

to be stored by a field. Thus, equivalent to that required to a stretched weight. However, if a increased in proportion to energy density as

$$(J m^{-3}) \quad (13)$$

ric medium

to the polarization of its mol- a stretched spring. ization and the energy density $\frac{1}{2}PE$ to a total energy density

It will be shown later that a moving electromagnetic field, or

itor of Fig. 4-10 is the integral which the electric field E has a

$$^2 dv \quad (14)$$

ates and that there is no fringing on evaluating (14)

$$QV \quad (J) \quad (15)$$

nsity throughout the volume be- h the relation given by (5).

fair weather the earth's electric field energy density and the total energy

side with imaginary 1-m square con- stitutes a capacitor of capacitance

$$\frac{1^2}{1} = 8.85 \text{ pF}$$

$$165^2 = 1.2 \times 10^{-7} \text{ J}$$

ensity in the fair weather atmosphere

$$2 \times 10^{-7} \text{ J m}^{-3}$$

unit capacitance in coaxial cable
(Book "Electromagnetics"
by John D. Kraus)

Taking the electrosphere height $h = 25 \text{ km}$ and the earth's radius $r = 6.37 \text{ Mm}$, the total energy in the earth-electrosphere capacitor is

$$W = wv = w4\pi r^2 h = 1.2 \times 10^{-7} \times 4\pi(6.37 \times 10^6)^2 \times 25 \times 10^3 \\ = 1.5 \times 10^{12} \text{ J}$$

Our calculation assumes that the fair weather field is uniform with height. Since it actually is not, the $1.5 \times 10^{12} \text{ J}$ result is significant only as an order of magnitude.

Example 4-7 Energy and energy density of three devices. Let us compare the energy storage and energy density of three commercially available devices:

- A 1-kV, 1- μF power supply capacitor measuring $3 \times 4 \times 8 \text{ cm}$
- A 5-V, 0.1-F CMOS backup capacitor of 0.4 cm^3 volume
- A 100-A-h, 12-V automobile storage battery measuring $15 \times 15 \times 20 \text{ cm}$

Solution. (a) Power supply capacitor energy;

$$W = \frac{1}{2}CV^2 = \frac{1}{2} \times 10^{-6} \times (10^3)^2 = \frac{1}{2} \text{ J}$$

and energy density:

$$w = \frac{W}{v} = \frac{1}{2} \frac{1}{3 \times 4 \times 8 \times 10^{-6}} = 5.2 \times 10^3 \text{ J m}^{-3}$$

(b) CMOS backup capacitor energy:

$$W = \frac{1}{2}CV^2 = \frac{1}{2}0.1 \times 5^2 = 1.25 \text{ J}$$

and energy density:

$$w = \frac{W}{v} = \frac{1.25}{0.4 \times 10^{-6}} = 3.1 \times 10^6 \text{ J m}^{-3}$$

(c) 12-V storage battery energy:

$$W = V \times I \times t = 12 \times 100 \times 3600 = 4.3 \times 10^6 \text{ J}$$

and energy density:

$$w = \frac{W}{v} = \frac{4.3 \times 10^6}{15 \times 15 \times 20 \times 10^{-6}} = 9.6 \times 10^8 \text{ J m}^{-3}$$

The results of the above examples are summarized in Table 4-4, page 154.

Although the lead-acid battery achieves the highest energy density, capacitors can make their stored energy available much more rapidly.

4-12 COAXIAL TRANSMISSION LINE

The concentric cylindrical conductors arranged as in Fig. 4-12a form a useful current-carrying arrangement called a *coaxial transmission line*. Much can be learned about its properties from a consideration of its behavior under static conditions. Let a fixed potential difference be applied between the inner and outer