

# Evaluation of Spurious Emission of New System of Wireless Power Transfer

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**Abstract:** The operation of system of wireless power transfer is considered in the paper. System design is based on the use of coupled strip lines. Considered system is distinguished from known coupled strip line by the coiling of strip lines into spiral. Mentioned approach ensures the softening the demands of mutual positioning the system elements and it leads to space saving. The main attention within the system of wireless power transfer operation is paid to spurious emission. It was shown the negative affect of system under consideration onto biological objects is negligible at relative high value of wireless transferred power

**Keywords:** microstrip line, symmetrical strip line, directional coupler, power transfer, power loss

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## 1. INTRODUCTION

The use of electric transport within urban infrastructure is non alternative solution in the developing of the city of future. Wired electric transport is not always convenient for use and applications are limited with the use of land electric transport only. The battery-driven electric transport is more flexible in use and possible application can be expanded to air medium where the limits of transport growth absent [1].

The main problem that has to be solved at exploitation of electric transport is its batteries charging. The widespread placing of charging station within urban infrastructure is the obligatory condition for the ensuring the normal operation of electric transport which became very popular recently.

Wire contact method of battery charging possesses known effectiveness and one ensures the energy transfer mostly without loss. However in such a case the precise connection of wire ended with power jack conjugated with socket on vehicle board has to be implemented. Man does this operation easily. So, the presence of service personal is obligatory in most cases and this approach to the solving of battery charging problem can be economically unjustified. Especially this problem will be clear at ensuring the battery charging of unmanned aerial vehicles (UAV) whose landing has to be implemented in hard access places such as rooftop of buildings, industrial facilities, remote areas etc.

Non contact method of battery charging excludes the need of personnel presence because of no need in precise connection of power jack and socket in this case. In other words, it is stated the task of replacing of contact method

with non contact one. The task of non contact power transfer on essential distances is not stated now.

The wireless power transfer is the matter of steadied investigations all over the world. Especial useful wireless technology of power transfer will be at the battery charging of electrical vehicles of urban transport of any kind, land or air.

Many technologies of wireless power transfer are well developed today. This is well known standard Qi [2, 3] which replace contact technology of power transfer with non contact one effectively enough. However the value of transferred power is limited and high precise conjugation of inductive elements of power transfer system has to be implemented in this case.

More progressive technology assumes the magnetic-resonance power transfer [4, 5]. There is no need in precise conjugation of system elements. The power can be transferred on increased distance, up to several meters. However, the affecting of this technology of power transfer onto biological object is not studied today at any level. Obviously the negative influence onto living organisms takes place if ones are in nearby proximity to wireless power transfer system elements.

At the same time the hard following to existing standards of safety of exploitation of electromagnetic wave emitting equipment hast to be ensured. The hazardous densities of electromagnetic flow at different frequencies have been determined for a long time and ones are well known [6]. Taking into account possible widespread placing of wireless charging station within urban infrastructure and the absent of our wishes in converting of our city into giant microwave oven the parasitic emission of each wireless power transfer

subsystem has to be negligible. Obviously mentioned above technologies are not suitable for discussed purposes.

## 2. NEW APPROACH TO SYSTEM DESIGN

The use of coupled strip lines for power transfer is well known application for a long time. However orthodox coupler built on strip lines with face coupling has 3 dB (a half of power!) losses in best case. The same power is dissipated in ballast resistor of the coupler. Furthermore, mentioned feature is realized at certain arrangement of mutual placing of strip lines only. Any deviation of strip lines mutual placing from stated leads to degradation of power transfer. So, such couplers are widely used in communication, radar technologies and are not used in energy applications.

It is proposed to use the same technology for wireless power transfer but with certain changes directed onto increasing the rate of power transfer and softening the demands on mutual placing of system elements [7]. These innovations can be reduced to following three features.

First of all of ballast resistors were excluded from system design. No active resistors, no power dissipation. Unused ends of strip lines were shorted on ground plane or ones were opened. Furthermore, the wave reflected from opened (shorted) end takes part in power transferring as well. That increases the ratio of power transfer.

Next, the lengths of coupled strip lines were increased and ones were much higher than a quarter of wavelength as in orthodox coupler. So, each segment (quarter of wavelength) takes part in power transferring. That increases the ratio of power transfer too.

And the last, each strip line was coiled into spiral. Besides the space economy this approach softens the demand onto the mutual placing of coiled spirals. In a coupler with straight strip lines any mutual lines displacement increases the distance between them, and power transfer ratio falls. In a case of coiled strip lines their mutual displacement does not lead to dramatic results in power transfer process. This is due to the neighbor arms of spiral take part in process of power transfer in contrary to straight lines.

All of mentioned above ensured the excellent characteristics of power transfer system for various applications. First of all the operation of wireless power transfer system for batteries charging of UAVs was studied.

The size of system element was  $220 \times 220 \text{ mm}^2$  [8]. System ensured power losses not worse than -1 dB with the changing the distance between system's strip-line structures from 5 till 15 mm and at its mutual displacement of the same order.

Then the system was scaled to application for electrical land vehicle [9]. The size of system element was approx.  $1 \times 1 \text{ m}$  and system ensured the same value of power losses, but at distance in 150 mm (standard automobile clearance).

## 3. SYSTEM OPERATION

The choice of strip line technology was caused with the tending of decreasing of spurious emissions of system of wireless power transfer. As it was well known the strip line structures (microstrip structures) do not emit the electromagnetic wave in surrounding space, at least in first approximation. So, it was supposed this technology will be suitable for wireless power transfer for battery charging of urban electric transport at widespread placing of charging station within urban infrastructure.

In present study it was decided to prove (or to refute) this fact experimentally.

First of all, new strip line structures were made. Strip lines were made by etching method on one-side foiled fiberglass with the thickness in 0.3 mm. The thickness of copper foil was 18  $\mu\text{m}$ . The outer size of structure was  $220 \times 220 \text{ mm}^2$ . Then the strip line structure was glued to polycarbonate substrate with the same outer size and with the thickness in 5 mm. From the bottom side of polycarbonate substrate the same non etched foiled fiberglass was glued. It was a ground plane. Then the support with SMA connector was screwed to assembled substrate and its central conductor was soldered to strip line. Opposite end of strip line was left opened.

The appearance of strip line structures is shown in Figure 1.



Figure 1. The appearance of strip line structures

Yellow bricks (seen from the left) from hard foam with calibrated thickness (5, 10, and 20 mm) were used for setting the distance between structures from 5 till 35 mm with step in 5 mm.

Then both strip line structures were placed one over another by face-to-face manner and connected to vector network analyzer E5063A. Then system characteristic S21 was studied at different distances between structures and different mutual displacement of them. The results were repeated with respect to previous study [8] but with a little bit degradation in power transfer ratio in 1.5 dB.

Obviously it was due to the decreasing of copper foil thickness up to 18  $\mu\text{m}$  (contrary to 300  $\mu\text{m}$  in previous study) and presence of fiberglass in sandwich. However this degradation was out of interest in present researches, it was for reference only. One of obtained dependences of

transfer ratio (S21) from frequency for distance between structures in 10 mm is shown in Figure 2.



Figure 2. Dependence of power transfer ratio from frequency

As it can be seen from Figure 2 the optimal frequency for wireless power transfer at a distance between structures in 10 mm is 223 MHz. Further analysis of system spurious emission will be made at the same conditions and at the same frequency.

#### 4. SYSTEM SPURIOUS EMISSION

It has to be understood the output power of network analyzer was not enough for measuring of system spurious emission. So, another scheme of these measurements was proposed.

Standard VHF/UHF oscillator type G4-164 (Russia) was used. The frequency was set equal to 223 MHz and output power was set equal to 80 mW.

Power amplifier for this frequency band was made and one ensured the output power about 25 W at mentioned above frequency in 223 MHz and input power 80 mW.

The power amplifier was loaded with the first of coupled strip line structures (transmitting line). The second one (receiving line) was loaded with external 45 dB attenuator with cooler, the output signal of which was entered the power meter type M3-51 (Russia).

The measurer of density of electromagnetic field power flow ATT-2592 of AKTAKOM was used for spurious emission measurements.

The appearance of wireless power transfer system is shown in Figure 3 with coupled strip line structures (a) and separate ones (b).

The spurious emission was measured at displacements of measurer ATT-2592 in horizontal and vertical directions onto the distances which were changed from 0.1 till 1 m. The 3D module of density of electromagnetic field power flow in microwatts on square centimeter was measured.

The measurements were implemented with loaded wireless power transfer system (coupled strip lines, upper strip line was placed onto lower one separated with 10 mm foam bricks) and unloaded system (upper strip line structure was removed). The presence of wooden rod in measuring area distorted the electromagnetic field.



(a)



(b)

Figure 3. The appearance of wireless power transfer system

In a case of coupled strip lines the measured power at the output of received strip line was about 17 W.

In a case of absent of received strip line all power was reflected from opened end of transmitting strip line and one was dissipated in ballast resistor of power amplifier.

Primary the position of measurer ATT-2592 was set with the help of wooden rod with marked scale. However, measurements were fixed after rod removing only, the position of measurer was kept visually. The results of measurements of density of electromagnetic field power flow for unloaded system are shown in Figure 4.

The results of measurements of density of electromagnetic field power flow for loaded system are shown in Figure 5.

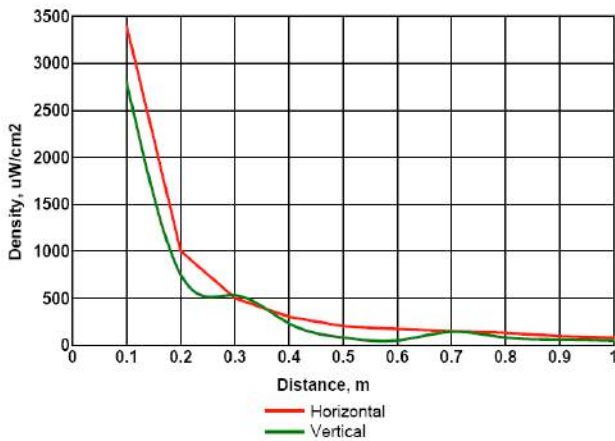


Figure 4. Density of electromagnetic field power flow for unloaded system

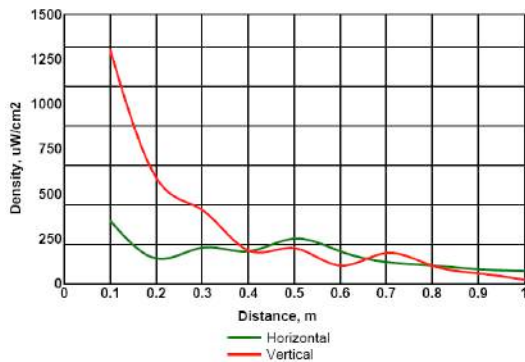


Figure 5. Density of electromagnetic field power flow for loaded system

## 5. RESULTS DISCUSSION

As it can be seen from Figure 4 and Figure 5 the level of density of electromagnetic field power flow is a little bit higher in all directions for unloaded system with regard to loaded one. It seems quite clear. The unloaded system is represented with single strip line structure (microstrip structure) while the presence of second strip line structure converts system into the coupler on symmetrical strip lines with facial coupling. The spurious emission of unshielded microstrip line is higher than emission of fully shielded symmetrical strip line.

At the same time, even for worse case, the density of spurious power flow falls below the critical level ( $200 \text{ uW/cm}^2$ ) at a distance in 0.5 m in all directions from system elements of wireless power transfer. Such a level of density of electromagnetic field power flow is assumed as safety threshold level in Russia. At a distance in 1 m the density falls below the level in  $50 \text{ uW/cm}^2$ , and such a level is absolutely safe for biological objects. It has to be understood such levels of spurious emission are achieved at primary generated power in 25 W. For the comparison similar level of emitted power takes place at operation of base stations of mobile communications, the radius of sanitary zone of which is calculated in hundreds of meters.

From the other hand the absence of coupled line leads to increasing of VSWR in primary excited line, and it can be used for reducing of primary generated power up to level in several milliwatts which will be enough for VSWR measuring only, as it was proposed in [7].

Analyzing obtained results it can be seen the dependencies have non regular nature. Obviously it is caused by appearance of space standing waves, the measurer ATT-2592 itself and the arm of operator are not radio transparent things. However, they do not change the general nature of system spurious emission, it is not high.

## 6. CONCLUSION

So, the design, operation, and spurious emission of newly proposed system of wireless power transfer were discussed. System possesses the simple design and one can be built in the body of existing electric vehicles intended for use in urban transport. The conjugated part of system of wireless power transfer easily can be built in roadbed or any other urban infrastructure object not disturbing its direct functionality.

The system possesses negligible level of spurious emission and this feature profitably distinguishes proposed system from existing ones.

The system has no resonant nature of power transferring process in contrary to magneto resonance system. There is an optimal frequency for realizing the power transfer process. However the system adjusting can be implemented at charging station by VSWR measuring and starting of iteration procedure. It is not a complex task.

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