Satellite surveying

Paper presented at the Times 1st Survey Congress held at School of Mines Kalgoorie, W.A. on 21/22 May 1978.
Published by courtesy of the author and the TIMES of WA.

HISTORICAL BACKGROUND

The first satellite Doppler tracking equipment to be successfully used was that developed by Guier and Weiffenbach at the Johns Hopkins Applied Physics Laboratory in 1957 to monitor the first Russian Sputnik. The development (1958-1963) of the United States Navy Navigation Satellite System, Transit, was based on the success attained in the determination of Sputnik's orbit from a single tracking station. The main factors contributing to the success of the Transit System have been the concept of dynamic geodesy and precision and ease with which Doppler frequency measurements could be taken.

Transit System involved the establishment of a worldwide network of tracking stations (TRANET) each employing a similar Doppler measurement system as the one used by Guier and Weiffenbach. Although the concept was relatively simple the instrumentation required was quite bulky. Hence, as Transit was designed primarily for navigational use, modification and miniaturisation of the tracking equipment was necessary. Several firms manufacture Doppler receivers that are designed for use in navigation, however, in recent years at least three companies have developed receivers specifically designed for geodetic applications. The first (Geoceiver), was introduced in 1971 by the Magnavox Corporation for use by the United States Navy. 1974 saw the introduction of a further two geodetic receivers, namely the CMA-722B manufactured by the Canadian Marconi Company, and the JMR-1 made be J.M.R. Instruments, Inc.

The United States Navy Navigation Satellite System

All Doppler survey sets use the United States Navy Navigation (NAVSAT) Satellites (U.S.N.N.S.) as their only source of reference in determining the three dimensional position of any point on the earth's surface. This satellite system has been in use on a global basis for fifteen years and for the last eleven years Transit has been made available to non military users. Currently (1978) there are five operational satellites in near circular polar orbits at a nominal altitude of

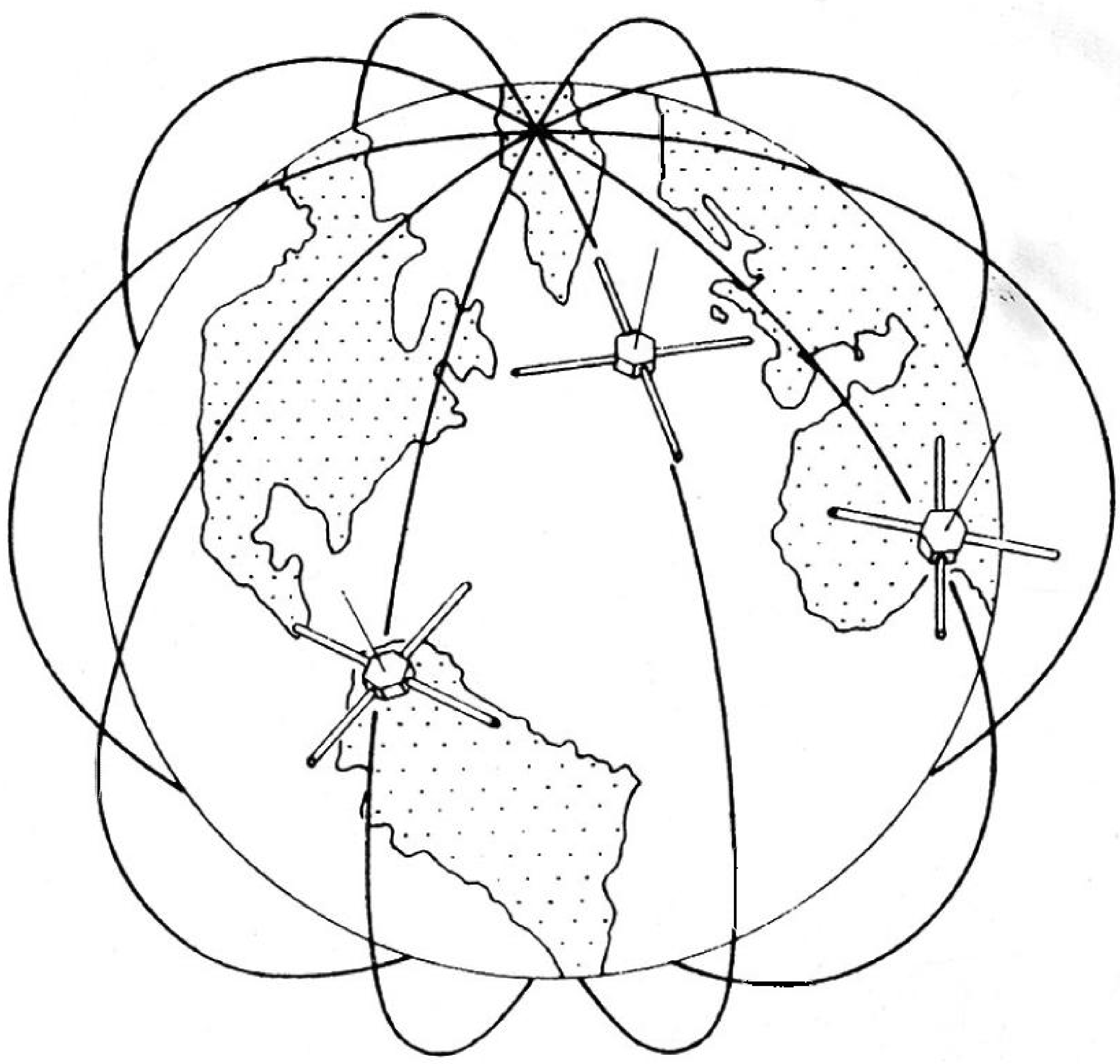

Figure 1 Navy Navigation Satellites in Circular Polar Orbits.

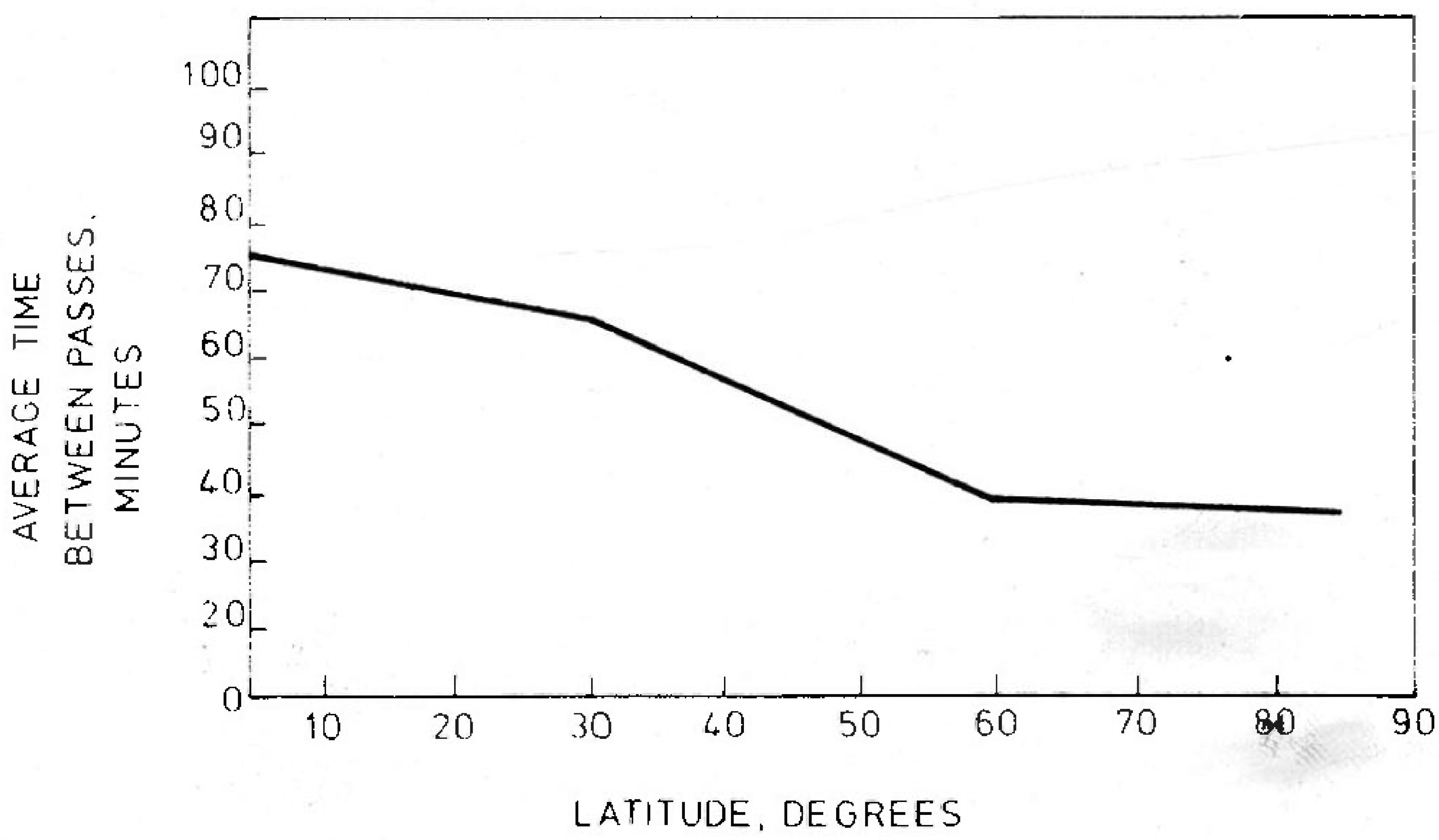

Figure 2 Satellite Availability Chart (5 Satellites)

1100km, with planes of revolution approximately evenly spaced covering the globe in a caged configuration. (see figure 1). Some of these satellites have been in continuous operation for over eleven years. Figure 2 illustrates the average time lapse between satellite passes at any given latitude.

All the U.S.N.N.S. transmit information on a continuous basis and their signals may be received and utilised by anyone with the appropriate instrumentation. Each satellite transmits on two frequencies using the same highly stable oscillator. One frequency is nominally 399.968MHz, but may drift and vary slightly from satellite to satellite. The second frequency is always three eighths of the higher frequency regardless of any drift or variation in the latter. For convenience the transmit frequencies are generally referred to as being 400 and 150MHz.

Modulated on these two carrier frequencies are a specific time marker for every even numbered minute of Universal Time, and the satellites path parameters (Broadcast Ephemeris) from which the position of the satellite at these epochs can be determined. A 16 hour batch of predicted ephemeral data is injected into the satellite's memory bank every 12 hours, for subsequent rebroadcast. Thirteen TRANET stations are used to track and establish the current satellite orbits in order to produce the post event satellite path (precise ephemeris) and to predict future values of the orbital parameters which form the broadcast ephemeris. This data is transmitted to the satellites on a separate frequency from an Injection Station. Verification that the received data is correct follows injection and any errors found can usually be rectified during the same pass.

User subsystem equipment

To be able to use the U.S.N.N.S. system a Doppler receiver such as one of the previously mentioned types is required. A set basically consists of a dual frequency antenna system and a receiver incorporating a precision 5MHz reference oscillator, a time clock and data receiving and recording equipment. During each two minute message period the receiver counts and records the difference between the number of cycles received from the satellite and the number generated by the reference oscillator; this is termed the Doppler Count.

The cause of the Doppler Count is due primarily to the relative motion between the satellite and receiving station. As the satellite approaches, the Doppler effect is such that the frequency appears to increase, and as the satellite recedes, frequency appears to decrease. Every cycle of increase in Doppler means that the satellite has moved one wave length nearer. This is a precise measurement since a wave length at 400MHz is 0.75 metre.

Signal refraction

Data could be transmitted from the satellite using a single ultra high frequency carrier. This frequency would travel along a line of sight path toward the receiving antenna, however, while passing through ionosphere and troposphere, the propagation path becomes refracted. Refraction of the signal path affects the accuracy of the Doppler count, resulting in errors in the computed fix. Dual frequency transmission is employed to correct for the major part of the ionospheric effect. During propagation both frequencies are affected by refraction, but by different amounts. This difference is measured by the receiver and is used to correct the Doppler count. If this correction is not made the position fix may be in error by a hundred metres or more, particularly during daytime passes. The correction for refraction (retardation) of the Doppler frequency by the troposphere is more complex than that of the ionosphere. Several mathematical models have been developed to account for this refraction, most of which involve measurements of pressure, wet and dry bulb temperature at the receiver. Hence for full survey accuracy correction for refraction is most important.

The three dimensional fix

As previously stated, the satellites describe their orbital position every two minutes, on the even two minutes. To obtain a position fix, it is necessary only to determine the user's location relative to the known location of the satellite. The user subsystem employs the integrated Doppler count for this purpose. In Figure 3, positions for the satellite in its orbit are shown for times t1 to t4. The slant range from receiver to satellite is given as S1 to S4.

It is evident that the number of wave lengths, of the transmitted signal, along path S1 at time t1 is greater than along S2 at time t2.

Every Doppler cycle received means that the satellite has moved one wave length closer. The integrated Doppler measurement is simply the count of the number of Doppler cycles received between t1, and t2 which is a direct measure of the total change in slant range during that time interval. Since the satellite's position at t1 and t2 is known, either from the broadcast or precise ephemeral data, then the receiver must be on some surface defined by the measured slant range difference between these points. This surface is a hyperboloid of revolution with the foci at the known satellite position. The receiver therefore must be located somewhere along the curve defined by this hyperboloid and the earth's surface. The next Doppler count will define a second curve, and so on. The intersection of these curves will result in the observer's position being fixed. A single pass can only produce two dimensions; to obtain the third dimension data from several passes is combined. The tracking of additional passes results in a higher accuracy of resolved co-ordinates.

OBSERVATION AND REDUCTION METHODS

A] Point Positioning

Point Positioning constitutes the simplest and most widely used approach to Doppler surveying. It consists of the independent reduction of observations made at a given station assuming that the ephemerides of all observed passes are perfectly known. Because in reality, errors do exist in these ephemerides their effects are necessarily transmitted directly to the recovered co-ordinates of the station. The effects of such errors can be

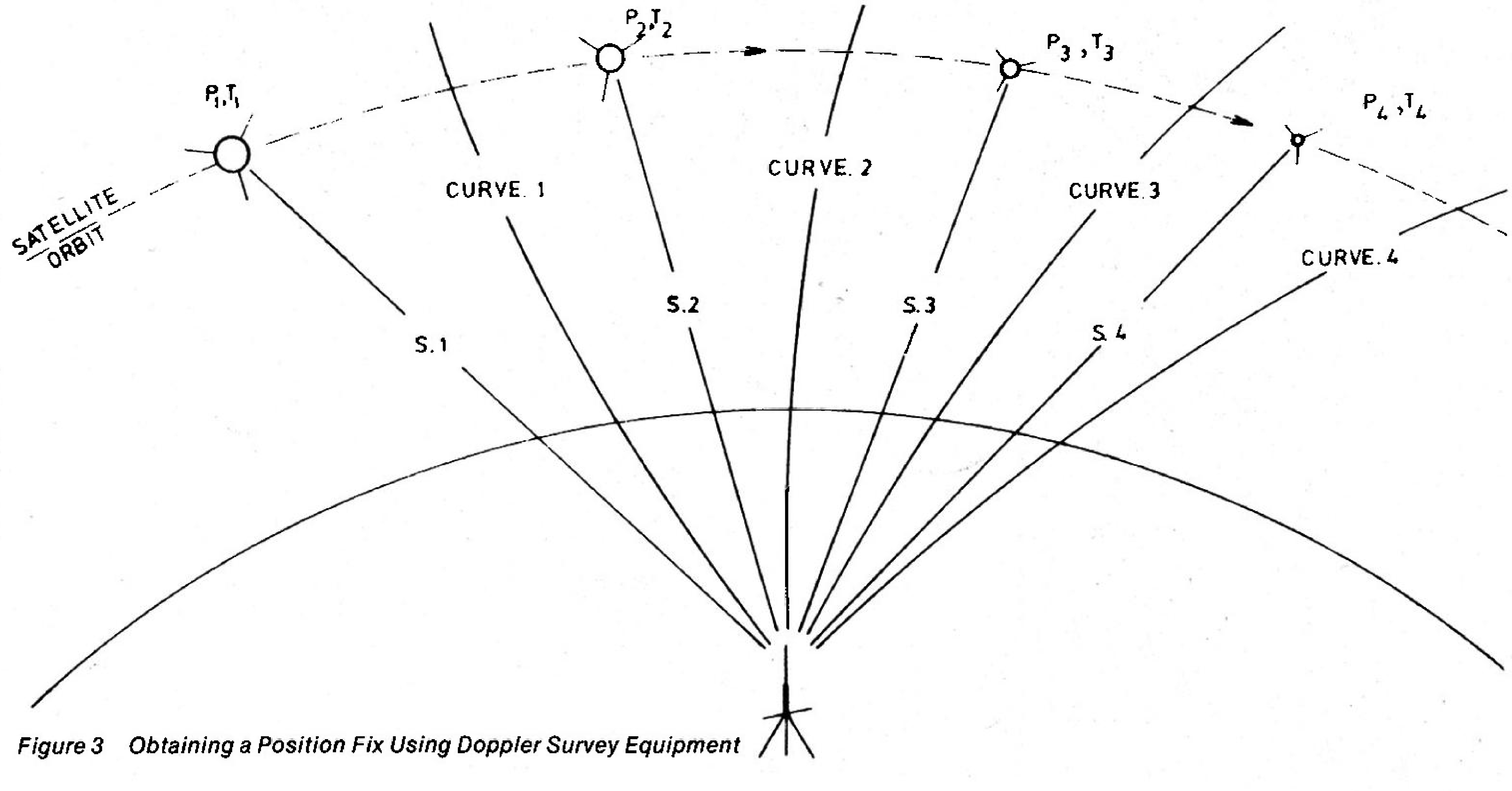

Figure 3 Obtaining a Position Fix Using Doppler Survey Equipment

reduced to a fairly low level by using a moderately large number of passes in the reduction. When the broadcast ephemeris is used, observation of approximately 100 passes will usually produce co-ordinates of accuracy ±3-5 metres. Acquisition of this number of passes will require some 6-8 days at mid-latitudes. If the precise ephemeris is employed an accuracy approaching ±1 metre can be obtained by using approximately 30 passes. As the precise ephemeris is maintained on only two satellites, acquisition of a suitable set of passes will take 5-6 days at mid-latitudes. The major advantages of Point Positioning are that data reduction is simple and can be carried out on a mini-computer, and, unlike, the more sophisticated methods it can be accomplished using a single Doppler receiver.

Disadvantages of this method are that by using broadcast ephemeris results are generally too inaccurate for geodetic purposes, and when the precise ephemeris is used there can be considerable time delay in obtaining the date from the Naval Surface Weapons Centre.

B] Translocation

Translocation is a special form of Point Positioning requiring participation of at least two receivers. The receivers are operated simultaneously at different stations so that a common set of passes can be observed. The initial reduction proceeds in accordance with the method for point positioning except that reduction is limited to those portions of arcs that are fully common to the participating stations. When separations between stations are not large compared with the altitudes of the satellites, the effects of errors in the ephemerides tends to be nearly the same for each combination of stations. As a result, the relative differential positions of stations is determined to a higher degree of accuracy than are the absolute positions.

In the simplest approach to Translocation one receiver remains at a known station on any given datum and the second receiver sequentially occupies all the unknown stations within the net. When using the broadcast ephemeris co-ordinate accuracies of ±2-3m can be expected from 25 passes.

The disadvantage of Translocation (apart from the fact that two receivers are needed) is its requirement for commonality of observational sets which can lead to a considerable sacrifice of otherwise good data. When precise ephemeris is used such losses of data can actually cause Translocation to yield poorer accuracies than Point Positioning. Advantage of Translocation is that it is a relatively simple means of partially eradicating errors in the broadcast ephemeris.

C] Short arc geodetic adjustment [SAGA]

This method constitutes the most rigorous approach to the reduction of Doppler observations. Here at least four receivers are used simultaneously on different stations within the given network.

Observations from all stations in the network are reduced and adjusted simultaneously. The major advantage of SAGA is that it can produce the most accurate values of latitude, longitude and height, from broadcast ephemeris. The accuracy in relative position of stations can approach ± 0.4 metre.

Its disadvantage lies in the amount of equipment needed, firstly for the observation of passes, and secondly, as the reduction and adjustment programme is quite complex at least a medium scale computer is needed for its execution.

Conclusion

Provision of control by the use of the Transit System is rapidly becoming an accepted extension to the science of surveying. This method has been welcomed by some who prophesy that it will change the nature of surveying overnight, while others claim that old ways will never be superseded. The truth invariably lies somewhere between these extremes.

Doppler surveys have a wide range of practical applications, but, consideration must always be given to the possibility that the end result may be achieved quicker and more economically by the use of more conventional methods.

Briefly, some applications of satellite surveying are for control surveys in remote or heavily timbered country for such purposes as medium-small scale mapping, determination of actual positions of pastoral lease boundaries, remote mineral claims, location of offshore drilling operations, etc. etc.