MICROWAVE TECHNOLOGY IN THE MICROWAVE LANDING SYSTEM

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Abstract

The purpose, format, principles of operation, and equipment used in the microwave landing system (MLS) are described. Special emphasis is given to microwave components in the system. Opportunities for innovation in technology development are discussed.

SYSTEM DESCRIPTION

Stated in its broadest terms, the purpose of the Microwave Landing System (MLS) is to provide lateral and vertical guidance to approaching aircraft from about 20 miles out through final approach, flare, touchdown, and roll-out, as well as through missed approach. Lesser capabilities can be obtained for some airports and some aircraft, all using the same basic format. The basic MLS outputs are azimuth angle, elevation angle, and (slant) range. Azimuth and DME (Distance Measuring Equipment) equipments and origins of coordinates are generally located beyond the stop end of the runway on the centerline, while elevation equipment is placed beside the runway opposite the glide path intercept point (GPIP) (see Figure 1). For flare guidance, the MLS output is the height above the touchdown point, obtained from the DME and flare elevation angle measurements. The DME ground transponder is adjusted so as to give a zero indication at the GPIP. The system allows even the nominally equipped user to approach the runway from a wide choice of azimuth angles and glide slopes. This feature enables the air traffic controller a great deal of flexibility in dealing with a mix of fast and slow aircraft, and enables routine flight paths over less populated areas for noise abatement.

The accuracy of the system is such that precisely controlled and timed maneuvers can be executed using the MLS guidance, whether coupled to an autopilot or not. The high accuracy and resistance to multipath results in precise guidance much closer to touchdown than with the present ILS, even when flare guidance is not used. Where flare guidance is used, the height accuracy matches that of the best radar altimeters.

Azimuth coverage is provided out to ±60° from the runway centerline, and reduced coverage can be custom-tailored to the site. Glideslopes from 2° to 15° are provided in elevation. Other system parameters are shown in Table 1.

ANGLE MEASUREMENT TECHNIQUE

The fundamental angle measurement is accomplished by sweeping a narrow fan beam (typically 1° wide) transmitted from the ground through its coverage, pausing for 0.2 milliseconds, and sweeping the beam back through the coverage (TO-FRO SCAN). The on-board receiver thus receives two pulses in the shape of the ground antenna pattern; the time interval between the receipt of the pulses is linear with the angle.

More specifically, consider the azimuth case. A phased array is fed with a CW signal; the antenna beam is initially pointed at about -61°, and is scanned at 20° per millisecond until the beam is pointing at +61°, where it is turned off for 0.2 milliseconds. It is then turned back on and the beam is swept back to -61°. The aircraft receives two beams as shown in Figure 2. A threshold is set at -4dB below the peak of the first beam. When the leading edge of the first beam exceeds the threshold, a counter is started at half frequency of a high-frequency clock; when the lagging edge of the beam drops below the threshold, the counter is gated to run at full frequency. When the second beam is received, the leading edge trigger causes the counter to run at half-frequency, and the lagging edge trigger stops the counter. The counter reading, minus 0.2 milliseconds of counts, is directly proportional to the angle. The beams are about 50 microseconds wide.

In order to identify the function, the angle transmission is preceded by an omnidirectional transmission from the ground. The data are encoded and transmitted as Differential Phase Shift Keying (DPSK) of the RF carrier. In addition to identifying the function, the Barker code initialization, ground system status, airport ID, and parity checks are transmitted at this time.

Elevation, flare, and back azimuth functions have similar formats; all angle functions are synchronized and time-shared.

RANGE MEASUREMENT TECHNIQUE

The range measurement technique is essentially the same as the present L-band DME. A pulse-pair is sent from the aircraft, received by the ground transponder, and, after a precisely timed delay, is retransmitted to the aircraft on a different RF frequency. Here again the time delay is the measure of the range, adjusted to give zero range indication at the GPIP.

MICROWAVE COMPONENTS

The basic antennas for the ground subsystems are phased arrays. While a large number of feasible configurations exist which can generate narrow fan beams which scan one-dimensionally over coverage angles from 20° to 120°, the most attractive are (1) planar arrays, consisting of a multi-arm power divider feeding a large number of radiating elements through individual phase shifters, and (2) beam-port antennas using doubly curved reflectors, either toroids or shaped paraboloids. The latter are generally illuminated by a four-feed manifold (see Figure 3), where the attenuators are programmed to yield pseudo-continuous, constant-width beams. The switches step the distribution along the beam ports, such that four adjacent ports are active at one time.

The ground angle transmitters must produce 10 watts of RF power, which has been generated in experimental solid state designs. The transmitter stability required is one part per million.

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For DME, the ground transmitter requirement of 2KW is probably out of reach in solid state, for the near future. The airborne power requirement of 500W (250W for some requirements) is just beyond the state-of-the-art. Airborne receivers will utilize solid state mixers, switches, preselectors and local oscillators.

Of the microwave components mentioned, the ones which offer the most opportunity for improved designs are the phase shifters, variable attenuators, and transmitter sources. These are discussed in more detail.

A. Phase Shifters

In addition to having good phase and amplitude control, phase shifters must exhibit rapid switching speeds (about 1 microsecond or better) with smooth phase transitions, low insertion losses, low power consumption, and, above all, low cost in production. While ferrite phase shifters have been demonstrated to give adequate electrical characteristics, they have the disadvantages of high power consumption, material nonuniformities, and temperature sensitivity. PIN-diode phase shifters meet the electrical and temperature requirements with low power consumption, but as yet the diode parameter variations do not allow production assembly techniques to be employed without diode testing and selection. State-of-the-art for diode phase shifters is 1.7dB insertion loss, with phase control of 5° rms and amplitude control of ±0.3dB[1].

B. Solid-State Sources

The present MLS feasibility equipment utilizes traveling-wave tube amplifiers for angle signal generation and planar triode amplifiers for range transmitters. The projected transmitter power requirement of 10 watts CW at C-band is now state-of-the-art for IMPATT and transistor amplifiers in parallel configurations of multiple units[2]. The chief problems are their experimental development stage and low effieicncy, about 5%. The most promising technique at present is to begin with a highly stable crystal oscillator at VHF, multiply up to C-band, and use an IMPATT amplifier. The experimental source described in reference 2 uses a base frequency of 108MHz, and is followed by a X48 varactor multiplier. The airborne DME transmitters may also be candidates for solid-state application; the present requirement is for 500 watts of pulsed power, and a duty cycle of less than 0.1%. TRAPATT amplifiers are now capable of generating 150 watts at 3 GHz[3], and may prove feasible here in the future.

C. Voltage-Controlled Attenuators

For wide angle coverage a cylindrical reflector illuminated by a four-feed manifold is the most promising technique for the azimuth ground subsystem (see Figure 3). Here voltage-controlled attenuators provide the aperture amplitude distribution control. They must be capable of handling 2 watts of RF input power, maintaining phase to within about 10° over 20dB of attenuation variation, have an off-to-on switching speed of about 1 microsecond, while maintaining good temperature characteristics, low insertion loss, and low spurious frequency generation.

ALTERNATIVE MICROWAVE TECHNIQUES

An alternative to Figure 3 is shown in Figure 4 and described in more detail. The disadvantage of using variable attenuators to set up the amplitude distribution on a set of feeds is that the effective insertion loss is about 5-6dB. A set of four medium-power amplifiers are used which incorporate amplitude control to achieve a desired amplitude as a function of time. Even at low gains and poor efficiency (5%), the DC power required can be reduced by 70% or more. Stable gain characteristics and constant insertion phase as a function of gain are crucial. A desirable feature of this approach is the possibility of modularizing the entire manifold to eliminate connectors, stabilize temperature, and increase reliability.

In addition to better technology for existing designs, there is considerable room for innovations in the designs themselves. For example, higher efficiencies might be obtained by using high efficiency sources at lower frequencies followed by a multiplier. One example of this is shown in Figure 5. It is clear that other configurations are feasible as well.

Acknowledgement

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References

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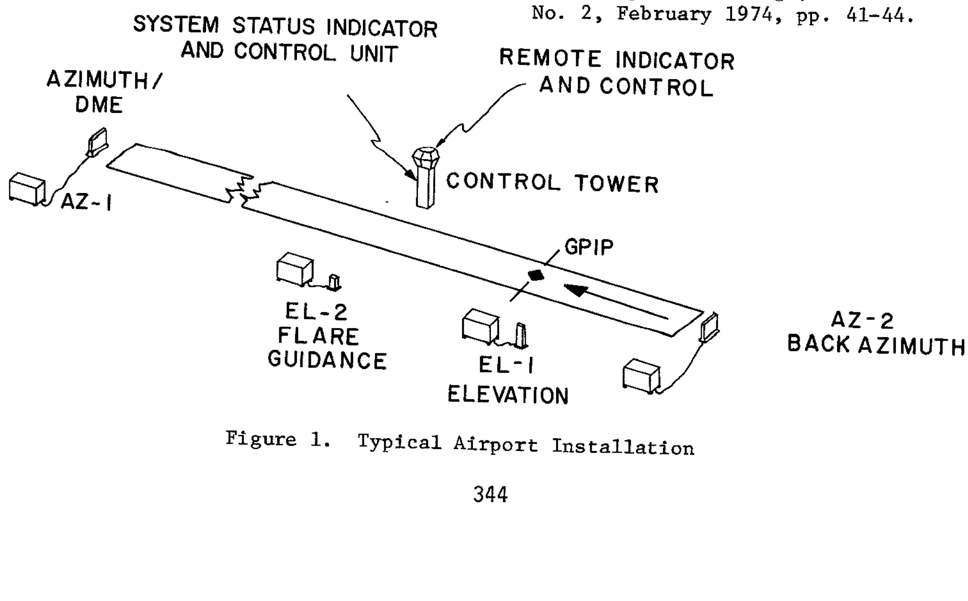

Figure 1. Typical Airport Installation

Frequencies allocated:	angle -- 5001.0 to 5120.4 MHz
	range -- 5128.2 to 5247.6 MHz
	flare -- 15402.9 to 15582 MHz
Number of Channels:	angle -- 200
	range -- 100
	flare -- 100
Channel separation:	600 KHz
Channel bandwidth:	angle -- 150 KHz
	range -- 600 KHz
	flare -- 150 KHz
Update rate:	azimuth -- 13.3 per second
	elevation -- 40 per second
	flare -- 40 per second
	range -- 40 per second
	back azimuth -- 6.7 per second
Beamwidth:	azimuth -- 1°
	elevation -- 1°
	flare -- 0.5°
	back azimuth -- 3°
Power transmitted:	angle -- 10 watts CW
	flare -- 10 watts CW
	range -- 500 watts, pulsed, down 2 KW, pulsed, up-link

Table 1. MLS System Parameters, High-Performance Configuration

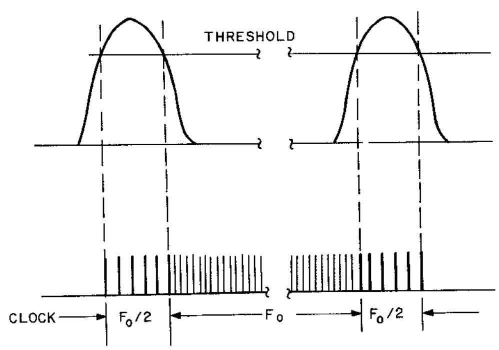

Figure 2. Angle Measurement-Total Count is Proportional to Angle

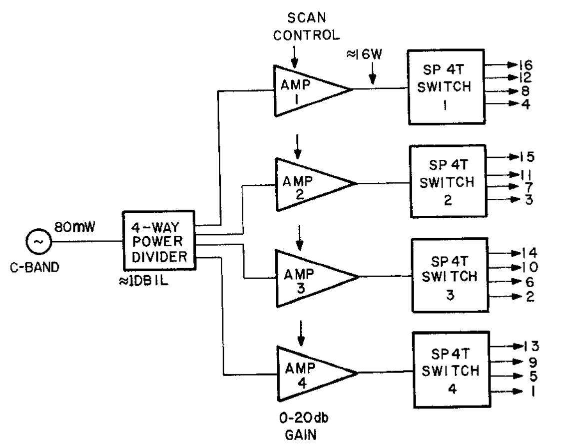

Figure 4. Alternate Combined Amplifier/Manifold for Cylindrical Array Feed

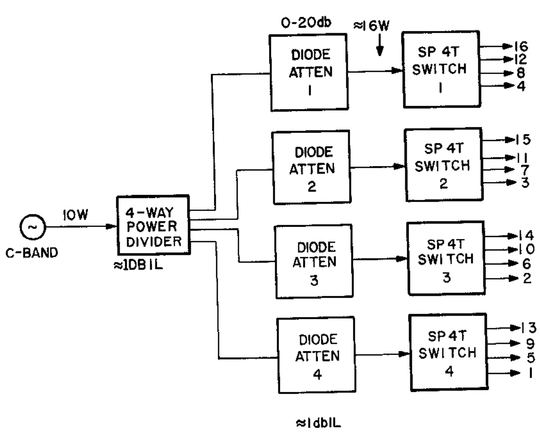

Figure 3. Manifold for Cylindrical Array Feed

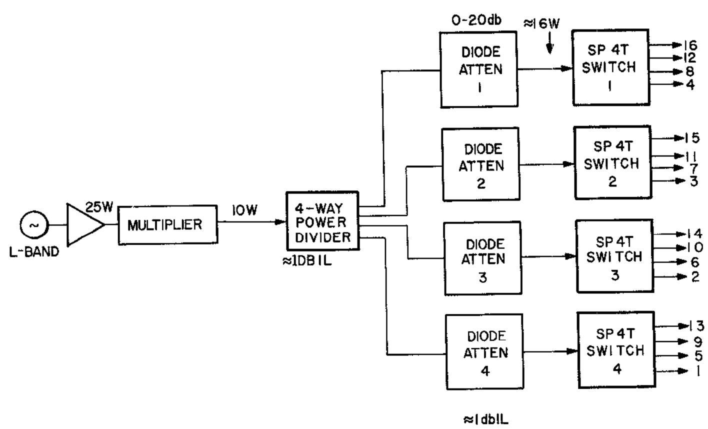

Figure 5. Amplifier/Multiplier Approach for Cylindrical Array Feed