94 GHz FMCW RADAR FOR LOW VISIBILITY AIRCRAFT LANDING SYSTEM

L. Q. Bui, Y. Alon, T. Morton

Lear Astronics Corp.
3400 Airport Blvd., Santa Monica, CA 90406

Abstract

This paper describes a 94 GHz bistatic FMCW radar currently under development for an aircraft landing system. Using a narrow vertical fan beam antenna, the system scans the runway rapidly in azimuth, processes the radar returns, and obtains a realistic real-time runway image with sufficient information and resolution to enable a pilot to operate in and out of the airport in conditions with visibility as low as zero without dependence on today's auto-land systems. This system may use an airport's glide slope indicator to approach the landing area. The range performance requirements of the landing system are illustrated in Fig. 1.

I. SYSTEM DESCRIPTION

Figure 2 shows the system block diagram consisting of the following major subassemblies:

- An antenna unit
- A linearized FMCW transceiver
- A Digital Signal Processing Unit (DSPU)
- A radar control unit
- A power supply unit

1. Antenna Unit

The antenna unit consists of two identical 4" x 24" reflector antennas operating in a bistatic configuration. This configuration provides maximum isolation between the transmitter and receiver, and avoids mixer saturation at high transmitted power in order to achieve the range requirements. At 94 GHz the required high angular resolution can be met simultaneously with rapid azimuth scanning by tilting the reflector. The reflector surface employs a unique design producing a circularly-polarized transmitted signal with a linearly-polarized feed horn.

2. Linearized FMCW Transceiver

The transceiver consists of the Tx/Rx unit and the Radar Interface Unit (RIU). The linearized transmitter produces 500 mW, linearly modulated over selectable bands up to 200 MHz, at 94 GHz. A closed-loop linearizer guarantees the system linearity better than 0.1%. A balanced mixer is utilized in the MIC down-converter consisting of a 180 degree microstrip hybrid and two GaAs Shottky beamlead diodes on quartz substrate. The RIU houses the IF baseband receiver, and the Radar Control Card (RCTRL) which interfaces the transceiver with the other subassemblies.

3. Digital Signal Processing Unit

A high speed signal processor supports the basic radar and image processing functions and provides the Head-Up Display (HUD) interface. The unit consists of: an FFT processor, five parallel CPUs, I/O interface card, and a scan converter. The scan converter receives the DSP's digital data on a parallel bus and converts it to RS-170 format for either Head-Up Display (HUD) or Head-Down Display (HDD). The CPUs also provide computational capability for future system enhancement such as aircraft motion compensation.

4. Control Unit

A PC based radar control unit selects the radar mode and functional parameters. The following functions can be selected by RS-232 commands:

- Sweep Control: CW/50/100/200 MHz
- Gain Control: Automatic/Manual
- Azimuth Control: ± 15 or ± 30 degrees
- Elevation Control

The head-up display unit and the data collection system are not part of the basic radar system. These units will be used for the tower and flight evaluation.

The complete FMCW radar specifications are summarized in Table 1.

II. PRINCIPLES OF OPERATION

The detail functional block diagram is shown in Fig. 3.

The antenna unit consists of two separate horn-fed reflectors using flat parabolic surfaces (FLAPS): one for transmitting and the other for receiving. The surfaces are made up of crossed shorted–dipoles (centered at 94.3 GHz) situated over a ground plane with intermediate low dielectric material. The dipoles convert the linearly polarized incident RF to the circularly polarized RF. The resulting secondary patterns are circularly polarized even though the feeds are linearly polarized. The azimuth beamwidth is less than 0.36 degree. In the elevation plane, a cosecant square shaped beam is achieved with 3 dB beam width of 4 degrees. The ± 15 degree azimuth scanning is accomplished by tilting the reflector, and the antenna gain is flat within 1 dB over the scan limits. The isolation between the two antennas is better than 50 dB.

The FMCW transceiver consists of the Tx/Rx unit and the RIU. The Tx/Rx unit contains the 94 GHz transmitter chain, and the MIC down–converter. The transmitter consists of a Gunn VCO, two IMPATT injection–locked oscillators, and the delay line linearizer. The ILOs are driven by the Gunn VCO and combined at output by a short slot hybrid. The transmitter output is connected to the T/X port of the antenna unit via WR–10 waveguide. A portion of the transmitted signal is coupled to a quartz MIC down–converter which provides two different IFs by mixing the sampled transmitter signal to the delayed return and to the linearizer local oscillator. The linearizer IF, which is the down–converted Tx sweep centered about 1.5 GHz, is fed to the delay line linearizer which provides an error signal to correct for the transmitter non–linearities. The radar IF is amplified and fed to the baseband receiver gain block with 50 dB AGC. The gain block output is then routed to the DSPU.

The FMCW transceiver is controlled by a radar interface card which communicates with the other subassemblies and converts the antenna RS–232 and DSPU RS–422 serial messages to parallel bit control to set all the radar functions.

The radar video signal is digitized by a 12–bit A/D converter. The 1024 point FFT is performed in a period of 400 micro–S. The resulting 512 range profiles are further processed by 5 CPUs to produce a clear C–scope radar image for the head–up display output. The radar functions, selected by the operator on the control unit, are sent to the DSPU and then to the radar via RS–232 and RS–422 serial data message format.

The antenna azimuth and elevation scanning is controlled by the servo amplifier. The angular setting, as selected by the radar operator and DSP software, and the resulting antenna instantaneous position are transmitted by the RS–232 communication link to the radar interface unit.

The radar system utilizes the 28 Vdc aircraft supply which is regulated in the switching power supply unit to produce all the dc power required by the radar system.

III. SYSTEM PERFORMANCE AND EVALUATION

For system performance evaluation the complete radar system will be mounted on a tower overlooking a runway. During the evaluation period, the radar will be used to collect the runway images. System performance will be judged on the quality of the images and how well it performed under various weather conditions. A data collection system will be used during tower test to gather data in several ways:

- The C–scope radar image from the DSPU which drives the HUD is recorded on a VCR.
- A video camera records the real–world scene, along with annotated information for HUD tape analysis.
- Raw time–domain radar video from the FMCW front–end is recorded on an analog tape recorder. This data can be played back through the DSPU. Simulating a live signal from the radar front end enables various DSP algorithms to be tested off–line.

A computer program was written for modeling the radar system. It provides a systematic approach to optimize the radar parameters by observing the changes in the radar images. It also allows one to see how the raw data can be refined by various image processing algorithms. Figure 4 shows a simulated runway image with Adaptive Offset Extraction (AOE) processing in foggy conditions. Using AOE, the image contrasts may be enhanced significantly, especially in rainy conditions as illustrated in the simulations of Figure 5(a) (without processing) and (b) (with AOE processing).

The system is currently being integrated for tower test. Real radar images are expected to be available for the presentation at this IEEE Symposium.

Acknowledgements

The authors wish to express their gratitude for the Joint FAA/DoD/Industry–funded program jointly managed and directed by the FAA and USAF with Malcolm Burgess of the FAA as Program Manager; to Marconi Defence Systems, Stanmore, UK, for the transmitter/receiver and general design support; to Malibu Research Associates, Inc., for the design of the FLAPS antenna; and to the Lear Astronics Corp. Analysis group, which developed the image simulations featured in this report.

Table 1. 94 GHz FMCW Radar Parameters

Radar Type	FMCW
Configuration	Bistatic/Homodyne
Center Frequency	94.3 GHz
Transmitted Power	500 mW min.
Tx/Rx Antenna Isolation	50 dB min.
Antenna Gain	39 dB
Polarization	Circular
Horizontal Beamwidth	0.36 deg
Vertical Beamwidth	4.0 deg (cosecant square beam spoiler)
Scan Rate	5 Hz
Azimuth Scan Angle	± 15 deg or ± 30 deg
Elevation Stabilization	± 15 deg
Modulation	FM-CW
Bandwidth	CW 50 MHz (Acquisition Mode) 100 MHz (Approach Mode) 200 MHz (Taxi Mode)
Sweep Time	1.8 ms
Linearity	< 0.1%
Sub-Ramp	4 per sweep
Display	C Scope (Elevation vs. Azimuth)
Maximum Process Range	6,000 meters, Acquisition Mode 3,000 meters, Approach Mode 1,500 meters, Taxi Mode
Range Resolution	14 meters at 6,000 Meter Range 7 meters at 3,000 Meter Range 3.5 meters at 1,500 Meter Range
Dc Power	28V @ 450 watts

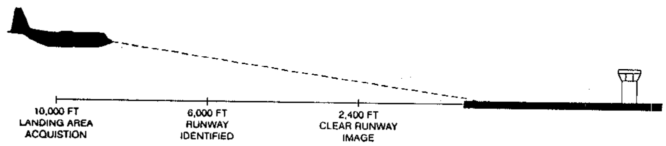


Figure 1. Landing System Range Performance Requirements

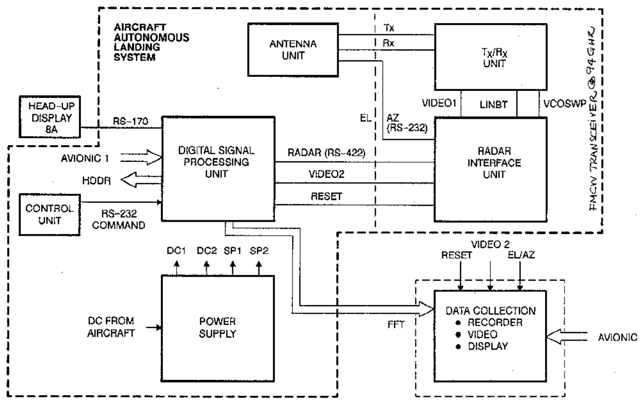


Figure 2. Block Diagram of the Landing System

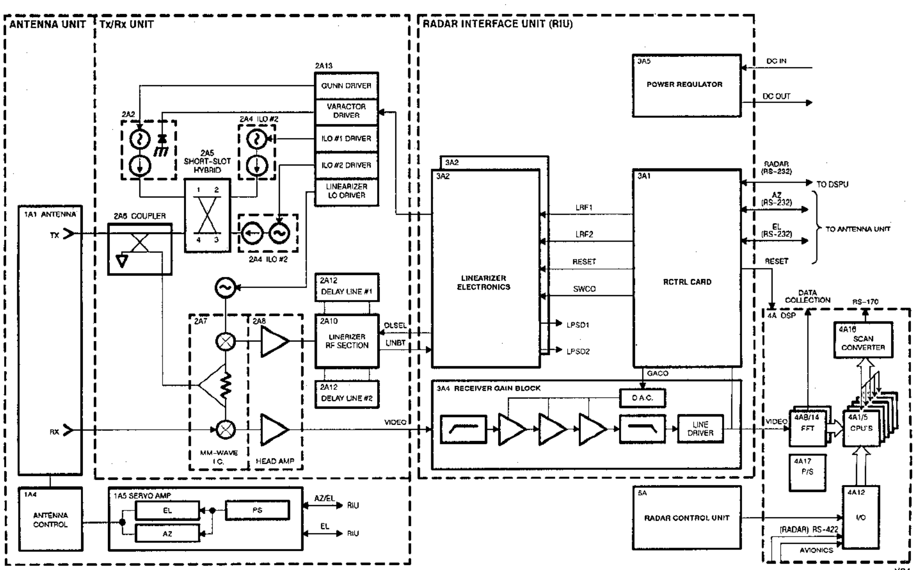
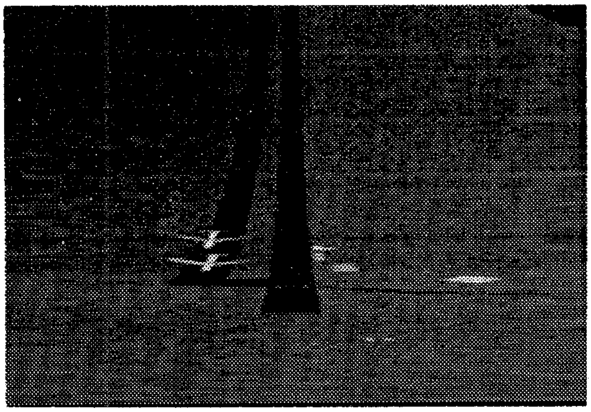
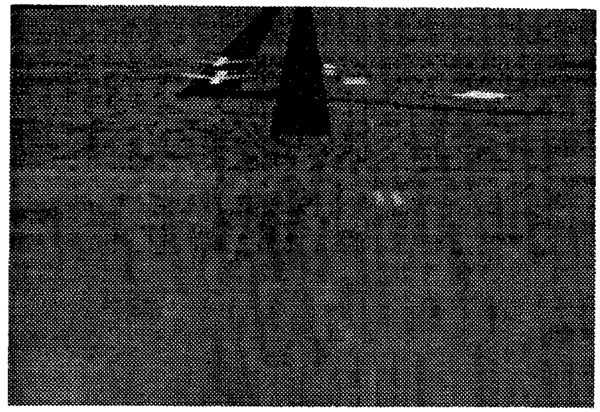


Figure 3. Detail Functional Block Diagram

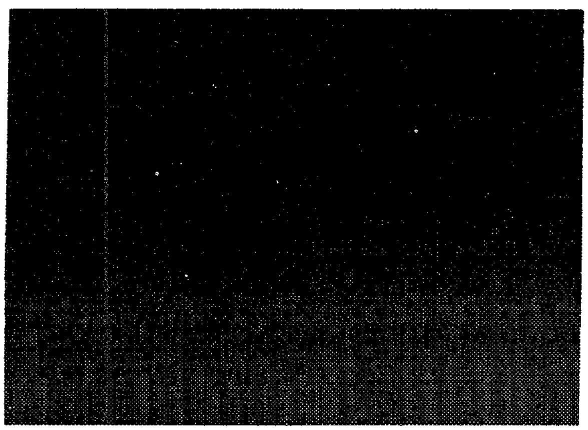


(a) B–Scope

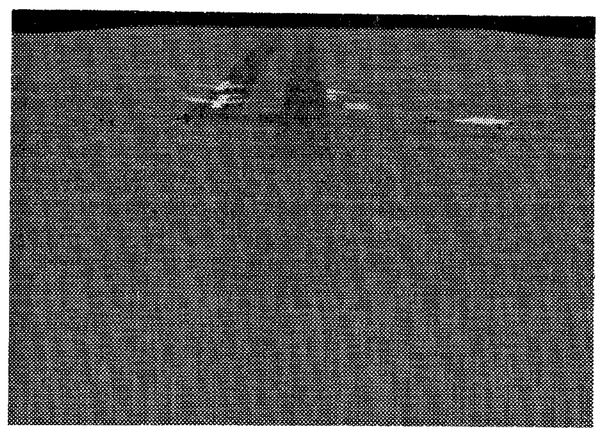


(b) C–Scope

Figure 4 (a) and (b). Simulated Runway Image in Foggy Weather, 0.2 gm/m^3, with AOE Processing



(a) Without AOE Processing



(b) With AOE Processing

Figure 5 (a) and (b). Simulated Runway Image in Rainy Weather, 5 mm/hr (a) without AOE Processing, and (b) with AOE Processing