

MORPHOLOGY OF RADIO AIDS TO NAVIGATION

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Radio direction finders and radio aids to navigation are finding ever-increasing applications. As the result of the demand for such equipment, the number of types and models offered by qualified industrial firms is also increasing. The question consequently arises as to whether this growth must follow certain definite channels and, furthermore, whether there are certain natural limits set to its further development. In order to reply to these questions, we must draw a genealogical tree of the physically feasible systems of location by radio and then follow up its branches for their technical, practical and economical possibilities of development. For such a survey, publications dating from 1947 on are available to us (1, 2, 3) (*). Those of the morphological findings which in the meantime have proved true may be considered verified and valid also for the future. Those for which practical evidence is still lacking may only give rise to forecasts with a certain probable tolerance for errors. I believe, however, that the purely technical possibilities of development are likely to be predicted with greater certainty than the extent and the speed by which the morphologically feasible techniques may be generally adopted. Experience has shown that economical and political motives play a decisive part in these matters.

We must first prove that the number of physically practicable techniques for position finding is not unlimited, but on the contrary is restricted. A synoptic systematization of radio location techniques must therefore be presented. This problem has usually been analysed from purely practical points of view (4, 5). It is, however, evident that any arrangement bound to the main practical characteristics of a system, such as wavelength, range and accuracy, cannot be flexible enough to be adapted at once to technical progress, (even the unforeseeable progress at the time). Such an adaptability can only be inherent to a systematization based on the physical fundamentals, i.e. morphology. In my concluding lecture at the Radar Meeting in Frankfurt, 1953, I had indicated the fundamental outline of such a physical systematization (6). The experience gained in the meantime

(*) The numbers refer to the bibliography listed at the end of this article.

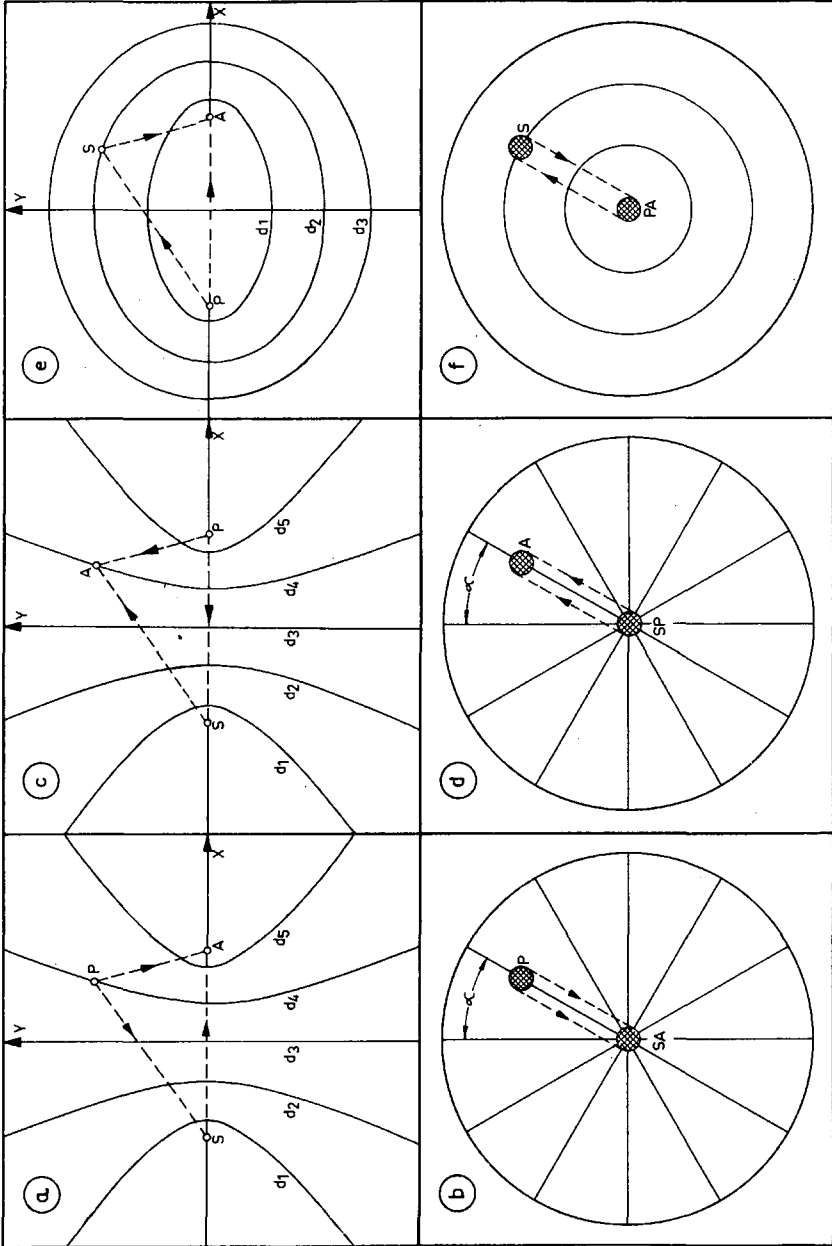


FIGURE 1

shows beyond doubt that this morphological layout really includes all of the systems put into practice since then and is therefore suitable to serve as a basis for further developments. Let us repeat the fundamental concepts (7). I shall use the following terms :

Primary radiation source P : Independent source of radiation.

Secondary radiation source S : Dependent source of radiation (also antenna elements).

Observing point A : Measuring point (also the respective antenna elements).

With these physical elements I occupy the angles of the so-called radio path triangle and thus build up the radio navigation link.

The radio path triangle (fig. 1) allows to derive the following basic techniques of electronic navigation aids :

	Non-stationary angle of the transit triangle (moving object)	Stationary angles with large distance	Stationary angles with small distance
Receiving systems	Primary radiation source P	Hyperbolic reception (a) (HYPAR)	Ground direction finder (b)
	Observing point A	Hyperbolic transmission (c)	Rotating radio beacon (d)
Radio echo systems	Secondary radiation source S	Elliptic Radar (e) (ELPAR)	Standard Radar (f)

These basic techniques, recognized also by other authors (8, 9), are only capable of contributing one single value to the position. For location on a plane, however, two coordinates are required and even three for location in tridimensional space. It is therefore necessary to combine two or three of the given basic procedures in a suitable way in order to achieve the purpose.

The advancements of the last years have resulted in a multitude of new devices in the field of electronic navigation aids, on which thorough reports were given during this meeting. This is therefore a favourable occasion for incorporating the novelties of the electronic industry into the morphological analysis. A very distinct representation of the combinations which are physically feasible is offered by the morphological box.

In constructing this *morphological box* the former symbols and abbreviations were deleted and the names of the basic techniques written in the divisions of the box (fig. 2).

In the right hand side of the box are placed the basic receiving systems with their elements, viz. hyperbolic transmitter systems, rotating radio beacons, beams, radio direction finder and hyperbolic receiving systems (HYPAR). In the lower left side part appear the radio echo systems. A distinction is made here between transmitter/receiver units for primary or secondary radar and long-base radio echo systems (elliptical radar = ELPAR). Each connecting line between two boxes indicates a morphological possibility for independently obtaining two positions. For

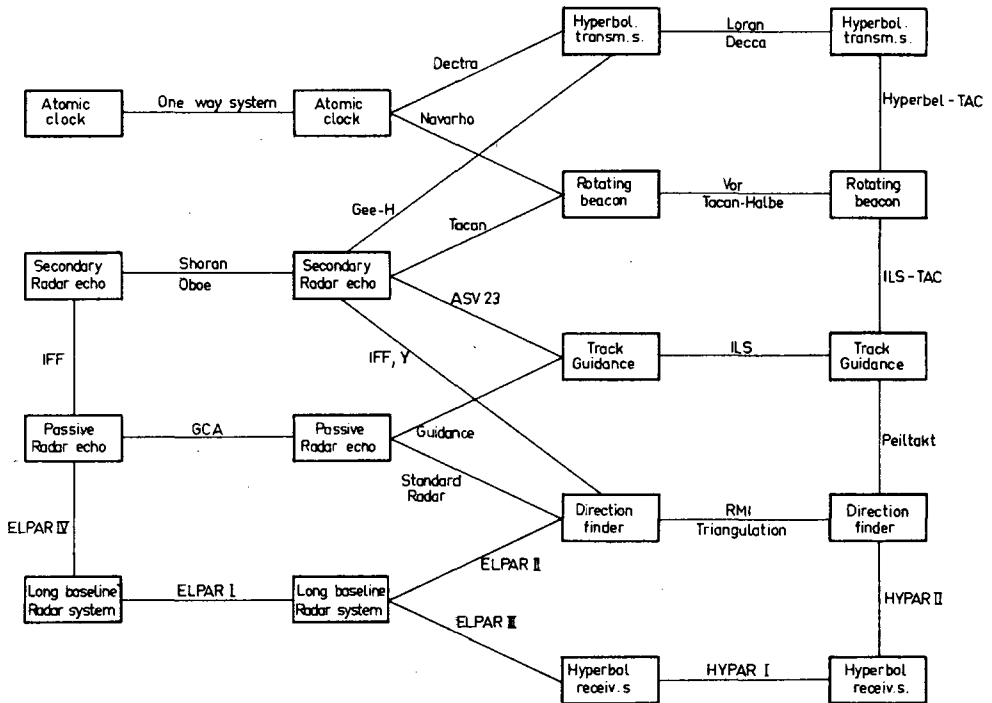


FIG. 2. — Morphological Box.

the sake of clarity, only the more important connecting lines have been drawn in fig. 2 and the examples for such techniques given. The more recent systems have received particular consideration.

At first, technical examples could not be given for all morphological connections, but instead only the morphological possibility pointed out. Nowadays the progress of electronics has already created practical applications for nearly all of the morphological connecting lines. Even more, I am of the opinion that there are no new devices for electronic transit-time location conceivable which could not be classified within the morphological structure.

I have even been able to predict morphologically some of the systems, such as the transit-time measurement with airborne crystal clocks and systems like Minitrack and storage devices. For other somewhat or completely unusual techniques or for the possibilities of such, only abbreviated code designations are given :

ELPAR = long-base radio echo system with elliptical position line.

HYPAR = long-base radio navigation aid with hyperbolic position line.

Hyperbola-TAC = hyperbolic transmitting system with TACAN transmitters and antennas.

Although morphology as we have seen covers all of the systems, its application in Europe has been practically insignificant up to now. This fact is all the more amazing since other branches of natural science, such as botany, geology and crystallography, have been making use of morphological analysis for a long time. Employment of morphology in engineering has found in ZWICKY an efficient champion for the United States (13, 14, 15).

Of course I must admit that, especially in the field of location by radio, the physical practicability of a given system is a necessity but by no means a sufficient qualification for its tangible realization. Suitability for practical operation and sufficient demand by the consumers are likely to be additional requirements. The coordination of the interests of both ground and carrier, together with the economical and political considerations do present a number of administrative difficulties, many times more difficult to overcome than the purely technical problems. Engine and vehicle builders, in the majority of cases, certainly have had it easier up to now to make their creations become solid realities. Nevertheless, I am convinced that the present state of engineering would make it possible to put any physically feasible technique into practical operation if one would only approach the task with the necessary resolution.

Active function of the craft

A very decisive question for the practical value of a morphological combination of techniques is that which refers to the part the craft will have to play (fig. 3). We seek the reply to the question whether the craft should carry for radio navigation purposes a transmitter and operate it continuously or intermittently. The increase in devices to be carried aboard and the number of available channels would set definite limits to such a procedure. A further inconvenience lies in the fact that any ground station within the propagation range of the moving transmitter may establish unnoticed a radio location link, even against the intentions of the located object. On the other hand, the active participation of the craft definitely enables the unmistakable establishment of the radio location link. At the same time it offers a basic solution of the identification problem. However, the fact that the solution may be simple in principle must not make us forget that so far there is no world-wide identification method in use with any civil navigation branch, whether in the air or at sea.

The active participation of the craft appears therefore convenient, if we disregard the direction finding through its radiotelephone traffic, most of all for special functions comprising only a limited number of participants. I may mention for instance :

- tracking of satellites (Minitrack),
- airborne distance measuring equipment (TACAN),
- aircraft remote control (Oboc).

Passive function of the craft

The airborne station requires no transmitter of its own for radio location. Ground stations can provide a practically unlimited number of crafts almost simultaneously with positioning information. Any craft provided with the necessary equipment may, if so desired, enter the radio location link and procure for itself the necessary positioning information, even in a clandestine way. Considering the ever-increasing number of radio location participants, the latter system of passive function of the craft

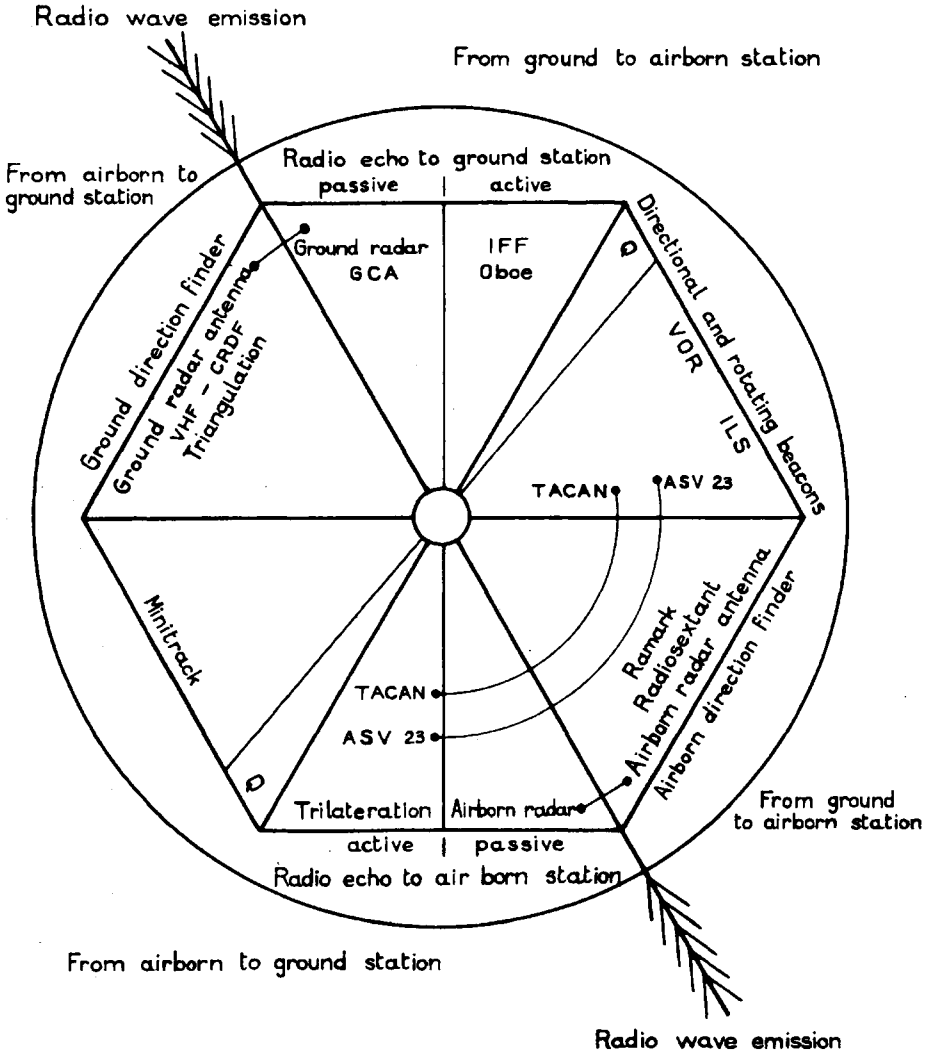


FIG. 3. — Function of the craft.

seems to be the most indicated for the future. In view of technological progress on the one hand and the overcrowded frequency bands on the other, two systems may be adopted :

- a) a small number of long-range stations operating on the lowest possible frequencies (Dectra, Navaglobe),
- b) a large network of short-range stations operating on the highest possible frequencies (Tacan, VOR, ILS).

Q-technique or single way system

As Q-techniques I would like to classify those apparently feasible methods employing a true transit-time measurement with a chronometrical device of the utmost precision, i.e. a quartz crystal clock or *atomic clock*. In introducing a Q_0 device at the reference point and and a Q_t device at

the measuring point, the transit triangle becomes obsolete. Its place is taken by the direct radio location link between reference point and measuring point. The evaluation of genuine time differences for the delayed arrival of a measuring signal at the craft's receiver, probably being carried out e.g. as phase shift measurement, would determine the distance from the ground station. The procedure can of course be reversed. This method allows determination of the distance of an object from its starting point and may well gain importance for establishing the distance of research rockets in space. Naturally, the Q-techniques can be combined with other well-known radio location methods, e.g. with a ground direction finder.

Setup of the radio navigation link

A further insight into the existing morphological possibilities for location with electrical waves is offered to us if we examine the most important types of setup for radio navigation links when combining two systems, i.e. an analysis of the possible transmitter sites. Let us commence with the transmitter site which is characteristic for hyperbolic navigation, viz. the triplet (fig. 4a). A central master station P synchronizes the two slave stations S_1 , S_2 and the equipment on the craft. Once synchronism has been established, the time difference to the two slave stations can be measured electronically by the equipment on the craft. This type of setup is not restricted to any particular frequency or modulation system. We find this method in the Standard-Loran, Gee, Decca-Navigator, etc. It has been possible to improve the equipment on the craft to such an extent as to achieve constant synchronism for lengthy periods without the need for continuous readjustment, as before. Reading off the time differences or the corresponding figures from counters or pointer instruments has also been considerably simplified. A further fundamental advancement will only be achieved when the links PS_1 , PS_2 and PA, which only serve the purpose of synchronization, may be dispensed with. That will only be possible if a crystal clock or « atomic clock » of the utmost accuracy is carried aboard and if the ground stations are able to keep their ratings over long periods. Continuous synchronization would then be needless. The measurement of the time differences would then be replaced by the measurement of the direct transit time from the fixed stations Q_0 to the movable station Q_t (fig. 4c). Instead of abandoning the synchronizing paths, which is not possible for the time being, one could dispense with the master station P and, in a mental experiment, situate it at the S_1 and S_2 points. These would then be fitted with rotating radio beacons (fig. 4b). Examples for this are Consol and VOR. The receiver on the craft is offered a rotating diagram by such stations, the phase angle of which is being compared with a reference signal (dotted line in the drawing). In principle, this reference signal would not be needed if highly accurate standards were available ashore and aboard. The rotating radio beacons would then not only operate with the same angular velocity of the rotating diagram but also pass entirely synchronically through the reference direction. The radio navigation links would therefore be superimposed with an absolute time service

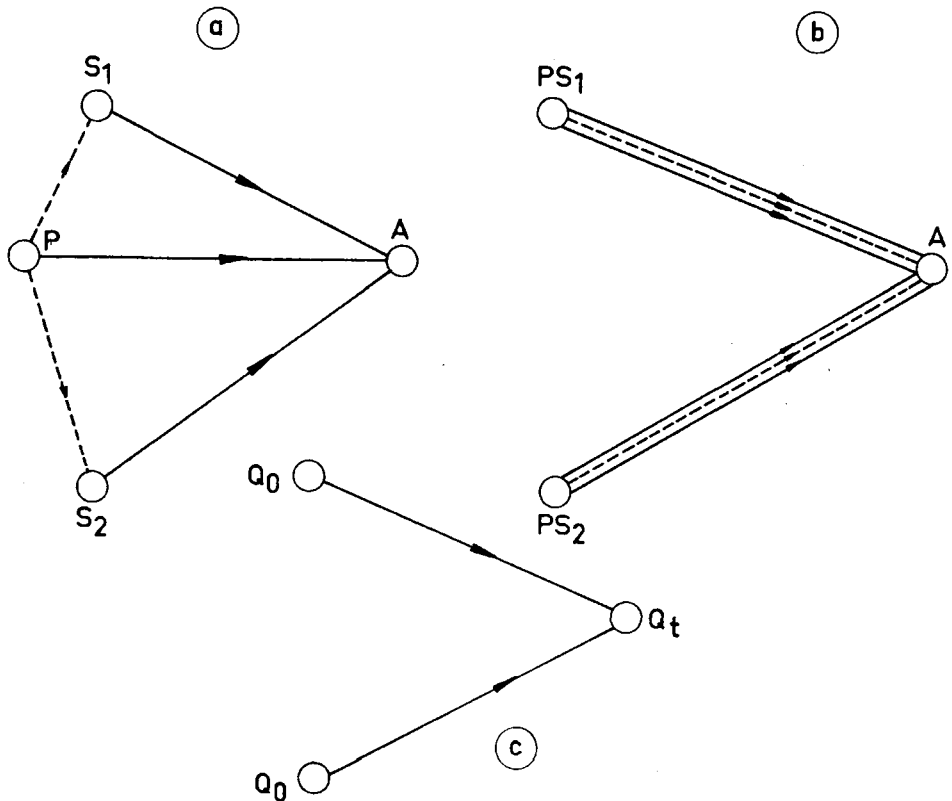


FIG. 4. — Radio Navigation Links.

which in effect could even be exploited for obtaining the standard watch time.

With the transmitter setup of fig. 4 the radiating ground stations are always located on one side and the receiving craft on the other. Let us now examine setups in which the craft is located between the transmitting stations. We shall examine first a setup of two pairs of stations P_1 , S_1 and P_2 , S_2 with comparatively small spacing (100... 200 km) between the relevant primary and secondary radiation sources but with a comparatively long distance (2 000... 3 000 km) between the two primary radiation sources. These should be placed so as to make the median perpendiculars of P_1 - S_1 coincide with P_2 - S_2 (co-linear setup). Such an arrangement (fig. 5a) has been chosen e.g. for the Dectra system, operating on frequencies around 85 kilocycles. One obtains first of all a tracking aid and then, if the conditions of propagation allow synchronization of P_1 by P_2 or vice versa, a range measurement. If we now had a highly accurate electronic clock aboard, we could dispense with the two secondary radiation sources for range determination (fig. 5c). This has already been provided for Dectra. Finally the four transmitters may be set up in such a way as to form a square (fig. 5b). This quadrilateral arrangement can be found for Radio Mailles with base lengths of some 100 km and for SS-Loran with base lengths of more than 2 000 km (16, 17, 18, 19).

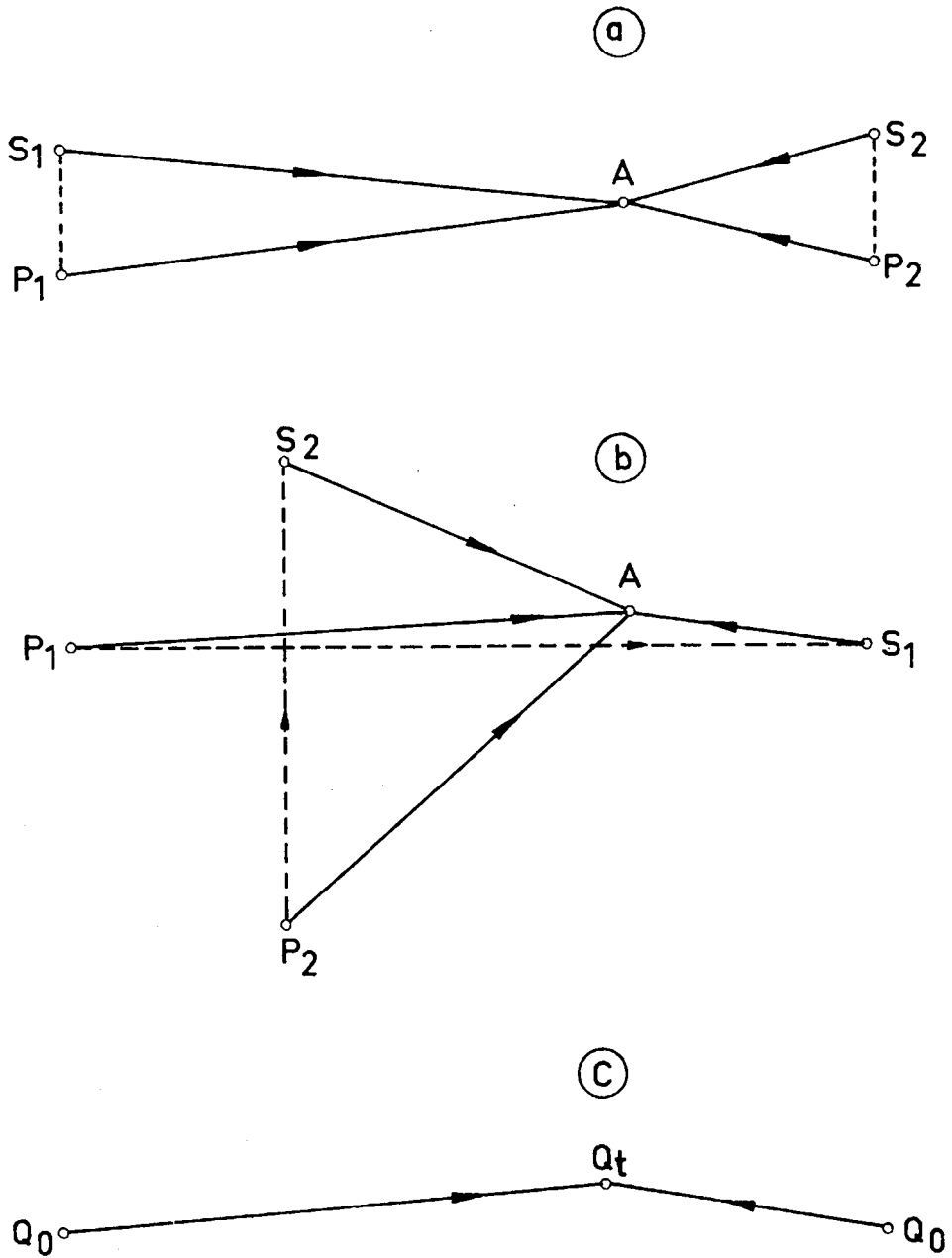


FIG. 5. — Arrangement of transmitters for long baseline system.

Frequency allocations

Finally the question of the frequency allocations remains to be discussed. From the practical point of view this problem should have priority, since without a frequency channel even the best and the fanciest system would remain an object of wishful thinking. The morphological examination of the technical possibilities, however, need not consider the practical feasibility of any proposal as its primary concern and may well deal with this matter last. Fig. 6 shows us the band presently used by electrical waves generated by technical oscillators. Allocations have already been granted up to 10 500 Mc/s. For location and navigation purposes the users must therefore make the best of the assigned bands in times of normal traffic. This does not exclude preparing in time other equipment which may allow operating in other bands or that special regionally limited arrangements may make exceptions possible.

Fig. 6 contains only the most important of the systems developed and tested in the last ten years for navigation on the sea and in the air. The approximate 3 000 nondirectional radio beacons registered mainly in the western hemisphere and a number probably at least twenty times greater of corresponding ship or aircraft direction finders are not shown. As to number, this oldest branch of location by radiogoniometry is therefore still in a leading position in civil navigation. Let us not forget that the earth surface covers approximately 500 million square kilometers of which a considerable part should be provided with navigational aids. Since the equipment operating above 100 Mc/s has been standardized for short- and medium-range navigation and considerable investments were necessary for the stations now in operation, developments in this sector should henceforth proceed smoothly.

Electronic long-range navigation

With electronic long-range navigation, however, much lies still ahead. The competent authorities are facing the far from easy task of selecting one of the systems proposed and of promoting its world-wide introduction with all their energy, postponing possible national interests in order to do so. The rapid developments in electronics call for a certain reserve in order not to prevent the application of better proposals in the future by taking hasty decisions now. The prospective users, on the other hand, press for a quick decision, for reasons which are readily understood. I have mentioned the « competent authorities ». Competence however should not be confused with power. Next to the competent authorities we must take the « influential agencies » into account. The present state in these matters shows us clearly the difference (10). In 1945 there were two proven systems for long-range navigation : Consol and Loran. Through the activity of the radio interception and detection services on both sides, sufficient information was available even before the doors were opened. Both systems should have been fully and validly adopted. Instead they were only given a period of grace... and are doing to-day as well as ever. In the meantime Dectra and Navarho have come to the fore; Radio Mailles, Omega, Loran-C and

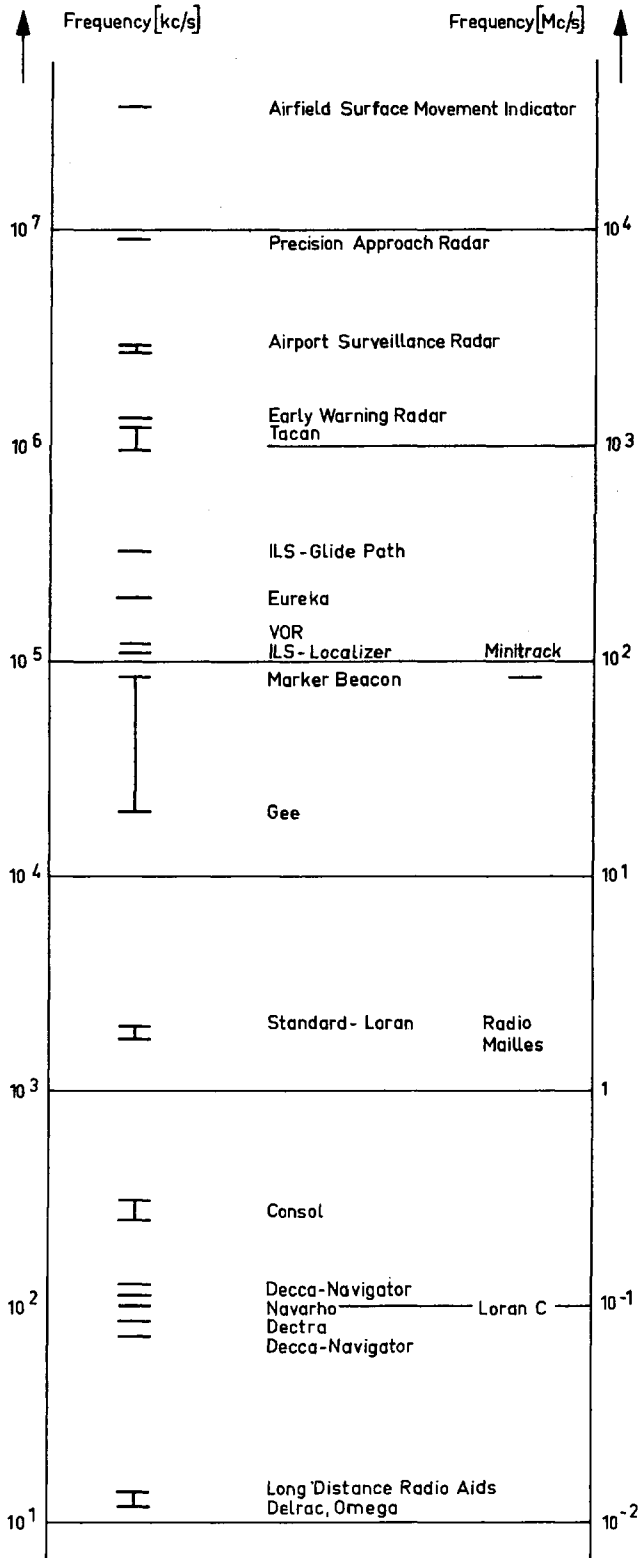


FIG. 6. — Frequency allocation.

Delrac are also competing for the ultimate prize. Loran and Dectra have influential parents and should be kept on and their equipment developed further, regardless of how the question of frequencies is considered by the « competent bodies ». Consol, due to its incomparable simplicity on the receiver side, is an excellent aid for smaller craft, being also used by large ships and transatlantic airliners. The exact number of users cannot be ascertained, unfortunately, but should be very high. All the more paradoxical is the observation made that Consol stations have been operating for months with the signal sequence 61 instead of the rated 60, until the defect was corrected. It is furthermore difficult to understand why the proposed improvements of the antenna system were not carried out, at least at one point (11). The only progress to be reported is that the former tiring and slow signal sequence of the old German Consol stations has generally been changed to the rapid sequence (12).

Summary

It was my wish to underline with my explanations that the sector of radio aids to navigation has definite boundaries imposed first by physical limitations, secondly by frequency allocations, and last but not least by the investments already made. Only within the remaining area can further developments flourish successfully. Increased dependability and simplicity of operation should in my opinion be the aims towards which efforts should be directed. Such aims can be pursued at any time, even with limited means, disregarding all difficulties of fundamental planning. The improvements achieved may some day spell the salvation of any one of us while happening to travel by air.

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