INDUCTANCE OF A COAXIAL CABLE

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References: Griffiths, David J. (2007), Introduction to Electrodynamics, 3rd Edition; Pearson Education - Problem 7.28.

Here's another simple example of calculating the energy in the magnetic field and using this to calculate the inductance. We have a coaxial cable with an inner cable of radius R in which the current I flows uniformly, and an outer sheath at radius R in which the current makes its return journey. The magnetic field within the inner cable is given by Ampère's law if we take a loop of radius r centred on the axis. The enclosed current is then

$$I_{enc} = I\frac{r^2}{R^2} = \frac{2\pi r}{\mu_0}B \tag{1}$$

$$B = \frac{\mu_0 r I}{2\pi R^2} \tag{2}$$

Outside the cable, $B = 0$, so the energy per unit length is

$$W_B = \frac{1}{2\mu_0}\int_0^R B^2 2\pi r dr \tag{3}$$

$$= \frac{2\pi}{2\mu_0}\left(\frac{\mu_0 I}{2\pi R^2}\right)^2\int_0^R r^3 dr \tag{4}$$

$$= \frac{\mu_0 I^2}{16\pi} \tag{5}$$

From $W_B = \frac{1}{2}LI^2$ we get the inductance per unit length:

$$L = \frac{\mu_0}{8\pi} \tag{6}$$

In this case, the inductance is independent of R.