Protection of fixed monitoring station against interference from strong electromagnetic fields

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***Abstract*—Method for calculation of maximum permissible field strength at fixed radio monitoring station site is suggested. If the field strength of the radio stations situated near radio monitoring station does not exceed the calculated value, then they do not cause radio interferences to the radio monitoring station.**

***Index Terms*—harmful radio interference; intermodulation products; fixed radio monitoring station; calculation of maximum permissible field strength.**

I. INTRODUCTION

Most national regulatory authorities apply procedures for protection of their radio monitoring stations from strong electromagnetic fields. One of the main provisions' of the regulations is that it is not allowed to install radio stations for any purpose near the fixed radio monitoring stations if their field strength exceeds limit values presented in Recommendation ITU-R SM.575-1.

Recommendation ITU-R SM.575-1 provides fixed values of maximum permissible field strength, generated by one signal. This is one of shortcomings of Recommendation ITU-R SM.575-1 because the limit values of field strength estimated to interfering (intrusive) signals are not related to a bandwidth of these signals. Obviously, the maximum permissible values of interfering (intrusive) signals should depend on the receiver's resistance to strong signals and on antenna gain.

Calculations of the maximum permissible field strength are presented bellow with regard to bandwidth of a signal and to the parameters of receiver system of monitoring station. The new Recommendation ITU-R SM.575-2 has been prepared based on these calculations.

II. INITIAL CONDITIONS FOR CALCULATION

A. Receiver overload and strong signal handling performance

Strong signals overload a receiver and may cause:

- receiver blocking;
- intermodulation performance;
- cross modulation.

Intermodulation products cause the highest risk to the performance of radio monitoring stations. Intermodulation products produce the unwanted signals which may mask out the smaller wanted signal. In addition, the intermodulation products, with the strongest among them the third-order products, occur at significantly lower levels of incoming signal than those when the effects of blocking and cross modulation occur.

It is possible to presume that intermodulation products do not distort performance of a radio monitoring system until their level does not exceed the level of noises.

B. Third-order intermodulation products

The third-order intermodulation products whose frequencies are close to incoming signals' frequencies are the most dangerous. When two incoming signals of f_g and f_h frequencies interact, only two intermodulation products of IM3(2,1) type are possible. Frequencies of these products f_{IMP} are equal to:

$$f_{IMP}(1) = 2f_g - f_h;\; f_{IMP}(2) = 2f_h - f_g\,. \qquad (1)$$

In case of three signals with f_k , f_l and f_m frequencies, intermodulation products of IM3(2,1) and IM3(1,1,1) type are possible. IM3(1,1,1) product frequencies f_{IMP} are equal to:

$$f_{IMP} = f_k + f_l - f_m\,. \qquad (2)$$

Each index k, l and m accepts one of three values of 1, 2 or 3 under the condition:

$$k + l + m = 6\,. \qquad (3)$$

If power of all incoming signals is equal, power of intermodulation product IM3(2,1) can be calculated according to a well-known formula [1]:

$$P_{IM3-1} = 3P_S - 2P_{IP3}\,, \qquad (4)$$

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where $P_{IM3\text{-}1}$ is the power of the 3rd order intermodulation product IM3(2,1) in dBm; P_S is the input power of incoming signal into the monitoring receiver in dBm; and P_{IP3} is the 3rd order intercept point (IP3) of the receiver in dBm.

Power of intermodulation product IM3(1,1,1) is 6 dB higher than IM3(2,1) [1] and is equal to:

$$P_{IM3-2} = (P_k + P_l + P_m) - 2P_{IP3} + 6\,, \tag{5}$$

where $P_{IM3\text{-}2}$ is the power of the 3rd order intermodulation product IM3(1,1,1) in dBm; $P_{k,}$ P_l, P_m is the input power of the signals incoming into the monitoring receiver in dBm.

If $P_{k,} = P_l = P_m = P_{s,}$ equation (6) becomes a well-known formula:

$$P_{IM3-2} = 3P_S - 2P_{IP3} + 6\,. \tag{6}$$

Speaking of harmful influence of intermodulation product, it is not enough to know its power, but it is important to know its spectrum. It is not easy to determine the bandwidth of intermodulation product when real signals interact (e.g. DVB-T or LTE). Usually these spectrums have no significant minimums and maximums. Thus, it is possible to presume, without making a great error, that spectrum of intermodulation product is rectangular.

C. Internal noise of the receiver

It is well-known that the average square value (r.m.s.) of internal noises of a receiver, calculated for receiver's input, is given by:

$$p_R = (f-1)kt_0B_n = (f-1)p_nB_n\,, \tag{7}$$

where f is the noise factor of the receiver; k is Boltzmann's constant; t_0 is the reference temperature taken as 290 K; B_n is the noise bandwidth of the receiver; and $p_n = kt_0$ is the available thermal noise power in 1 Hz bandwidth.

Usually sensitivity of the receiver in specification sheet is characterized with noise figure NF=10$logf$ in dB. Then equation (7) can be written:

$$p_R = (10^{\frac{NF}{10}} - 1)p_nB_n\,. \tag{8}$$

Usually receiver's internal noises are presented in dBm:

$$P_R(dBm) = 10\log(10^{\frac{NF}{10}} - 1) + 10\log B_n - 174(dBm)\,, \tag{9}$$

where $-174(dBm) = 10\log(1000p_n)$.

Technical specifications of the receivers give the values of measurement bandwidth but not of noise bandwidth. Usually measurement bandwidth of the receiver is approximately only 10-20 % greater than noise bandwidth. Therefore, for calculation of internal noises of the receivers it will be no great error to put measurement bandwidth of the receiver in equations (7)-(9), instead of noise bandwidth. Besides, equation (9) becomes less complex, if noise figure is larger than 10 dB:

$$P_R(dBm) = NF + 10\log B - 174dBm\,, \tag{10}$$

where B is the measurement bandwidth of the receiver in Hz.

In such case, when NF=10 dB of the receiver, the result of calculation according to the formula (10) is only 0,5 dB higher than the result of calculation according to the formula (9). But when NF = 1 dB, calculation results differ in 6,9 dB.

III. CALCULATION OF MAXIMUM PERMISSIBLE FIELD STRENGTH

We'll calculate maximum permissible field strength of one signal in three cases. The first case is when a signal in receiver input circuits interacts with no less than two equal signals of equal power and bandwidth. The second case is when a signal interacts with no less than two signals of equal power but less bandwidth. The situations of three signals interacting are most probable when signals are radiated constantly. The sources of such signals are the public mobile communication base stations. If a radio station radiates in short intervals, then most likely we will have the third case when two signals interact. In this case we will presume that their power and bandwidth are the same. In all three cases we will presume that:

- spectrum of intermodulation products is rectangular;
- losses of antenna feeder are uncounted;
- internal noise of the receiver significantly exceeds the radio noise.

As it follows from the Recommendation ITU-R P.372-10 'Radio noise', the last assumption is valid for frequencies above 100 MHz in case when receiver's noise figure exceeds 5-6 dB.

1) As follows from formula (2), in case of interaction of equal signals, the bandwidth of intermodulation product IM3(1,1,1) exceeds three times the bandwidth of a single signal.

Using formula (6), we can get IM3(1,1,1) products power ΔP_{IM3}, registered in the receiver band B:

$$\Delta P_{IM3}(dBm) = 3P_S - 2P_{IP3} + 6 + 10\log(B/3B_S)\,, \tag{11}$$

where B_s is the bandwidth of incoming signals.

Interference due to IM products becomes visible when the level ΔP_{IM3} exceeds the receiver noise floor:

$$\Delta P_{IM3} \geq P_R . \tag{12}$$

The “critical” point, where this situation occurs, can be calculated using formulas (10) and (11) as follows:

$$3P_S - 2P_{IP3} + 6 + 10\log(B/3B_S) = NF + 10\log B - 174dBm . \tag{13}$$

It fallows from this equation that

$$P_S = \frac{2P_{IP3} + NF + 10\log(B_S)}{3} - \frac{174 + 6 - 10\log 3}{3} . \tag{14}$$

As it is well known, field strength *E* and electric power in the antenna output (and receiver input) *P* are related according to formula:

$$E(dB\mu V / m) = P(dBm) + 20\log f(MHz) - G_i(dB) + 77dB , \tag{15}$$

where *f* is frequency in MHz; G_i is antenna gain in the direction of signal source dBi.

In combination of formulas (14) and (15), final expression for maximum permissible field strength is received:

$$E_{\max}(dB\mu V / m) = \frac{2P_{IP3}(dBm) + NF(dB) + 10\log B_S(Hz)}{3} + 20\log f(MHz) - G_i(dB) + 18,6dB . \tag{16}$$

As can be seen from this expression, the value of maximum permissible field strength depends not on the receiver measurement bandwidth but on bandwidth of the signal, generating this field.

2) In this case it is logical to accept that these are top levels of two narrow-band signals and can be expressed by formula (14). In such case power P_{IM3-2} of intermodulation product IM3(1,1,1) is:

$$P_{IM3-2} = (P_{SB} + 2P_S) - 2P_{IP3} + 6 , \tag{17}$$

where P_{SB} is the input power of broadband signal in dBm;and P_S is input power of narrow-band signal in dBm.

As the bandwidth of intermodulation product in this case is equal to the width B_{SB} of a broadband signal, thus registered power ΔP_{IM3-2} in receiver band *B* is equal to:

$$\Delta P_{IM3-2}(dBm) = P_{IM3} + 10\log\left(\frac{B}{B_{SB}}\right) = P_{SB} + 2P_S - 2P_{IP3} + 6 + 10\log B - 10\log B_{SB} . \tag{18}$$

In combining the equations (10) and (18), we get:

$$P_{SB} + 2P_S - 2P_{IP3} + 6 + 10\log B - 10\log B_{SB} = NF + 10\log B - 174\,dBm . \tag{19}$$

When combining this equation and (14), we get:

$$P_{SB}(dBm) = \frac{2P_{IP3} + NF + 10\log B_{SB}}{3} + \frac{2}{3}(10\log\frac{B_{SB}}{B_S}) - \frac{174 + 6 + 2*10\log 3}{3} . \tag{20}$$

When combining formulas (15) and (20), we receive final expression for maximum permissible field strength:

$$E_{\max}(dB\mu V / m) = \frac{2P_{IP3}(dBm) + NF(dB) + 10\log B_{SB}(Hz)}{3} + \frac{2}{3}(10\log\frac{B_{SB}}{B_S}) + 20\log f(MHz) - G_i(dB) + 13,8dB . \tag{21}$$

As can be seen from this expression, in this case the value of maximum permissible field strength depends on the bandwidth of the signal, generating this field, and on its relation to the bandwidths of other two incoming signals.

3) As follows from formula (1), in case of interaction of equal signals, the bandwidth of intermodulation product IM3(2,1) exceeds three times the bandwidth of a single signal.

Using formula (4), we can get IM3(2,1) products power ΔP_{IM3}, registered in the receiver band *B*:

$$\Delta P_{IM3}(dBm) = 3P_S - 2P_{IP3} + 10\log(B) - 10\log 3B_S . \tag{22}$$

Then after analogical actions as in case 1), we may receive final expression for maximum permissible field strength:

$$E_{\max}(dB\mu V / m) = \frac{2P_{IP3}(dBm) + NF(dB) + 10\log B_S(Hz)}{3} + 20\log f(MHz) - G_i(dB) + 20,6\,dB \tag{23}$$

The results of calculation show that the permissible field strength is only 2 dB higher when 2 signals interact, comparing to the case when 3 equal signals interact.

IV. CALCULATION OF MAXIMUM PERMISSIBLE FIELD STRENGTH OF TYPICAL SIGNALS

In most cases calculations according to the formula (21) give 2-5 dB larger values of permissible field strength than calculations according to the formula (16). Therefore, our calculations will be based on formula (16). We'll take typical values for receiver's and antenna's parameters:

- 3rd order intercept point of the receiver P_{IP3}= +15dBm;
- noise figure of the receiver *NF*=10 dB;
- antenna gain G_i=2,15 dB.

After putting these typical values into formula (16) and expressing signal bandwidth in kHz, we will get:

$$E_{\max}(dB\mu V/m) = \frac{10}{3}\log B_S(kHz) + 20\log f(MHz) + 29{,}78\,dB \quad . \tag{24}$$

Maximum permissible field strength values for several typical signals have been calculated using this formula. Summary of the results is presented in Fig. 1.

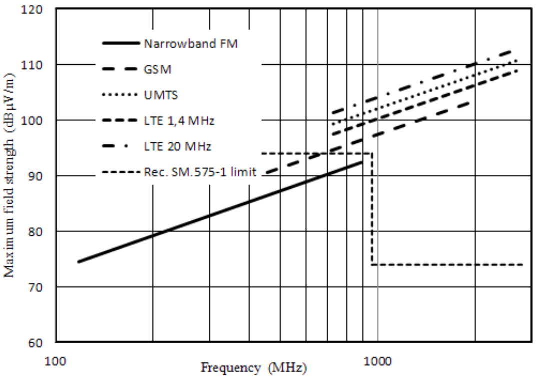

Fig. 1. Dependence of maximum permissible field strength values of several typical signals on a frequency

As follows from Fig. 1, in the frequencies above 960 MHz the values of maximum permissible field strength for typical signal significantly exceed the limit values of the field strength, presented in Recommendation ITU-R SM.575-1.

V. EXPERIMENTAL RESULTS

The aim of experimental measurements was to evaluate the uncertainty of maximum permissible field strength calculations, which appears because the real spectrum of intermodulation products is not flat (in order to make calculations simpler, it was assumed that the spectrum of intermodulation products is flat). The experimental measurements were carried out using digital TV broadcasting (DVB-T) and analogue FM signals.

Experimental measurements of DVB-T signals were carried out in the following way. Two or three tunable narrowband filters, each passing only one TV channel, were connected to a broadband antenna using matching circuit. Outputs of filters were connected to individual adjustable attenuators. Attenuators are necessary to smooth the signals. Then signals of equal level were added with combiner and fed to a broadband amplifier. Amplifier output signal, including intermodulation products, was investigated using the test receiver ESPI.

Experimental measurements of FM analogue signals were not carried out with real signals received from the air. In this case three signal generators SML03 were used; signals were fed to a combiner ant then to a broadband amplifier.

Fig. 2 shows spectrum of a third order intermodulation product, which was obtained as a result of interacting signals of DVB-T channels 53 and 57. It can be seen that the bandwidth of intermodulation product exceeds the bandwidth of a single DVB-T signal three times and is equal to 24 MHz.

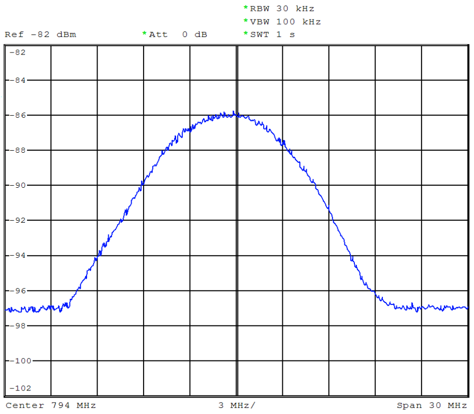

Fig. 2. Spectrum of intermodulation product IM3(2,1) of two interacting DVB-T signals

Measurements showed that the power of intermodulation product, registered in band *B*, is equal to:

$$\Delta P_{IM3}^{\exp} = P_{IM3} + 10\log(B/3B_S) + K \equiv \Delta P_{IM3} + K \quad , \tag{25}$$

where P_{IM3} is a full power of intermodulation product, ΔP_{IM3} is a power of intermodulation product in band *B* in case of a flat spectrum, *K* is a coefficient depending on *B*. Coefficient K monotonically increases as bandwidth decreases, and obtains values from 0 (when B=$3B_S$ =24 MHz) to 2,8 dB (when *B* is less than 300 kHz).

Similar results were obtained during analysis of a spectrum of third order intermodulation products of analogue FM signals. During the experiment, carrier frequencies were taken from 100 MHz to 200 MHz range, deviation – from 1 kHz to 75 kHz. The maximum registered value of coefficient K was 2.1 dB.

By deriving formulas (16), (21) and (23) and inserting coefficient *K,* it is easy to prove that the maximum permissible field strength will decrease by a value of *K*/3. It follows from the above-showed experimental results that this value is less than 1 dB. That is why in many cases correction of *K*/3 because of the form of intermodulation products spectrum can be ignored.

REFERENCES

[1] Recommendation ITU-R SM.1134-1 "Intermodulation interference calculations in the land-mobile service", Radiocommunication Sector of ITU, February 2007.