Application of Spectrum Analyzer FSP-30 for Radiation Measurements from Indoor

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Abstract - **This paper treat problems linked with radiated power and wall parameter measurements and its possible solution. Power measurements are easily done in a free-room without obstacles. Various obstacles located in the room and its possible movement to another place of location are distorting measurements. The paper contains several suggestions how to decrease these effects or to keep them in mind for interpretation of results.**

The objective of authors is associated with simulation of radiation from indoor that requires adequate models for walls of the room. Therefore spectrum analyzer is applied in addition to the power measurements to measure wall parameters too.

1 Introduction

Radiation from indoor sometimes is desirable but sometimes causes problems. It's positive for wireless communication but negative for undesirable leakage of information. The evaluation of radiation using different models of wave propagation and penetration has rather low accuracy. For more exact results numerical simulation or experimental measurements have to be used. Authors are interested in measurement of radiated signal outside room and in measurement of necessary wall parameters for numerical simulation.

This paper is summarizing our approach of application of spectrum analyzer FSP-30 (manufactured by Rhode&Schwarz). Spectrum analyzer measures the power spectrum of received signal until 30 GHz without any information about signal phase. In time domain measurements FSP-30 are limited to 1 µs, appropriate for demodulators but not for direct observation of microwave signals.

FSP-30 has also embedded sweep generator, useful for wall parameters measurement

2 Measurement radiation from indoor

Experimental measurement was carried out at the faculty of Electronics and telecommunications. In some classroom was located a simple radiator, created as a coaxial line with extended interior wire as shown in Fig.1.

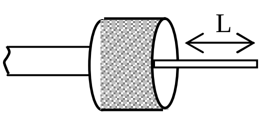

Figure 1. A simple radiator

Microwave generator at frequency 2.5 GHz with the power 16.7 dBm excites the cable.

In future research, experimental results will be compared with numerical simulation, therefore the room parameters and location of radiator in the room are fixed.

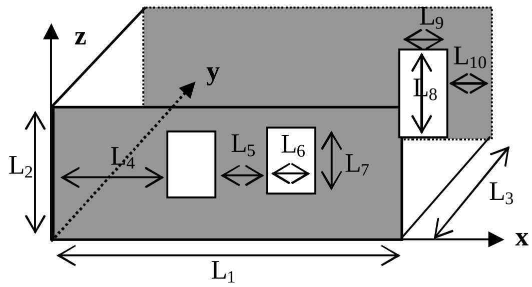

Figure 2. Geometry of the room

For room L_1=6.29 m, L_2=3.73 m, L_3=5.51m, L_4=0.91 m, L_5= 1.05 m, L_6=1.94 m, L_7=2.43 m, L_8=2.19 m, L_9=1.37 m, L_{10}=0.74 m. The source is located at coordinate x=3.37 m, y=3.04 m, z=1.00 m. The received power is measured by FSP-30 in observation points (Fig.3.)

Figure 3. FSP-30 with horn antenna

The power is measured for radiator oriented along z-axis. The receiver antenna is located outside room at coordinate y=-1.91 m, z=0.54 m for vertical and horizontal polarization's with different x coordinates. (See Table 1).

x m	P vertical, dBm	P horizontal, dBm
1.33	-55.6	-56.9
1.73	-47.3	-74.7
2.13	-40.3	-56.9
2.53	-66.4	-63.2
2.93	-42.9	-51.4
3.33	-49.2	-56.7
3.73	-50.6	-59.5
4.13	-45.5	-60.0
4.53	-43.2	-52.3
4.93	-41.9	-53.5

Table 1. Power outside room

3 Measurement of wall parameters

For numerical simulation of the radiation from indoor we need such a wall parameters: structure, thickness, dielectric permittivity and conductivity. The mathematical model of wall is complicated and not included in this paper. For simplification the room with brick walls (without metallic reinforcing) is modeled like a dielectric layered slab. In most cases for recognition of thickness, dielectric permittivity and conductivity the wall is radiated by a short pulse. Reflected or transmitted pulse contains information necessary for slab's parameters calculation [1], [2]. The duration of pulses is about nanosecond, but FSP-30 can not observe such pulses. Therefore measurement is based on power measurement at several frequencies with assumption that dielectric permittivity and conductivity are constant in selected frequency region.

Two methods are chosen for wall parameters measurement with FSP-30.

1. Measurement of transmitted power that is proportional to square of transmission coefficient $|\tau|^2$.

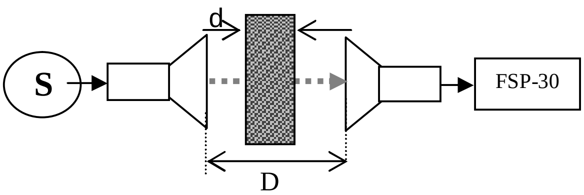

Figure 4. Transmission coefficient measurement

An external wave source (S) must be applied for this experiment. The square of transmission coefficient can be obtained comparing FSP-30 received power with and without wall between horn antennas.

2. Measurement of reflected power, proportional to square of reflection coefficient $|r|^2$. For frequencies below 3 GHz we can use FSP-30 embedded sweep generator. Embedded generator works in network analyze regime with maximum output power 1 mW.

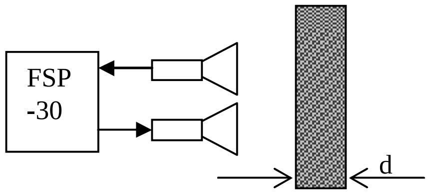

Figure 5. Reflection coefficient measurement

Location of both antennas in plane (see Fig.6.) realizes minimal coupling between transmitter and receiver.

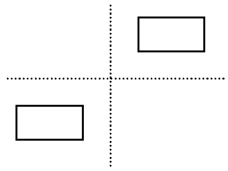

Figure 6. Location antennas in plane

To calibrate the reflection measurement the wall is covered with a thin metal plate. Comparing results with and without metal plate we find square of reflection coefficient $|r|^2$. Also it is useful for wall parameters measurement to measure reflection coefficient from the wall covered with metal plate on the other side.

The wave normal incidence is treated for simplicity. In comparison with radiation measurements, wall parameters measurement is causing some problems, as transmitted and received signals must characterize wave interaction only with one wall. Unfortunately, the wall is not located in free-room, but is one of the room walls and presence of other walls creates undesirable reflections distorting received signal. For normal incidence between opposite walls multiple reflections are being formed.

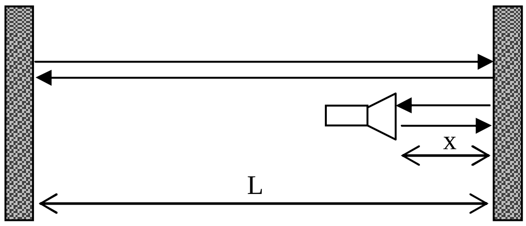

Figure 7. Multiple reflections between opposite walls

The distortion can appear if reflection from opposite wall modify incident wave on investigative wall. Therefore it is necessary to evaluate distortion of the incident wave. Let the transmitter antenna create in room cone-shaped beam with angle α (see Fig.8.).

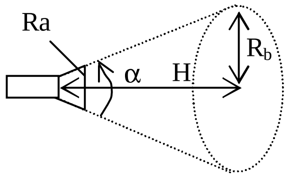

Figure 8. Cone-shaped beam

The distortion depends on dimension of room and beam angle. For example, simple evaluation will be given. Let the distance between opposite walls - L=10 m, beam angle α=30^0 and electrical field intensity on aperture of horn antenna with radius R_a=0.05 m is E_0. The power flux density on aperture is

$$\Pi_0 = E_0^2 / Z_0,$$

where Z_0 is the free-room wave impedance.

The radiated power $P_\Sigma = \Pi_0 \cdot S_a = \Pi_0 \cdot p \cdot R_a^2$. Before reflection beam twice traverses room and H=2·L. In lossless environment the radiated power remain constant in all splits

$$\Pi_0 \cdot p \cdot R_a^2 = \Pi_{refl} \cdot p \cdot (R_a + 2 \cdot L \cdot \tan(a/2))^2 .$$

We found that ratio of reflected and incident power flux densities is 85.45·10^{-6}, but in real case it will be lower as the reflection coefficients from both walls are smaller than 1. Such power changes can be fixed only with rather precise device having field intensity change sensitivity less than 1%. For smaller rooms and smaller beam angles the reflection can be noticeable.

To calculate the distortion of reflection coefficients some additional measurements are required. FSP-30 measures only received power and to measure two reflection coefficients there must be carried out five measurements and solved system of four non-linear equations. Reflection coefficients from walls (Fig.7.) are $r_1 = a_1 + i \cdot b_1$ and $r_2 = a_2 + i \cdot b_2$. The field intensity decreasing function *f(y,z)* is found extending the beam distance from y to y+*z*:

$$f(y,z) = \frac{y}{y + z \cdot \tan(a/2)} = \frac{1}{1 + (z/y) \cdot \tan(a/2)} .$$

The incident field on right wall Fig.7. is the sum of geometric progression:

$$S = \frac{f(R_a, R_b) \cdot \exp(-i \cdot k_0 \cdot R_b)}{1 - \dfrac{r_1 \cdot r_2 \cdot \exp(-i \cdot 2 \cdot k_0 \cdot L)}{1 + 2 \cdot L \cdot \tan(a/2) / R_b}},$$

where k_0 is the free-room wave number.

For calculating reflection coefficients there are necessary five power measurements. The simplest system can be obtained if calibration measurements are carried out when both walls are covered with metal plates: $r_1 = r_2 = -1$. This power measurement will be marked S_0. Others measurements are carried out for cases:

S_1 for r_1 and r_2 (without metal plates);

S_2 for $r_1 = -1$ and r_2 (plate on the right wall);

S_3 for r_1 and $r_2 = -1$ (plate on the left wall);

S_4 for r_1 and $r_2 = 1$ (plate λ/4 from the left wall).

Measured power ratios S_1/S_0, S_2/S_0, S_3/S_0, S_4/S_0 gives four equations for calculating reflection coefficients for both walls that take into account multiple reflections between two walls.

4 Calculation of wall parameters

To calculate wall parameters we chose a large room where reflections between other walls are negligible. For every frequency three measurements were carried out (Fig.5.):

P_0 – calibration, when plane is covered with metal plate;

P_1 – measurement without metal plate;

P_2 – measurement, when other side of wall also is covered with metal plate.

Results of power measurements are summarised in Table 2.

f, GHz	P_0,dBm	P_1,dBm	P_2,dBm
2.0	-26.05	-34.50	-35.71
2.1	-26.44	-36.86	-31.83
2.2	-23.42	-34.86	-36.01
2.3	-24.90	-33.58	-36.51
2.4	-25.78	-35.64	-32.66
2.5	-26.76	-36.71	-35.26
2.6	-26.10	-34.96	-36.58
2.7	-25.12	-37.13	-34.80
2.8	-25.47	-35.09	-33.15
2.9	-28.10	-36.34	-38.13
3.0	-27.10	-40.96	-42.28

Table 2. Results of power measurements

The ratio of power measurements gives square of reflection coefficients:

$$|r_A|^2 = 10^{(P1-P0)/10}$$
$$|r_B|^2 = 10^{(P2-P0)/10} .$$

Measurements results allow to calculate parameters of wall model [3]. In our case wall model is layered media where every layer can be characterised with thickness d_i, dielectric permittivity e_i and conductivity s_i. The summary thickness of wall $d = d_1 + d_2 + \ldots + d_k + \ldots + d_n = 0.55$ m.

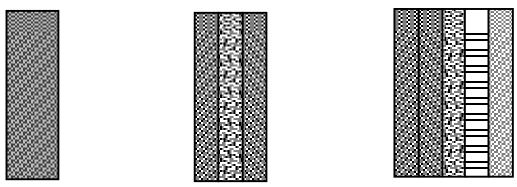

Figure 9. Wall models with 1, 3 and 5 layers

In the model every layer is characterised by thickness, complex dielectric permittivity

$$e_{ci} = e_i - i \cdot \frac{s_i}{2 \cdot p \cdot f \cdot e_0},$$

wave impedance $Z_i = Z_0 / \sqrt{e_{ci}}$ and wave number $k_i = k_0 \cdot \sqrt{e_{ci}}$.

The mathematical model of wall is a system of equations resulting from boundary conditions for electrical and magnetic field intensity continuities on layer boundaries. Electrical field intensity in layer i can be represented as a pair of travelling waves:

$$A_i \cdot \exp(-i \cdot k_i \cdot z) + B_i \cdot \exp(i \cdot k_i \cdot z)\,.$$

A_0 stands for incident wave intensity on the wall and B_0/A_0 represents reflection coefficient. The system of equations is:

$$\begin{cases} A_0 + B_0 = A_1 + B_1; \\ Z_1 \cdot (A_0 - B_0) = Z_0 \cdot (A_1 - B_1); \\ A_1 \cdot \exp(-ik_1 d_1) + B_1 \cdot \exp(ik_1 d_1) = \\ \quad = A_2 \cdot \exp(-ik_2 d_1) + B_2 \cdot \exp(ik_2 d_1); \\ Z_2 \cdot (A_1 \cdot \exp(-ik_1 d_1) + B_1 \cdot \exp(ik_1 d_1)) = \\ \quad = Z_1 \cdot (A_2 \cdot \exp(-ik_2 d_1) + B_2 \cdot \exp(ik_2 d_1)); \\ \quad .... \\ A_n \cdot \exp(-ik_n \sum_{s=1}^{n} d_s) + B_n \cdot \exp(ik_n \sum_{s=1}^{n} d_s) = \\ \quad = A_{n+1} \cdot \exp(-ik_0 \sum_{s=1}^{n} d_s); \\ Z_0 \cdot (A_n \cdot \exp(-ik_n \sum_{s=1}^{n} d_s) - B_n \cdot \exp(ik_n \sum_{s=1}^{n} d_s)) = \\ \quad = Z_n \cdot A_{n+1} \cdot \exp(-ik_0 \sum_{s=1}^{n} d_s). \end{cases}$$

The system can be solved analytically for a small number or numerically for a large number of equations. The same system can be obtained for a metal plate on opposite side of the wall. Reflection coefficients calculated from equations for given frequency f [GHz], number of layers n, each layer thickness d_i [m], dielectric permittivity e_i and conductivity s_i $[\mathrm{S \cdot m^{-1}}]$ will be marked as

$r_a(n, f, d_i, e_i, s_i)$ - without metal plate;

$r_b(n, f, d_i, e_i, s_i)$ - with a metal plate on the other side of the wall.

The wall parameters are determined by solving minimization problem for different number of layers:

$$Q = \sum_{m=1}^{M} \left| \left| r_a(n, f_m, d_i, e_i, s_i) \right|^2 - \left| r_A(f_m) \right|^2 \right|^2 + \\ + \sum_{m=1}^{M} \left| \left| r_b(n, f_m, d_i, e_i, s_i) \right|^2 - \left| r_B(f_m) \right|^2 \right|^2 \Rightarrow \min,$$

where M is number of frequencies used in reflection coefficients measurement.

For n=1 results are Q= 0.17394, d_1=0.550, ε_1= 3.780, σ_1= 0.0180.

For n=3 results are Q= 0.101448,

d_1= 0.204, ε_1= 3.800, σ_1= 0.0130,
d_2= 0.105, ε_2= 2.850, σ_2= 0.0000,
d_3= 0.241, ε_3= 4.200, σ_3 =0.0370.

For n=5 results are Q=0. 101270,

d_1= 0.204, ε_1= 3.800, σ_1= 0.0130,
d_2= 0.103, ε_2= 2.850, σ_2= 0.0000,
d_3= 0.000, ε_3= 2.800, σ_3 =0.0000,
d_4= 0.002, ε_4= 3.050, σ_4 =0.0040,
d_5= 0.241, ε_5= 4.200, σ_5 =0.0370.

Indication of exact measurement results for corresponding structure is Q=0. Searching for better results, let us imagine that every power measurement is carried out with a ±5% tolerance. Now:

$$\left| r_A \right|^2_{\mathrm{mod}} = \left| r_A \right|^2 \cdot (1 - 0.05 + 0.1 \cdot \mathrm{frand}(\,))\,,$$

$$\left| r_B \right|^2_{\mathrm{mod}} = \left| r_B \right|^2 \cdot (1 - 0.05 + 0.1 \cdot \mathrm{frand}(\,))\,,$$

where frand( ) is evenly distributed random function in interval [0.,1.].

Due to computing time limitations, calculation was carried out only for n=3 and n=5 with 30 realisations, for that reason statistic evaluations were impossible.

5 Conclusion

The spectrum analyzer FSP-30 is well suitable for power measurements in spectral domain. For wall parameters measurement below 3GHz frequency most suitable is embedded sweep generator.

Authors are thankful to Latvia Telecommunication State Inspection and personally director K.Bogen for possibility to use Inspection's equipment - FSP-30 for experimental measurements.

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