Energy Harvesting System Using Wi-Fi Signal

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Abstract—Radio wave exists everywhere in the form of signals transmitted from TV, Radio, Wireless LAN, Mobile phone etc. A technology of capturing and storing the energy from the radio wave sources is Energy Harvesting. RF energy is harvested by capturing radiated energy at the desired frequency and converted into DC voltage in usable form. The range at which the energy radiated from wireless sources is around(10-100) Mw but the receivers utilizes only a small amount of energy, rest is dissipated as heat or absorbed by other materials. Electricity can be generated from the wasted energy that has been harvested.An experimental RF energy harvesting system from Wi-Fi hotspots 2.4 GHz is to be presented.

Keywords—Schottky Diodes, Dickson Charge Pump, E-Shaped Microstrip Patch Antenna.

I. INTRODUCTION

Life has become impossible without electricity. The demand for electricity has been very high nowadays and hence the generation of electricity by usual means is not sufficient. On the other hand, the deposition of battery causes environmental pollution. Finite battery life has encouraged companies and researches to come up with new ideas and technologies to drive wireless mobile devices for an infinite or enhanced period of time. A technology of deriving the energy from external ambient sources and then it is captured and stored is known as Energy Harvesting.

RF energy harvesting requires capturing of energy at the desired frequencies and converting that energy into DC voltage. Energy harvesters take fuel from enormous sources around us and hence are free for the user. The various available sources are wind, solar, thermoelectric, vibration, electromagnetic, temperature gradient radio frequency, acoustic etc. Energy harvesting using Electromagnetic energy presents an enhancing future in low power electronics and wireless networks. The energy transmitted from these wireless sources is very high in the range of (kW) but the receivers take in only a small amount of this energy and the rest is dissipated as heat or absorbed by other materials or eliminated by any other means. The energy that is wasted this way can be harvested to generate electricity. The block diagram for energy harvesting system is shown in Fig.1.

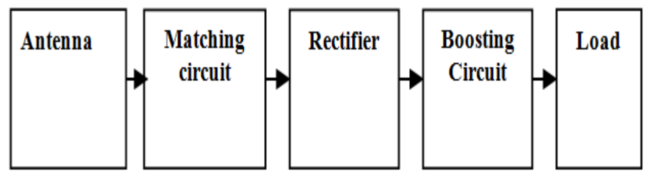

Fig. 1. Block Diagram

The significant element of an energy harvesting system is rectenna, which is a combination of an antenna and a rectifier. The antenna receives the RF power, and the rectifier converts it into dc power. In this project the RF signals are Wi-Fi 2.4-2.5 GHz range, so it demands dual-band antenna. The received ambient RF power level is normally in nW range or in a range to increase the power. Therefore an array of dual-band antenna is needed. The received RF power is converted into dc power by a rectifier circuit.

Villard Voltage Multipliers are used to convert the high frequency AC signal into DC signal. The received RF power is very low and the signal frequency is high so the diodes are required to have a very low turn ON Voltage and it should have a very high operating frequency. When compared to other diodes Schottky diodes have very high switching speed and low forward voltage which makes them efficient. At high frequencies the low value inductors are too difficult to construct but using an inductor along with capacitor at integrated circuit level highly improves the performance. Matching Circuit is required for matching the impedance of dual-band antenna array and the impedance of the rectifier circuit. Load may be any wireless sensor modes which consume dozens microwave in sleep mode and hundreds microwave in active mode and also we can use load as lowest power Microcontroller.

II. E-SHAPED PATCH ANTENNA

A. Antenna Selection

There is always been a great demand to have small size, low cost, and compact wireless systems.A small size antenna was highly preferred because the size of communication devices was decreased. The antenna should be designed in planar form to match with the rapid developments in wireless communication applications. A serious limitation of these microstrip patch antennas is Narrow Bandwidth. The other drawbacks include low power handling capability, loss, half plane radiation and limitation on the maximum gain. Different techniques are implemented to overcome this narrow bandwidth limitation. These techniques include increasing the thickness of the dielectric substrate, decreasing dielectric constant and using parasitic patches. However, research is still going today to overcome some of the above disadvantages. This paper, introduces an analysis and designing of E-shape microstrip patch antenna with slots for wireless communication applications.

B. Antenna Design and Structure

E-shape microstrip patch antenna has been designed with dimensions W(mm) x L(mm). E-shaped microstrip patch antenna with slots has been designed with the resonant frequency fr = 2.4GHz and the dielectric substrate glass epoxy is used for fabrication. The dielectric constant of the substrate is ε_r = 4.6 and thickness of the substrate is h = 1.6 mm to design the E-shaped microstrip patch antenna with slots.

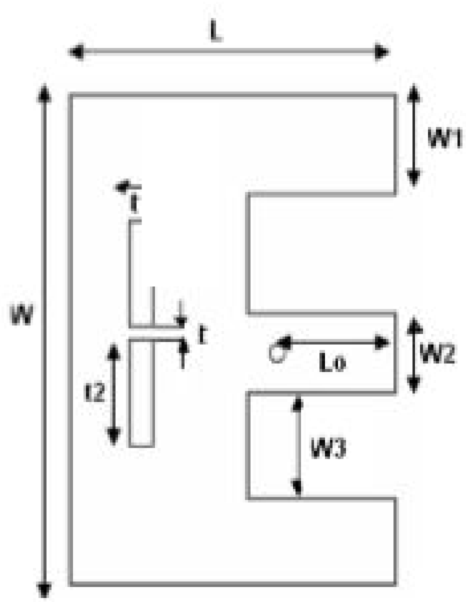

Fig. 2.E-Shaped Patch Antenna

Length (l)	27.5 mm
Width (w)	37 mm
Height (h)	1.59 mm
W1	7.5 mm
W2	6mm
W3	7.5 mm
L	12 mm
S1	8 mm
S2	8 mm

Table 1. Specification

Based on the given parameters an E Shaped microstrip patch antenna was designed with a better performance at the desired center frequency of 2.4 GHz using Micro strip Asymmetric Coupled Lines. The patch conductor is of copper developed on a FR4 substrate. The important specifications chosen in simulation for this design are: thickness of substrate 1.6 mm, thickness of copper 1.377 mm, relative permittivity 4.6, and loss tangent 0. Return Loss is defined as the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line or optical fiber. This discontinuity can be either a mismatch with the terminating load or with a device inserted in the line.

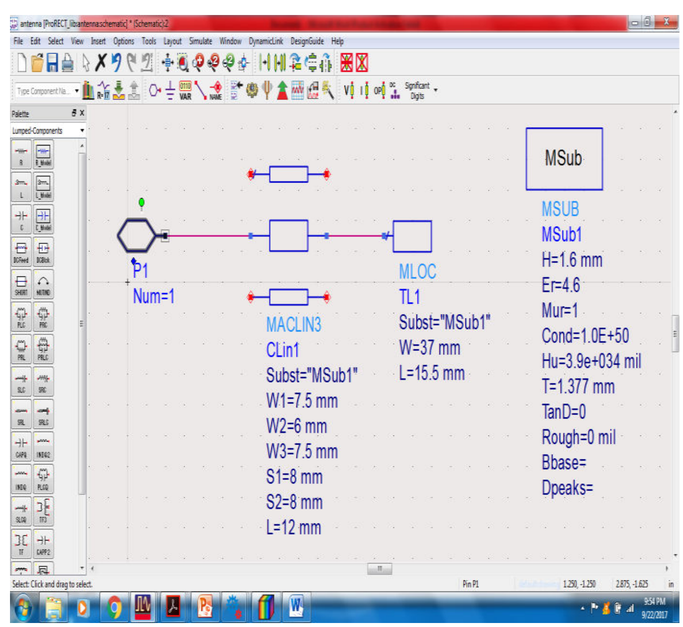

Fig. 3. Antenna Schematic

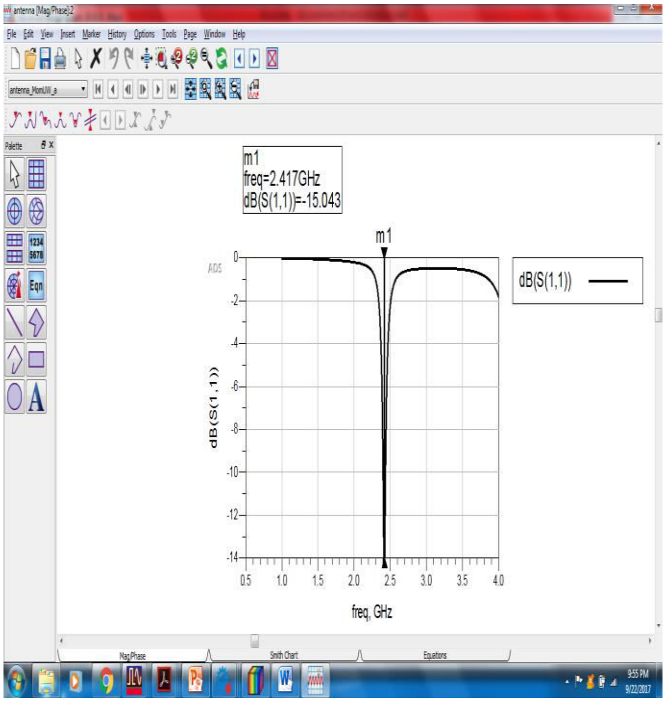

Fig .4. Return Loss

Firstly, the Return Loss (-15.043 dB), Bandwidth (80MHz) and VSWR (1.43) at operating Frequency 2.4 GHz for the E-shaped Microstrip Antenna with Slots using Advanced Design System(ADS) Software.

III. IMPEDENCE MATCHING

A matching circuit is required to transmit the power from the source (antenna) to the load (rectifier) completely without any return loss. With the help of ADS 2009, Smith chart is employed to design the matching circuit with the transmission line values generated by the software itself.

A) You can choose any from three different passive components, each could be set in series or in parallel (shunt) with the matching network, so six different setups can be framed.

a) Series resistor
Along the Z-segments, bigger value moves the current point to the right.

b) Shunt resistor
Along the Y-segments, bigger value moves the current point to the left.

c) Series capacitor
Along the Z-circle, smaller value moves the current point counter-clockwise.

d) Shunt capacitor
Along the Y-circle,bigger value moves the current point clockwise.

e) Series inductor
Along the Z-circle,bigger value moves the current point clockwise.

f) Shunt inductor
Along the Y-circle, smaller value moves the current point counter-clockwise.

B) DC blocking capacitor is preferred to be big because bigger the series capacitor, the less impact it has on the S-parameters. If you use a choke, the bigger inductor value that is in parallel would have less impact on the S-parameters and matching.Resistors are frequency independent, while capacitors and inductors are frequency dependent.

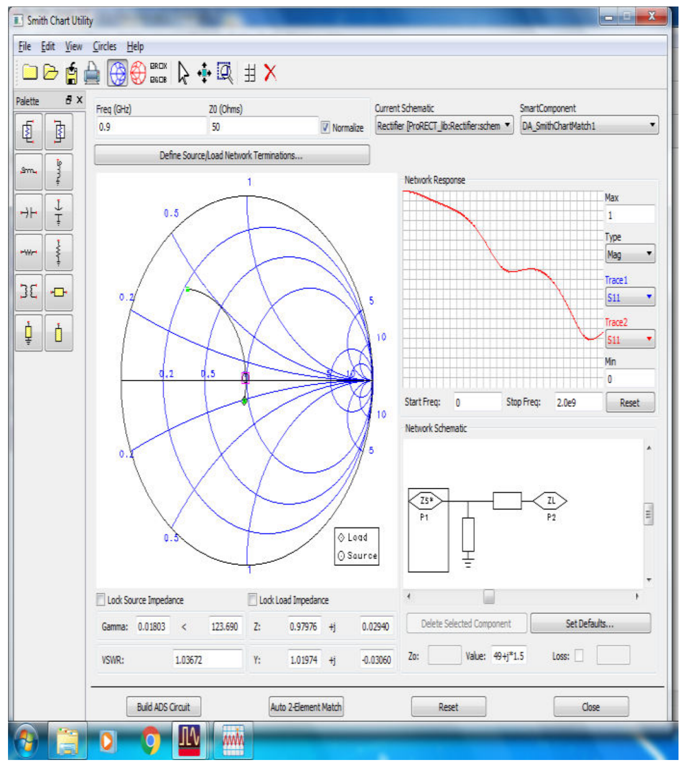

Fig .5.Smith Chart Setup

IV. RECTIFIER CIRCUIT

The design used in this paper for the energy conversion module is derived from the function of peak detector. The multiplier circuit used here contains several stages of voltage doublers that can be used for the generation of DC voltage. The Villard voltage multiplier circuit was chosen due to its capability to produce two times of the input signal voltage towards ground at a single output and can be cascaded to form a voltage multiplier with arbitrary output voltage and its design simplicity.

A. Diode Modeling

The voltage multiplier circuit was designed using zero bias Schottky diode HSMS-2850. This diode has been modeled for the energy harvesting circuit which comes in a one-diode configuration. The special features of HSMS-2850 diode is that, it provides a low forward voltage, low substrate leakage and uses the non-symmetric properties of a diode that allows unidirectional flow of current under ideal conditions. The diodes are fixed and are not subjected to optimization or tuning.

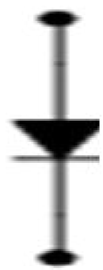

Fig.6.Schottk Diode

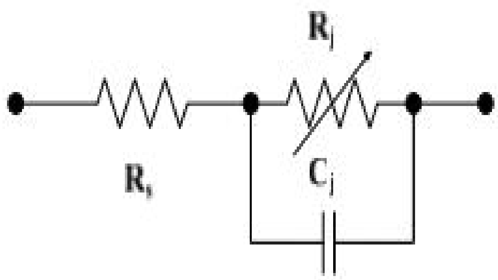

Fig. 7. Linear Circuit Model of Diode

B. Single Stage Voltage Multiplier

The circuit shown in fig.8 is also called as a voltage doublers because in theory, the voltage that is arrived at the output is approximately twice that of the input. The circuit consists of two sections; each comprises a diode and a capacitor for rectification. The RF input signal is rectified in the positive half of the input cycle, followed by the negative half of the input cycle. But, the voltage stored on the input capacitor during one half cycles is transferred to the output capacitor during the next half cycle. Thus, the voltage on output capacitor is two times the peak voltage minus the turn-on voltage of the diode.

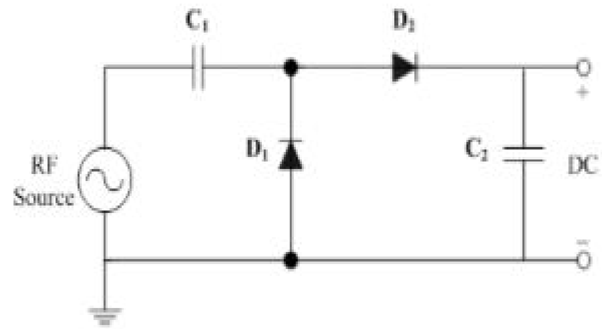

Fig. 8.Single Stage Voltage Multiplier Circuit

The most interesting feature of the single stage voltage multiplier circuit is that when these stages are connected in series. This is similar to that of stacking batteries that is in series to get more voltage at the output. The output of the first stage is not a pure DC voltage and it is basically an AC signal with a DC offset voltage. This is equivalent to a DC signal superimposed by ripple content. Due to this distinctive feature, succeeding stages in the circuit can get more voltage than the preceding stages. If a second stage is added in series to the first stage of multiplier circuit, the only waveform that the second stage receives is the noise of the first stage. This noise is then doubled and added to the DC voltage of the first stage.Therefore, the addition of the stages in the multiplier circuit theoretically increases the output voltage regardless of the input signal level. Each independent stage with its dedicated voltage doubler circuit can be seen as a single battery with open circuit output voltage V_0, internal resistance R_0. Assuming load resistance as R_L, the output voltage, V_{out} is expressed as

$$V_{out} = \frac{V_0}{R_0 + R_L} R_L$$

When n number of these circuits are put in series and connected to a load of R_L,then the output voltage V_{out} obtained is given by

$$V_{out} = \frac{nV_0}{nR_0 + R_L}$$

$$= V_0 \frac{1}{\frac{R_0}{R_L} + \frac{1}{n}}$$

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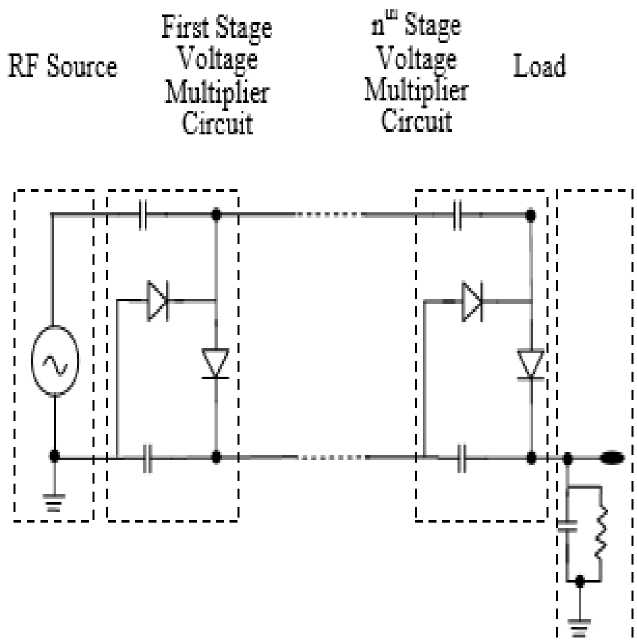

Fig. 9. N- Stage Voltage Multiplier Circuit

The circuit design uses a capacitor across the load resistor to store and it provides DC leveling of the output voltage. The value of this capacitor affects the speed of the transient response. The output is not a good without the capacitor, but more of an offset AC signal. An equivalent load resistor is connected across the final DC output voltage. Without this load resistor on the circuit, the voltage would be hold indefinitely on the capacitor and look like a DC signal, assuming ideal components. In the design, the individual components of the stages need not to be rated to withstand the entire output voltage. Each component only needs to be concerned with the relative voltage differences directly across its own terminals and of the components immediately adjacent to it. In this type of circuitry, the circuit does not change the output voltage but increases the possible output current by a factor of two. The number of stages in the system is directly proportional to the amount of voltage obtained and has the greatest effect on the output voltage as explained in the above equation.

AC input: z=1.5+j*4 Freq= 2.4 GHz P_{ac}= 7.5 Mw	**Passive components** c1= 100 pF c2= 0.002 pF R= 100 kΩ

Table 2: Specification

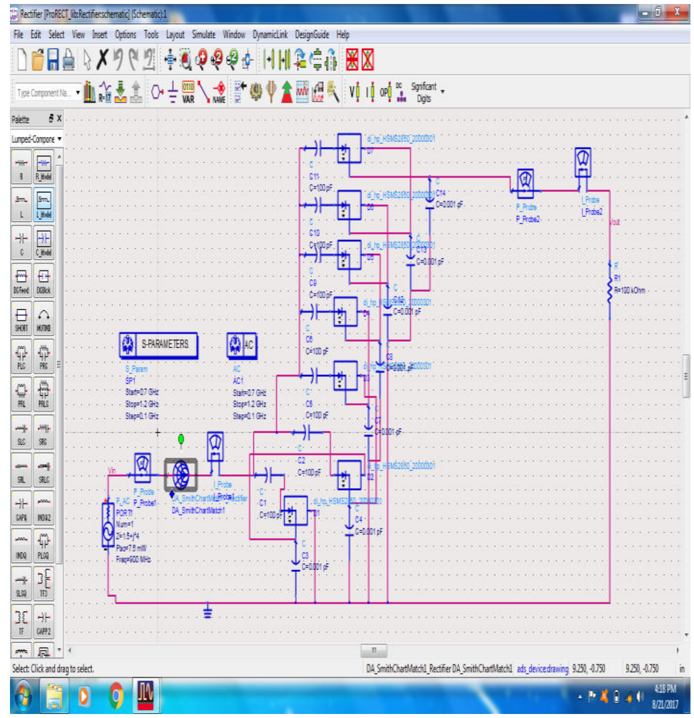

Fig. 10. Rectifier Schematic

The output obtained from the rectifier for the range 1-2.5 GHz has been tabulated below with voltage input and voltage output obtained along with the power obtained at the output. Since the obtained output DC voltage is very low it is boosted for practical application purpose using Dickson charge pump.

V. BOOSTING CIRCUIT

The Dickson charge pump, or Dickson multiplier, is a modification of the Greinacher /Cockcroft–Walton multiplier. Unlike that circuit, however, the Dickson multiplier takes a DC voltage supply as its input so is a form of DC-to-DC converter. The Dickson multiplier is intended for low-voltage purposes. The circuit requires a feed of two clock pulse trains with amplitude swinging between the DC supply rails.

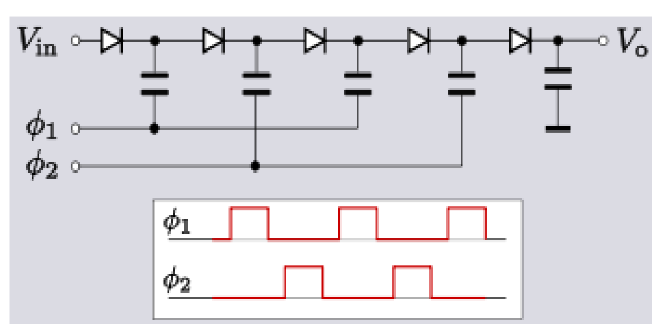

Fig.11. Dickson Charge Pump (4 stages : 5×multiplier)

When the clock $\varnothing_1$ is low, D1 will charge C1 to V_{in}. When $\varnothing_1$ goes high the top plate of C1 is pushed up to $2V_{in}$. D1 is then turned OFF and D2 turned ON and C2 begins to charge to $2V_{in}$. On the next clock cycle $\varnothing_1$ again goes low and now $\varnothing_2$ goes high pushing the top plate of C2 to $3V_{in}$. D2 switches off and D3 switches on, charging C3 to $3V_{in}$ and so on with charge passing up the chain, hence the name charge pump. The final diode-capacitor cell in the cascade is connected to ground rather than a clock phase and hence is not a multiplier; it is a peak detector which merely provides smoothing.

There are a number of factors which reduces the output from the ideal case of nV_{in}. One of these is the threshold voltage, V_T of the switching device, that is, the voltage required to turn it ON. The output will be reduced by nV_T due to the voltage drops across the switches. Schottky diodes are used in Dickson multipliers for their low forward voltage drop. Another limitation is that there are parasitic capacitances to ground at each node. These parasitic capacitances act as voltage dividers with the circuit's storage capacitors reducing the output voltage still further. Up to a point, a higher clock frequency is required the ripple is reduced and the high frequency ripples out the remaining frequency. Also the size of capacitors needed is reduced much since less charge has to be stored per cycle. However, losses through stray capacitance increase with increasing clock frequency. Consequently, the diodes in the Dickson multiplier are replaced with MOSFETs wired to behave as diodes.

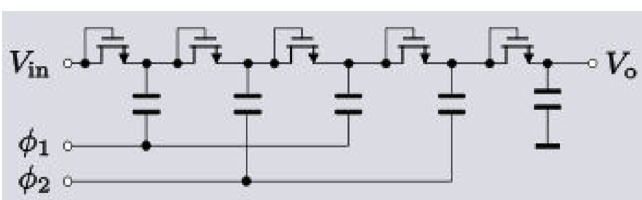

Fig .12.Dickson Charge Pump Using Diode-Wired Mosfets (4 Stages : 5×Multiplier)

An ideal 4-stage Dickson multiplier (5× multiplier) with an input of 1.5 V would get an output of 7.5 V. However, a diode-wired MOSFET 4-stage multiplier might only get an output of 2 V.

VI. CONCLUSION

RF energy harvesting has potential to charge low power electronic devices and source of RF energy is freely available from space at ambient. The proposed system complements the currently used low power sources. A rectenna is designed and simulated for RF energy harvesting using Advanced Design System Software. Here the Energy harvesting circuit is designed for the dominant RF Signal of Wi-Fi 2.4 GHz. An E-Shape microstrip antenna is designed at 2.4 GHz frequency. The minimum return loss of -15 dB is obtained near 2.4 to 2.5 GHz. By using the S Parameter the input impedance of the rectifier is matched with the rectifier feed impedance. A seven stage voltage multiplier circuit is designed and simulated using ADS Software. The output voltage of 1.2 volts is obtained for the input voltage of 0.2 volts. Also the output current of 25µA is. A Transmission Line matching circuit for matching the antenna impedance with the rectifier impedance is studied by using smith chart in the ADS Software.

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