Modelling & Analysis of High-Power , High-Frequency Wireless Power Transmission

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Abstract - *Wireless Power Transmission is an emerging technology in recent years. It provides the power transmission without requirement of wires. It can be useful application for increasing demand of smart gadgets. In this paper, two models of the wireless Power Transmission system have been presented. The first model represents the RF inductive coupling model that uses power transmission through inductor coils. Thus, the behaviour of the system has been examined. The boost converter has been introduced to increase the efficiency up-to 70%. This model is represented for high power criteria for high DC voltage.*

Second model represents High Frequency model for power transmission. It is popularly known as Microwave Power Transmission. In the simulation results, various analysis have been done for the output power at sender and receiver end. Thus, efficiency of the system has been found to be 92%.

***Keywords*:** Wireless Power Transmission, Inductive coupling, Coupling coefficient, Boost converter, Microwave Power Transmission.

1. INTRODUCTION

Wireless power transmission is an emerging technology in the field of energy transmission. It's the transmission of the power without the need of wires. Thus, power can be transferred without physical power connection. Previously, it is found to be low efficient and very lossy due to requirements of bulky elements.

A wireless power system generally comprises of a transmitter connected with the source of power, which further converts the power to a time-varying electromagnetic field. After then receiver receives the power and convert it back to DC or AC electric current which is used by an electrical load. At the transmitter , the input power is converted to an oscillating electromagnetic field by some type of antenna as shown in figure 1.

Figure 1 shows the concept of power transmission which is known as microwave power transmission (MPT). Antenna consists of element that generates a magnetic field, a metal plate which generates an electric field, an antenna which radiates radio waves, or a laser which generates light. A similar antenna or coupling device at the receiver converts the oscillating fields to an electric current. Generally, the power transmission can be done using electromagnetic fields as well as microwave transmission.

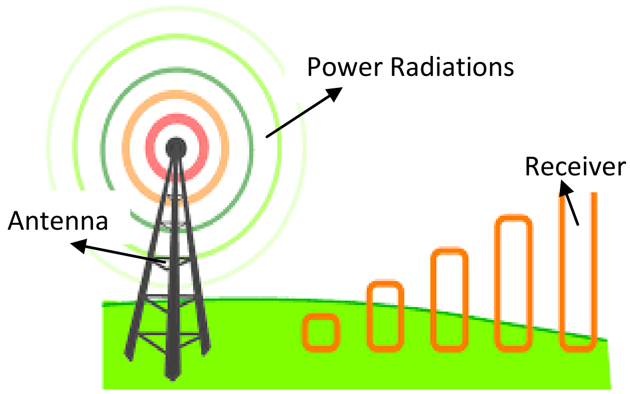

Figure.1 Wireless power transmission

Wireless power transfer has the ability to change the world with all the different applications it has to offer. As simple as charging a cell phone to supplying the Earth with all the energy it needs. The first applications that consumers are most likely to see would be a charging station that will range from about one to five meters. This is a small box-like object that will be able to charge compatible electronics within the range of the system.

Wireless power transfer charging systems are proven to have efficiencies near that of conventional charging devices. For example, a household would need about one transmitter per room and allow the house be completely wireless. This will strictly be a convenience to consumers and not serve any other service. Electronic companies may not like this new concept due to the fact that they will not be able to make a different charger for everything they make and force consumers to pay for the different chargers.

The biggest advantage, especially with personal devices incorporating wireless chargers is that one does not have to consciously 'charge' the devices, they charge themselves every time they come within the range of a power transmitter.

Table 1 shows that wireless power transfer can be done in following ways:

(i) Near Field Coupling Techniques – Inductive coupling, capacitive coupling

(ii) Far-field coupling techniques - Microwaves, Laser

In Inductive coupling, power is transmitted by the coils through magnetic field generation. Near field coupling is done for shorter range and found to be have higher losses. The magnetic field passes through the receiving coil (L2), where it induces an alternating EMF (voltage) by Faraday's law of induction, which creates an AC current in the receiver. The induced alternating current may either drive the load directly, or be rectified to direct current (DC) by a rectifier in the receiver, which drives the load.

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. A rectenna may be used to convert the microwave energy back into electricity.

Table 1 Modes of wireless power transfer

Technology	Range	Frequency
Inductive coupling	Short	Hz – MHz
Resonant inductive coupling	Mid-	kHz – GHz
Capacitive coupling	Short	kHz – MHz
Magnetodynamic coupling	Short	Hz
Microwaves	Long	GHz
Light waves	Long	≥THz

2. INDUCTIVE COUPLING

In electrical engineering, two conductors can be said to be inductively coupled or magnetically coupled when they are configured in such a technique that change in current through one wire induces a voltage in other wire through electromagnetic induction phenomenon.

Figure 2 shows circuit diagram for WPT system based on inductive coupling. The amount of inductive coupling between two conductors is analyzed by their mutual inductance. Inductive coupling uses magnetic fields that are a natural part of current's movement through wire. Any time electrical current moves through a wire, it creates a circular magnetic field around the wire. Bending the wire into a coil amplifies the magnetic field. The more number of turns the coil makes, the bigger the field will be induced.

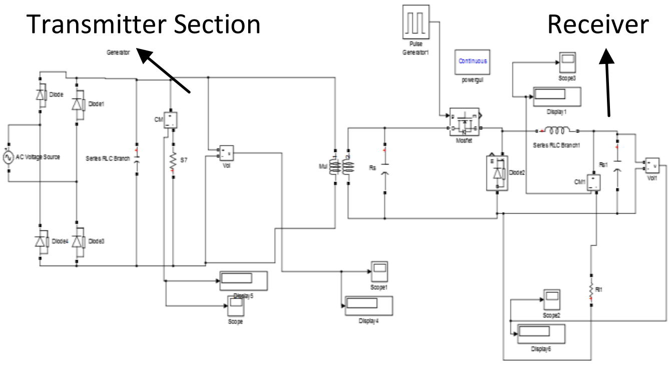

Figure.2 Inductive coupling based WPT system

Table 2 shows various parameters and their values for the desired response for the circuit shown in figure 2 which is for inductive coupling based wireless power transmission.

Table 2 Parameters

Components	Value
Input voltage	220V
Filter capacitor	4700uF
L1	50nH
L2	50nH
M	45nH
Receiver capacitor	1000uF
L(boost converter)	10uH
Load capacitor	1000uF
Load resistance	100 ohm

Mutual induction can be given as :

$$M = \frac{\mu_0 \mu_r N_1 N_2 A}{l} \quad \text{.........equation.1}$$

Where,

μ_0 = permeability of free space ($4\pi \times 10^{-7}$ H/m)

μ_r = relative permeability of iron core

N = number of coil turns

A = cross-sectional area in m^2

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l = coils length in m

Coupling Coefficient

Basically, inductive coupling between the two coils is expressed as a fractional number which exist between 0 and 1 where 0 indicates, no inductive coupling, and 1 indicating maximum inductive coupling.

if k = 1 the two coils are perfectly coupled, if k > 0.5 the two coils are tightly coupled and if k < 0.5 the two coils are loosely coupled. Thus, coefficient of coupling, k is given as:

$$K = \frac{M}{\sqrt{L_1 \times L_2}}$$ equation.2

where, M is induced mutual inductance

L_1 and L_2 are inductance of two coils.

3. BOOST CONVERTER

Figure 3 shows the basic circuit for boost converter. A step-up or boost converter is basically a DC-DC power converter that develops an output voltage greater than the source voltage. A boost converter is also called a step-up converter because it "steps up" the input (source)voltage. Since power P=VI should be constant, the output current has value lower than the input current. In this paper, boost converter is used to increase the power generated by the mutual induction of the two coils and the results can be observed shown in table 4 (receiving end) that voltage is stepped up.

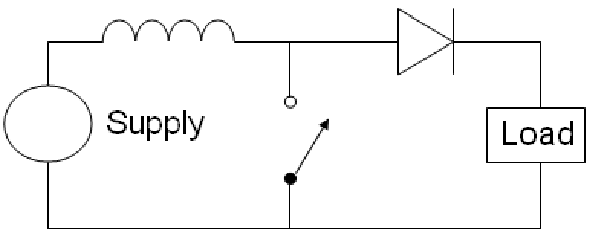

Figure.3 The basic schematic of a boost converter

So I can say that boost converter can be used for high power generation technique as mentioned in this paper. Importance of boost converter can be analyzed in high power transmission method.

4. MICROWAVE POWER TRANSMISSION

This technique of power transmission introduced by William C. Brown who presented the concept of rectenna which is basically a combination of Rectifier & Antenna. Long distance wireless power transmission for communication become possible by the invention of rectenna.

Figure 4 shows the MPT system for wireless communication. Conceptually, the antenna receives microwave radiation which passes through a low pass filter as well as a matching filter and diodes. Then it is converted to DC by means of a rectifying circuit. Various experiments shows that the 2.45 GHz frequency achieves the maximum efficiency for the rectenna for maximum information carrying capacity. Thus I can say that rectenna is used for reception and conversion of energy signal.

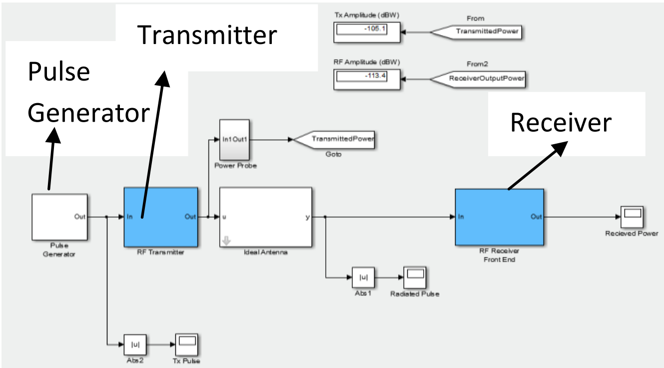

Figure.4 Microwave power transmission system

As shown in figure 5, In the transmission side, microwave power is generated by microwave power source and there is electronic control circuit that controls the output power. The wave guide ferrite circulator is connected with the microwave power source through the Coax – Waveguide Adaptor. There is a tuner for impedance matching . It matches the impedance between the transmitting antenna and the microwave source. Power is radiated uniformly through free space to the rectenna by transmitting antenna. Transmitted power is received by rectenna that converts the microwave power into DC power. Filter and impedance matching circuit is provided to set the output impedance of both i.e. signal source and rectifying circuit to be equal. The rectifying circuit consists of Schottky barrier diodes which converts the received microwave power into DC power.

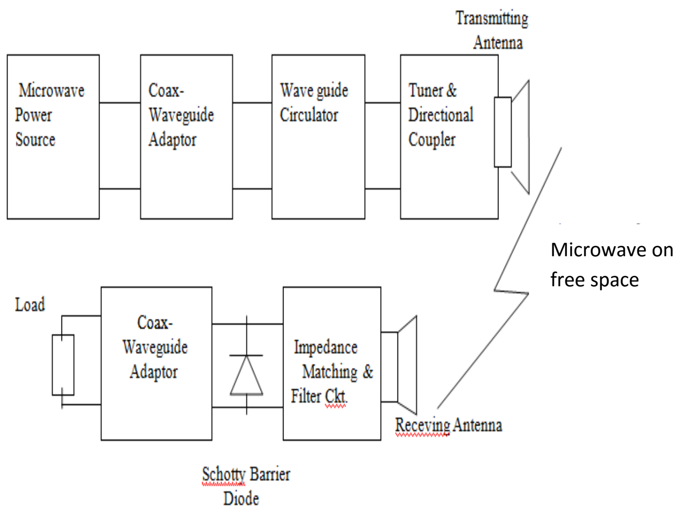

Figure.5 Block Diagram Of MPT

5. RESULTS AND DISCUSSION

Simulation results has been presented here for high power transmission based on inductive coupling. The Inductive coupling model as detailed in section II has been simulated using MATLAB-SIMULINK. The model has been divided into two separate parts viz. transmitter and receiver. The analysis has been done for both the ends by varying the distance.

Table 3 presents the analysis for the transmitter end. The power in watts (~100W) has been transferred very efficiently. Here, the AC has been rectified and transferred though the inductive coupling. The filter circuit and inductive coupling forms the radiating circuit. Mutual inductance between the coils forms the coupling for power at higher rates and capacity. Thus, following table shows how much power can be generated with the given parameters as illustrated in table 2.

Table 3 Transmitter Power Analysis

SN	Distance (cm)	Voltage (V)	Current (A)	Power (W)
1	0.1	108.6	1.086	117.939
2	1	108.1	1.081	116.856
3	4	106.8	1.068	114.062
4	8	105.2	1.052	110.670
5	12	103.9	1.039	107.952
6	16	102.8	1.028	105.678
7	20	101.9	1.019	103.836
8	24	101.2	1.012	102.414
9	28	100.7	1.007	101.404
10	32	100.2	1.002	100.400
11	36	99.88	0.9988	99.7601
12	40	99.6	0.996	99.201
13	44	99.6	0.996	99.201
14	48	99.21	0.9921	98.4262

Table 4 presents the analysis on the basis of the results for the power generated at the receiver end for the inductive coupling model for high power. Here, the simulation has been done for high power (in Watts). Thus, to increase the efficiency the boost converter has been used in the receiver side. I observed that on increasing the distance between the inductive coils, the efficiency and the output voltage decreases. However, even after transferring power at high voltage, the efficiency is found to be greater than previous models. Table 4 shows the variation in generated power with increasing the distance which clearly depicts that high power can be generated by using the boost converter.

Table 4 Receiver Power Analysis

SN	Distance (cm)	Voltage (V)	Current (A)	Power (W)
1	0.1	88.96	0.8896	79.138
2	1	86.96	0.8698	75.637
3	4	80.62	0.8062	64.995
4	8	72.48	0.7248	52.533
5	12	64.98	0.6498	42.224
6	16	58.28	0.5828	33.965
7	20	52.2	0.522	27.248
8	24	46.68	0.4668	21.790
9	28	41.82	0.4182	17.489
10	32	37.48	0.3748	14.047
11	36	33.61	0.3361	11.296
12	40	30.1	0.301	9.060
13	44	30.1	0.301	9.060
14	48	24.12	0.2412	5.817

Table 5 shows the efficiency of WPT system with respect to distance(cm). As per the first observation (table 4), I found that 80 watts of power can be transmitted from the generated power which is 117 watt. Thus, 70% of efficiency is achieved for this data. This result shows that boost converter can be used efficiently to achieve desired results to fulfill the requirements for high power transmission in wireless power transmission techniques. Efficiency is calculated by following formula.

$$Efficiency(\eta) = \frac{received.power}{transmitted.power} \times 100 \quad \text{...equation.3}$$

Table 5 Efficiency Analysis

SN	Distance (cm)	Efficiency
1	0.1	67.101
2	1	64.727
3	4	56.982
4	8	47.468
5	12	39.113
6	16	32.140
7	20	26.241
8	24	21.276
9	28	17.2468
10	32	13.991
11	36	11.323
12	40	9.133
13	44	9.133
14	48	5.910

Here, figure 6 shows variation of input and output power with respect to distance(cm). I observed that approximately 117 watts of power can be generated at the transmitting end and 80 watts of power can be obtained at the receiving end by using boost converter. I also found that power transmitting range is more than 50 cm for inductive coupling based wireless power transmission system.

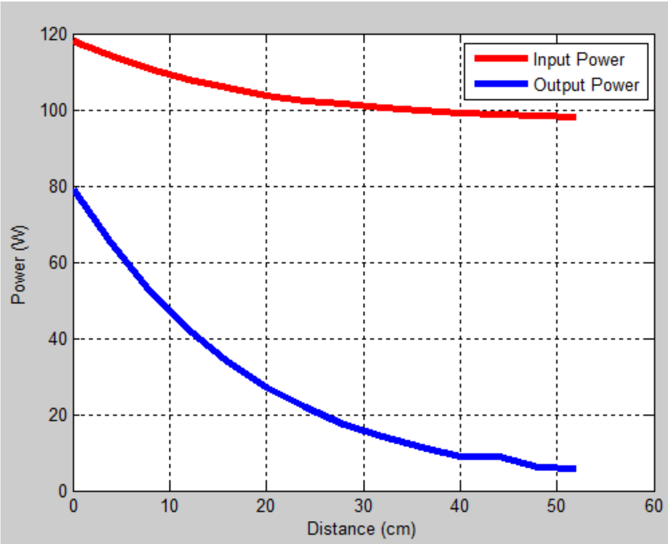

Figure.6 Analysis of Power vs Distance

Figure 7 shows variation of efficiency with respect to distance. I observed that approximately 70% of efficiency is obtained and efficiency is decreasing with increase in distance. It is found that this model is able to transfer the high power for lower distances.

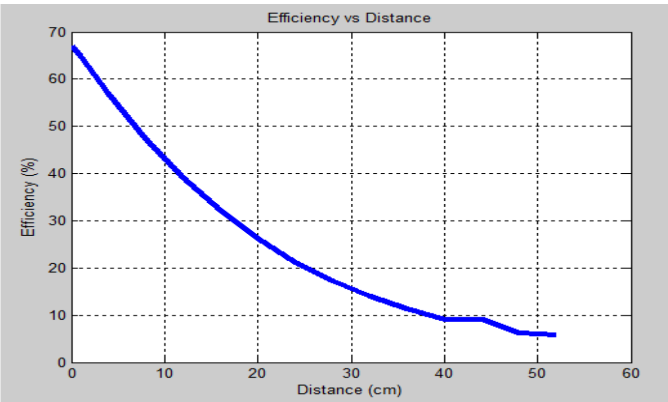

Figure.7 Efficiency vs. Distance Analysis

Table 6 describes performance of different antennas on desired frequency. I observed that proposed model which operates on the frequencies clustered around 2.4GHz, is highly efficient in terms of maximum information carrying capacity at 2.4GHz.

Table.6 Analysis of Microwave Power Transmission

TYPE OF ANTENNA	FREQ (GHz)	EFF (%)
PRINTED DIPOLE	2.45	85
CIRCULAR PATCH	2.45	81
PRINTED SQUARE RHOMBIC	5.6	78
SQUARE PATCH	8.41	66
PROPOSED MODEL	2.4	92.11

Figure 8 shows the comparative analysis of efficiency of microwave power transmission system at different frequency range. It is found that at 2.4GHz loss is minimum and thus efficiency is higher(approximately 92%). Thus I can say that microwave power transmission system at 2.4GHz is able to transfer more information with higher efficiency. Here, high frequency means maximum information carrying capacity with minimum loss for the transmission of information signal.

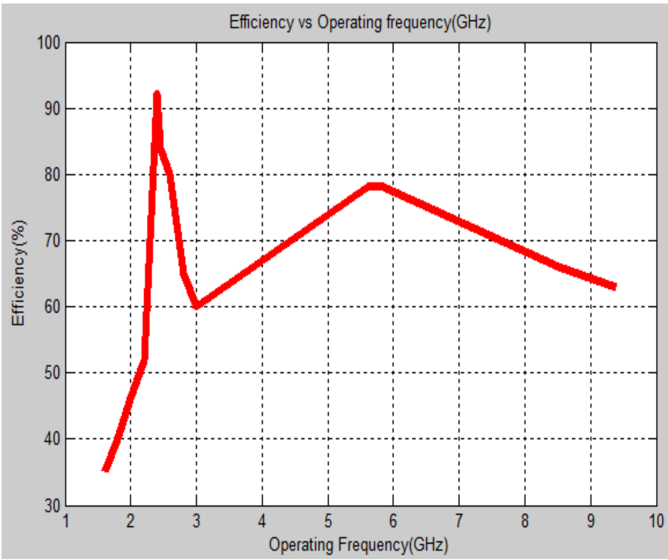

Figure.8 Analysis of Efficiency at 2.4GHz

Figure 9 shows the power spectrum of the received signal in microwave power transmission system. It is the measure of a information carrying capacity of a signal at different time interval for desired frequency. Generally, information carrying capacity is measured in dBm or dBW to denote the power ratios in logarithmic scale. I presented the strength of transmitted signal in dBW for higher efficiency.

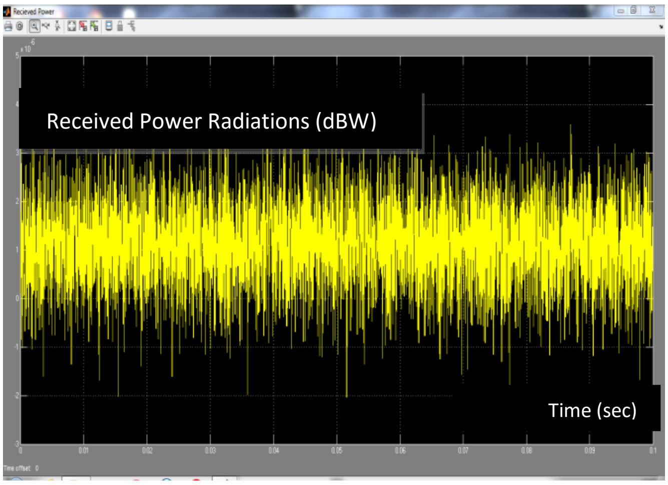

Figure.9 Power spectrum of received signal

6. ADVANTAGES

WPT has various benefits such as it gives us fecility to eliminate the existing high-tension power transmission line wires or cables, towers & sub-stations in between the generating station and consumers. Life of the product can be increased by WPT. This is very safe technique of energy transfer because possibility of faults on cables and short circuit would never exist.

7. DISADVANTAGES

WPT method also has some demerits. The Initial Cost for practical implementation of wireless power transmission seems to be very high.

8. APPLICATIONS & FUTURE ASPECTS IN WPT

Wireless power transmission can be used in such cases where continuous transfer of energy is needed, but use of inter-connecting wires are inconvenient, hazardous, or practically impossible. In home , there are number of switching points that receives electric power at the same frequency using single transmitting coil as long as they all are at resonance. Thus this technique could recharge all the devices at some distance (eg. Room) simultaneously.

In future, WPT technique can be used in moving objects such as moving robots, fuel free electric vehicles etc. Various types of wireless sensors can also be made which can detect variations in parameters. Apart from these, largest application of wireless power transmission is solar power satellites where power can be transmitted as a microwaves to the earth.

9. CONCLUSION

Here, I have presented the analysis of the two wireless power transmission models separately: (i) Inductive coupling based high power wireless transmission model (ii) Microwave based high frequency wireless power transmission model. I have designed the model for power transmission upto 80W using inductive coupling. The simulink model has been presented and simulation results have been shown. Figure 6 shows that high power can be generated. Thus as per the analysis of the first model (figure.2), detailed experimental simulation measurement results has been presented. Thus, the analysis of input power, output power transmission and efficiency has been analyzed with respect to the distance (figure.6 and figure.7). Here, the transmission takes place using inductive coils and thus represents the RF range power transmission. Almost 70% efficiency has been achieved for shorter distances. However, medium power range transmission has been tested. Microwave power transmission model (figure 4) also has been presented where efficiency of 92.11% has been achieved in proposed model. The model included the microwave waveguide components that make it feasible for very high range power transmission at very high frequency without requirement of the bulky components.

10. REFERENCES

[1] R. Sato, "EMC – The past, present and future," in Proc. Int. Symp. on Electromagn. Compat., Nagoya, Japan, Sept. 1989, pp. 1-9.
[2] C. R. Paul, "Introduction to Electromagnetic Compatibility," New York: Wiley-Intersciences, 1992, pp. 402-428.
[3] J. Wang, K. Sasabe, and O. Fujiwara, "A simple method for predicting common-mode radiation from a cable attached to a conducting enclosure," IEICE Trans. Commun., vol. E85-B, no. 7, pp.1360-1367, July2002.
[4] Nikola Tesla, My Inventions, Ben Johnston, Ed., Austin, Hart Brothers, p. 91,1982.
[5] Nikola Tesla, "The Transmission of Electrical Energy Without Wires as a Means for Furthering Peace," Electrical World and Engineer. Jan. 7, p. 21, 1905.
[6] The Electrician (London), 1904).
[7] W.C. Brown, J.R. Mims and N.I. Heenan, "An Experimental Microwave-Powered Helicopter", 965 IEEE International Convention Record, Vol. 13, Part 5, pp.225-235.
[8] J.C. Lin, "Biological aspects of mobile communication fields," Wireless Networks, vol. 3, pp. 439-453, 1997.
[9] Syed Khalid Rahman, Omar Ahmed, Md. Saiful Islam, A. H. M. Rafiul Awal," Design and construction of wireless power transfer system using magnetic resonant coupling", American Journal of Electromagnetics and Applications 2014; 2(2): 11-15 (http://www.sciencepublishinggroup.com/j/ajea)
[10] P. Koert and J.T. Cha, "35 GHz rectenna development," in Proc.1st Annu. Wireless Power Transmission Conf., San Antonio, TX, 1993, pp. 457-466.
[11] T.-W. Yoo, "Experimental and theoretical study on 35 GHz RF-to-DC power conversion receiver for millimeter-wave beamed power transmission," Ph.D. dissertation, Dept. of Electrical Engineering, Texas A&M Univ., Dec. 1993