ALGORITHM FOR NOISE-DATA REDUCTION FOR LONG-TERM EMF MONITORING SYSTEMS

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Abstract
In addition to present popular 'in situ' EMF-measurements performed at critical locations like schools, hospitals or in front of base stations for one-time, long-term evaluations of RF-fields become more and more essential. This is especially because of the continuously increasing number of new applied technologies and even more emitting base stations. To perform such long-term investigation, fully automatic, stand alone EMF-monitoring stations are suited very well. Typically, several of such stations are connected to one environmental network, fully remote controlled by one server. To yield maximum of information, each station is continuously in operation, performing frequency selective measurements and generating an enormous amount of measurement data. The data communication often represents the bottleneck of such systems and therefore the reduction of these data becomes very essential. By implementing an intelligent algorithm for data reduction directly on the measurement station this problem could be reduced. Therefore we will provide in this paper a methodology suited for a considerable reduction of noise points without loosing any relevant signal information. The specific nature of this algorithm and his efficiency in data reduction will be discussed and explained, including how it works and what parameters are needed. The results which can be achieved with this technique are demonstrated with the existing monitoring system 'Field Nose' from ARC Seibersdorf research.

I. **Introduction**

Today more than 1 billion people are using mobile telephones world-wide, about 360 million people of them in Europe. Such wide use of this technology led to an increase in the environmental exposures to RF-fields and the introduction of new, additional technologies has intensified this process.

In the meantime most countries have national laws, regulations, guidelines or standards and more or less accurate defined measurement procedures and protocols how to handle RF-exposure. The ICNIRP guidelines [1] are used as reference in most European countries. However, many countries apply more restrictive limits, e.g. Switzerland and Italy [2]. Independent of the absolute values of limits, different measurement procedures are used in different countries. In general, the limit are frequency dependent and given over a wide frequency range. There are different concepts regarding the kind of exposed people and the considered areas, i.e. general public versus workers or controlled versus uncontrolled areas. For EMF-exposure evaluation, the contributions of all relevant RF-emitters for the whole body have to be investigated, considering individual signal form, frequency range, bandwidth, polarisation, direction and deviation over time. This leads to a lot of essential requirements for EMF measurement systems and especially also for the data evaluation procedures of such equipment. Another need for adequate measurement and evaluation techniques is the demand for epidemiological studies on the potential health effects caused by the numerous RF-emitters. In the frame of an international project the feasibility of epidemiological studies on potential health effects arising due to the exposure from mobile telephone base stations was jointly assessed by a team of RF experts and epidemiologists. A major outcome of this study was the need for reliable exposure assessment procedures [3]. Frequency selective, monitoring exposure assessment equipment is one of the best suited approaches to assess exposure in a reliable way. Also one COST 281 program activities are focusing at that topic.

II. EMF Measurement Systems

One of the most important requirements for EMF-measurement systems for exposure evaluation is an isotropic (receiving) radiation characteristic over the whole frequency range to add all contributes of different RF-emitters (technologies) in the same way, independent of their distance and direction in relation to the measurement point and their polarisation. Further the sensitivity of the measurement systems have to be high enough to measure very small signals of modern communication technologies of a few mV/m as well as the dynamic range has to be large enough to consider signals close to the limit level, which is typical at 4 V/m to 60 V/m. Of course measurements have to consider the effective field strength or power flux density independent on the kind of signal or technology (e.g. modulation, pulsing or frequency hopping) and they should be fast, easy to handle, accurate and reliable. The instruments should be small, low cost, easily to operate and the requirement to enable long-term evaluation is essential for RF-dosimetry. Currently three different technical solutions are on the market to perform EMF measurements and each one has its individual assets and drawbacks in relation to the requirements mentioned above.

First there are the well known wideband field probes. They are low priced, easy to handle, have a wide frequency range typically from 100 kHz to 3 GHz, good isotropic characteristic and they are popular also for other kind of measurements e.g. for classical EMC. Some types also enable to select some frequency dependent limits and return the result in percentage of that limit. Unfortunately this is a global result without any information of the relative contribution of the considered transmitters. Also the sensitivity is limited at about 0.1 V/m. Therefore field probes are popular and well suited for preliminary measurements, e.g. to decide if and at what position frequency selective measurements should be performed.

A second group is represented by so called transmitter-selective or narrowband instruments. With these instruments, which are relatively new on the market, fixed or user definable frequency bands corresponding with the bands of transmitter-technologies are measured. Each narrowband is evaluated separately but of course there is, similar to field probes, no possibility to get any information about signal intensity within a band e.g. any differences in channels or for competitive providers. Depending on the system, data acquisition in the time domain is very flexible, from milliseconds to minutes for long-term evaluations. Typically 7 to 15 narrow-bands are measured together at each time cycle and therefore the resulting data amount is relatively easy to handle. Some systems are small enough to carry them on the body or in a rucksack and use these instruments for ‘live time’ RF-dosimetry during the whole day or to evaluate typical exposure at a working place. Typical limitations of those systems are given if signals occur out of the predefined narrow-bands because they were totally ignored. Another problem is caused by crosstalk of bands close together which is often used for up- and downlink of one technology, but could also affect different technologies, if their frequency bands are proximate to each other. Increasing the number of RF-technologies or even the number of bands which should be evaluated will increase that crosstalk problematic. The sensitivity of the systems is typically given at the data-sheets with 10 to 50 mV/m, which is suitable for most applications. Unfortunately the isotropic behaviour and measurement uncertainty are often not clearly specified especially if these data are needed for the individual bands.

The third group of systems is a more or less traditional method using a wideband antenna or field sensor in combination with a frequency selective measurement instrument like a spectrum analyser. Due to the fact that no antenna has an isotropic radiation characteristic by itself, one solution consists in the addition of the contributions of three measurements of an antenna with a dipole like radiation pattern to yield an isotropic receiving characteristics for the system. ARC Seibersdorf research developed small RF-antennas with a dipole like radiation pattern and established the so-called ‘Add3D Method’ [2] in 2002. An automatic positioner can be used to realize the three orthogonal antenna orientations. Figure 2 is showing a schematic drawing of the ARC Seibersdorf research system ‘Field Nose Complete’ and a picture of the real system (see also at http://www.seibersdorf-rf.com). This EMF-measuring and monitoring system is fully remote controlled by the software ‘Nose’, and enables the user to perform automatic measurements as well as many data evaluation procedures. The following examples and evaluations of that publication are based on this system.

Other manufacturers offer systems based on three small sensors with dipole characteristic and switch between them or combine them by an electrical network. In those cases there is the challenge to get an acceptable isotropic radiation pattern of the system because the three sensors interfere with each other. On the other hand such systems are faster, because they need no time to rotate the receiving antenna.

All these systems based on frequency selective spectrum analyser measurements enable individual RBW-settings, rms-, peek- or average signal detection, max-hold trace functionality, very high dynamic range and best sensitivity (low noise level) caused by the performance of state of the art spectrum analysers. The measurement time for a frequency scan is different and mainly depending on the trace speed, the analyser settings, the number

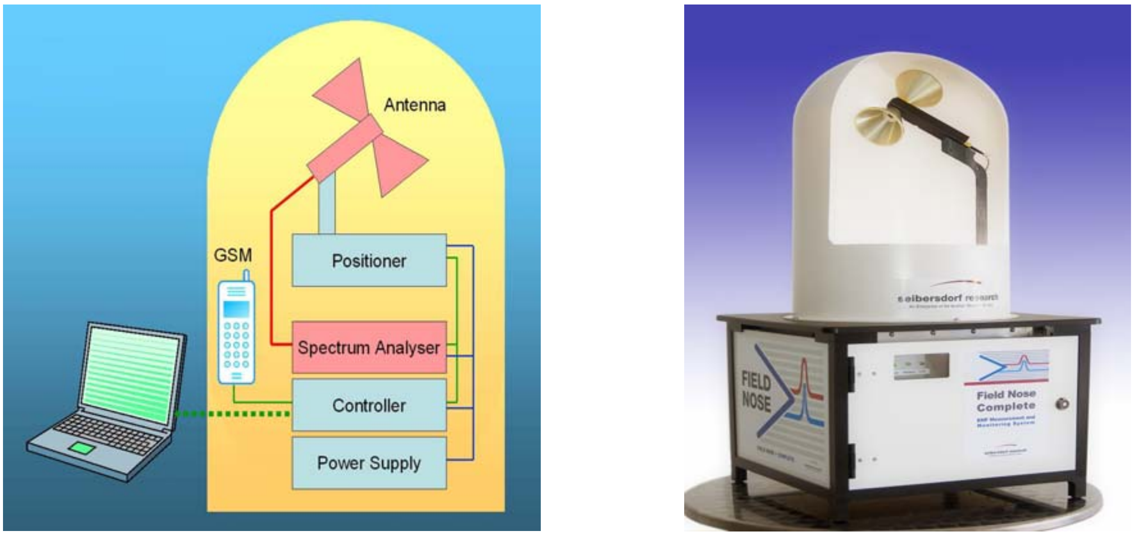

Figure 2: EMF-monitoring system Field Nose Complete (schema and picture)

of repetitions and the sensor type. Measurement cycles of a scan from e.g. 80 MHz to 2.5 GHz can be done within a minute or less. With these frequency selective measurements most information is generated and available for evaluation on the one hand. On the other hand especially that large amount of data can make problems. One possible way of the challenging task to reduce the amount of data without any loss of relevant information is presented in the next chapters.

III. Evaluation problematic of frequency selective systems

Figure 3 is showing a measurement trace and the corresponding data evaluation of a frequency selective, wideband EMF-measurement performed in the centre Vienna. Radio and TV signals as well as the typical downlink signals of mobile phone technologies (GSM 900, DCS 1800 and UMTS) can be seen. The frequency bands of those technologies are marked by coloured, vertical areas corresponding to technology bands as common for band-selective data evaluation. The measurement was done from 80 MHz up to 2.5 GHz using a Field Nose system with a PCD8250 antenna, a 5 m long RF-cable and an Anritsu MS 2711D spectrum analyser.

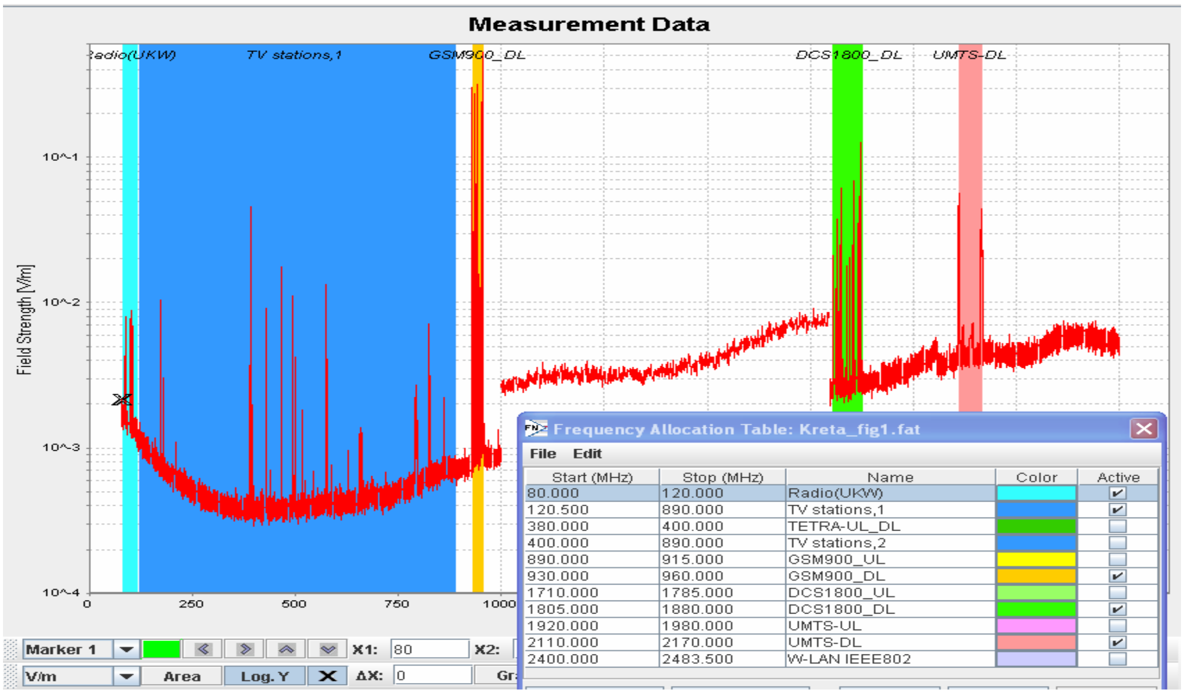

Figure 3: Frequency selective EMF-wideband measurement trace (overview measurement) from Vienna

The characteristic 'bathtub' noise floor for this frequency selective, wideband measurement trace can be seen very clearly because of the logarithmic scaling of the field strength axis. It is caused by the noise floor of the spectrum analyser itself (primary depending on its RBW setting, internal attenuator setting or an activated preamplifier), the cable- and connector losses and the antenna factor of the used PCD-antenna. Also caused by the logarithmic scaling and the high sensitivity of the system, the small signals from radio and TV-stations and less strong mobile technology signals with a few mV/m can be detected well. For the measurements from 80 MHz to 1 GHz and from 1.8 GHz to 2.5 GHz a RBW-setting of 100 kHz was used to get a good frequency resolution of the measured technologies. Between those bands we do not expect any signals. Therefore the RBW at that frequency range was set to 1 MHz to save time for the frequency scans and to reduce the number of measurement points too. The higher noise floor does not disturb in that case because of the lack of public communication technologies in that range.

Caused by the selected RBW-settings with 100 kHz respectively 1 MHz and the wide frequency range, 17.000 measurement points are needed for the one single scan according to Figure 3. For example if one scan should be performed each 5 minutes during one day, 288 scans respectively nearby 5 million measurement points are needed. To save that data including measurement information like settings, used antenna and cable factors, time and date, the Field Nose system needs approximately 15 MByte of memory, if the data was stored in a binary format. Even up-to-date computers need considerable time (from a few seconds to minutes) to process such big amount of data, e.g. to print them on screen, perform any data calculations, load and save them or to send them to a host system computer in case of a monitoring system consisting of several measurement stations. In practice measurement may differ to that example, but still a huge amount of data could be produced and the resulting time delay for data processing will not be accepted by the user. This would limit the application of frequency selective systems for long-term evaluation in a considerable way.

IV. Algorithm for noise-data reduction

Having a look to Figure 3, it can be seen that most of the measurement points are representing noise. The only important information of this noise floor is that all signals below that level could not be detected by the measurement system and not considered for any evaluation. On the other hand if the level of noise is deep enough, the signals below that do not affect the evaluation results in a significant way. This fact is the starting point to overcome the problem of extremely large amount of data for frequency selective measurements. Based on an effective signal detection method it should be possible to divide the signals from noise sequences and reduce or eliminate the noise data. Of course the efficiency of that process depends on the relation of signal and noise parts in a measurement scan but especially for wideband measurements it should reduce the number of data points in a considerable way and help to speed up the systems.

The simplest solution segmenting noise and signals is a user defined threshold line near above the noise. All values above that threshold will be accepted as signals. Unfortunately this works only for small frequency ranges because for wideband measurements the noise floor usually is frequency dependent and there is the question where to set the threshold limit. Another method is to select the largest signals by a peak detection algorithm. There of course is always the question of a proper predefinition of the number of relevant peaks as well as the problem that the highest signals not necessary are the one with most of energy because of different bandwidths. Approaches like they are typical in the noise reduction of sound signals were not applicable because of the fact that EMF signals sometimes look like noise to them. Other approaches which are used in image processing are not really applicable too.

Therefore we developed a specific algorithm for signal detection considering the unique requirements in the area of EMF signal processing. The processing of the data can be applied to measured data that is already available, but the main intention was to perform the reduction during measurements on the embedded system of the Field Nose Complete system. Therefore the reduction algorithm works completely automatically but it is also possible to set some parameters manually to improve the results for certain measurements. The noise data can be reduced so that the noise floor is still present or it is possible to remove the noise data completely. Signals are not affected by the algorithm in any way.

The noise data reduction algorithm itself works in the way that first the noise floor is detected and segmented from the signals. The next step is to calculate the new reduced noise floor with less data points and finally this new noise floor is merged with the original signal data. The most difficult part was to find a way how to distinguish very efficient between the noise floor and the signals because sometimes signals share many characteristics with the noise. For that purpose an upper and a lower envelope of the noise are calculated by using a 'Noise Height' factor in dB. Based on this predefined noise-amplitude factor the decision is derived if the measured points are noise or not. If a Gaussian distribution function is assumed for the noise, this factor should be 2 sigma of the noise amplitude to catch approximately 99 % of noise by the envelope curves. For that process it is essential to consider not only the difference between adjacent measurement points, but also the amplitude differences of proximate points have to be considered.

Between the envelope curves of the noise a new noise curve is calculated with much less points in correlation to the original measured curve. The reduction of noise points for the calculated noise curve is predefined in the software or can be selected manually by a percentage value, which is typically around 90 % (this is an input value for the software and not correlating with exact 90 % of noise point reduction; see also Table 1). The resulting, data reduced measurement curve consists of the original signals matched with the sequences of reduced noise points. In Figure 4 an example of the signals is displayed. The thick (red) curve is the new calculated curve with reduced number of points in the noise sequences and unchanged points for all signals.

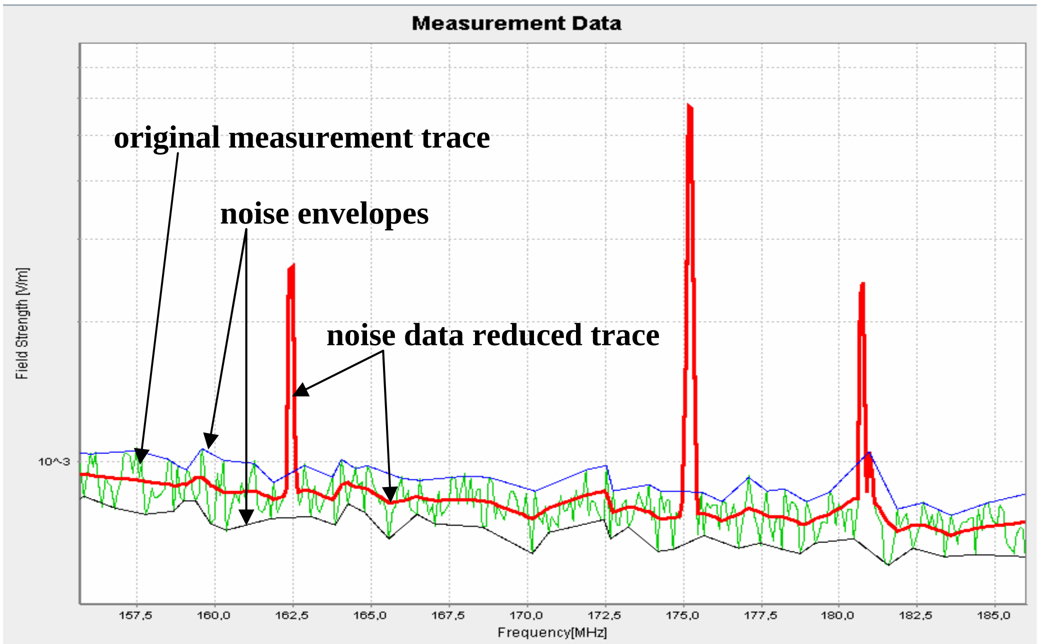

Figure 4: Noise points reduced measurement trace with noise envelopes

However there are still some kinds of signals making problems like typical UMTS signals. Because of their 5 MHZ bandwidth and the RBW-setting of 100 kHz these signals look like noise to the algorithm. This can be solved in a second signal check, where it is assumed that the noise floor is continuous. Jumps in the noise floor because of different analyser settings are handled by the evaluation of each measurement trace separately.

The next step to reduce the amount of data is to eliminate the noise sequences totally. Therefore simply all noise points are neglected and only the signals are still part of the data reduced, noise points excluding trace. In the graphic chart the flanks of signals are connected by a line. In Figure 5 the UMTS-DL band of the overview measurement from Vienna (Figure 3) is shown magnified. For the original measurement trace the noise data reduced trace and the trace with eliminated noise points were calculated and displayed together. The difference in the number of needed data points for these three signals is obvious.

Another powerful effect of the presented algorithm besides the data reduction is the possibility to evaluate the effective signal power without any incorrect additional integration of noise to the signals. To demonstrate that we have again a look at the UMTS band of Figure 5 respectively Figure 6 at left side. This time the vertical bands in Figure 6 are representing the DL-channels of the Austrian UMTS providers, which are used for data evaluation of the three UMTS-traces. On the right side of this figure the evaluation results are given. In all 3 diagrams the results for the active channels are identical because the algorithm does not affect the signal parts.

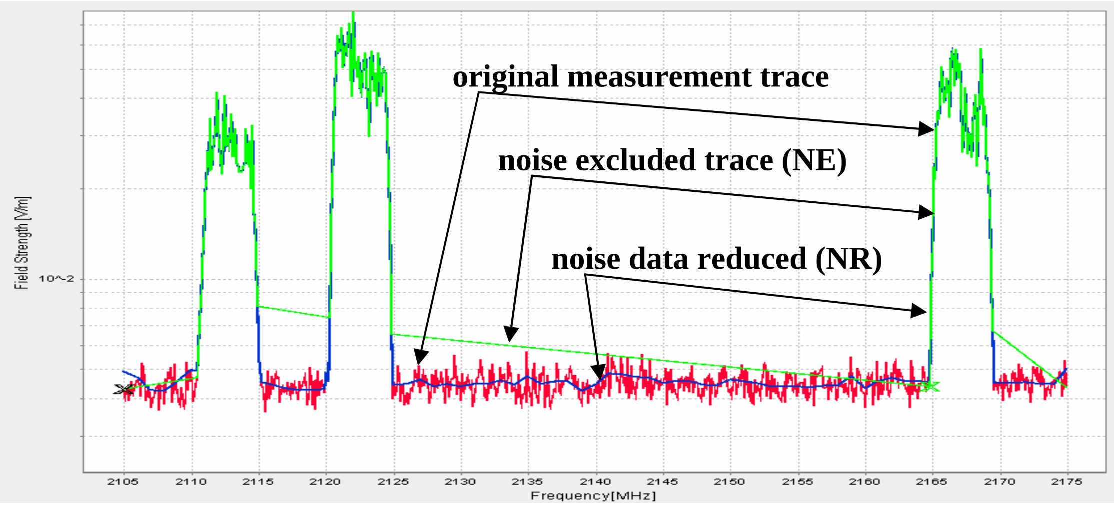

Figure 5: UMTS-DL traces after noise data reduction

Also the results of the other channels, representing the noise power, are very similar for the original trace and the noise data reduced trace. However for the trace without any noise points the evaluation result for inactive bands is zero. Therefore the presented algorithm enables the user to add only the power of measured signals to yield in fact EMF-field strength evaluation results without any disturbing noise contributes.

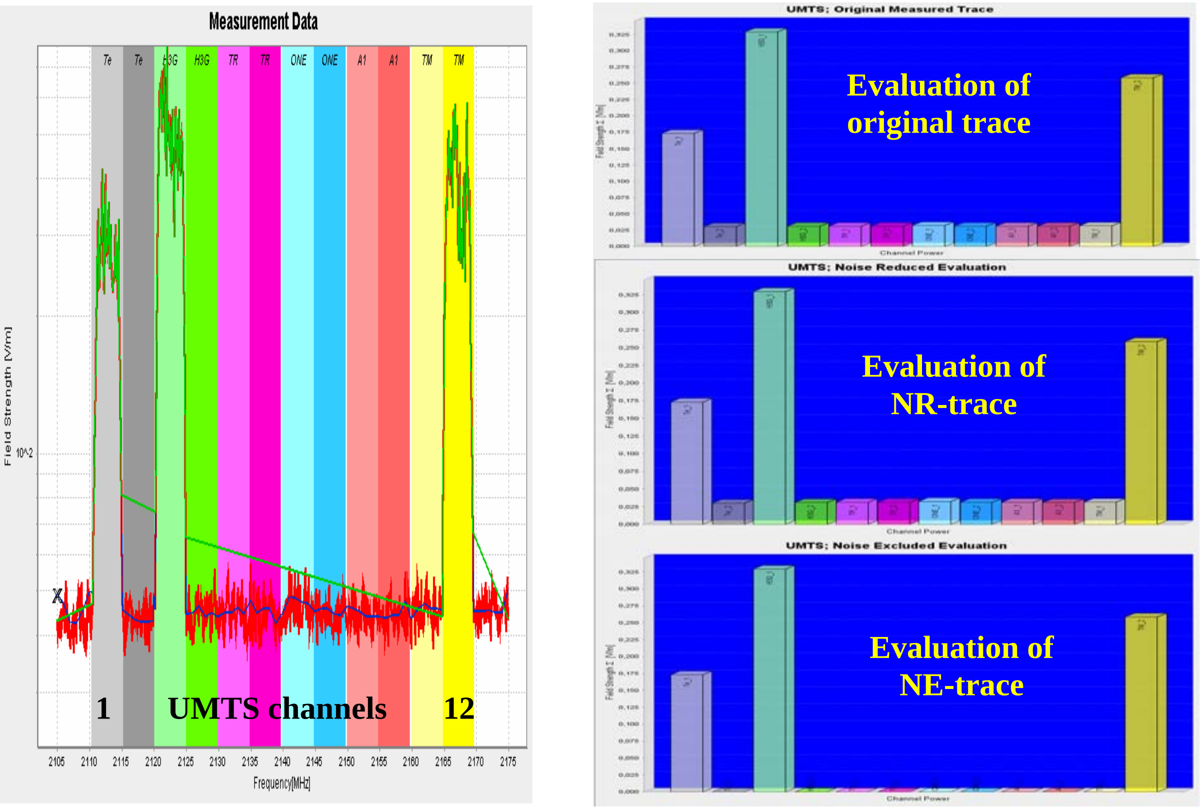

Figure 6: UMTS-DL traces and corresponding channel selective evaluation results

V. Results

Figure 7 is showing 4 original measurement traces and the noise excluded traces after implementation of the algorithm to the original measurement traces. At the top there are typical GSM900-DL measurements performed from 930 MHz to 960 MHz. The left one was made in the rural environment at Seibersdorf and the right during an EMC-exhibition at Stuttgart in 2005. Below them there are 2 of the overview measurements corresponding to the measurements described in Figure 3. The left one is again from Seibersdorf and the other one from the centre of Vienna. These 4 pictures are showing typical traces which are used to investigate the efficiency in data reduction of the presented algorithm. The results are given in Table 1 for one, ten and fifty similar measurement traces (repetitions) for each of the 4 signal groups.

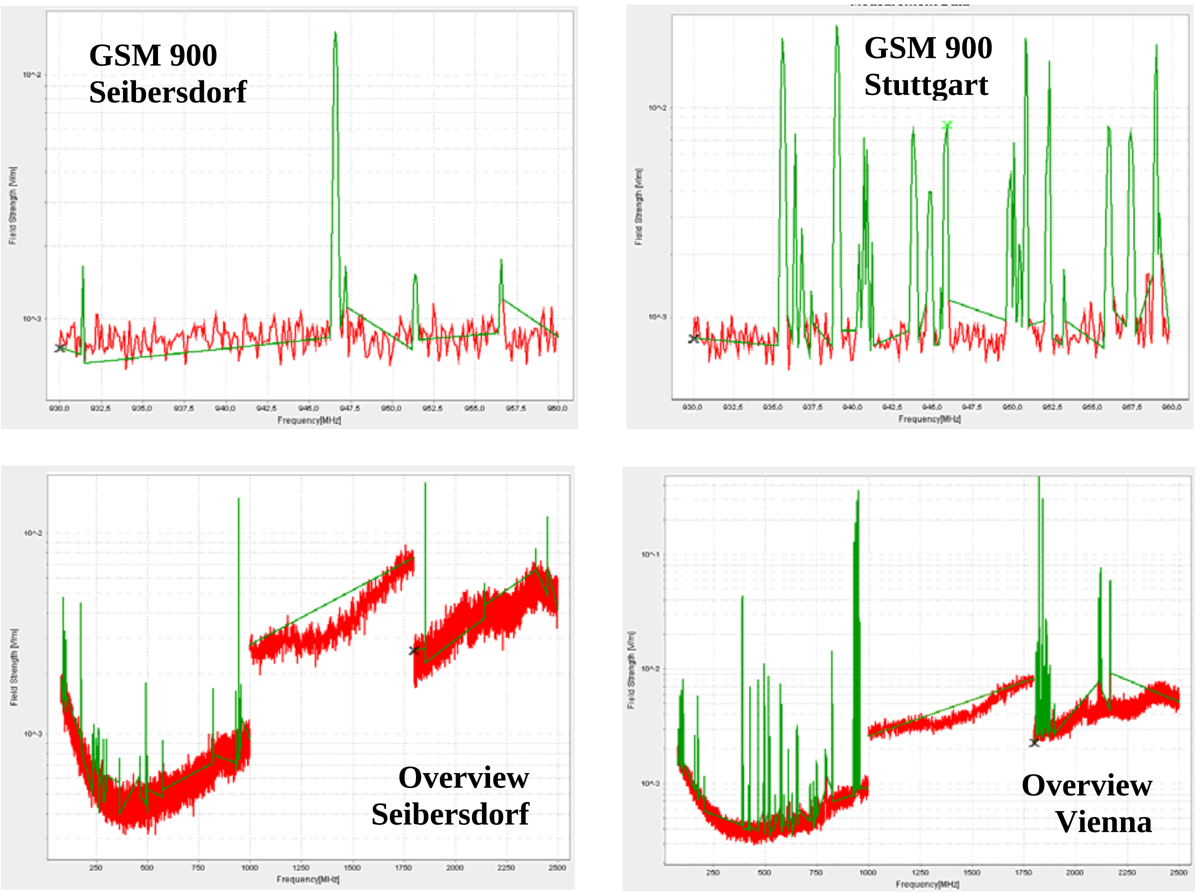

Figure 7: Example traces for the evaluation of Table 1

The values given in percentage are relating to the original measurement traces and give the amount of needed disk space after data reduction. That means a number of 30 % corresponds with a data reduction of 70 %. For the original measured traces the necessary disc space to save the measurement including all settings, factors and other useful information is given in kByte.

	Signal Group	GSM 900; Seibersdorf	GSM 900; Stuttgart	Overview; Vienna	Overview; Seibersdorf
1 Trace	Original Sig. [kB]	9	9	178	178
	NR [% of the original sig.]	77,8	77,8	19,7	14,6
	NE [% of the original sig.]	66,7	77,8	8,4	3,9
10 Traces	Original Sig. [kB]	34	34	1721	1721
	NR [% of the original sig.]	52,9	61,8	12,9	12,3
	NE [% of the original sig.]	32,4	44,1	1,8	1,6
50 Traces	Original Sig. [kB]	140	140	8515	8515
	NR [% of the original sig.]	54,3	59,3	12,3	12,1
	NE [% of the original sig.]	32,9	37,9	1,6	1,5

Table 1: Efficiency of the data reduction algorithm (Noise Height factor = 5dB and 90 % Reduction Value)

As expected the best results are given for overview measurements in a rural environment like Seibersdorf. There are only a few signals present and the noise reduction is very efficient with up to 87,9 % data reduction for the noise data reduced traces and up to 98,5 % for the noise excluded traces at 50 repetitions. That means that the needed disc space is reduced from about 8.5 MByte to less than 130 kByte. This is a data amount which can be processed easily within short time by computers. Also for the noise excluded wideband trace performed in the city of Vienna the reduction is quite similar with 1.6 % of remaining data instead of 1.5 % like Seibersdorf. For the scenario of 288 wideband traces during one day as assumed in chapter III including the evaluation problematic for frequency selective measurements, a total disc space of about 620 kByte would be generated if the presented algorithm is used. This data amount is still not a large problem to process at modern PCs and therefore in fact this algorithm supports frequency selective EMF-measurement systems to overcome the problematic of time delay caused by too much data generation. For a single overview trace the efficiency of the data reduction is a little bit less because of the data overhead necessary for each measurement job independent of its number of repetitions but with about 80 % to 95 % still excellent. For the GSM900 evaluations the reduction of data is from about 22 % for noise reduced signals for one single trace up to 77 % at the 50 noise excluded traces for the GSM900 band at Seibersdorf, but the absolute amount of data is much less than for the overview measurements and therefore not a problem in processing. In addition to that it is a big advantage of the algorithm too, that it is working automatically as a selector to differ between the existing signals and noise, which is not of interest. Only pure signal information is kept in opposite to other methods like band-selective methods or by wideband measurements using field probes where signal and noise is mixed without any possibility for differentiation.

VI. Conclusion

Recapitulating it was found that especially for wideband measurements with a lot of repetitions the presented algorithm has its best efficiency with typically more than 98 % of data reduction for the investigated traces and measurement settings. This enables frequency-selective measurements for sophisticated single investigations on site as well as for long-therm monitoring e.g. for dosimetry studies. Caused by the fact that the data reduction algorithm can automatically be applied in real-time to the measured data and it is not specific for any spectrum analyser, it could be used generally for data reduction purposes. Another big advantage of that data reduction process is the differentiation between signal and noise. This enables the user to define the pure signal power for EMF-evaluation instead of a mixture of signal and noise contributes. Furthermore the frequency selective measurement method is still the most sensitive procedure which allows best isotropic behaviour, sharp frequency differentiation and accurate uncertainty estimation. Drawbacks of those systems are the relatively high cost, large mechanical dimension of the some equipment and typically the engineer needs measurement expertise and experience to perform well suited settings that the advantages of frequency selective systems could be utilized.

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