RFID objects monitoring in space bounded by metallic walls.

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Abstract. Considered problem is the reading of multiple RFID tags in the region of space, which is bounded by metal walls and has resonant radio-engineering properties. Obtained results show that it is possible to get reliable automated monitoring of items with tags by forming of a local electromagnetic field (EMF) with the help of slow-wave structures (SWS).

Introduction

The development of RFID and thus growing number of options for its applications puts the actual problems to read a large number of RFID tags attached to objects or items that are in the region of space bounded by metallic walls. Such a situation occurs when there is a need for a reliable, automated inventory and real-time monitoring of items or objects (important documents, jewelry, weapons, etc.) that are typically placed in relatively small closed metal boxes (in racks, cabinets or safes, for example). In addition, as a rule, this situation does not require large range of tags reading.

For reliable and automated real-time monitoring of objects it is necessary that the EMF exists with intensity exceeded tag's sensitivity at any point of space where the objects with passive RFID tags are placed.

There is some problem, however. If at least one of the linear dimensions of closed box with metal walls exceeds the signal wavelength, the box has the properties of a multimode cavity [1].

Introduction of radiating elements - antennas, for example, into the box leads to currents launching of significant intensity on the inner surfaces of the metal walls, which in turn create the secondary EMF. As a result of the electromagnetic waves' interference standing waves with peaks and dips of intensity EMF exist in the box. The location in the box of some marked by tags objects may coincide with EMF dips, so their real-time automatic reading is impossible.

Excitation of the other modes of the cavity allows to displace intensity dips coordinates, but such a decision in each practical situation is very difficult and expensive and, most importantly, does not guarantee the absence of EMF intensity dips in any particular point of space. Semi-automatic method with handheld RFID scanners for objects inventory or monitoring would guarantees a reliable result, but don't provide the quick real-time process.

Near-field antennas using [2, 3] also does not solve the problem of forming a limited area of RFID tags reading, since antennas with loop as proposed in [4] have undesirable radiation in the far EMF field. The reflecting metal walls presence in the reading area produces an interference of the direct RFID reader signal and the signals reflected by these walls, which also gives rise to standing waves with peaks and dips of the EMF intensity and corresponding disadvantages.

Thus, the use of traditional RFID technology solutions does not provide guaranteed resolution of the automated real-time objects monitoring problem.

Reasons for the decision of problem

Waveguide impedance transmission lines are known. They are the microwave structures in which the energy is transmitted by slow electromagnetic waves (EMW) with phase velocity less than the speed of light - the so-called slow-wave structure (SWS) [5, 6]. Slowed EMW are concentrated and distributed in the vicinity of the impedance microwave line, which can be implemented as a comb or a flat strip line. An example of the planar SWS executed in the form of a layered metal-dielectric device is shown in Figure 1.

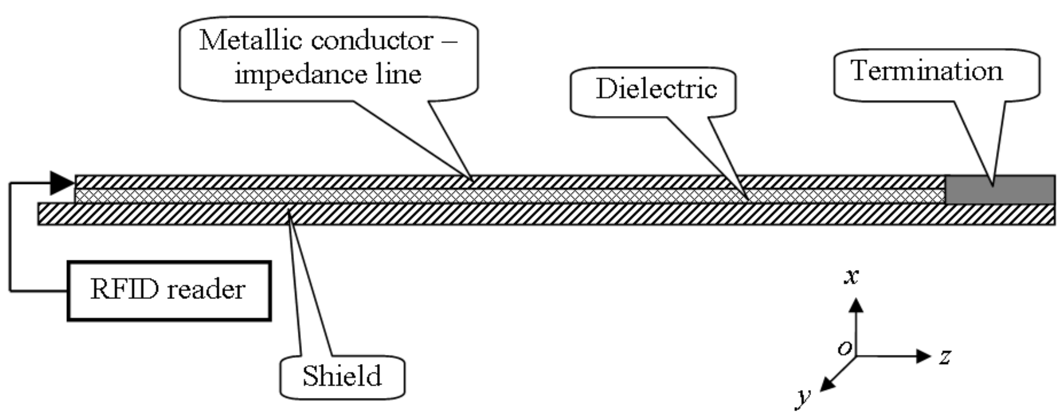


Figure 1 Slow-wave structure

Unique feature of SWS is that in the direction of the axis *ox*, which is transverse to direction of wave propagation along the axis *oz*, the surface electromagnetic wave is not radiated but is attenuated exponentially, i.e. much faster than attenuation of waves whose phase velocity equals or exceeds the speed of light. The absence of surface wave radiation is due to the fact that the components H_y and E_z are in phase quadrature [5]

$$H_y = H_0 \cdot exp(-\alpha x - i\beta z);$$
$$E_z = (-\alpha / i\omega\varepsilon_0) \cdot H_0 \cdot exp(-\alpha x - i\beta z), \quad (1)$$

where α - coefficient of field damping in the transverse direction (axis *ox*), and β - phase coefficient in the longitudinal direction (along the axis *oz*), mutually interconnected by $\alpha^2 = \beta^2 - \kappa_0^2$, where $\kappa_0 = 2\pi/\lambda_0$ - wavenumber in free space, $\beta = 2\pi/\lambda_g$, and λ_g is the wavelength of the slow electromagnetic wave.

The mean value of the Pointing vector S_x - the energy flux density in the direction *x*, is zero because of it's imagine value

$S_x = -(E_z \cdot H_y)/2.$

Such properties enable SWS to form local EMF and therefore, RFID tag reading zone with a fairly defined boundaries [7].

Dimensions of this zone on the axis *ox* are defined by an exponential multiplier exp $(-\alpha x)$ and may vary depending on the field attenuation coefficient α or deceleration factor k_s which related with the coefficient α by relation

$$k_s = c / v_p = \beta / \kappa_0 = \sqrt{(\alpha / \kappa_0)^2 + 1} > 1,$$

where v_p - the phase velocity of EMW and *c* - the speed of light.

Dimensions of the reading zone on *oy* and *oz* axes are defined by the fact that slow wave exists only above the wave-impedance structure, along which surface electromagnetic wave extends on the axis *oz*. Thus, in the plane *yoz* negligibly small intensity EMF exists outside the area bounded by the SWS's geometric dimensions.

The electric field above the SWS surface is determined from the Maxwell equation rot $\mathbf{H} = j\omega\varepsilon_0\,\mathbf{E}$

$$E_x = (\beta / \omega\varepsilon_0) \cdot H_0\, exp(-\alpha x).$$

In the approximation of a smooth waveguide line the field strength of the surface electromagnetic field is [5]

$$E_x = E_0\, exp(-\alpha \cdot x) = 4\, k_s\, (\sqrt{P_0\, Z_s} / \lambda_0) \cdot exp(-\, \kappa_0\, (\sqrt{k_s^2 - 1}) \cdot x), \qquad (2)$$

where E_0 - electric field on the surface of SWS, Z_s - characteristic impedance of SWS, and λ_0 – signal wavelength in a free space.

Thus, the EMF without dips of intensity creates in the local spatial inside a metal box area.

Corresponding zone of RFID tags reading in *xoz* and *yoz* planes has sections close to rectangular, and in the plane *xoy* is described by sharply falling exponential function. In this case, area of space effectively interacting with the tags can be approximated as parallelepiped.

Locality, i.e. limitation of space with a sufficiently high EMF intensity, means that outside this space, including on the walls of the cavity, the strength of EMF is small. In this case the surface currents on these walls, a secondary EMF in the cavity that they excites, as well as a standing wave with intensity dips that causes insecurity labels reading, are negligible.

Another unique feature of the SWS, according to (1) is theoretical independence of the electric field intensity along its longitudinal section - along the axis *oz*, what allows to use such structures as microwave feeder lines [8]. On the practice, decrease of traveling wave intensity along the SWS is determined by ohmic and dielectric losses (it can be small when the high quality materials - metal and dielectric are used), and negligible radiation losses due to irregularities of impedance line's geometry. As to RFID, this feature can provide a significant increase in linear length of the label's reading zone.

Generally, when SWS is considered in RFID applications it is logical to call it by EMF shaper or simply “field shaper” - FS.

Using (2), we will estimate the reading range of labels above SWS surface.

If the field E_x corresponds to the sensitivity labels E_t, then label’s reading range r with reader output power P_0 is equal

$$r = -\left(\lambda / 2\pi \sqrt{k_s^2 - 1} \right) \cdot \ln \left(E_t \lambda / 4\, k_s \sqrt{P_0 Z_в} \right). \qquad (3)$$

Figure 2 shows the dependence of $r(k_s)$ for different values of labels sensitivity E_t at a fixed reader output power P_0. There is the same dependence in Figure 3 for different values of reader output power P_0 at a fixed sensitivity of labels E_t.

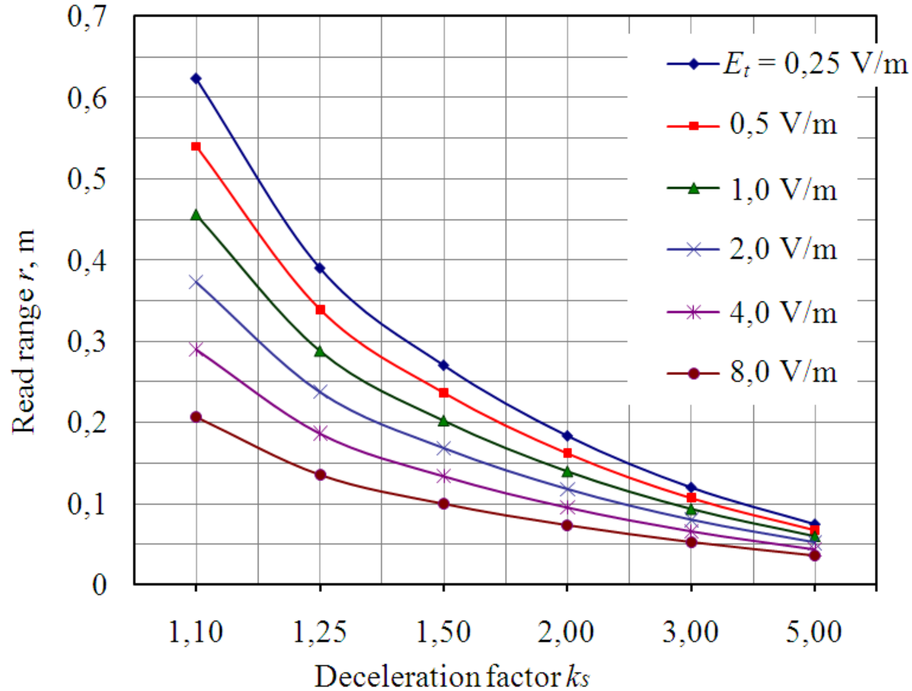


Figure 2 Dependence of the reading range for different label sensitivities at P_0 = 1W.

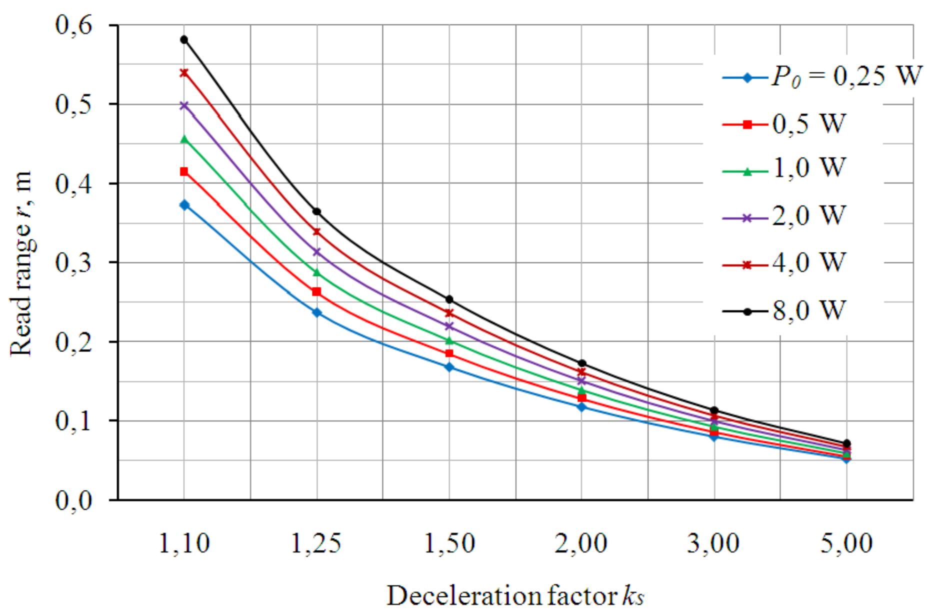


Figure 3 Dependence of the reading range for different values of reader output power at E_t = 1 V/m.

The figures show that the maximum reading range with technologically easily realizable the deceleration factor k_s = 1.5...3.0 for typical parameters of RFID tags and readers in the UHF band is moderate and is 10 ... 20 cm. In a large enough among applications, however, this is quite sufficient.

Tag's reading range, according to (2), can be increased by reducing of the carrier signal frequency $f = c/\lambda$. Dependence of $r(f)$ is shown in Figure 4 at a fixed SWS deceleration factor k_s = 2.0 for various achievable parameters of tag and reader.

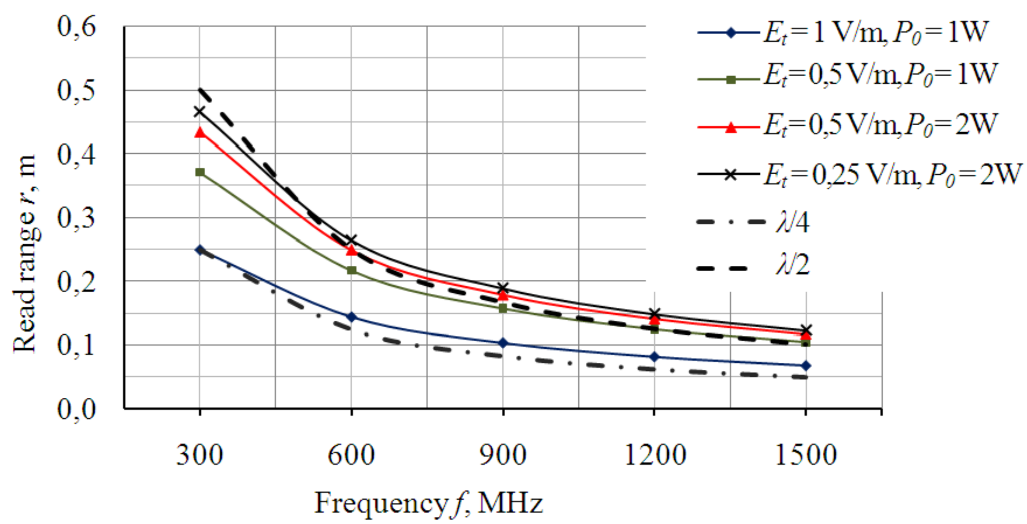


Figure 4 Dependence of the reading range from signal frequency at k_s = 2.0.

In the same figure the dotted line and dash-dotted line show the distance corresponding to the values $\lambda/4$ and $\lambda/2$. It shows that reading range of passive RFID tags may be estimated as (0.25…0.5) of reader wavelength with a small error then the SWS are used. The maximum reading range of (20…40) cm can be achieved in RFID frequency band of 433 MHz.

Simulation

Proposed method of solving the problem of automated UHF RFID tags reading in a limited space needed estimation of its feasibility. The electrodynamics' simulation of the 600×160×6 mm SWS was carried out with deceleration factor $k_s \cong 3$. Figure 5 shows the view of impedance line (a meander) of the SWS pilot.

Figure 5 Impedance line of the SWS pilot.

A feature of SWS is the ability to implement it in the form of almost nonradiating device. The simulation results and experimental studies have confirmed that the scattering in the form of the active losses and radiation in space can make up only a small part of the surface wave energy. Figure 6 shows the radiation pattern of experimental SWS in the far field EMF, wherefrom very low radiation efficiency is obvious (total efficiency less than 1.5%), which is a useful effect with respect to RFID technology.

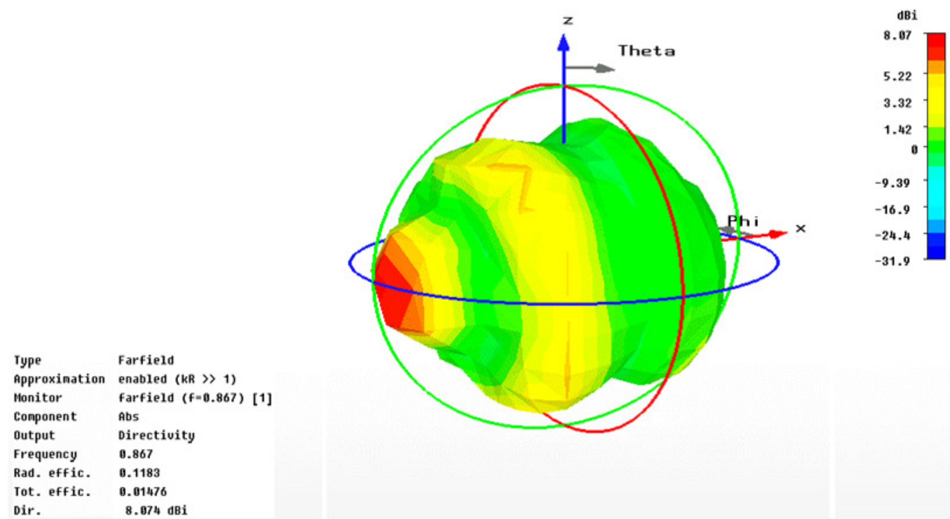


Figure 6 Radiation patterns of SWS.

Figure 7 represents the result of simulation for S11 and S21parameters, which shows that loss of SWS-through at a frequency of 867 MHz, does not exceed 0.6 dB. The calculation of loss of the equivalent microstrip line with the length equal to the length of "straightened" impedance line (everything else being equal) shows that the active losses are approximately 0.3 dB. Consequently, the SWS's radiation loss can also be considered close to 0.3 dB.

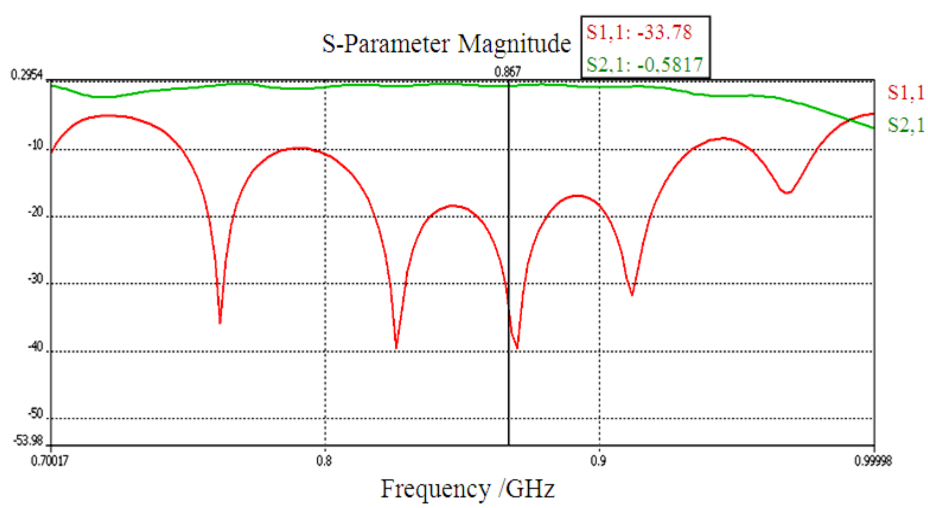


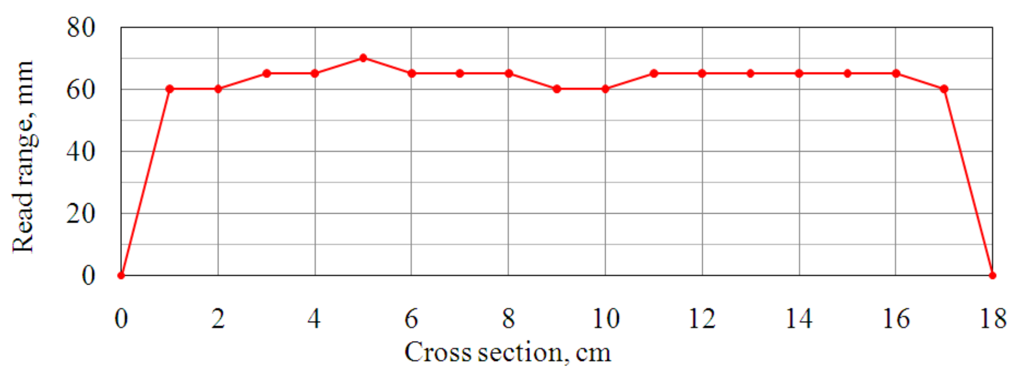
Figure 7 S-parameters of SWS.

Such a low radiation level of RFID apparatuses with slow-wave structures could raise the question of attributing such systems to the class of non-emitting high-frequency units with relevant, much slimmed-down electromagnetic compatibility requirements.

Experimental results

The pilot model of SWS has been manufactured on the base of simulation results.

Figure 8 shows two reading ranges distributing of the pilot SWS in central orthogonal cross sections. The measurements has been carried out with a tag Jem (Raflatak, 10×30 mm, E_t = 2.5 V/m) and reader Speedway (Impinj) for frequency of 865 MHz at P_0 = 0.5 watts.



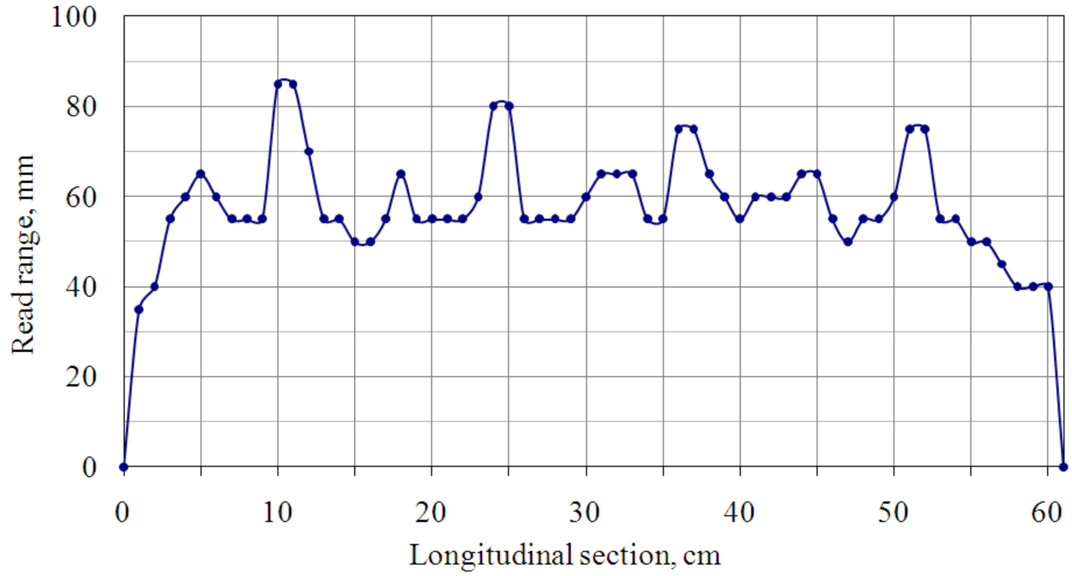


Figure 8 Orthogonal transverse sections the SWS's area of RFID tags reading.

The experimental data confirms the above results of simulation and calculations concerning the possibility of SWS using to realize reliable reading of UHF RFID tags in the region of space bounded by metallic walls.

In Figure 9 measured VSWR of the SWS pilot is shown.

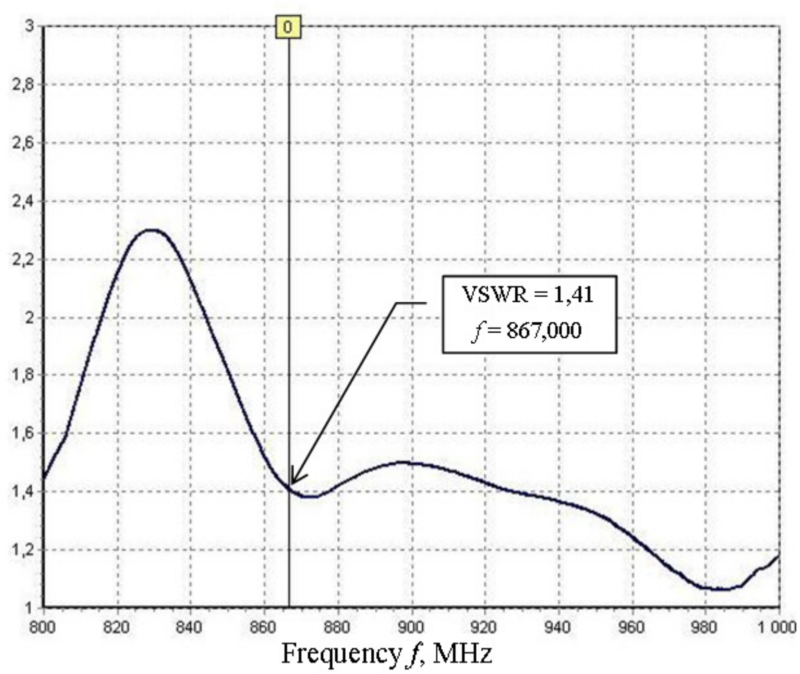


Figure 9 VSWR of the SWS pilot.

The result VSWR of the pilot SWS's matching in a rather broad frequency band (of more than 100 MHz) is close to the result of S11simulation on Figure 7.

Comparison of the frontal axial radiation of patch antenna AR900-2L [9] with the gain G = + 8dB and pilot SWS showed that at 1 meter the latter has a lower radiation level by 44...45 dB. This result of measurements corresponds to SWS's unwanted radiation in a far field with the "gain" of minus 36...37 dB.

Conclusions

1. The application of slow-wave structures in RFID systems can resolve the problem of reliable and automated real-time monitoring of the objects in metal boxes - safes, cabinets, racks, etc.

2. Slow-wave structure creates a local area of RFID tag's reading without dips of intensity EMF. The size of this area in a SWS's plane is close to its geometric dimensions.

3. Maximal reading range of RFID tags in a direction perpendicular to the plane of slow-wave structure is close to (0.25…0.5) wavelength of radio signal.

4. Unwanted radiation of slow-wave structure in a far field compared to the typical RFID patch antennas is minus 40…45 dB.

References

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