

Why Decca Works

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RADIO position-fixing systems employing the continuous-wave hyperbolic principle, such as the Decca Navigator and Loran C, are now used by ships and aircraft numbering tens of thousands and the theory of their operation has become part of the syllabus in many courses of instruction on navigational aids. Although accepting that these systems produce position-lines along which the difference in the distance from the user to a master and slave station is constant, and that such a line is obtained by time-difference measurement in the form of phase comparison between the two received signals, it may be asked whether this process is affected by the doppler frequency-shifts that will occur if the craft is moving with respect to the stations. Surely, the question goes, these must complicate or modify the behaviour of the system and give rise to an error unless the receiver is stationary? It sometimes seems to come as a surprise to learn that, far from being adversely affected by it, the operation of these systems is a practical example of the phenomenon to which Prof. C. J. Doppler gave his name: they work not in spite of his 'shift', but because of it.

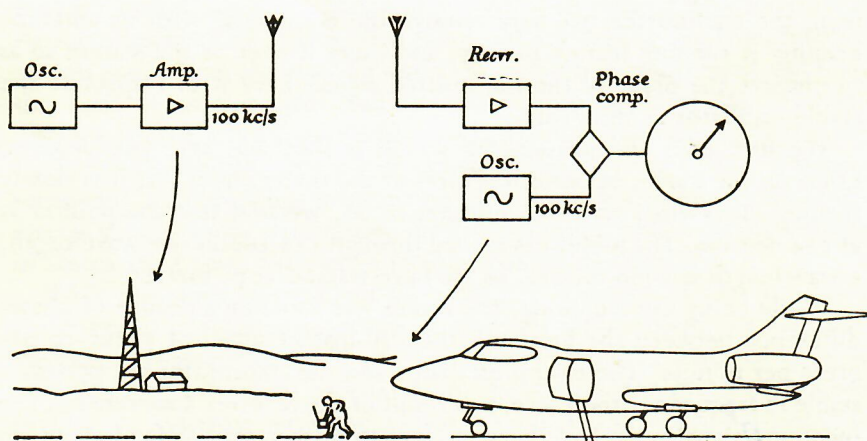


FIG. 1. Aircraft one wave-length from the station

A look at the statement just made can help to impart a feel for how the radio aids function, and we can start by conducting a hypothetical experiment with a suitably equipped aircraft and a single ground radio station. Fig. 1 represents such a station, sending a pure continuous-wave signal of 100 kc/s—a representative frequency for Loran C and Decca—

and shows the aircraft in a field at a spot less than one wavelength away from the station. This rather close distance is chosen solely in order to prevent the matter of cycle-ambiguity from intruding on the discussion.

In the aircraft are an antenna and receiver for the 100 kc/s signal; a stable local oscillator running at that same frequency; and a phase comparator with a meter showing, on a 0-360-degree scale, the difference in phase between the local and the received signal. When the stable oscillator has settled down, the meter will take up some reading which, if the oscillator and the station are indeed running at exactly the same frequency, will remain fixed. What does this reading tell us about the transit-time of the signal from the station to the aircraft, and hence about the distance between them, knowing the speed of radio propagation to be 300 metres per microsecond? It tells us nothing.

The reading that the pointer takes up is merely a matter of chance, depending as it does on the interplay of warming-up drifts and suchlike, and on the unknown phase of the transmitted signal as it leaves the station. Radio or light or sound emissions can be used for measuring the distance from a receiver to the emitter, by measuring the time they take to travel that distance, but this obviously entails knowing the time at which the signal starts as well as the time at which it arrives at the end of the line. Radar solves the problem of timing the round trip of the pulse to the target and back, and dividing the answer by two; continuous-wave distance measuring devices like the Tellurometer and the Lambda system do the same thing by comparing (in effect) the phase of the signal at the start of the round trip with its phase on returning. If we want the phase-meter in the present experiment to indicate the distance of the aircraft from the transmitter, we may remove the equipment with its antenna, keeping it running from a battery, and carry it over to the station so as to observe the phase of the transmitted signal there with respect to the stable oscillator as the datum.

We first read the phasemeter which is showing, say, 108 degrees. Once on the move, occasional glances at the meter show that it is slowly turning clockwise: after ten minutes or so, we find that the pointer is at 234 degrees. The meter has moved through 126 360ths of a wavelength, a wavelength is 3000 metres, so we have walked 1050 metres.

While being carried along, the meter was showing a change of phase-difference between the local and the still-distant signal of about 10 degrees per minute. The datum oscillator and the transmitter are perfectly stable in frequency; therefore, as a result of the receiver's movement, the incoming signal must have been subject to a frequency-shift of about 10 360ths of a cycle per minute. In other words, the received signal had a doppler shift. The extent of the shift, as Doppler pointed out, depends on the ratio between two velocities—that with which the observer is moving with respect to the source of the emissions, and that with which the emissions are coming to him from the source. In the experiment, the receiver was moving towards the source at (say) 1.7 metres per sec., and

for the speed of radio wave propagation we assume the nominal value of 300 metres per microsecond; these two velocities are in the approximate ratio $1 : 1.77 \times 10^8$ and the rate of rotation of the pointer will bear that ratio to the frequency of the transmitted signal. One can surmise that this direct display of the frequency-shift as the cyclical rotation of a pointer would have appealed to Doppler as a way of demonstrating his principle.

Having stumbled on the fact that the rate of change in the phase of a C.W. signal received by a moving observer is one and the same thing as the doppler frequency shift, we shall take it on trust that the equipment could have measured the distance from the aircraft to the station, so long as the phase comparison was performed at the station as well as in the aircraft, and look at its behaviour in the air.

A useful rule for discussion on doppler-shifted radio signals—and these effects can be very important in the design of Decca or Loran C receiver circuits—is to postulate a flying speed of mach 1, which is not too untypical a value for the present day and happens to be in the region of 300 metres per second. Since the propagation speed of radio waves is nominally a million times this value, the arithmetic becomes very easy; as we fly towards the station at mach 1, the phasemeter is turning at the rate of one revolution every 10 seconds, which is one-millionth of the transmitted frequency of 100 kc/s. On passing over the station the pointer will slow down and reach some value before reversing to show the negative doppler shift on receding from the station.

A stable oscillator used in the manner just described is an excellent tool for measuring the velocity of a craft with respect to a fixed radio station, assuming, of course, that the oscillator driving the transmitter is no less stable than the moving one. The velocity measurement can form the basis of an accurate dead-reckoning process giving the aircraft's distance from a known start point, and two such measurements can give the aircraft's position, but it is obviously incorrect to call this a 'distance-measuring' system. Thus it means nothing to draw a series of concentric circles about a radio station used in this way since, unlike the hyperbolae of Decca and Loran, the circles have no positional existence.

What one does know about such circles, however, if they are taken to represent successive rotations of the user's phasemeter, is that they are one wavelength apart: if the craft moves through a distance equal to one wavelength towards or away from the station, the meter makes one revolution, whereas with the Decca Navigator the fraction pointer of the decometer makes one revolution for a movement equal to half a wavelength along the line between the master and slave station. In Decca, the local oscillator discussed above is replaced by a receiving channel for a second station, so that moving half a wavelength along the baseline towards one of the stations also causes *ipso facto* a half-wavelength increase in the distance to the other, making a total phase change of 360° or one lane.

Reference to movement through lanes is made because the question

is sometimes asked, 'Don't the lanes appear narrower, or displaced, to an aircraft flying fast across them, compared with their computed positions?'. Returning to the airborne oscillator moving straight towards the single 100 kc/s ground station (on the principle that there is no point in thinking about two stations when one will do), it is clear that the phasemeter will make one revolution per wavelength passed through however fast the aircraft is travelling, and that if a small marker could be dropped overboard each time the meter repeated a given reading, the markers would be spaced exactly 3 km. apart. Indeed, the wavelength is the only thing about the signal that stays constant so far as the airborne user is concerned; if he is moving with respect to the station, the apparent propagation speed depends on his own velocity, and the frequency of the received signal is thereby shifted in the manner associated with a certain professor of experimental physics at the University of Vienna.