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PROPOSED REVISION OF SECTION 4.10 OF THE HANDBOOK ON SPECTRUM MONITORING

4.10 Spectrum occupancy measurements

Introduction

The attached text is intended for consideration by the Rapporteur Group of ITU-R Working Party (WP) 1C for the development of a new edition of the *Handbook on Spectrum Monitoring*. Its purpose is to propose corrections and additions under § 4.10 of the 2011 edition of the handbook, in view of the abrogation of Recommendations ITU-R SM.182, ITU-R SM.1536 and ITU-R SM.1793 and the adoption of Recommendation ITU-R SM.1880 and Report ITU-R SM.2256. It would also be appropriate to reflect the results of studies carried out in this area since 2011. As it is not only the measurements themselves, i.e. obtaining of samples, that are important for the spectrum parameter being considered but also the manner in which they are processed, it is proposed to modify the heading of § 4.10 of the handbook in line with the titles of Recommendation ITU-R SM.1880 and Report ITU-R SM.2256.

The proposed modifications to § 4.10 of the handbook are contained in Annex 1.

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Attachment: 1

ATTACHMENT

ANNEX 1

4.10 Spectrum occupancy measurements and evaluation

4.10.1 General observations

The term spectrum occupancy measurements refers to the recording of emissions over a period of time. Measurement of current occupancy is usually performed at time intervals, or integration times (T_I), in multiples of 15 minutes. The resulting measurements, which can be presented in a variety of graphs, tables, etc., reflect changes in the current occupancy of a specific frequency resource during a given period of time, usually 24 hours. ~~From the gathered raw data an almost unlimited number of plots, tables etc can be produced, e.g. the calculated occupancy per frequency band or per channel exceeding a threshold level.~~

Occupancy is understood as the percentage of time (for the integration time T_I) that the signal level in the frequency domain being analysed is above a certain threshold. Questions concerning the identification of who, where and when occupies a radio frequency channel or band are not considered part of spectrum occupancy but rather are discussed in § 4.8 (Signal analysis and transmitter identification).

The inventory of the use of the radio spectrum provides information to the frequency management department officers about the actual use of that spectrum and gives them the possibility to assign new frequencies in a frequency band. But it also gives the frequency management department information about tendencies in the use of the spectrum. This information can be used to prepare national points of view for international conferences.

Measuring receivers (narrow- or broadband) or spectrum analyzers with characteristics conforming to the relevant ITU-R Recommendations (see Chapter 3) are used as receiving equipment. We note that combining the two makes little sense. A spectrum analyzer or a wideband measuring receiver has the advantage of having a higher scanning speed whereas a monitoring receiver allows individual frequencies to be monitored at random.

The frequency range to be monitored depends on systems used in the frequency band to be measured (e.g. transmission length and bandwidth) and the equipment used. Occupancy is a function of time of signals beyond a defined threshold.

Occupancy measurements are performed for frequency channels, frequency bands and spectrum resources:

– For frequency channel occupancy (FCO) measurements, a channel is considered occupied as long as the measured level is above the threshold;
– For frequency band occupancy (FBO) measurements, occupancy counts every measurement at different frequencies for the whole band, regardless of the usual channel spacing;
– For spectrum resource occupancy (SRO) measurements, the occupancy evaluation is the ratio of the number of channels in use to the total number of channels in a whole frequency band.

The differences between FCO, FBO and SRO are described in greater detail in §§ 2.16-2.18 of Report ITU-R SM.2256.

To perform good spectrum occupancy measurements the ITU-R Recommendations mentioned in the bibliography should be taken into account.

4.10.2 Measurement techniques

The inventory of the use of the radio spectrum provides information to the frequency management officers about the actual use of that spectrum and gives them the possibility to assign new frequencies in a frequency band. But it also gives the frequency management department information about tendencies in the use of the spectrum. This information can be used to prepare national points of view for international conferences.

The spectrum can be monitored either manually or automatically or both simultaneously.

Manual monitoring complementing automatic monitoring is required in those cases where it is necessary to analyse and identify observed emissions (§ 4.8). However, manual monitoring is very labour-intensive and time-consuming and only expedient when the basic characteristics to be recorded cannot be registered automatically.

Data usage periods or the scope of occupancy of a frequency band are not derived expediently by manual means.

The main method of measuring occupancy is the automatic registration technique. To ensure sufficiently accurate evaluations with a suitable level of confidence, the statistical nature of the measurements should be taken into account, as should the recommendations contained in Report ITU-R SM.2256 and Recommendation ITU-R SM.1880. In particular, when evaluating occupancy for radio signals of an unknown nature along a time axis divided into 15-minute intervals, the channel state should be monitored ideally at least twice per second. Subsequently decreasing the rate of channel state monitoring (i.e. increasing the revisit time T_R) is only possible if the occupancy evaluations are formed at integration times T_I that significantly exceed 15 minutes.

When the above-mentioned manual storage technique is not desired, then a technique of automatic registration is more applicable. This is based on the various tasks of spectrum occupancy monitoring. Automatic monitoring can be divided into 3 different measuring methods:

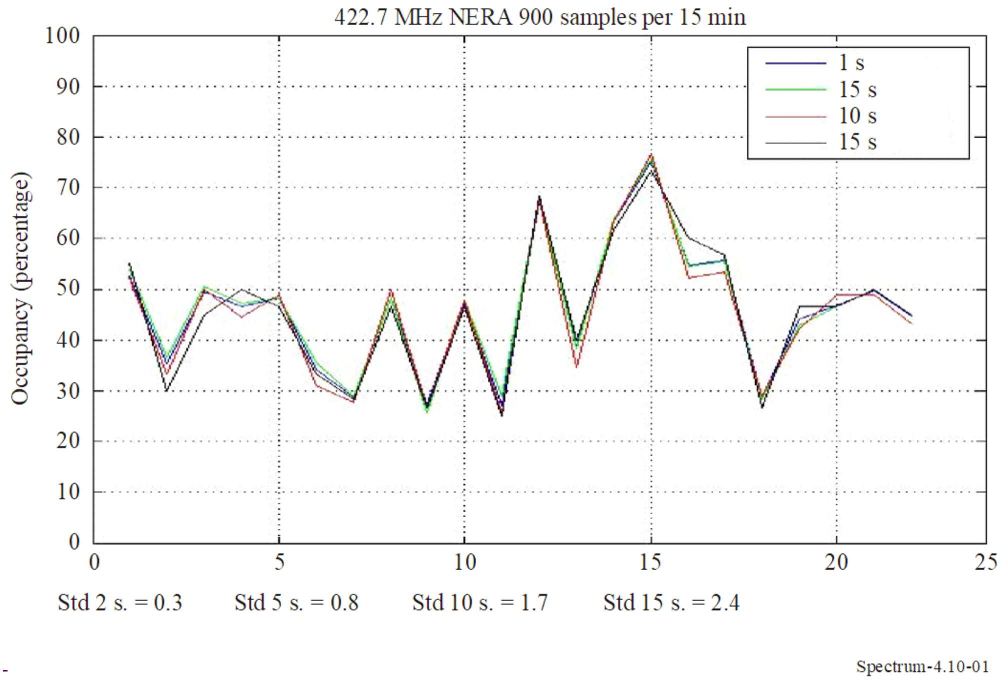
– Scanning a certain frequency band from F-start to F-stop, in a number of frequency steps, e.g. 1 000, with a certain scan (or sweep time or re-visit time), e.g. 10 s with a certain bandwidth filter. This is normally performed with a spectrum analyzer or a (fast) monitoring receiver. The results shown in different plots, tables etc. give an indication of the occupancy in that particular frequency band over a period of time, normally 24 h. These measurements are called frequency band occupancy measurements (FBO) or frequency band registrations (Recommendation ITU-R SM.1809).

– Measuring a number of preset channels, not necessarily separated by the same channel spacing. These measurements are normally performed with a receiver and are called frequency channel occupancy measurements (Recommendation ITU-R SM.1536).

– Frequency channel occupancy measurements (FCO) use the frequency band measurements as described above. Assume that F-start to F-stop is divided in 1000 frequency steps. These steps could be considered as channels. In case sweep/scan/re-visit time is for instance 10 s this means that for every step from these 1 000 channels over a measurement of 24 h about 8 630 samples are available. These results could easily be processed as frequency channel occupancy measurement (Recommendation ITU-R SM.1793) Studies have shown that increasing the re-visit time from 1 to 10 s does not influence the results to much, as shown in Fig. 4.10-1.

FIGURE 4.10-1

Comparison of different re-visit times



Many emission parameters such as signal strength (minimum, maximum or median value) and the percentage of time that the signal is above a certain threshold level can be evaluated over the whole measurement period or over smaller periods, e. g. 1 h. The recordable parameters can be determined both by frequency band and frequency channel occupancy measurements and are not bound to specific methods.

Spectrum occupancy monitoring may be carried out with a spectrum analyzer or with a monitoring receiver, both computer controlled. A combination of these two makes little sense. A spectrum analyzer or a wideband monitoring receiver has the advantage of having a higher scanning speed whereas a monitoring receiver allows individual frequencies to be monitored at random.

The frequency range to be monitored depends on systems used in the frequency band to be measured (e.g. transmission length and bandwidth) and the equipment used. Occupancy is a function of time of signals beyond a defined threshold.

Automatic emission monitoring yields information on the following:

Spectrum overview

– This does not comprise the degree of occupancy expressed in per cent but merely general usage information. This includes, among other things, the presentation of level over time, such as spectrograms, min/max/median/average, waterfall plots etc.

Current cChannel, frequency band and spectrum resource occupancy

– A classic occupancy measurement, it reveals the occupancy (%) over any period, normally 15 min, of time (%).

Traffic load

– Occupancy data averaged over periods of 60 min may be expressed as traffic intensity in Erlang. The time dependent behaviour of the traffic may serve as a basis for the determination of channel requirements and a Quality of Service (QoS) evaluation. Of special significance in this context is the determination of the peak hour. The peak hour and busy hour, are specified by the beginning of the relevant measurement interval, e.g. 13:15 and means the occupancy within the measurement interval of e.g. 13:15-14:15.

Spectrum occupancy analyses are not necessarily limited to registering emissions in the spectrum but may also be applied to data recorded by other measuring equipment such as protocol analyzers.

Many emission parameters such as signal strength (minimum, maximum or median value) and the percentage of time that the signal is above a certain threshold level can be evaluated over the whole measurement period or over smaller periods, e.g. 1 h. The recordable parameters can be determined both by frequency band and frequency channel occupancy measurements and are not bound to specific methods.

Furthermore, spectrum occupancy analyses together with a combination of different data sources allow many more parameters to be recorded and evaluations to be presented in a more differentiated manner. Plots and tables can also (automatically) be provided by user information retrieved from, for instance, planning tools, user databases, observations resulting from simultaneously manual monitoring.

Examples are:

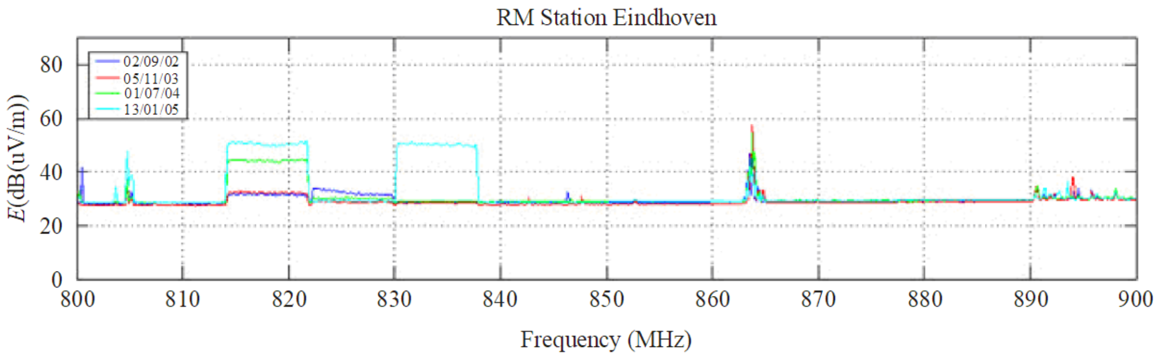
– Determination of the number of users or the spatial distribution of applications.

– Usage behaviour over distribution functions to the length of occupancy sequences. For this kind of determination the occupancy a good knowledge of the user behaviour is essential.

– Determination of usage variability or usage stability by correlating the measurement data of identical periods. This is called Delta monitoring (comparing the results of different measurements of the same frequency band on different dates, by plotting all curves in one plot).

FIGURE 4.10-1~~2~~

Example of a Delta Monitoring



Spectrum-4.10-02

4.10.3 Receivers for spectrum occupancy monitoring

The monitoring receivers and spectrum analyzers used for this application should be as a minimum requirement compliant with the recommendations reflected in other chapters of this Handbook. The monitoring receiver used for spectrum occupancy measurement should fit the following parameters:

– provide high RF selectivity (in particular, there should be sufficient RF filters properly distributed in the receiver's operating band to prevent, as far as possible, the formation of inter-modulation products);

– be fitted with sufficiently narrow IF filters, and/or an I/Q output for IF filtering by means of external digital signal processing;

– be fitted with a step attenuator;

– be able to use an external frequency standard;

– be able to measure field strength precisely;

– be able to rapidly scan selected channels from a frequency band, especially above 30 MHz.

Whether the measurement of the exact field strength is necessary during an occupancy measurement depends on the task in question. In most cases an input voltage value is sufficient for the detection of occupancy.

When selecting a receiver the circuit design of the measuring equipment should be borne in mind since it affects the measurement result: Receivers with a synthesizer can be set to any frequency. However, their scanning process is slower than that of broadband systems based on FFT. In case of using FFT the measuring bandwidth is divided by a fixed number of calculation points. Therefore it is not possible to measure just any frequency. The setting of the measuring equipment is taken into account, especially in the case of channel occupancy measurements, and it is to choose one in which the FFT points are on the frequencies to be measured.

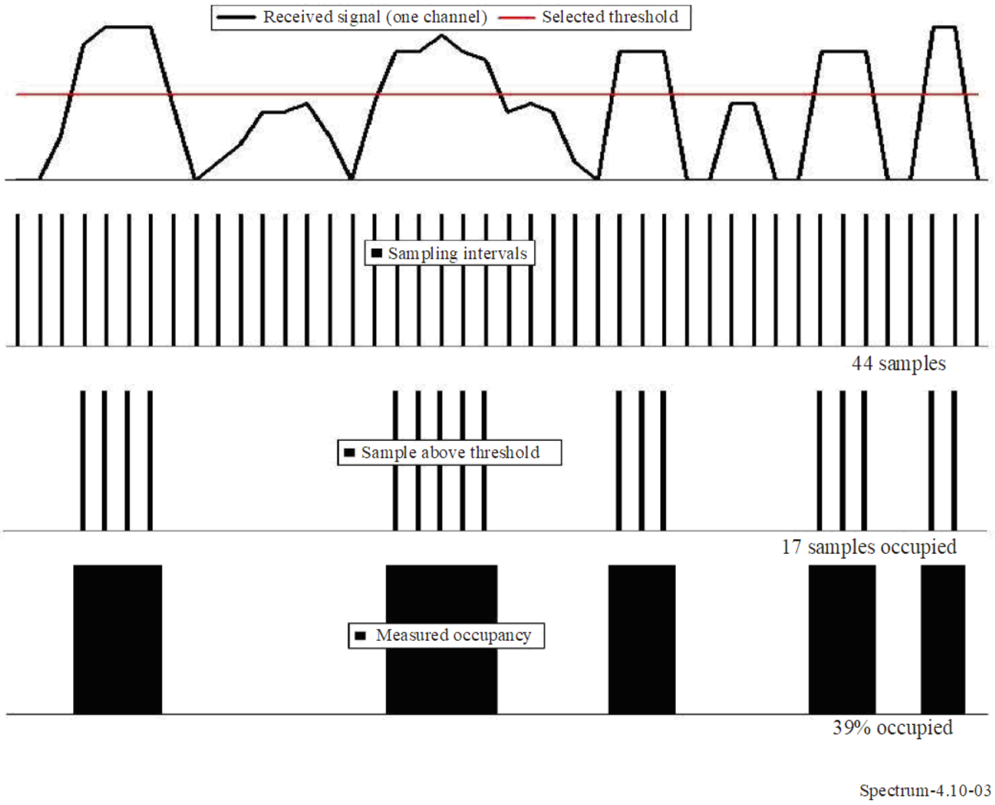
4.10.4 Basic principles and measurement parameters

4.10.4.1 Sampling principles

A typical varying strength signal is shown in Fig. 4.10-2~~3~~ with a selected threshold as indicated. The sampling instants are shown together with those samples recording "occupied". In this example 17 of the 44 sampling periods were found to be occupied leading to a 39% occupancy record. This data can be summarized into 1, 5, 15 min, 3 h, 6 h, 12 h or 24 h intervals as desired.

FIGURE 4.10-23

A typical varying strength signal



The sample technique usually gives a good estimation of channel occupancy provided sufficient samples are taken to give statistically significant result. Recommendations on ensuring statistical confidence in occupancy measurements will be provided in §§ 4.10.4.3.4-4.10.4.3.5. Table 4.10-1 shows the number of samples required to give a reasonable confidence in the results.

TABLE 4.10-1

Number of dependent and independent samples required to achieve 10% relative accuracy and 95% confidence level at various occupancy percentages (assumes a 4 s sampling period)

Occupancy (%)	Number of required independent samples	Number of required dependent samples	Required hours of dependent sampling
6.67	5 368	16 641	18.5
10	3 461	10 730	12.0
15	2 117	6 563	7.3
20	1 535	4 759	5.3
30	849	2 632	2.9
40	573	1 777	2.0
50	381	1 182	1.3
60	253	785	0.9
70	162	166	0.2

In order to achieve certain accuracy with a reliable statistical confidence interval a defined number of samples are required. In the event of occupancy of 100% only a few samples are needed to achieve a good result. Where occupancy is low, more samples are needed to obtain the same accuracy and statistical confidence. The intention of the table is to indicate that the accuracy in relation with the number of samples over time strongly depends on the transmission length of systems in the wanted frequency band and how often they are "on air". In case of a PMR user (e.g. taxi) which is once an hour on air for 12 s should longer be monitored to get a certain accuracy since the broadcast station transmits continuously).

Normally the values in Table 4.10-1 are sufficient to determine the confidence level. For special applications, e. g. very low occupancy, very long sweeptime, etc., the text "On the Definition and Estimation of Spectrum Occupancy" [Spaulding/Hagn, 1977] should be consulted.

The sample numbers given in Table 4.10-1 always refer to the period for which data with the corresponding accuracy is to be obtained. In other words, if dependent sampling (always at the same interval) is done in the case of an anticipated occupancy of 20%, 4 759 samples will have to be taken per interval. If data is needed on the traffic load, the required interval is 60 min. If 4 values per day (i.e. one over 6 h) are sufficient in long-term sampling, then the interval is 6 h.

The requisite measuring speed is hence basically dependent on the interval concerned. In the example given here, for intervals of 15 min samples would have to be taken at least every 0.15 s, for intervals of 60 min every 0.6 s and for intervals of 6 h every 3.5 s.

From the viewpoint of frequency management the measurement of low occupancies is not very critical. Nevertheless, short-term occupancies may also be of interest, e. g. when endeavours are made to discover frequency uses per se. The statements "no use" and "occasional use" are worlds apart.

4.10.4.2 System parameters

In order to assess the occupancy of as many channels as possible, an enormous amount of data has to be collected and processed. For example, a scanning receivers is programmed in such a way that 50 samples are recorded every 2 s from different radio frequency channels. This means that the system operates with a revisit time of 2 s. The receiver needs time to adjust accurately to the channel and generate reliable results. In this example the observation period per channel or dwell time is about 5 ms. The observation period per channel depends on the receiver's scanning speed.

When programming the measurement system it must be borne in mind that in case different types of receivers are used, the settings must be the same to obtain comparable results.

4.10.4.2.1 Transmission length

Different types of users have different transmission lengths. Normally data bursts are shorter of duration than speech. User density differences in urban or rural areas have an influence on the transmission length and the occupancy statistics as well.

A distinction has to be made between the time measured during which an emission is on air and the time during which a communication occupies the channel. For example, in the case of simplex channels the switching time between the radios involved is a part of the channel usage. Intelligent recording systems can register these delay times and add them to the actual periods of occupancy.

4.10.4.2.2 Relationship between some relevant parameters

There is a strong relationship between the observation time, the number of channels, the average transmission length, the wanted accuracy and the duration of monitoring.

The revisit time is directly dependent on the observation time and the number of channels:

Revisit time = (observation time per channel) × (number of channels)

For this type of measurement the revisit time should be (much) shorter than the average transmission length. In order to maintain a reasonable short revisit time with relatively slow equipment, the number of channels to be measured must be reduced.

The monitoring system should scan at an acceptable speed to detect individual short transmissions to obtain information with accuracy and confidence level according to Recommendation ITU-R SM.182 as mentioned in § 4.10.4.1.

4.10.4.32.2 Resolution of the measurements

It is not expedient to record raw data since data volumes are too large and difficult to process. It hence makes sense to reduce the data to a specified interval during the actual measurement. Depending on the task on hand and the length of the measurement, intervals of 1 min, corresponding to 1440 data records per day, may constitute an acceptable compromise between the registration of all data and too high a compression loss. If such a resolution is not necessary or if the monitoring period is very long (covering several months), larger intervals of 5, 15 or 60 min may be adequate. However, the time resolution of the measure equipment should be much higher also in these cases in order to obtain a higher precision when creating moving averages.

The monitoring software should therefore be capable of generating the occupancy data for freely selectable resolutions.

4.10.4.3 Ensuring statistical confidence in occupancy measurements

4.10.4.3.1 Differences in occupancy measurements for stationary and non-stationary radio channels

The means of ensuring statistical confidence in occupancy measurements vary according to whether the statistical properties of the channel remain unchanged along the time axis (channel is considered stationary) or change dynamically (channel is considered non-stationary).

If the channel properties are presumed to remain unchanged for long periods of time, the purpose of the occupancy measurements is to assess probability of spectrum occupancy *SO* that the channel will be in an “occupied” state at an arbitrary point in time, i.e. the signal in the channel will exceed a predetermined threshold. Overall occupancy value refers only to the channel (or frequency band or resource) and has no specific time reference, and, as a rule, such an assessment requires prolonged measurements. Data collection may take many hours (although data may initially be accumulated piecemeal, e.g. in 15-minute segments of time), and the procedure requirements for overall occupancy measurements are based on Spaulding and Hagn (1977).

If the channel is considered non-stationary, the purpose of the occupancy measurements is to monitor the change in occupancy along the time axis. Current spectrum occupancy calculation results $SOCR_r$ are generated for specific time intervals, or integration times T_I, the length of which is fixed. Current occupancy is understood as the percentage of time (for integration time T_I) that the signal level in the frequency domain being analysed (frequency band) is above a certain threshold.

If the hardware capabilities of the radio monitoring apparatus allow, occupancy measurements for both stationary and non-stationary channels should be performed at 15-minute integration times T_I. Then, an average is taken using the current spectrum occupancy calculation results $SOCR_r$ in order to generate the constant (overall estimate of probability of stationary radio channel being in an occupied state).

$$SOCR = \frac{1}{R}\sum_{r=1}^{R} SOCR_r \qquad (4.10\text{-}1)$$

If the radio monitoring equipment is not sufficiently sophisticated to generate accurate occupancy evaluations with suitable confidence levels for 15-minute integration times T_I, a larger T_I value may be used. Alternatively, occupancy estimates may be performed for a single monitoring period lasting multiple hours if the channel can be considered stationary.

4.10.4.3.2 Importance of accounting for signal duration in planning of measurements

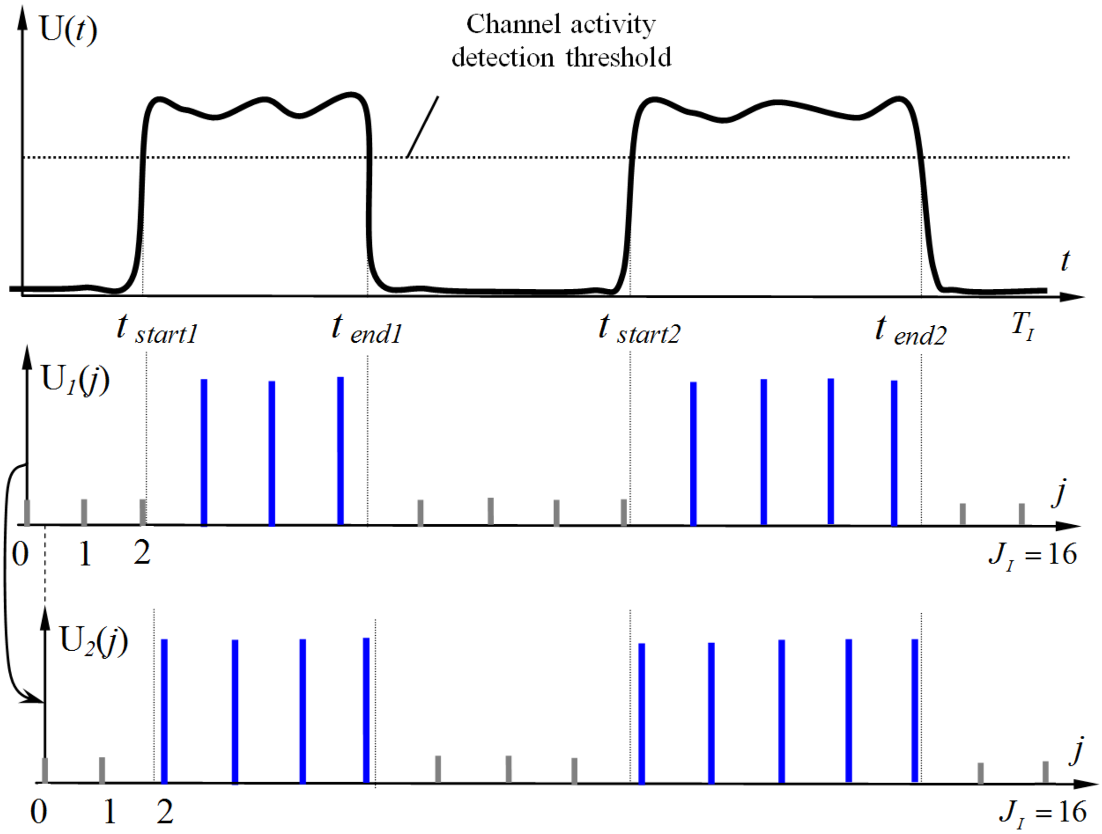
The statistical spectrum occupancy calculation results vary according to the ratio between typical signal duration in the radio channel under study and the revisit time T_R. If the average signal is longer than the revisit time T_R, such signals cannot be missed and are often recorded as a sequence of "occupied" samples, meaning that the states of consecutive samples appear dependent. When signal duration is shorter than the revisit time, signals will only be recorded from time to time; the probability of an "occupied" sample occurring does not depend on whether the preceding sample was "occupied"; thus, consecutive samples are statistically independent. Sample dependence affects confidence level when evaluating occupancy and must be considered in the planning of measurements; moreover, sample dependence can have different effects on current occupancy measurements at integration times T_I and on overall occupancy measurements for a stationary radio channel.

4.10.4.3.3 Accuracy and confidence level of occupancy measurements

There are a number of factors that can lead to errors in occupancy measurements. When generating current spectrum occupancy calculation results $SOCR_r$ for specific integration times T_I, errors occur owing to both the possible missing of discrete short-duration signals and the randomness of the relative placement of samples and edges of prolonged radio signals on the time axis. For example, the top diagram $U(t)$ in Figure 4.10-3 shows the continuous change in the signal level in the channel over time, corresponding to a value $SO \approx 50\%$. The two following diagrams illustrate occupancy measurement with the same number of samples J_I, but with a slight "mismatch" of the points from which the time is counted. Comparing diagrams $U_1(j)$ and $U_2(j)$, it can be seen that the measured occupancy value in the first case will be $SOCR_1 = 7/16 \approx 43.75\%$ and in the second case $SOCR_2 = 9/16 \approx 56.25\%$.

FIGURE 4.10-3

Sources of occupancy measurement error



When evaluating the overall constant (stationary radio channel occupancy), irregular signal placement at large intervals on the time axis may be added to the sources of errors described above. Its influence is most pronounced on channels with low occupancy and lengthy signals (i.e. in the case of dependent samples).

As a result, occupancy measurement error ($SOCR_r – SO$) is a random value with, as a rule, a close-to-normal distribution. Error magnitudes may vary significantly in different measurements; thus, quality requirements for occupancy evaluation have to be determined from the standpoints of accuracy and confidence level.

Confidence level P_{SOC} is the probability that the calculated occupancy *SOCR* will differ from the true value *SO* by no more than the permissible absolute error Δ_{SO}.

$$P_{SOC} = P\{|SOCR - SO| \le \Delta_{SO}\} \qquad (4.10\text{-}2)$$

where:

P_{SOC}: confidence level of the occupancy measurement

SOCR : calculated occupancy value obtained for the current integration time

SO : true value of occupancy over the integration time

Δ_{SO}: permissible absolute measurement error tolerance corresponding to half of the confidence interval

Accuracy requirements are also often expressed in terms of the permissible relative measurement error tolerance δ_{SO}, which is linked to the permissible absolute error by the equation:

$$\delta_{SO} = \Delta_{SO} / SO \tag{4.10-3}$$

Recommendations on specific values for the accuracy of occupancy measurements are given in § 4.10.4.3.4.

4.10.4.3.4 Accuracy and confidence level requirements for evaluations from practical occupancy measurement. Requirements for number of samples in current occupancy measurements

When measuring occupancy based on independent samples, the necessary number of samples $J_{I\,min}$ can be calculated as:

$$J_{I\min} = SO \cdot (1 - SO) \cdot \left(\frac{x_p}{\Delta_{SO}} \right)^2, \tag{4.10-4}$$

where:

- SO: expected radio channel occupancy for the channel with pulse signals;
- x_P: percentage point of the probability integral ($x_{0.95} = 1.96$; $x_{0.90} = 1.64$);
- Δ_{SO}: maximum permissible absolute measurement error, corresponding to half of the confidence interval.

In accordance with the formula (4.10-4), the required number of measurements for integration time T_I is usually quite high. However, the following considerations should be taken into account:

– When performing measurements in radio channels with a high level of occupancy, it is appropriate to express evaluation accuracy requirements in terms of the permissible relative measurement error δ_{SO}. Indeed, where the true level of occupancy is 90%, evaluations with maximum permissible relative error of δ_{SO} = 10% are acceptable for practical purposes, whereas attempting to limit the confidence interval with absolute measurement error of Δ_{SO} = 0.5% results in a requirement to lie in the range 89.5-90.5%, which is excessive from the point of view of practical requirements;

– When performing measurements in radio channels with a low level of occupancy, it is appropriate to express evaluation accuracy requirements in terms of maximum permissible absolute measurement error Δ_{SO}. Indeed, from the point of view of frequency management, measurement of low occupancy is not very important (it is only necessary to reliably distinguish between the cases “not used” and “used occasionally”, which are very different). Thus, for a true occupancy value of, for example, 2%, evaluating with a maximum permissible error of Δ_{SO} = 1% translates into a requirement to lie in the range 1-3%, which suits practical requirements perfectly. However, attempting to limit relative error to δ_{SO} = 10% results in a narrowing of the confidence interval to the range 1.8-2.2%, which corresponds to an excessive level of measurement accuracy and results in an overly high required number of samples to be used for occupancy measurement.

An effective compromise solution, which eliminates the observed contradictions, is to perform an estimate while, for large occupancy values, customarily limiting the permissible relative error, and, for small values, limiting the permissible absolute error. If the transition from one type of limitation to the other is at the 10% occupancy level, the required number of samples will be determined by the values shown in bold type in Table 4.10-1, which is acceptable from the practical standpoint.

TABLE 4.10-1

Number of samples required to achieve a maximum 10% relative error δ_{SO} or a 1% absolute error Δ_{SO} with a 95% confidence level

Channel occupancy (%)	Required relative error δ_{SO} = 10%		Required absolute error Δ_{SO} = 1%	
	Resulting magnitude of absolute error (%)	Required number of independent samples	Resulting magnitude of relative error (%)	Required number of independent samples
1	0.1	38 047	100.0	**380**
2	0.2	18 832	50.0	**753**
3	0.3	12 426	33.3	**1 118**
4	0.4	9 224	25.0	**1 476**
5	0.5	7 302	20.0	**1 826**
10	1.0	**3 461**	10.0	**3 461**
15	1.5	**2 117**	6.7	4 900
20	2.0	**1 535**	5.0	6 149
30	3.0	**849**	3.3	8 071
40	4.0	**573**	2.5	9 224
50	5.0	**381**	2.0	9 608
60	6.0	**253**	1.7	9 224
70	7.0	**162**	1.4	8 071
80	8.0	**96**	1.3	6 149
90	9.0	**43**	1.1	3 459

In practice, however, the revisit time T_R is often taken as identical for all radio channels analysed in parallel, as adjusting the settings of the radio monitoring receiver when moving from channel to channel and inputting individual T_R values for each of the many radio channels, is highly problematic. Thus, in view of the data contained in Table 4.10-1, taking 3 600 samples for integration time T_I can be used as the universal standard, corresponding to a sampling frequency of four times per second for 15 minutes (Kozmin V.A., Pavlyuk A.P., Tokarev A.B., (2014)). If the equipment does not allow for such a sampling rate, the rate can be halved to 1 800 samples for integration time T_I, corresponding to a sampling frequency of twice per second for 15 minutes. The measurement quality indicators corresponding to this approach are presented in Table 4.10-2 (for more detail see Report ITU-R SM.2256).

TABLE 4.10-2

Occupancy measurement errors corresponding to a 95% confidence level, achievable when evaluating occupancy with exactly 3 600 and 1 800 data samples

Occupancy (%)	Number of samples: 3 600		Number of samples: 1 800	
	Resulting absolute error (%)	Resulting relative error (%)	Resulting absolute error (%)	Resulting relative error (%)
1	**0.33**	32.5	**0.46**	46.0
2	**0.46**	22.9	**0.65**	32.3
3	**0.56**	18.6	**0.79**	26.3
4	**0.64**	16.0	**0.91**	22.6

5	**0.71**	14.2	**1.01**	20.1
10	**0.98**	**9.8**	**1.39**	**13.9**
15	1.17	**7.8**	1.65	**11.0**
20	1.31	**6.5**	1.85	**9.2**
30	1.50	**5.0**	2.12	**7.1**
40	1.60	**4.0**	2.26	**5.7**
50	1.63	**3.3**	2.31	**4.6**
60	1.60	**2.7**	2.26	**3.8**
70	1.50	**2.1**	2.12	**3.0**
80	1.31	**1.6**	1.85	**2.3**
90	0.98	**1.1**	1.39	**1.5**

Since, when measuring current occupancy, sample dependence contributes to increasing the confidence level of occupancy measurements, the requirements presented above are relevant both when samples are independent and when evaluating current occupancy from dependent samples.

4.10.4.3.5 Required number of samples for the generation of stationary radio channel overall occupancy

Spaulding and Hagn (1977) state that a very long monitoring time is necessary when evaluating the occupancy of a stationary radio channel, as the higher the level of sample dependence (which increases with a higher revisit time and a higher average transmission duration) and the lower the occupancy of the radio channel, the slower the processes are for the radio channel and the longer the monitoring needs to be to ensure overall occupancy measurements with the requisite levels of accuracy and confidence. Tokarev, Kozmin, Pavlyuk and Polev (2024) showed that, when evaluating stationary radio channel occupancy, the duration of monitoring T_T must extend at least as long as the amount of time required for an average of 800 transmissions. The duration of monitoring required to evaluate stationary radio channel overall occupancy with a suitable level of confidence can be determined with the equation:

$$T_{T\min} = J_{I\,min} \cdot T_R \cdot (1 + e^{-1/q}) / (1 - e^{-1/q}), \qquad (4.10\text{-}5)$$

where:

$J_{I\,min}$: minimum required number of independent samples corresponding to expected radio channel occupancy *SO*;

T_R : revisit time;

$q = T_{TL}/T_R$: average duration of transmissions expressed in revisit times T_R.

It should be noted that, when it is possible to choose different revisit times T_R, attempting to use $T_R \ll T_{TL}$ does not allow either to significantly reduce the time required for data collection with fixed evaluation quality standards or to noticeably improve evaluation accuracy while keeping the same data collection time, as a reduction in T_R is accompanied by an increase in sample dependence and, consequently, a rise in the required number to ensure a confident evaluation of the constant (stationary radio channel occupancy).

If the occupancy measured over data collection time $T_{T\min}$ results in a lower than *a priori* expected value, then, based on this lower *SO* value, it is appropriate to calculate a new value $T_{T\,\min 2}$ and continue to gather samples and evaluate occupancy over this extended monitoring interval.

Table 4.10-3 gives an example of increasing the required number of dependent samples relative to independent samples where revisit time T_R = 1 second. For a different value of $q = T_{TL} / T_R$, the data collection time required for evaluating occupancy should be determined from (4.10-5).

TABLE 4.10-3

Number of dependent and independent samples required to achieve 10% relative accuracy and 95% confidence level in evaluating stationary radio channel occupancy (sampling time is assumed to be 1 second)

Occupancy (%)	Number of required independent samples	Average duration of transmission: 1.5 s (q = 1.5)		Average duration of transmission: 12 s (q = 12)	
		Number of required dependent samples	Required hours of dependent sampling	Number of required dependent samples	Required hours of dependent sampling
6.67	5 368	16 641	4.6	12 8910	35.8
10	3 461	10 730	3.0	83 112	23.1
15	2 117	6 563	1.8	50 837	14.1
20	1 535	4 759	1.3	36 861	10.2
30	849	2 632	0.72	20 388	5.7
40	573	1 777	0.5	13 760	3.8
50	381	1 182	0.32	9 149	2.5
60	253	785	0.22	6 076	1.7
70	162	502	0.15	3 890	1.1

4.10.4.4 Site considerations

Various factors should be taken into consideration when selecting a site for frequency channel occupancy measurements.

In common with most sites used for receiving purposes, the monitoring equipment should be placed at a location that is:

– remote from strong radio transmissions;

– remote from structures and buildings which could cause reflections;

– within the service area of the radio systems to be monitored. Coverage prediction software may be a useful tool to determine the range of reception;

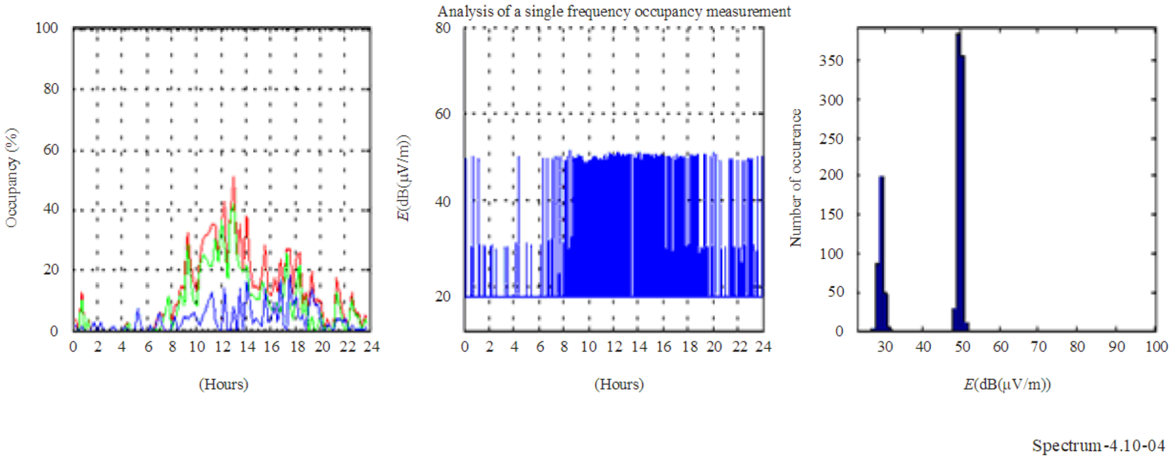
– away from sources of electrical noise, i.e. computers, motor speed controllers, etc.

4.10.4.5 Limitations of monitoring and possible solutions

Although accurate occupancy results are expected, it is wise to bear in mind the limitations associated with automatic occupancy monitoring and areas where inaccuracies could occur. Simple automatic monitoring is not able to discriminate between signals received from station A and those from station B (wanted and unwanted emissions, respectively).
Advanced automatic monitoring is able to discriminate between signals from different stations. The occupancy caused by the different stations working on the same frequency channel could be both plotted in an occupancy plot as shown in Fig. 4.10-4.

FIGURE 4.10-4

Example of determining fixed transmitters



Two users can be identified, green is the user received with a level of about 50 dB(µV/m), blue curve shows occupancy caused by the other station (about 30 dB(µV/m)). The red curve is total occupancy (green + blue).

To achieve distinct results (sharp needles, representing the fixed stations in the right diagram of Fig. 4.10-4) a low number of discrete levels with high number of each occurrence is desirable.

4.10.4.5.1 Undesired signals

Most automatic occupancy monitoring systems use a threshold level to establish when a frequency is occupied.

Although the obvious intention is to record the activity of wanted signals, simple automatic monitoring is not able to discriminate between wanted and unwanted emissions. Both types of emission are treated as legitimate channel occupancy.

Undesired signals could originate from any of the following sources:

– unauthorised transmissions;
– strong adjacent channel users;
– spurious and out-of-band emissions from transmitters;
– man-made interference (e.g. unsuppressed electric motors);
– enhanced propagation due to weather and environmental conditions;
– co-channel users from a distant location.

From a user's point of view, however, all types are deemed to constitute an occupancy and as such are uncritical as far as the measurement is concerned.

Care must be taken in system design to either avoid receiver intermodulation products, or to identify these products for removal by software algorithms. An intermodulation product is taken into account by automatically inserting fixed, known RF attenuation on alternate scans and then automatically removing all recorded signals which are attenuated by a greater value. However, this measurement technique halves the recording time. Also, it is not necessarily reliable since it assumes that the emissions do not change between the two sweeps.

4.10.4.5.2 Total occupancy

Even if the monitoring system does not suffer from any of the above problems and receives only legitimate signals, the occupancy results must still be treated with a certain degree of caution.

If more than one user is active on a frequency within the coverage area of the monitoring system, the occupancy recorded will be a combination of the radio traffic from each user.

It is possible that a wanted mobile unit (mobile A) will be located significantly further from the monitoring site than the user’s own base site (Base A). Therefore the received signal strength may be less than the monitoring threshold value set although strong enough at the intended base site to be usable. Conversely, a mobile unit from an out-of-area user (mobile B) may be received at the monitoring site but not be heard at the main user’s base site.

These two examples may lead to incorrect interpretations of the occupancy results. These error options need to be evaluated and documented in a measurement report. The selection of the measurement site and the quality of the receiving chain has a significant impact on the measurement result.

4.10.4.6 Threshold setting

A distinction is made between setting a fixed and a dynamic threshold.

A fixed threshold can be defined as the minimum field strength necessary for radio coverage. It would thereby emulate the situation of a radio station in the monitored radio network. In case a fixed threshold value is used one can compare the results from the latest measurements with those from previous measurements. In case a dynamic (changing) level is used, one can not compare the results.

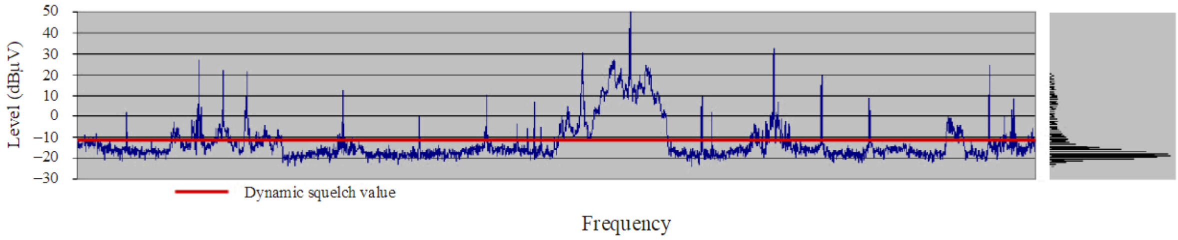
The threshold may also be defined by having knowledge of the levels at the measurement site. To determine the threshold, a margin of 8-12 dB may be added to the noise. The actual value which should be added to the noise level depends on “what is expected to see”. If there is a need to have knowledge of all signals within the coverage area of the receiver then, not more than 3 up to maximum 5 dB should be added to the calculated noise level. In case of a fixed threshold level, one should determine the noise level from all the (remote) sites (receivers) and store them into a simple database. The values in this database should be used when processing the data.

It will be evident that the background noise level for processing results in the FM broadcasting band 87.5 MHz-108 MHz will be different from the frequency band 118 MHz-133 MHz of the Aeronautical Service.

Where measurements are carried out with a spectrum analyzer or receiver, a dynamic squelch can be calculated by means of various algorithms. It can be derived most easily from the frequency distribution of the samples over a sweep. A fixed margin of 5-10 dB is added to the level, which is represented by the highest number of discrete level values. In this way the threshold for the occupancy detection of this particular sweep is constituted (see Fig. 4.10-5).

FIGURE 4.10-5

Determination of the dynamic squelch



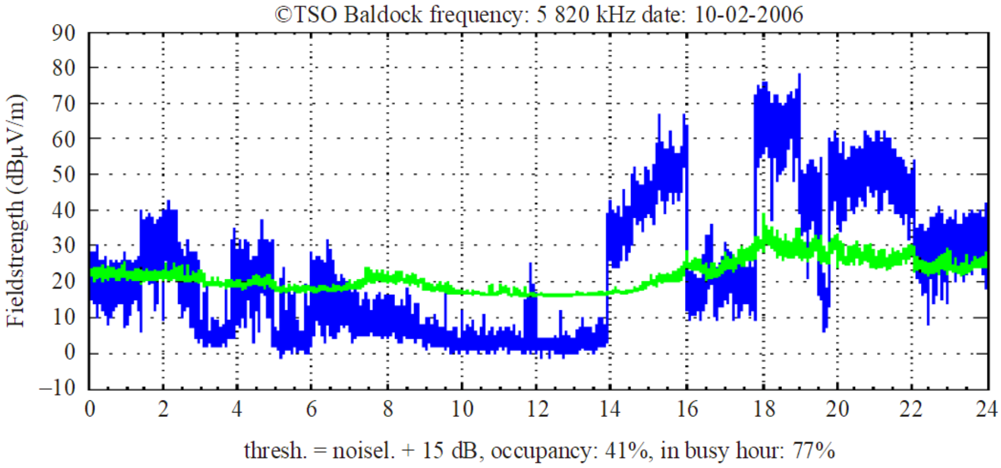
Spectrum-4.10-05

In this manner a new threshold is calculated for each sweep. This method offers a big advantage in longer measurement cycles. Changes in the noise level or broadband unwanted signals do not falsify the occupancy measurement or render it unusable. However, care must be taken to ensure that the spectra recorded contain an adequate number of samples replicating the noise. The noise floor will change slightly over time in VHF/UHF/SHF. However, the change is under normal conditions not more than a few dB. Since a number of dB (3 to 5 dB) are added to the noise, this will have no influence. This shows that it is not always needed to calculate a new threshold for every sweep. In case the noise floor is changing more than 5 dB then there are exceptional (propagation) conditions and the results may be corrupted and should not be relied on.

For the HF bands the situation is completely different. The noise level is changing during the day and season with big differences over 24 h. In that case one should indeed calculate a dynamic threshold versus time._And one should add more dB to the noise level to determine the threshold. In the Fig. 4.10-6 15 dB may be added.

FIGURE 4.10-6

Variation of HF-Noise during a day



Spectrum-4.10-06

A later change of the threshold value is not expedient since this would require raw data to be registered.

Assuming a 24-hour measurement with a sweep time of 500 ms and 1 000 steps this would yield a data volume of about 700 MB. (1 000 data points with 4 bytes each = 4 kB per spectrum sweep or spectrum scan), 172,800 spectra in 24 h * 4 kB = approximately 700 MB).

Depending on the transmission length of signals expected in the frequency band to be measured, it is not always necessary to use a sweep time of 500 ms, For instance broadcast frequency bands can be measured with a 10 s sweep time (file size about 35 Mb). But even in the case of 500 ms, a data file of 700 MB will shrink to about 230 MB when zipped.

An external hard disk from 1 Tb is very easy to obtain and one can store more than 4 000 zipped files, each containing a 24 h measurement with 500 ms

Even if sufficient hard-disk storage space would be available, saving such an amount is problematic and data evaluation difficult. A data reduction during data collection certainly makes sense for various reasons but does imply that the parameters to be set must be known before the measurement is begun.

4.10.5 Measurements in frequency bands

Conducting spectrum occupancy measurements below and above 30 MHz is in principle the same. The same methodology as described in Recommendation ITU-R SM.1809 can be used for the entire radio spectrum.

On frequencies below 30 MHz normally no frequency channel occupancy measurements are used. (One exception is the channel occupancy on HF broadcasting channels during European monitoring campaigns in the preparation for WRC-2007).

~~For frequency channel occupancy above 30 MHz, normally the measurement method described in Recommendation ITU-R SM.1536 or the frequency band measurements as described in Recommendation ITU-R SM.1809 combined with the processing method from Recommendation ITU-R SM.1793 is applied. This last mentioned method gives the possibility to discriminate between more than one user on the same channel.~~

4.10.5.1 Frequencies below 30 MHz

For manual occupancy monitoring below 30 MHz, the analysis unit must provide a judicious choice of analysis filters of bandwidth between about 100 Hz and 10 kHz. Frequency measurement (up to an accuracy of 1 Hz) assists the occupancy measurement process in particular by helping to identify signals.

As a rule it should be possible to adjust the measurement equipment in such a way that it is capable of recording the emissions correctly. In order to increase sensitivity in occupancy determination, it is also possible to measure in a narrower band.

The measurement period and the associated number of measurement samples/intervals depend on the task on hand. It may suffice to measure only a short period (e.g. one day) but with a higher resolution, e.g. to identify the peak traffic hour, or in the case of long-term measurements over weeks or months, to measure with the same number of measurement samples over longer intervals.

Occupancy measurements can be based on channels or frequencies. The latter only makes sense if a spectrum analyzer is used. If the occupancy of a single channel/single frequency is of no interest for the task on hand, band-related measurements should be preferred. In principle, in such measurements the individual occupancies are added and thus information is gleaned about the frequency band or the channels observed. The loss of individuality on the individual channels/frequencies results in findings with a lower variance.

4.10.5.2 Frequencies above 30 MHz

Also spectrum occupancy measurements above 30 MHz can support various frequency management and enforcement tasks.

– Channel occupancy registration.
– Frequency band registration.
– Traffic analyses.
– To show that a frequency band is available for new usage after “refarming”.
– Identification of illegal frequency use.
– Interference prevention.
– Long-term analyses.
– Analysis of cellular networks with dynamic channel assignment (determination of the behaviour of a cell a as a whole).

4.10.5.2.1 Frequency channel occupancy measurements

In most countries the frequency bands above 30 MHz are planned according to well known planning systems as for instance the honeycomb structure. Radio channels are assigned to users according to availability. Information about licensed users retrieved from frequency management databases only indicates that the use of the frequency is authorized. The number of assignments on a frequency does not always give adequate information about the actual use of that particular frequency.

Therefore in congested areas, it is necessary that frequency assignments be based on more realistic data. Measurements of traffic density on radio channels will result in more accurate values for the occupancy of these channels. Repeating these measurements at regular intervals enables frequency managers to establish trends from historical data.

4.10.5.2.2 Services

Private mobile radio services have been traditionally based on analogue speech. However, data transmission has been introduced either as an add-on facility or as a principal means of communication. Where users wish to incorporate the exchange of data messages in their existing mobile networks, data appears on shared radio channels. In that case, the regulatory authority will have to know the characteristics of the radio channel in order to determine how the data communication system will perform. Some users may have requirements that can only be met by the assignment of more appropriate radio channels.

In general, new services also will have an impact on the occupancy of a radio channel on a per-mobile-station basis. This generally increases the total traffic volume in a radio channel. As this does not show up in an administrative system that only registers the number of mobile stations additional details have to be taken into account.

4.10.5.2.3 Additional information about certain users

Apart from the single determination of the signal strength above the threshold in form of a yes/no statement, there are many more parameters that can be stored such as signal level, type of modulation or information for identification purposes (e.-g. selective calls).

Apart from merely registering occupancy it is useful to record the maximum, mean and minimum level values in each interval. This not only yields occupancy data but also enables further analyses about frequency activities because, for example, regular short-term emissions are recognised which would otherwise be concealed by the averaging process.

The recorded behaviour over time also allows information to be derived about the type of use.

4.10.5.2.4 Slow channel scanning

This method is very similar to the frequency occupancy measurements described before except that frequencies are scanned at a very much slower rate, perhaps only 2 frequencies/s. This method can be used when the identity of the user is transmitted throughout the entire length of the user's transmission and can therefore be obtained by sampling at any point.

This is possible with the following systems:

– continuous tone-coded squelch system (CTCSS).

– digitally coded squelch (DCS).

If a more differentiated statement about the frequency uses is required it is usually necessary to record and evaluate additional protocol data.

In digital radio systems which are transmitting continuously, e.~~-~~g. TETRA, GSM, recording of the protocol contained in a control channel constitutes the only means of deriving information about the occupancy level.

4.10.5.2.5 Static channel monitoring

This enables the collection of information about transmission length and can also be used in systems where the end user only sends its identification once per transmission. It is not possible to employ scanning techniques because the receiver must remain on a single frequency in order not to miss any information (see Fig. 4.10-7).

~~n~~This is applicable for the following types of system:

– 5-tone Selective Calling (SELCAL).

– Automatic Transmitter Identification System (ATIS).

– MPT 1327 trunking control channel.

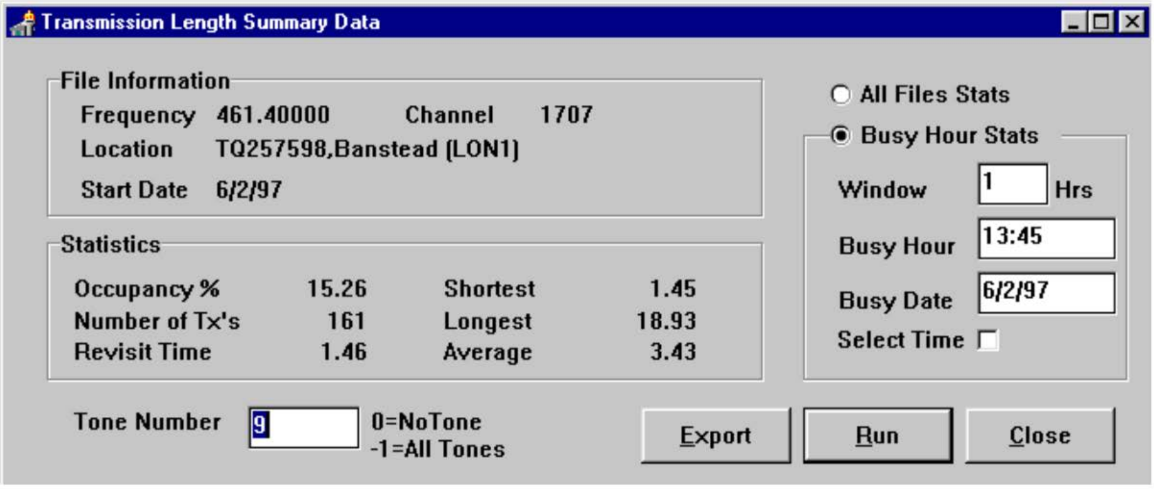
– POCSAG paging.

If additional information on individual users is obtained, it is then possible to sub-divide the total occupancy for that frequency into specific occupancy values for each user.

In the case of applications controlling traffic flow over control channels, e.~~-~~g. as in trunked radio, or which can be reduced to a single channel (e.~~-~~g. DSC, POCSAG) it is possible to derive a very accurate traffic analysis from the recorded protocol data.

FIGURE 4.10-7

Example of static channel monitoring



Spectrum-4.10-07

4.10.5.2.6 Frequency band occupancy measurements

Generally the following approach is valid:

Automatic monitoring starts with frequency band occupancy (FBO) measurements. There is no threshold needed for a number of plots (e.g. spectrogram, waterfall, min/max/med etc). A threshold level is needed only to calculate the frequency band occupancy.

~~So one should start with frequency band occupancy measurements (Recommendation ITU-R SM.1809), but if more detailed information per channel is required, then frequency channel occupancy measurements should be carried out. Or even better process the with Recommendation ITU-R SM.1809 obtained result as FCO described in Recommendation ITU-R SM.1793~~

The settings of the receiving equipment depend on the frequency band to be scanned. The scan time depends on the amount of desired data. The setting of the threshold level must be as low as possible, avoiding, however, the recording of noise. It is very helpful if the threshold level can be changed afterwards thus allowing for different kind of evaluations. The signal level is recorded at every sweep, e.g. at 900 sweeps during 15 min at 1 sweep/s. Frequencies at levels above the selected threshold level are regarded as occupied. Using dedicated software there is also a possibility to zoom the scanned frequency band in time and frequency.

Monitoring receivers with highly selective IF filters with a shape factor of 2:1 or better are preferable to spectrum analyzers for spectrum occupancy measurements. For speed requirements often spectrum analyzers are used. They are normally equipped with Gaussian IF filters to prevent ringing. However, this type of filter does not discriminate adequately against signals in adjacent channels. Nevertheless, a Gaussian filter is the best compromise between speed and resolution. As a result, spectrum analyzers tend to overestimate the actual occupancy. Using monitoring receivers, the bandwidth of their IF filters of should be matched to the bandwidth of channelized bands. Therefore, a set of IF filters is required which matches the channel widths of the bands to be monitored. It is recommended that the receiving equipment has preferably low noise figures.

Also, tuneable preselection filters are highly desirable and the low-noise amplifiers can be integrated in the preselector after the filter. Special band pass filters may be required to help improve the measurement system’s dynamic range for some monitoring situations when using either a monitoring receiver or a spectrum analyzer.

For example, such filters may be needed to obtain valid occupancy data on channels containing relatively small (low-level) signals in bands adjacent to bands containing relatively large signals (e.-g. broadcasting bands).

Finally it may be necessary to use a pre-attenuator ahead of a monitoring receiver or spectrum analyzer preamp in order to properly position the dynamic range of the monitoring system when monitoring bands with large signals.

During every sweep of this type of spectrum measurement from all measuring points (e.-g. 1 000 points) the received signal strength is stored. These steps can be considered as 1 000 single channels. From every channel the received data can be processed.

Distribution plots of the measured values to get a good indication of the number of base stations, received signal strength over time (mostly 24 h), information about average speech length etc. can be obtained rather easily.

Because the size of the resolution bandwidth (RBW) filter normally is bigger than the size of the steps not all of the “channels” can be used. For instance the band to be examined is 7.5 MHz. As an example this is done in 1 000 steps so the step size is 7.5 kHz. The RBW filter can be 10 kHz.

Now from every third step the information can be processed which will result in occupancy information every 25 kHz, which could be the existing channel spacing in the measured band. In case 12.5 kHz as frequency step is used one can process every second step.

Another solution could ~~to~~ be to change the filter size (if possible) to 10 kHz and the problem is solved. This can only be applied for FCO because in every step a small portion of the spectrum is skipped (not measured). For every channel -5 and + 5 kHz is observed.

The occupancy will not differ if measured with a 15 kHz filter. It should be understood that the sweep time, which is comparable with the re-visit time of the frequency channel occupancy measurements, in this case is about 10 s and cannot be reduced infinitely.

~~It is of importance to note that extended tests have shown that the accuracy will not dramatically change in case the re-visit time increases from 1 to 10 s. (See § 4.10.2)~~

Text of §§ 4.10.6 and 4.10.7 unchanged

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TOKAREV A. B., KOZMIN V. A., PAVLYUK A. P., POLEV V. Y. (2024), *Duration of data collection when measuring occupancy of stationary radio channels // Systems of Control, Communication and Security*, No. 1. https://sccs.intelgr.com/arch.html (in Russian – the article translated into English is available at: http://www.ircos.ru/en/articles.html).

ITU-R Recommendations

NOTE – In every case the latest edition of the Recommendation is encouraged to be used.

Recommendation ITU-R SM.182* – Automatic monitoring of occupancy of the radio-frequency spectrum.

Recommendation ITU-R SM.1536* – Frequency channel occupancy measurements.

Recommendation ITU-R SM.1753 – Method for measurements of radio noise.

Recommendation ITU-R SM.1793* – Measuring frequency channel occupancy using the technique used for frequency band measurement.

Recommendation ITU-R SM.1809 – Standard data exchange format for frequency band registrations and measurements at monitoring stations.

Recommendation ITU-R SM.1880 – Spectrum occupancy measurements and evaluation

**Note by the Secretariat*: This Recommendation has been suppressed and replaced by Recommendation ITU-R SM.1880 – Spectrum occupancy measurements.

ITU-R Reports

Report ITU-R SM.2256 – Spectrum occupancy measurements and evaluation.