MLS – A PRACTICAL APPLICATION OF MICROWAVE TECHNOLOGY

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Abstract

A brief system overview of the U.S. Candidate for the Microwave Landing System is presented. Practical implementations of two types of ground antenna designs are discussed, including measured data.

Introduction and System Overview

The system which has emerged from the FAA Microwave Landing System (MLS) Development program as the U.S. Candidate System to ICAO is the Scanning Beam System using a Time Reference Signal Format. This technique will be prototyped and tested in various configurations during 1976 under FAA sponsorship. A runway implemented with the most comprehensive MLS configuration, known as the Expanded Configuration, is shown in Figure 1. This implementation provides ICAO Category III C services.

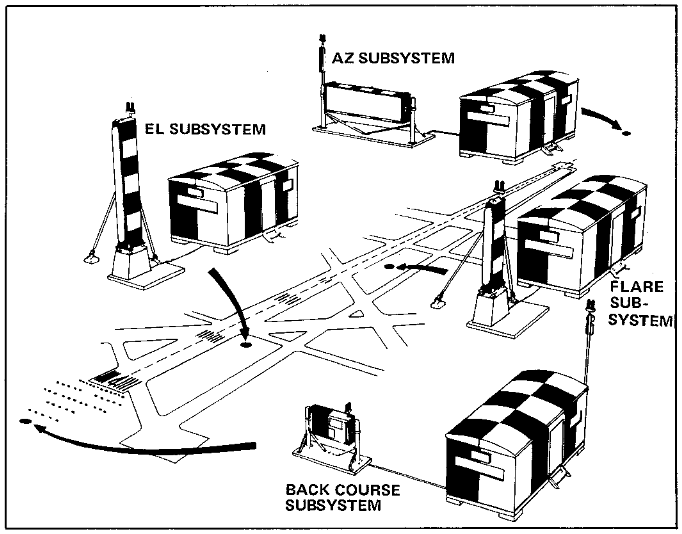

FIGURE 1. INSTALLATION ON A TYPICAL RUNWAY

The MLS signal format uses Time Division Multiplexing (TDM) of all functions using a common carrier frequency. The entire format is synchronized, and guard times are included within the function time slots. The beam scan rates and angle encoding rates for the format are:

Function	Beam Scan Rate (deg/s)	Angle Encoding Rate (μs/deg)
Azimuth	20,000	100
Back Azimuth	20,000	100
Elevation	20,000	100
Back Elevation	20,000	100
Flare	10,000	200
360°	60,000	33.33

Data are transmitted using differential phase shift keying (DPSK) of the RF carrier at a 15-kilobit data rate. This technique is used to transmit elementary data on the omni ID antennas at the beginning of each function time slot, and to transmit auxiliary data.

The standard scan format incorporates a variable-length auxiliary data time slot at the end of each basic 70-ms data group. Auxiliary data blocks of variable lengths are used to provide data time jitter, which serves to prevent synchronization with periodic interference effects such as propeller blockage.

Figure 2 shows a typical subsystem time slot in more detail. Each time slot consists of a sector omni ID transmission of elementary data, followed by transmission of one or two sidelobe suppression (SLS) pulses, as necessary, followed by the high-speed "to–fro" beam scan. The omni ID signal is a data signal transmitted on a "sector omni" antenna which covers the function guidance volume.

Figure 3 shows the angle measurement technique used in the avionics equipment with the centroid of the beams being determined by accumulating half-frequency clock pulses during the dwell gate.

The airborne receiver/decoder, in conjunction with appropriate C-band antennas and a suitable flight control system, will provide the following services:

- Fail passive Category III autoland with dual system configuration
- Curved approach guidance
- Missed approach guidance
- 360° airborne azimuth coverage
- 200-channel capability
- 20-nmi minimum range with expanded ground system
- Reliable guidance in the presence of multipath from time reference scanning beam angle guidance encoding.

Distance information is provided by an independent DME subsystem.

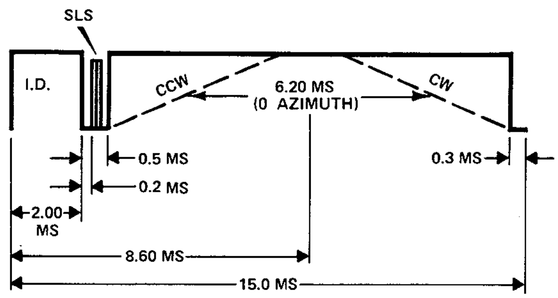

FIGURE 2. AZIMUTH TIME SLOT

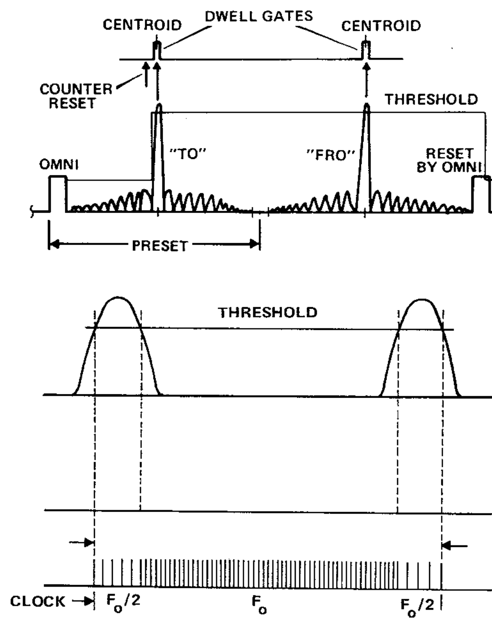

FIGURE 3. ANGLE MEASUREMENT

Ground Antenna Implementation

C-band line array antennas with pattern shaping in the non-scan plane have been implemented for all antenna beamwidths in the 0.5 to 3.0-degree range with accuracies of 0.01 to 0.10 beamwidth. Two types of array antennas have been implemented. The first type is the classical line phased array configuration, consisting of a discrete aperture, a phase shifter per element, and an RF power distribution network. The phased array, because of the degree of amplitude and phase control, is a very high performance antenna over wide scan angles. This antenna is used to satisfy the 0.5 and 1.0-degree high accuracy requirements.

The second type of antenna is the lens array, consisting of a discrete aperture, a parallel plate lens, and a commutation network. The lens antenna is limited in the degree of amplitude and phase control achievable at the aperture plane, and, in general, is a lower performance antenna than the phased array. The beam steering in the lens array is achieved by commutating an amplitude function along the parallel plate lens input. The lens antenna is used to satisfy the 1.5 to 3.0-degree requirements, and is very attractive, from the standpoint of cost, for limited scan requirements.

Both types of arrays are equally applicable to azimuth and elevation scanners. In fact, the radiating apertures are identical for both the phased array and lens array antennas. The polarization is vertical in both cases. The azimuth aperture assembly consists of an array of coaxial-fed, edge-slotted, waveguide elements, with element spacings from 0.5 to 0.6λ depending on the scan requirements. Each waveguide element has four feet of aperture (31 slots) in the vertical plane, to provide the shaped pattern for multipath control and the upper angle coverage. The use of array aperture technology in both planes of this aperture results in maximum utility of the antenna size.

The elevation aperture consists of a colinear array of coaxial dipoles in a shaped ground plane. Element spacing is typically 0.75λ, consistent with the limited elevation scan (0–20 degrees). The dipole ground plane is shaped in the azimuth plane to increase antenna gain on runway centerline and minimize pointing errors due to lateral multipath. The pattern in the elevation plane is a scanning beam with good sidelobe control. Both coaxial and printed circuit dipoles have been implemented, and there is little difference in cost or performance.

Phased Arrays – 1-Degree Beamwidth High Precision

A block diagram of the phased array antenna is shown in Figure 4. The array can be divided into four major sections: (1) the radiating elements, (2) the phase shifters, (3) the RF power divider, and (4) the beam steering electronics. The aperture is, as described previously, either slotted waveguide or coaxial dipole elements. The phase shifters are 4-bit digital, with a phase accuracy of 12 degrees peak, 5 degrees RMS. A center-fed series-type power divider generates a 27-dB Taylor amplitude illumination function with minimum cost and complexity. Frequency

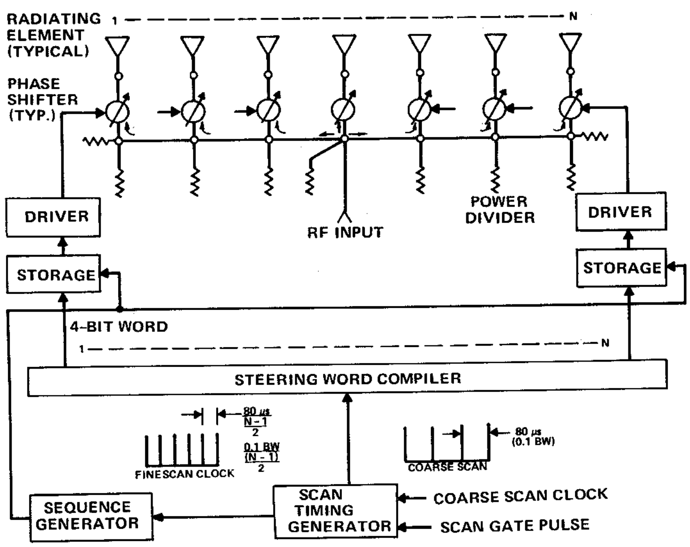

FIGURE 4. MLS PHASED ARRAY ANTENNA BLOCK DIAGRAM

compensation and array calibration are economically performed with logic input adjustments at the element phase shifters. The beam steering unit scans the beam at a rate of 20,000 degrees per second. A coarse/fine scan technique provides coarse scan increments of 0.1 BW, and fine scan increments of $\frac{0.1\ BW}{\left(\frac{N-1}{2}\right)}$, where N is the number of array elements.

The construction of the azimuth phased array is shown in Figure 5. The 1-degree azimuth array has 104 slotted waveguide elements in a 12-foot aperture, fed with a stripline power divider. The phase shifter connects directly to the stripline divider and radiating elements, thus eliminating the need for coaxial cables. The 1-degree elevation array has 82 dipole elements in a 12-foot aperture. A photograph of the elevation array is shown in Figure 6. Measured patterns on this array are shown in Figure 7 for some of the coarse scan increments.

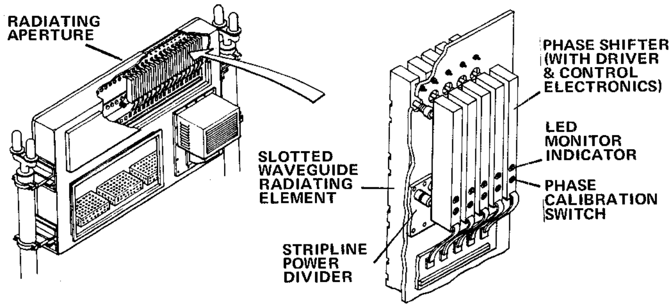

FIGURE 5. CONSTRUCTION OF AZIMUTH PHASED ARRAY

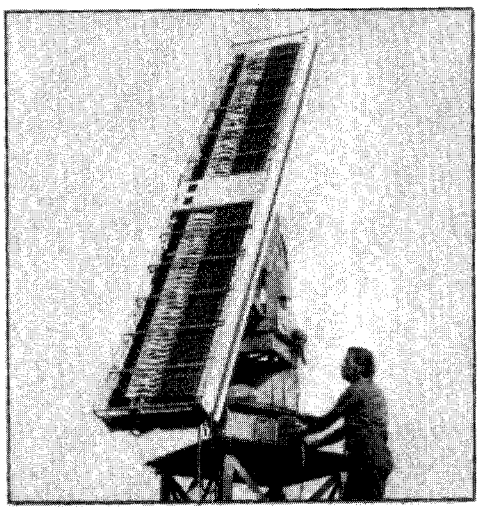

FIGURE 6. ELEVATION ARRAY

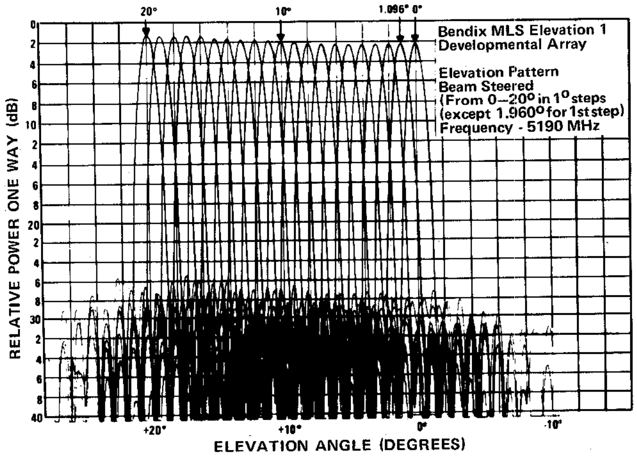

FIGURE 7. STATIC TYPE SCAN PATTERN (EL-1)

The phased array, being a parallel system, has the inherent advantage that it is a "fail soft" unit. Field measured data show that 20% of the total phase shifter bits, when randomly failed, still allow satisfactory array operation.

Lens Array – 1.5 to 3.0-Degree Beamwidth

The lens array concept is illustrated in Figure 8. The lens design uses the theory presented by Rotman and Turner in their paper published in IEEE-AP, November 1963.[1] The lens consists of a parallel plate air dielectric section, a group of lens coaxial cables (one to each element in the array aperture), and a commutation scan network. The lens concept is used with both azimuth and elevation scanners. Beams at various angles in space are generated, corresponding to the input probe excited. For example, if a probe at the center of the input probe focal arc is excited (position # 1), a plane wave, with uniform illumination, is generated at the aperture plane corresponding to boresight beam # 1. If a probe around the input focal arc (position # 2) is excited, a new phase gradient is produced, and beam # 2 is generated at a new angle in space. Likewise, a probe excited at position # 3 will generate still another beam at angle #3, etc. Lens input probe spacing corresponds approximately to one beamwidth spacing. To provide a cosine illumination function for sidelobe control and a means of fine scanning (generating beams corresponding to positions between input probes), a group of four input probes is excited with a precise set of amplitude weights. The beam is scanned in 0.1-beamwidth increments by commutating this set of amplitude weights around the input probe arc. The number of beamwidths scanned is controlled by the number of input probes on the focal arc. The lens has three perfect focal points, and the design is generally such that one is at boresight and one each at the plus and minus scan limits. Phase aberrations between focal points cause pointing errors which are compensated for in the beam steering units. Lens antennas have been implemented with scan angles from ±10 to ±40 degrees.

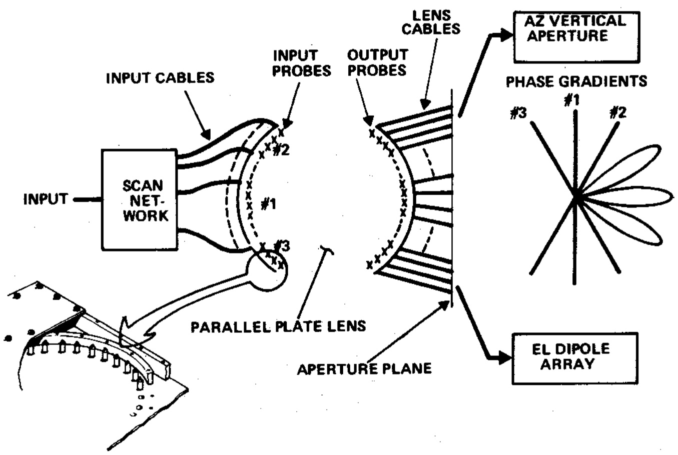

FIGURE 8. LENS ARRAY CONCEPT

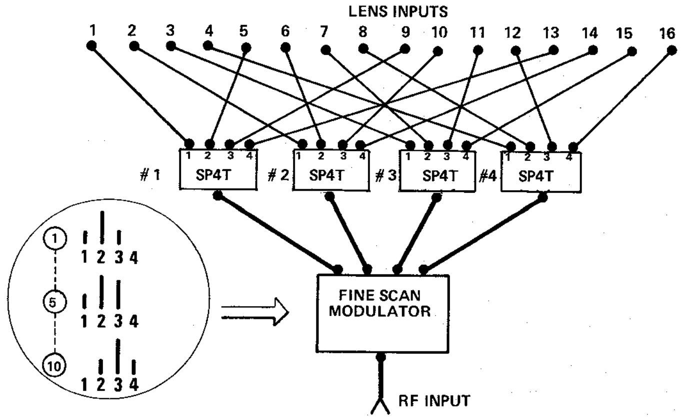

FIGURE 9. SCAN NETWORK FOR 1.5-DEGREE BEAMWIDTH ANTENNA

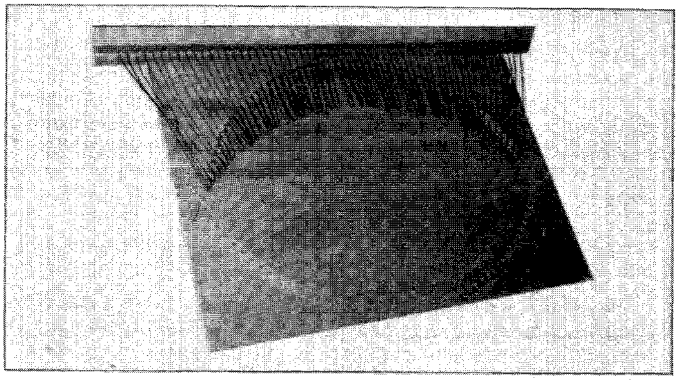

FIGURE 10. CONSTRUCTION OF LENS ANTENNA

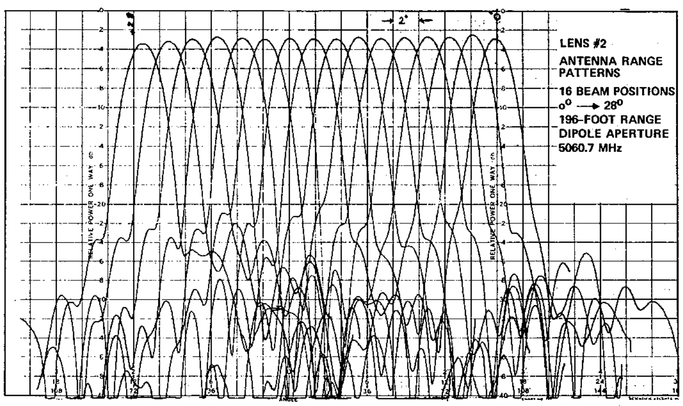

FIGURE 11. LENS ANTENNA MEASURED PATTERNS

The scan network for a 1.5-degree beamwidth antenna with 15-degree scan is shown in more detail in Figure 9. Sixteen coaxial cables and four SP4T diode switches interconnect the sixteen lens input probes to the four fine scan modulator outputs. The fine scan modulator generates ten sets of fine scan weights, resulting in ten increments between probe positions, and fine scan steps of approximately 0.1 beamwidth. The diode switches commutate these weights over the 16 input lens probes. The beam is scanned in 0.1 beamwidth increments at a rate of 20,000 degrees per second.

Figure 10 shows the construction of the 2-degree lens antenna. This antenna has a dipole radiating aperture consisting of 64 elements extending six feet. The parallel plate lens is 5 feet by 6 feet by 1 inch thick, and has 64 output probes and 48 input probes. The lens cables are 0.141-inch semirigid coaxial cables cut to specific lengths. The measured patterns on this antenna are shown in Figure 11. These patterns were measured with two-probe excitation on the lens input. As shown, there is very little amplitude variation with scan, and the average sidelobe level is 20 dB down.

Summary

A system overview of a Microwave Landing System satisfying the entire spectrum of users has been described. Ground hardware implementations to overcome the environmental problems encountered at airports have been discussed. Two classes of scanning beam array antennas have been designed and evaluated. Each class of antenna has performance and cost merits depending on the application. All aspects of the designs presented have been field tested, or are now in the process of field tests.

Acknowledgements

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Reference

[1] Rotman, W., and Turner, R.F., "Wide Angle Microwave Lens for Line Source Applications," IEEE Transactions on Antennas and Propagation pp 623–632, November 1963.