Project: Electromagnetic Ring Launcher

Introduction:

In science museums and physics-classrooms an experiment is very commonly demonstrated called the "Jumping Ring" or "Electromagnetic Ring Launcher". The test involves a several centimeters long cylindrical iron core inserted in a large solenoid, a copper ring runs through the extended iron core. When the solenoid is powered by the AC mains, the ring jumps out of the core. There are various reasons for the experiment being so popular and so significant in science and engineering. Firstly, it is interesting to observe a metal ring jumps out or hover. Secondly, It utilizes Faraday's law of induction, Lenz's law, mutual induction and forces due to electromagnetic induction to make it possible for the ring to hover or jump. The main problem with this type of conventional ring launcher is its bulky size and weight, as it requires a large number of turns of thick copper wire for the solenoid and heavy iron core inside. Furthermore, as it operates at the line voltage (115V or 230 V, AC), it is not safe to operate. Calculations show that the launching of the ring is many times more efficient at frequencies several times higher than that of the AC mains (50/60Hz). In this project I used a square wave generator of adjustable frequency from 700 Hz to 18 kHz employing a 555 timer IC; the output of which drives a power MOSFET. The MOSFET drives a small coil of ~50 – 60 turns wound on a 10 cm long ferrite cylinder instead of an iron core. A copper ring is placed through the extended part of the ferrite cylinder. A 16μF capacitor is placed in parallel with the coil to achieve parallel resonance. At resonance the current through the coil can be achieved several times higher than that is supplied by the power source. Using a thick copper wire (AWG #14) for making the coil, the coil-resistance is lowered, which makes the quality factor (Q) of the coil high. High Q of the coil maintains nearly ~ 8 times higher current than the power supply can provide. The high primary current is essential to induce high current in the coper ring, the interacting field makes the ring levitate. The circuit needs only 24V DC do levitate, hover and shoot the ring. A 10 Ohm resistor is used in series with the 24V power supply, as the frequency of the oscillator is slowly increased, supply current goes down gradually. At resonant frequency supply current reaches to minimum, (~1.2 A), and also at this point the copper ring levitates and hover midway on the extended ferrite rod. Another switch is used to short the 10 Ohm resistor, when it is shorted, the ring jumps few centimeters out of the rod. Now, keeping the 10 Ohm resistor shorted, if the power supply is turned ON, the ring jumps tens of centimeters above the rod. The video shows these effects.

Video: https://youtu.be/fskS_bFsXeM

The circuit:

The circuit consists of a square wave oscillator implemented by a 555 timer IC, a power MOSFET and a MOSFET driver circuit. The circuit needs two power supplies, a 15V supply to deliver power to the oscillator and MOSFET driver Circuit and a 24V, 4A supply is powering up the coil.

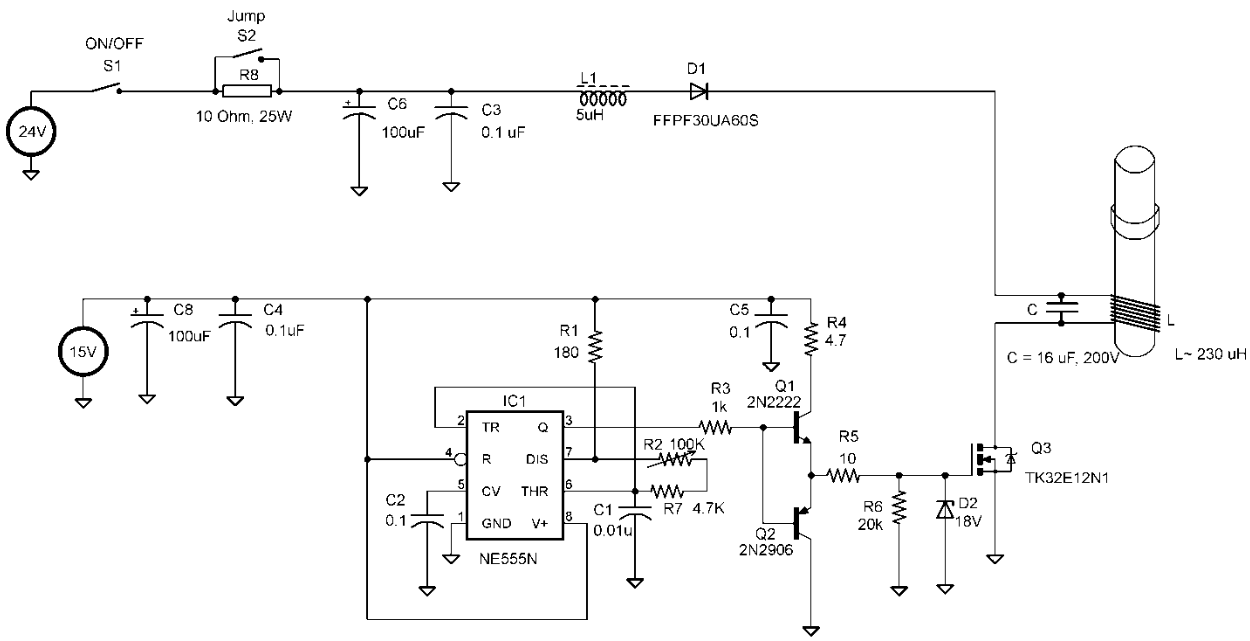

Fig.1. Circuit diagram of the ring launcher

To achieve near-50% duty cycle resistor R1 is chosen 180 Ohm, which is a much smaller value compared to R2+R7 (minimum~4.7k). By varying R2 from 100K to 0 Ohm, square wave output is obtained from 700Hz to 18 kHz. This square wave output at pin-3 of 555 timer IC should not be used directly to drive the MOSFET (Q3), for the gate capacitance. A MOSFET driver is implemented using two transistors, Q1 and Q2. To limit the initial high gate current, R5 is used. A high power and high current MOSFET (Q3) is used to drive the coil-capacitor combination. A fast recovery diode, D1 is used to leave the LC circuit to run free during the OFF time of the MOSFET. An inductor of 5 micro Henry (L1) is used to limit the initial high current, when the MOSFET is switched ON. When the MOSFET is ON energy is delivered to the LC circuit, when the MOSFET is OFF, the stored energy in the capacitor C and coil L begins to flow within L and C. When the switching frequency of the MOSFET matches the resonance frequency of the LC circuit, minimum energy is used by the LC circuit. In this situation, though low current is drawn from the supply, much higher current flows in the LC circuit. This high current creates intense magnetic field in the ferrite core. The copper ring which runs through the core, acts as a single turn coil of low resistance. The alternating magnetic field in the ferrite core induces a voltage in the copper ring, thereby high current flow through the ring as well. These two interacting field forces the ring jump out of the core.

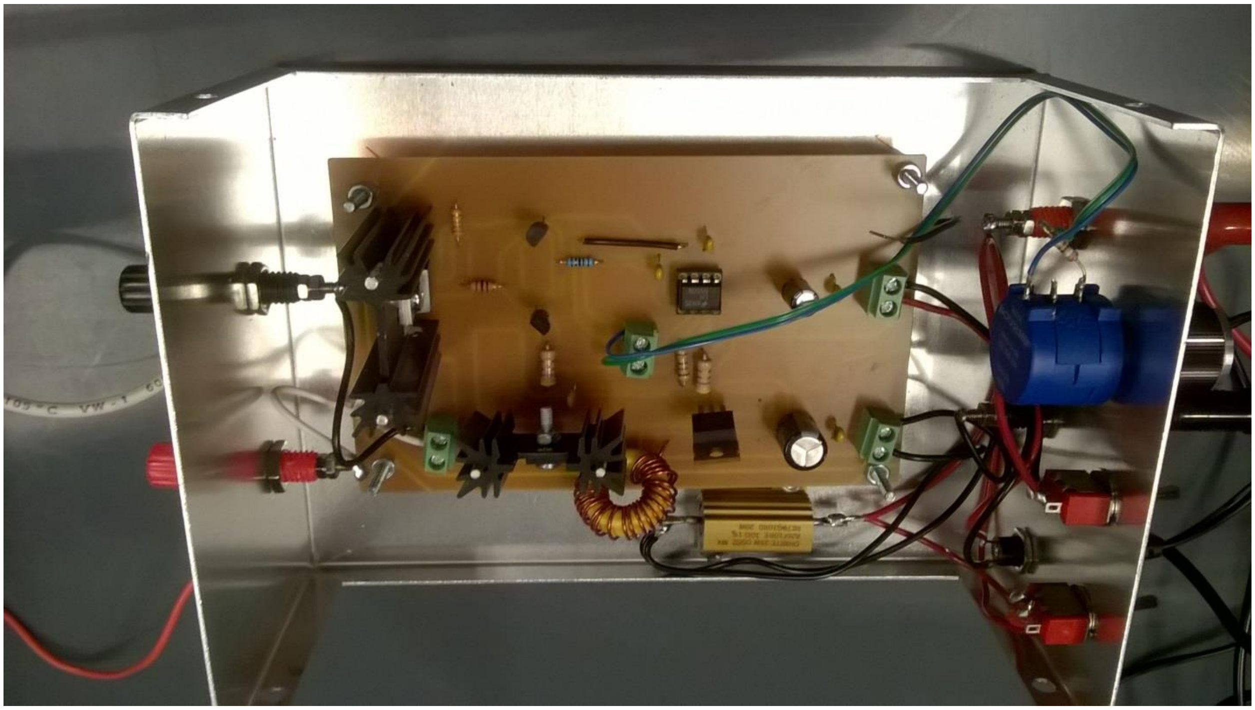

Fig.2. Circuit-PCB inside enclouse

Fig.3. Front panel

The Coil:

Diameter (coil former): 26 mm, length: 16 mm, number of turns, N: 50 ~ 60, wire size: # 14 AWG. Ferrite cylinder of diameter ~16 mm was inserted through the coil (two cylindrical ferrite rods were attached using nylon screws and stand-offs). Measured inductance is ~ 110 μH (~235 μH, with the ferrite core inside). Measured resistance ~ 0.1Ω, with C = 16 μF measured resonant frequency, *fr* ~ 2.6 kHz

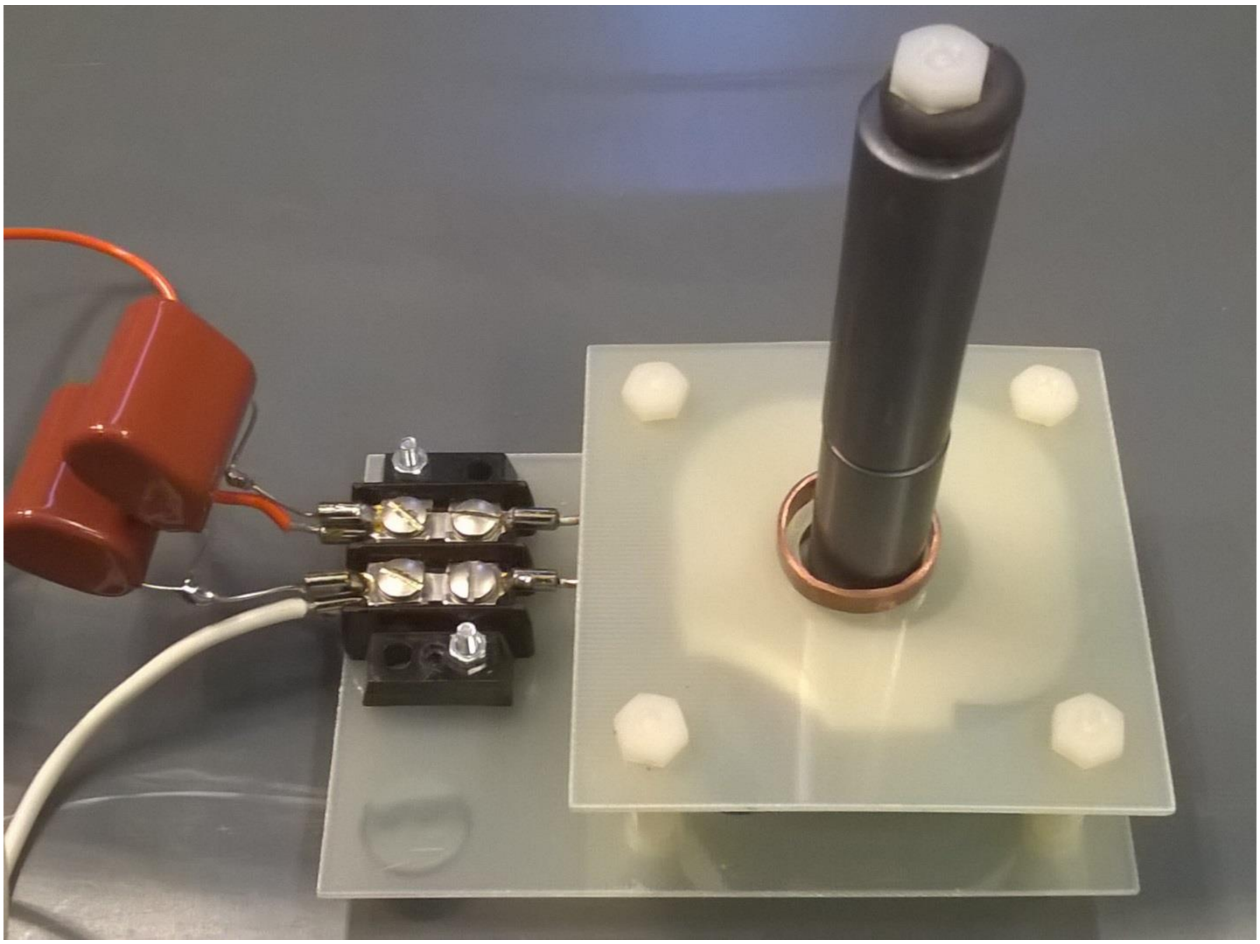

Fig.4. Coil with 16 micro Farad capacitor in parallel

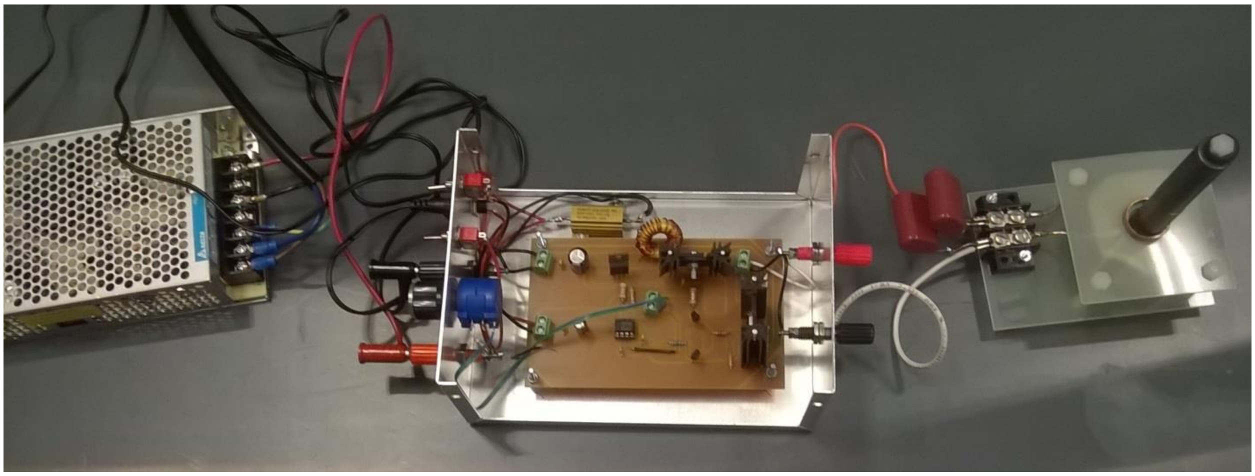

Fig.5. Photograph of the complete system

Test Procedure:

To set the condition for optimum operation, the coil-Capacitor circuit should be set at resonance. Without using any expensive equipment, we can easily make sure of this condition following the block schematic as shown in Fig-6.

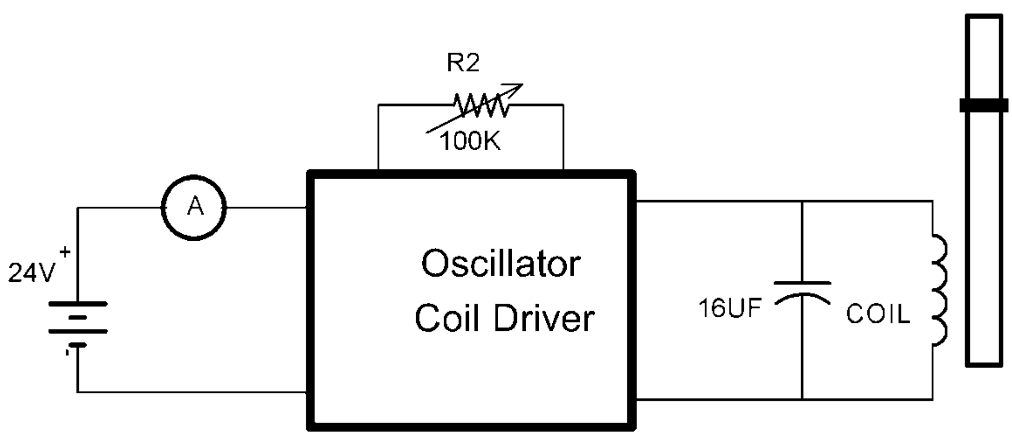

Fig.6. Setup for resonance

Before connecting the 24V supply we have to make sure that the 10 Ohm resistor-shunt-switch (S2) is open. Now connecting the 24V supply is connected to an Ammeter in series with the circuit and the tuning resistor R2 is slowly turned from high to low, which causes frequency to go from low to high. As the frequency goes up the current goes down and we can see the ring starts to levitate. At resonance, the current goes to the minimum at ~ 1.2 A. At the resonance, the copper ring levitates ~2 cm above the coil. Now if the 10 Ohm resistor is shorted by closing S2, the ring jumps out of the ferrite rod. Keeping the switch S2 closed, if power switch S1 is turned ON from OFF, the ring jumps tens of centimeter above the rod. All of this tests are shown in the video. The circuit can be even run at voltages higher than 24V. If driven 48V, even much higher jump is seen.

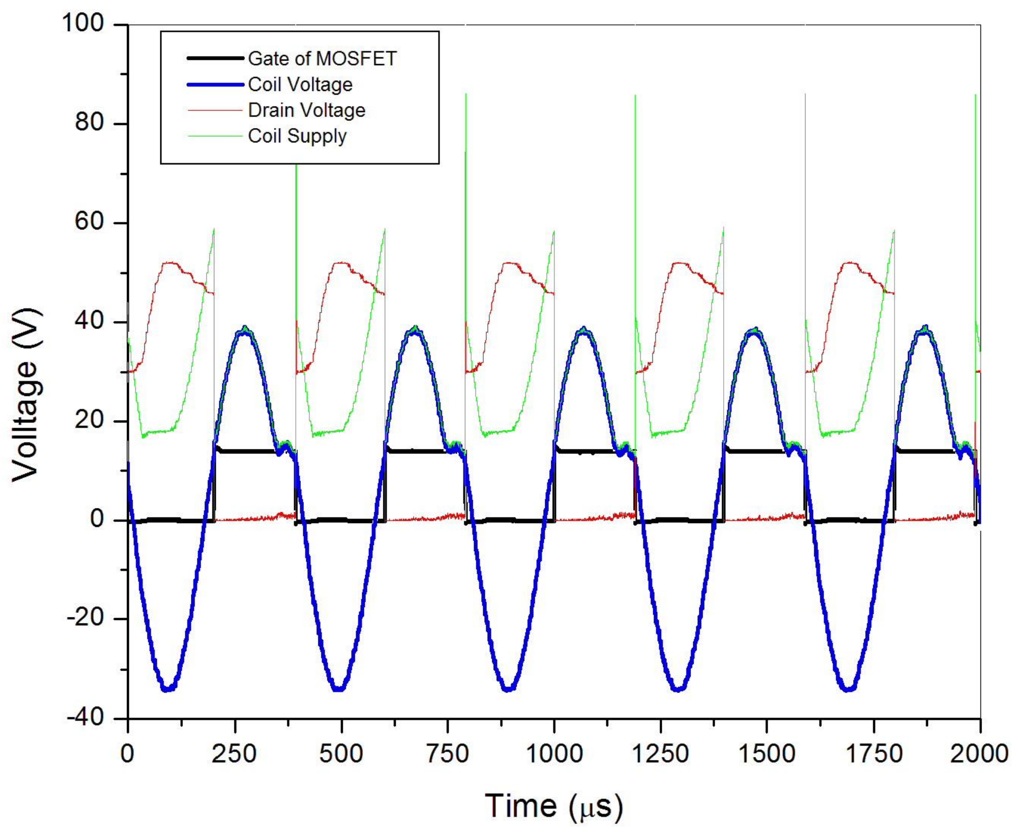

Fig.7. Waveform at the MOSFET Gate, Drain, Coil-high side and across coil

Bill of Materials (BOM):

Part	Value	Description
C1	0.01u	Ceramic Capacitor
C2	0.1 uF	Ceramic Capacitor
C3	0.1 uF	Ceramic Capacitor
C4	0.1uF	Ceramic Capacitor
C5	0.1 uF	Ceramic Capacitor
C6	100uF	polarized capacitor
C8	100uF	polarized capacitor
D1	FFPF30UA60S	Fast RecoveryDiode
D2	18V	Zener Diode
IC1	NE555N	Timer IC
L1	5uH	Inductor
Q1	2N2222	NPN transistor
Q2	2N2906	PNP transistor
Q3	TK32E12N1	Power MOSFET
R1	180 Ohm	Resistor,
R2	100K	Resistor
R3	1k	Resistor
R4	4.7 Ohm	Resistor
R5	10 Ohm	Resistor
R6	20k	Resistor
R7	4.7K	Resistor
R8	10 Ohm, 25W	Power Resistor
C	16 uF, 200V	Ceramic Capacitor
L	~238 uH	Coil with ferrite core