UDC 621.391, 621.396

OBTAINING CONDITIONS FOR TECHNOLOGY NEUTRALITY OF COMMUNICATION SYSTEMS WITH MINIMUM COUPLING LOSS METHOD

Volodymyr I. Korsun, Anatolii V. Tychynskyi

Ukrainian State Centre of Radio Frequencies, Kyiv, Ukraine

Background. Technology neutrality is widely used in frequency bands, where communication systems are evolving, but there are strict restrictions on the parameters and deployment of base stations of different technologies using adjacent channels. Ways to mitigate this effect have not been sufficiently studied and require further analysis and development.

Objective. The purpose of this article is to investigate the methodology for obtaining technical conditions of technological neutrality with minimum coupling loss method to determine the value of additional filtering requirements and present the results of practical implementation of this technique.

Methods. The method of detailed power analysis of frequency characteristics of filters for base stations' transmitter and receiver is applied.

Results. The article presents the results of obtaining minimal guard band and additional filtering requirements in the adjacent channels of transmitter and receiver belonging to different technologies. Examples of practical implementation of the minimum guard band and frequency characteristics of additional filters are given.

Conclusions. The general method of determining the technical conditions for ensuring technology neutrality is presented and the value of the minimal required guard band between the adjacent transmitter and receiver channels is obtained.

Keywords: parameters of compatibility; adjacent channel leakage; adjacent channel selectivity; minimal guard band; additional filtering; steepness of frequency response.

Introduction

The diversity and high-speed evolution of modern mobile technologies have led to a shortage of radio spectrum resource. The same frequency bands can be used by traditional technologies of different generations, with different channel widths, radiation power, duplex mode FDD (Frequency Division Duplex) or TDD (Time Division Duplex), different antennas, including massive MIMO and AAS (Active Antenna Systems) 5G technology. Given the different national frequency allocations, this leads to significant restrictions on the introduction of new technologies, such as undue frequency guard band between adjacent channels of two different technologies, restrictions on radiation power, restrictions on deployment of base stations (BSs) in the service and border areas, etc. Therefore, the defined frequency bands that fall under the concept of Technology Neutrality (TN) or Wireless Access Policy for Electronic Communications Services (WAPECS) [1], [2], 3] are harmonized at the regional level within European Conference of Postaland Telecommunications Administrations (CEPT) by developing of the least restrictive technical conditions (LRTC). Due to LRTC, it is possible to overcome a considerable number of limitations in the technology evolution process that occurs in certain frequency bands. However, in cases of substantial differences in national frequency allocations for most cases of conflicting frequency plans for communication systems in a common frequency band, such as FDD-TDD, there is a need of coordination the location of BSs for different communication systems. As a result of that the spectrum is used inefficiently. CEPT has investigated many conflict situations between the frequency plans for different communication systems in the frequency bands that fall under the concept of TN.

Meanwhile, the issue of BSs deployment for planned network in case of conflicting frequency plans remains a national priority due to the complexity of implementation of additional changes in the characteristics of BSs transmitters and receivers at global and even at regional levels. The practical characteristics of the operating BSs equipment remain unchanged and are determined by pre-agreed standards at ITU and CEPT level for agreed frequency allocations and frequency plans in defined frequency bands, while national allocation and frequency plans obviously can be different and therefore are forcing to find the way how to change characteristics of operating BSs in order to reach compatibility between systems by practically available method while saving maximum licensed spectrum.

Tasks for study

The analysis of theoretical and practical research [4], [5], [6] shows the possibility of practical implementation of the requirements for additional filtering in adjacent channels of the transmitter and receiver of different communication technologies in case of inconsistent frequency plans at the national level. The introduction of new equipment characteristics allows deploy BSs with use adjacent channels of different technologies even at a distance limited by the size of the common site, without coordination between operators, though with subsequent coordination of spatial parameters of antennas directly on site to achieve the necessary isolation between receivers and transmitters of relevant BSs. The main difficulty in solving this task is the practical realization of characteristics defined for the filters, which are significantly steep due to strict requirements for interference suppression. Therefore, it is essential to consistently consider the requirements for additional filtering separately for the transmitter and receiver, determining such levels of requirements, when their implementation can already be achieved in practice.

The results of existing studies are usually limited to recommendations for restricted radiation power or deployment density of BSs, coordination of deployment sites [6], the introduction of a frequency guard band [7], sometimes excessive, which reduces the efficiency of spectrum use. Thus, in most cases [7], [8], [9], [10], [11] and without additional restrictions, the frequency guard band can reach twice the width of the broadband channel or such spectrum of useful destination is changed on another one for low-power applications [7] or requirements remain only defined without recommendations on how to implement them in practice [11].

To determine the requirements for additional filtering, it is necessary: to select the appropriate compatibility model; to determine with the help of this model the general requirements for BSs isolation; to obtain the minimum technical requirements for carriers offset and choose the method of its implementation. The remaining additional filtering requirements can already be implemented by upgrading the characteristics of proper transmitter and receiver filters for BSs of relevant communication systems, which are planned for use in adjacent frequency bands.

The purpose of this article is to present the theoretical approach how to obtain the technical conditions and to show the example of practical implementation of additional filtering for ensuring technological neutrality by determining the value of the frequency guard band between adjacent channels of different communication technologies with Minimum Coupling Loss (MCL) method.

The guard band determined in this way is insufficient for necessary isolation of BSs located at short distances, but is already sufficient for the practical aproaching of the characteristics required for the additional filters in order to achieve the proper isolation between BSs.

MCL compatibility model

The least restrictive technical conditions are determined by performing compatibility analysis for networks and systems in a certain frequency range using the parameters of networks and systems expected in the range, and in the absence of interference under a certain compatibility criterion. If the system meets the requirements of LRTC according to a certain compatibility criterion, then, regardless of the technology, it meets the TN concept conditions.

TN concept provides 6 different compatibility models [3], which are used depending on the chosen system interaction scenario. The MCL method is the best known and most common model of compatibility of different systems using compatibility parameters such as the transmitter's Adjacent Channel Leakage Ratio (ACLR) and the receiver's Adjacent Channel Selectivity (ACS). These parameters together determine the Adjacent Channel Interference Ratio (ACIR) and are related as [3] (in linear values):

$$ACIR^{-1} = ACLR^{-1} + ACS^{-1}, \quad (1)$$

where: $ACIR = P_{ADJ} / P_{IALLOW}$, (2)

P_{ADJ} - interference power from the adjacent channel of the transmitter determined at the input of the receiver;
P_{IALLOW} - allowed (permitted) or "sensitive" (experienced) interference power at the input of the receiver;

$$P_{IALLOW} = P_N \times INR, \quad (3)$$

where: P_N - power of the receiver's thermal noise;
INR - Interference-to-Noise Ratio (I / N), needed to keep the sensitivity degradation of the receiver at no more than X dB;

$$ACLR = P_{EIRP}/P_{OOBE}, \quad (4)$$

where: P_{EIRP} - equivalent (effective) isotropically radiated power (EIRP) of the transmitter;

P_{OOBE} - Out of Band Emission (OOBE) power in the adjacent transmitter channel;

$$ACS = P_{IBL} / P_{IALLOW}, \quad (5)$$

where: P_{IBL} - interference blocking power at the input of receiver.

The value of ACIR shows the required degree of isolation between the transmitter and receiver of two BSs relating to different systems and operating in adjacent frequency bands, when due to imperfect filtering in the channels of the transmitter and receiver (Fig. 1) there is a possibility to impact one to another.

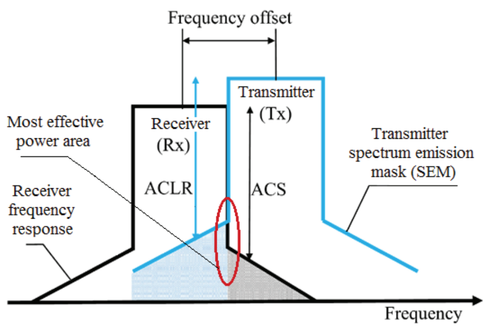

Fig. 1. Explanation for the physical content of ACLR and ACS parameters [12,13]

Particularly, imperfect filtering in the transmitter channel creates powerful out-of-band emission, which penetrates the receiver adjacent channel under certain conditions and degrades its sensitivity, and imperfect filtering in the receiver channel helps the part of the main radiation from transmitter adjacent channel penetrate to receiver and can block the receiver.

The main factor in this power effect is the value of the frequency offset or guard band between the channels of transmitter and receiver. That is the reason why the task of the study is the determination of such guard band so that in the further study it comes possibility to "couple" or adapt one system to another in a practical way.

The calculation of the required ACLR and ACS is carried out under the condition of a certain separation distance between the BSs of different systems and by taking into account the real values of channel widths, in-system inter-channel guard intervals and frequency raster (grid of channel carriers) of system equipment. Such obtained ACLRs and ACS are theoretical requirements for the equipment characteristics of BS receiver and transmitter of different systems, which makes it possible to deploy networks in a common area without coordination or with minimal coordination of BSs locations for systems belonging to different operators.

Real transmitters and receivers have their own values of ACLR and ACS, which are determined by the harmonized standards and could not be worse than standardized values. But these ACLRs and ACSs are defined by the requirements of inter-channel compatibility in the networks of a single standard communication system.

The difference between calculated and standardized ACLR and ACS shows how much ACLR and ACS of real equipment needs to be improved by additional filtering in order to reduce the interference and mutual coordination requirements for BSs locations. The final goal of analysis these characteristics is to find the optimal technical and regulatory solution for placing different communication technologies in adjacent frequency bands in order to save and ensure efficient use of spectrum.

An example of an MCL method is addressed to a BS-BS interaction scenario in which the transmission power is high and the corresponding antennas have high gain and are within range of each other when the radio propagation conditions approach free space conditions. This is obviously the case for macro-cellular BSs shown in Fig. 2 for the similar case [7] of the study.

Formula (1) is represented in logarithmic values through the parameters of the transmitter Tx and the receiver R_X as:

$$ACIR = P_{ADJ} - P_{IALLOW} = (P_{EIRP} - G_{Tilt} - G_{PL} - G_{Tilt} + G_A) - (P_N + INR), \quad (6)$$

where: G_{Tilt} – directivity loss due antenna tilt T_X and R_X, dB;

G_{PL} – propagation path loss (PL) in free-space conditions [15], dB,

$$G_{PL} = 32.5 + 20\, log_{10}(f) + 20\, log_{10}(d), \quad (7)$$

where: f - carrier in MHz; d – separation distance between BSs, km;

G_A – antenna gain of receiving BS.

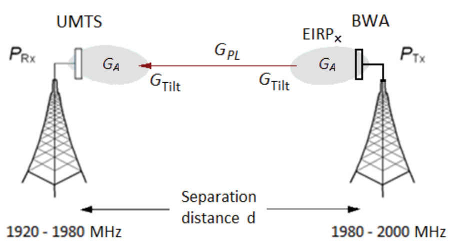

Fig. 2. Interference scenario and parameters of the BSs interaction at a separation distance

According to the assumptions in the main CEPT reports [3, 7] on the provision of TN, the ACIR is calculated for the distance between the BSs of 100 m. Such or less distance implies some kind of cooperation (coordination) between operators, which may include the proper choice of carrier frequencies and / or antenna orientation, or any other kind of interference mitigation tool. In order to facilitate such cooperation, at the request of the operators, the coordination distance may be limited to the size of the common area / site (e.g. 30 m), when it is easier to agree on the necessary changes in the antenna parameters. However, in this case, the restrictions on the respective characterstics and parameters of the transmitter and receiver will be more strict.

The ACIR calculation was performed for the case of a conflict situation [14] that arose around the frequency 1980 MHz when determining the compatibility conditions between the neighboring uplink (UL- uplink) channel of the introducing UMTS / WCDMA mobile communication system and the downlink (DL- downlink) channel of the acting broadband wireless access (BWA)/ OFDMA system around the frequency 1980 MHz. At the beginning of the study, the required guard band was not determined. As in previous similar scenarios of interference impact [3], [7], [8], [9], [10], [11], [16] the increase in P_N noise power by 1 dB was taken as the criterion of sensitivity degradation. The values of other parameters according to the interference scenario (Fig. 2) are determined from the data of current standards and are given in Table 1. The calculation was performed for the distances between BSs of d_1 = 100 m [7] and d_2 = 30 m.

For a separation distance of 100 m, the $ACIR_{100}$ was defined of 101 dB [7].

Table 1. Parameters of BWA BS transmitter and the UMTS BS receiver, which were taken into account in the calculations

Parameter symbol	**Parameter name**	**Value and measurement symbol**	**Reference**
Transmitter of BWA / OFDMA BS			
P_{EIRP}	Equivalent isotropically radiated power	61 dBm/5 MHz	ETSI TS 136 104 [17]
G_{Tilt}	Antenna gain tilt loss	3 dB	-2,5°
G_{PL}	Free-space wave propagation loss	79 dB/d_1 68 dB/d_2	Recommendation ITU-R P.525-4 [15]
ACLR	Adjacent Channel Leakage Ratio	45 dB/50dB (1-st channel/2-nd channel)	ETSI TS 136 104 **Ошибка! Источник ссылки не найден.**
SEM	Spectrum Emission Mask of T_X		Table 6.6.3.2.2-1[17]
Receiver of UMTS / WCDMA BS			
B_{NOM}	Channel nominal bandwidth	5 MHz	ETSI TS 125 104 [18]**Ошибка! Источник ссылки не найден.**
B_T	Information bandwidth	3,84 MHz	
N_F	Noise figure	5 dB	
P_N	Noise power of R_X	-102 dBm	kTB_{NOM} N_F
P_{RxMIN}	Reference sensitivity level	-121 dBm	
P_{RxIM}	Receiver sensitivity level for intermodulation (IM) interference of 3-d order	-48 dBm (offset ±20 MHz)	Table 7.6 [18]
P_{IBL}	Receiver sensitivity level for blocking interference	-52 dBm (1-st adjacent block) -40 dBm (2-nd adjacent block)	Table 7.3 [18] Table 7.4
ACS	Adjacent Channel Selectivity (1980-1985 MHz/ 1985-1990 MHz)	46 dB/58 dB (1-st channel/2-nd channel)	Table 12 [18]
X	Threshold degradation criterion of C/N (Carrier to Noise) ratio	1dB	[12]
INR	Interference-to-Noise ratio	-6 dB	[12]
P_{IALLOW}	Allowed interference power at the input of receiver	-108 dB	P_N + INR
G_A	Antenna gain	17 dBi	
G_{Tilt}	Antenna gain tilt loss	3 dB	

For a separation distance of 30 m $ACIR_{30}$ is equal to:

$$ACIR_{30} = P_{ADJ} - P_{IALLOW} = (P_{EIRP} - G_{Tilt} - G_{PL} - G_{Tilt} + G_A) - (P_N + INR) = (61 - 3 - 68 - 3 + 17) - (-102 - 6) = 112\ dB$$

Since the effective suppression of interference on the adjacent channel is determined by a combination of two parameters ACLR and ACS, respectively, the equality of these parameters as a fair requirement can be considered in order to impose equal requirements on equipment and responsibilities for operators of both systems. If we put the contributions from BWA ACLR and UMTS ACS equal in achievement, for example, ACIR = 112 dB, then it follows that ACS = ACLR = 115 dB. The required 112 dB ACIR level can be achieved by various combinations of ACLR and ACS. The ACIR curve as a function depends on the obtained ACLR and ACS for distances of 30 and 100 m is shown in Fig. 3.

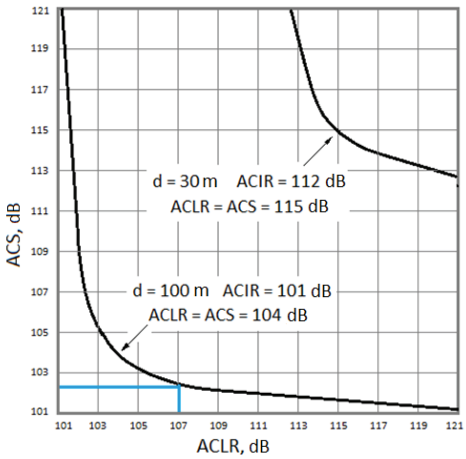

Fig. 3. ACIR dependence on BWA ACLR and UMTS ACS

Thus, depending on the technical capabilities of filters and additional frequency guard band, greater restrictions may be placed, for example, on the interfering transmitter (ACLR = 107 dB for ACIR = 101 dB in Fig. 3). Then smaller restrictions can be applied to the interfered receiver (ACS = 102.2 dB in blue in Fig. 3) and vice versa, smaller restrictions can be applied to the transmitter and larger to the receiver (for example, ACLR = 102.2 dB and ACS = 107 dB).

According to formula (4) we obtain the P_{OOBE} level or the basic radiation level of the transmitter in the adjacent under conditions of different distances between BSs antennas:

$$P_{OOBE}(d_1) = P_{EIRP} - ACLR = 61 - 104 = -43\ dBm / 5\ MHz;$$

$$P_{OOBE}(d_2) = P_{EIRP} - ACLR = 61 - 115 = -54\ dBm / 5\ MHz$$

Obtained P_{OOBE} values for BWA give an opportunity to assess the requirements for additional suppression of out-of-band emission compared with P_{OOBE} level defined by the requirements of the standard for BWA, as well as to identify possible technical solutions for the practical implementation of such requirements. To determine the technical measures to achieve the required isolation between the UMTS and BWA BSs, it is necessary to refine the parameters of SEM, ACLR and ACS according to the current standards, produced equipment and practical measurements.

Evaluation of SEM and ACLR values according to standards, produced equipment and practical measurement

Evaluation of values is based on references and practical information that are analogs and facilitate to the solution of the problem. The SEM evaluation of the LTE / OFDMA BS transmitter as analog of BWA/OFDMA BS is performed according to the 3GPP TS 36.104 v.11.2.0 technical specification [17].

Power limits of unwanted emission for BS BWA are estimated according to the IMT / LTE for the 36.104 v.11.2.0 and presented in Table 6.6.3.2.2-1 (Category B (Europe), Option 2), [17], p. 41. Graphical representation of the left edge of the spectrum emission mask (SEM) for IMT / LTE BS signal in accordance with mentioned above table is shown in Fig. 4.

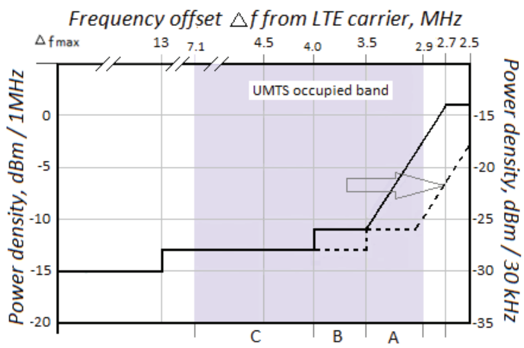

Fig. 4. Left edge of SEM (f ≤ 1980 MHz) for the IMT / LTE BS transmitter channel [17]

The P_{OOBE} power level is represented in the 30 kHz and 1 MHz measuring bands, respectively, depending on the frequency offset Δf from the edge of the LTE channel with nominal width of 5 MHz. Given the fact that the occupied bandwidth of the UMTS BS transmitter according to the measurement results is of 4.2 MHz at the level of -26 dB, the width of the receiver filter shown in grey background in Fig. 4. The bandwidth for a channel with nominal width of 5 MHz is 4.5 MHz according to specfied limits of unwanted emission for BS BWA are estimated according to the IMT / LTE for the band 33 (3GPP) 1900-1920 MHz / TDD in accordance with technical specification 3GPP TS 36.104 v.11.2.0 and presented in Table 6.6.3.2.2-1 (Category B (Europe), Option 2), [17], p. 41.

The occupied bandwidth for the LTE channel with nominal width of 5 MHz is 4.5 MHz (Table 5.6-1 [17]). Thus, the guard interval for the left edge of the transmitter channel is 0.25 MHz. The guard interval for the right edge of nominal UMTS channel width of 5 MHz will be 0.4 MHz, and the total spacing between the edges of occupied channels (guard band between channels) will be: 0.25 + 0.4 = 0.65 MHz. Accordingly, the P_{OOBE} value of the transmitter should be determined for the range from 2.9 to 7.1 MHz from the LTE carrier.

LTE out-of-band emission affects the operation of UMTS receivers in the crossover area of the occupied UMTS band, which can be divided into three sections: A, B and C with different levels of P_{OOBE}. Then the total power of the LTE P_{OOBE} falling in to UMTS channel band can be defined as:

$$P_{OOBE}, dBm = 10 \cdot \log\left(10^{\frac{P_A}{10}} + 10^{\frac{P_B}{10}} + 10^{\frac{P_C}{10}}\right) = = -4{,}3\ dBm/4{,}2\ MHz, \quad (8)$$

where: $P_{OOBE\ A}$ = - 7.7 dBm in the band 0.6 MHz; $P_{OOBE\ B}$ = - 13.8 dBm in the 0.5 MHz band; $P_{OOBE\ C}$ = - 8.1 dBm in the band 3.1 MHz, respectively. The value of referenced $ACLR_{REF}$ is defined by formula (4) as: $ACLR_{REF} = P_{EIRP} - P_{OOBE}$ = 61 + 4.3 = 65.3 dB. Thus, to provide the required ACIR isolation of 101dB (100m separation distance), additional suppression L_{ADD} in the LTE transmitter channel must be at least: L_{ADD} = ACLR - $ACLR_{REF}$ = 104 – 65.3 = 38.7 dB, and to provide 112 dB ACIR (30 m separation distance), L_{ADD} must be at least: 115 – 65.3 = 49.7 dB (Table 3).

Table 3. Required additional suppression (L_{ADD}) in the LTE transmitter channel, determined according to SEM [17] and assigned to the occupied band of the UMTS receiver

Separation distance, m	100	30
Isolation needed (ACIR), dB	101	112
ACLR required, dB	104	115
P_{OOBE} , obtained from SEM, dBm/4,2 MHz	-4,3	-4,3
$ACLR_{REF}$, dB	65,3	65,3
L_{ADD}, dB/4,2 МГц	38,7	49,7

Determination of the minimal guard band between UMTS and LTE channels

To assess the effect of frequency offset between UMTS and LTE channels on the LTE P_{OOBE} in the adjacent UMTS channel band and, accordingly, the ACLR value, let us conditionally move the SEM LTE mask to the right (dotted line in Fig. 4) from the edge of the UMTS channel and recalculate P_{OOBE}.

Significant reduction of P_{OOBE} is already achieved by removing sections A and B, which provide a decrease in the level of P_{OOBE} with maximum steepness, outside the occupied UMTS band, i.e. with additional shift between channels of at least 1 MHz (Fig. 5). This allows us to conclude about the *required minimal guard band* to ensure a significant reduction in the impact of the OOBE and reduce the requirement for the steepness of the frequency response of the additional transmitter filter.

From Fig. 5 it follows that the minimal required guard band between the edges of the occupied UMTS and LTE bands ($\Delta f_{T\text{-}R}$) is 2.05 MHz. This is the guard band that provides almost achievable practically steepness of the

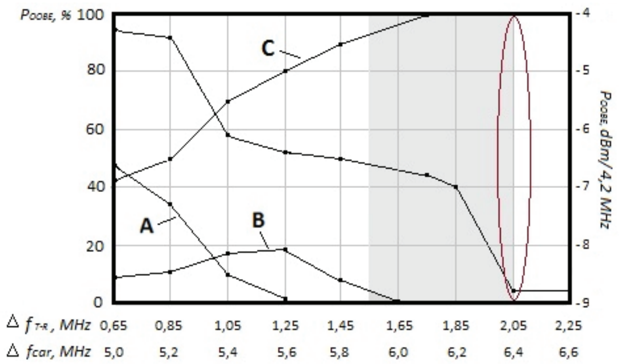

Fig. 5. P_{OOBE} BS LTE level inside the UMTS channel as dependence on the guard band between the edges of the occupied bands of LTE and UMTS channels ($\Delta f_{T\text{-}R}$) and between carriers (Δf_{car})

frequency characteristic for the additional filter of the BS LTE transmitter under the condition of relaxed requirements for coordination between operators on the spatial parameters of the UMTS and LTE BSs antennas. Subject to additional coordination between operators, the guard band in the range of 1.5 - 2.05 MHz (marked with a gray background) can be considered as practically suitable either.

It should be noted that, even with additional channel spacing, the standard SEM mask does not provide isolation requirements at close location of the UMTS and LTE BSs.

Obviously, to assess the practical requirements, it is necessary to use SEM data obtained from produced equipment, and the mask itself must be subject to *spe-*

cific requirements for the steepness of the frequency response for the transmitter filter, which would allow realization the minimum separation between adjacent channels $\Delta f_{T\text{-}R}$, for example, of 1.5 MHz (total protection interval 2 x 0.75 MHz, if there are equal requirements for protection intervals of 0.75 MHz in UMTS and LTE channels), to obtain the P_{OOBE} level not more than - 42.2 dBm / 4.2 MHz (d_1 = 100 m) and - 53.2 dBm / 4.2 MHz (d_2 = 30 m).

Example of practical implementation of the minimal separation for adjacent channels

The practical implementation of minimal separation between UMTS and BWA channels should be within the standard frequency plans for these technologies so as not to change the overall frequency band allocated for licensing of each technology, for example:

1. By changing the width of the adjacent BWA / OFDMA channel from 5 to 3 MHz according to standard [17]. Then, from the BWA channel to the frequency 1980 MHz, an additional protection interval of 2.15 MHz appears, which, when combined with the 0.4 MHz protection interval from UMTS adjacent channel, gives a total guard band of 2.55 MHz. This interval is sufficient to implement the minimum requirements for P_{OOBE}, but such technical decision is ineffective in terms of spectrum usage.

2. By introducing of the combined frequency plan for multi-standard base station MSR (Multi Standard Radio), for example, CDMA and LTE technologies, when it is possible to create a new configuration of carriers within first adjacent BWA channel based on the three CDMA channels with a standard channel width of 1.25 MHz, and for the remaining channels to keep the standard LTE frequency plan. CDMA's carriers are defined by the equipment manufacturer [19] and provide a protection interval of 0.8 MHz from left edge of the occupied band of the adjacent BWA channel to the frequency of 1980 MHz.

3. By reducing the internal guard intervals in UMTS channels through assigning non-standard carriers from the frequency raster. Shifting the carrier to the left by 100 kHz in each UMTS channel from the 15 MHz licensing block provides an increase in the total protection interval of 300 kHz. Thus, the total protection interval from the right edge of the occupied band of the adjacent UMTS channel to the frequency of 1980 MHz will be 0.7 MHz (Fig. 6).

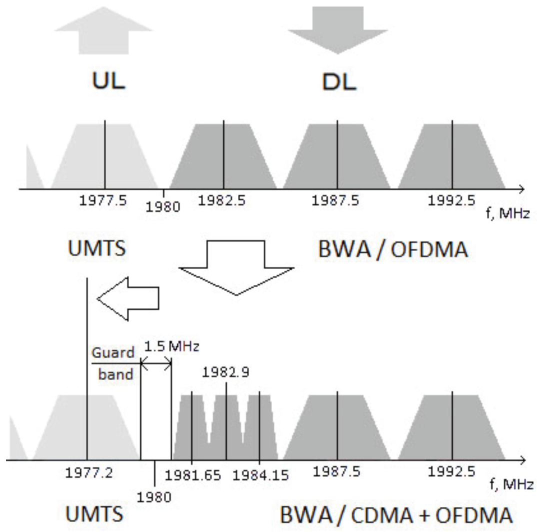

Fig. 6. New carriers plan for UMTS and hybrid BWA (CDMA+OFDMA) technology to increase the guard band

Fig. 6 explains the case of practically [16, 19, 20] implemented frequency plans for hybrid BWA technology with changing the configuration of BWA and UMTS carriers to increase the guard band between BWA and UMTS channels to 1.5 MHz. Only such value of guard band was mutually agreed between operators, although the equipment manufacturer set by introducing technical requirements with minimum value of the guard band of 2.5 MHz and produced a filter that corresponds to the carrier configuration for the adjacent UMTS channel in 1976.1 MHz instead of set by study results of 1977.2 MHz.

The results of measuring [21] the frequency response of the filter for BWA BS mixed (CDMA + OFDMA) technology to verify compliance with the requirements for distances d_1 and d_2 showed (Fig. 7) that the frequency response of the filter has an attenuation at test points 1974 and 1978, 2 MHz, respectively -57.93 dB and -52.63 dB, which satisfies the requirements for d_1 and d_2.

Due to the technical difficulty of direct measuring the low P_{OOBE} level at the filter output along with a strong transmitter signal, the P_{OOBE} power was determined with more accurate substitution method. The P_{OOBE} was measured for LTE / OFDMA signal with a channel width of 10 MHz in the upper filter band of the PCS duplexer (1980-2000 MHz) with a carrier frequency of 1995 MHz and a power of 45.8 dBm in the band 9, 015 MHz. The $P_{OOBE} \approx 18$ dBm / 4.2 MHz was determined with a carrier of 1986.1 MHz. The measured attenuation characteristic of the upgraded filter is presented on Fig. 7.

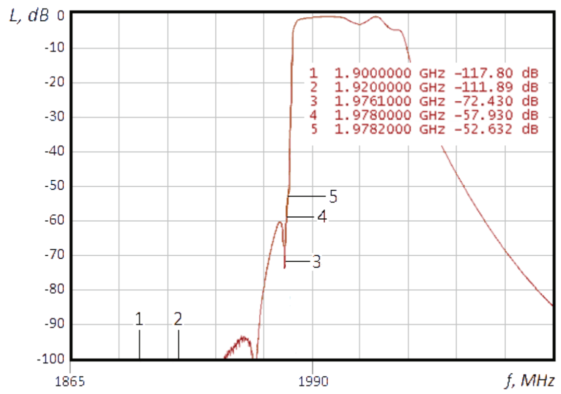

Fig.7. Measured attenuation characteristic of the upgraded filter

This is the frequency characteristic of readjusted upper duplexer filter of the transmitting RRH block (KS24829 model) for the PCS communication system (PCS - Personal Communication Service - Family of North American standards of IMT systems (including CDMA and OFDMA technologies), using the frequency bands 1850-1915 MHz (UL) and 1930-1995 MHz (DL), Band 25, according to 3GPP classification [17] in the frequency band 1980-2000 MHz.

The resulting P_{OOBE} power after the filter was determined as subtraction result between P_{OOBE} value measured by the substitution method and the average attenuation of the filter (P_{OOBE} - L_{ADD}, dB) in the 4.2 MHz band. The results are shown in Table 4.

Table 4. Measurement results of LTE / OFDMA signal in the 4.2 MHz band with the channel width of 10 MHz at a guard interval of 2.5 MHz between the edges of the occupied bands

Parameter	Calculated requirement (guard band 1.5 MHz)		Measured value (guard band 2.5 MHz)
	d_1 = 100 m	d_2 = 30m	
P_{OOBE} at the transmitter output	-4.3 dBm/4.2 MHz	-4.3 dBm/4.2 MHz	-17.99 dBm/ 4.2 MHz
L_{ADD} additional filter attenuation	**38.7 dB/4.2 MHz**	**52.7 dB/4.2 MHz**	**51.81 dB/4.2 MHz**
P_{OOBE} after filter	-43 dBm/4.2 MHz	-57 dBm/4.2 MHz	-69,8 dBm/4.2 MHz

Intermediate conclusion: the designed and produced / upgraded filter with additional suppression values for the BWA transmitter provides the following requirements for the P_{OOBE} level of the LTE / OFDMA signal with a channel width of 10 MHz with a guard band of 2.5 MHz:

P_{OOBE} requirement 1 (antennas separation of 100 m): not more than - 42.2 dBm / 4.2 MHz;

P_{OOBE} requirement 2 (antennas separation of 30 m): not more than - 53.2 dBm / 4.2 MHz.

Evaluation of ACS values according to standards, produced equipment and practical measurement

As mentioned above, both parameters ACLR and ACS determine the interference factor ACIR on the adjacent channel (formula (2)) and, in order to impose equal restrictions on the transmitter and receiver, their performance should be taken equal. In fact, the conditions under which ACLR and ACS are determined are different and, accordingly, the requirements for ACLR and ACS may also be different. If the ACLR is determined by the transmitter parameters (transmitter power and OOBE power) that can be measured directly on the transmitter, then it is not possible to measure the interference signal level from the adjacent transmitter channel to determine the ACS because interference filtering takes place inside the receiver.

Therefore, the 3GPP standards make assumptions about the high level of interference at the receiver's input, such as the level of blocking of the receiver, and the corresponding degradation of the receiver's sensitivity due to such interference. Thus, according to the technical specification [18], selectivity on the adjacent channel is a measure of the receiver's ability to process a useful signal, while suppressing a strong interference signal in the adjacent frequency channel. ACS is defined as the ratio of the external interference power to the interference power transmitted to the receiver input. The power of the interference at the input of the receiver can be expressed through the degradation of the sensitivity of the receiver. Thus, if the P_N – power of the receiver's noise is equal to:

$P_N = 10^{\frac{kTB+N_F}{10}}$, mW, then under the effect of interference the sensitivity degrades by X dB as

$$P_{N+I} = 10^{\frac{kTB+N_F}{10}} \times 10^{\frac{X}{10}} \text{ , } mW,$$

and interference power at the receiver input is equal to

$$P_I = 10 \lg \left\{ 10^{\frac{kTB+N_F+X}{10}} - 10^{\frac{kTB+N_F}{10}} \right\}, dBm \qquad (9)$$

According to the TS [18] for the UMTS BS receiver, the selectivity on the adjacent channel is determined in paragraph 7.4.1 of TS 125 104 under the following conditions: the bit error rate (BER) with a level of 0.001 must be maintained for a useful signal -115 dBm and interference signal with WCDMA modulation shifted by 5 MHz (i.e. in the band 1980-1985 MHz), and with average power of -52 dBm. In this case, the useful signal must exceed the standard (reference) sensitivity (-121 dBm) by 6 dB, i.e. the interference effectively degrades the sensitivity of the receiver by 6 dB.

Table 7.4 of TS 125.104 (band I: 1980-2000 MHz) presents the following blocking specifications for the UMTS BS receiver, when the receiver input has both a useful signal and an interferencee: BER = 0.001 must be maintained for a useful signal of -115 dBm and interference type WCDMA with an offset of 10 MHz (i.e. in the range 1985 - 1990 MHz), with an average power of -40 dBm. In this case, the useful signal must exceed the standard (reference) sensitivity (-121 dBm) by 6 dB, i.e. the interference effectively degrades the sensitivity of the receiver by 6 dB.

Taking into account (9) and the standard data, we obtained the allowable power at the input of the receiver and the ACS for the adjacent channels 1980-1985 and 1985-1990 MHz (Table 5).

If we consider the effect of interference due to the imperfect sensitivity of the UMTS receiver separately from the influence of out-of-band LTE emission, then ACS defined by standard provides protection of the receiver at a distance that can be determined by a formula similar to (1):

$$(EIRP_{LTE} - ACS_{UMTS}) - G_{Tilt\,1} - G_{PL} - G_{Tilt\,2} + G_{A\,UMTS} = P_{I\,ALLOW}\,, \quad (10)$$

where parameters are defined in logarithmic values from (1) and Table 5:

$(61 – 46) – 3 – G_{PL} – 3 + 17 = - 98$;

$G_{PL} = 124$ dB;

From formula (7) it follows:

$\log_{10}(d_{km})$, dB = (124 - 32,5 - 66)/20;

d = 18,8 km.

Therefore, at shorter separation distances between BSs, it is necessary to further suppress the interference from the adjacent channel *at the input circuit* of the UMTS receiver with an additional filter or adjust the lower filter of the UMTS duplexer (Fig. 8).

The required additional suppression L_{ADD} is defined as the difference between the ACS required to suppress the interference from the adjacent channel for the distance of the BS, for example, in 100 m, and the standard / real ACS: $L_{ADD100} = ACS_{100}$ - ACS.

Table 5. Determination of ACS values according to the TS [18] and equipment BTS Flexi WCDMA 2100, Nokia [23]

Parameter	**According to TS [18]**		**BTS Flexi WCDMA 2100, Nokia [23]**
Frequency band of interfered UMTS receiver, MHz	1975 <F< 1980	1975 <F< 1980	1975 <F< 1980
Frequency band of interfering LTE transmitter, MHz	1980 <F< 1985	1985 <F< 1990	1980 <F< 1985
Reference sensitivity P_{RxMIN}, dBm	-121	-121	-121
Wanted (useful) signal power P_{WANT}, dBm	-115	-115	-115
Adjacent channel interference power P_{ADJ}, dBm	-52		-32
Blocking interference power P_{IBL}, dBm		-40	-40
Intermodulation interference power P_{IIM}, dBm		-48	-30
Sensitivity degradation $X = P_{WANT} - P_{RxMIN}$, dB	6	6	6
Receiver noise figure N_F, dB	5	5	5
Transmitting data bandwidth B_T, Hz	3.84E+06	3.84E+06	3.84E+06
Receiver noise power, dBm: $P_N = 10\log(1.38e\text{-}23 \times 290 \times B_T) + N_F + 30$	-103.1	-103.1	-103.1
Allowed power at the input of receiver in 5 MHz band, dBm: $P_{IALLOW} = P_N + 10\log(10^{(X/10)}-1)$	-98.4	-98.4	-98.4
$ACS = P_{IBL} - P_{IALLOW}$, dB	46.4	58.4	66.4

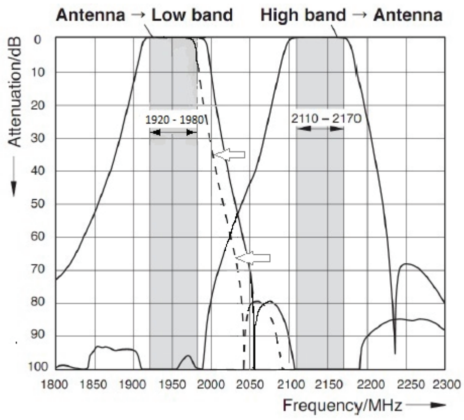

Fig. 8. Method of tuning (dashed line) frequency response of the lower filter for an acting UMTS duplexer [24]

Requirements for additional filtration can be obtained from formula (10) by setting the separation distance between BSs at 100 and 30 m, respectively. The results of the calculations of UMTS ACS values and the required additional suppression L_{ADD} for different kinds of interference are shown in Table 6.

Presented results should be clarified due to other interference effects in the UMTS receiver, which may occur simultaneously, in particular and mainly due to its own intermodulation (IM) of the broadband LTE signal in the frequency band 1980 -1990 MHz on the nonlinear characteristic of the mixer. A 3-rd order IM products will be generated in the UMTS receiver under certain frequency and amplitude conditions, when the resourse block (RB) carriers will simultaneously interact on the UMTS receiver mixer at frequencies $2f_1$ and f_2, where f_1 is any lower frequency from the band 1980 - 1985 MHz, and f_2 is the relevant upper frequency from the frequency band 1985 -1990 MHz so that the difference between the signals at the frequency $2f_1 - f_2$ falls in the band 1975-1980 MHz. It follows that the RB carriers that fall into the lower filter of the acting UMTS duplexer (Fig. 8) can be a source of potential interference.

To assess the impact of IM interference and the UMTS protection requirements needed, the method for determining ACS according to formula (9) and the data of Table 7.6 of TS 125.104 [18] (for all interference signal ranges, including 1980-2000 MHz) is used. By considering analogy with the blocking interference, we obtain the requirements for suppressing the IM interference signal: $P_{IM} - P_{OFDM} = -48 - (-98.4) = 50.4$ dB. A more accurate result can be obtained by summing the individual IM products formed by individual RB carriers as narrowband signals in the frequency band 1980-1990 MHz.

Table 6 UMTS ACS values and the required additional suppression of L_{ADD} for interference from LTE operating in frequency band 1980-1990 MHz according to the standard / for equipment BS Flexi WCDMA 2100

Kind of interference and origin band	**Separation distance between UMTS and LTE BSs**		
	1340 m	**100 m**	**30 m**
	ACS, dB	**Additional suppression needed L_{ADD}, dB/5 MHz**	
Adjacent channel interference, 1980-1985 MHz	46.4/66.4	45.6/25.6	**55.6**/35.6
Blocking interference, 1985-1990 MHz	58.4/58.4	32.7/32.7	**43.1**/43.1
Intermodulation interference, 1980-1990 (2000) MHz	50.4/68.4	40.7/22.7	**51.1**/33.1

In the general case, both interference from out-of-band emission of the transmitter and interference due to imperfect selectivity of the receiver act simultaneously, that corresponds to the real situation when planning networks. However, in order to simplify the theoretical evaluation of filtration requirements, each effect of interference is considered separately. Similarly, when operators coordinate the location of the BS for the calculation purpouse the interference power of different origin are also carried out separately, and then the interference powers determined separately are subject to summation.

It follows from Table 6 that: 1. The best ACS values obtained according to the standard are achieved to prevent blocking interference; 2. The maximum required additional interference suppression is also determined for the blocking interference and is of 32.7 and 43.1 dB / 5 MHz at a BSs separation distance of 100 and 30 m, respectively; 3. Actual equipment (Flexi WCDMA 2100) has better ACS performance than the standard, and also better values for additional suppression.

Panasonic Company, on the request, upgraded the lower filter of the UMTS BS duplexer to provide additional suppression of interference. The frequency response of the filter is presented in Fig. 9. The critical requirements for the frequency response was to obtain the minimum loss in the WCDMA spectrum when the channel carrier is shifted by 300 kHz below the nominal value, which corresponds to the right edge of the UMTS channel occupied band of 1979.3 MHz. It was also necessary to provide maximum suppression at a frequency of 1980.75 MHz, which corresponds to the left edge of the occupied band of the BWA channel, when applying a change in the configuration of the BWA carrier frequencies and the use of multi-standard BWA BS. The attenuation of the filter at frequencies 1979.3 and 1980.75 MHz is of -3.6 and -30 dB, respectively.

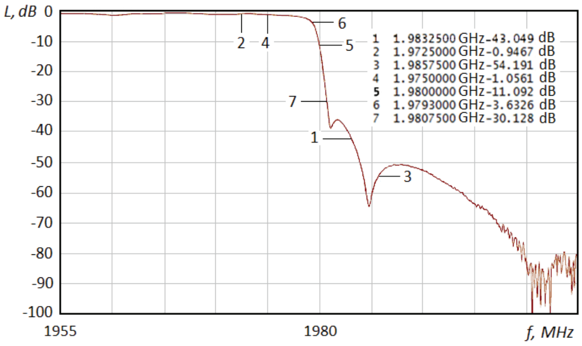

Fig. 9. Frequency response of the upgraded lower filter of the UMTS BS duplexer

Measurement of the filter suppression value by the substitution method showed that the filter in the frequency band 5 MHz with a center frequency of 1983 MHz provides signal suppression of 40.2 dB / 5 MHz, which is worse by 3 dB (Table 6, 43.1 dB / 5 MHz) than the required value.

In order to evaluate the degradation of UMTS quality indicators after changing the characteristics of the duplexer's lower filter, the signal from the filter output had been passed through the UMTS terminal and parameters were checked at the output of terminal. The test showed that the changes in the constellation state for the QPSK and 16QAM modulations did not exceed the allowable values, and the width of the occupied band did not exceed 4.2 MHz at the level of -26 dB in the entire operating range of UMTS BS.

Measures to coordinate the spatial parameters of antennas placed on common sites

Additional measures to coordinate the spatial parameters of the antennas can be predicted by conducting preliminary calculations to determine the isolation between the antennas in accordance with the layout of the BSs and the actual gain of the antennas. According to 3GPP studies [25, i.10.1 Antenna-to-Antenna Isolation], BS antennas placed / planned to be placed by operators on sites / roofs of buildings can be located in distant areas next to each other, and the isolation that occurs between antennas, can be analyzed using the usual Harald Friis transfer equation.

According to such equation, for the frequency of 1980 MHz, the use of mixed (horizontal and vertical) separation is possible in the area with a radius of 30 m. In line with the results of research [4], the average loss of radio wave propagation at different locations of BS antennas within the 30 m zone can be up to 80 dB. This allows achieve the complete isolation and minimal interference, with taking into account the measures taken for additional filtering in BWA transmission and UMTS reception channels.

Conclusions

The introduction of technological neutrality with the help of special technical conditions allows access spectrum with maximum efficiency in the use.

1. The model of obtaining technical conditions for the access to the spectrum usage based on the method of minimum coupling loss between adjacent channels of different technologies makes it possible to use parameters of compatibility such as ACIR, ACLR and ACS to set requirements for additional filtering in adjacent transmitter and receiver channels of different technologies. The described compatibility model can be used to obtain the rights of use of spectrum by operators in the case when the choice of communication systems operating in adjacent frequency bands was already made, but the conditions of compatibility was not determined yet.
2. The methodology given in the practical example of UMTS and BWA systems around frequency 1980 MHz allowed determination the technical limitations on the characteristics of receiver and transmitter when implementing other technologies in the adjacent frequency band. To mitigate the requirements for realization of additional filtering, the evaluation of the standard spectrum emission mask was used. This allowed determination the minimum necessary frequency guard band between adjacent channels of the transmitter and receiver of base stations. The values of the minimum guard band of 2.05 MHz and the range of permissible minimum values of the guard band of 1.5-2.05 MHz between the edges of the occupied bands of neighboring technologies were determined theoretically.
3. Based on the analysis of UMTS and BWA standards and implemented in practice values ACLR and ACS of BSs operating equipment the requirements for additional filtering wereobtained. Then a frequency responses of the modernized operating duplexer upper filter for the transmitter and modernized operating duplexer lower filter for the receiver were developed practically. The results of measuring the new characteristics confirmed the possibility of implementing the requirements of additional filtration.

4. In general, verification of the practical characteristics of additional filtering in adjacent UMTS and BWA channels confirmed the possibility of ensuring compatibility between the BSs of these systems with frequency spacing between the edges of adjacent channels of 2.5 MHz with using additional measures for spatial coordination of antennas within common site. Compatibility can also be ensured for smaller values of the guard band (2.05 MHz or 1.5-2.05 MHz) providing that additional measures are taken for the spatial separation between antennas of two systems, if they are located on a common site or on distances from 30 to 100 m.

5. The obtained results are proposing to be the basis of general method of determining the technical conditions of effective spectrum use on the basis of technology neutrality. Formalization of these conditions in license / permission documents and introduction of the above technical restrictions in base station equipment along with additional measures for coordination of antenna locations between operators make it possible to ensure compatibility of different technologies in adjacent frequency bands without imposing strict restrictions at the network planning and deployment stages.

References

1. Framework Directive 2002/21/EC, ‘common regulatory framework for electronic communications networks and services’, *Official Journal L 108 , 24/04/2002,* March 2002. *pp. 0033 – 0050. Retirieved from ttps://www.eumonitor.eu*

2. “Enhancing Harmonisation and introducing flexibility in the spectrum regulatory framework”, ECC Report 80, Murch 2006, pp.2-98. *Retirieved from* https://docdb.cept.org/document/ category/ECC_Reports

3. Report from CEPT to the European Commission in response to the Mandate to develop least restrictive technical conditions for frequency bands addressed in the context of WAPECS CEPT Report 19, October 2008, pp. 3-92. *Retirieved from* https://docdb.cept.org/document/category/CEPT_Reports

4. Evaluation of Co-existence interference between CDMA 1900 MHz & UMTS 2100 MHz, AUSPI Report. October 2007, pp. 2-11. *Retirieved from http://www.cdg.org/resources/ files/white_papers*

5. V.I. Korsun, “Technical aspects of harmonization of radio frequency resource of Ukraine for the use when implementing up-to-date and promising radio technologies”, Proceedings of the ITU Workshop for the European Regions and the CIS "Information and Communication Technology Infrastructure as a Basis for Creating a Digital Economy", Kyiv, STU, May 2019. Retirieved from http://www.dut.edu.ua/ua/1867-materiali-konferencii-seminar-praktikum-mse-dlya-regioniv-evropi-ta-snd-infrastruktura-ikt-yak-osnova-cifrovoi-ekonomiki

6. Practical mechanism to improve the compatibility between GSM-R and public mobile networks and guidance on practical coordination, ECC Report 162, May 2011, p.p. 2-53 Retirieved from https://docdb.cept.org/document/category/CEPT_ Reports

7. Report from CEPT to the European Commission in response to the Mandate to develop least restrictive technical conditions for 2 GHz bands, CEPT Report 39, June 2010, pp.2-61. Retirieved from https://docdb.cept.org/ document/ category/ CEPT_Reports

8. Coexistence between mobile systems in the 2.6 GHz frequency band at the FDD/TDD boundary, ECC Rep119, 10 p. Retirieved from https://docdb.cept.org/document/category/ CEPT_Reports

9. Sharing and adjacent band compatibility between UMTS / / IMT-2000 in the band 2500-2690 MHz and other services, ECC REPORT 45, 37 p. Retirieved from https://docdb.cept.org/document/ category/CEPT_Reports

10. Compatibility/sharing studies related to PMSE, DECT and SRD with DA2GC in the 2 GHz unpaired bands and MFCN in the adjacent 2 GHz paired band, ECC Report 220, September 2014, pp. 2-137. Retirieved from https://docdb.cept.org/document/category/ECC_Reports

11. Compatibility between RMR and MFCN in the 900 MHz range, 1900-1920 MHz band and 2290-2300 band, ECC Report 318, July 2020, pp.2-123. Retirieved from https://docdb.cept.org/document/category/ CEPT_Reports

12. Yoo Seung Song, Shin Kyung Lee, Jeong Woo Lee, Do Wook Kang, and Kyoung Wook Min, “Analysis of adjacent channel interference using distribution function for V2X communication systems in the 5.9 GHz band for ITS”, ETRI Journal, V 41, Issue 6, September 2019, pp. 703-714. Retirieved from https://onlinelibrary.wiley.com/doi/ full/10.4218/ etrij.2018-0249

13. Erik Dahlman, Stefan Parkvall and Johan Sköld, “22.9.3 Adjacent Channel Leakage Ratio” in 4G LTE-Advanced Pro and The Road to 5G (Third Edition), 2016, pp. 487-526. Retirieved from https://www.sciencedirect.com/topics/engineering/ adjacent-channel-interference

14. Resolution № 295 of 14 May 2015 of the Cabinet of Ministers of Ukraine on Amendments to the Resolution № 815 of 9 June 2006 on Approval of the Plan for the Use of Radio Frequency Resources of Ukraine. Retirieved from https://zakon.rada.gov.ua/laws/show/295-2015

15. Calculation of free-space attenuation, ITU-R Recommendation P.525-4 (08/2019). Available: https://itu.int

16. Characteristics of terrestrial IMT-2000 systems for frequency sharing/interference analysys, ITU-R Report M.2039-3, 20 p., Noveber 2014. Retirieved from https://itu.int

17. LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception, 3GPP Technical Specification TS 36.104 version 11.2.0 Release 11, ETSI Technical Specification TS 136 104 V11.2.0, 2012-11

18. Universal Mobile Telecommunications System (UMTS); Base Station (BS) radio transmission and reception (FDD), 3GPP Technical Specification TS 25.104 version 8.2.0 Release 8, ETSI Technical Specification TS 125 104 V8.2.0, 2008-04

19. BBTRX-05 PCS RRH 4x45W Test Report Alcatel-Lucent USA, June 2015. Retirieved from https://fccid.io/AS5BBTRX-05/Test-Report/Test-Report-2673912

20. V.I. Korsun, “Frequency provision for introduction and development of broadband mobile communication networks in Ukraine”, Proceedings of the ITU Regional Seminar "Trends in Convergent Networks: Post-NGN, 4G and 5G Solutions", Kyiv, STU, November 2016, pp. 70–72.

21. V.I. Korsun, V.F. Korsak, T.M. Naritnik and O.V. Lutchak, “New solutions for ensuring electromagnetic compatibility between base stations of communication systems in adjacent frequency bands”, Proceedings of the 6th International Radioelectronic Forum

“Applied Radioelectronics. State-of-Art and future development” (IRF-2017), Kharkiv, 2017, pp. 273–277.
23. V. I. Korsun, V.F. Korsak and T.M. Naritnyk, “Electromagnetic compatibility between base stations of UMTS standard mobile communication and broadband wireless access systems: development, testing, certification”, Proceedings of the 3rd International Scientific and Technical Conference "Problems of electromagnetic compatibility of promising wireless communication networks” (EMC 2017), Kharkiv, 2017, pp. 36–42.
24. Test Report №D1FH0005. Nokia Siemens Networks Oy (NSN) Flexi WCDMA BTS 2100 MHz Conformance test according to ETSI EN 301 908-3 V4.2.1, Center for Quality Engineering. Munick, 2010, pp. 3-40
25. Kathrein 698-6000 MHz catalogue, Duplexer 1920-1980/2110-2170 MHz (UMTS), 2012, 238 p. Retirieved from https://www.olifantasia.eu/gnuradio/usrp/files/datasheets
26. RF System Scenarios. 3GPP Technical Specification RAN 25.942 V11.0.0, October 2012, pp. 3-136. Retirieved from https://www.etsi.org/deliver/etsi_tr/125900_125999/125942/11.00.00_60/tr_125942v110000p.pdf

Корсун В.І., Тичинський А.В.

Визначення умов технологічної нейтральності для систем звя’зку методом мінімальних втрат на сполучення

Проблематика. Технологічна нейтральність широко використовується в смугах частот, де еволюціонують системи зв'язку, але існують жорсткі обмеження щодо параметрів та розміщення базових станцій різних технологій із використанням суміжних каналів. Шляхи пом'якшення цього ефекту недостатньо вивчені і вимагають подальших аналізу та розробки.

Мета. Метою даної статті є дослідження методології отримання технічних умов технологічної нейтральності методом мінімальних втрат на зчеплення для визначення значень додаткових вимог до фільтрації та представлення результатів практичної реалізації цієї техніки.

Методи. Застосовано метод детального енергетичного аналізу частотних характеристик фільтрів передавача і приймача базових станцій.

Результати. У статті представлені результати отримання мінімальної захисної смуги та додаткових вимог до фільтрації в сусідніх каналах передавача та приймача, що належать до різних технологій. Наведений приклад практичної реалізації мінімальної захисної смуги та частотних характеристик додаткових фільтрів.

Висновки. Представлено загальний метод визначення технічних умов для забезпечення технологічної нейтральності та отримано значення мінімально необхідної захисної смуги між сусідніми каналами передавача та приймача.

Ключові слова: параметри сумісності; витік по сусідньому каналу; вибірковысть по сусідньому каналу; мінімальна захисна смуга; додаткова фільтрація; крутість частотної характеристики.

Корсун В.И., Тычинський А.В.

Определение условий технологической нейтральности для систем связи методом минимальных потерь на сопряжения

Проблематика. Технологическая нейтральность широко используется в полосах частот, где эволюционизируют системы связи, но существуют жесткие ограничения на параметры и размещение базовых станций различных технологий с использованием соседних каналов. Пути смягчения этого эффекта недостаточно изучены и требуют дальнейших анализа и разработки.

Цель. Целью данной статьи является исследование методологии получения технических условий технологической нейтральности методом минимальных потерь на сопряжение для определения значений дополнительных требований к фильтрации и представление результатов практической реализации этой техники.

Методы. Применен метод детального энергетического анализа частотных характеристик фильтров передатчика и приемника базовых станций по критерию совместимости.

Результаты. В статье представлены результаты получения минимальной защитной полосы и дополнительных требований к фильтрации в соседних каналах передатчика и приемника, принадлежащих к различным технологиям. Приведен пример практической реализации минимальной защитной полосы и частотных характеристик дополнительных фильтров.

Выводы. Представлены общий метод определения технических условий для обеспечения технологической нейтральности и получено значение минимально необходимой защитной полосы между соседними каналами передатчика и приемника.

Ключевые слова: параметры совместимости; утечка по соседнему каналу; избирательность по соседнему каналу; минимальная защитная полоса; дополнительная фильтрация; крутизна частотной характеристики.