SURFACE AND VOLUME CURRENT IN A WIRE

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A couple of examples of surface and volume current.

If we have a wire of radius $a$ which carries a current $I$, what is the surface current $K$ if the current in the wire is spread uniformly over the surface of the wire?

Since $K$ is defined as the charge per unit width per unit time, we need the width over which the surface current is spread. This is just the circumference of the wire, so

$$K = \frac{I}{2\pi a} \quad (1)$$

Now suppose the current is distributed in the volume of the wire such that volume current density is inversely proportional to the distance from the axis. That is,

$$J = \frac{A}{r} \quad (2)$$

for some constant $A$. We need the total flow across the cross-sectional area of the wire to be the total current $I$, so we must have, using cylindrical coordinates:

$$I = \int_0^a \int_0^{2\pi} Jd\phi dr \quad (3)$$

$$= \frac{2\pi A a}{2\pi a} \quad (4)$$

Thus the volume current density is

$$J = \frac{I}{2\pi ar} \quad (6)$$