Design of Power Electronic Converters
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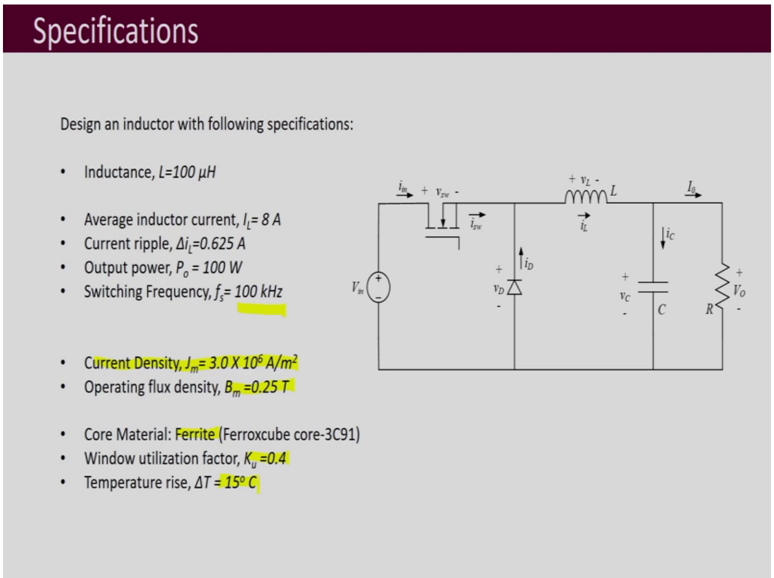
Lecture: 52
Inductor Design Example

Welcome back to the course on Design of Power Electronic Converters. We were discussing magnetics design and we saw how we can design inductors.

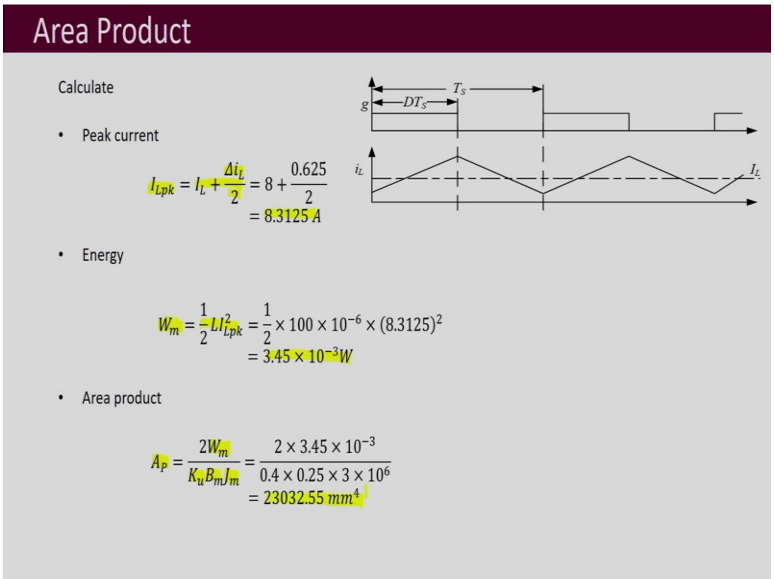


Now, let us take an example of inductor design. So, we need to design an inductor for a buck converter. Let us say that we have to design the inductance for *100 µH*. The average inductor current for that particular converter is *8 A* and the ripple allowed is *0.625 A*. Output power that means, the total output power here is *100 W* and the switching frequency chosen is *100 kHz*.

Then for design of the inductor the current density is chosen as $3*10^6\ A/m^2$ and the operating flux density is chosen as *0.25 T* and for the design we choose ferrite core and that is reasonable because for this frequency range ferrite is very suitable.

So, that material is chosen and window utilization factor of *0.4* is taken and further the specification is chosen such that the temperature rises up to *15°C*. So, whatever we design, it should be such that the temperature rise is below *15°C*. So, here

$L=100\ \mu H$, $I_L= 8\ A$, $\Delta i_L=0.625\ A$, $P_o = 100\ W$, $f_s= 100\ kHz$, $J_m= 3.0\ X\ 10^6\ A/m^2$, $B_m =0.25\ T$, $K_u =0.4$, $\Delta T = 15^o\ C$.



So, what do we do? We first calculate the area product and for that what we have to do? We have to first calculate the peak current. So, you know the equation to calculate the peak current. So, you substitute here and you obtain that this is the value of the peak current.

$$I_{Lpk} = I_L + \frac{\Delta i_L}{2} = 8 + \frac{0.625}{2}$$

$$= 8.3125\,A$$

Then we calculate the energy. So, energy will be

$$W_m = \frac{1}{2} L I_{Lpk}^2 = \frac{1}{2} \times 100 \times 10^{-6} \times (8.3125)^2$$

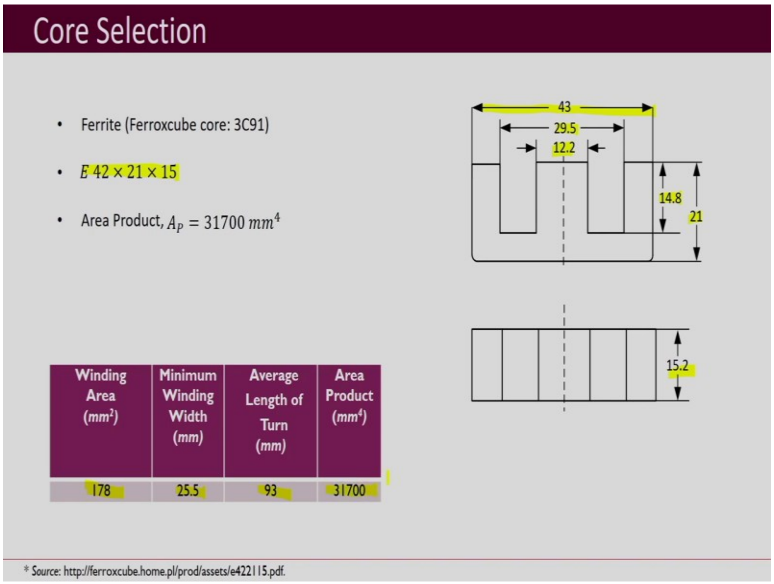
$$= 3.45 \times 10^{-3} W$$

Then, now, we have everything for the area product. So, we know this energy and we know K_u, B_m and J_m. So, this is the area product that we are going to obtain.

$$A_P = \frac{2W_m}{K_u B_m J_m} = \frac{2 \times 3.45 \times 10^{-3}}{0.4 \times 0.25 \times 3 \times 10^6}$$

$$= 23032.55\, mm^4$$

Now, after obtaining the area product, you can google. You can find out the various cores that are available. What are the area products of them? You have to choose a core which has an area product with somewhat greater than the calculation.

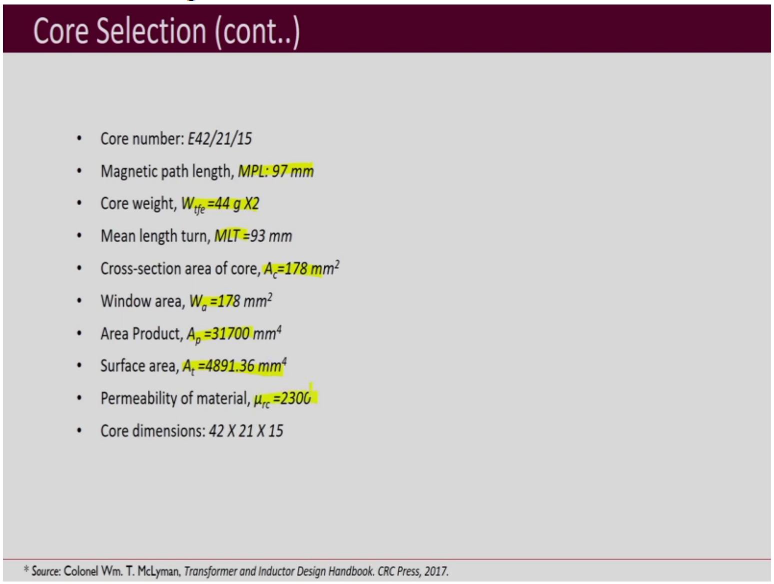


So, we have done that and we came up with this *E 42* core. Core selection and the dimensions of that core are shown here.

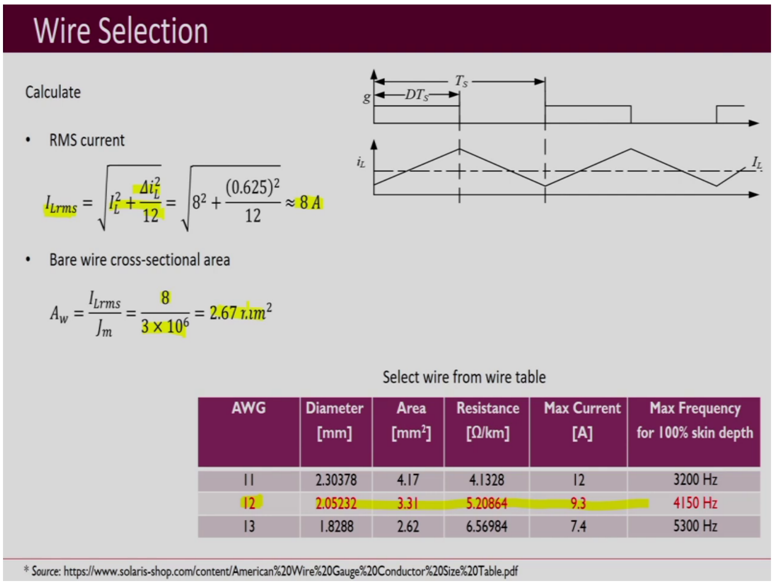
$$E\ 42 \times 21 \times 15$$

So, you can see here these dimensions. This is the width of the central limb. So, all these various dimensions are shown here. What is the winding area in mm^2, minimum winding width, average length of the turn and area product? All are given here for this chosen core.

$$A_P = 31700\ mm^4$$



Further, all the other parameters related to the core are noted down. Those are the magnetic path length, the core weight and, then mean length turn, further the cross-sectional area of the core, the window area, area product, the surface area (A_t), and the permeability of the material and also the core dimensions.



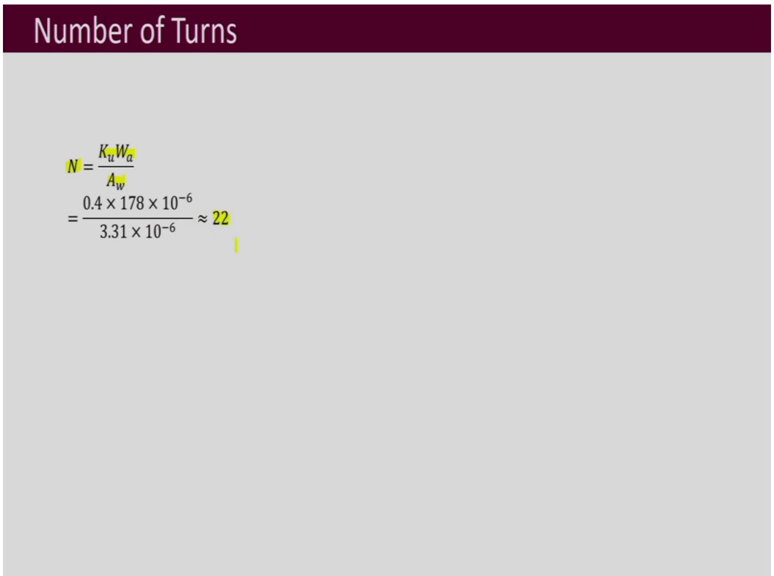
Then next step is to do calculations for the wire selection. So, for that you have to calculate the RMS of the current. So, that has been done here using this equation and approximately *8 A* is again obtained. So, if the ripple is small, RMS current is going to be close to the average current.

$$I_{Lrms} = \sqrt{I_L^2 + \frac{\Delta i_L^2}{12}} = \sqrt{8^2 + \frac{(0.625)^2}{12}} \approx 8\,A$$

So, then we divide that RMS current with the current density.

$$A_w = \frac{I_{Lrms}}{J_m} = \frac{8}{3\times10^6} = 2.67\,mm^2$$

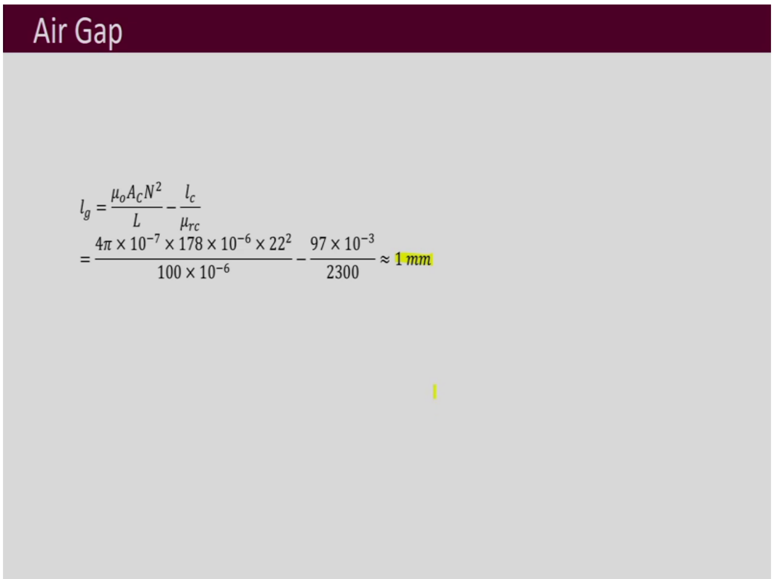
So, you obtain the gauge of the wire, the cross-sectional area of the wire and from there you obtain that *12 AWG* is going to be suitable because that has a cross-sectional area which is slightly greater than this $2.67\ mm^2$ that we are obtaining from the calculations.



Further, you calculate the number of turns. So, the equation is here. We substitute everything and we see that

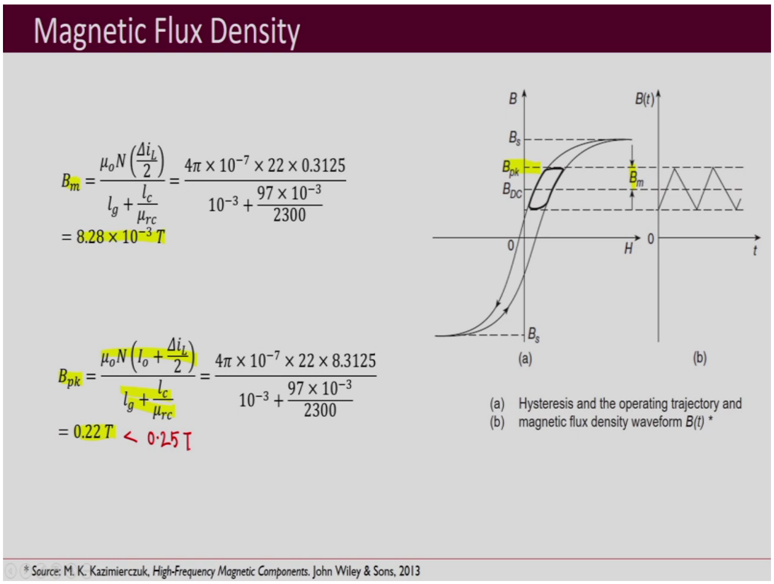
$$N = \frac{K_u W_a}{A_w} = \frac{0.4 \times 178 \times 10^{-6}}{3.31 \times 10^{-6}} \approx 22$$

Now, this may be coming in fraction which you may be getting. You have to approximate it.



Then for the air gap again you have the equation for calculating this, you substitute all the values there in the air gap and you obtain that.

$$l_g = \frac{\mu_0 A_C N^2}{L} - \frac{l_c}{\mu_{rc}} = \frac{4\pi \times 10^{-7} \times 178 \times 10^{-6} \times 22^2}{100 \times 10^{-6}} - \frac{97 \times 10^{-3}}{2300} \approx 1\ mm$$



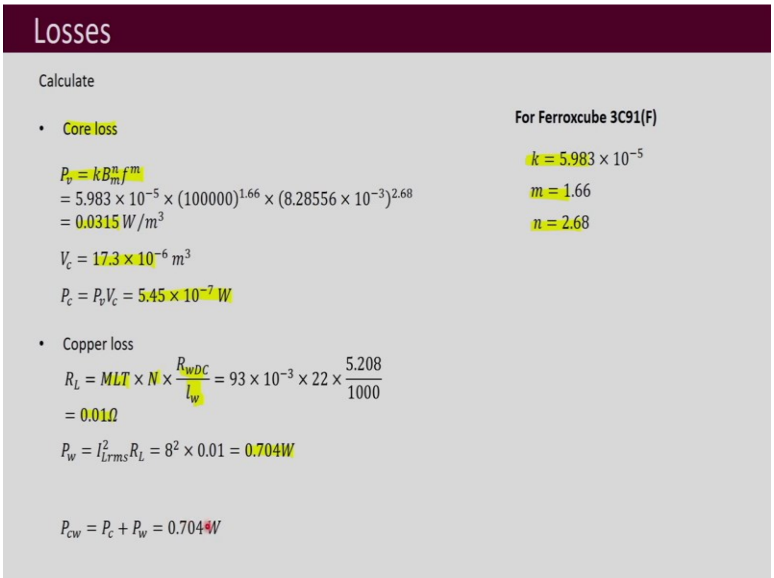
Now, let us do some checking whatever we have designed. We obtain the air gap length, we obtained the number of turns, the gauge of the wire, and also we selected the core. So, we calculate the B_m. So, what is B_m? You know that B_m is this much of the flux density. So, you have the equation for that and you substitute again all the values. That will be

$$B_m = \frac{\mu_o N\left(\frac{\Delta i_L}{2}\right)}{l_g + \frac{l_c}{\mu_{rc}}} = \frac{4\pi \times 10^{-7} \times 22 \times 0.3125}{10^{-3} + \frac{97 \times 10^{-3}}{2300}} = 8.28 \times 10^{-3}\, T$$

Now, this is the B_m that affects the core loss and so, that is required for calculating the core loss. We also need to know the (B_{pk}) maximum flux density. We want to ensure that this is less than the material's flux maximum flux capability. So,

$$B_{pk} = \frac{\mu_o N\left(I_o + \frac{\Delta i_L}{2}\right)}{l_g + \frac{l_c}{\mu_{rc}}} = \frac{4\pi \times 10^{-7} \times 22 \times 8.3125}{10^{-3} + \frac{97 \times 10^{-3}}{2300}} = 0.22\, T$$

It. is less than *0.25 T*, that we have chosen or the specification was given to begin with. So, our design is okay in that respect.



Then you calculate these core losses. So, for core loss, this is the equation. You have to find out this *k*, *m* and *n* values for the ferrite core that is chosen and then you substitute in this.

$$k = 5.983 \times 10^{-5}$$
$$m = 1.66$$

$$n = 2.68$$

We obtain as the core loss density, we multiply it with the volume of the core. So, you have the dimensions of the core. You can find out the volume of the core. So, the total core loss is obtained. So, we see that the core loss is very small.

$$P_v = kB_m^n f^m = 5.983 \times 10^{-5} \times (100000)^{1.66} \times (8.28556 \times 10^{-3})^{2.68} = 0.0315\, W/m^3$$

$$V_c = 17.3 \times 10^{-6}\, m^3$$

$$P_c = P_v V_c = 5.45 \times 10^{-7}\, W$$

Then you calculate the copper loss, we have the mean length turn, the number of turns and then the resistance per unit length. So, we substitute all that for the copper wire that we have chosen and this is the total resistance that we obtain

$$R_L = MLT \times N \times \frac{R_{WDC}}{l_w} = 93 \times 10^{-3} \times 22 \times \frac{5.208}{1000} = 0.01\Omega$$

$$P_w = I_{Lrms}^2 R_L = 8^2 \times 0.01 = 0.704W$$

Now, the core loss is very small as compared to the copper loss. So, the total loss will be almost equal to copper loss. So, that is the loss which is going to happen in the inductor that we have designed.

$$P_{cw} = P_c + P_w = 0.704\ W$$

Now, this is

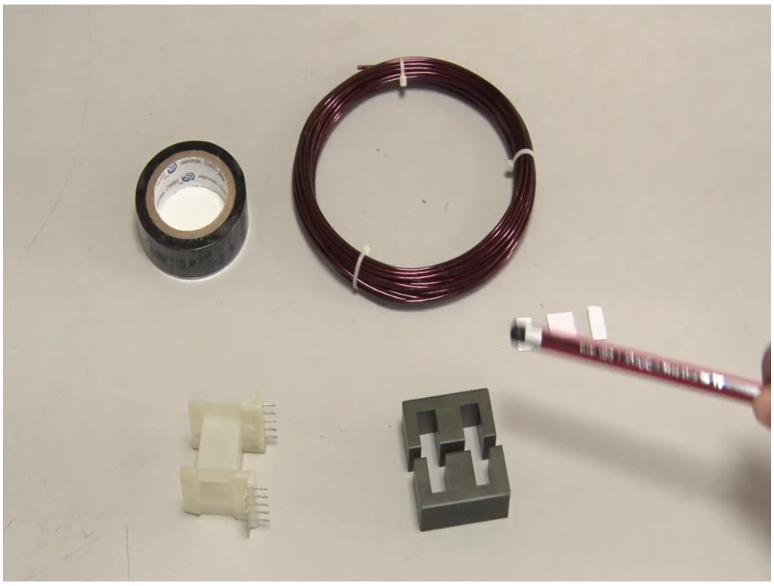
$$A_t = 48.91\ cm^2$$

$$\Psi = \frac{P_{cw}}{A_t} = \frac{0.704}{48.91} = 0.0144\ W/cm^2$$

$$\Delta T = 450\Psi^{0.826} = 450 \times (0.0144)^{0.826} = 13.55^oC$$

This is less than *15°C*. That was the specification to begin with. So, our design here is well suited for the specifications that were chosen initially. So, now, one of my students will give you a demo of how to practically design this inductor.

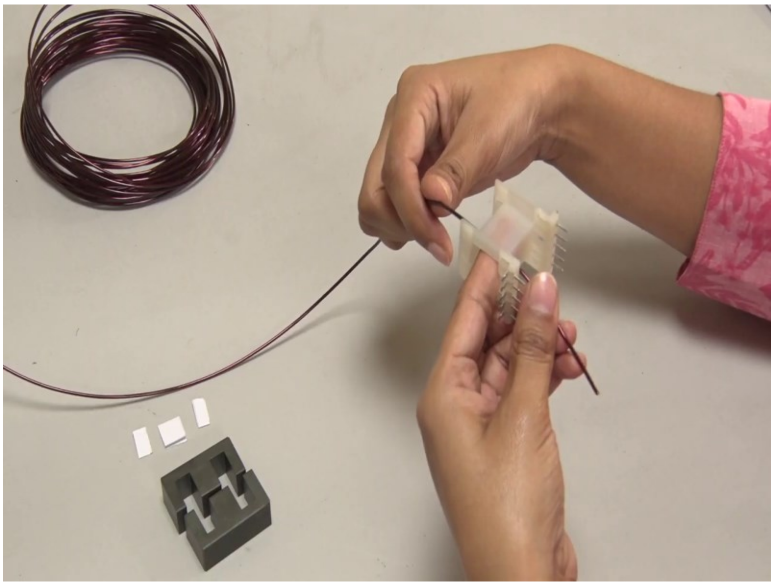
Student- Hello everyone this is Nupur, and I will show you a design procedure to make a handmade inductor of value *100 μH*. The inductor is designed for a buck converter, with average inductor current of *8 A*. The peak inductor current is *8.3125 A* and the switching frequency is *100 kHz*.

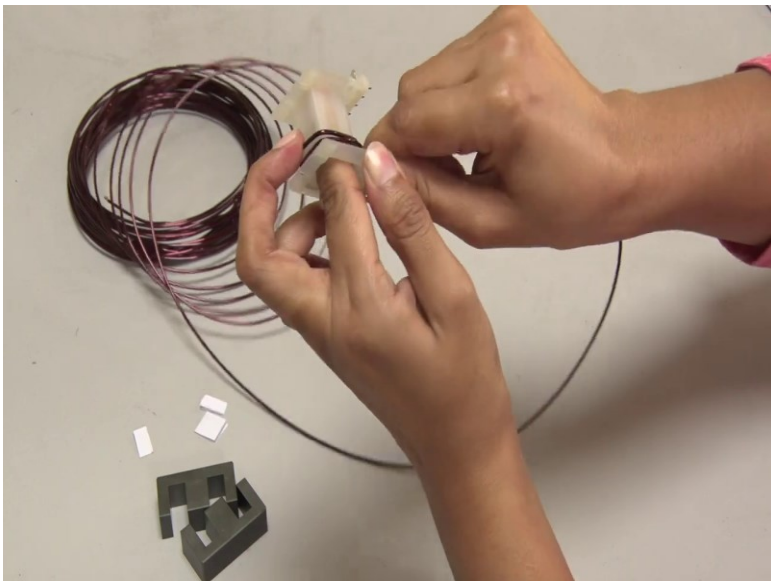


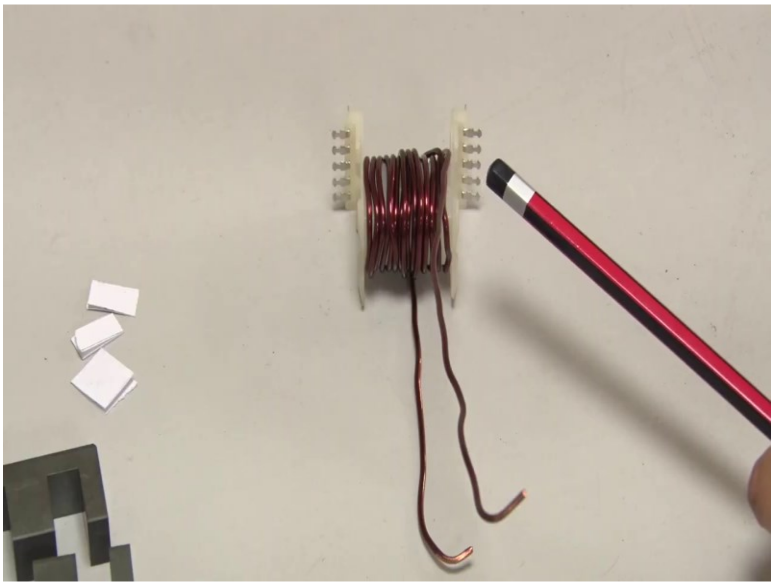
As per the area product calculation, the selected core is EE ferrite core which is made by Ferrox cube. The dimension of this core is

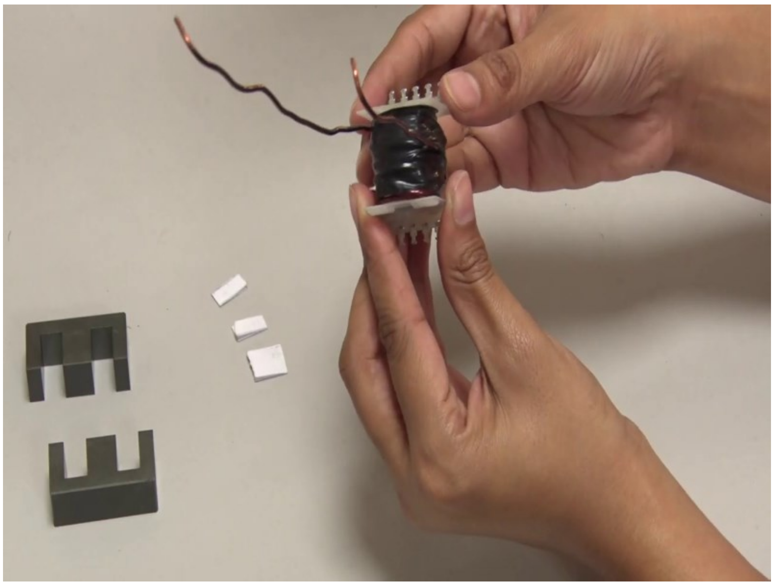
$$E\,42 \times 21 \times 15$$

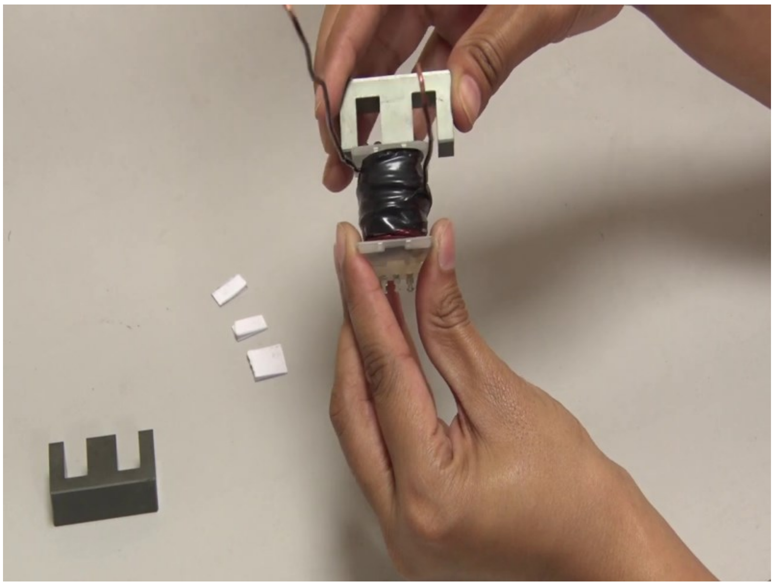
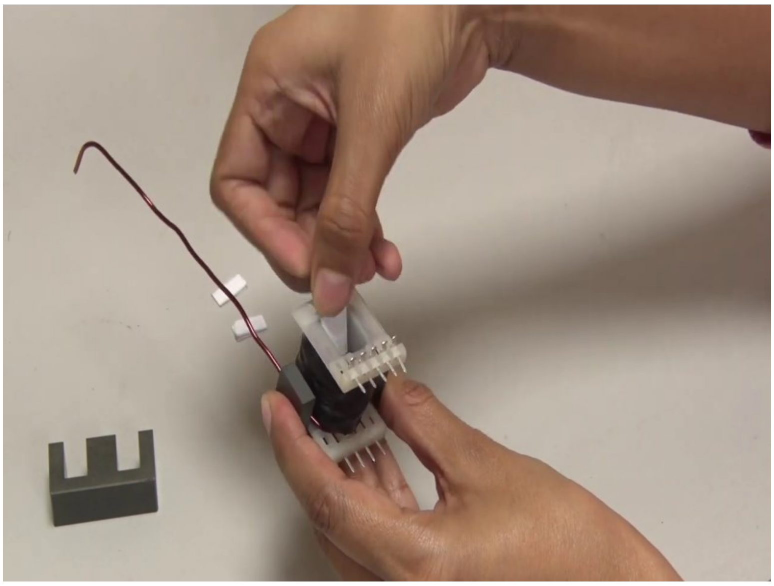
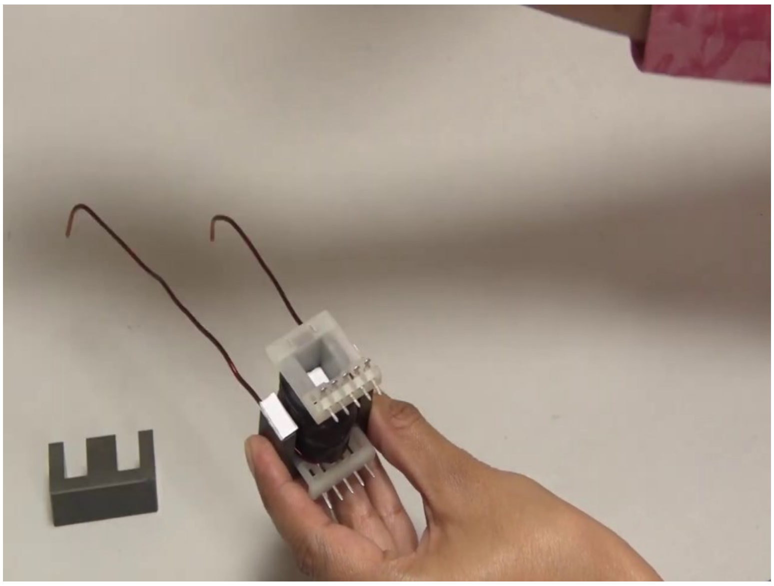
The selected copper wire is *12 AWG* and this is the *1 mm* thick paper. It will be used to give the air gap between these two cores and this is the bobbin where windings will be done and this is a tape that will be required to fix these two cores.

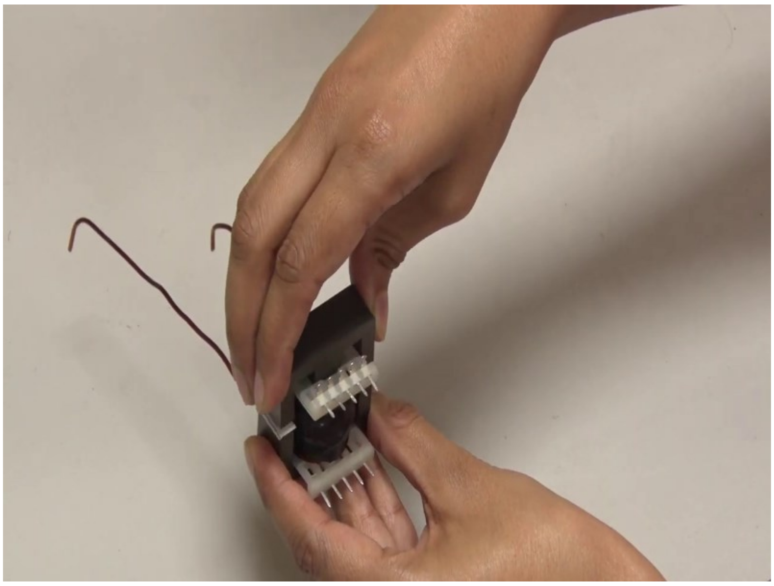


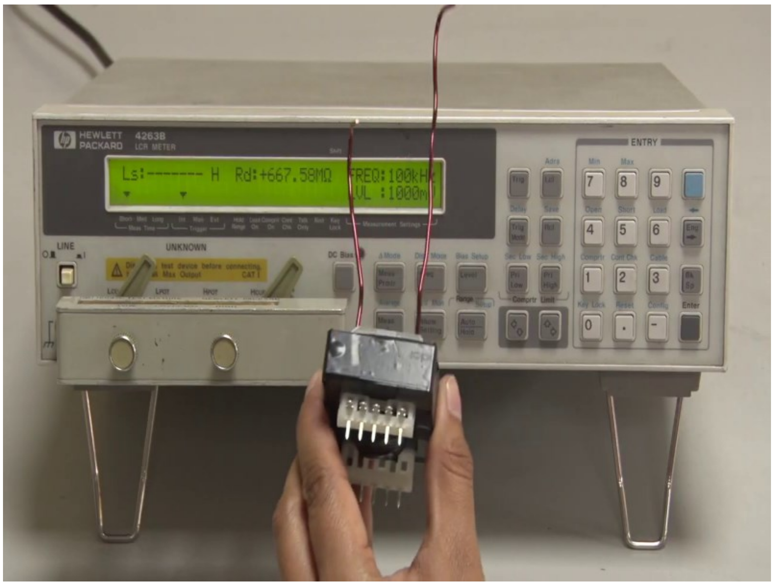




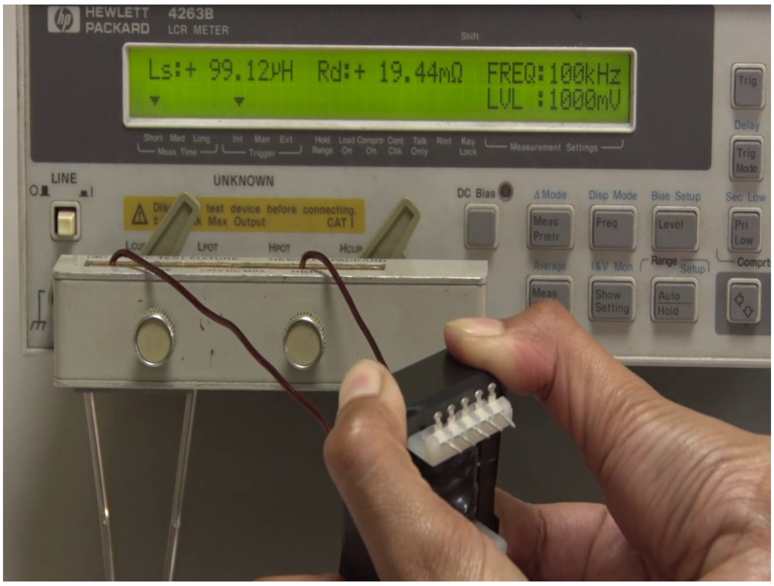






HEWLETT PACKARD
4263B
LCR METER
UNKNOWN
ENTRY



HEWLETT PACKARD
4263B
LCR METER
Ls:+ 99.12μH Rd:+ 19.44mΩ FREQ:100kHz
LVL :1000mV
LINE
UNKNOWN
DC Bias
Meas Prmtr
Freq
Level
Show Setting
Auto Hold
Trig
Delay
Trig Mode
Pri Low

Now, I will start winding this enameled copper wire on this bobbin. So, this is the first turn, then this is the second turn and in this way, we will continue with the *22* turns. Now, you can see that the enameled copper wire has been wound on this bobbin with the required number of turn and that is *22*. The enameled copper wire is secured using the tape now. I will assemble the inductor. So, one E core is placed here and now, this paper is placed here to provide the air gap.

Now, I will place the second E core and now I will use the tape to secure these two cores. Now, this is the completed inductor. Now, I will measure this inductor using this LCR meter. We can see the inductor value that we are getting, and it is around $99\ \mu H$.