

# ADJUSTING BORDERS OF THE COVERAGE ZONES ASSOCIATED WITH VARIOUS SPECTRUM MONITORING FUNCTIONS<sup>1</sup>

**Pavlyuk (Pavliouk) A.P.**

*JSC IRCOS, Moscow, Ph.D., Consultant*

**Plossky A.Yu.**

*Radio Research and Development Institute (NIIR),*

*Moscow, Deputy Head of laboratory*

## **Abstract**

The International Telecommunication Union provides methodological and software materials related to the planning and optimization of the spectrum monitoring networks operating in the frequency band most commonly used in practice. The article provides additional explanations to these materials concerning adjustment of the coverage zone borders associated with various spectrum monitoring functions.

**Keywords:** spectrum monitoring, spectrum monitoring functions, network of monitoring stations, planning, optimization, spectrum monitoring coverage zones, borders of coverage zones.

## **Introduction**

According to Article 16 of the Spectrum Regulations (RR) of the International Telecommunication Union (ITU) [1], spectrum monitoring is one of the most critical functions of international and national spectrum management systems. As highlighted in Recommendation SM.1392-2 of ITU Radiocommunication Sector (ITU-R) [2], the task of the optimal planning of national spectrum monitoring networks is of a high importance which taking into account the high cost of the relevant equipment can provide a significant economic effect.

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The methodology of planning and optimization of spectrum monitoring networks in the VHF/UHF (Article 2 of RR [1]) frequency band, operating according to the traditional technology of measuring the angle of signal arrival (Angle-of-Arrival, AOA) [3], was developed in the early 2000-s [4, 5]. Then, on the basis of the relevant contributions of the Russian Federation Communications Administration to ITU-R Study Group 1 "Spectrum management" (SG 1), its provisions were included in sections 4.7.3.1.4 and 6.8 of the ITU-R Handbook on Spectrum Monitoring [3]. A description of the software that allows implementing this technique was presented in [6], and then by the same procedure, it was included in Annex 5 of ITU-R Handbook on Computer-aided Techniques for Spectrum Management (CAT) [7].

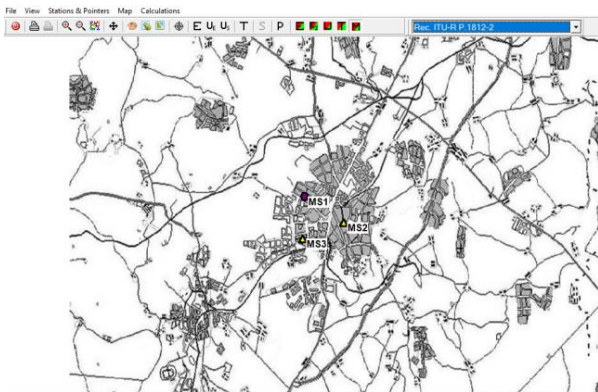
These methods and software allow providing calculations of coverage zones related to various functions of spectrum monitoring by a network of fixed spectrum monitoring stations, namely listening, measuring the parameters of monitored emissions, direction finding and location. By calculating the coverage zones for the different configurations and the number of spectrum monitoring stations in the network, it is possible to determine the minimum number of stations and their configuration in the network, which provides spectrum monitoring coverage of the required territory, thus achieving the above-mentioned economic effect. In addition, the technique and the software not only allow for the determination of the location zone, which is a part of the joint direction finding zone, where the location of the desired emission source is provided by triangulation of the bearings provided by at least two direction finders, but also to calculate the distribution of location uncertainty throughout this location zone. Graphic images of such distributions in [4, 5] named as Location Coverage Templates (LCT) or, briefly, Location Templates.

The experience of the practical use of the abovementioned methods and software has allowed developing a detailed step-by-step procedure of planning and optimization of spectrum monitoring networks [8, 9], which according to the same scheme was then reflected in the ITU-R Report SM.2356-1 [10].

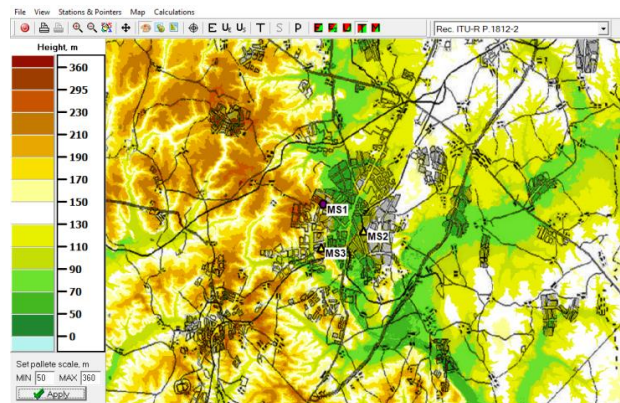
In General, the practical use of these guidances and related software is quite simple and understandable. Nevertheless, the practice has shown that there are a couple of issues that deserve further explanation, which is the subject of this article.

### **Uncertainty in determining boundaries of coverage zones by spectrum monitoring functions**

The phenomenon of some uncertainty in the definition of coverage zones boundaries by spectrum monitoring functions and measures to improve this situation can be more clearly explained by specific examples. Let, in accordance with Fig. 1, there is a local spectrum monitoring network consisting of three fixed stations MS1 – MS3, providing, inter alia, direction finding. The network is situated in a slightly rugged terrain, which follows from the Fig. 2, where the palette of height gradations is shown on the left. The altitude difference is not more than 170 m.



**Fig. 1.** Considered local spectrum monitoring network



**Fig. 2.** Terrain

Let us calculate the coverage zones by listening, measuring emission parameters, direction finding, and location. Parameters of the test transmitter and threshold values of the field strength at the borders of these zones are set in accordance with the data of table 6.8-1 of the Handbook [3], namely:

- test transmitter:
  - category 1 - power 10 W, antenna height 1.5 m;
- threshold field strength values:
  - listening: 0 dB ( $\mu\text{V}/\text{m}$ ),

- emission parameter measurements: 12 dB ( $\mu\text{V/m}$ ),
- direction finding: 20 dB ( $\mu\text{V/m}$ ).

The calculation results of monitoring coverage zones by all three stations, performed at a frequency of 2900 MHz, are shown in Fig.3, and a LCT – in Fig. 4. Palettes of field strength values and LCT uncertainty gradations are shown at the left edges of the pictures. The red contour line in Fig.3 corresponds the boundary of the zone covered by the location; and in Fig. 4, vice versa, the same line indicates the border of the joint coverage zone by direction finding. These two coverage zones are usually of the greatest interest since within them the spectrum monitoring is the most efficient.

From these figures it is clearly seen that for each spectrum monitoring function there are three distinct areas:

- a confident coverage zone (which may contain "holes" within itself and at the edges, i.e. where the coverage, in accordance with calculations under these parameters. is not provided; the number of such uncovered sites may significantly increase in rugged and mountainous terrains);
- an area of unconfident coverage where the areas covered and not covered by the spectrum monitoring are heavily interspersed, and
- the most remote areas from the group of monitoring stations where monitoring coverage is not provided at all.

The presence of pronounced areas of unconfident coverage by spectrum monitoring functions is explained as follows.

In addition to uncertainty in the conditions of radio waves propagation when using any propagation model, it is necessary to take into account the pronounced threshold nature of the boundary field strength values used in the calculations. If the threshold field strength values used in calculations (the abovementioned 0, 12 and 20 dB according to table 6.8-1 of the Handbook [3]) are designated as  $E_t$ , the area where the field strength is, for example,  $E_t + 0.1$  dB will belong to the coverage zone, and the area with  $E_t - 0.1$  dB will no longer be considered as to be covered. It is clear, however, that service conditions in sites with  $E_t + 0.1$  dB and  $E_t - 0.1$  dB are

virtually identical. Depending on the terrain, especially in hilly and mountain regions, variations in field strength on either side of its threshold values  $Et$  can occur within vast territories, even exceeding the zone of the confident coverage. Each small hill or hollow within such territories may or may not be considered as the coverage zone, although the corresponding field strengths may differ by a tiny amount. However, it is quite possible to have heavily shaded sites within which the field strength deficit is of great value. It is desirable not only to identify such uncovered sites but also to separate them from areas with a small deficit. All of this can add considerable uncertainty to the determination of the real coverage zone borders.

In order to include in confident coverage zones some parts of unconfident coverage areas, having a small deficit of field strengths, which does not have a noticeable impact on the performance of spectrum monitoring functions, it is recommended to additionally carry out control calculations with threshold field strength values equal to  $Et - \Delta$ , where  $\Delta$  is a value from 1 to 3 dB. Thus, the user has to decide what exact value of such small deficit of the field strength is acceptable.

Spectrum monitoring and location coverage by the same group of monitoring stations as in Figures 3 and 4, but with a deficit  $\Delta = 3$  dB are shown in Figures 5 and 6. The used values of the field strength thresholds are visible in the palette of Fig. 5.

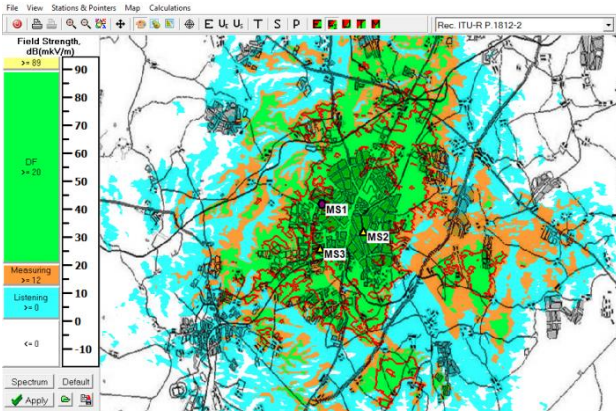
As it can be seen from these figures, under the implementation of this approach, portions of the unconfidently covered areas within or at the boundaries of the confidently covered zones seen in Figures 3 and 4 disappear, indicating that the deficit of the field strength in them was less than 3 dB. Areas of unconfident coverage do not, of course, disappear, but they move further away from the group of spectrum monitoring stations under consideration. At the same time, depending on the terrain, areas of unconfident coverage may change and/or new such areas may occur.

In order to identify sites of the territory that are actually potentially out of coverage inside or at the edges of zones of a confident coverage, it is possible to carry out control calculations with  $\Delta$  equals to 6 - 9 dB. If these sites really are out of coverage by fixed monitoring stations, in the process of monitoring they need

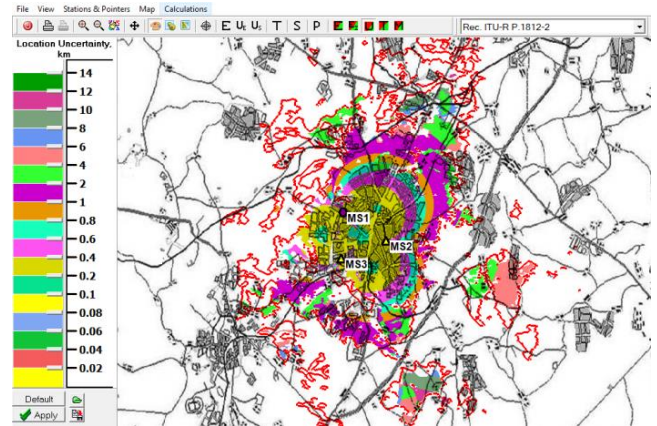


particular attention, for example, more often to send inside them mobile monitoring stations or time to time to place therein transportable monitoring stations.

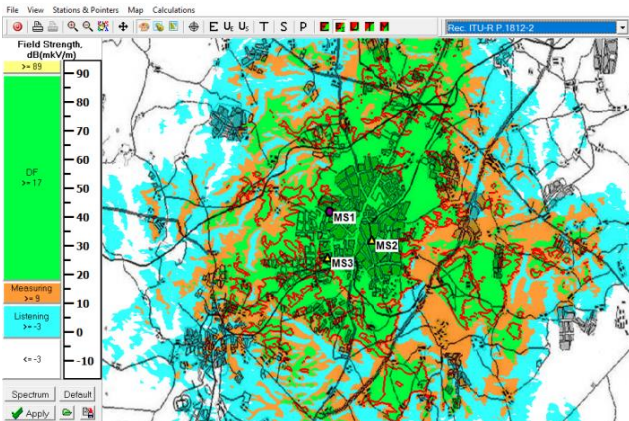
The results of calculations with  $\Delta = 6$  dB are shown in Fig. 7 and 8.



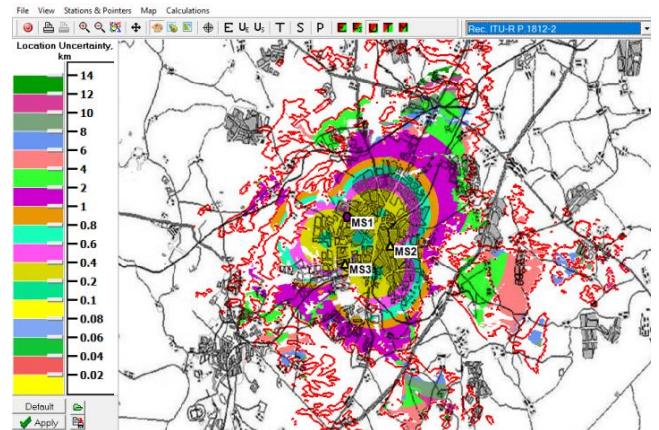
**Fig.3.** Joint monitoring coverage zones for  $E_t$  values equal to 0, 12 and 20 dB



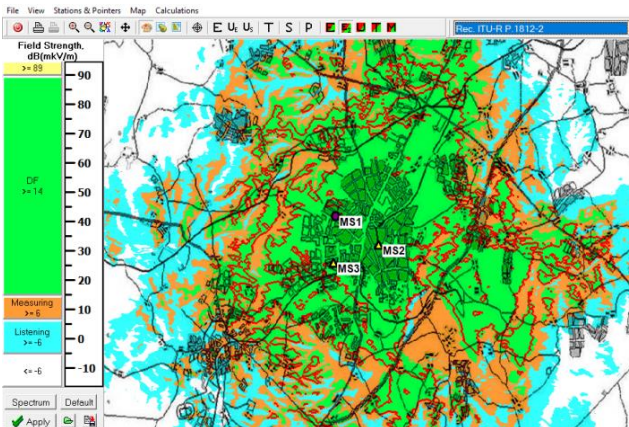
**Fig.4.** LCT for  $E_t$  values equal to 0, 12 and 20 dB



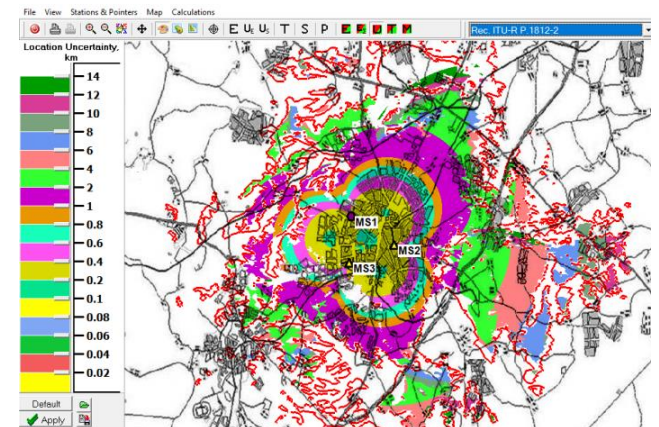
**Fig.5.** Joint monitoring coverage zones for  $E_t$  values equal to -3, 9 and 17 dB



**Fig.6.** LCT for  $E_t$  values equal to -3, 9 and 17 dB



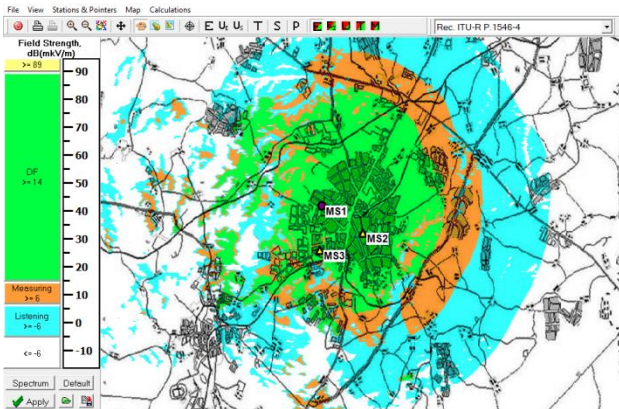
**Fig.7.** Joint monitoring coverage zones for  $E_t$  values equal to -6, 6 and 14 dB



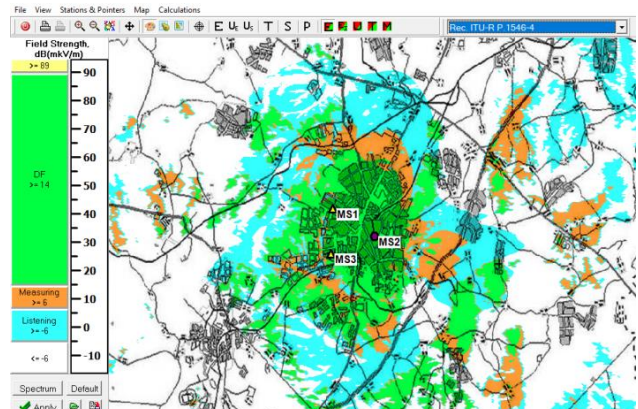
**Fig.8.** LCT for  $E_t$  values equal to -6, 6 and 14 dB



From a comparison of Figures 7 and 8 with Figures 5 and 6, it can be seen that the calculation with such parameters allows identifying sites within and/or at the edges of confident coverage zones by spectrum monitoring functions, where there is a small and large deficit of field strength. In particular, on the southern outskirts of the considered city, a sufficiently large district has been identified, which can be recognized as uncovered by location since the field strength deficit in it (relative to the required for direction finding at least by two stations) exceeds 6 dB. It can be seen from Fig. 9 and 10, which represent zones of monitoring coverage by not all three stations, as in Fig. 7, but separately by stations **MS1** and **MS2**. For both of these stations in this district, direction finding is not provided due to a great deficit of the field strength. This district is covered by direction finding, as shown in Fig. 7, only by **MS3** station, but it is not enough to make a location by triangulation.



**Fig. 9.** Coverage zones of monitoring station **SM1** for  $E_t$  values equal to -6, 6 and 14 dB



**Fig.10.** Coverage zones of monitoring station **SM2** for  $E_t$  values equal to -6, 6 and 14 dB

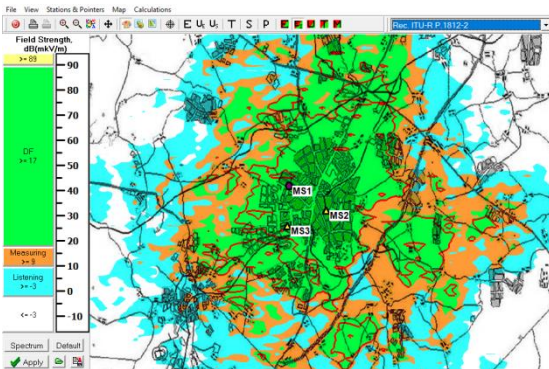
### **Irregularity of confident coverage zone boundaries related to various spectrum monitoring functions**

As it can be seen from the above Figures 3 – 10, the boundaries between confident and unconfident coverage areas are very jagged, making somewhat difficult their clear identification. In order to eliminate this difficulty by smoothing the boundaries, the software algorithm presented in Fig.A5 - 1 of Appendix 5 to the Handbook [7], in part related to field strength calculations, contains a block of linear

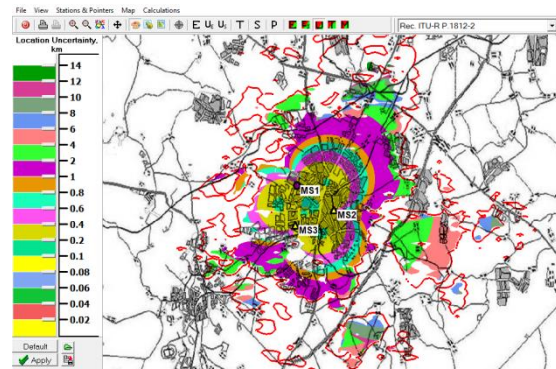
interpolation. Unfortunately, the purpose and operation of this unit are not described in any of the abovementioned publications. Let us fill this gap.

The unit works in the following way. The virtual grid containing equal rectangular or square cells, each of which includes  $X$  pixels horizontally and  $Y$  pixels vertically, i.e. totally  $X \cdot Y$  pixels (for square cells, obviously,  $Y = X$ ) is programmable superimposed on the PC monitor's screen. Calculation of the field strengths according to the models of radio wave propagation used in the software (Recommendations ITU-R P.1546-4 [11] or P.1812-2 [12]) is carried out only for grid nodes (i.e. from the test transmitter programmably installed in each grid node to each spectrum monitoring station). The field strength for all other pixels in each grid cell is determined by linear interpolation horizontally and vertically within each cell. Since the time required for such interpolation significantly less than the time required for calculations in accordance with those very complicated propagation models, the whole process of calculating field strengths for all pixels is carried out much faster, with computation time decreasing rapidly with increasing the base  $X \cdot Y$  of the interpolation. At the same time, it leads to smoothing the boundaries of coverage zones, and in a greater degree with increasing the base  $X \cdot Y$  of the interpolation.

For an illustration of this phenomenon, Figures 11 – 12 and 13 - 14 present coverage zones and LCT for  $X \cdot Y = 64$  and  $X \cdot Y = 256$ , respectively. The productive work of the interpolation block in smoothing the boundaries of coverage zones is well traced.

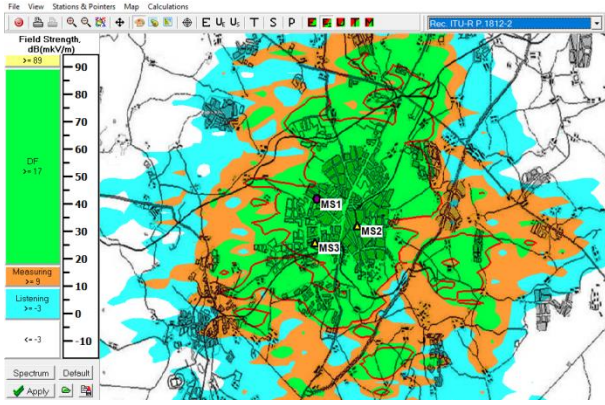


**Fig.11.** Joint monitoring coverage zones for  $Et$  values equal to -3, 9, 17 dB and  $XY = 64$

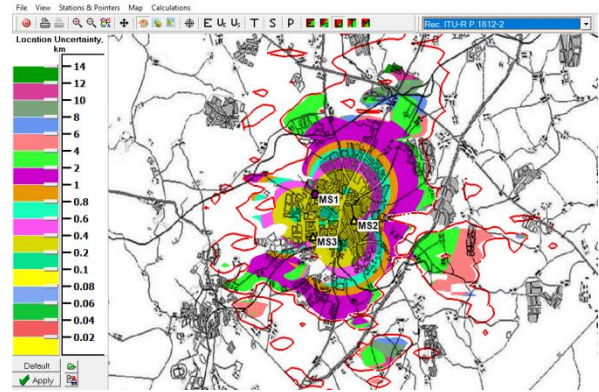


**Fig.12.** LCT for  $Et$  values equal to -3, 9, 17 dB and  $XY = 64$



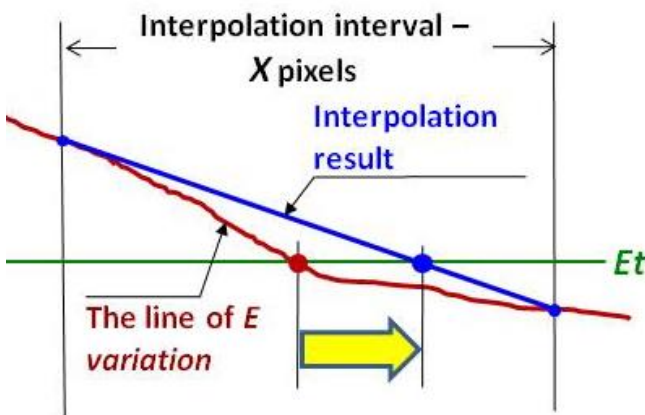


**Fig.13.** Joint monitoring coverage zones for  $Et$  values equal to -3, 9, 17 dB and  $XY = 256$

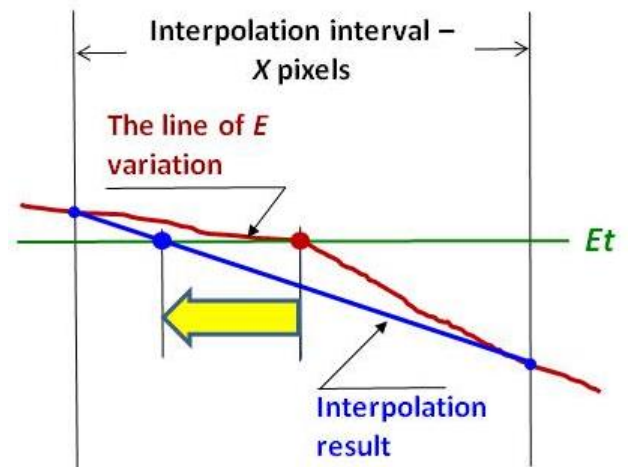


**Fig.14.** LCT for  $Et$  values equal to -3, 9, 17 dB and  $XY = 256$

At the same time, it should be borne in mind that when smoothing the boundaries of coverage zones, the zones of confident coverage can slightly increase or decrease depending on the speed of the field strength changing from pixel to pixel within the coverage zone and outside it throughout the interpolation interval. This is explained by Figures 15 and 16. For Fig. 15 the velocity of the field strength changing within the coverage zone is higher, and the coverage zone boundary is shifted to larger values. For Fig. 16, contrary, the velocity of the field strength changing is higher in the area outside the coverage zone, which leads to shifting the boundary to lower values. The calculations show that for values  $X \cdot Y \leq 64$  such shifting is almost imperceptible.



**Fig. 16.** The shift of the boundary towards larger values



**Fig. 17.** The shift of the boundary toward smaller values

For clarity, it is necessary to mention that lines of change in field strength shown in Figures 15 and 16 are not related to the field strength values in the considered pixels of the PC screen. They correspond to a change in the field strength at the receiving point of a spectrum monitoring station from a test transmitter programmably installed in these pixels of the screen. Nevertheless, the above analysis is valid due to the reciprocity principle of radio wave propagation conditions, i.e. preserving these conditions when exchanging the sites of the transmitter and receiver [4]. This fully applies to the above description of the linear interpolation block operation.

## **Conclusion**

It is hoped that with the additional clarifications provided above the use of the abovementioned methodological guidances and software will become even more straightforward and understandable.

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