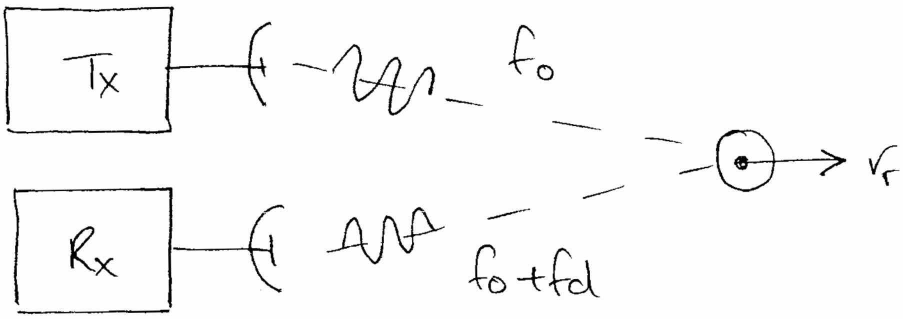
THE DOPPLER EFFECT



R - DISTANCE FROM RADAR TO THE TARGET
λ - WAVELENGTH OF RADAR

THE NUMBER OF WAVELENGTHS IN THE TWO-WAY PATH EXCURSION IS;

$$\frac{2R}{\lambda}$$

SINCE ONE WAVELENGTH = 2π RADIANS, THE TOTAL ANGULAR EXCURSION TO AND FROM THE TARGET IS;

$$\phi = \frac{2R}{\lambda} \times 2\pi = \frac{4\pi R}{\lambda}$$

IF THE TARGET IS IN MOTION R AND ϕ ARE BOTH CHANGING WITH TIME.

A CHANGE IN ϕ WITH TIME IS EQUAL TO A FREQUENCY

HENCE THE DOPPLER ANGULAR FREQUENCY ω_d IS GIVEN BY;

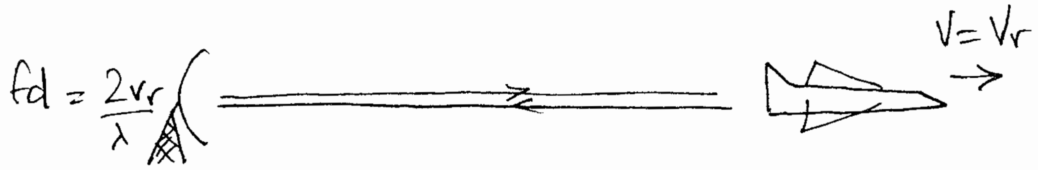
$$\omega_d = 2\pi f_d = \frac{d\phi}{dt} = \frac{4\pi}{\lambda}\frac{dR}{dt}$$

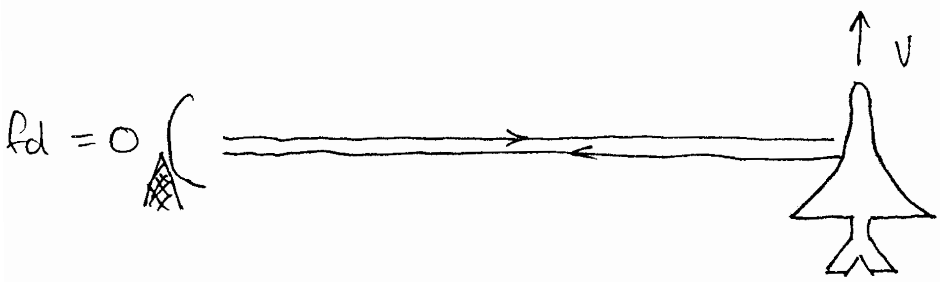
SINCE $\frac{dR}{dt}$ IS VELOCITY WE CAN WRITE

$$f_d = \frac{2v_r}{\lambda} = \frac{2v_r f_0}{c}.$$

HENCE IF WE CAN MEASURE THE DOPPLER FREQUENCY WE CAN DETERMINE THE VELOCITY.

NOTE THAT THIS ONLY MEASURES THE <u>RADIAL COMPONENT</u> OF VELOCITY.



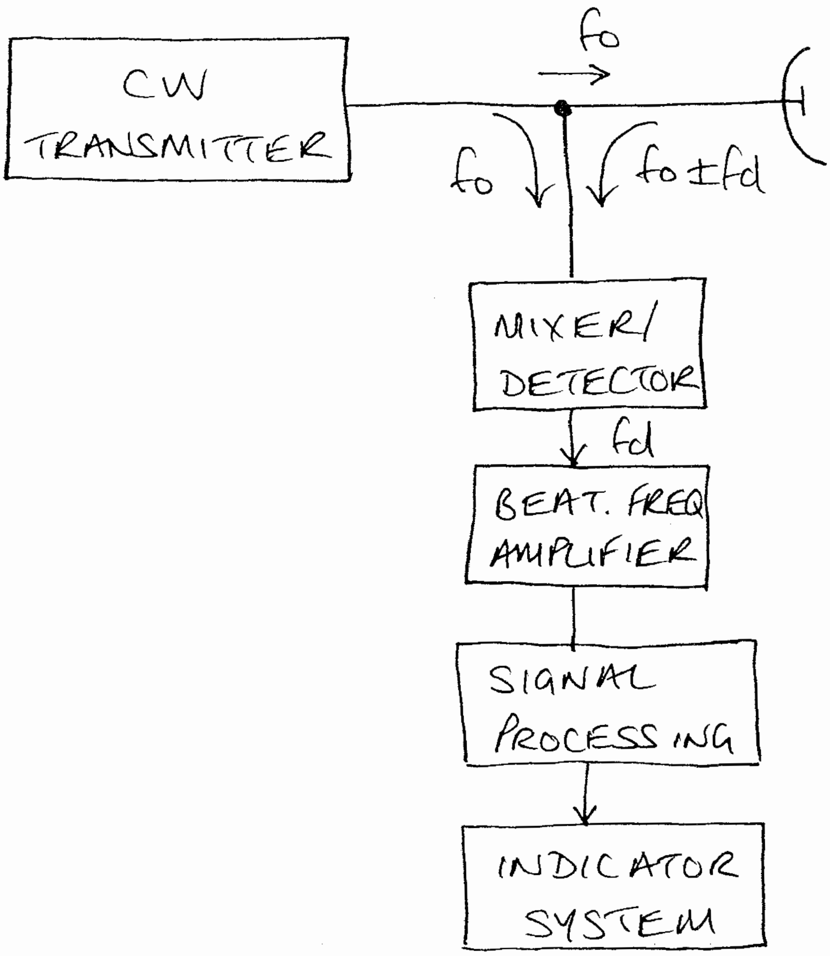


THE VELOCITY $V_r = V\cos\theta$ WHERE θ IS THE ANGLE BETWEEN THE RADAR ANTENNA AND THE TARGET'S TRAJECTORY

CW RADAR

THE TRANSMITTER GENERATES A CONTINUOUS WAVE (UNMODULATED) SIGNAL AT f_o. SOME OF THE ENERGY IS SCATTERED BACK TOWARDS THE RECEIVER

IF THE TARGET HAS A RADIAL VELOCITY OF $\pm V_r$ WE HAVE A DOPPLER SHIFT OF $\pm f_d$.



NOTE: THIS IS A HOMODYNE OR "ZERO IF" SYSTEM, AFTER MIXING, WE LOSE THE SIGN OF THE VELOCITY.

THE PREVIOUS DIAGRAM OF A SIMPLE CW RADAR USED A SINGLE ANTENNA FOR BOTH THE RECEIVER AND THE TRANSMITTER

IN PRACTICE WE MUST USE TWO ANTENNAS FOR CW RADARS TO ACHIEVE ISOLATION BETWEEN THE TRANSMITTER AND THE RECEIVER.

FOR EXAMPLE, IF OUR TRANSMITTER OUTPUT IS 1kW AND OUR RECEIVER HAS A SAFE MAXIMUM INPUT OF 10mW, WE NEED 50dB OF ISOLATION. IF WE ALSO WANT TO MEASURE VERY WEAK (LONG RANGE) TARGETS WE NEED MORE ISOLATION SUCH THAT THE TINY RETURN SIGNAL IS NOT SWAMPED BY THE TRANSMITTED SIGNAL.

- THE EASIEST WAY TO ACHIEVE THE HIGH ISOLATIONS REQUIRED IS TO SEPARATE THE TRANSMITTER AND RECEIVER ANTENNAS

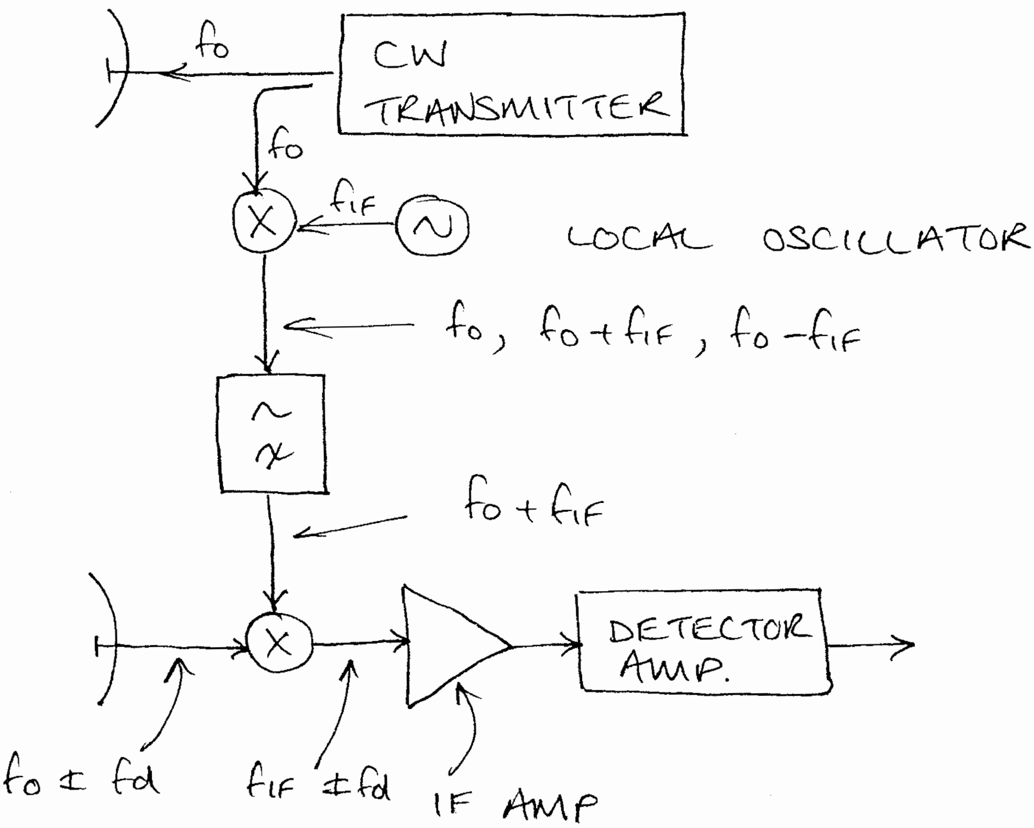
  TYPICALLY AROUND 80dB ISOLATION IS POSSIBLE IN THIS WAY.

CW RADAR WITH NON-ZERO IF

ONE OF THE MAJOR PROBLEMS WITH THE SIMPLE CW RADAR IS NOISE.

SINCE THE DOPPLER FREQUENCY IS CLOSE TO D.C FLICKER NOISE WHICH OCCURS IN SEMICONDUCTORS AND VARIES AS 1/f CAUSES CONSIDERABLE SENSITIVITY PROBLEMS

AT THE COST OF COMPLEXITY, WE CAN SOLVE THIS PROBLEM;



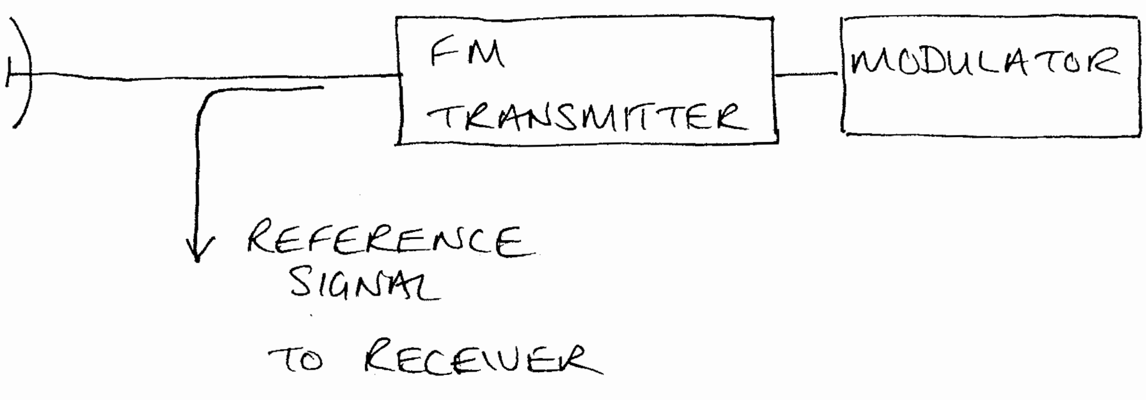
FREQUENCY - MODULATED CW RADAR

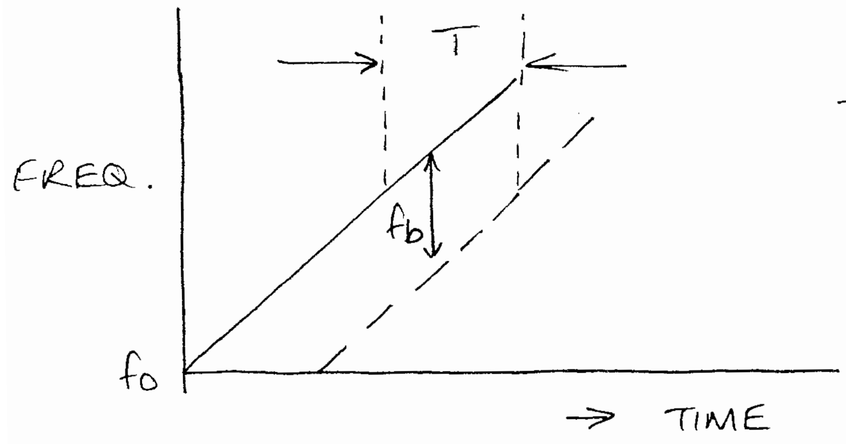
THE LARGEST SHORTCOMING OF THE CW RADAR IS ITS INABILITY TO MEASURE RANGE.

TO MEASURE RANGE WE NEED TO ADD SOME FORM OF TIMING MARK, ALLOWING US TO RECOGNIZE THE TIME OF TRANSMISSION.

IF WE FREQUENCY MODULATE THE SIGNAL WE TRANSMIT, THE TIMING MARK IS THE CHANGE IN FREQUENCY. THE TRANSIT TIME IS PROPORTIONAL TO THE DIFFERENCE IN FREQUENCY BETWEEN THE ECHO SIGNAL AND THE TRANSMITTER SIGNAL.

THE TRANSMITTER IS MODIFIED TO ALLOW FM MODULATION





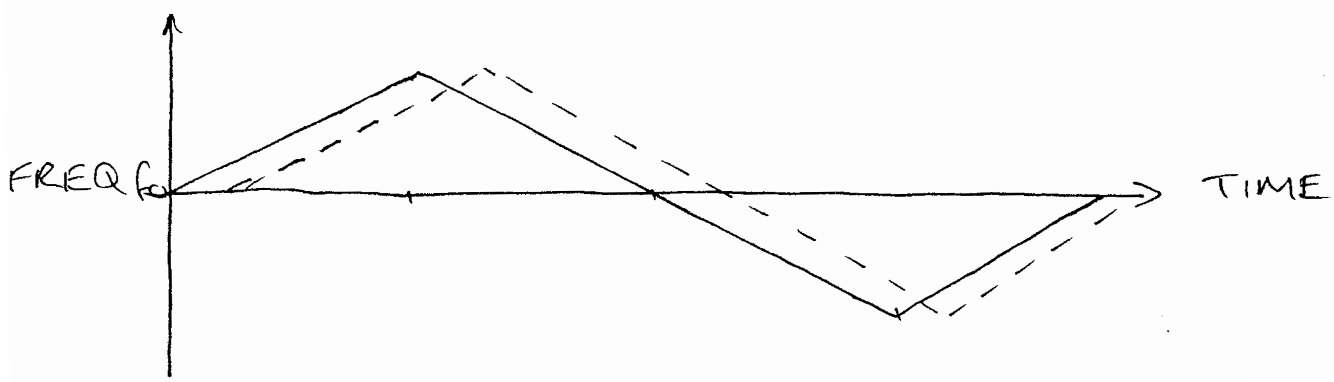
$$T = \frac{2R}{c}$$

ASSUMING THERE IS NO DOPPLER SHIFT, THE BEAT FREQUENCY f_b WILL BE A MEASURE OF THE TARGET'S RANGE THAT IS THE BEAT FREQUENCY $f_b = f_r$.

IF THE RATE OF CHANGE OF THE CARRIER IS f_0' THE BEAT FREQUENCY IS;

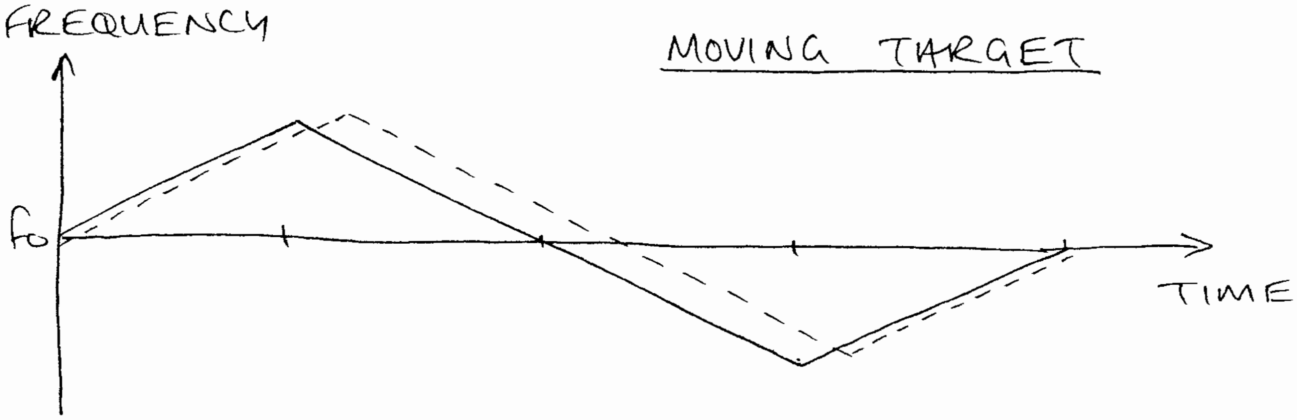
$$f_r = f_0' T = \frac{2R}{c} f_0'$$

OBVIOUSLY, WE CAN'T KEEP INCREASING THE FREQUENCY FOREVER - WE USUALLY USE A TRIANGULAR WAVEFORM FOR THE MODULATION



WE CAN DETERMINE THE RANGE BY USING FFT TECHNIQUES TO FIND THE BEAT FREQUENCY AND HENCE DETERMINE THE RANGE

IF THE TARGET IS MOVING, WE HAVE TO MODIFY OUR PROCEDURE;



FOR A MOVING TARGET, WE HAVE TWO BEAT FREQUENCIES;

$$f_b \text{ (UP)} = f_r - f_d$$

$$f_b \text{ (DOWN)} = f_r + f_d$$

FROM THE SUM: $f_r - f_d + f_r + f_d = 2f_r$

FROM THE DIFFERENCE: $f_r + f_d - (f_r - f_d) = 2f_d$.

(ASSUMING VELOCITY IS CONSTANT OVER A MODULATION CYCLE)

MTI AND PULSE DOPPLER RADAR

* USE DOPPLER FREQUENCY TO MEASURE SPEED

* RANGE MEASUREMENT FROM PULSE DELAY.

THERE ARE TWO BASIC TYPES

* MTI - MOVING TARGET INDICATOR
  OPERATES WITH DOPPLER AMBIGUITIES - (BLIND SPEEDS)
  BUT
  NO RANGE AMBIGUITIES

* PULSE DOPPLER - NO VELOCITY AMBIGUITIES, BUT RANGE PROBLEMS.

THE DIFFERENCE BETWEEN THE TWO LIES IN THE SPEED OF THE TRANSMIT PULSES

MTI RADAR

THERE ARE TWO BASIC FORMS OF MTI RADAR DEPENDING ON THE TYPE OF TRANSMITTER USED.

RADARS CAN BE BASED ON EITHER

* POWER AMPLIFIER (e.g KLYSTRON)
* POWER OSCILLATOR. (e.g MAGNETRON)

KLYSTRON

A KLYSTRON IS A VERY HIGH POWER DEVICE THAT CAN FUNCTION AS AN AMPLIFIER. POWERS FROM 1 – 10 + WATTS

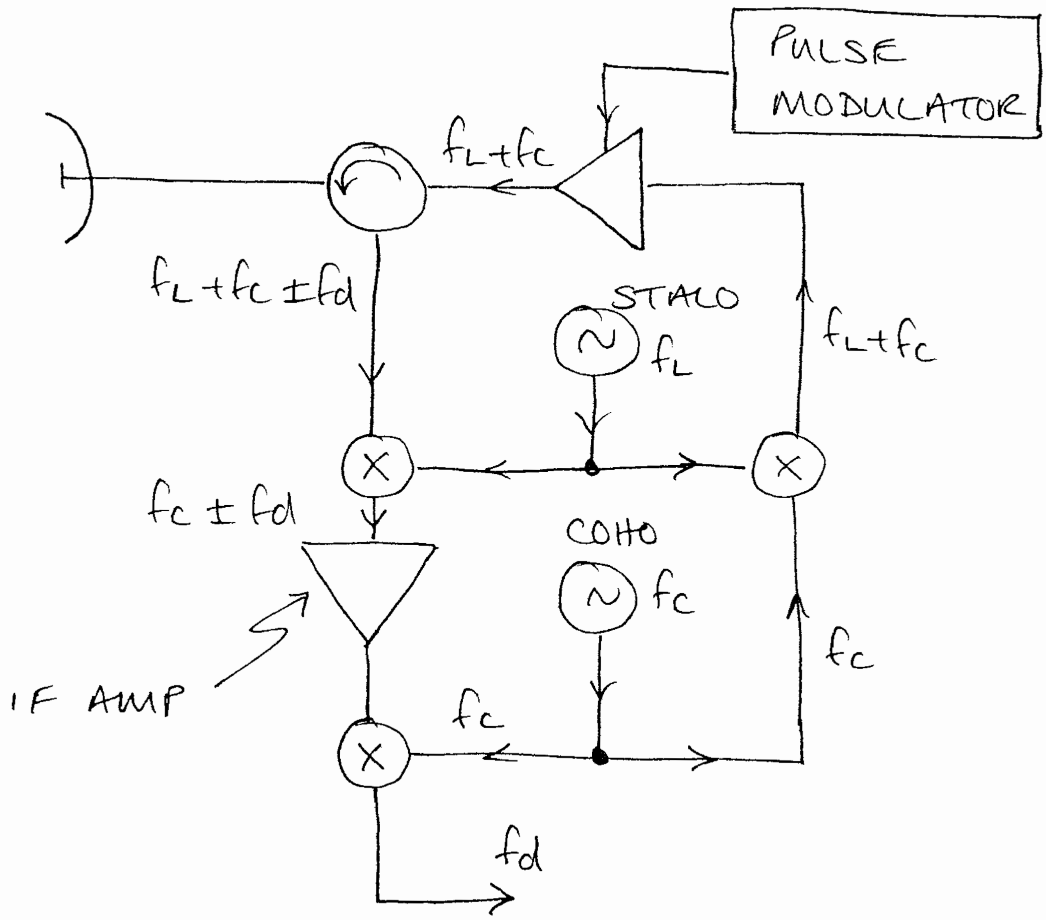
MAGNETRON

A POWER OSCILLATOR. HIGH POWER OUTPUT 500 – 500 kW. THE PROBLEM WITH A MAGNETRON IS THAT YOU CAN NEVER BE SURE OF THE OUTPUT PHASE WHEN PULSE MODULATED

- THIS IS NOT THE CASE WITH THE KLYSTRON

POWER AMPLIFIER TRANSMITTER

(COHERENT ON TRANSMIT)

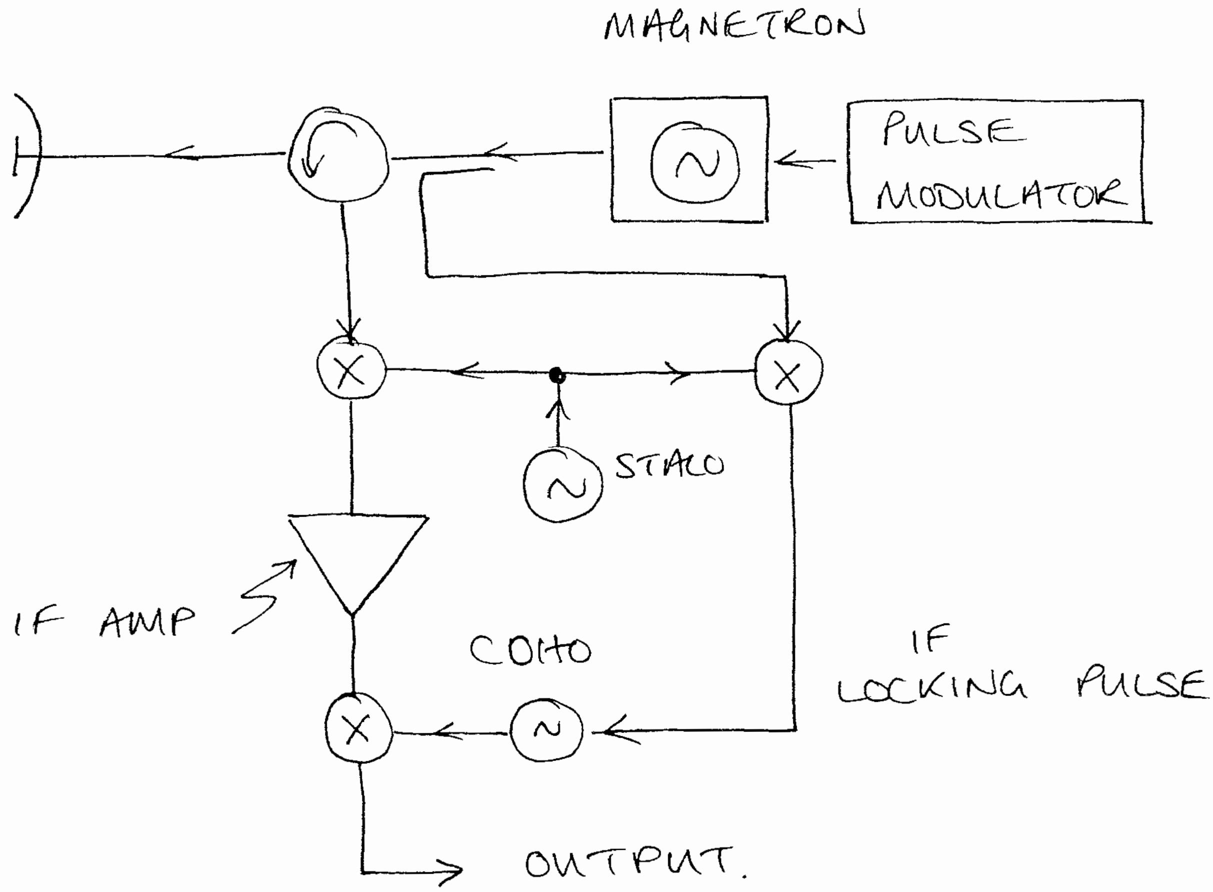


* COHO – COHERENT OSCILLATOR

* STALO – STABLE LOCAL OSCILLATOR

$f_c \sim 30 - 70\,MHz$
$f_L = 3\,GHz$ (SAY)

POWER OSCILLATOR TRANSMITTER



MODERN DOPPLER RADARS

MODERN DOPPLER RADARS USUALLY DO NOT DIRECTLY MEASURE THE DOPPLE FREQUENCY.

VELOCITY ESTIMATION IS USUALLY PERFORMED VIA A NUMBER OF PHASE MEASUREMENTS OVER TIME.

$$\omega d = 2\pi f d = \frac{d\phi}{dt}$$

THE DOPPLER DILEMMA

THE DOPPLER DILEMMA IS DESCRIBED BY THE FOLLOWING;

$$R_{MAX} V_N = \frac{c\lambda}{8}$$

FOR A GIVEN WAVELENGTH, THE RHS IS CONSTANT.

HENCE IF WE WANT TO INCREASE THE UNAMBIGUOUS RANGE R_{MAX} WE MUST SUFFER A DECREASE IN THE NYQUIST VELOCITY.

THIS FAVOURS RADARS WITH LONGER WAVELENGTHS

	R = 100km	200km	500km
$\lambda = 10cm$	$37.5ms^{-1}$	$18.75ms^{-1}$	$7.5ms^{-1}$
$\lambda = 5cm$	$18.75ms^{-1}$	$9.375ms^{-1}$	$3.75ms^{-1}$
$\lambda = 3cm$	$11.25ms^{-1}$	$5.625ms^{-1}$	$2.25ms^{-1}$

HENCE LONG RANGE AIR-SURVEILLANCE RADARS USUALLY OPERATE AT S-BAND ($\lambda = 10cm$) OR BELOW (EVEN LONGER WAVELENGTH

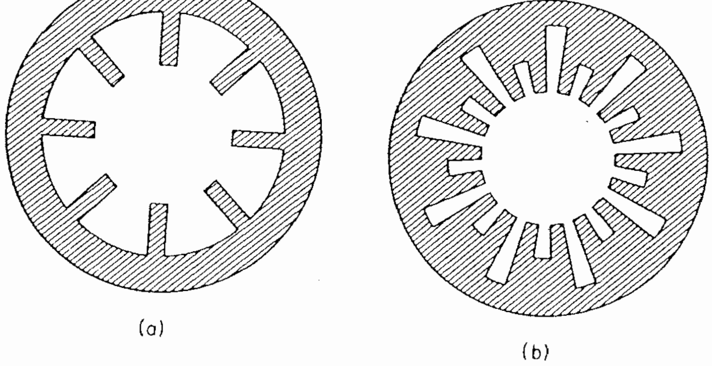


Figure 6.2 Magnetron resonators. (*a*) Vane type; (*b*) rising sun, with alternate slot lengths.

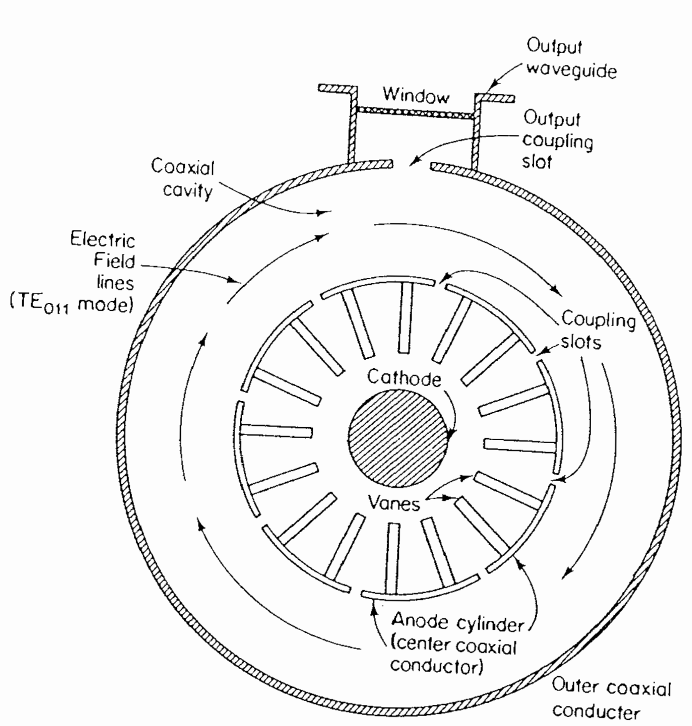


Figure 6.3 Cross-sectional sketch of the coaxial cavity magnetron.

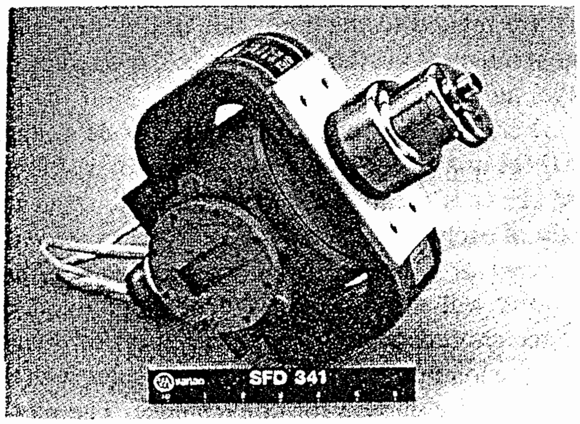


Figure 6.4 Photograph of the SFD-341 mechanically tuned *C*-band coaxial magnetron for shipboard and ground-based radars. This tube delivers a peak power of 250 kW with a 0.001 duty cycle over the frequency range from 5.45 to 5.825 GHz. The efficiency is 40 to 45 percent. *(Courtesy Varian Associates, Inc., Beverly, MA.)*

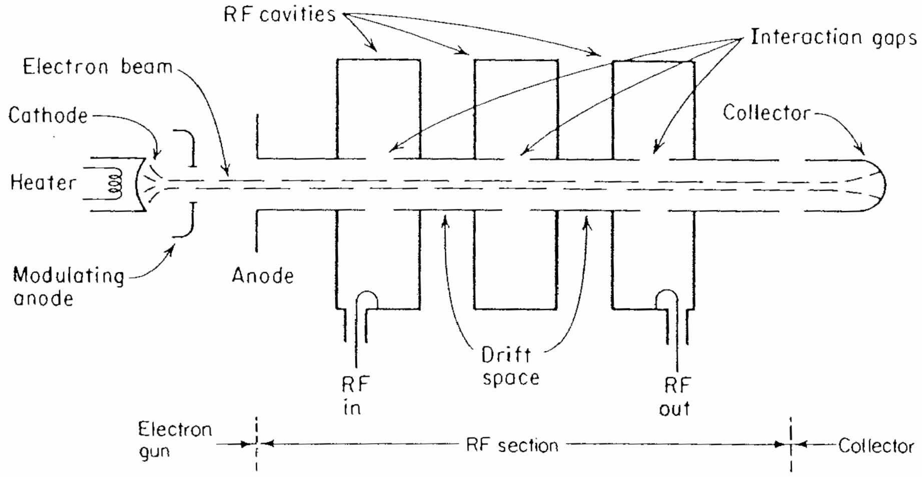


Figure 6.9 Diagrammatic representation of the principal parts of a three-cavity klystron.

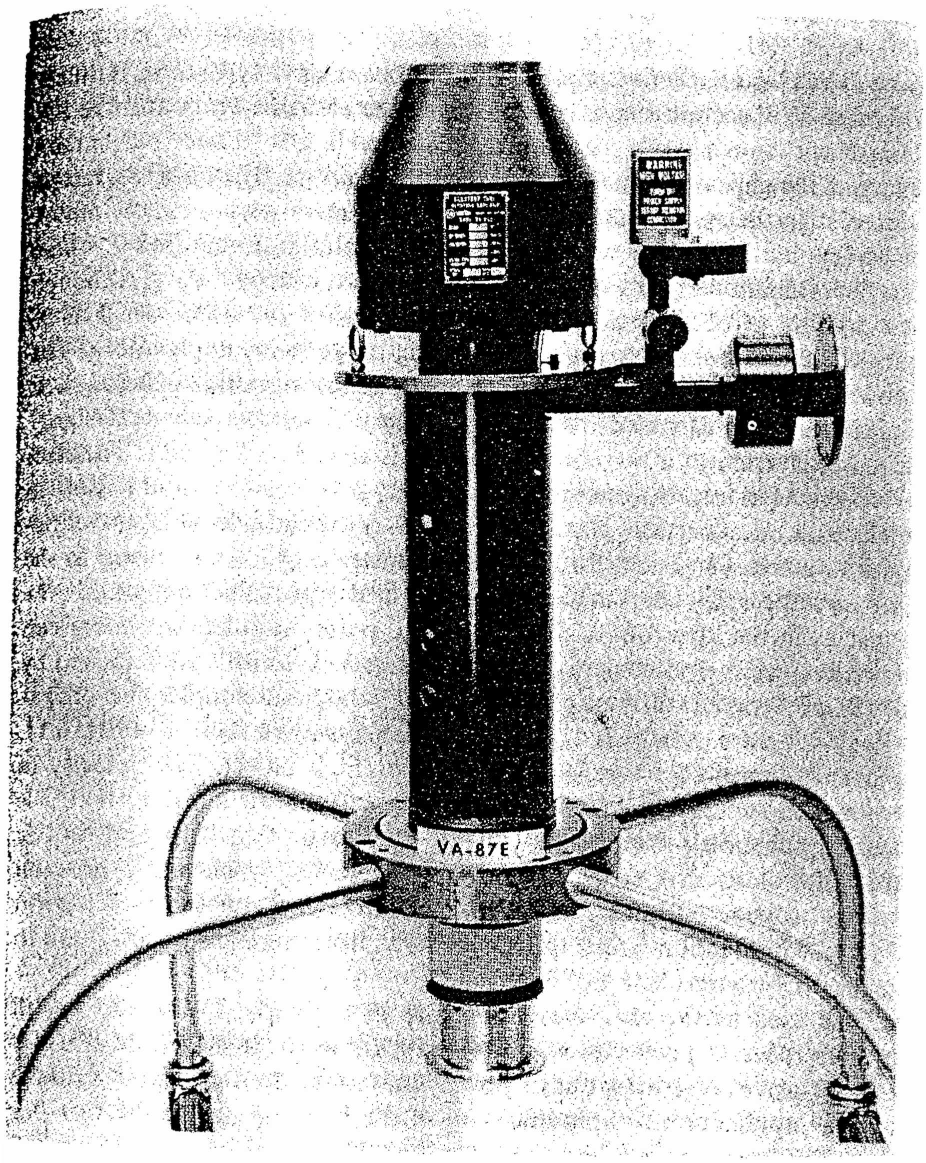


Figure 6.10 Photograph of the VA-87E 6-cavity S-band klystron mounted on a dolly. (*Courtesy Varian Associates, Inc., Palo Alto, CA.*)