AUTOMATIC COMPUTATION OF HYPERBOLIC LATTICES

PHASE-VELOCITY CORRECTIONS

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In a previous paper (*Int. Hydr. Rev.* XXXIV-2) an automatic code for computing hyperbolic lattices (e.g. for Decca Chains) was described. The prime object was to compute the geodetic distances from a given point to two radio stations: S_{pm} (distance point to master) and S_{psl} (distance point to slave), then using the formulae:

$$\frac{S_{pm} - S_{psl} + S_{msl}}{\text{Wavelength}}$$

in which S_{msl} and the wavelength are constants, calculate the lane value of the point.

If the velocity of radio-waves was constant, and known, the computed and observed values would agree but this, unfortunately, is not the case. We adopted a constant speed of radio-wave propagation so we knew there would be a systematic error in the result given by the machine for we should have used not the geodetic but the radio-wave distance, i.e. the number of actual wavelengths from the radio station to the point.

With this in mind the Hydrographic Office of Sweden prepared working maps based on the Gauss projection which were used in the control surveying during the summer. As far out to sea as visibility permitted a ship's position to be fixed, Decca corrections were obtained. From these, error-charts were constructed showing contours of constant error (iso-error lines). After this surveying, the lattice was once again computed, this time using Mercator's projection with the points given in X- and Y- coordinates from the lower left corner of each map. When plotting the lanes, corrections were added by hand, thus producing charts far nearer to the true picture. This is, of course, better than having theoretical charts and corrections tabulated in a book which no one will bother to look at.

However, we may ask when using this method whether we have made the most of the valuable help an automatic calculator like Besk can give. In this paper it is intended to discuss the possibility of the machine taking over a much larger share of the work.

Having calculated the patterns in accordance with the author's previous paper and assuming that one has controlled the net to the best of one's ability and extrapolated the error curves, one can then proceed as follows in the second computation. It is known exactly along which latitudes (or longitudes) Besk will pace, and from the error map it is also known where the iso-error lines cut the

latitudes (or longitudes). When computing, Besk will make proper allowance for this, add the corrections and for future control write them out:

	59	05.000	
054	18	54.367	—.072

Which means that in pacing 59° 05', lane 54 cuts at 18° 54'.367 and the correction is —.072 lane.

Having completed the pacing along 59° 05' the machine will pace 59° 10' in the same way, and so on until all the work is complete in the required area.

When using this method the computed hyperbolae can be directly transferred to the maps which will then be true images, but the cost of one summer's surveying and double computing must be considered a considerable disadvantage.

It would be more advantageous if the same computed values could be obtained with a minimum of surveying; or, even better, with no surveying at all, thus reducing the necessary computing stages to one.

While considering this problem it will be useful to reexamine our present knowledge of the phase velocity of radio-waves, limiting our review to that which has practical implications for our problem and without endeavouring to dive deep into this very difficult but interesting subject. As the author has not conducted experiments himself, he has to rely on what others have written.

A radio-wave spreads spherically, its phase velocity depending on the medium in which it propagates, the terrain near and over which it passes and the frequency. In a vacuum we can put it equal to the velocity of light, $299\ 775 \pm 10$ km/s. (Note. The field-strength is only circularsymmetrical but the wave-front is spherical). In a gaseous medium speed drops with increased pressure and density; it does not depend on frequency and can thus be measured by the refracting index which gives the velocity of light. The terrain within a few wave-lengths of the path of the wave causes the speed to drop still more according to the conductivity of this medium, and this effect is known as land correction. As the transmitted frequency is increased the wave becomes shorter, and is affected less by the medium mentioned previously at the same range from it. This being the case, for our problem we can safely assume that UHF is not at all disturbed by land — a fact which is used in the experimental measuring of land correction (6). It is the conductivity of the ground that is of importance in our case, and topographical features like hills and so on appear to be of only minor importance. Mendoza (3) has measured the speed of long waves (100 kc approx.) between stations in Belgium to $299\ 250 \pm 40$ km/s, which closely agrees with earlier Russian figures, and in Sweden measurements have given 297 500 km/s over land of much poorer conductivity. Mendoza's value corresponds to a mean ground conductivity of 10^8 e.s.u. Bremmer (1), Norton (5) and Millington (7) have all contributed theoretical considerations.

As speed depends on distance from nearby media the wave will travel faster from the transmitter as the receiver is raised above the dragging influence of the ground (i.e. the wave-front will not be vertical but inclined). This implies that aeronautical charts will differ from nautical charts.

If we compute using a speed of propagation of 299 650 km/s (a good value for sea water, which has a high conductivity: about 4.10^{10} e.s.u.) and ignoring

any land correction, even a short distance overland in the path of the wave will give a noticeable systematic error. In the discussion following Millington's paper (7) Struszynski stated that land correction can never exceed $\frac{\lambda}{2}$ (in our case approx. 1500 metres at a frequency of 100 kc), but Waite-Householder (8) gives no such limitations.

In passing the coast line seawards several things happen; first, the speed will increase to normal *over water* speed and, in addition, it will regain some of the lost phase. This regaining effect is noticeable in both amplitude and phase. Very good experiments have been carried out by Pressey-Ashwell-Fowler (6).

Within $\frac{\lambda}{2}$ on both sides of the coast line some very abrupt and elusive changes are apparent (6). Along with the change of speed, there also occurs a refraction effect. Coastal refraction is often noticeable when taking delicate bearings of radio stations from a ship. Eckersley (2) states, however, that it is only significant for waves between 15 and 1500 metres, and in any case it is rather difficult to predict as it is essential to have a very good knowledge of the coast line in all its detail.

The problem now arises as to how to measure the land correction in a given direction. One may compare the low frequency wave with UHF or, for a Decca Chain, install an extra slave station in a ship and so adjust the resulting standing wave field as to have an oscillation node in the master just as a common slave station. In the latter case, by reading the phase of the slave on board and comparing it to the known geodetic distance to the master, land corrections for the master can be obtained; and then a reading of the Decca value of, say, the Red pattern with the addition of the land correction from the master station will give one the correction for the slave. In this way the resulting error in the Decca chain has been broken up into its components. These measurements ought to be done at least one nautical mile offshore because of the erratic behaviour of the wave close to the coast.

For simplicity one can presuppose a uniform speed over land and correct for the amount of land path as measured from a map, but in doing so there is a risk of missing a strip of land with high conductivity and thus greater speed. This happened in the case of the chain in the Baltic. Such risks may be eliminated by carefully surveying the ground conductivity of the land area, but this is a back measurement — quite a different thing to what we really want to know. Such a step can be likened to the behaviour of the tailors of Laputa in *Gulliver's Travels* (9), and their clothes were cut accordingly. Near the transmitting station the induction field introduces a further phase lag which depends on distance from the transmitter only. When the wave leaves the station it is lagging by 180°, but this lag is regained within about a wavelength of the transmitter.

Let us now see which of these effects it may pay us to account for in an automatic code. All circular effects are very easy to manage, but it might be that they are so unimportant we need not bother with them. The land correction is, however, not circular and therefore more difficult. Suppose that we know the land correction for each of the 360 geodetics that correspond to the whole degrees from the master and the same for the slaves, having either measured or guessed them as described above. When computing the lane value for a point, Besk also calculates the geodetic bearings to the master and slave, so that the land correction can be

interpolated linearly from the surrounding whole degree values. In this way we approximate the coast with a 360-sided polygon, though, if we need only part of a circle, the number of sides is of course reduced. Now allowance can be made for both land effect and the recovery effect just as we desire: for instance, by putting the speed over land at one value, the speed over sea at another, and accounting for phase recovery by linearly completing it after as long a path over sea as over land. The refraction effect I think we can dispense with, and the behaviour of the wave near the coast line is too irregular for prediction. Therefore in the main the calculation proceeds as in the author's former paper. Other factors are the inner irregularities of the transmitting equipment and disturbances of the pattern by bad weather and skywave, etc., but as these are not constant in time they cannot be taken into account.

The first method described in this paper is of course good and safe as it is only an application of actual measurements, and is supported by practical experience. The second method with the polygon is somewhat more dubious, but I think it will give you significantly better results than would be obtained if the speed were assumed to be constant throughout. Its use may also increase our chances of acquiring a better knowledge of wave propagation, and in any case I think it is worth a try.

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