Level Cruise @ 30,000 ft
Radar Tilt Down 5º

Most Reflective

Wet Hail
Rain
Wet Snow
Dry Hail
Ice Crystals
Dry Snow

Least Reflective

10,000 ft

Airborne Weather Radar

PART II: Theory & Operation for More Effective Troubleshooting

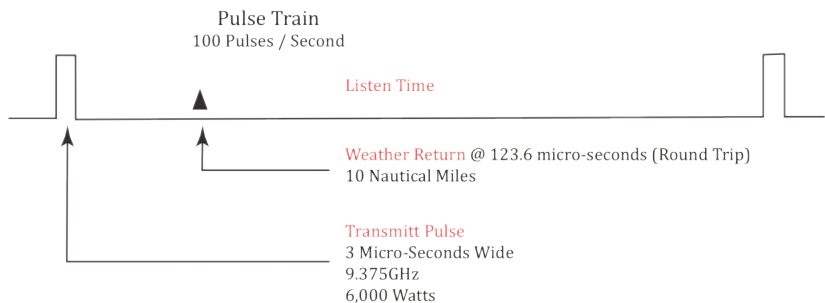STORY BY DAVID W. MANSEN, TEXASGYRO

THEORY

► *Pulse Train*

RADAR, an acronym for RAdio Detecting And Ranging, works on the principle of emitting a high frequency RF pulse and listening for its return. In theory, this is simple, but in real world applications, radar is incredibly complex.

Today's typical weather radar systems will emit 100 pulses-per-second, called the pulse repetition frequency and operate at a frequency of 9.345GHz or 9.375GHz.

A RF pulse travels at the speed of light, taking 12.36m (micro) seconds to travel one nautical mile out and back. Round trip time will give the operator distance to the target. For example; a RF pulse will take 123.6m seconds out and back from a target 10 nautical miles away.

Pulse Train
100 Pulses / Second

Listen Time

Weather Return @ 123.6 micro-seconds (Round Trip)
10 Nautical Miles

Transmitt Pulse
3 Micro-Seconds Wide
9.375GHz
6,000 Watts

-- Figure 3-1: RF Pulse Train --

The radar transmits a pulse of 6 kilo (6,000) watts, yet receives a very tiny signal of -110dbm, or .01 Nano (.000,000,000,000,01) watts. The receiver will be blanked during transmit, and for a very short period of time after transmit, to prevent the sensitive receiver crystals from being damaged. For this reason, the system will not paint targets at close range, typically less than one-fourth mile in weather mode.
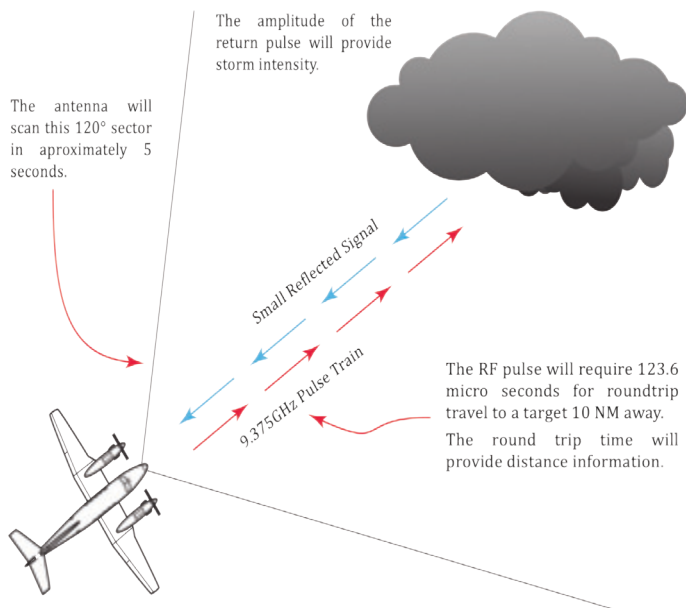
Sensitivity time constant is a means of ensuring that targets both near and far are displayed at the rainfall density level. STC provides consistent target returns throughout the system's range by adjusting the receiver gain over time, thus insuring that a target at 10 nautical miles will be displayed at the same level as a target at 200 nautical miles.

Minimal discernable signal refers to the smallest signal detected by the radar system. This is viewed on the bench and measured in dbm. Typical MDS will be -110dbm.

► Target Detection

Azimuth, distance and amplitude are determined by the following:
- The direction the beam is focused gives the azimuth.
- Roundtrip time is calculated to give distance to target.
- Relative amplitude of the returned pulse will give an indication of the size of the target.

The amplitude of the return pulse will provide storm intensity.

The antenna will scan this 120° sector in aproximately 5 seconds.

Small Reflected Signal

9.375GHz Pulse Train

The RF pulse will require 123.6 micro seconds for roundtrip travel to a target 10 NM away.

The round trip time will provide distance information.

*-- Figure 3-2: Target Detection --*

► Radar Beam

The radar transmits a beam of radiation which gets wider as it travels farther from the source, similar to a flashlight beam which will illuminate a larger area at a distance than it will close up. The radar beam is a cone of radiation which will be tightly focused in the middle and less so towards the edges. This is often called the radar "beam width" or "beam diffusion." The larger the parabolic dish or array, the tighter the focus of the beam. More RF radiation is focused on the target with a tighter, focused radar beam. The more radiation that is focused on the target, the greater the return.

Diameter of Radar Beam

10" Array = 10º Beam Width
12" Array = 8º Beam Width
18" Array = 5.5º Beam Width
24" Array = 4º Beam Width

-- Figure 3-3: Radar Beam Width --
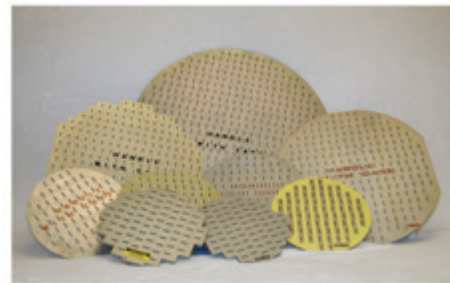
-- Figure 3-4: Radar Arrays of Various Sizes --

One degree of beam width will illuminate a circle 100 feet in diameter at one nautical mile. Most radar arrays will have a beam width anywhere between 6 degrees to 10 degrees. This image illustrates the large areas of illumination at various distances.

Beam width versus array size can vary with each manufacturer's unique array designs.

Continued on following page

► *Search (Small/Near Targets)*

Design requirements that engineers must consider in system development are:

• Size of target.
• Distance (near/far) of target.
• Relative speed of target.

These requirements will determine the system basics, such as frequency, pulse width and the pulse repetition frequency.

Frequency is fixed by the choice of the magnetron; this is not variable. Pulse width and PRF are dynamically variable and will change depending upon range and mode.

A typical weather cell is approximately three miles in diameter. This is the size of the target that today's weather radar systems are designed to detect.

Most systems in use today have a ground map or search mode. In map mode, variable gain will be enabled. (Operation of variable gain is discussed in detail in the Pilot's Perspective section, which will be featured in Part 3 of the May issue.) PRF will be varied and the PW will be varied. It is not uncommon for PRF and PW to be varied with range in weather also, but not to the extent as in search or map modes.

Map/Search modes have different STC curves and are calibrated differently than weather modes and should never be used for weather detection.

A wide pulse width on a large target will generate a larger return; however, wide pulse widths poorly illuminate the smaller targets. In search, we are usually looking for a small target.
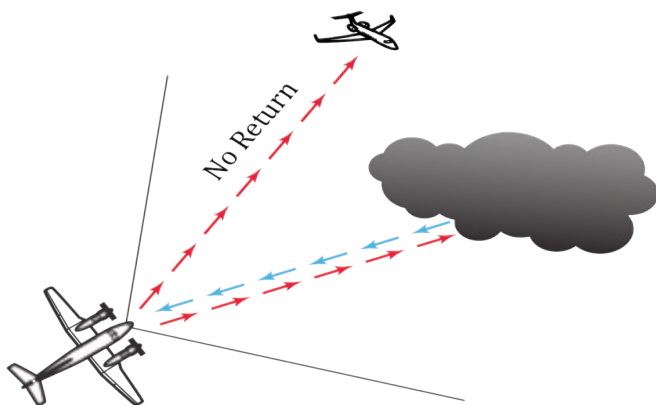
Weather radar will not identify small objects, such as other aircraft.

-- Figure 3-5: Small Object Identification --
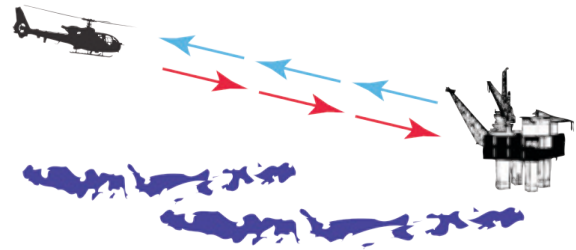
Small and/or close targets must use a narrow pulse with a high PRF.

-- Figure 3-6: Search Operations --

► *Radar System Components*

All radar systems, regardless of make, model or intended function must have the following basic components:

1. A method of transmitting and receiving a pulse of RF radiation.
2. A method of directing and scanning this pulse of RF radiation from the RT in both the horizontal and vertical axis (the antenna pedestal and array - ANT). The radar antenna will focus and direct this pulse train into a radar beam that scans in both azimuth and elevation.
3. A method of displaying the results to the pilot (the Display - DSP). Often the display and controller will be combined in one unit; this unit is usually called the Indicator –IND.
4. A method of controlling the operation of the radar system (the Controller - CON).

Each of these functions is placed in a line replaceable unit. Often, multiple functions will be combined in one LRU. Typically, weather radar systems are classified as two-box, three-box or four-box systems.

A two-box radar system combines the functions of the receiver/transmitter and the antenna pedestal into one LRU, called an ANT/RT. Some system manufacturers refer to this as an ART, while others call it a sensor. This LRU is mounted on the nose of the aircraft where the antenna pedestal normally goes. The second LRU is the indicator, combining the functions of the controller with the display.
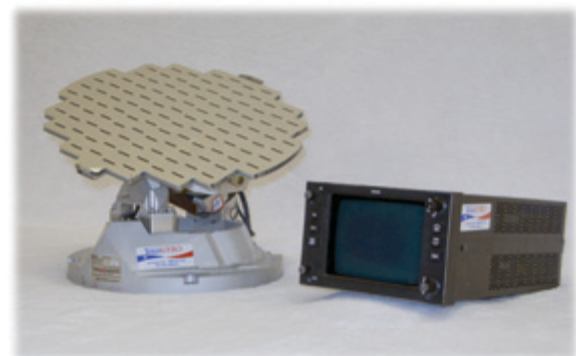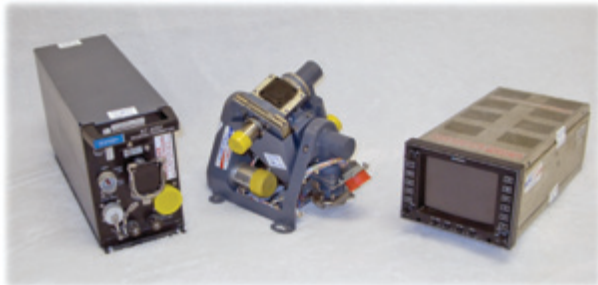

-- Figure 3-7: RDR-2100 --
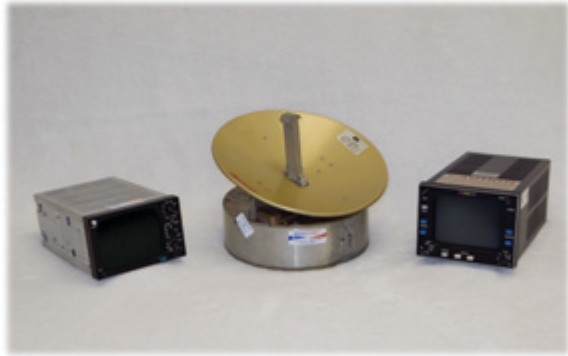
-- Figure 3-8: RDR-160 Monochrome/Color --

A three-box radar system consists of a receiver transmitter, an antenna pedestal and an indicator, combining the functions of the controller with the display.

-- Figure 3-9: Primus 400 --

A four-box radar system consists of a receiver transmitter, an antenna pedestal, a controller and a display. Most aircraft with EFIS have a radar controller and use the aircraft's EFIS MFD to display the radar's target information, thus eliminating the need for an indicator.

-- Figure 3-10: Primus 700 Controller --

► LRU Functions

This section will discuss and focus on a typical three-box radar system. It is meant to present the general concept and theory, not to teach specifics of any one system.

As a general convention when referring to the indicator, we mean a display and controller as one unit. When we discuss a display, we are referring to the multi-function display only.

► System

System control and target data is communicated in many different methods by the manufacturers. Older systems used proprietary control and data methods, either analog, digital or some combination. Most newer systems use ARINC-429 for control of the RT and antenna and ARINC-453 for target data transfer.
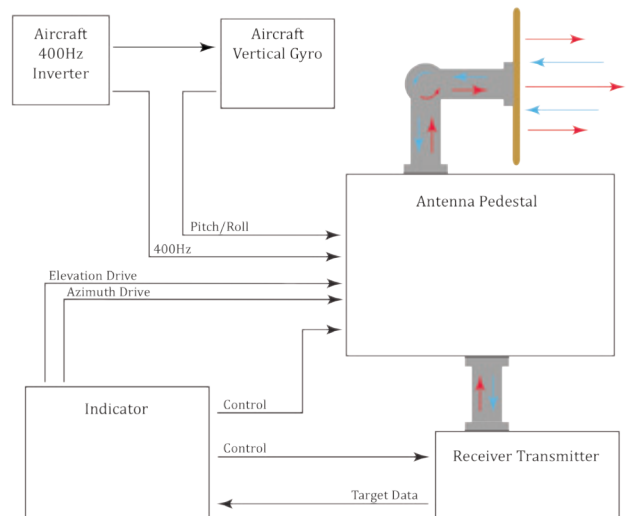
-- Figure 3-11: Radar System Block Diagram --

► Receiver Transmitter

The receiver transmitter contains all of the circuitry to generate the RF pulse and to listen for its return. It sends this data to the display in many different ways, depending on the system.
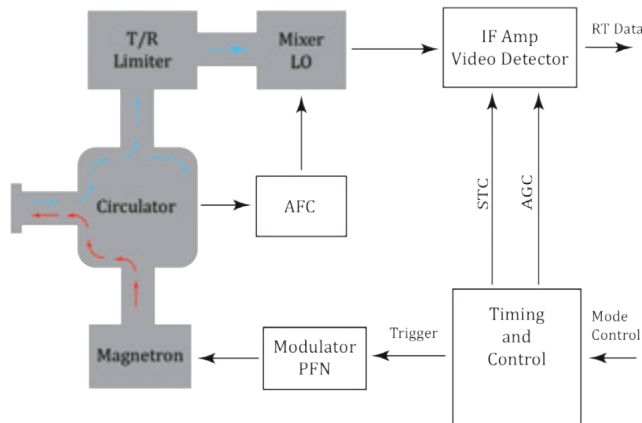

-- Figure 3-12: RT-4001 Receiver Transmitter --

Continued on following page

-- Figure 3-13: Receiver Transmitter Block Diagram --

The timing and control synchronizes all circuitry in the RT. It sets the PW and PRF and generates the trigger. It controls the STC and AGC to the IF amp and the AFC sweep/lock to the LO. Operation of the timing and control is controlled by the system's indicator or controller in the cockpit.

The magnetron is a special vacuum tube that is at the center of the RT. It will generate a clean pulse at 9.375GHz when excited by a high voltage pulse. This will be a narrow, clean pulse with balanced harmonics. The first harmonic will be 10db down from the main.

-- Figure 3-14: Magnetrons --
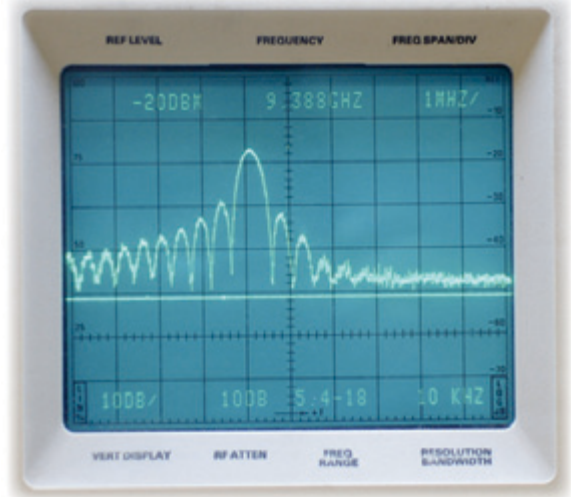
-- Figure 3-15: RF Spectrum --

The modulator Pulse Forming Network creates the high voltage (5,000 volt), high current (5 amp) pulse to fire the magnetron. The timing and control sends a trigger pulse to the "modulator."

The circulator is a RF device with four ports: magnetron, antenna, receiver and AFC. High power RF from the magnetron will travel from the magnetron port out and out the antenna port.

The transmit/receive limiter is a RF switch. This switch opens during transmit, preventing high power RF from damaging the receiver.

The mixer/duplexer-local oscillator combines the received signal (9.375GHz) with a 9.405GHz signal from the local oscillator thus creating an intermediate frequency of 30MHz.

It is a known principle that when two RF signals of different frequencies are combined in a non-linear device (diode), the result is four frequencies: the two originals, the sum and the difference. This is how the very high 9.375GHz RF signal is down-converted to a workable 30MHz frequency.

The mixer/duplexer is a terminated waveguide component. Two crystal diodes in the mixer/duplexer detect the RF signal, changing it from electromagnetic radiation in the waveguide to electron flow.

The IF amp and video detectors (video in the radar world refers to a low frequency signal that contains target interrogation data) process the signals and send the data to the indicator.

Automatic frequency control keeps the local oscillator locked to exactly 30MHz difference from the magnetron. Magnetrons drift in frequency; the receiver is tuned for exactly 30MHz.

▶ *Indicator*

This LRU contains all the circuitry to display the weather data to the pilot. Older systems will utilize a cathode ray tube, while newer units will have a LCD.

*-- Figure 3-16: DI-2007
Radar Indicator --*
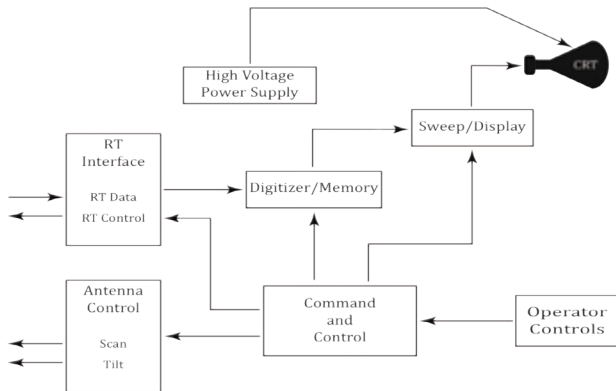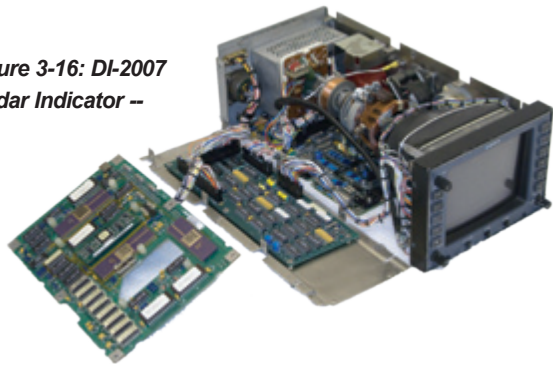
-- Figure 3-17: Indicator Block Diagram --

The indicator will display the data on a CRT. The CRT is an electron tube which requires 12,500 volts to pull the electrons off of the grid. This voltage is provided by the high voltage power supply. Often, the HVPS will get a high voltage drive pulse from the sweep/display.

Command and control is commanded by the operator controls. This circuitry sends azimuth scan and elevation tilt controls to the antenna control and then to the antenna pedestal.

Command and control sends the RT its mode and range commands through the RT interface.

Command and control directs the digitizer/memory and sweep/display circuits to display the desired data to the pilot.

The RT interface will interface the RT with the indicator. It will send mode and range commands received from command and control to the RT. Target data from the RT is received and sent to the digitizer/memory.

The digitizer/memory processes the target data, converts it from Rho-Theta to raster and sends the data to the sweep/display.

Rho-Theta scan is from the apex out; this is how the radar
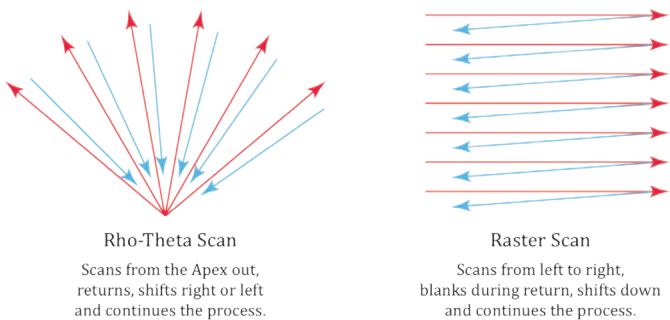
scans for targets. A raster scan is from left to right; similar to how you would read a book. This is how the display will show the data.

The digitizer/memory reads the radar data as a Rho-Theta format and sends the display data out as raster scan.

Some of the older monochrome displays will scan the CRT in a Rho-Theta scan.


Rho-Theta Scan
Scans from the Apex out, returns, shifts right or left and continues the process.

Raster Scan
Scans from left to right, blanks during return, shifts down and continues the process.

-- Figure 3-18: Rho-Theta Scan vs. Raster Scan --

The sweep/display generates the horizontal, vertical and color intensity drive signals for the CRT. It is commanded by the command and control and gets its data from the digitizer/memory.
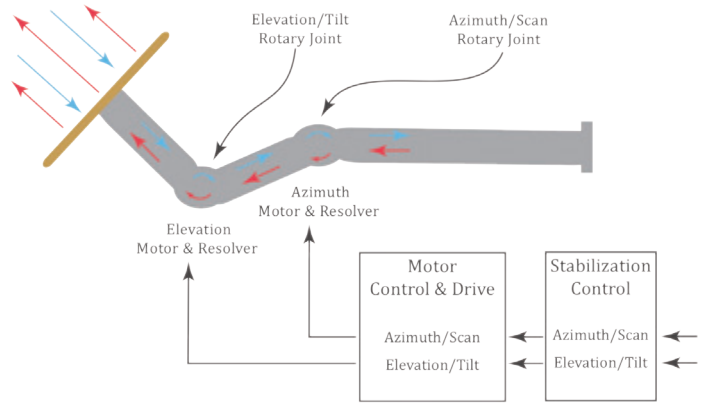
The operator control allows user interface and system control, i.e. mode, range and tilt.

► Antenna

The Antenna will direct the RF beam in the desired scan and tilt as commanded by the Indicator or Controller.
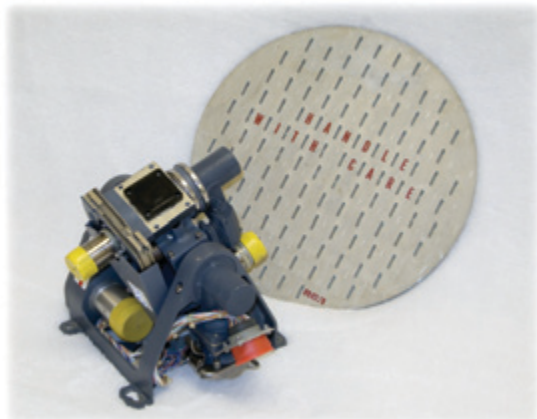
-- Figure 3-19: AP-4001 Antenna Pedestal --

-- Figure 3-20: Antenna Block Diagram --

The Antenna contains rotary joints, which are essentially rotary waveguides, allowing motion in both azimuth and elevation. Motors and gears move the assembly in both azimuth and elevation to scan and tilt the array. Resolvers provide feedback to maintain precise control.

A stabilization control circuit monitors the pitch and roll from the aircraft's vertical gyro. A comparison of pitch and roll with the 400Hz reference from the inverter gives direction of pitch or roll. The amplitude of the pitch and roll signals gives the amount of pitch and roll. This is sine wave of 50 millivolt per degree for fixed wing aircraft or 200 millivolt per degree for helicopters.

The concept of stabilization will be discussed in detail in Part 3 next month.

A stabilization alignment will be discussed in flight-line troubleshooting and repair.

► Waveguides

Waveguide Principles

A waveguide is a transmission device, similar to a coaxial cable. A coaxial cable will experience severe losses at the high frequency of today's radars. A waveguide is a hollow aluminum tube whose diameter is dependent upon the operating frequency. This hollow tube will allow high frequency RF to pass with very little loss.

A flexible waveguide must never be flexed or bent beyond the manufacturer's rated specs. A rigid waveguide must never be bent or twisted. This will impede the RF transmission down the center of the waveguide.

Rigid waveguides can have bends by design; these bends are called an H-Bend and E-Bend. Imagine an H-Bend as "hard" and an E-Bend as "easy."

The connector at the end of the waveguide will either be a "Flange" (Flat) or "Choke" (deep choke groove and shallow o-ring groove). An o-ring must be installed in the o-ring groove. The deep groove is a RF choke, used for impedance matching and must be left empty.

When connecting waveguides together, you must connect a Flange to Choke for best impedance matching, this will minimize voltage standing wave ratio (VSWR, reflected RF waves).
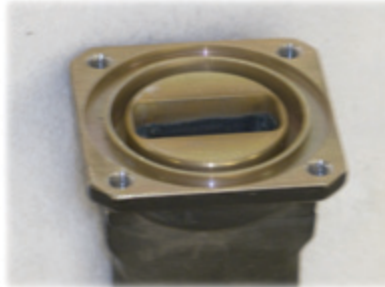
-- *Figure 3-21: Waveguide Components* --

-- *Figure 3-22: Waveguides* --

-- *Figure 3-23: Flange Termination* --

-- *Figure 3-24: Choke Termination* --

Waveguide Pressurization

At altitudes above 25,000 feet, the high power RF pulse will arc in the waveguide due to low atmospheric pressure. Special fittings allow aircraft cabin pressurization to be pumped into the radar's waveguide. This waveguide pressurization prevents arcing of the RF.

O-rings and pressure windows must be used on a pressurized system. If an O-ring or pressure window is left out, the system will leak, with a constant flow of air through the system. Moisture will accumulate, and corrosion in the waveguide will occur. Corrosion and moisture will deteriorate the performance of the radar system. ❑

Editor's Note: Part III of "Airborne Weather Radar" will appear in next month's issue of Avionics News.