1

Introduction

1.1 Travel time around the Earth.

Assuming a perfect sphere, the Earth's circumference is πD, where D is the diameter. Hence we have

$$t = \frac{l}{v} = \frac{\pi D}{c} \simeq \frac{\pi \times (1.274 \times 10^4 \text{ km})}{3 \times 10^5 \text{ km-s}^{-1}} \simeq 0.1334 \text{ s}$$

1.2 Travel time between the Earth and the Moon.

The time t it takes to travel a distance $d =$ 4,54,000 km is

$$t = \frac{d}{c} \simeq \frac{4{,}54{,}000 \text{ km}}{3 \times 10^5 \text{ km-s}^{-1}} \simeq 1.51 \text{ s}$$

1.3 Earth-Moon communication.

Using the average Earth-Moon distance $d = 384,400$ km, and a noting that the one-way time delay is given by $t_d = (2.7/2)$ s, we have

$$c = \frac{d}{t_d} = \frac{384,400 \text{ km}}{(2.7/2) \text{ s}} \simeq 2.847 \times 10^5 \text{ km-s}^{-1}.$$

1.4 Time delay of a radar signal.

We note that since the round trip time of the radio pulse is 40 μs, the one-way travel time t is 20 μs. Hence the distance d from the radar system to the target is

$$d = ct \simeq \left(3 \times 10^5 \text{ km-s}^{-1}\right)\left(20 \times 10^{-6} \text{ s}\right) = 6 \text{ km}$$

1.5 Echo from a cliff.

Since the one-way travel time is given by $t_d = 5/2$ s, the cliff's distance d from the man is given by

$$D = vt_d = 340 \times \left(\frac{5}{2}\right) = 170 \times 5 \text{ meters} = 850 \text{ meters}$$

1.6 Sonar.

We note that the round trip time of the sonar signal is 6 s, which means that the one-way travel time is 3 s. Speed of sound wave is 2.5×10^3 m-s^{-1}. Thus the depth d is given by

$$\text{Distance } (2d) = 6 \times 2.5 \times 10^3$$

$$d = 3 \times 2.5 \times 10^3 = 7.5 \times 10^3 \text{ meter} = 7.5 \text{ km}$$

1.7 Sonar.

Time taken by the Sonar Pulse = 3.7 s. Speed is 3 km-s^{-1}. The depth d is given by

$$2d = 3.7 \times 3 \text{ km}$$

$$d = (3.7 \times 3)/2 = 10.2/2 = 5.05 \text{ km}$$

1.8 Auto-focus camera.

We note that the round trip time of the ultrasonic sound wave is 0.1 s, which means that the one-way travel time t is 0.05 s. Hence the distance from the camera to the object is

$$d = vt = \left(340\text{m-s}^{-1}\right)(0.05 \text{ s}) = 17 \text{ m}$$

1.9 Lightning and thunder.

The approximate distance is given by

$$d = vt = (340 \text{ m-s}^{-1})(5 \text{ s}) = 1700 \text{ m} = 1.7 \text{ km}.$$

1.10 A light-year.

Speed of the light in the vaccum = 3×10^8 m/s = 3×10^5 km/s.

$$\text{Time} = 1 \text{ year} = 12 \text{ month} = (365.25) \times 24 \times 3600$$

$$1 \text{ light year} = 9.467 \times 10^{12} \text{ km}$$

$$3/2 \text{ light year} = 14.2 \times 10^{12} \text{ km}$$

1.11 A light-nanosecond.

The light-nanosecond length l in meters is

$$l = ct = \left(3 \times 10^5 \text{ km-s}^{-1}\right)\left(10^{-6} \text{ s}\right) = 0.3 \text{ km} = 3 \times 10^2 \text{ m}.$$

1.12 1 Astronomical Unit.

$$1 \text{ AU} = 1.5 \times 10^8 \text{ km}$$

$$2 \text{ AU} = 2 \times 1.5 \times 10^8 \text{ km}$$

$$= 3 \times 10^8 \text{ km}$$

1.13 Distance between Proxima Centauri and Earth.

Assuming 365.25 days in a year, one light year is equivalent to

$$\begin{aligned}1 \text{ light year} &= \left(3\times10^5 \text{ km-s}^{-1}\right)\left(365.25\ \frac{\text{day}}{\text{year}}\right)\left(24\ \frac{\text{hour}}{\text{day}}\right)\left(3600\ \frac{\text{s}}{\text{hour}}\right)\\ &\simeq 9.467\times10^{12} \text{ km}\end{aligned}$$

Hence the distance d between Proxima Centauri and Earth, given in light-years (ly), is

$$d = 4\times10^{13} \text{ km} \simeq \frac{4\times10^{13} \text{ km}}{9.467\times10^{12} \text{ km-ly}^{-1}} \simeq 4.225 \text{ ly}$$

1.14 Seismic waves.

The time delay from the epicenter of the earthquake to the seismograph station t is

$$t = \frac{d}{v} = \frac{900 \text{ km}}{5 \text{ km-s}^{-1}} = 180 \text{ s} = 3 \text{ minutes}$$

1.15 Tsunami waves.

The average speed of the tsunami wave is

$$v_{\text{average}} = \frac{d}{t} = \frac{8020 \text{ km}}{10 \text{ hr}} = 802 \text{ km-hr}^{-1} \simeq 223 \text{ m-s}^{-1}$$

1.16 The Indian Ocean tsunami.

The delay t of the tsunami between the epicenter of the tsunami and a location a distance d away from it is given by

$$t = \frac{d}{v}$$

where $v = 800 \text{ km-hr}^{-1}$. Hence the delay between the epicenter to Sumatra is

$$t_{\text{Sumatra}} = \frac{160 \text{ km}}{800 \text{ km-hr}^{-1}} = 0.2 \text{ hr} = 12 \text{ minutes}$$

and the delay between the epicenter to Africa is

$$t_{\text{Africa}} = \frac{4500 \text{ km}}{800 \text{ km-hr}^{-1}} \simeq 5.63 \text{ hr}$$

1.17 Micro-bats.

The round-trip distance d between the micro-bat and the insect is 2×10 m, so the total time delay t between the emitted and detected pulses is

$$t = \frac{d}{v} = \frac{2\times10 \text{ m}}{340 \text{ m-s}^{-1}} \simeq 0.0588 \text{ s} = 58.8 \text{ ms}.$$

1.18 Overhead power lines.

The propagation delay t_d is related to the propagation distance l by $t_d = l/v$, where v is the propagation speed.

$$l_{\text{lumped}} < 0.01\frac{v}{f}$$

Once again assuming propagation at the speed of light, a 50 Hz signal corresponds to a maximum line length of

$$l_{\max} = 0.01 \cdot \frac{3 \times 10^8 \text{ m-s}}{50} = 60{,}000 \text{ m} = 60 \text{ km}$$

1.19 Maximum path length.

From (1.1), lumped-circuit analysis is appropriate when $t_r/t_d > 6$, or

$$t_d < \frac{t_r}{6}$$

Using $t_r = 250$ ps, the limit on t_d becomes

$$t_d < \frac{250 \text{ ps}}{6}$$

Using $t_d = l/v$, where $v = c/3$, we have

$$l_{\max} = vt_d = \left(\frac{c}{3}\right)\left(\frac{250 \text{ ps}}{6}\right) \simeq 4.17 \times 10^{-3} \text{ m} = 0.417 \text{ cm}.$$

1.20 Maximum coax length.

The one-way time delay of the maximum cable length for a lumped-circuit analysis is given by

$$t_d = 0.01T$$

Hence the maximum cable length $l_{\max}$ for a lumped-circuit analysis satisfies

$$\frac{l_{\max}}{v} = \frac{0.01}{f}$$

Solving for $l_{\max}$, we have

$$l_{\max} = 0.01\frac{v}{f} = \frac{2 \times 10^8}{2 \times 10^6} \times 0.01 = 0.6 \times 0.01 = 0.006 \text{ m}.$$

1.21 Travel time of a microstrip transmission line.

The one-way travel time t_d is given by

$$t_d = \frac{l}{v} = \frac{9 \text{ cm}}{1.5 \times 10^8 \text{ m-s}^{-1}} = 6 \times 10^{-10}\,\text{s}$$

1.22 Maximum cable length.

Using (1.3), the one-way time delay of the maximum cable length for a lumped-circuit analysis is given by

$$t_d = 0.01T$$

Hence the maximum cable length $l_{\max}$ for a lumped-circuit analysis satisfies

$$\frac{l_{\max}}{v} = \frac{0.01}{f}$$

Solving for $l_{\max}$, we have

$$l_{\max} = 0.01\frac{v}{f} = (0.01)\frac{2 \times 10^8 \text{ m-s}^{-1}}{30 \times 10^6 \text{ s}^{-1}} \simeq 6.66 \times 10^{-2} \text{ m} = 6.66 \text{ cm}.$$

1.23 Microstrip transmission line.

The time-delay t_d of the transmission line is

$$t_d = \frac{v}{l} = \frac{6 \text{ cm}}{1 \times 10^{10} \text{ cm-s}^{-1}} = 10^{-10} \text{ s} = 0.1 \text{ ns}$$

1.24 Stripline transmission line.

The time delay t_d of the stripline is

$$t_d = \frac{l}{v} \simeq \frac{12 \text{ cm}}{(3 \times 10^{10} \text{cm-s}^{-1})/2} = 8 \times 10^{-10} \text{ s} = 0.8 \text{ ns}$$

Using (1.1),

$$\frac{t_r}{t_d} = \frac{0.5 \text{ ns}}{0.8 \text{ ns}} = 0.625 < 2.5$$

Thus, it is appropriate to consider transmission line effects.

1.25 On-chip GaAs interconnect.

Using (1.1), for a lumped-circuit analysis to be valid, we need

$$\frac{t_r}{t_d} > 6 \quad \rightarrow \quad \frac{t_d}{t_r} < \frac{1}{6} \quad \rightarrow \quad t_d < \frac{t_r}{6}$$

Hence the time delay must satisfy

$$t_d = \frac{l}{v} < \frac{50 \text{ ps}}{6}$$

Hence the largest length $l_{\max}$ is given by

$$l_{\max} = \left(\frac{50}{6} \times 10^{-12} \text{ s}\right)\left(8 \times 10^7 \text{ m-s}^{-1}\right) \simeq 6.7 \times 10^{-4} \text{ m} = 0.67 \text{ mm}$$

1.26 A coaxial cable-lumped or distributed analysis?

Using (1.3), the shortest period T of the sinusoidal steady-state signal for the coaxial cable to be considered as a lumped system satisfies

$$t_d = 0.01T$$

Thus the highest frequency for which lumped-circuit analysis is still applicable can be found as

$$\frac{l}{v} = \frac{0.01}{f}$$

Solving for f, we have

$$f = \frac{0.01v}{l} \simeq \frac{0.01\,(0.75)\left(3 \times 10^{8}\ \text{m-s}^{-1}\right)}{10\ \text{m}} = 225,000\ \text{Hz} = 225\ \text{kHz}$$

If the frequency f exceeds 225 kHz, then the coaxial cable must be treated as a distributed element.