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Comparative study regarding corrosion in time of the ground electrodes, Part 3 – Electrical measurements

Studiu comparativ privind coroziunea în timp a electrozilor în sol, Partea 3 – Măsurători electrice

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***Rezumat**:Obiectivul lucrării este de a prezenta, aspecte referitoare la: coroziunea metalelor acoperite şi neacoperite cu zinc în solul oraşului Timişoara (electrozi de împământare a Instalaţiei de Legare la Pamânt aferentă Instalaţiilor Electrice din Construcţii), analiza parametrilor de sol, prototipuri de electrozi, măsurători electrice, microbiologice şi analiza de prognoză-predicţie matematică, materiale şi dicţionare de termeni aferenţi. Un alt aspect prezentat în acest material este efectuarea de măsurători ale spectrului câmpului elecromagnetic oscilografiat al elementelor de metal acoperite şi neacoperite cu zinc din sol.*

***Cuvinte cheie**: coroziune, electrod de împământare, sol, legare la pământ, microbiologia solului*

***Abstract:** The objective of this paper is to present aspects related to: corrosion of metals covered, and not covered with zinc in the soil of Timișoara (grounding electrodes of a grounding installation related to Electrical Installations of Constructions), analysis of soil parameters, prototype electrodes, electrical, microbiological analysis and mathematical prognosis analysis-prediction, materials, and dictionaries of related terms. Another aspect presented in this material are the measurements related to the spectrum of the oscillograph electromagnetic field of the grounding electrodes, which are covered, and not covered with zinc.*

***Key words**: corrosion, ground electrode, soil, grounding, soil microbiology*

1. Electrical measurements of the metal samples from the soil

After mounting the samples of galvanized and not galvanized earthing electrodes at the predetermined depth, several measurements were performed. Thus the resistance **R** of the sample (electrode) as well as the resistivity **ρ** of the soil in contact with it, at different time intervals. In *Table 1* are mentioned the measurements at different time intervals: metal sample (electrode) no. 2 not galvanized and positioned in the soil at the depth of 2.3 m has an increase of the resistance **R** [Ω] from 20.8 to 29.1 and **ρ** [kΩ^{m}] from 1.306 to 1.821; the metal sample (electrode) no. 6 is galvanized and positioned in the soil at the same depth, 2.3 m, and has an increase of the resistance **R** [Ω] from 45.1 to 59.1 and **ρ** [kΩm] from 2.83 to 3.74. These aspects are mentioned in Fig. 1, which demonstrates that on the surface of the non-galvanized and galvanized electrodes a microfilm was formed, so physico-chemical as well as microbiological phenomena take place.

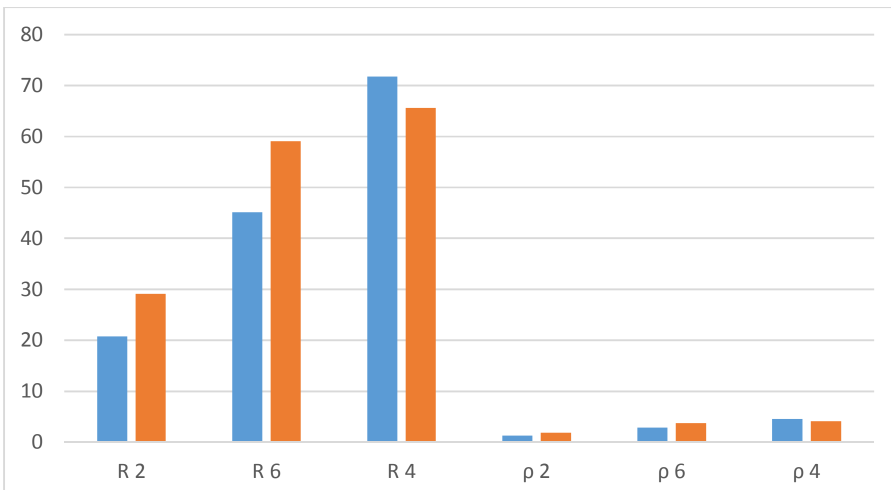


Fig. 1 Evolution in the soil at a depth of 2.3 m of the galvanized and non-galvanized samples during 05.12.2019-22.03.2020

Table 1

Measurement results of the resistivity and resistance in soil

Eşantion	***Date***	***05.12.2019***	***19.01.2020***	***19.02.2020***	***22.03.2020***
Sample 1	Resistance R[Ω]	83.8	91.7	68.8	72.2
	Resistivity ρ sol [kΩ^{m}]	5.31	5.72	4.39	4.52
Sample 2	Resistance R[Ω]	20.8	27.4	28.3	29.1

Eşantion	***Date***	***05.12.2019***	***19.01.2020***	***19.02.2020***	***22.03.2020***
	Resistivity ρ sol [kΩ^{m}]	1.306	1.717	1.797	1.821
Sample 3	Resistance R[Ω]	62.4	62.1	33.2	34.1
	Resistivity ρ sol [kΩ^{m}]	3.93	3.89	2.08	2.14
Sample 4	Resistance R[Ω]	71.8	75.7	48.1	65.6
	Resistivity ρ sol [kΩ^{m}]	4.52	4.78	2.94	4.15
Sample 5	Resistance R[Ω]	53.3	63.7	46.2	46.8
	Resistivity ρ sol [kΩ^{m}]	3.35	3.94	2.85	2.89
Sample 6	Resistance R[Ω]	45.1	58.6	58	59.1
	Resistivity ρ sol [kΩ^{m}]	2.83	3.69	3.64	3.74

1.1 Electrical conductivity σ [mS/m] of non-galvanized metal samples (electrodes) and mounted in the ground. Sample 1 is in contact with the soil, with the following geotechnical characteristics: dusty clay, brown clay, plastic clay with porosity of n = 45.6 [%] and natural humidity w = 23.8 [%]. Sample 2 is in the soil with the following geotechnical characteristics: dusty clay, black clay, plastic clay, with the porosity of n = 46.3 [%] and natural humidity w = 33.1 [%]

Table 2

Electrical conductivity

Date	σ [mS/m]	
	Sample 1	***Sample 2***
02.01.2020	0.183	1.455
03.01.2020	0.200	1.410
05.01.2020	0.183	1.404
09.01.2020	0.175	1.320
11.01.2020	0.178	1.302
29.01.2020	0.161	1.147
30.01.2020	0.165	1.134
01.02.2020	0.163	1.129
09.02.2020	0.178	1.100
17.02.2020	0.175	1.105
22.02.2020	0.166	1.042
13.03.2020	0.141	1.089
02.04.2020	0.125	0.997
08.05.2020	0.100	1.097

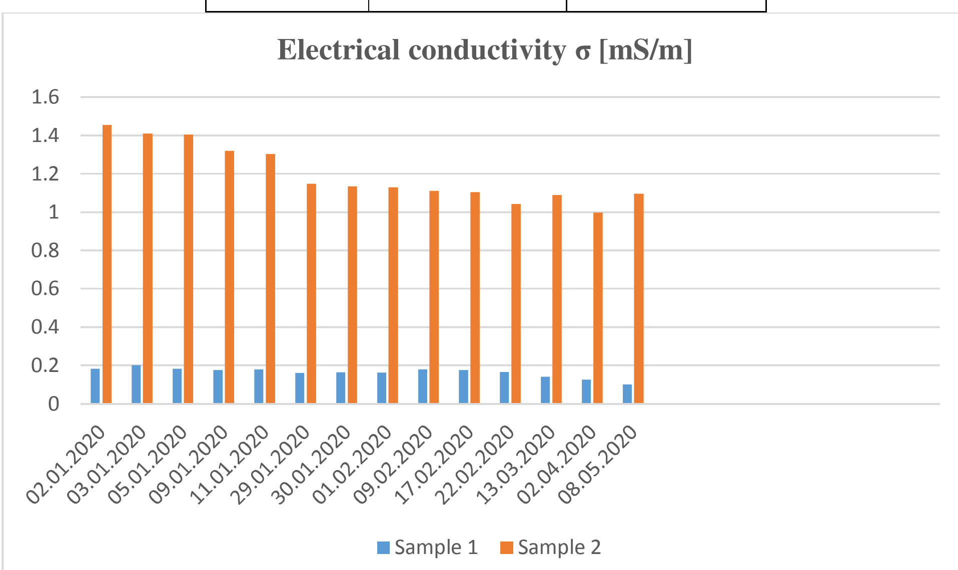


Fig. 2 Graphical representation of the electrical conductivity

The decrease of the electrical conductivity parameter σ of the non-galvanized samples confirms the increase of the resistance ρ on the surface of the two samples mounted into the ground at different depths, 1.5 m respectively 2.3 m. At the same time we notice that sample 2 mounted at a depth of 2.3 m, has a higher electrical conductivity σ than sample 1, the two samples having the same predetermined size. In conclusion, we found that the electrical conductivity σ in dusty, sandy, plastic black clay at the depth of 2.3 m it's higher than sample 1 and the two samples have the prospect of decreasing electrical conducitivity σ, thus increasing the electrical resistance ρ on the surface contact of the non-galvanized sample, which confirms the aggressive action of the physico-chemical and microbiological processes in the soil.

Electrical conductivity σ [mS/m] of the galvanized and ground mounted samples:

Table 3

Electrical conductivity measurement results for samples 3,4 and 6

Date	**σ [mS/m]**		
	Sample 3	***Sample 4***	***Sample 6***
02.01.2020	0.823	0.443	0.362
03.01.2020	0.686	0.483	0.348
05.01.2020	0.627	0.417	0.337
09.01.2020	0.472	0.404	0.326
11.01.2020	0.437	0.409	0.318
29.01.2020	0.256	0.409	0.316
30.01.2020	0.235	0.396	0.298
01.02.2020	0.236	0.395	0.292
09.02.2020	0.570	0.435	0.305
17.02.2020	2.271	0.480	0.323
22.02.2020	1.846	0.455	0.306
13.03.2020	2.587	0.910	0.331
02.04.2020	2.02	-	0.323
08.05.2020	1.139	-	0.272

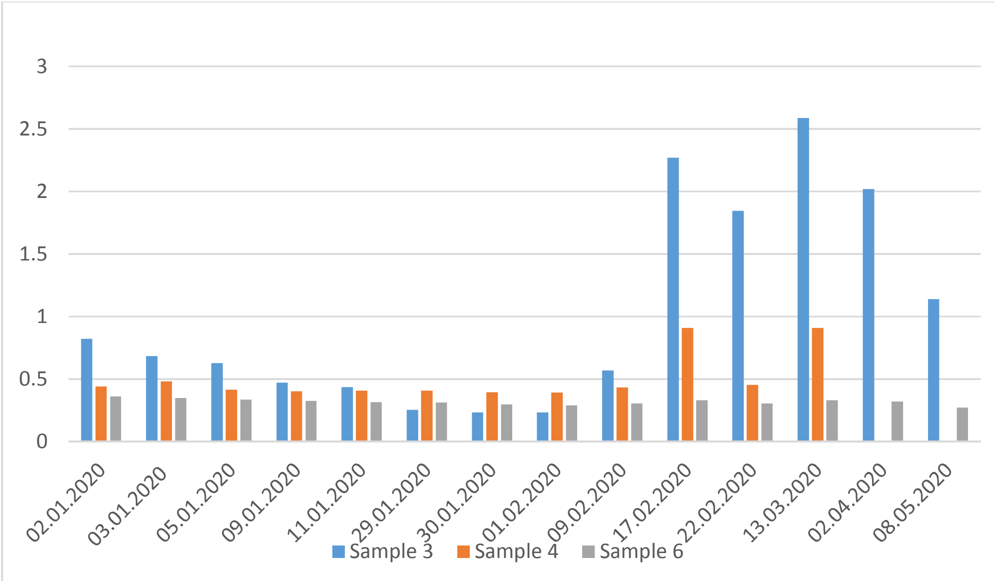


Fig. 3 Graphical representation of the electrical conductivity

We find that sample 3 found in the soil (dusty, brown, plastic clay) at a depth of 1.5 m, after a downward evolution in terms of electrical conductivity *σ,* for a certain amount of time, it has an upward evolution. The electrical conductivity *σ* of sample 4 behaves in the same way, but with a lower evolution. We mention that sample 4 is mounted in the same type of ground (dusty, black, sandy, plastic clay) at the level of 2.3 m, and sample 6 has a stability in the evolution of the electrical conductivity mounted in the ground at the level of 2.3m.

In conclusion, the zinc coated samples that were mounted into the ground, at 2.3 m present a higher stability in terms of electrical conductivity.

Electrical potential of the metal sample (electrode) galvanized, and non-galvanized mounted into the ground

Table 4

Electrical potential E [V]

Date	Sample					
	1	***2***	***3***	***4***	***5***	***6***
05.01.2020	0.766	0.737	0.884	1.145	1.040	0.917
09.01.2020	1.1229	1.080	0.998	1.171	0.907	1.162
11.01.2020	1.074	1.028	1.115	0.926	0.881	0.907
12.01.2020	0.706	0.685	0.835	0.926	0.881	0.907
29.01.2020	1.032	0.873	0.877	1.030	0.787	0.803
30.01.2020	0.823	0.890	0.953	1.035	0.887	1.127
01.02.2020	1.073	1.025	0.869	1.124	0.889	1.092

Date	Sample					
	1	***2***	***3***	***4***	***5***	***6***
09.02.2020	1.004	0.890	0.931	1.076	0.832	1.067
17.02.2020	1.161	1.073	1.042	1.050	0.911	1.068
22.02.2020	1.121	1.031	0.982	1.046	0.895	1.009
13.03.2020	1.04	1.07	1.07	1.116	0.81	0.98
02.04.2020	1.22	1.7	1.04	0.93	0.87	1.04
08.05.2020	1.17	0.67	0.66	0.72	0.86	1.09

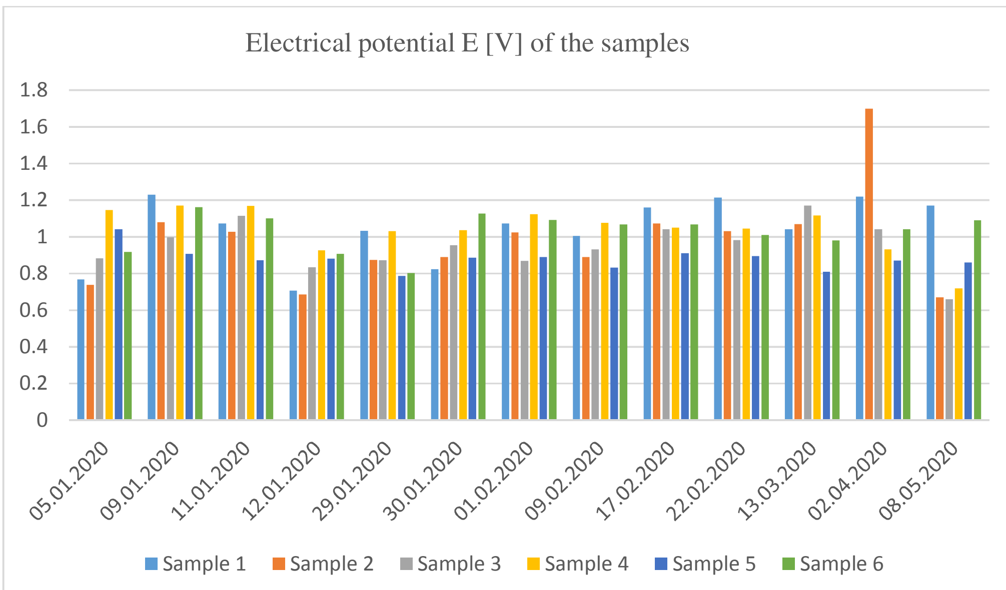


Fig. 4 Graphical representation of the electrical potential

1.2. Electrical resistivity

Definition of resistivity [6]: ***Electrical resistivity*** *is the quantity that characterizes the distinct behavior of materials, under the action of an* *electric current*. *Resistivity is the specific property of a particular material to oppose the passage of an electric current through it. Homogeneous material of a given size and load time and at a fixed electric current shall be taken into account. Resistivity is characteristic of each type of material and is the basis for calculating the electrical resistance of different bodies made of that material.* At a voltage of 12 volts dc, the following values were obtained on the galvanized and non-galvanized samples:

Table 5

Electrical resistivity of the samples mounted in the ground [Ωm]

Date	Sample			
	1	***2***	***3***	***6***
02.02.2020	5448.63	678.257	1214.141	2760.798
28.06.2020	9220.76	897.53	4144.82	3920.33
Growth variation [%] over a period of 147 days	↑69.23	↑32.33	↑241.38	↑42

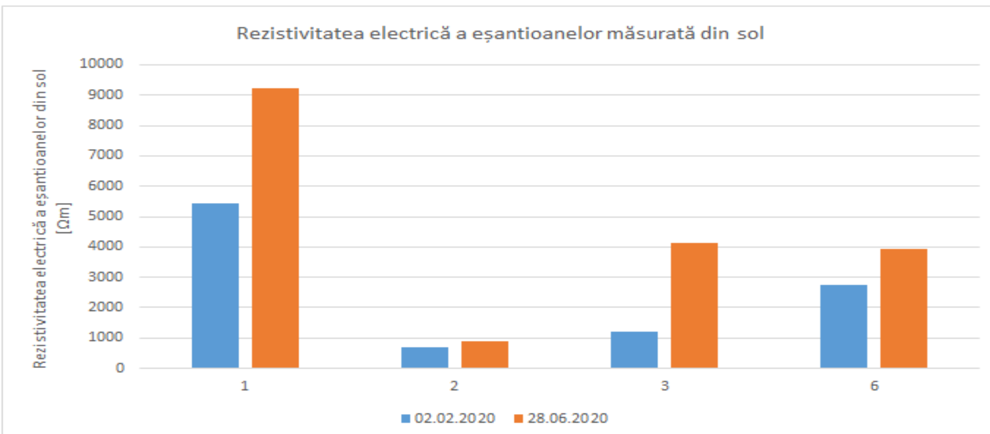


Fig. 5. Graphical representation of the electrical resistivity

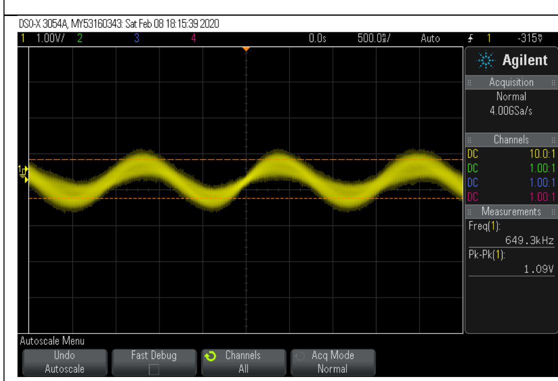
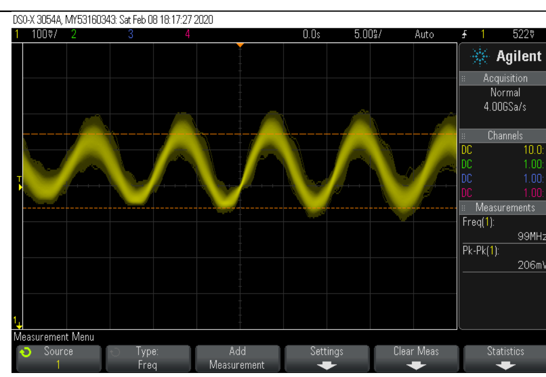
The galvanized sample 3, positioned into the soil at a depth of 150 cm, shows greater increase in electrical resistivity, thus resulting in a more intense activity of electrochemical and microbiological processes in clay soil (dusty, sandy, brown, and plastic clay) with microbial activity: number of colonies, 83 and bacteria (col/ml) $1.09*10^5$ at a dilution of 10^{-3}. As mentioned in the material [7] there is a feedback between the phenomenon of electrochemical corrosion and microbioal corrosion (biofilm formation and its deterioration mechanisms). At the same time, we notice that the electrical resistivity of the non-galvanized sample 1, is approximately 2 times higher than the electrical resistivity of the non-galvanized sample 2, both being placed in the soil at a depth of 150 cm respectively 230 cm. We find that the electrical resistivity of the samples is increasing in a period of 147 days for both non-galvanized and galvanized, and is between 32.33÷241.38 %.
At the same time, we also mention that the thickness of the zinc layer on the sample 3 is smaller than the thickness of sample 6.

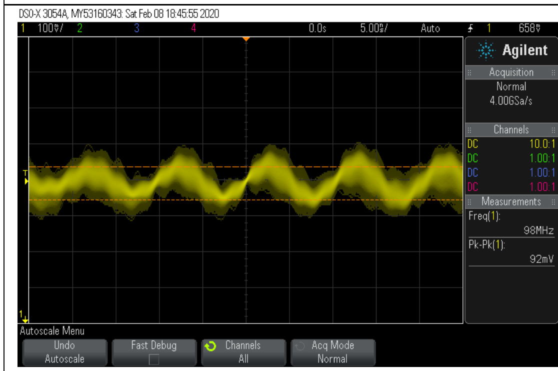
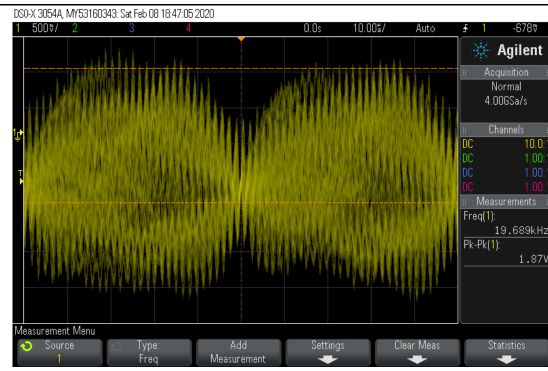
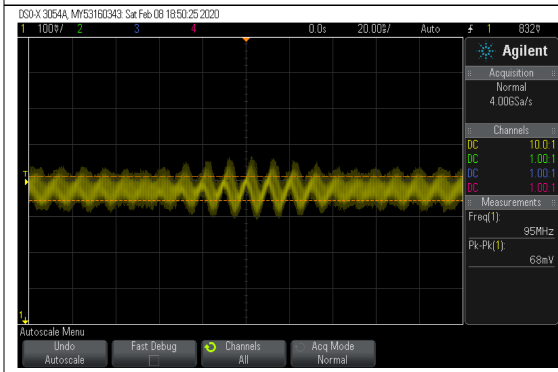
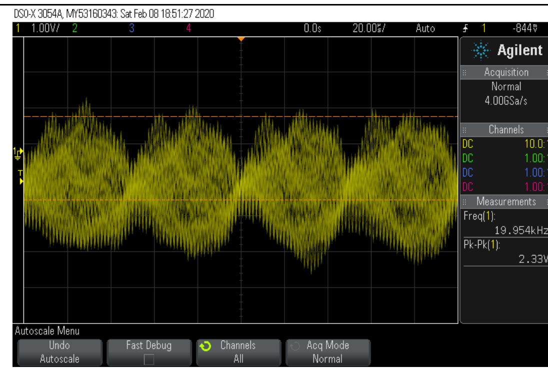
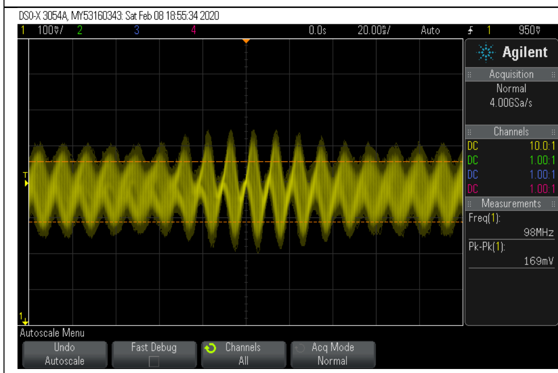
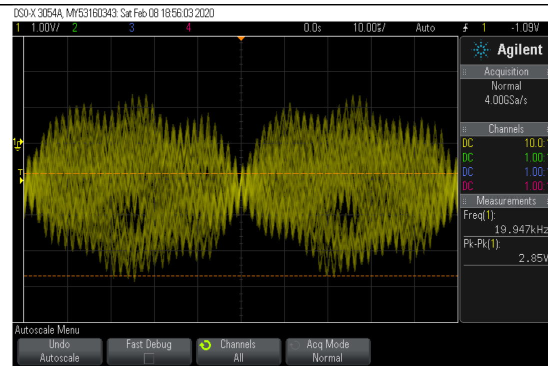
1.3. Electromagnetic field spectrum

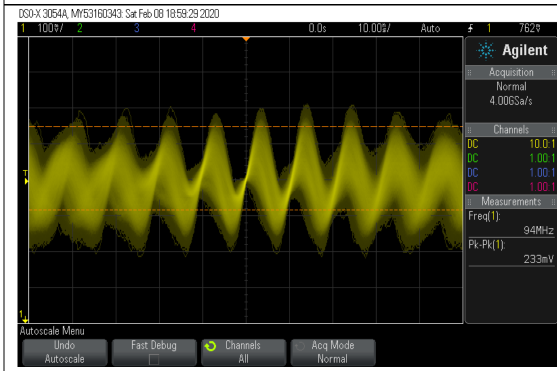
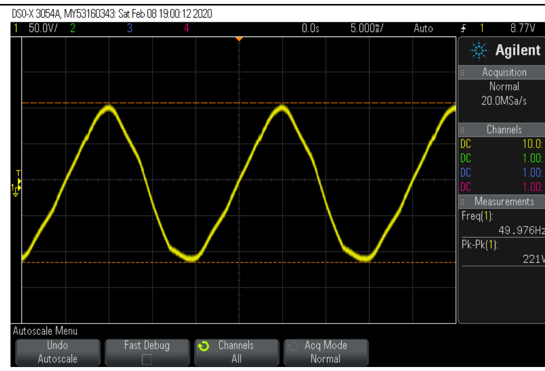
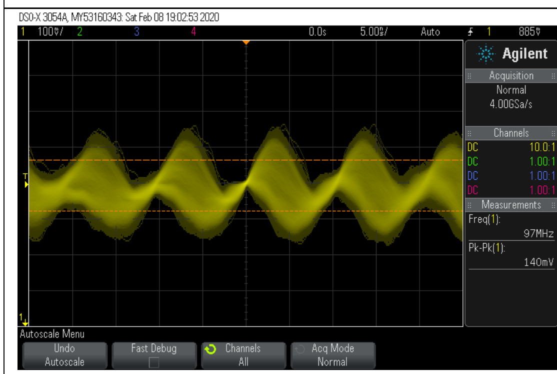
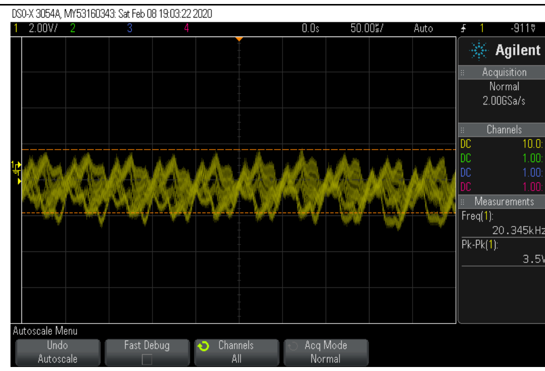
The spectrum of the electromagnetic field radiated by various local emitters in the area can be found in the electromagnetic spectrum oscillated on the metal samples in the ground of the non-galvanized and galvanized samples. It is possible that some energies of the electromagnetic field spectrum as well as its harmonics, (with no negligible energy level) received by the non-galvanized and galvanized metal samples (earthing electrodes) may accelerate the physico-chemical and especially microbiological processes on the contact surface of the samples. It should noted that magnetic bacteria [3] with an important role in the corrosion of iron in the soil and living mainly in swamps [4] (the hearth of the city of Timișoara was built on a swampy land and the drainaged and arrangement of the Bega canal – navigable canal with a port in Timișoara, began in 1728), bacteria which reacts to magnetism and was first discovered by [5] Salvatore Bellini in 1963 and rediscovered by Richard Blakemore in 1975 and called magnetotactic bacteria. Recent research on this type of bacterium has been directed and funded more in the medical field and recently in the field of civil engineering, respectively in the decontamination of wastewater – removal of heavy metals from the wastewater [6]. In addition to this type of bacteria and bacteria named SRB [7] (sulfate-reducing bacteria), on which opinions are still divided about their role in metal corrosion. It is important that a more in-depth research area has been opened in the connection of multidisciplinary fields related to in-soil corrosion of metals. In the material [8] related to the research in the field of electromagnetic spectrum, which is very diverse it is mentioned the importance of this study due to the constant increase of devices that use a fraction of this electromagnetic spectrum, and the future allocation of frequency bands (radars, mobile phones, Wi-Fi systems, broadcasting, navigation beacons, satellite communications and Schumann resonance).

Table 6

Electromagnetic spectrums of the samples found in soil at 150 cm respectively 230 cm

Electromagnetic spectrum of sample 1	Electromagnetic field spectrum in sample 1 from a predetermined point
	

Electromagnetic spectrum of sample 2	Electromagnetic field spectrum in sample 2 from a predetermined point
	
Electromagnetic spectrum of sample 3	Electromagnetic field spectrum in sample 3 from a predetermined point
	
Electromagnetic spectrum of sample 4	Electromagnetic field spectrum in sample 4 from a predetermined point
	

Electromagnetic spectrum of sample 5	Electromagnetic field spectrum in sample 5 from a predetermined point
	
Electromagnetic spectrum of sample 6	Electromagnetic field spectrum in sample 6 from a predetermined point
	

From [1] ***dBM*** *(in other words dBmW or Decibels-miliwatts) is an abbreviation for the power ratio expressed in decibels (dB) as a unit of measurement for power in reference to a single milliwatt (mW). This is used in radio, microwave and optic fiber services as well as an absolute convenient measure of dBW power energy which refers to the 1 watt (1000 mW).* Thus, the ratio between the signal strength measured in [dBμV] (decibels relative to a microvolt) and the resistance of the non-galvanized and galvanized sample can be calculated.

Dictionary of terms:

- *Freq [Hz]*: wave, signal frequency [2] (Radio waves extend over a wide frequency band. For example, ordinary FM radio waves are broadcasted in the "western band" – CCIR (88-108 MHz) and "eastern band" – OIRT (65-74 MHz). Visible light is an electromagnetic wave with an average frequency of 500 THz *($500 \cdot 10^{12}$ Hz, ie 500 millions of millions of oscillations per second)*
- *dBm*: energy level of the electromagnetic electromagnetic field spectrum 0 dBm at 1 watt;

- *mW*: electric power in milliwatt;
- *U[V]ef*: effective electrical voltage in volts;
- *dBμV/R[Ω]:* the ratio between the signal strength of the received electromagnetic field spectrum and the resistance of the metal sample, non-galvanized and galvanized in the soil;
- *-126 dBm "Thermal noise of the earth"* the energy level of the spectrum of the electromagnetic field in the ground.
- *649.3 Hz..* electromagnetic field spectrum with frequency (ultra low frequency) with λ=100÷1000km (f=300÷3000Hz);
- *94÷99MHz...* electromagnetic field spectrum with frequency (very high frequency) with λ=1÷10m (f=30÷300MHz)...[9] Frequency band applicable in Romania for radio broadcasting/multimedia applications on FM radio, , 87,5000÷100,0000MHz;
- *19.954÷20.345kHz* electromagnetic field spectrum with frequency (ultra low frequency) with λ=100÷100km (f=3÷30kHz)...[10]. Frequency band applicable in Romania for standard frequency and time signals.

Obs. The resistance values of the non-galvanized, galvanized sample in [Ω] are given in Table 1

Table 7

Electromagnetic field measurements of the samples within the soil

Sample	Freq [Hz]/[Mhz]	dBm	mW	U[V]ef	R[Ω]	dBμV/R[Ω]
1	649.3 Hz	0	1	0.273861279	68.8	0.124032849
	649.3 Hz	12	15.84893192	1.09	68.8	0.24747807
	649.3 Hz	-126	2.51189E-13	1.37256E-07	68.8	8.78085E-05
	99 MHz	-2	0.630957344	0.206	68.8	0.008428931
2	98 MHz	0	1	0.273861279	28.3	0.079549182
		-9	0.125892541	0.097169648	28.3	0.005633425
		-126	2.51189E-13	1.37256E-07	28.3	5.63165E-05

Sample	Freq [Hz]/[Mhz]	dBm	mW	U[V]ef	R[Ω]	dBµV/R[Ω]
	19.689 Hz	-123	5.01187E-13	1.93879E-07	28.3	7.95742E-06
3	95MHZ	0	1	0.273861279	33.2	0.086161161
		-12	0.063095734	0.068790843	33.2	0.004739936
		-126	2.51189E-13	1.37256E-07	33.2	6.09974E-05
	19.954 kHz	-81	7.94328E-09	2.44079E-05	33.2	8.92838E-05
4	98MHZ	0	1	0.273861279	48.1	0.103708664
		-4	0.398107171	0.172794785	48.1	0.007512293
		-126	2.51189E-13	1.37256E-07	48.1	7.34201E-05
	19.947kHz	20	100	2.738612788	48.1	0.327955591
5	94MHz	0	1	0.273861279	46.2	0.101639727
		-1	0.794328235	0.244079122	46.2	0.008928377
		-126	2.51189E-13	1.37256E-07	46.2	7.19554E-05
	49.976Hz	-	-	-	46.2	-
6	97MHz	0	1	0.273861279	58	0.11388237
		-6	0.251188643	0.137255777	58	0.006695338
		-126	2.51189E-13	1.37256E-07	58	8.06225E-05
	20.345kHz	22	158.4893192	3.447709231	58	0.404069898

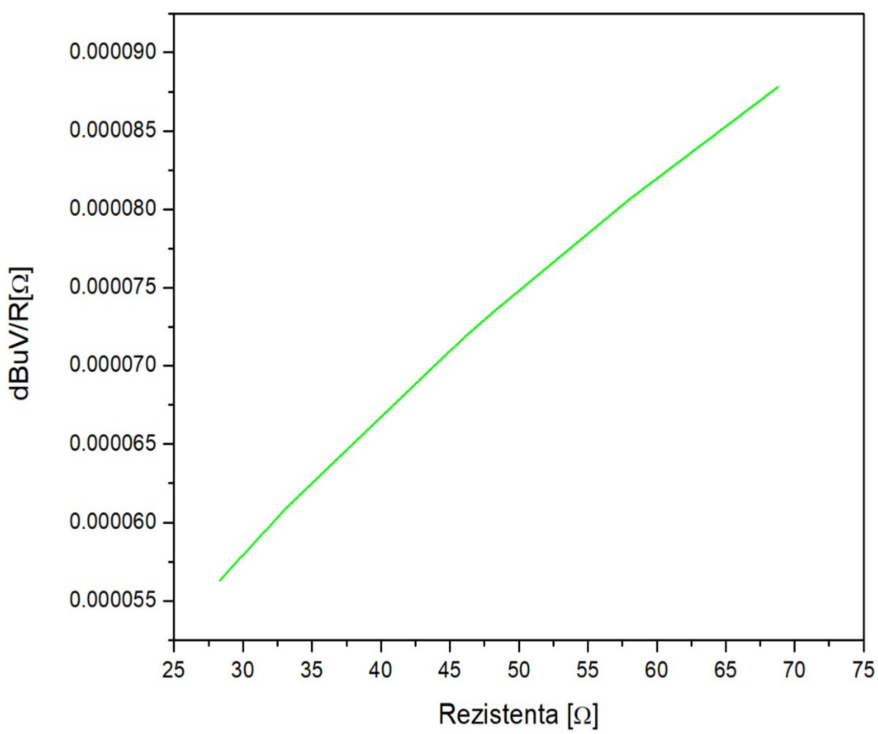


Fig. 6 Graphical representation of the resistance according to the “noise” of the earth

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