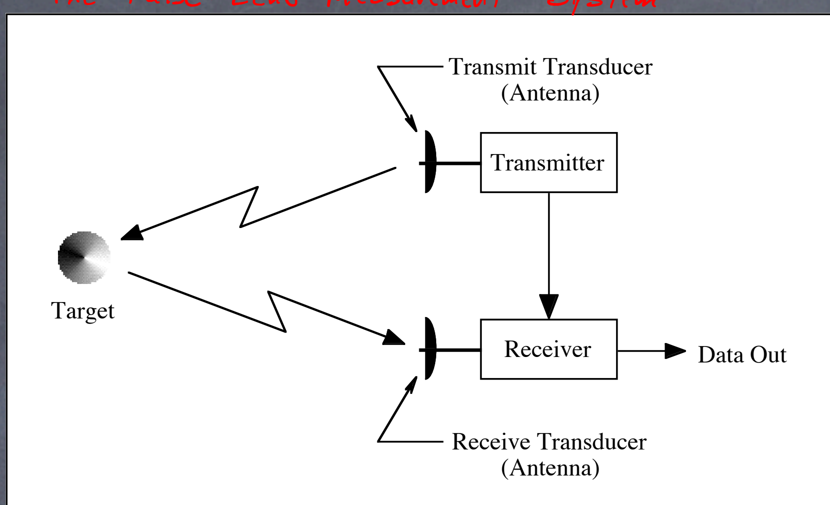
Session 2

Recall ... The Pulse-Echo Measurement System

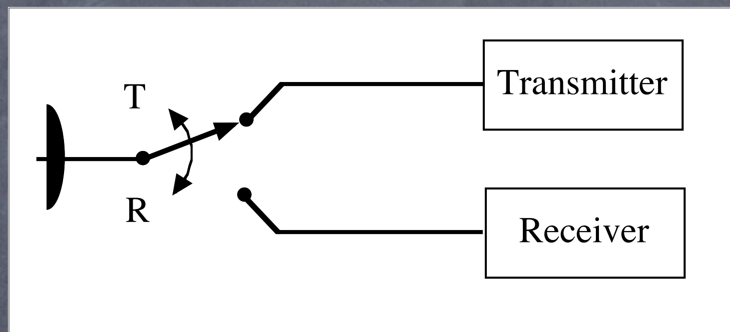


> It consists of

1. Transmitter
2. Transmit Transducer (Antenna)
3. Receive Transducer (Antenna)
4. Receiver

Recall ...

The transmit and receive antenna may or may not be the same physical antenna:



T/R Switch

Radars that use the same antenna for transmit and receive—or have the two antennas co-located— are called monostatic radars.

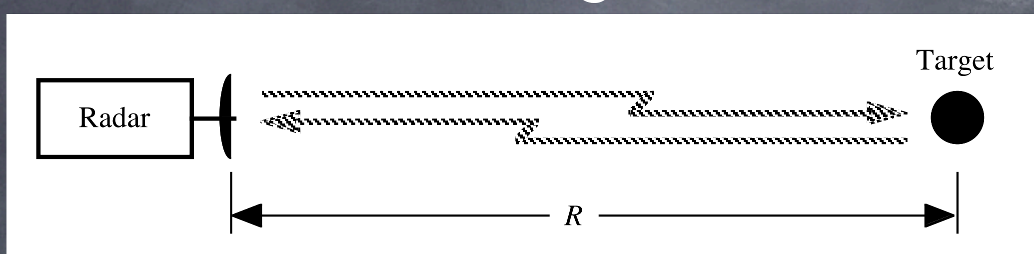
- The "Transmitter" includes:
  - Signal Generators
  - Modulators
  - Power Amplifiers

- The "Receiver" includes:
  - RF Amplifiers
  - Mixers
  - IF Amplifiers
  - Detectors
  - Filters

and...

  - Doppler Filters, Range Gating Circuits, CFAR Processors, SAR Processors, etc.

Delay and Range in Radar



An electromagnetic pulse transmitted through space travels at a velocity of $c = 2.998 \times 10^8$ m/sec, while covering a distance of 2R.

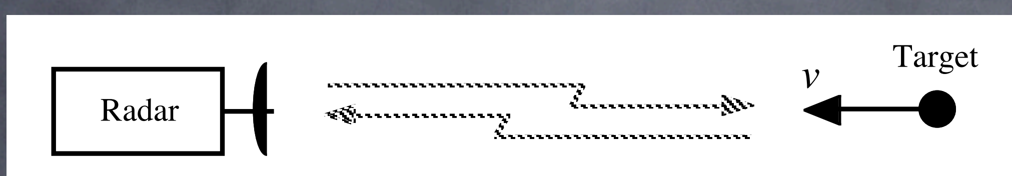
Rate x Time = Distance $\Rightarrow$ $c\tau = 2R$

$$\Rightarrow \quad \boxed{\tau = \frac{2R}{c}} \quad \text{or} \quad \boxed{R = \frac{c\tau}{2}}$$

$$\boxed{\tau = \frac{2R}{c} \qquad \text{or} \qquad R = \frac{c\tau}{2}}$$

- Thus we can determine the range to the target by measuring the delay until the echo is heard.
- For EM waves in free space, $c = 2.998 \times 10^8$m/sec.
- For an acoustic wave in air at Standard Temperature and Pressure (STP), c =341 m/sec.
- Do determine R, you must accurately measure (estimate) delay. This can be difficult in noise.

The Doppler Effect



- The radar transmits waveform s(t).
- The received waveform is of the form

$$r(t) \;=\; \sqrt{\alpha}\cdot s(\alpha t - \tau) \;=\; \sqrt{\alpha}\cdot s(\alpha(t-\tau')),$$

where

$$\alpha = \frac{1+v/c}{1-v/c}.$$

is the Doppler compression factor.

Expanding α in a Taylor series about $v/c = 0$,

$$\alpha = \alpha\left(\frac{v}{c}\right) = 1 + 2\frac{v}{c} + 2\left(\frac{v}{c}\right)^2 + \cdots$$

$$= 1 + 2\sum_{k=1}^{\infty}\left(\frac{v}{c}\right)^k$$

$$= 1 + 2\left(\frac{v}{c}\right) + \o\left(\left|\frac{v}{c}\right|\right)$$

For a radar utilizing EM radiation, where v<<c

$$\alpha \approx 1 + 2\left(\frac{v}{c}\right)$$

Hence it follows that the received signal is

$$r(t) = \sqrt{1 + \frac{2v}{c}}\, s\left(\left(1 + \frac{2v}{c}\right)t - \tau\right)$$

$$\approx s\left(\left(1 + \frac{2v}{c}\right)t - \tau\right)$$

Now suppose that

$$s(t) = \sin\left(\omega_o t + \theta\right)$$

Then the received signal is

$$r(t) = s\left(\left(1+\frac{2v}{c}\right)t-\tau\right)$$

$$= \sin\left(\omega_o\left(\left(1+\frac{2v}{c}\right)t-\tau\right)+\theta\right)$$

$$= \sin\left(\underbrace{\omega_o\left(1+\frac{2v}{c}\right)}_{\text{Frequency Shifted}}t+(\theta-\underbrace{\omega_o\tau}_{\substack{\text{Propagation delay}\\ \text{phase shift}}})\right).$$

This is a sinusoid of radian frequency

$$\omega_R = \omega_o\left(1+\frac{2v}{c}\right)$$

or cyclic frequency

$$f_R = f_o\left(1+\frac{2v}{c}\right).$$

We call

$$f_D = f_R - f_o = \boxed{\frac{2vf_o}{c}}$$

the Doppler shift.

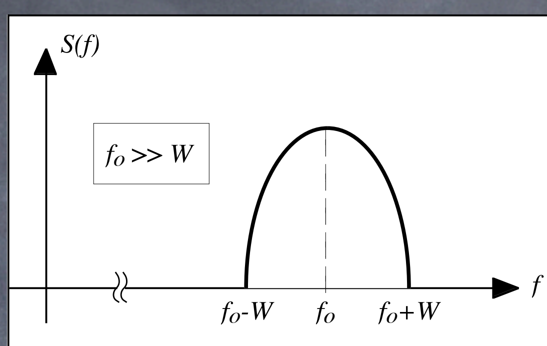
$$\boxed{f_D = \frac{2v f_o}{c} = \frac{2v}{\lambda}}$$

where

$$\lambda = \frac{c}{f_o} = \text{wavelength.}$$

- For signals of a single frequency, the Doppler effect corresponds to a shift in frequency.
- Doppler shift is proportional to carrier frequency and velocity.

The Narrowband Approximation



- If we have a narrowband signal (bandwidth << carrier freq.), we assume that each frequency component is shifted by the same amount
- This is an approximation—the "Narrowband Approximation

In general, if $s(t) \overset{\mathcal{F}}{\Leftrightarrow} S(\omega)$

$$\sqrt{\alpha} s(\alpha t) \overset{\mathcal{F}}{\Leftrightarrow} \frac{1}{\sqrt{\alpha}} S\left(\frac{\omega}{\alpha}\right)$$

- This is a scaling in frequency, not a frequency shift.
- But for narrowband signals and v<<c, the narrowband approximation is good.
- In sonar, the narrowband approximation is often bad.