A PHYSICAL CLASSIFICATION OF RADIO AIDS TO NAVIGATION

CONCLUDING LECTURE HELD AT THE RADAR MEETING IN FRANKFURT/MAIN

by Walter STANNER.

The lecture given by my learned colleagues revealed impressively that the purpose of radio location is much more than mere position finding of airplanes or ships. On the contrary, our attention was directed to the infinity of the universe containing innumerable unknown objects which will be located in the future, though, to-day, they are still in the dark. Now, at the conclusion of this meeting, we survey so vast a field of activity for radar and radio location that it was next to impossible in the past to even imagine anything of this nature ever to be realized.

The multitude of methods and equipment so far tried out or merely considered for application have fallen into oblivion, generally speaking. Since in the course of this convention the most important data were brought back to our recollection I think this to be an opportunity to arrive at a consequent physical classification that may lead us to a synoptical view of the problem. I am convinced that, by doing so, we shall succeed not only in determining the advantages and disadvantages of the different methods, but we may, at the same time, establish what has remained unchanged in spite of technical progress. In addition thereto we may find indications for future development. Such a backward glance, I believe, also may result in a favourable effect on all those eager to learn, because first of all students are looking for some guide to help them not to get lost on their way through the immense world of science.

I deem it appropriate before attempting to classify the methods of radio location according to physical aspects to make a preliminary arrangement as shown in the following table:

For the time being we shall disregard radar and similar distance measuring equipment, displaying in the table direction finders, fixed course beacons, omnidirectional and rotating directive beacons as well as hyperbolic systems. In this table a rough distinction between long, medium and short range systems is made, as well as a subdivision into systems with or without shipborne transmitters necessary for radio location.

Systems without air- or shipborne transmitters (free running systems) require only an aerial, receiver, indicator unit and power supply. For that reason they are preferable to systems needing air- or shipborne transmitters with regard to space, weight and energy. From the ground station (beacon or master station) information can be obtained almost simultaneously by a practically unlimited number of ships and for air planes.

Systems with airborne transmitters are of importance only for special tasks, such as electronic altimetry, blind bombing, etc. The radiation of shipborne

TABLE I

RADIO AIDS TO NAVIGATION WITHOUT DISTANCE MEASURING EQUIPMENT

	With Shipborne Transmitter	Without Shipborne Transmitter (only receiver needed)			
	Ground based Direction finders	Non-directive Marine beacons	Fixed course beacons	Omnidirectional and rotating directive beacon	Hyperbolic systems
Long Range	Adcock Brommy Wullenwever	High energy beacons for shipborne direction finders, homing systems and radio compasses	Radio Range Elektra	Consol Consolor Navaglobe POPI Orfordness	Loran Decca-Navigator Gee Ingolstadt
Medium Range	Loop Aerials VHF-Adcock	Medium energy beacons	VAR	VOR Bernhard Erika MTR Navar Sperry	Raydist Rana/Loran Dick Turpin
Short Range	ZZ-System for aircraft landing	Low energy beacons	SBA ILS ONERA Sperry	TVOR	

transmitters played a considerable role in the past in order to locate ships through the net of shore based direction finders, a method still applied at present, though it no longer constitutes the only possible way of radio location. All these methods, however, show certain defects from the military aspect inasmuch as the radiation of shipborne transmitters may be tapped by any station interested in picking up enemy signals.

With regard to physical classification we need not lay too much weight on certain pecularities common to the various systems, of consequence only in practical application, as I am about to show:

From the physical point of view the wavelength of a system is of little importance because we do not know any system that requires a method of measurement operating only on a certain radio frequency band. For that reason wavelength cannot be considered a decisive factor in this connection. The range of a radar-set or of a radio-aid equipment to navigation is determined, however, by wavelength, power of transmitter, sensitivity of receiver, aerial gain and noise level. Thus the greatest range possible depends upon physical factors but any equipment for shorter ranges can be chosen pursuant to practical requirements within the frequency bands provided by law.

The physical principles of Radar are quite similar regardless of whether the target is acting as secondary Radar or as a natural reflector. As to certain Radar-systems (such as IFF) we may select between the much stronger pulse of the secondary Radar or the weaker pulse reflected by a ship or airplane.

First of all I intend to compare with one another in a conspicuous manner the various systems of the table as shown in Figure 1. Hyperbolic finding of a fix is done by measuring the time interval of synchronised signals from transmitters set up far apart from each other with respect to the lengths of the waves emitted. The extension of the base lines in question lies beween 100 - 2500 kms and vouches for highly precise locating. At great distances from the focal points the hyperbolae may be replaced with sufficient approximation by asymptotes, which fact permits us to react as if radiation were travelling to the receiving point in the direction of the asymptotes on 2 or 3 parallel rays. For the sake of uniform illustration (in Figure 1) and in order to clearly point out the relationship between the various systems the base lines used were drawn as if they were equal, though in fact their natural lengths differ a great deal.

At the top of Figure 1 we see the sky wave synchronised Loran system. The pulse of the master station triggers, by means of sky wave propagation, beyond a base line of even more than 2000 kms (from Scotland to North Africa), the radiation of a slave on the same frequency. The pulses of master and slave arriving one after another are indicated by a Cathode Ray Tube. I want to emphasize that, when selecting a base line of such length, we aim at finding the position between the two focal points.

The length of the base line in the Decca Navigator System (lower image of Figure 1) lies between 100 and 200 kms. The master station, with short interruptions for the emission of additional signals, continuously radiates the unmodulated frequency 6 f_0 which is received at the purple, red and green slave stations where they are converted into 5,8 and 9 f_0 and re-emitted. Multiplication of the incoming waves takes place in the receiver, resulting in oscillations of the following frequencies, namely 18, 24 or 30 f_0, of which we measure the phase difference. It

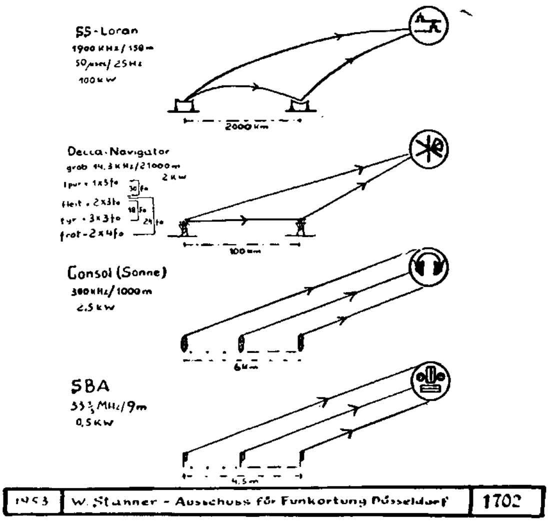

Fig. 1.
(From top to bottom) shows a comparison between the various systems, such as Loran, Decca, Consol and SBA.

is possible to get a fix within 7 to 10-metre accuracy, but unfavourable intersection angles and inaccurate propagation are responsible for somewhat more inexact results.

With regard to Consol (see third image of Figure 1) the base length has again grown smaller. It is only approximately 6 kms long. Hence calculation of the phase difference on the assumption of parallel radiation paths is justified, as indicated in the respective figure. From the three aerials of a Consol-Beacon the central aerial radiates the unkeyed and unmodulated carrier wave. The phases of the two outer aerials undergo a 180° phase reversal during a dot dash keying sequence and are swept at the same time continuously. (With any common ship receiver it is possible to hear the characteristic Consol signals. By counting the dots and or dashes we get the bearing. The length of the base line has diminished by one more unit with regard to blind landing systems, as the Lorenz System and the SBA-System. The aerial array consists of three vertical dipoles of half a wavelength. Along a line perpendicular to the baseline of the aerial array the field strength during the keying sequence does not change, and we have an equisignal line.

Though we picked out only two types of beacons and hyperbolic systems we took a look at a remarkable variety of ground based as well as of ship- or air-borne equipment. Either their bases are contracted on a simple wooden structure or they may extend over an entire continent. Despite that fact we apply the same principle for measuring both kinds. It, therefore, is not too far-fetched to consider beacons and hyperbolic systems to be two possible methods of one basic system. I should like, before pointing out later on details on Radar, to first discuss the accuracy of beacons and hyperbolic systems in order to substantiate the above statements. In doing so, we must keep in mind that hyperbolic systems are beacons with extremely large bases, which means that we have to convert the accuracy obtained by measuring the time differences in hyperbolic systems into appropriate errors at long ranges on a line perpendicular to the base, such errors being expressed in degrees.

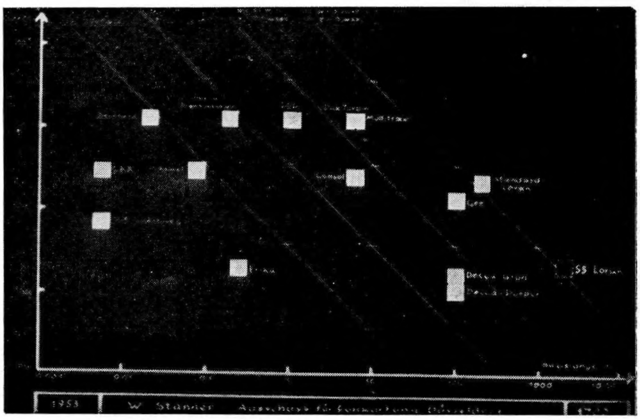

Fig. 2.

A accuracy of hyperbolic systems and omnidirectional beacons (baselength on horizontal, accuracy on vertical axis).

Figure 2 demonstrates the results obtained. For this purpose the most favourable resuls referred to in books dealing with this subject were used as a basis for calculation. As indicated the results are scattered. The logarithmic scale in the figure shows the base length in kilometers on the horizontal axis and the accuracy in degrees on the vertical axis.

We may see at once that there are 3 groups, i.e. systems with an accuracy of about 1 degree, of some tenths of a degree and of some hundredths of a degree. The first group comprises systems the indicator units of which were not developed to procure utmost precision. The systems in use in the early days of radio location also fall within this category. In addition some experimental stations may be also included in this group, by means of which real time measurement was done in spite of the small bases available, such as Dick Turpin and Multitrack. The accuracy obtainable could, with respect to all the above-mentioned systems, be increased by further technical progress.

Consol, Gee, Standard-Loran and Blind Landing Beacons are part of the second group. It is interesting to compare the accuracy of angle measurement arrived at with the equivalent accuracy of time measurement, which is also shown in the figure.

The third group finally comprises Erica, Decca-Navigator and SS Loran. As to the latter system the accuracy obtained is a mere fiction inasmuch as the results are affected by bad conditions of propagation. I believe that with the three categories mentioned the limit of possibility in the realm of physics has been attained because even utmost accuracy of the recording methods will not make up for the inaccuracies caused by propagation through a non-homogeneous medium.

I further am of the opinion that a comparison between the different methods of operation is very useful in order to clearly establish the efficiency of the various systems. In doing so we only arrive at the fact that the great number of radio aids to navigation, notwithstanding the individual lengths of waves, base-lines, modulation and indication types can be considered as branches generated by the same tree. It is, furthermore, obvious that many more branches may grow from the same roots, the form of which, it is true, will depend upon scientific progress, practical and economical requirements.

By shedding light on the close connection between radio beacons and hyperbolic systems we have already coped with a considerable part of the task presented. It remains to examine whether or not we may also find such a cross-connection with the radar systems. In order to do so we must analyse the different methods of radar, but should not restrict ourselves merely to the well known PPI-Presentation, though in fact this is the most important one, as practical application has taught. The results obtained have been set forth in Figure 3, in which the measuring base always shows the same length for the sake of uniform representation.

The first part of Figure 3 demonstrates a little known method for obtaining the distance of an enemy short wave transmitter by means of time measurements during great circle path propagation around the earth, which in Germany was called « Nordlicht ». The signals of the transmitter to be located arrive via the ionosphere at a receiver station about 6000 kms away where they put a time measuring equipment into operation. They, may however, also run in the opposite direction around the globe and, if the ionospheric conditions are favourable, pass by once more. The time interval will be measured as usual and the result evaluated for calculating the distance between receiver and transmitter.

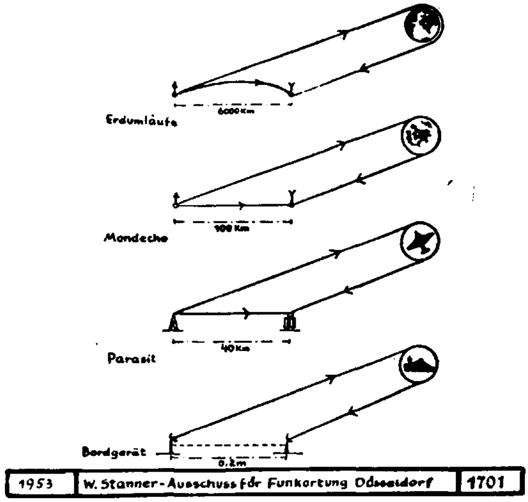

Fig. 3.

(From top to bottom). Comparison of various systems with one another, namely Nordlicht-System, Moon-Echo, Parasit-System and usual radar.

In the case of radar experiments for obtaining an echo from the moon surface on short waves, we find base lines a few hundred kilometers long. A commercial short wave transmitter and receiver station in Australia, for instance, set up at this distance were used for moon experiments. Inasmuch as the moon is approximately 380.000 kms away we may estimate that outgoing and incoming rays run in the same direction (see Figure 3).

A very significant method for obtaining radar echoes is displayed in the lower part of Figure 3, and was applied by the Germans during the war, especially between the English and French coasts of the Channel, i.e. the so-called Parasit-Ortung. By this method, which the author described for the first time in his book « Leitfaden der Funkortung », direct radiation from the transmitter of the English coastal chain was received with a small non-directive aerial; the pulse was indicated on the screen of a Cathode Ray Tube. Weak radiation scattered back by any target was picked up also, by means of a highly directive aerial array, and the pulses were indicated in the same screen. After calibration the transit time difference between the direct pulse and the echo pulse could be measured. The base length between the English transmitter and the German receiver was about 40 kms. The geometrical points for the location of an airplane in this case are marked by ellipses with transmitter and receiver at the foci.

The other extreme regarding the base length is contained in ship - and air-borne radar where transmitter and receiver often have been assembled into one unit. The distance of the two aerials might, to some extent, be taken as a base (lowest part of figure 3) though technically speaking the adjustment of departing and arriving pulse in this way is obsolete and handled today internally through a special trigger tube. It is evident that the measuring methods are always identical regardless of their external variety in equipment, whether the bases disappear within the installation itself, as just pointed out, or extend across the oceans.

The relationship claimed between all systems becomes especially obvious when making a uniform sketch of the three methods, drawing them side by side with a small base as well as with a large one (See Figure 4). P always stands for a primary radiation source of any frequency, energy and physical nature, such as nondirective beacons, master stations of hyperbolic chains, broadcasting transmit-

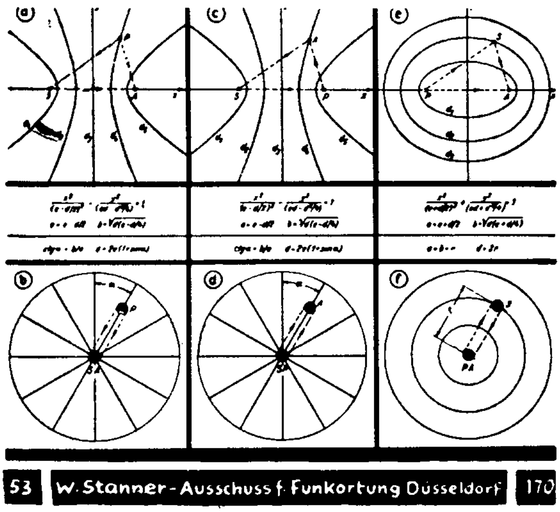

Fig. 4.

Represents the 6 fundamental principles involved in any position-fixing or target-detection system by means of radio waves.

ters or natural sources of electromagnetic energy. S indicates a secondary source of radiation that is a radiating unit, the functioning of which depends entirely upon the radiation of P, such as slave stations of hyperbolic chains, aerial arrays for directive transmitting and receiving, radar-reflectors, secondary radar-sets. A indicates the point where an observer handles the receiving and measuring equipment.

As is displayed in the diagram (a) radiation from P is received in S and A where the transit time is measured. This occurs, for instance, in the case of the Raydist-E System, while (b) shows an assembly of S and A. The hyperbolae are replaced by their asymptotes, which is the principle of all direction finders.

Under (c) the radiation of P is re-radiated from S to A and the transit time is measured, as in the case of Loran, Gee, Decca-Navigator and Rana.

(d) represents a reversion of (b) : P and S are assembled in one unit which acts as directive rotating and/or omnidirectionnal beacon.

The above-mentioned radar-system called Parasit-Ortung is illustrated in (e) of the diagram, while (f) displays the well-known type of radar-system.

Hence it became evident that in every instance as shown throughout Figure 4, the fundamental law, to wit

$$d = ct = Ps + SA - PA$$

proved to be valid, t representing the transit time measured, c the velocity of light. Naturally, by all methods based on this simple law established by means of analysis, only one position line or coordinate can be obtained regardless of the fact, as everybody knows, that navigation requires two or even three coordinates. It is therefore necessary, by means of synthesis, to combine for this purpose two of these principal methods fitting together as indicated above.

At the end of my statements I should like to point out a procedure for clearly showing the different combinations possible. This is done through symbolization of what I consider the six basic methods contained in Figure 4. Hence I have marked them with letter groups, i.e. in capitals for long baselines, and small letters for short baselines. Furthermore, by adding numbers I could indicate details about modulation measuring equipment. Every line by which a point can be connected with another is equivalent to a practicable method. Figure 5 gives an illustration

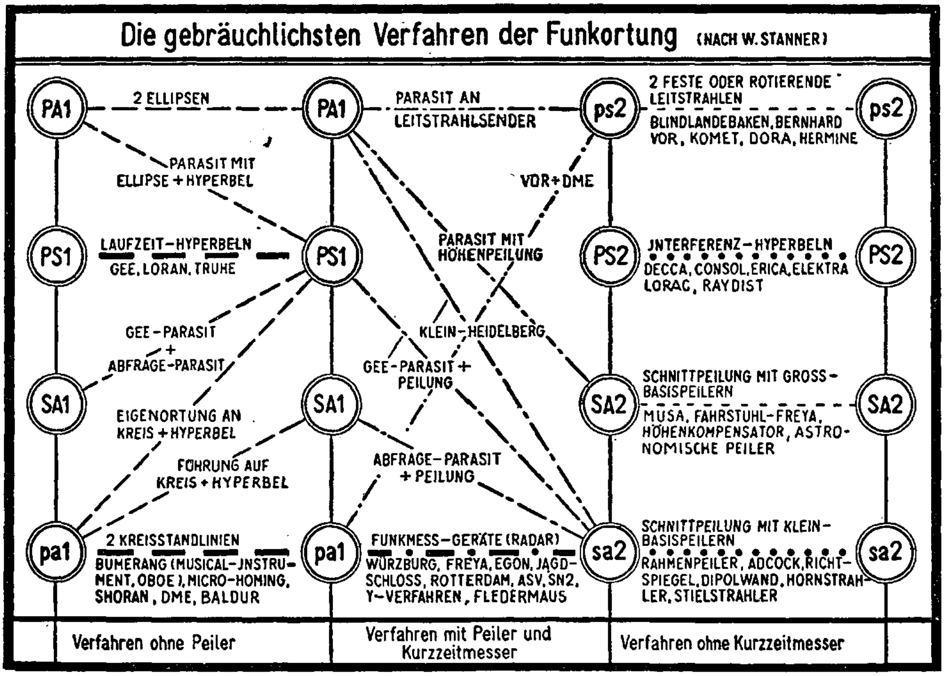

Fig. 5.
Morphological Chart of all possible systems derived from Fig. 4.

thereof. To discuss it at length is not the purpose of this lecture. I shall therefore merely underline that experiments made with a few of these combinations proved to be very efficient while others have not yet been thoroughly examined.

This fact, however, does not affect at all the nature of the proposals made. A long period of time elapsed before it was possible to develop out of the knowledge by then acquired suitable equipment for radio location. Often fearful international complications were necessary to finally overcome various obstacles on the road to technical progress. I should not like to close this lecture without stating that an institute under the direction of Prof. Zwicky exists in the USA for the special purpose of solving combination problems of the kind just referred to which over there are called « Morphological Methods ».

There is no doubt that the practical application of the morphological system constitutes something completely new and I am aware of the fact that many years will have to pass before the competent authorities are fully cognizant of the advantages offered by this method.

Taking into consideration the decisive role played by radar and radio location in securing human life and property under any conceivable aspects arising out of political circumstances and traffic conditions, any efforts seem justified in order to come closer to the solution of all the existing problems, even by the detour of a consequent morphological method, until better ways may open up in the future.