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ENGINEERING STUDY OF FACTORS AFFECTING THE CHOICE OF FREQUENCIES OF DME

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TABLE OF CONTENTS

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FOREWORD

The Special Radio Technical Division of ICAO recommended for standardization a Distance Measuring Equipment (DME) operating in the 200 Mc/s. frequency band. However, it has become apparent that the recommendation to standardize 200 Mc/s. DME will likely need revision in view of allocations made in the 200 - 300 Mc/s. band by the International Telecommunications Union at Atlantic City (1947).

The Engineering study reproduced in this circular was issued by the U.S.A. Radio Technical Commission for Aeronautics, and should prove to be of interest in considering the specification of Distance Measuring Equipment for standardization on a world-wide basis.

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ENGINEERING STUDY OF FACTORS AFFECTING THE CHOICE OF FREQUENCIES FOR DME

1. - GENERAL CONSIDERATION

The choice of a frequency for a distance measuring equipment depends on several factors. First and most important is that the operation shall be technically feasible at the frequency chosen. Second is a consideration of the operational characteristics, such as the traffic handling capacity, which the equipment must have, both now and in the future, and whether they can be met at the frequency selected. Third is the availability of the frequency band for assignment to this purpose. Fourth is the availability and cost of the equipment at this frequency.

It will be shown later that the operation of measuring distance is feasible anywhere from 200 Mc/s. to 10,000 Mc/s. and in at least some fashion, however crude, has been made at all frequencies by the use of either specially-designed equipment or, at the higher frequencies by the use of radar and associated beacons. It will be further shown that there is little guidance in choice of frequency to be obtained from purely technical considerations, although there is a slight preference for the region of 1000 Mc/s. Hence, the selection of the proper frequency devolves largely on the operational characteristics required of the equipment and on the current availability of both the frequency band and of the equipment.

The results of the best study available of the operating requirements for DME are presented in Appendix A. It will be noted that these characteristics were set down by a State Department Technical Subcommittee made up of representatives of the Navy, Army, and the CAA, and were subsequently approved unanimously by the Radio Technical Commission for the Aeronautics executive Committee in their meeting of May 1st 1946, at which all interested government services; airline operators and industry were represented, and later by R.J. Dippy of the Office of the British Director of Communication Development of the Ministry of Supply of the United Kingdom. They have therefore not only the cachet of official approval, but the actual basis for discussion of the proposed choice of frequency.

In addition to these requirements, others have subsequently been set down by the RTCA (see Appendix B). The first is the immediate requirement of 51 channels and the ultimate requirement for 101 channels. (It should be realized that the reason for desiring 101 channels is that the channel spacing for the omni-ranges, localizers, and communication channels will eventually be reduced from 200 kc/s. to 100 kc/s. The second requirement is that the DME output be such as to feed a simple arbitrary course computer (R/θ) to permit the pilot to fly any operationally desirable track. To make effective use of the flexibility of this navigation system, automatic position reporting air to ground and ground to air is required as well as ground to air orders. For efficient utilization of equipment and spectrum, it is desirable that these facilities be provided by the DME equipment. Hence, a third requirement is that it be so designed that it will permit future incorporation of these services. To provide facilities for expanding air traffic, the fourth requirement is that each ground station associated with an omni-range and every airborne unit shall be capable of servicing at least 100 aircraft simultaneously. The purpose of the above additional requirements is to make the system easier to integrate in any over-all traffic control system.

The present allocation of the frequency band is somewhat confused by the fact that during the war many countries were forced to arrogate to themselves the choice of frequencies for military purposes since (a) there was no meeting of any international body during this period, (b) the use of frequencies in many instances had to be kept secret. In some instances, this has resulted in considerable equipment being now available at frequencies which have not been formally allocated for the specific use involved.

Figures of delivery and cost will be taken from those presented at the recent meeting of the Special Radio Technical Division of PICAO at Montreal since it is believed that these are the most reliable and up-to-date figures available. Detailed considerations of all of these factors are given below.

2. - TECHNICAL PERFORMANCE CAPABILITIES

On the basis of a study of the technical factors affecting a choice of operating frequency for distance measuring equipment, as covered in Report No. R-2853, "Factors Affecting Choice of Operating Frequency for DME/", dated June 5th 1946, and R-3005, "Factors Affecting Choice of Transmission Frequencies for Line of Sight Systems", dated October 29th 1946, the Naval Research Laboratory concluded that a selection of any particular frequency between 200 and 10,000 Mc/s. is not justified on the basis of differences between any of the following factors:

1) Equipment involved;
2) Volume of equipment;
3) Weight of equipment;
4) Power input required.

From this standpoint, the Naval Research Laboratory concluded that any technical choice of any such frequency would have to be made on the basis of other items. Those listed below were treated, with the following evaluation:

1) Improve as frequency is made higher:

   a) Low-angle coverage;
   b) Shorter distance between interference lobes;
   c) Effect of terrain;
   d) Size of antenna;
   e) Broad frequency-band availability.

2) Improve as frequency is made lower:

   a) Interference patterns over land;
   b) Anomalous propagation;
   c) Precipitation, clouds and atmosphere;
   d) Omni-directional antenna patterns in aircraft;
   e) Frequency stability.

In regard to one other point, that of the state of the art, the conclusion was reached that except at 5000 Mc/s., highly-developed r-f techniques are available on all the frequencies considered.

This analysis referred to indicates, as brought out above, that there is no defensible choice of frequency on the basis of weight, volume or power consumption of equipment, and that as far as the other factors are concerned, the same number improve as frequencies are made lower as improve as frequencies are made higher. Taken together, these things indicate that 1000 Mc/s. is an excellent compromise frequency.

The above study restricted itself insofar as possible to the purely technical aspects and hence took little cognizance of traffic requirements, the present use of frequency band, and the possibilities of an ultimate integrated system. It does, however, ably eliminate the purely technical factors from influencing the decision.

It is interesting to note that the PICAO Subcommittee appointed to consider distance measuring equipment, comprising Messrs. D.W.R. McKinley of Canada, J.R. Mills of the United Kingdom, and Knox McIlwain of the United States independently came to the conclusion that no particular frequency can be chosen purely from technical considerations.

3. - OPERATIONAL CHARACTERISTICS

As stated above, the set of operational characteristics adopted by the RTCA and Ministry of Supply of the United Kingdom, and appearing herein as Appendix A, will be used for the present discussion. All items of the specification can be equally well met at any frequency under consideration with the exception of 1, 3, 11, and 13.

The most serious difference between the frequency bands for pure distance measuring equipment comes in connection with a combination of Items 1 and 3.

A) Item 1 states: "The system shall eventually provide:

a) 30 channels for those systems used with omni-ranges;
b) 15 channels for those systems used with approach aids;
c) 1 channel for emergency rescue use."

B) Item 3 states:

a) "The system shall simultaneously accommodate at least 50 aircraft on each channel associated with an omni-range; and

b) At least 20 aircraft on each channel associated with an approach aid;

c) No feature of the beacon system shall preclude development to accommodate larger numbers of aircraft.

Since each operating channel requires separate frequencies for challenge and for reply, the requirement of 46 operating channels actually is a requirement of 92 total challenge and reply channels. These channels can be provided either by using 92 separate frequencies, 92 unique frequency and pulse code combinations, or by composing a beacon channel of a unique combination of a particular challenge frequency with a particular reply frequency. Thus, if only three frequencies were available and no codes were used, six beacon channels could theoretically be obtained. For instance, challenge could be on A and reply on either B or C. Similarly, challenge could be on

B and reply on either A or C; or challenge could be on C with reply on either A or B. For large groups of frequency assignments, the same relations to the total number of "cross-banded" channels available is N (N-1), where N is the number of separate frequencies available.

In order to provide 46 channels at 1000 Mc/s., 24 frequency channels would be used--12 for challenge and 12 for reply--and each of these frequency channels would have four operating channels provided by pulse spacing so as to achieve a unique challenge path and a unique reply path for each operating channel. This proposal gives 46 completely individual paths wherein the pulses pertinent to one path do not directly interfere with the operation of any other path.

In view of the United States requirement for 51 channels immediately, the 1000 Mc/s. system is now designed to use 26 frequency channels, but the comparison will be made on the basis of the 200 Mc/s., 45 channel proposal (see Appendix C) and the corresponding 1000 Mc/s., 46 channel system postulated above.

The proposal at 200 Mc/s., as drawn up by a PICAO Subcommittee, used a total of 8 frequencies. Three of these were picked for challenging frequencies and were pulse-coded with three individual codings, giving a total of nine challenging channels. The other five were used for reply and not coded for channeling. Thus with nine challenging channels and five reply channels and full cross-banding, a total of 45 channels can theoretically be obtained. This means, however, that each challenge combination will challenge five beacons. Therefore, each beacon operates at a repetition rate which is 500% of its real needs. Furthermore, each receiving channel is used nine times so that each plane receiver receives replies from nine beacons instead of one. Compounding the fact that each beacon is challenged by every one of five challengers with the fact that each receiver receives nine beacons, in the worst condition of all channels fully loaded, each receiving channel is receiving 45 times as many unwanted replies as it would if all channels were completely independent. Thus, both beacons and aircraft receivers are overloaded. The effect of overloading the beacon is that the beacon will overheat with a small traffic load. This can be alleviated in two ways. The first is to add additional beacons and allow them to time-share. For instance, each one of five beacons might be turned on for 12 seconds out of a minute so that overheating of the tubes is reduced to normal. This runs up the cost of the equipment and the space requirements. The second is to have the beacons "count-down"--that is, refuse to accept more than a percentage of the challenges. This, however, tends to reduce the margin of reliability of airplane indication.

For the purposes of this discussion, let us define an unwanted reply which appears in the receiver of a particular plane as "fruit", and let us further define the ratio of unwanted replies to wanted replies as the "fruit factor". It will be seen that in the worst case, the fully cross-banded system has a "fruit factor" 45 times that of the unique channel system. The deleterious effect of this can be mitigated by slowing down the time of search during which a challenger seeks out a particular beacon. In the demonstrated American 1000 Mc/s. beacons, the time of search was ten seconds. This has been calculated to hold, approximately, even for a traffic capacity of 50 aircraft per channel. On the other hand, the present search time of the British beacon with its 30 channels is about one minute. It is not known whether this contemplates full use of 50 planes per channel, since apparently the British had never envisaged densities of this order. Certainly this will have to be increased for 45 channel cross-banding. On a straight linear basis, of course, the search time of the proposed 200 Mc/s. system would be 45 times that of the unique channel system, making the 200 Mc/s. search time about seven minutes. Whereas in practice it might not be this bad, it would certainly be a matter of several minutes.

Such a long search time may be operationally feasible in low traffic density areas. It is, however, believed not satisfactory for dense traffic conditions. Furthermore, one of the desirable characteristics of a navigation system is the ability to use arbitrary course (R/θ) computers, with such a computer continuously operable over a distance of several hundred miles. At 50 to 100 miles, the omni-range and DME settings must be changed to pick up the next desired combination. This may be done either manually or preferably automatically. In any case, a search time of several minutes occurring at each change of beacon would be intolerable to an R/θ computer. Consequently, it appears that use of 200 Mc/s. frequency would postpone the use of arbitrary course (R/θ) computers for many years.

It has been argued that many countries, such as Belgium, The Netherlands, etc., will never require the full number of channels postulated by the United States and United Kingdom design criteria. This is doubtless true when considering one country at a time, but it must be remembered that radio transmissions have no respect for national sovereignty. Accordingly, many frequencies utilized in one country will not be available for use in a contiguous area. Therefore, when areas such as Europe are considered as a unit, essentially the same 500 mile grid proposed for the United States will be required, and it becomes apparent that the full number of operating channels will be needed.

The second pair of requirements which can more readily be met at 1000 Mc/s. than at 200 Mc/s. comprise: Item 11. "Bearing in mind the use of the system by high speed aircraft, with speeds of the order of 500 mph, the frequency band chosen for the system should not preclude the use of low drag airborne antenna." Item 13. "The possible association of automatic direction finding equipment in the aircraft, with 360° coverage, with the over-all system should be borne in mind." For rotatable directional antennas, the drag is lower the higher the frequency to be used, so that whereas a fully automatic direction finder antenna has been demonstrated at Indianapolis in connection with DME equipment on 1000 Mc/s., it is not believed feasible at all at 200 Mc/s. because the antenna is too large for the normal size plane.

Rotatable directional antennas are extremely important where a single point fix is necessary from a DME beacon alone. Such antennas used against an emergency rescue beacon may well result in successful rescue operations where otherwise lives might have been lost. Other specialized uses include DME for position fixing with respect to a weather ship, as an aid in ship navigation, and so forth. Furthermore, for presently developed omni-directional airborne antennas the situation also favors 1000 Mc/s. For frequencies below a certain critical value a quarter-wave stub antenna may be used with the skin of the aircraft serving as the ground plane. As the frequency is made higher, the size of the antenna and consequently its drag decreases. However, above the critical frequency, experience has indicated that such an antenna is no longer practicable, and the antenna must be built as a dipole, off-set sufficiently far from the skin of the aircraft to avoid the effect of an interference pattern from it. This critical frequency is not known precisely. However, it is known to lie above the 1000 Mc/s. band and probably below 5000 Mc/s.

4. - AVAILABILITY OF FREQUENCY BAND

During the war, the lack of any international body to allocate frequencies and the further necessity to move rapidly and to preserve secrecy resulted in several countries building large amounts of equipment in frequency regions which had not been internationally allocated. Examples of this are the Rebecca Mark II and Mark IV equipments built by the United Kingdom and much high frequency communication and radar equipment in the United States, all in the 200-400 Mc/s. band. In both cases, millions of dollars worth of present equipment is involved.

In the United States, proposed allocation at frequencies from 200 to 216 Mc/s. is to commercial television, from 216 to 200 Mc/s. to government, and the frequencies from 200 to 225 Mc/s. are allocated to amateurs, whereas those from 225 to 400 Mc/s. (except for 328.6 to 335.4 Mc/s. which is allocated for ILS Glide Path) are also allocated for government use. While no such assignment has been made in the proposed international allocation as set down by the FCC report of January 16th 1945, it is our informal understanding that the British Military Services also desire the band from 225 to 400 Mc/s. It should furthermore be noted that the lower part of the 200 to 300 Mc/s. band is not really "available" for DME equipment since it unfortunately lies in the region of the second harmonic of the frequencies of the runway localizers, omni-directional ranges, and VHF communication services with which the equipment normally will be associated. This means that the British request to ITU will presumably be for the upper portion of the 200 to 300 Mc/s. range, thereby causing direct interference with United States military frequency assignments. Any change in this frequency allocation for the military services is considered impractical.

However, in the United States plan, 960 - 1215 Mc/s. has been allocated for navigation aids. This spectrum allows the design criteria (Appendix A) to be met.

One further fact should be noted in that the proposed channel spectrum assignment at 200 Mc/s. of 4.5 Mc/s. per channel is about 2% of the mean frequency of the band, whereas at 100 Mc/s. the 9.5 Mc/s. channel proposed is less than 1% of the band. This indicates that the techniques of building and using components which give a high degree of inherent stability for DME use are much farther advanced at 1000 Mc/s. than at 200 Mc/s.

5. - AVAILABILITY AND COST OF EQUIPMENT

Despite the above indicated comparative lack of development of frequency-stable components in the 200 Mc/s. region, the general knowledge of 200 Mc/s. techniques is somewhat more widespread than that of 1000 Mc/s. techniques. One of the controlling factors in the PICAO decision to apply for a band in the 200 Mc/s. region was expressed in the report of the Subcommittee on DME which stated: "It was noted that the production of 1000 Mc/s. - type DME's in countries other than the USA may involve more difficulty and delay than the production of 200 Mc/s. - type DME/s provided that the present number of channels now available in each equipment is considered adequate." Furthermore, some countries felt that sources of component manufacture, maintenance, and operation of 200 Mc/s. equipments were better known, and the PICAO decision was based upon these assumptions.

The one flaw in the PICAO decision in this respect was that it was not pointed out that the present 200 Mc/s. equipments and even the proposed 200 Mc/s. equipments in no sense do the job which is required and outlined in Appendix A. In the first place, the only airborne equipment which the Canadians could offer had a total of three channels, and this was only laboratory design. Furthermore, the best equipment which the British have designed currently offers 30 channels obtained by full cross-banding of six frequencies. After the decision to adopt 200 Mc/s., the Canadians and British were unable to envisage a device in the 200 Mc/s. range which would give the full 46 required channels and only squeezed their device into 45 channels by the dangerous use of extensive cross-banding. (See Appendix C for details of the proposal.) This results in the above mentioned "fruit factor" of 45 times that of the unique channel DME possible at 1000 Mc/s.

The facts that the present equipment is completely unable to do the required job, and that the proposed equipment cannot handle anywhere near the traffic proposed, were never fully explored at PICAO. In the discussion on the floor of the plenary session, they were barely mentioned and no discussion ensued. It is very important that use of either the proposed 200 Mc/s. equipment or the present 200 Mc/s. equipment with modifications would entail design and manufacturing difficulties even in countries other than the United States which would probably be as great as would be the case with the standardization of 1000 Mc/s.

The most accurate figures of availability and "cost in the country of origin" are given in the report of Committee D of the Special Radio Technical Division of PICAO in the Montreal meeting. These state that both forms of 1000 Mc/s. beacons could be available in substantial quantities for delivery from factories in 1948 and for installation and operational use by 1950. (This last figure is taken from the PICAO document stating the American position as stated by RTCA and approved by ACC.) These figures check with the estimates on the Canadian equipment, and the estimates on Rebecca Mark IV units. Parenthetically, it may be noted that neither of these last two do a satisfactory job in their present form, and that re-design might delay their introduction.

The estimated cost of the various equipments per service rendered in general is substantially independent of frequency. The Canadian DME in its present form is cheaper, but it is noted in the report of the Subcommittee on DME: "However, if an equivalent number of channels were required, the weight and cost would rise to nearly the weight and cost figures of the Hazeltine DME". Similarly, Rebecca IV has higher figures for weight and cost than the simple DME equipments, but Rebecca IV furnishes additional facilities.

6. - GENERAL CONCLUSIONS

As pointed out above, the technical factors, cost and availability of the equipment represent approximately a standoff between the use of 200 versus 1000 Mc/s. Furthermore, this standoff applies, except possibly in regard to cost, up to at least 3000 Mc/s. Frequencies much above 1000 Mc/s. are not here recommended for adoption because no equipment has been demonstrated at these higher frequencies allowing rapid change to a series of stabilized frequency channels.

There remain the practical considerations of where the frequency channels are available to give adequate traffic handling capacity of the system, and the possibility of use of ADF, and of ultimate incorporation into a comprehensive air-navigation and traffic-control system. These factors appear to us to be the major basis for choice between the two frequencies. All of these point to the use of 1000 Mc/s. rather than 200 Mc/s., since it has been pointed out above that 200 Mc/s., while equally satisfactory for low traffic conditions, is entirely inadequate to handle the heavy traffic which will be encountered around major airports in the near future.

Furthermore, it has been pointed out that it is impossible to use ADF on any reasonable size airplane at 200 Mc/s. Additionally, all the ultimate comprehensive air-navigation and traffic-control systems have been proposed at frequencies much higher than 200 Mc/s. and would consequently incorporate a 1000 Mc/s. DME system more readily. Unique channels at 1000 Mc/s. permit the DME gear and spectrum to be used for automatic position reporting which is intolerable with cross-banding at 200 Mc/s.

We, therefore, unreservedly recommend immediate adoption of 1000 Mc/s. for universal use for DME at the earliest possible date.

Along with this basic recommendation, it is additonally recommended that consideration should be given to the fact that the United Kingdom has a considerable amount of 200 Mc/s. equipment actually in service which they might as well use until 1000 Mc/s. equipment is readily available to them, and that a reasonable time allowance should be granted them to amortize this equipment. The fact that this would probably be satisfactory to both Canada and the United Kingdom was indicated by Group Capt. Hendrick of Canada at the Montreal PICAO meeting when he stated that: "Canada in no sense wanted to be on record as recommending 200 Mc/s. as the ultimate solution to the DME problem, that they believed with the United States that 1000 Mc/s. offered much better possibilities for ultimate development. It was only an attempt to get an interim equipment used, say up to January 1st 1951, that the Canadians introduced 200 Mc/s. for discussion."

APPENDIX A

November 12th 1946

MEMORANDUM TO: The Executive Committee of the Radio Technical Commission for Aeronautics.

1. Attached you will find a copy of "Design Criteria for Distance Measuring System" which was obtained by the undersigned from Mr. R.J. Dippy, who is in the Office of the British Director of Communication Development which is part of the British Ministry of Supply. This document represents a substantial agreement of the Representatives of the British Ministry of Supply to the fourteen design criteria which were previously accepted by the RTCA as a working document. Minor changes were agreed to by the undersigned and Commander F.A. Darwin; however, none of these changes alters the intent of the original criteria.

2. It should be noted that the British Representatives did not commit themselves to using a distance measuring system as part of their short-distance navigational network. However, they did agree that if a distance measuring system were ever used in a short-distance navigational network it would conform to the attached design criteria.

NATHANIEL BRAVERMAN, Member
Special Committee for Standardization
of Radio Distance Indicator
between
The United States of America, and
The British Commonwealth and Empire

C & N Laboratory
Wright Field
Dayton, Ohio

DESIGN CRITERIA FOR DISTANCE MEASURING SYSTEM

Introduction

There has been discussion between Mr. N. Braverman and Commander F.A. Darwin representing the American RTCA and Messrs. J. Stewart and R.J. Dippy representing the British Ministry of Supply with a view to agreement on the Design Criteria for Distance Measuring System.

Agreement was reached on the following criteria (a) those systems that might be used in conjunction with omni-directional ranges to provide a short distance navigational network, and (b) those systems that might be used in conjunction with localizer and glide path system.

Design Criteria

1. The system shall eventually provide:

   a) 30 channels for those systems used with omni-ranges;

   b) 15 channels for those systems used with approach aids;

   c) 1 channel for emergency rescue use.

2. The system shall indicate slant distance with an accuracy of at least:

   a) ± 1/5th mile up to 20 miles and ± 1% of distance up to 100 miles thereafter;

   b) ± 250 feet for an agreed distance which shall be used as a "boundary marker";

3. a) The system shall simultaneously accomodate at least 50 aircraft on each channel associated with an omni-range; and

b) At least 20 aircraft on each channel associated with an approach aid;

c) No feature of the beacon system shall preclude development to accommodate larger numbers of aircraft.

4. The reliable service distance of the system shall be at least:

a) 100 statute miles at line of sight altitudes, and

b) 45 statute miles at 1,000 feet altitude,

when transmission is over flat terrain and the transmitter antenna is 50 feet above mean elevation;

5. The system shall be capable of supporting an airborne equipment designed to supply distance data suitable for both automatic and manual flight using "arbitrary course" computers in connection with omni-ranges;

6. It is desirable, but not essential, that the system should provide for the measurement of rate of change of distance to the beacon with an accuracy of at least ±4% of true rate within the range 50 to 600 mph.

7. The system shall be capable of supporting an airborne set with display of distance on:

a) Pointer-type indicator; or
b) Veeder type 'counter' indicator

8. Beacons for use with approach aids shall have provision made for:

a) Adjustment of delay to permit the accurate setting of 'touchdown' point;

b) The use of directive antennae to concentrate radiation along the localizer plane.

9. Provision shall be made in the system for light weight emergency rescue beacons on a channel assigned exclusively for this use.

10. All beacons, whether used with omni-ranges or approach aids, shall be identity coded.

11. Bearing in mind the use of the system by high speed aircraft, with speeds of the order of 500 mph, the frequency band chosen for the system should not preclude the use of low drag airborne antennae.

12. The system shall be capable of supporting airborne equipment designed to include the use of heading attachment.

13. The possible association of automatic direction finding equipment in the aircraft, with 360° coverage, with the overall system should be borne in mind.

14. The airborne equipment weight (not including heading, rate indicator or A.D.F. attachments) shall not exceed 30 lbs. when arranged for operation from either a 14 volts or a 28 volts D.C. primary supply (two separate equipments intended).

The bulk of "cockpit" equipment is of even greater importance than weight; but it is not possible to agree on a specification.

(Sgd.) R.J. DIPPY

APPENDIX B

DISTANCE MEASURING SYSTEM STANDARDIZATION

Under date of December 20th 1946, the Executive Committee of RTCA unanimously approved the report of its Special Committee SC-21 which was established for the purpose of developing recommendations for the standardization of Distance Measuring Systems.

RTCA recommendations for Distance Measuring Equipment Standardization are as follows:

I. - Operational Requirements

1. The system shall initially provide:

a) 30 channels for omni-range distance measuring use;

b) 20 channels for localizer distance measuring use;

c) 1 channel for emergency rescue use.

Eventually, the number of channels in (a) and (b) must be doubled.

2. The system should provide slant distance to aircraft with the following accuracy:

a) ± ½ statute mile or ±3% slant distance, whichever is the greater, up to 115 statute miles. This accuracy shall be provided for at least 95% of the indications (based on normal Gaussian error law) and includes all errors in air and ground equipment;

b) Comment. The committee especially noted the fact that comparison of accuracies had been made previously on several different bases. The basis used for formulation of (a) above was considered in agreement with PICAO and the report of the Combined US-UK Technical Group on Design Criteria for Distance Measuring

Systems. In addition, a discussion was carried on concerning the ± 250 foot accuracy point at the boundary marker just outside the approach end of the runway. A 1000 Mc/s. band marker was considered for this purpose to work with distance measuring equipment, as it was believed that an accurate point determined solely by DME would be difficult to establish. It was decided that no new marker should be recommended and further that no recommendation be made at present as to the boundary marker method.

3. The system shall provide eventually for:

a) 100 aircraft maximum on the omni-range DME;

b) 20 aircraft maximum on the localizer DME (It is pointed out that a number of aircraft may have DME turned on when they are parked on, or taxying on, the airport itself. Thus, there may be some chance of the 20 aircraft maximum being exceeded, but the number will probably never exceed 50 aircraft on the localizer DME channel.);

c) No feature of the beacon system shall limit the utilization of airdromes or airspace.

4. The reliable service distance of the system shall be:

a) At least 115 statute miles at line of sight altitude;

b) 45 statute miles at 1000 feet of altitude over flat, level terrain.

5. The distance data provided in the aircraft shall be suitable for both manual and automatic flight using course computers in connection with the omni-range.

6. The system shall provide indication of distance on either:

a) Dual pointer clock type indication; or

b) Veeder counter type indication.

7. Beacons for use with the localizer shall provide for a setting of a zero point at any distance up to 15,000 feet from the ground beacon by suitable adjustment of the ground beacon itself.

8. All beacons shall be identity coded.

II. - Additional Uses

The five following indications should be considered as early additional uses of DME equipment:

1. R-theta position of aircraft relayed to the ground automatically;

2. Altitude as requested from the ground or automatically reported to the ground;

3. Identity of aircraft;

4. Radar assist by means of special receiving attachment to the DME;

5. A signal system for giving directives to a selected aircraft.

III. - Frequency Range

A frequency range such as that existing between 960 - 1215 Mc/s. is necessary because:

a) Facilities can be provided in this allocation to handle anticipated traffic;

b) Sufficient directivity, in moderate-size antennas, can be attained to permit flexibility for other functions such as for automatic direction finding, etc.;

c) The spectrum allows for sharper rise of the pulses with better accuracy;

d) Gapless coverage at low altitudes without interference from ground lobes can be attained on these frequencies.

IV. - Frequency Channels

Fifty-one (51) frequency channels should be available immediately for DME, with provision for the ultimate utilization of one hundred and one (101) channels. Four principal reasons for the ultimate provision of 101 channels are:

a) Flight of aircraft at high altitudes is such that the DME can be received over long distances and thus interference proves severe unless additional channels over the 51 are provided;

b) The distance measuring facility alone might become overloaded (even with no other features added) unless sufficient channels were eventually provided;

c) Siting flexibility would be provided by not restricting the number of channels to 51 in the eventual system;

d) Correlation between the channel assignments of the DME and those of the associated VHF navigation and approach facilities cannot be ensured without 51 initial and 101 ultimate channels.

V. - System Characteristics

The system characteristics follow and are based on the premise of the eight operational requirements set forth under Paragraph I:

1. It is recommended that frequency assignments shall be based on 9.5 Mc/s. frequency separation for the present and eventually 4.75 Mc/s. or less frequency separation for the future (to provide for the 101 channels and additional features to be added).

2. It is recommended that the band from 960 - 1215 Mc/s. be utilized for this service.

3. It is recommended that frequency assignments be made as follows:

a)	960 - 963	lower guard band;
b)	967.75	first assignable challenge frequency;
c)	1081.75	thirteenth assignable challenge frequency;
d)	1086.5 - 1088.5	intermediate guard band;
e)	1093.25	first assignable reply frequency;
f)	1207.25	last assignable reply frequency;
g)	1212 - 1215	upper guard band.

Note.- As used in this paragraph, challenge means transmission from air to ground and reply means transmission from ground to air.

4. The pairing of these frequencies with other navigational and approach frequencies should be the subject of immediate study by a Special RTCA Committee.

5. A double pulse coding shall be used with 4 pulse spacings for challenge and reply.

6. The pulse spacing shall be 5 microseconds, 9 microseconds, 14 microseconds, and 20 microseconds, ± 3%.

7. The pulse repetition frequency shall be 30 for tracking as a nominal maximum and must have random variation of about ± 20%. The pulse repetition frequency for search may be as high as 150 maximum ± 20% for not more than 15 seconds in any one minute.

8. The pulse width used at the half power point shall be 1.5 microseconds ± 0.2 microseconds.

9. The spectrum produced from any cause by the actual pulse shall not lie outside of the spectrum produced by test pulse of error function shape one-half micrisecond long at the half power point.

10. The maximum allowable search time shall be below 15 seconds at 115 miles. The search shall be from zero to 115 statute miles (or to 1000 statute miles for statute mile indicators) when selecting a new station, but, when a station is temporarily lost, search shall begin from a point at somewhat shorter distance (5 or more miles) in order to reduce the time of search to re-establish the distance. This shall be accomplished in spite of a 67% count-down and fruit equivalent to 1000 pairs of pulses per second.

11. Gap coding shall be utilized to identify the ground beacon as specified under the ground beacon later.

12. The ground beacon antenna shall have:

a) Vertical stacking of 4 to 4½ wave lengths high and be situated at an elevation of approximately 50 feet, except that the localizer DME antenna shall be less than 50 but over 10 feet in elevation;

b) Vertical polarization shall be employed;

c) A non-directional pattern in the horizontal plane;

d) Approximately a 10 degree beam width in the vertical plane with the lower half power point on the horizontal.

13. Aircraft Antenna. The aircraft antenna shall be:

a) Vertically polarized;

b) Non-directional in the horizontal plane;

c) One-half wave length in vertical height.

14. Ground Beacon. The ground beacon shall conform to the following requirements:

a) The stability of both transmitter and receiver shall be ± 0.007% or better;

b) The peak power of the transmitter output during a pulse shall be 8 kilowatts. This power shall be maintained between 5 and 12 kilowatts;

c) A 50 ohm transmission line shall be used;

d) The triggering level shall be 25 microvolts or 73 DBM open or 79 DBM with a 50 ohm load;

e) Time delay shall be adjustable between 24 and 71 microseconds. This time delay is from the leading edge of the second challenge pulse to the leading edge of the first reply pulse;

f) The minimum dead time after the second received pulse of a pair of challenge pulses shall be at least 60 microseconds and shall be at least long enough to last 10 microseconds after the second reply pulse. The maximum dead time shall not exceed the minimum dead time by more than 30 microseconds. This means that the receiver shall be fully cut off for at least the minimum dead time and shall be fully recovered by the maximum dead time;

g) The duty cycle shall be 0.5% for a unit beacon. A unit beacon shall handle at least 50 aircraft and more aircraft may be handled by pairing with a second unit beacon;

h) Duty cycle limitation. Gain shall begin to reduce at 0.5% duty cycle and shall be at least 50 db. down at 0.6% duty cycle;

i) Coding. Gap coding, three letters wide with the dot equivalent to 0.16 ± 0.03 seconds shall be used. A dash is equivalent to four dots. Space between letter elements is one dot. Space between characters is six dots. The code cycle shall repeat every 45 seconds ± 5 seconds. The code used shall be suitably co-ordinated with omni-range coding, if used;

j) The receiver shall incorporate adequate echo and CW suppression circuits;

k) Image rejection shall be at least 25 db. and the IF rejection shall be at least 60 db. Both of the above figures include rejection due to antenna discrimination;

l) Provision shall be made for input and output connections for special uses of the DME equipment for other purposes;

m) The selectivity of the receiver for initial installation and reception of low stability aircraft transmitters shall be 3 db. down at more than 5 Mc/s. band width and 30 db. down at less than 9 Mc/s. band width. Later, with high stability aircraft transmissions, this selectivity shall be changeable to a band width between 2.3 to 3.1 Mc/s. at 30 db. down;

n) For localizer use, provisions shall be made for a reduction of the power to about 1/4 power. Such power reduction or antenna gain reduction to about 1/4 power, and possibly directional transmissions, will allow further power reduction if operationally acceptable in the future.

15. Aircraft Equipment. The aircraft shall conform to the following:

a) For low stability aircraft transmitters, the drift shall be within ± 2 Mc/s. For high stability aircraft transmitters, with 3.1 Mc/s. wide receivers employed on the ground, the aircraft stability shall be within ±.03%. The aircraft transmitter drift, with 2.3 Mc/s. wide selectivity receivers employed on the ground, shall be ± .01%.

b) Aircraft reception band width shall be at least 4.5 Mc/s. wide at 3 db. down and 7 Mc/s. at 30 db. down with stability better than ± 0.12% for wide selectivity receivers. Aircraft reception band width shall be 2.3 Mc/s. to 3.1 Mc/s. wide at 30 db. down with stability better than ±.01% to ± .03% for high selectivity receivers;

c) The aircraft transmitter shall have peak power output of 2 kilowatts. This shall not be less than 1.7 kilowatts (An additional 6 db. improvement will result when higher ground selectivity is used with these transmissions. Further, above 15,000 feet of pressure altitude, the power may be reduced by as much as 50% as line of sight reduces the power requirements.);

d) A 50 ohm transmission line shall be employed;

e) The triggering level (or tracking level) shall be less than 25 microvolts or 73 DBM open or 79 DBM with a 50 ohm load;

f) The suppressed time delay shall be 75 microseconds, measured from the leading edge of the second challenge pulse to the leading edge of the second reply pulse;

g) The duty cycle shall be 0.1% maximum capacity which includes not only distance measuring but other functions. (In normal distance measuring use, the duty cycle will be .009%);

h) The receiver shall incorporate adequate echo and CW suppression circuits;

i) Image suppression shall be at least 25 db. and IF suppression shall be at least 60 db. including antenna discrimination;

j) Provision shall be made for input and output connections for use of the equipment as an aircraft beacon and for other types of use.

APPENDIX C

200 Mc/s. DME Proposal

Excerpt from PICAO Final Report--First Session, Special Radio Technical Division, Doc 2553-COT/26, January 1947, Montreal, Canada, "Appendix B to Section IV, Standardization of Distance Measuring Equipment", Page 36.

1. The system shall provide 45 operating channels.

1.1. Eight spot frequencies 4.5 Mc/s. apart shall be chosen within a total available band of 40 Mc/s. This allows 4.5 Mc/s. guard band at each end of the assigned band. (It is desirable, but not essential, that the band be so chosen that the second harmonics of VHF communication transmissions do not fall within it.)

1.2. If the eight spot frequencies be denoted by the letters A, B, C, D, E, F, G, H in the order of increasing frequency, it is recommended that A, C, D, F, and H be beacon transmitter frequencies, and B, E, and G be beacon receiver frequencies.

1.3. On each beacon receiver frequency the interrogator shall be capable of radiating double pulses. The facility of choosing any one of three pulse separations shall be provided.

Note.- No conclusion was reached on the values of pulse spacings and this point was left over for consideration at a later date. The intervening period is to be used for an experimental investigation of the problem.

1.4. The widths of the component parts of this double pulse will be specified at a future date (see note under Paragraph 1.3).

2. The pulse repetition frequency of the interrogator transmitters shall be less than 100 cps.

Note.- The interrogator timing circuits must operate satisfactorily when the ratio between transmitted and received pulses is as great as 1:2.

3. The transmitted peak power of the DME navigation beacon shall be greater than 5 kW., and for the DME landing beacon (associated with the ILS) greater than 500 W.

4. The sensitivity of the DME navigation and landing beacons shall be such that the transmitter shall radiate a pulse signal after reception of a double pulse of the type specified in Paragraph 1.3 at a peak power level of 4 x 10 - 12 W.

5. The width of the transmitter pulse of the beacons shall lie between 3 and 5 microseconds. Its time of rise shall be between $\frac{1}{4}$ and 1 microsecond and its time of decay less than 2 microseconds.

6. The frequency stability of all RF components of the system shall be ± 0.25 Mc/s.

7. The beacons shall be capable of transmitting at all rates up to 10,000 cps and, within this range, the ratio of transmitted to received pulses shall not be less than 1:2. An automatic gain control system shall be employed which, coming into operation at a repetition rate of not less than 8,000 cps, shall restrict the maximum transmitter pulse repetition frequency to 10,000 cps.

8. There shall be incorporated in the beacon a time delay of 12.4 ± 0.2 microseconds (equivalent to one nautical mile) between the arrival, at the receiver, of the front edge of the second component pulse of the incoming double pulse and the front edge of the outgoing transmitter pulse.

9. The total band width of the receiver shall be such that:

9.1. Within ± 1.25 Mc/s. off the spot frequency, the sensitivity of the receiver shall not be greater than that at the spot frequency and not more than 3 db. down from that at the spot frequency;

9.2. At ± 4.5 Mc/s. off the spot frequency, the sensitivity shall be more than 60 db. down from that at the spot frequency;

9.3 At ± 9 Mc/s. off the spot frequency, the sensitivity shall be more than 80 db. down from that at the spot frequency.

10. It is important that adequate precautions be taken to avoid the possibility of the beacon performance being adversely affected by interfering local CW transmissions.

11. The radiation of the beacon aerial system shall be vertically polarized.

12. The diagram of the aerial shall:

12.1. Be non-directional in the horizontal plane for both navigational and landing beacons;

12.2. Include the area between minimum line of sight and 40,000 feet (12,000 m) for navigation and landing beacons, and shall extend for 120 nautical miles (220 km) for navigation beacons and 50 nautical miles (90 km) for landing beacons;

12.3. Include a zone of silence above the beacon in the form of an inverted cone, with a vertical axis from the beacon, having a total angle at the apex not greater than 30°.

13. Beacon identification shall be provided by the transmission of three letters in Morse Code.

13.1. A dot shall be represented by a second pulse transmitted after the normal reply of the beacon for a period of 0.25 seconds.

13.2. A dash shall be represented by a second pulse duration of 0.75 seconds.

13.3. The second pulse shall be transmitted 30 ± 2 microseconds after the normal beacon reply.

13.4. The identification shall be repeated every 30 seconds.

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