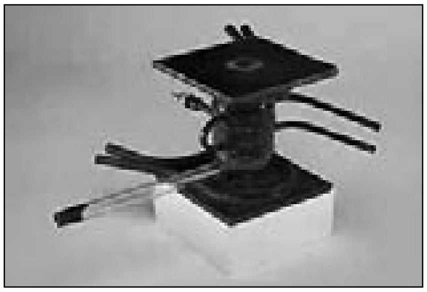
WEATHER RADAR

The Magic Within

BY TONY BAILEY

Radar. The very word tends to entice feelings of Super Science and Magic. In order to understand weather radar, we must have a little background.

Radar, an acronym for Radio Detection and Ranging, was patented by British scientist Sir Robert Watson-Watt for meteorological applications in 1935. Since practical applications for airborne microwave radar had not been developed before World War II, the government of England requested assistance from the U.S. National Defense Research Committee (NDRC) to develop this capability. Britain's secret Tizard Mission, named after its organizer Sir Henry Tizard, rector of the Imperial College of Science and Technology and chairman of the government's key scientific committee on air defense, was dispatched to Washington, D.C. in September 1940 to introduce the 10-centimeter cavity magnetron. A book written by Robert Buderi published in 1996 by Simon & Schuster titled "The Invention that Changed the World: How a small group of radar pioneers won the Second World War and launched a technological revolution," portrays the efforts of Eddie Bowen in his efforts to bring Britain's most closely guarded secret, the Resonant Cavity Magnetron, to American shores and also provides some insights as to the design and principles of radar systems.



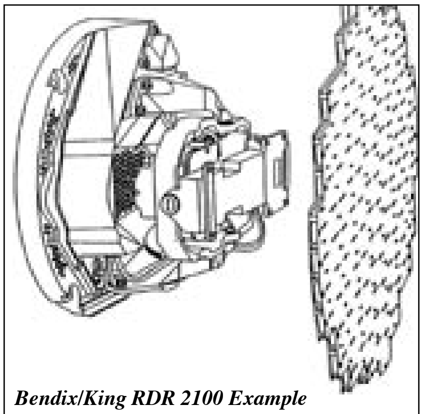
The first magnetron

During World War II, large-scale research at MIT's Radiation Laboratory was devoted to the rapid development of microwave radar. Projects included physical electronics, microwave physics, electromagnetic properties of matter, and microwave communication principles. The "RadLab" designed almost half of the radar deployed in World War II, created over 100 different radar systems, and constructed $1.5 billion worth of radar. At the height of its activities, the RadLab employed nearly 4,000 people working on several continents. What began as a British-American effort to make microwave radar work, evolved into a centralized laboratory committed to understanding the theories behind experimental radar while solving its engineering problems.

One of the evolutions of radar happened during the war when units in England were trying to get advance warning of Nazi air strikes during the Battle of Britain utilizing Radar systems. They noticed that when it rained the radar screens were covered in a gray haze ... and planes could not be detected. While scientists tried to get around the problem, weather forecasters quickly saw the advantages of the new invention. Weather radar was born!

Basically, radar works by sending out a radio wave at a very high frequency. When the radio signal hits raindrops part of the signal bounces back to the radar. The signal travels at the speed of light (over 350,000 kilometers per second). Knowing exactly how fast the signal is traveling, means that a computation can be made to tell how far away the rain is by timing how long it takes for the signal to travel to the rain and then bounce back to the radar. This happens so fast that most radars send out about 1,000 signals (called pulses) each second.

So it makes sense that radar systems would utilize a transmitter to send out the radio waves and a receiver to collect the returned signal all channeled through an antenna and a display. Older airborne radar systems were plagued with huge components often connected with miles of wiring. Not so anymore. The newer systems are often contained in one neat little package connected to a display which can perform many different functions (multi-function) or smaller components closely located in the nose of the aircraft.



Bendix/King RDR 2100 Example

The transmitter portion of the radar usually consists of a high voltage power supply, pulse transformer, magnetron, magnetron isolator, circulator, harmonic filter and the antennas. The high voltage power supply and the pulse transformer provide the magnetron with a pulse for a set amount of time, depending upon the model. The timing of the pulse is generated by the pulse timing circuit on the logic board. Once the magnetron fires, the Radio Frequency (RF) pulse passes through a magnetron isolator. This isolator is necessary to protect the magnetron from being pulled in the case of a bad Voltage Standing Wave Ratio (VSWR) from either the antenna or radome. From the magnetron isolator the RF pulse then passes through a port circulator. This circulator allows the magnetron energy to pass through to the antenna and not on to the receiver.

From the circulator, the RF pulse then passes through a harmonic filter which is necessary to reduce the power in the second harmonic of the magnetron in order to pass radiated harmonic specifications. The RF pulse is then radiated by the antenna into the atmosphere with a gain that is dependent upon the antenna size.

The weather data accumulator circuit consists of video Analog to Digital Converter (A/D), Weather Transmit (WX) Read Only Memory (ROM), weather compensation and an extended Sensitivity Timing Control (STC) control circuit, WX Random Access Memory (RAM), radial sum circuit, circuit RAM, and the serial data transmitter. The digitized video from the video A/D is passed onto the lower address bits of the WX ROM. Additional address bits of the WX ROM are used for weather compensation control. The final address bits of the WX ROM are used for extended STC.

The extended STC increases the level of the returned signal at a linear rate. The extended STC provides additional STC range, but not at a true calibration rate. The compensated video from the WX ROM is then clocked into the WX RAM at the range clock rate. The WX RAM consists of different pages. Each page holds bytes of compensated video from one radial with numerous radials involved. At approximately 4 msec. after the magnetron fires, the radial summation starts. The radial summation sums all radials and then divides the sum by its number to obtain an average compensated video. The average compensated video is transferred to the circuit RAM at approximately 5 msec. after the magnetron fires. During the transfer, the average compensated video is converted to a color level. Once the data has been sent to the circuit RAM, the microprocessor then sends a request to the circuit transmitter to start transmitting data to the indicator. The data format of the transmission follows the modified ARINC 708 Data Specification with compatibility to the Radar Distribution Switchboard (RDS) series radars.

As for the configuration of the average receiver, the RF pulse travels from the antenna at a rate approximately equal to the speed of light to a weather target and then is reflected back to the antenna. The antenna provides a gain to the received energy depending upon the antenna size. The received energy from the antenna is then passed through the harmonic filter into the port circulator. The circulator prevents the received energy from passing towards the magnetron and allows the energy to pass to the receiver.

From the circulator, the received energy passes through the diode limiter. The diode limiter is used to protect the receiver from the high amount of energy produced by the magnetron. Although the circulator provides isolation to the receiver from the magnetron, there is still a very large amount of energy which is allowed to pass. The diode limiter is self biasing when a large amount of energy enters the input port. The limiter is then biased on and allows only a portion of the power out the output port. The received signal is of low enough energy level to prevent self-biasing of the limiter. Once the received signal passes through the limiter, it is then passed on to the receiver module.

The receiver module consists of a low noise amplifier, mixer, local oscillator, and a unity gain buffer. The received signal is amplified, mixed, and the buffered intermediate frequency (IF) is then sent to the preamp. The pre-amplifier consists of a one stage amplifier with a noise gain and a temperature sensor. The temperature sensor is used for all receiver calibration operations. From the pre-amplifier the received signal is then passed to the IF section of the logic board. The IF section consists of a band pass filter, two stages of gain, an active detector, a low pass filter, and a video amplifier. Also in the IF section of the logic board is the Automatic Frequency Control (AFC) sample amplifier which is used to supply a strong signal to the AFC circuit during the time the magnetron is firing. There are different stages of gain in the IF section used to control the calibration and noise level of the receiver.

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The first stages of the amplification are the STC and the Automatic Gain Control (AGC). The STC is used to calibrate the receiver to compensate for the two way loss of energy through the atmosphere. This gain level will vary with time starting with the magnetron fire and ending at a set nautical mile distance, depending upon the size of the antenna. Once the STC time is complete, the final gain level will be the AGC gain. The second amplifier is the Manual Gain control. The gain of this amplifier will vary depending upon the gain setting selected by the pilot. After the received signal is amplified to a calibrated level, it is then detected by an active detector with a gain. From the detector, the signal is once again filtered by a selectable low pass filter. This switching of filters increases the receivers performance by reducing the noise of the signal. From the low pass filter, the signal is buffered through a unity gain amplifier and passed on to the video A/D.

Included in the receiver is the AFC which is used to control the frequency of the local oscillator in the receiver module. The local oscillator is mixed with the received signal and a frequency is produced. In order for the IF to remain at a set level, the AFC circuit must adjust the local oscillator periodically to correct for magnetron frequency drift. The AFC circuitry consists of three basic parts—the frequency sample circuit, the microprocessor, and the local oscillator voltage drive circuit. During the magnetron fire, a small amount of energy is allowed to pass into the receiver and is mixed with the local oscillator.

The IF signal is then amplified by the preamp and sent on to the IF section of the logic board. In the IF, the AFC amplifier increases the magnetron frequency sample to a level which activates the discriminator circuit. The output from the discriminator circuit is then passed on to a unity gain amplifier to the discriminator A/D. “Samples” from the discriminator A/D are saved in the STC RAM and recalled by the microprocessor for AFC control.

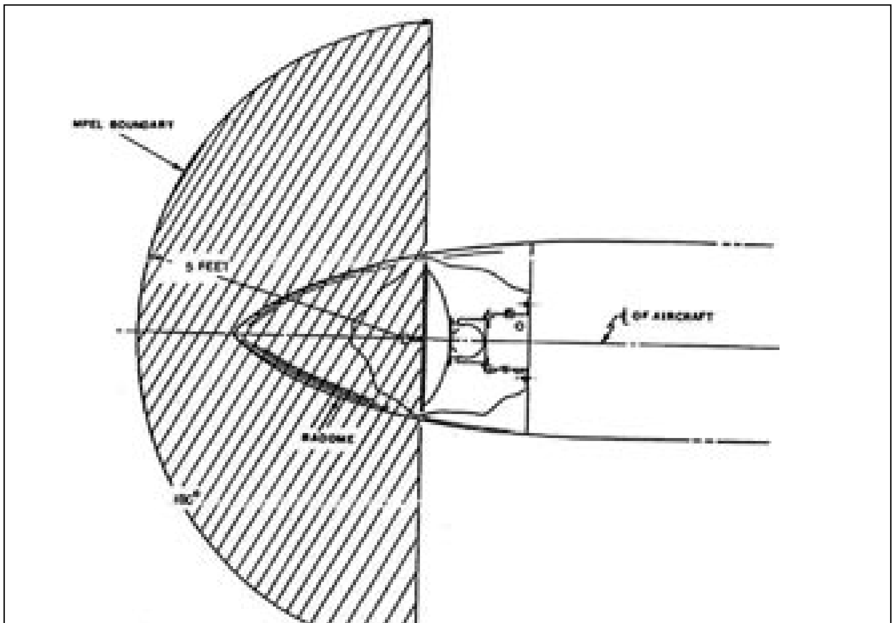
The microprocessor reads the samples from the memory and determines if the intermediate frequency is either too high, too low or on frequency. If the local oscillator is off by a large amount, either high or low, then the microprocessor drives the local oscillator at large frequency steps. Once the IF is within a pre-determined range from desired, then the microprocessor drives the local oscillator by smaller frequency steps. The local oscillator drive circuitry consists of D/A converters. The output from these converters is summed together and sent to the receiver as the LO drive. The converters consist of the course, fine and offset. The offset is adjusted by the microprocessor in the AFC software procedure. The offset is also controlled by the microprocessor and accounts for the frequency pulling of the local oscillator by the magnetron.

A key component of the radar system is the gyro and antenna stabilization circuit. The gyro and antenna stabilization circuit consists of three parts—the analog gyro inputs, the azimuth and tilt motor drive circuits, and the Hall effect sensors. The analog gyro inputs consist of the 400 Hz reference, pitch and roll. There are numerous gyro systems which the radar system must interface to. Each of these systems have varying parameters from aircraft to aircraft. The gyro reference input can vary depending upon specific component ranges. The gyro reference input therefore has a switchable gain amplifier so that the same level of reference voltage may be applied to the detector circuit. The pitch and roll inputs are applied to fixed gain amplifiers and then detected. The detected outputs from the three signals are then integrated and multiplexed to a programmable amplifier. The gain values for the programmable amplifier are stored in the configuration module and applied to the amplifier when the appropriate input is selected.

The pitch and roll data is multiplexed by the microprocessor to the A/D converter and then read by the microprocessor. The pitch and roll data is then used to calculate the appropriate tilt of the antenna in accordance with the current azimuth setting. Once the tilt angle has been calculated, then the microprocessor determines if the tilt of the antenna should be increased or decreased from its current setting. The microprocessor,

TERMS AND DEFINITIONS

TERM	DEFINITION
RAM	Random Access Memory
ROM	Read Only Memory
RADAR	Radio Detection and Ranging
NDRC	National Defense Research Committee
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
A/D	Analog to Digital Converter
IF	Intermediate Frequency
WX	Weather Transmit
STC	Sensitivity Timing Control
RDS	Radar Distribution Switchboard
AFC	Automatic Frequency Control
AGC	Automatic Gain Control



Bendix/King RT 2100 RADAR Safety Boundary

in a fixed interrupt time, instructs the azimuth drive circuit and the pitch drive circuit to step their motors. The azimuth motor drive circuit and the tilt motor drive circuit are located on the power supply/modulator/motor drive board due to the heat generated by the driver circuit. These drivers receive commands from the microprocessor to either step the motors up or down or not to step the motor at all. The azimuth and pitch motors are usually stepper motors and step the antenna in a measured degree of steps. The two Hall effect sensors are used to determine the position of the antenna in both the tilt and azimuth axis.

As far as troubleshooting a problem with any radar system, it is imperative that you utilize the proper maintenance manual and observe all of the safety precautions. Radar is dangerous! Some common sense rules apply and each manufacturer has set guidelines that must be followed for your safety. One common safety element while working with radar systems is that the area in front of the aircraft or radar antenna must remain clear during transmit or WX operation. Another rule is to never, never, expose any part of your body to an unterminated wave guide (connecting portion from the magnetron to the antenna) during operation. This also applies when a wave guide has been damaged. Take the time to read FAA Advisory Circular AC 20-68B, Recommended Radiation Safety Precautions for Ground Operation of Airborne Weather Radar. Your safety may depend upon it.

That pretty much sums up the basic operation of an airborne weather radar system. The truth is, it is a combination of super science and magic, although the experts may disagree. From an avionics technician standpoint, the magic involved comes from the science of a specific installation doing funky stuff! That is the radar we really see. At least now, the science makes sense. Clear as mud, right? ❑

Reference Material: FAA Advisory Circular AC 20-68B, Recommended Radiation Safety Precautions for Ground Operation of Airborne Weather Radar; The Invention that Changed the World: How a small group of radar pioneers won the Second World War and launched a technological revolution by Robert Buderi published in 1996 by Simon & Schuster; ARINC 708 Data Specification; Honeywell Bendix/King ART 2100 Color Weather Radar Antenna/Receiver/Transmitter Manual Number 006-05390-0001Revision 1, June, 2000.