INSTRUMENT LANDING SYSTEMS FOR THE SPACE SHUTTLE

Herbert P. Raabe

IBM Corporation
Gathersburg, Maryland

Abstract

The terminal flight characteristics of the returning space shuttle are described and the requirements for an instrument landing system (ILS) derived. The presently available systems are reviewed and their deficiencies to serve the shuttle are pointed out. The effort of the special committee SC-117 of the Radio Technical Commission for Aeronautics (RTCA) is reported. This effort consists of defining future requirements for aircraft ILS's, screening proposed techniques for their potential in meeting these requirements and establishing a common waveform. The requirements for space shuttle and aircraft landing operations are compared. An ILS concept potentially capable of meeting shuttle and aircraft requirements is described.

Terminal Flight Characteristics and Requirements for a Shuttle ILS (Figure 1)

The terminal flight characteristics of the space shuttle have not been definitized yet. Since the shuttle may have to land safely in various configurations as dictated by emergency conditions, various terminal flight paths will have to be accommodated. From preliminary studies two configurations have been selected which place extreme demands on an instrument landing system:

1. Space Shuttle unpowered with wings.
2. Space Shuttle powered without wings.

These two configurations operate on glide angles of 20 degrees and 3 degrees, respectively. Both flight paths flare out into a final glide angle of 0.75 degrees to touchdown. The horizontal speed will be 300 ft/s with a corresponding sink rate of 4 ft/s. Except for the steep glide angle the approach of the shuttle is like that of a jet plane. The required range of the landing guidance system should be 20 nmi where the altitudes are 40,000 feet and 6,000 feet, respectively, for the two configurations.

Angular guidance and distance data must be available from a 20 nmi range all the way to roll out. The sampling rate of these data should be at least 5Hz at long ranges and at least 15Hz before the shuttle enters the flare-out maneuver until it reaches the end of the roll out. Various glide angles up to 20 degrees must be provided. Hence manual as well as automatic landing capability must be provided.

Fly-out guidance for a missed approach and repeated landing support must be provided.

The allowable error at touchdown shall be ±15 feet lateral, ±800 feet longitudinal on a runway of 150 ft. x 10,000 ft.

The Present FAA ILS and its Suitability to Serve the Space Shuttle and to meet future Requirements of Aircraft Operations (Figure 2)

The present ILS is shown schematically. It consists of a localizer, glide slope facility and distance measurement equipment. The localizer defines the vertical plane over the center of the runway by radiating two overlapping beams from the end of the runway. The carrier of both beams is the same ≈110 MHz but the two beams are modulated by different audio frequencies, 90 Hz and 150 Hz, respectively. Balance of the modulation intensity identifies the localizer plane.

The glide slope equipment operates on the same principle as the localizer. The radiating array is vertical and positioned off the forward end of the runway. Again two overlapping beams are formed. Radiation of the carrier of ≈330 MHz is restricted to the forward sector. The two beams are also modulated by 90 Hz and 150 Hz, respectively. The glide slope angle is ~3 degrees. The intersection of the glide slope cone with the localizer plane defines the single available approach path. However, guidance to touchdown is not provided so that landing requires pilot control and visibility of the runway on the final approach.

The distance measurement equipment (DME) requires the initial pulse transmission from the spacecraft to which the ground transponder responds. Thus range measurement requires a wide band signal.

The present ILS can serve the space shuttle only when approaching as configuration 2, with manual landing control with visibility assured before the flare-out maneuver starts. Even in this case the present ILS must perform nearly ideally.

The major deficiencies of the present ILS to serve the space shuttle and aircraft operations are:

1. Limitation to one approach path of low glide angle. The space shuttle requires guidance along a variety of glide angles up to 20 degrees. Many types of aircraft will require steeper glide paths and curved approaches in the horizontal plane.
2. The glide path does not terminate on the ground. Flare-out to touchdown and roll out maneuvers must be made manually and visibility of the runway is required.
3. The wide VHF beams of the localizer lead to RF scattering from buildings and terrain features resulting in errors of the flight path.
4. No guidance in elevation is provided by the present system for the fly-out in the case of a missed approach.

In January 1969 SC 117 published the "Tentative Operational Requirements for a New Guidance System for Approach and Landing" and invited submission of proposals to meet these requirements. In response to this invitation twenty-three specific proposals were received. From the SC 117 membership the Techniques Assessment Team (TAT) of experts was chosen which divided the proposals into three categories. The first category comprised seven microwave Scanning Beam Systems, the second category included Multilateration Systems, while the remainder of proposals based on various techniques was placed into the third category of Miscellaneous Systems.

Although no single proposal met all requirements,TAT decided in October 1969 that the scanning beam techniques held the greatest promise and that the signal structure should be based on the capabilities of these techniques. Therefore the proposers of the seven scanning beam techniques were invited to participate in the Signal Format Development Team and to establish final specifications for the signal structure.

So far the effort of SC 117 has been highly successful considering the complexity of the task. The working group of Signal Format Development Team will present their recommendations to SC 117 in August 1970. If these recommendations are supported by the full committee, then it is up to the Federal Aviation Administration (FAA), the military, foreign governments and other interests if they are willing to accept the recommendations of SC 117.

In the case of acceptance by these interests, verification hardware should be built and tested at selected locations. Thus a number of years will pass before the new system will begin to replace the existing installations. This may occur by 1980.

The Effort of Special Committee SC-117 of RTCA to Promote the Evolution of an Advanced ILS (Figure 3)

In 1967 the airlines agreed that it was about time to start work on the evolution of an advanced ILS to overcome the deficiencies of the present system. These deficiencies were not and still are not severe enough as to require a pursuit of this effort with great urgency. On the contrary, the system is still doing such a good service that more installations are recommended which will be quite useful for years to come. However, in anticipation of increased traffic density and a greater variety of aircraft with different flight characteristics and in order to overcome certain restrictions due to inclement weather, an advanced ILS was eventually needed, and an early coordinated effort was necessary to avoid wasteful proliferation of new techniques.

The task was not merely a technical one, economic and political consideration played a major part. The military had already adopted advanced systems, meeting very specific requirements and the future system should serve the military as well.

Furthermore, international acceptance was required to make the effort a success. Last but not least the cost should be low, especially for smaller aircraft, although they may not get the full service of the system.

To maximize the chance of success for the evolution of a new ILS,it was mandatory that a committee was organized in which all interests were represented. Thus, the Executive Committee of the Radio Technical Commission of Aeronautics (RTCA) established in 1967 the Special Committee 117 under the able leadership of S. Poritzky of the Air Transport Association (ATA).

The task of SC 117 was two-fold. First they had to establish specifications or requirements for the future ILS, second a standard signal structure had to be agreed upon so that any airborne equipment could communicate with any ground installation. Specifications of techniques and hardware were to be limited to the absolute minimum to allow full participation and competition between manufacturers. However, techniques and hardware considerations were initially important so that the final specifications and signal structure would be realistic and economical. Thus an Operational Working Group developed a Statement of Operational Requirements during 1968.

Principles of Angle and Distance Measurement Techniques (Figure 7)

To generate the two angular inputs for the guidance function on-board of an aircraft or the space shuttle a receiver records the time t_Θ when the scanner illumination takes place. If the angular positions of the scanners with respect to time are known, azimuth and elevation angles can be derived. To avoid the requirement of a clock which is accurate in absolute time, a timing signal is transmitted from the ground. Two principles are illustrated, the time reference and the code reference technique.

To provide the time reference signal an omnidirectional transmitter generates a pulse at the periodicity of the scanner transmission. For example in the case of an azimuth scanner the omnidirectional pulse may be transmitted whenever the fan beam is parallel to the center line of the runway which happens at time t_o. In the case of code reference, the timing information is modulated on the scanner signal.

To obtain distance information, an on-board transmitter generates a wideband signal, e.g. a short pulse. The pulse is received by a ground transponder which generates a pulse to be received by the on-board receiver. From the time delay the distance is derived.

Integrated Precision Angle and Distance Measurement Technique (Figure 8)

The precision of time measurement when the peak illumination of the scan beam function occurs is inadequate. A split beam technique offers much greater precision. To generate this beam system, a phased array with two RF inputs may be used. Perfect symmetry of the split beam system is assured if the same frequency is applied to these inputs. To enable the receiver of the scanner signal to keep the two beam signals apart, pulse transmission and time multiplexing is suggested.

The receiver demultiplexes the received pulse series and derives the beam envelope-time function of the two beams in two low-pass filters. A subtractor generates the difference function of the two beam envelopes. This function shows a zero crossing which triggers a pulse. The timing of this pulse indicates the time t_θ when the fan beam plane scans the on-board receiver, except for a fixed time delay due to the low-pass filters.

The precision of the zero crossing time is also assured by the fact that no electronic components are used in the separate paths between the demultiplexer and the subtractor.

To automatically generate distance measurement signals at the rate of the angular signals, the on-board pulse transmission is triggered by the pulse at time t_θ which propagates to the ground and releases a pulse in the ground transponder. This pulse is received by the on-board receiver at time t_D.

The ILS V-Beam Concept by IBM (Figures 9, 10)

An ILS concept which shows promise of meeting all requirements for the service of the space shuttle as well as the great variety of aircraft is based on the V-Beam scanning technique. The scanner which rotates continuously in azimuth generates a left beam system B_l and a right beam system B_r. Each beam system consists of split beam pair, a leading and a tracking beam, B_{ll} with B_{lt} and B_{rl} with B_{rt}, respectively. These beam systems define precise beam planes I_l and I_r which are inclined 45 degrees to form a "V". As the scanner rotates, two scanner pulses f_l and f_r are triggered in the airborne receiver during each revolution. The receiver also receives a pulse 0 from the omnidirectional transmitter 0 every time when the scanning beam plane intersection is parallel to the runway center. From the timing of the three pulses the azimuth angle α and the elevation angle ϵ can be derived. While aircraft A is still waiting outside of the main approach path of the runway, shuttle S is descending over the runway center line. Thus the fan beam pulses are symmetrically disposed to either side of the omnidirectional pulse. The distance measurement may be triggered by the leading fan beam signal and is not shown. The scanner may be located beyond the runway on the center line or off the side of the runway. Its location determines the variation of α and ϵ with distance D for a given approach pattern. The space shuttle computer will derive these angles.

The range and angular accuracy requirements necessitate the use of two frequencies: C-band offers adequate penetration of dense rain over a distance of at least 20 nmi, K_u-band enables the construction of narrow-beam antennas of reasonable dimensions. Furthermore, the sampling rate of guidance information should be at least 15 Hz during the final phase of the landing while a sampling rate of 5 Hz is adequate for the long range guidance.

These requirements are met by a spinning antenna system consisting of a pair of coarse-beam arrays on one face of a cube and 4 pairs of fine-beam arrays covering 4 faces of a cube. Each array has two RF inputs to generate a split-beam fan pattern as previously described. While the coarse-beam arrays are energized over the full azimuth of 300 degrees, the fine-beam arrays are energized only over the quadrant pointing in the direction of the approaching space shuttle. The signal structure due to the two systems is the same, except that the repetition rate of the fine-beam system is 4 times that of the coarse-beam system and the precision of the former is 2.5 times greater. Thus the computation of the guidance data does not require any change in the computer.

By switching the receiver from the coarse-beam to the fine-beam scanner, the distance measurements also repeat at the higher rate.

FIG. 1.

TERMINAL FLIGHT CHARACTERISTICS OF THE SPACE SHUTTLE

CONFIGURATION 1: SPACE SHUTTLE UNPOWERED WITH WINGS.
CONFIGURATION 2: SPACE SHUTTLE POWERED WITHOUT WINGS.

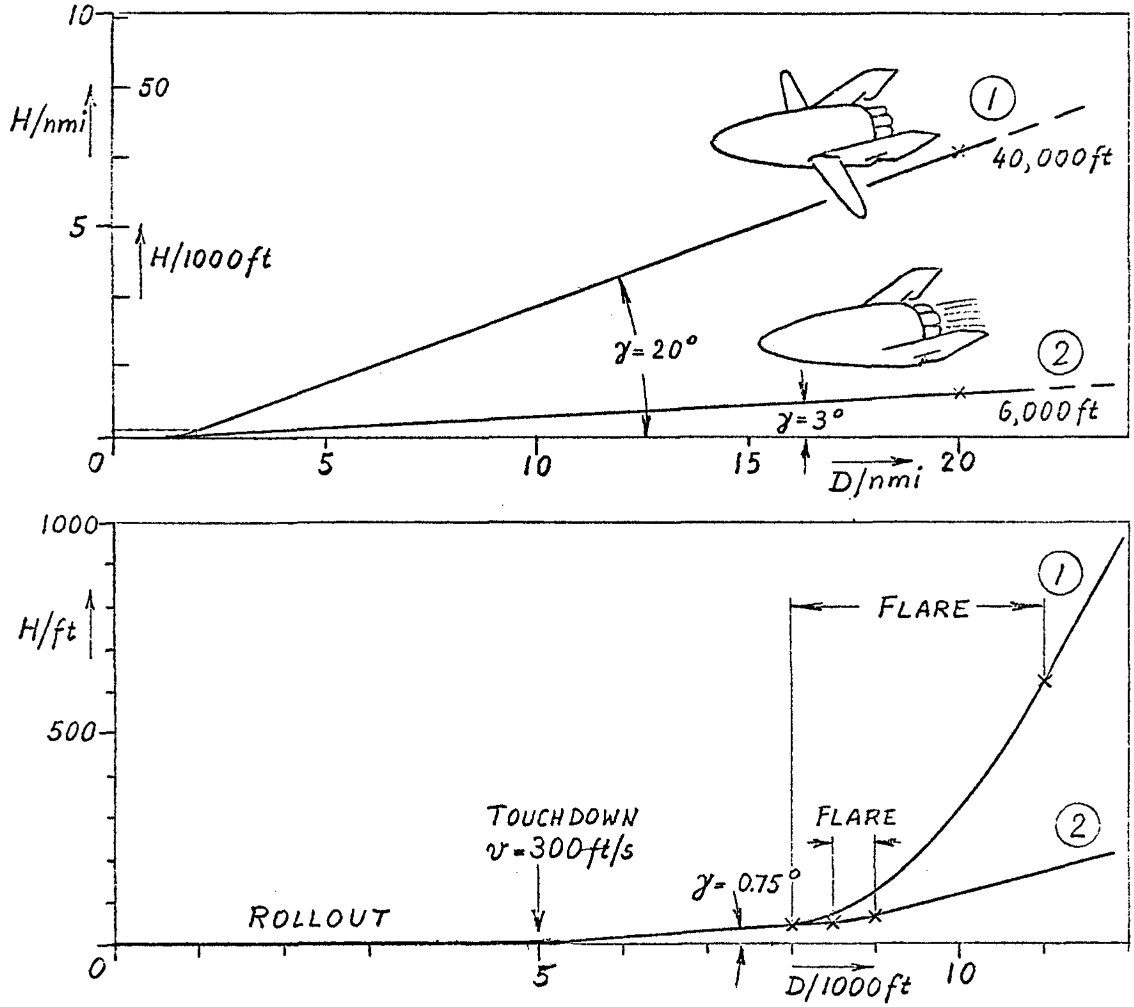


FIG. 2

THE PRESENT FAA ILS
AZIMUTH AND ELEVATION GUIDANCE

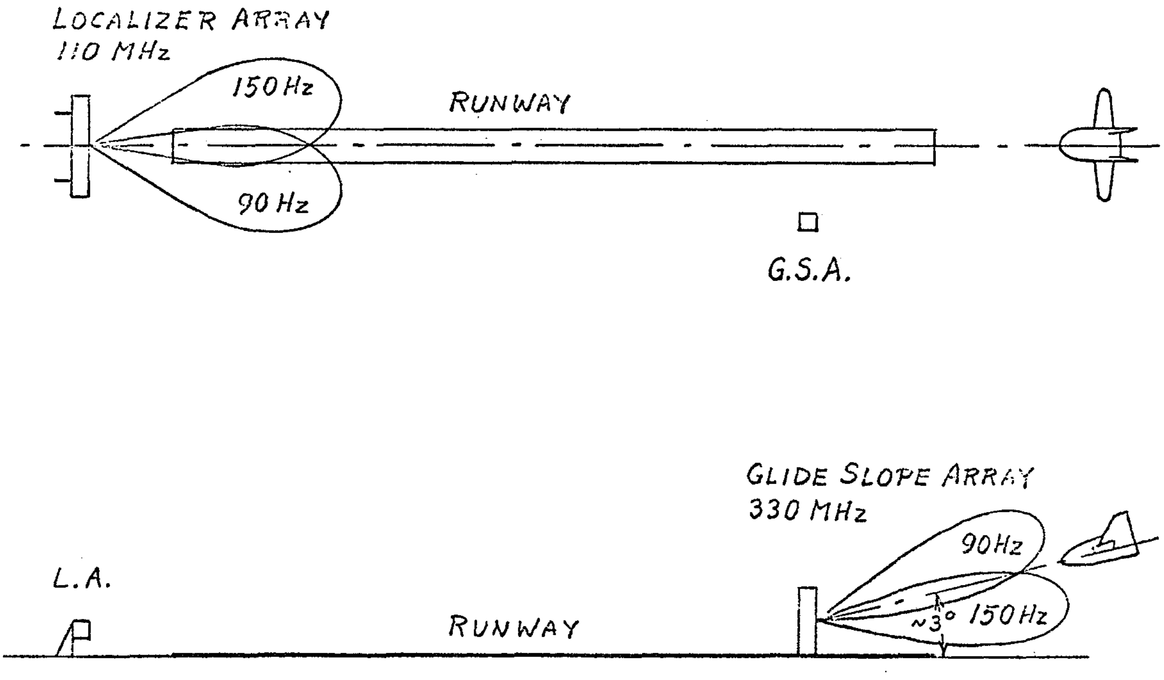


FIG.3

THE EFFORTS OF SPECIAL COMMITTEE SC 117 OF RTCA TO PROMOTE THE EVOLUTION OF AN ADVANCED ILS

(1) IN ANTICIPATION OF THE NEED OF AN ADVANCED ILS, THE SC 117 WAS ESTABLISHED BY THE EXECUTIVE COMMITTEE OF THE RADIO TECHNICAL COMMISSION OF AERONAUTICS IN 1967.

(2) AN OPERATIONAL WORKING GROUP DEVELOPED A STATEMENT OF OPERATIONAL REQUIREMENTS DURING 1968.

(3) TENTATIVE OPERATIONAL REQUIREMENTS FOR A NEW GUIDANCE SYSTEM FOR APPROACH AND LANDING PUBLISHED JANUARY 1969.

(4) CALL FOR PROPOSALS OF NEW GUIDANCE SYSTEM FOR APPROACH AND LANDING ISSUED FEBRUARY 1969.

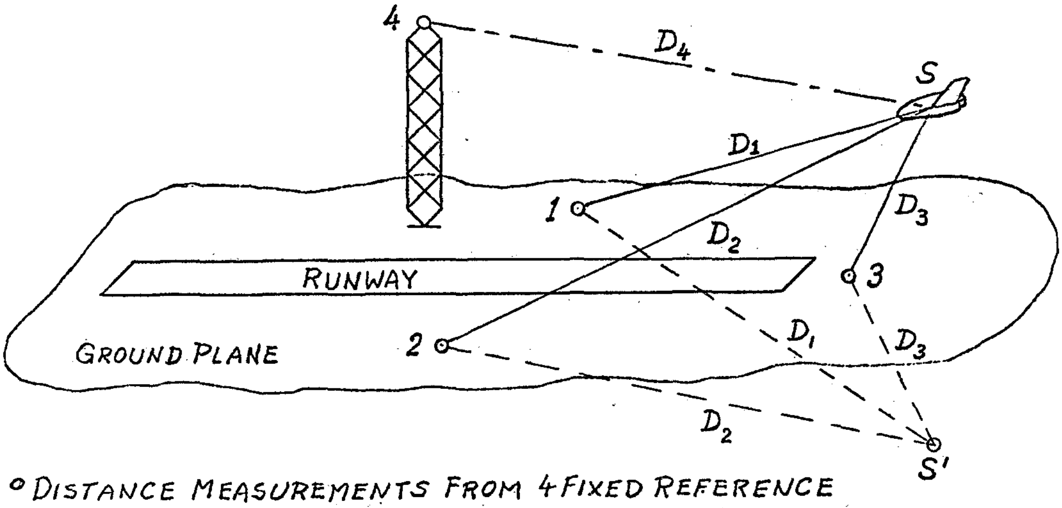
(5) EVALUATION OF PROPOSALS BY THE TECHNIQUES ASSESSMENT TEAM DURING APRIL THROUGH SEPTEMBER 1969.

(6) RECOMMENDATIONS MADE BY THE TECHNIQUES ASSESSMENT TEAM AND ESTABLISHMENT OF THE SIGNAL FORMAT DEVELOPMENT TEAM OCTOBER 1969.

(7) RECOMMENDATION OF A SIGNAL FORMAT BY THE SIGNAL FORMAT DEVELOPMENT TEAM TO SC 117 AUGUST 1970.

FIG.4

GUIDANCE BY MULTILATERATION



- DISTANCE MEASUREMENTS FROM 4 FIXED REFERENCE POINTS REQUIRED TO DEFINE LOCATION IN SPACE.
- 3 REFERENCE POINTS DEFINE PAIR OF LOCATIONS IN SYMMETRIC POSITIONS WITH RESPECT TO PLANE OF REFERENCE POINTS.
- AMBIGUITY RESOLVED WHEN REFERENCE POINTS ON GROUND PLANE, BUT LOW ELEVATION ANGLES ARE POORLY DEFINED.
- LOW ELEVATION ANGLES REQUIRE 4th ELEVATED REFERENCE POINT.
- RADIATION OMNIDIRECTIONAL, WIDE BANDWIDTH (MICROWAVE), HIGH POWER.

ADVANTAGES:

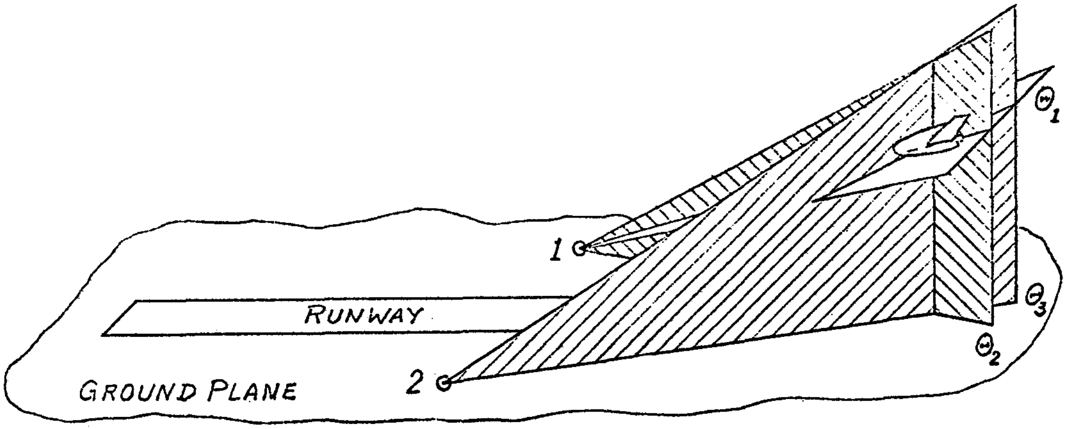
- SMALL ANTENNAS
- REJECTION OF MULTIPATH PROPAGATION
- SMALL RADIAL POSITION ERROR

DISADVANTAGES:

- 4 DISPERSED RADIATORS (ONE ELEVATED)
- HIGH POWER
- WIDE BANDWIDTH
- TANGENTIAL POSITION ERROR INCREASES WITH DISTANCE
- COMPLEXITY OF COMPUTATION

FIG. 5

GUIDANCE BY TRIANGULATION



- ANGLE MEASUREMENTS FROM AT LEAST 2 GROUND BASED REFERENCE POINTS REQUIRED (E.G. ONE ELEVATION ANGLE Θ_1 AND TWO AZIMUTH ANGLES Θ_2 AND Θ_3.
- PLANAR OR CONICAL FAN BEAMS.
- SCANNING REQUIRED TO COVER SPACE.
- RADIATION DIRECTION (MICROWAVE), NARROW BANDWIDTH (CW), LOW POWER.

ADVANTAGES:

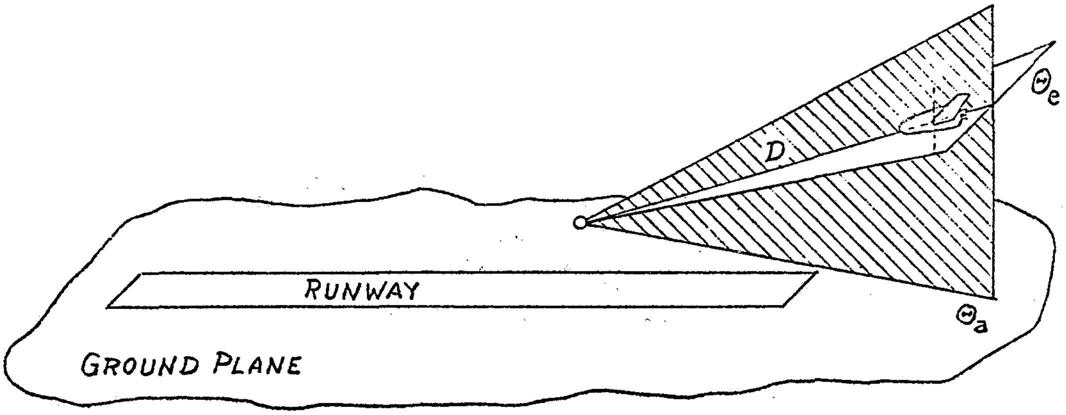
- RADIATORS ON GROUND PLANE
- NARROW BANDWIDTH
- LOW POWER

DISADVANTAGES:

- TWO DISPERSED RADIATORS
- SCANNING WIDE-APERTURE ANTENNAS
- MULTIPATH CAN BE A PROBLEM
- RADIAL AND TANGENTIAL POSITION ERRORS INCREASE WITH DISTANCE

FIG. 6

GUIDANCE BY COMBINATION OF TECHNIQUES



COMBINATION OF ANGLE AND DISTANCE MEASUREMENTS RESULT IN SUPERIOR SYSTEMS.

EXAMPLE:

TWO SCANNING FAN BEAMS SERVE TO DETERMINE AZIMUTH AND ELEVATION ANGLES, WHILE DISTANCE IS DERIVED FROM THE TWO-WAY PROPAGATION TIME OF A WIDE-BAND WAVEFORM.

ADVANTAGES:

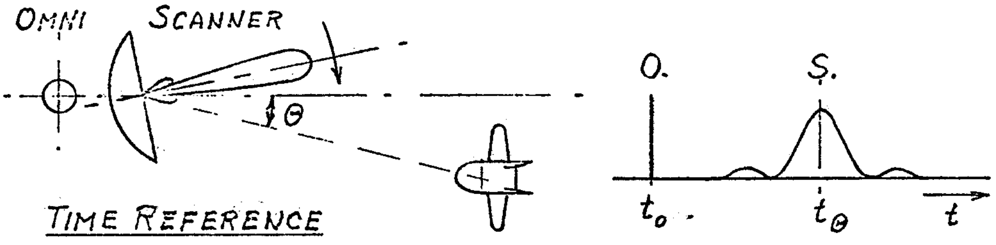
- ALL RADIATORS IN ONE LOCATION ON GROUND PLANE
- SMALL RADIAL POSITION ERROR INDEPENDENT OF DISTANCE
- SIMPLICITY OF COMPUTATION

DISADVANTAGES:

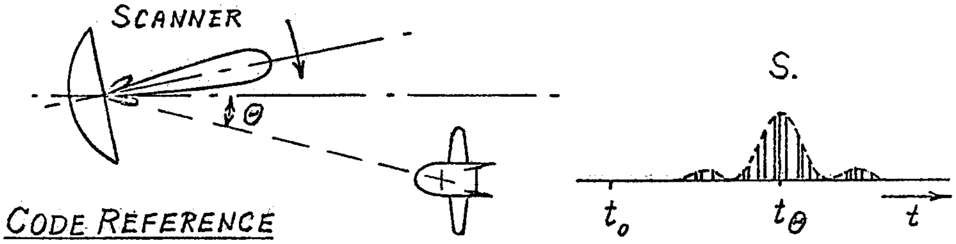
- SCANNING WIDE APERTURE ANTENNAS
- WIDE BANDWIDTH
- TANGENTIAL POSITION ERROR INCREASES WITH DISTANCE

FIG. 7

PRINCIPLES OF ANGLE AND DISTANCE MEASUREMENT TECHINQUES



TIME REFERENCE



CODE REFERENCE

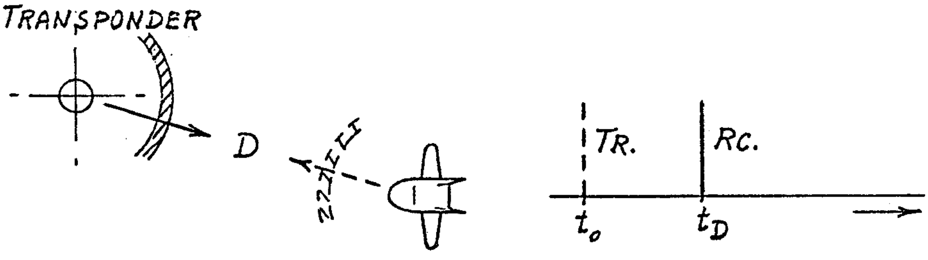


FIG. 8

INTEGRATED PRECISION ANGLE AND DISTANCE MEASUREMENT TECHNIQUE

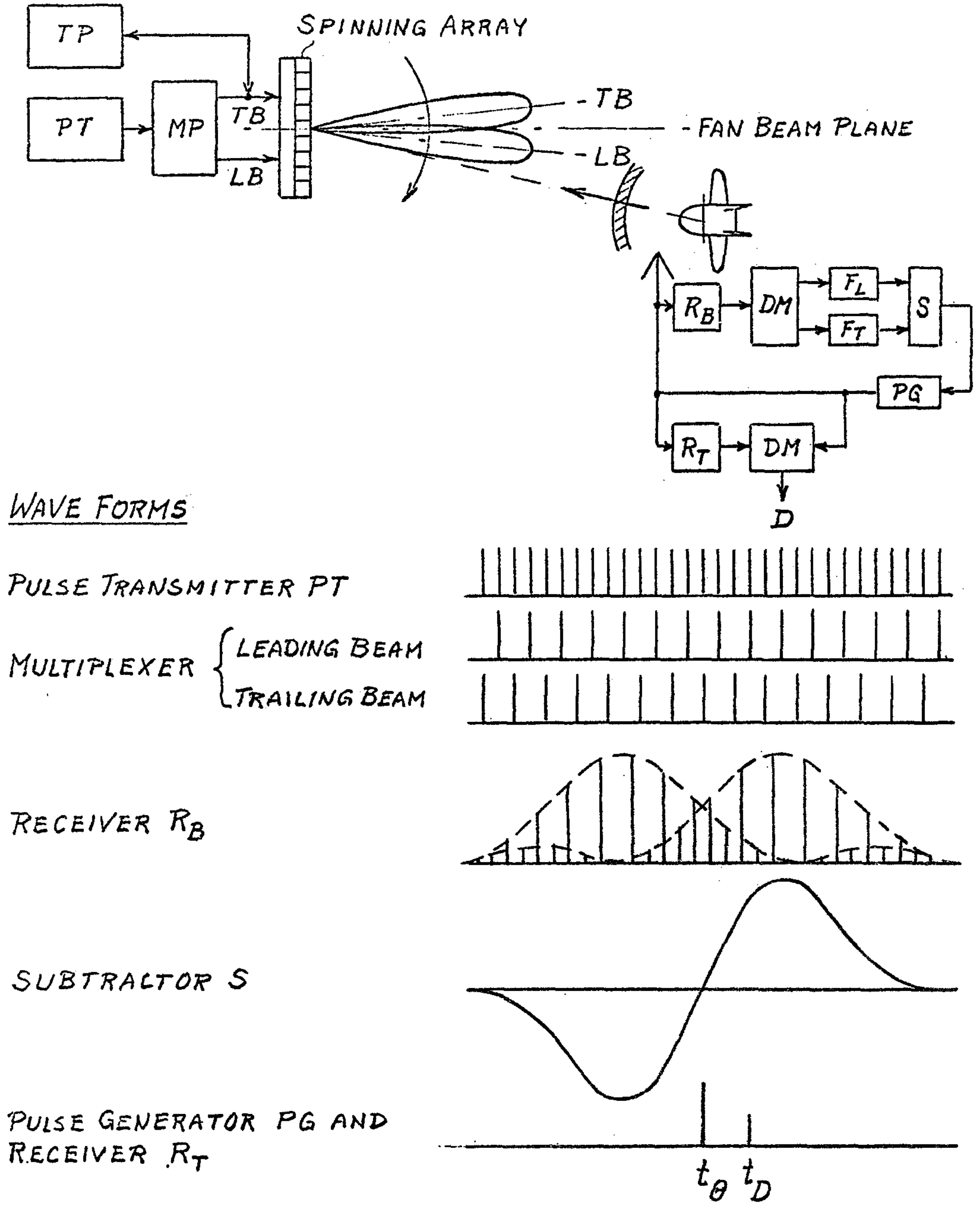
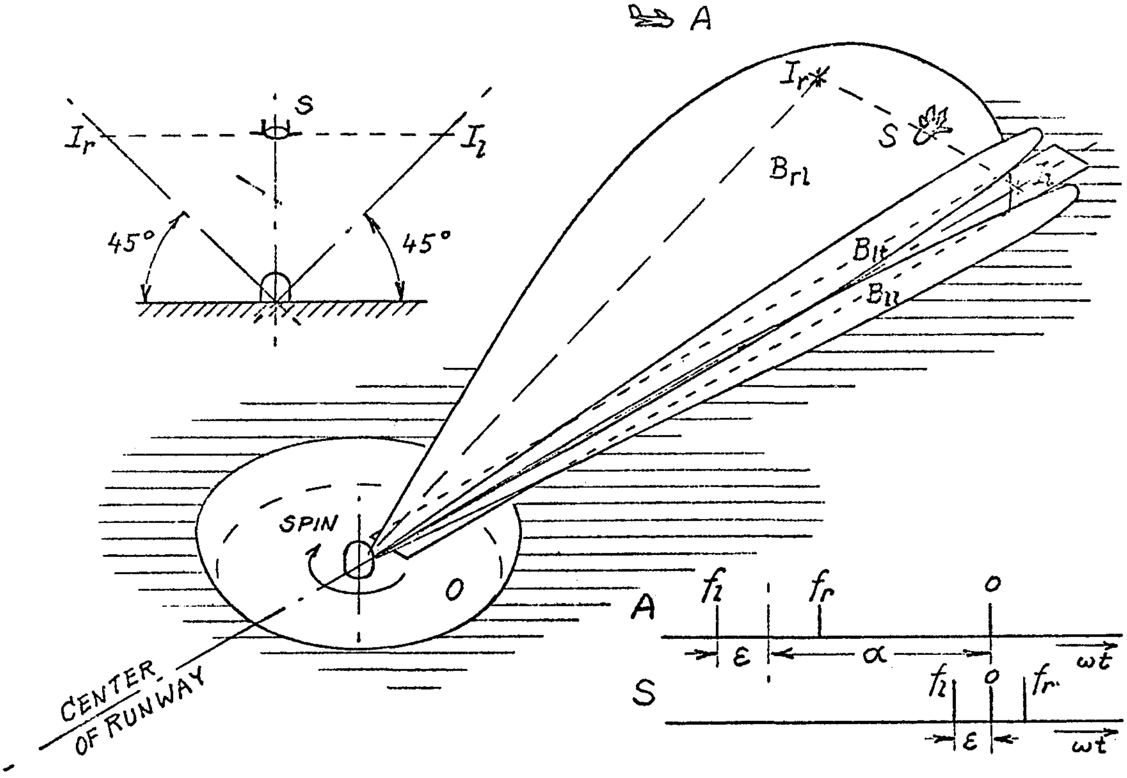
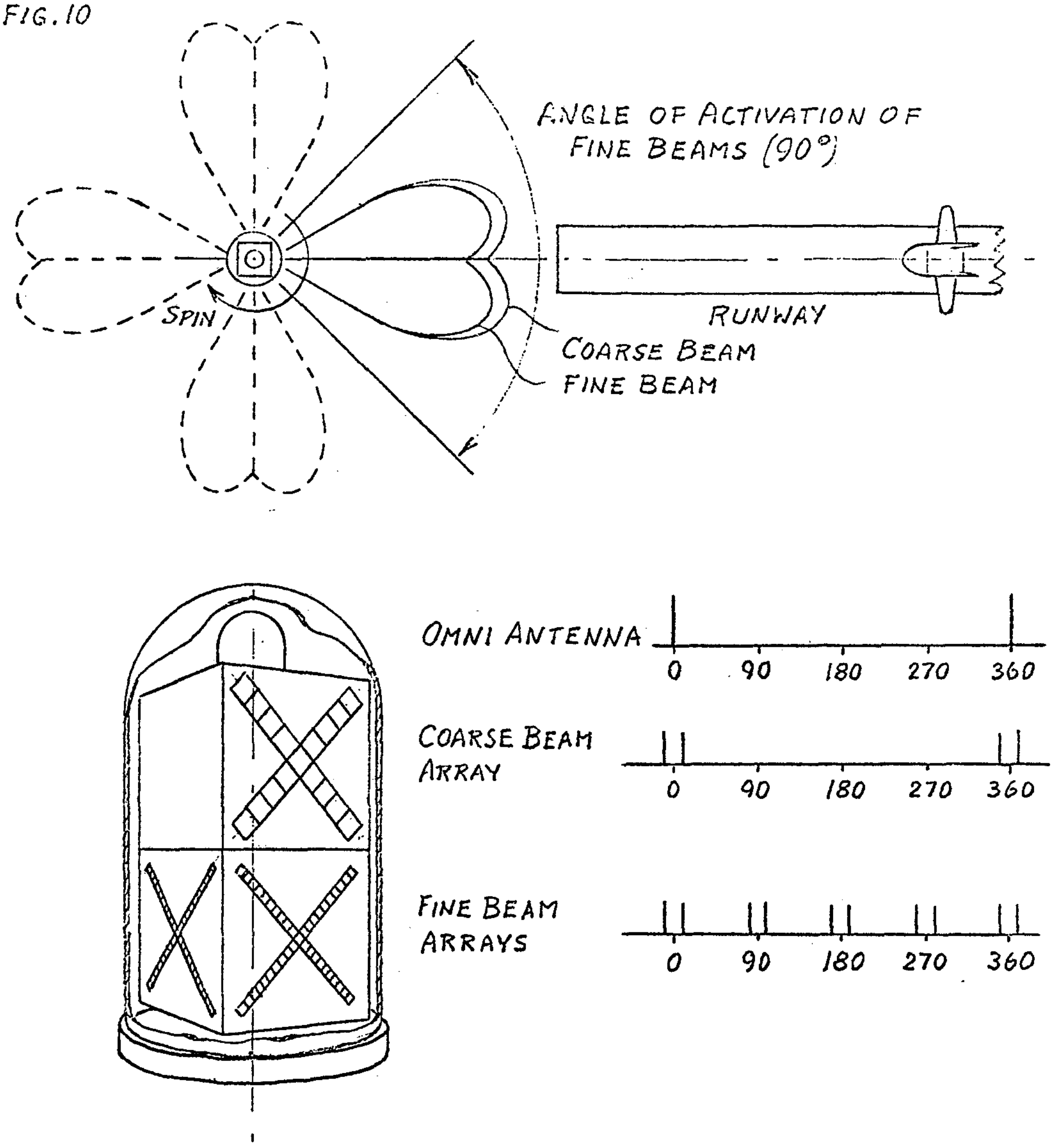


FIG. 9



THE ILS V-BEAM CONCEPT BY IBM

FIG. 10



	COARSE BEAM	FINE BEAM
RADIO FREQUENCY	5 GHz	15 GHz
PULSE REPETITION RATE	12,800/2 Hz	32,000/2 Hz
POLARIZATION	VERTICAL	VERTICAL
BEAM WIDTH, SLANTED	3.54°	1.414°
BEAM WIDTH, HORIZONTAL	5°	2°
PULSES PER BEAM WIDTH	18	18
ARRAY LENGTH	46 in.	39 in.
SIGNAL DWELL TIME	2.78 ms	1.11 ms