined, where the interfering signal is scaled to a larger bandwidth of 20 MHz.
- *Out-of-band blocking*: The blocker level is defined to be 5 dB lower for frequencies above 4 GHz, due to implementation with full-band 5 GHz RF filters.
- *Wideband intermodulation*: A modified requirement for carrier aggregation is defined, where the interfering signal is scaled to a larger bandwidth of 20 MHz.

22.15 RF REQUIREMENTS FOR BS WITH ACTIVE ANTENNA SYSTEMS

For the continuing evolution of mobile systems, advanced antenna systems have an increasing importance. While there have been several attempts to develop and deploy BSs with passive antenna arrays of different kinds for many years, there have been no specific RF requirements associated with such antenna systems. With RF requirements in general defined at the base station RF antenna connector, the antennas have also not been seen as part of the base station.

Requirements specified at an antenna connector are referred to as *conducted requirements*, usually defined as a power level (absolute or relative) measured at the antenna connector. Most emission limits in regulation are defined as conducted requirements. An alternative way is to define a *radiated requirement*, which is assessed including the antenna by accounting for the antenna gain in a specific direction. Radiated requirements require more complex *over-the-air* (OTA) test procedures using, for example, an anechoic chamber. With OTA testing, the spatial characteristics of the whole BS including the antenna system can be assessed.

For base stations with *active antenna systems* (AAS), where the active parts of the transmitter and receiver may be an integral part of the antenna system, it is not always suitable to maintain the traditional definition of requirements at the antenna connector. For this purpose, 3GPP developed RF requirements in Release 13 for AAS base stations in a set of separate RF specifications.

The AAS BS requirements are based on a generalized AAS BS radio architecture, as shown in Figure 22.13. The architecture consists of a *transceiver unit array* that is connected to a *composite antenna* that contains a *radio distribution network* and an *antenna array*. The transceiver unit array contains multiple transmitter and receiver units. These are connected to the composite antenna through a number of connectors on the *transceiver array boundary* (TAB). These TAB connectors correspond to the antenna connectors on a non-AAS base station and serve as a reference point for conducted requirements. The radio distribution network is passive and distributes the transmitter outputs to the corresponding antenna elements and vice versa for the receiver inputs. Note that the actual implementation of an AAS BS may look different in terms of physical location of the different parts, array geometry, type of antenna elements used, and so on.

For an AAS BS, there are two types of requirements:

- *Conducted requirements* are defined for each RF characteristic at an individual or a group of TAB connectors. The conducted requirements are defined in such a way that they are in a sense "equivalent" to the corresponding conducted non-AAS requirement, that is, the performance of the system or the impact on other systems is expected to be the same. All non-AAS RF requirements (see Sections 22.6 to 22.11) have corresponding AAS conducted requirements.

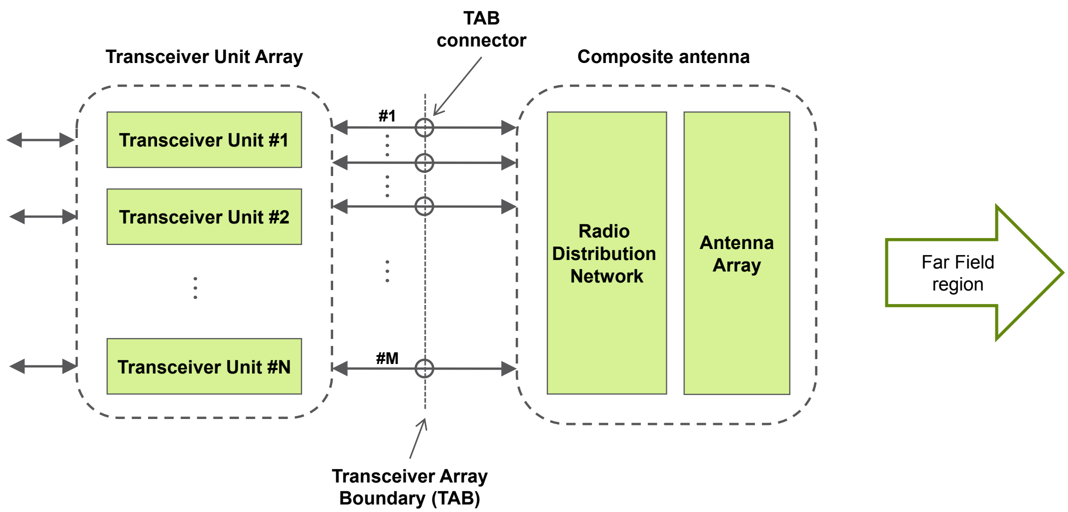

FIGURE 22.13

Generalized radio architecture of an active antenna system.

- *Radiated requirements* are defined over-the-air in the far field of the antenna system. Since the spatial direction becomes relevant in this case, it is detailed for each requirement how it applies. Radiated requirements are defined for *radiated transmitter power* and *OTA sensitivity* and these two do not have a direct corresponding non-AAS requirement.

The radiated transmitter power is defined accounting for the antenna array beamforming pattern in a specific direction as *effective isotropic radiated power* (EIRP) for each beam that the BS is declared to transmit. In a way similar to BS output power, the actual requirement is on the accuracy of the declared EIRP level.

The OTA sensitivity is a requirement based on a quite elaborate declaration by the manufacturer of one or more *OTA sensitivity direction declarations* (OSDD). The sensitivity is in this way defined accounting for the antenna array beamforming pattern in a specific direction as declared *equivalent isotropic sensitivity* (EIS) level toward a receiver target. The EIS limit is to be met not only in a single direction but within a *range of angle of arrival* (RoAoA) in the direction of the receiver target. Depending on the level of adaptivity for the AAS BS, two alternative declarations are made:

- If the receiver is adaptive to direction, so that the receiver target can be redirected, the declaration contains a *receiver target redirection range* in a specified *receiver target direction*. The EIS limit should be met within the redirection range, which is tested at five declared sensitivity RoAoA within that range.
- If the receiver is not adaptive to direction and thus cannot redirect the receiver target, the declaration consists of a single sensitivity RoAoA in a specified receiver target direction, in which the EIS limit should be met.

The characterization of AAS BS through the requirements on radiated transmitter power and OTA sensitivity provides the flexibility to account for a range of AAS BS implementations with different types of adaptivity.

It is expected that more requirements will be defined as OTA requirements in coming releases of 3GPP specifications. Also for 5G systems, including LTE Evolution, it is expected that RF requirements for AAS BS will be an essential part of the specifications, since multi-antenna transmission and beam forming will play a major role as a component of 5G (see also Section 24.2.5). Such systems using digital beam forming would have active antennas and the RF requirements would be specified as for AAS BS. It is also expected that there will be multi-RAT BSs which combine LTE Evolution and the new 5G radio access in the same BS hardware, making AAS BS supporting multiple RATs a possibility, when they operate in the same or in nearby frequency bands.