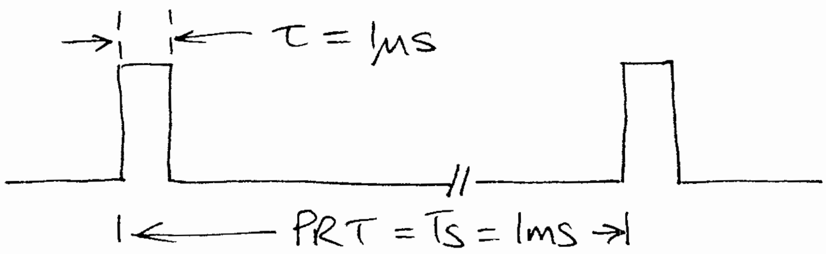
MODERN RADAR SYSTEMS

PULSE MODULATOR GENERATES A TRAIN OF MICROWAVE PULSES SPACED A THE PRT. EACH PULSE LAST τ (USUALLY μs)



IN AN IDEALIZED SITUATION THE RADIATED POWER DENSITY CAN BE REPRESENTED AS;

$$S(r,\theta,\phi)\,u(t - R/c)$$

WHERE;

$S(r,\theta,\phi)$ POWER DENSITY RADIATION FUNCTION OF SYSTEM, INCLUDING ANTENNA

$$u(t - R/c) = \begin{cases} 1. & R/c \leq t \leq (R/c + \tau) \\ 0 & \text{OTHERWISE} \end{cases}$$

IN REALITY, WE CANNOT GENERATE A PERFECT PULSE, SO...

τ IS USUALLY DEFINED AS THE TIME BETWEEN INSTANCES WHEN THE POWER IS 25% OF THE PEAK.

← REAL PULSE

THE PULSE SHAPE OF MAGNETRON SYSTEMS IS GENERALLY POORER THAN THAT OF KLYSTRON SYSTEMS

DURING THE TRANSMIT PULSE, THE RECEIVER IS PROTECTED BY A T-R CELL - A DEVICE FILLED WITH GAS THAT WHEN IONIZED BY A LARGE ELECTRIC FIELD APPEARS AS A SHORT CIRCUIT ACROSS THE GUIDE.

DURING THE LISTENING PERIOD $T_s - \tau$ THE T-R CELL IS OPEN CIRCUIT WHICH ALLOWS THE REFLECTED (VERY WEAK - $1/R^4$ REMEMBER) SIGNAL TO PASS UNIMPEDED.

THE UPPER LIMIT ON THE PRF = 1/PRT IS USUALLY DUE TO THE DUTY CYCLE LIMITATIONS IMPOSED BY THE MODULATOR / MAGNETRON

IF WE ARE ONLY INTERESTED IN THE ECHO STRENGTH AND AREN'T CONCERNED WITH PHASE MEASUREMENTS WE USUALLY USE A LOGARITHMIC AMPLIFIER

- THE RECEIVED SIGNAL HAS A VERY LARGE DYNAMIC RANGE USUALLY ≈ 90dB.

- IF WE ONLY MEASURE REFLECTED POWER THE RADAR IS SAID TO BE INCOHERENT.

RANGE RESOLUTION

THE RANGE RESOLUTION IS PRIMARILY DETERMINED BY THE PULSE LENGTH OF THE TRANSMITTER

$$R_{RES} = c\tau.$$

$$= 300\,m\,\mu s^{-1}$$

RANGE GATES

USUALLY WE SPLIT THE RECEIVE PERIOD UP INTO A NUMBER OF RANGE GATES, SPACED BY THE RANGE RESOLUTION

THE COHERENT RECEIVER

IF WE WANT TO MAKE PHASE MEASUREMENTS (TO DERIVE VELOCITY INFORMATION) WE ARE FORCED TO USE A COHERENT RECEIVER, WHICH MUST BE LINEAR.

BUT

WE NEED A LARGE DYNAMIC RANGE - LINEAR AMPLIFIERS ARE DIFFICULT AND COSTLY TO PRODUCE TYPICALLY DYNAMIC RANGE ≈ 60dB

WE CAN SOLVE THE PROBLEM USING IAGC - INSTANTANEOUS - AUTOMATIC GAIN CONTROL.

PHASE DETECTION CAN BE PERFORMED BY MIXING THE IF SIGNAL WITH THE COHO - THIS ENABLES US TO DETERMINE THE MAGNITUDE OF THE VELOCITY. IF WE USE TWO PHASE DETECTORS IN QUADRATURE WE CAN DETERMINE THE DIRECTION ALSO.

AFTER BEING DOWN-CONVERTED BY THE RECEIVER THE IF SIGNAL CAN BE REPRESENTED BY;

$$V(t,R) = A \exp[j2\pi f_{IF}(t - 2R/c) + j\psi]\, u(t - 2R/c)$$

WHERE;

$$A = |A| \exp(j\psi_s)$$ – DUE TO THE SCATTERING

↑ ψ_s – SCATTERING PHASESHIFT.

NOTE: THIS ASSUMES A POINT TARGET AND THAT THE RECEIVER BANDWIDTH IS SUFFICIENTLY LARGE

THE PHASE-SHIFT TERM CAN BE WRITTEN AS;

$$\psi_E = -\frac{4\pi R}{\lambda} + \psi_t + \psi_s$$

- ψ_E ← ECHO PHASE
- $\frac{4\pi R}{\lambda}$ ← PHASE SHIFT OVER PATH
- ψ_t ← TRANSMITTER PHASE: FIXED FOR A KLYSTRON, RANDOM FOR A MAGNETRON
- ψ_s ← SCATTERING PHASE SHIFT

[NEGLECTING THE PHASE TERM $2\pi f_{IF} t$]

IF WE COHERENTLY DETECT THIS SIGNAL, AFTER LOW-PASS FILTERING WE OBTAIN;

$$I(t,R) = \frac{|A|}{\sqrt{2}} \cos(\psi_E)\, u(t - 2R/c)$$

AND

$$Q(t,R) = \frac{|A|}{\sqrt{2}} \sin(\psi_E)\, u(t - 2R/c)$$

IF THE TARGET IS STATIONARY,

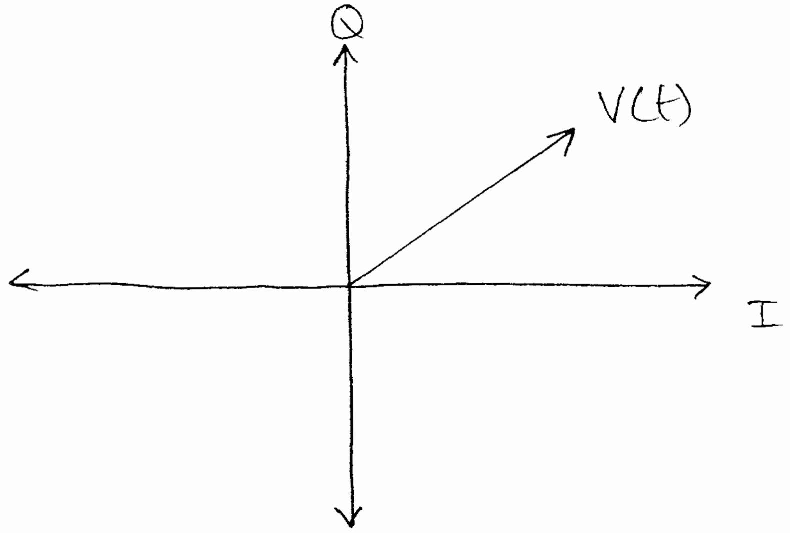
$$\psi_E = -\frac{4\pi R}{\lambda} + \psi_t + \psi_s \quad \text{- TIME INDEPENDENT.}$$

IF THE TARGET IS IN MOTION;

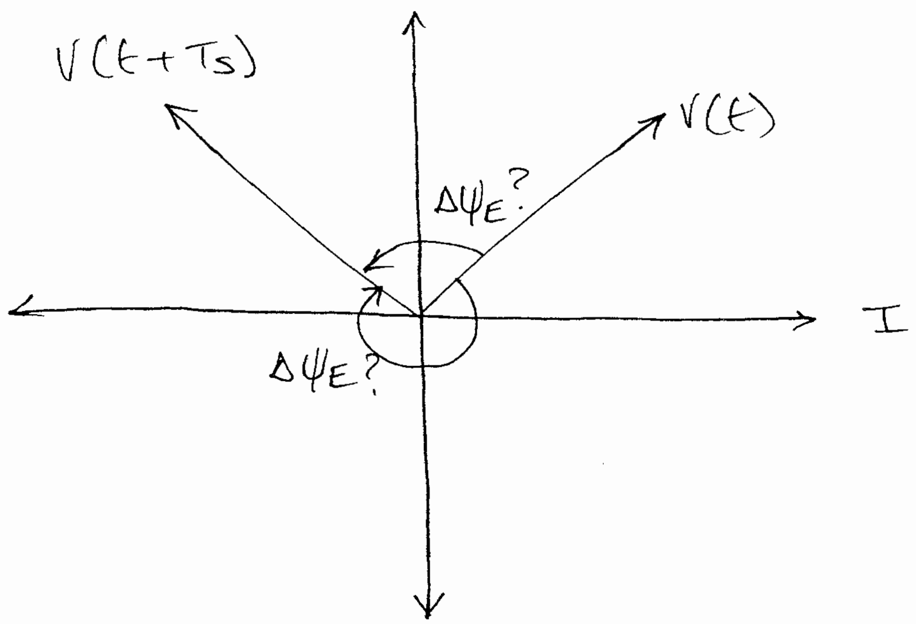
$$\frac{d\psi_E}{dt} = -\frac{4\pi}{\lambda}\frac{dr}{dt} = -\frac{4\pi}{\lambda} v_r \quad \text{- AS BEFORE}$$

I AND Q REPRESENT THE SINE AND COSINE OF THE PHASE ANGLE, OR THE REAL AND IMAGINARY PARTS OF A COMPLEX NUMBER.

WE CAN REPRESENT I AND Q AS A PHASOR



TO MEASURE VELOCITY WE MEASURE THE CHANGE IN PHASE $\Delta\psi_E$ OVER A PRT = T_S



WHICH PHASE DO WE CHOOSE? WE COULD REDUCE T_S TO MAKE MORE SAMPLES, BUT THAT REDUCES THE UNAMBIGUOUS RANGE!

WE CANNOT TELL IF $V(t+T_s)$ ROTATED CLOCK WISE, OR ANTI-CLOCKWISE, OR EVEN IF IT HAS CIRCLED THE ORGIN IN THE TIME T_s. HENCE ANY OF THE FREQUENCIES;

$$\frac{\Delta\psi_E}{2\pi T_s} + \frac{n}{T_s}, \quad -\pi < \Delta\psi_E \leq \pi, \quad n \in \mathbb{Z}$$

COULD BE A CORRECT DOPPLER SHIFT.

ALL SUCH SHIFTS ARE CALLED ALIASES AND $f_N = \frac{1}{2T_s}$ IS THE NYQUIST FREQUENCY.

HENCE ALL DOPPLER FREQUENCIES BETWEEN $\pm f_N$ ARE THE PRINCIPAL ALIASES, AND FREQUENCIES HIGHER THAN f_N ARE AMBIGUOUS WITH THOSE BETWEEN $\pm f_N$. THUS, V_N,

$$V_N = \pm \frac{\lambda}{4T_s}$$

VELOCITIES BETWEEN $-V_N$ TO $+V_N$ CAN BE RESOLVED WITHOUT AMBIGUITY.

WE CAN EXTEND THIS BY INTERLACING TWO PULSE REPETITION RATES AND USING SOME SIGNAL PROCESSING

AUTOCOVARIANCE PROCESSING: PULSE PAIR

THE PULSE PAIR ESTIMATOR CALCULATES THE FIRST MOMENT OF THE DOPPLER SPECTRUM FROM THE AUTOCOVARIANCE FUNCTION.

WE CAN DO THIS BECAUSE THE AUTOCOVARIANCE FUNCTION AND THE POWER SPECTRAL DENSITY FUNCTION ARE A FOURIER TRANSFORM PAIR;

$$R(T_s) = \exp(j2\pi f_d T_s) \int_{-1/2T_s}^{+1/2T_s} S(f) \exp(j2\pi f_d T_s (f - f_d))\, df.$$

FROM A SEQUENCE OF "M" SAMPLES EVENLY SPACED EVERY T_s SECONDS, THE AUTOCORRELATION AT A TIME LAG T_s IS;

$$\hat{R}(T_s) = \frac{1}{M-1} \sum_{m=0}^{M-2} V^*(m)\, V(m+1)$$

$*$ - CONJUGATE

$$V(m) = I(m) + jQ(m)$$

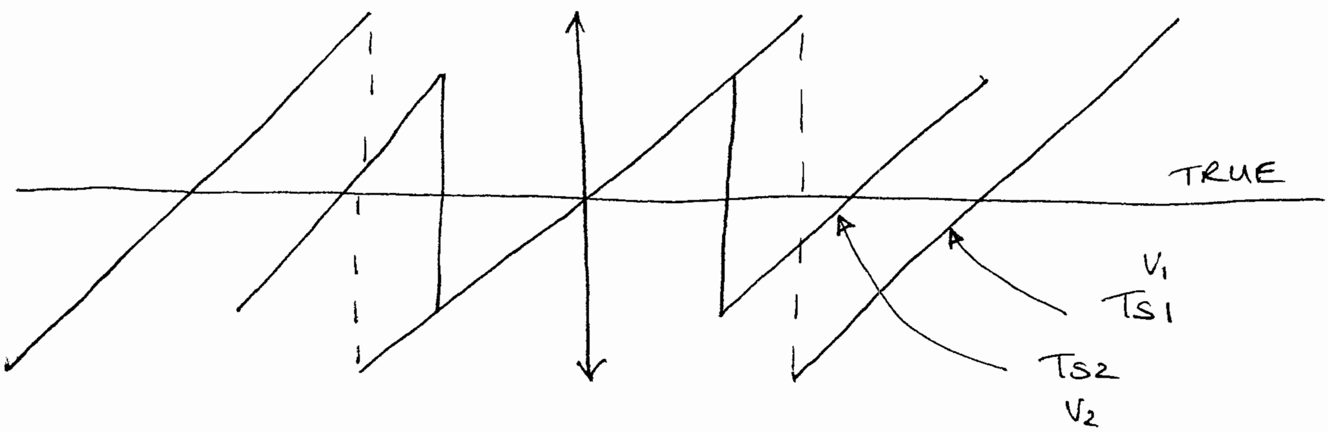
THE VELOCITY ESTIME IS;

$$\hat{v} = \frac{-\lambda}{4\pi T_s} \arg(\hat{R}(T_s))$$

DUAL OR STAGGERED PRF TECHNIQUES

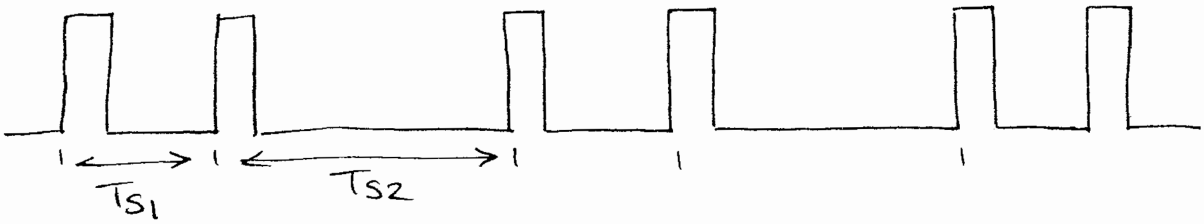
VELOCITY ESTIMATES FROM TWO DIFFERENT PRFS COMBINED TO EXTEND THE UNAMBIGUOUS VELOCITY

IN THE DUAL PRF TECHNIQUE, A NUMBER OF SAMPLES ARE GATHERED AT A PRT OF T_{s1}, FOLLOWED BY A SCAN AT $PRT = T_{s2}$



BECAUSE THE VELOCITIES V_1 AND V_2 ARE FROM DIFFERENT PRFS THEY ALIAS AT DIFFERENT VELOCITIES, THIS CAN BE USED TO EXTEND THE NYQUIST VELOCITY.

IN THE STAGGERED PRF SCHEME, INSTEAD OF SENDING UNIFORMLY SPACED PULSES WE SEND.



BY FORMING TWO AUTOCORRELATION SEQUENCES;

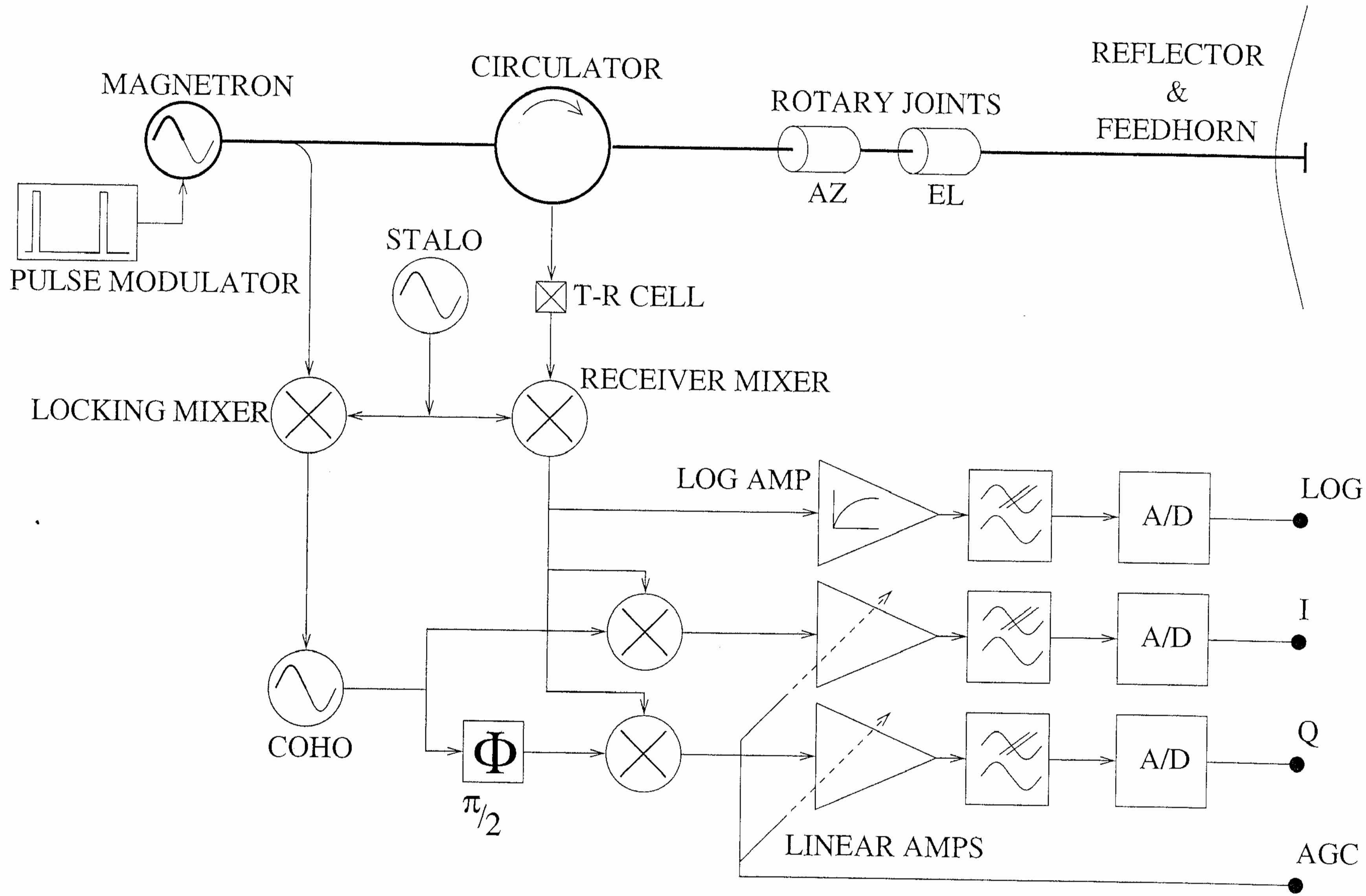
$$\hat{R}_1(T_{s1}) = \frac{1}{M-1}\sum_{m=0}^{M-2} v^*(m)\, v(m+1)$$

$$\hat{R}_2(T_{s2}) = \frac{1}{M-1}\sum_{m=0}^{M-2} v^*(m)\, v(m+1)$$

THE VELOCITY CAN BE ESTIMATED FROM THE PHASE DIFFERENCE BETWEEN THE TWO;

$$\hat{v} = -\frac{\lambda}{4\pi(T_{s2}-T_{s1})}\arg\left[\frac{\hat{R}_1}{\hat{R}_2}\right]$$

$$\Rightarrow \quad v_N = \pm\frac{\lambda}{4(T_{s2}-T_{s1})}$$


MAGNETRON
CIRCULATOR
ROTARY JOINTS
AZ
EL
REFLECTOR
&
FEEDHORN
PULSE MODULATOR
STALO
T-R CELL
LOCKING MIXER
RECEIVER MIXER
LOG AMP
A/D
A/D
A/D
LOG
I
Q
COHO
Φ
π/2
LINEAR AMPS
AGC