

# **THE DECCA HI-FIX/6 POSITION FIXING SYSTEM**

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## **INTRODUCTION**

The Decca Hi-Fix and Sea-Fix radio position fixing systems have been widely used since the early 1960's and their principles and characteristics are well known [1]. The present paper describes a derivative known as Hi-Fix/6 which has been undergoing field trials in prototype form and will shortly be in production.

## **SYSTEM CHARACTERISTICS**

Hi-Fix/6 employs radiated frequencies in the band 1.6 MHz - 5.0 MHz and depends upon the groundwave mode of propagation. Essentially, the range and accuracy are of a similar order as for the previous 2 MHz Hi-Fix systems, since the limiting factors are those imposed by the propagation phenomena associated with the frequencies concerned; the new system does, however, embody refinements which result in better accuracy and/or coverage, under certain conditions, than was previously possible. The main features of Hi-Fix/6 may be summarised as follows.

A given chain can comprise a total of six stations (hence the suffix " 6 ") in the form of one prime and up to five secondary stations. The prime station controls the phasing and timing of the secondary stations but it need not necessarily act as the master station in the geometrical or charting sense.

In hyperbolic operation, a chain of four stations can be used, at will, either as a common-master layout with contiguous baselines, or as a " crossed-baseline " layout comprising two separate station pairs.

In circular (range/range) operation, up to four ships can use a given chain simultaneously.

A chain can be used for hyperbolic (multi-user) and circular working simultaneously.

To generate the basic hyperbolic and/or circular patterns, the chain uses a single radio frequency; coarse patterns for ambiguity resolution may be superimposed at will, with no equipment changes, by radiating a second frequency. The two frequencies do not have to be harmonically related.

Frequency synthesizers rather than crystals are used as the transmitters and receivers, giving continuously variable frequency selection in 100 Hz steps.

Although the transmissions are sequential, neither the stations nor the receivers depend for their operation upon continuous reception of a trigger signal.

In order to simplify maintenance and logistics, modular construction is employed for the transmitting and receiving equipment with maximum use of common electronic assemblies.

### TRANSMISSION FORMAT

Several of the facilities of the Hi-Fix/6 system derive from the manner in which the sequential transmissions are organised. As shown in the first line of the table, the transmission sequence for a six-station hyperbolic chain lasts 260 ms and starts with a 20 ms trigger signal radiated from the prime station. The trigger is followed by two 20 ms signals from the prime and from secondary stations 2-6 in turn. Nominally each station sends  $f_1$ , the basic or "fine" pattern frequency, in the first of its two 20 ms slots, and  $f_2$ , which together with  $f_1$  produces the coarse pattern, in the second.

The system can be used in many different configurations, of which twelve examples are shown in the table. Four of these provide for hyperbolic working only, with coarse patterns for ambiguity resolution. Where the chain comprises fewer than five stations, the cycle duration can be shortened, e.g. to 180 ms, by adjusting pre-set links on one circuit board. Five circular configurations are shown, covering up to four simultaneous user craft A, B, C and D; as explained later, the lower-case a, b, c, d in the table refer to the corresponding transmissions from the shore stations, and the asterisks refer to cases where the slot normally allocated to frequency  $f_2$  for the coarse pattern is used to generate a fine pattern. The table also includes three compound (hyperbolic and circular) configurations.

TABLE 1

*Hi-Fix/6 transmission sequence, showing twelve of the possible system configurations*

Time (milliseconds) :		0	20	60	100	140	180	220	260	20	Notes						
Mode	System	Configuration	sync	f1	f2	f1	f2	f1	f2	f1	f2	f1	f2	f1	f2	sync	
Hyperbolic	1	Sites 1,2,3,4,5,6	1	1	1	2	2	3	3	4	4	5	5	6	6	1	The basic six-station chain
	2	Sites 1,2,3,4,5	1	1	1	2	2	3	3	4	4	5	5	nil	nil	1	Sequence can be shortened as shown
	3	Sites 1,2,3,4	1	1	1	2	2	3	3	4	4	sync	f1	f2	f1		
	4	Sites 1,2,3	1	1	1	2	2	3	3	nil	nil	1	1	1	2		
Circular	5	Sites 1,2 Craft A	A	A	A	1a	1a	2a	2a	nil	nil	A	A	A	1a		Coarse pattern for A only
	6	Sites 1,2 Craft A,B	A	A	A	1a	1a	2a	2a	B	B	1b	1b	2b	2b	A	
	7	Sites 1,2 Craft A,B,C	A	A	A	1a	1a	2a	2a	B	C	1b	1c	2b	2c	A	
	8	Sites 1,2 Craft A,B,C,D	A	A	B	1a	1b	2a	2b	C	D	1c	1d	2c	2d	A	
	9	Sites 1,2,3,4,5 Craft A	A	A	A	1a	1a	2a	2a	3a	3a	4a	4a	5a	5a	A	
Compound	10	Hyperbolic sites 1,2,3 Craft A	1	1	1	2	2	3	3	A	A	2a	2a	3a	3a	1	Coarse pattern for hyperbolic only
	11	Hyperbolic sites 1,2,3 Craft A,B	1	1	1	2	2	3	3	A	B*	2a	2b*	3a	3b*	1	
	12	Hyperbolic sites 1,2,3 Craft A,B,C	1	1	A	2	2a	3	3a	B	C	2b	2c	3b	3c	1	No coarse patterns
			Prime station ← Secondary stations →													Prm.	*f2 can be equal to f1

**HYPERBOLIC WORKING**

The fact that a single chain, using one or at most two spot frequencies, can comprise up to six stations obviously represents a substantial increase in position-line redundancy. It also extends the adaptability of the system, as is indicated in fig. 1 which shows a chain covering a curving river estuary with the prime station, S1, so placed that all the phase-locking paths lie over water. In this example, the paths from S1 to S2, S3 and S5 are the baselines of hyperbolic patterns to which the prime station contributes directly; the full lines S4-S5 and S4-S6 in the diagram are also the baselines of hyperbolic patterns that would be depicted on the lattice charts, although they do not involve station S1 geometrically. Electrically, however, the trigger signal and phase datum transmissions from the prime station S1 are the means of controlling the timing and phasing of the entire chain, including stations S4 and S6 via the dotted

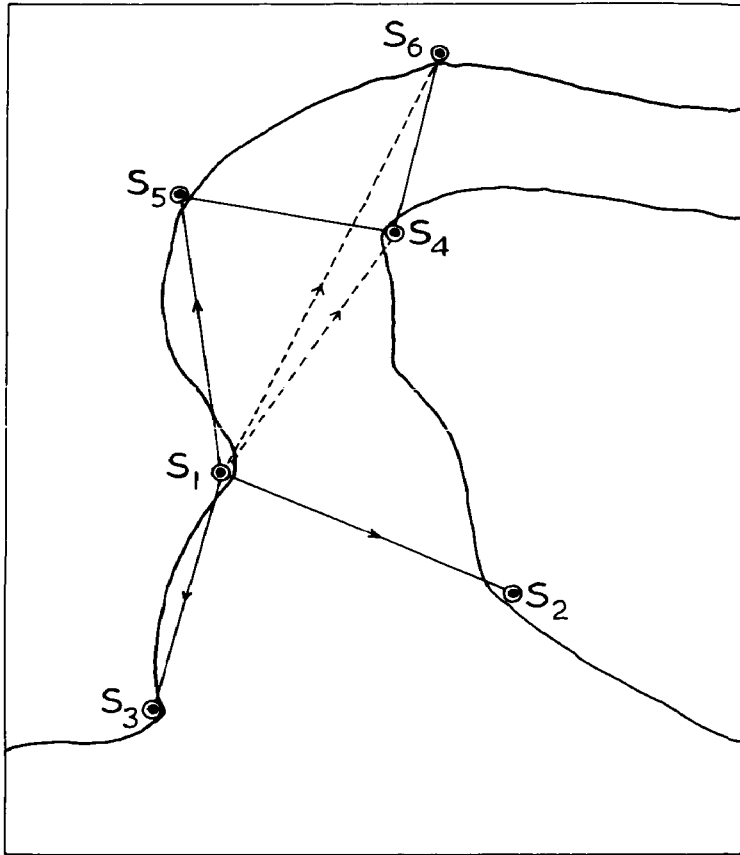


FIG. 1. — Hi-Fix/6 layout covering a curved waterway. Full lines represent pattern baselines, dotted lines are transmission paths for phase/time locking only.

transmission paths, with the effect that the three upper stations in the diagram are mutually phase-locked with S4 acting geometrically as the master and S5, S6 as slaves.

The ability to isolate the prime station from the chain geometry and to site it at a point where it gives the best electrical performance is an important new facility of Hi-Fix/6 which can be applied also to a simple two-pattern hyperbolic chain as illustrated in fig. 2. Here it is desired to cover an offshore survey area from three coastal sites, between which sites the presence of high ground would impair, or even prevent, satisfactory phase-locking by signals emanating from the central station as in the classical common-master layout. By siting the prime station on a suitable promontory, its signals serve to mutually phase-lock the three secondary stations, of which S2 represents the master from the charting point of view, the prime site being so chosen that the locking paths lie almost entirely over water. The prime can equally be placed on an island or offshore rig for this purpose; although it must be stationary and would therefore be difficult to operate satisfactorily on a floating platform, the position of the prime with respect to the secondary stations need not be

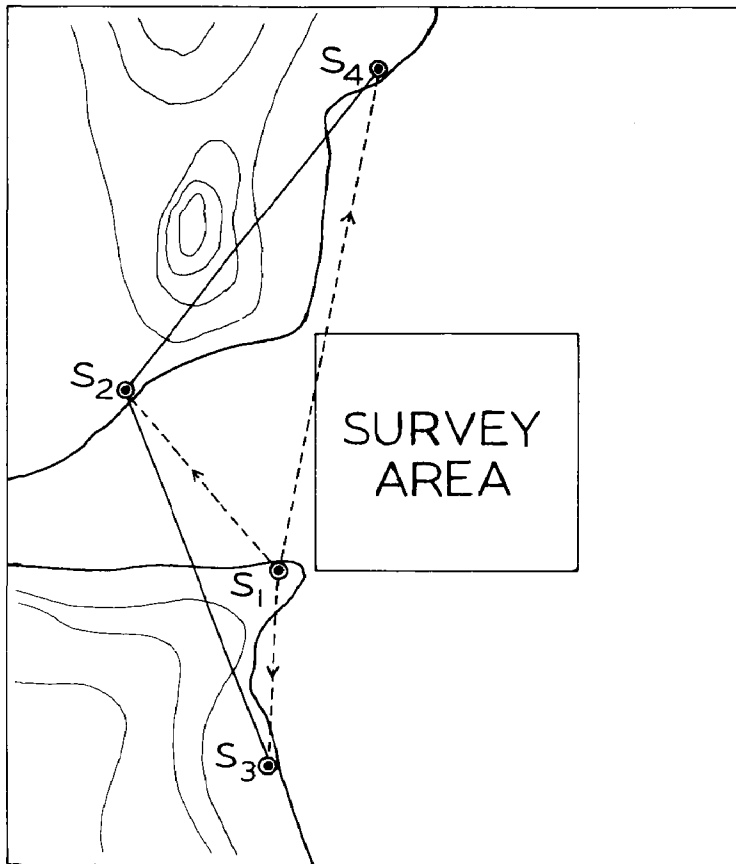


FIG. 2. — Control of chain by separate prime station. When terrain conditions preclude direct locking from the central station, the hyperbolic chain S3-S2-S4 can be phase-locked by the optimally-sited prime station S1.

accurately known, provided that suitable observations can be made on the baseline extensions and/or at known points in the coverage.

This method of phase-locking can be applied to the case where four sites exist around a bay, in order to take advantage of the favourable geometry obtained from a pair of hyperbolic patterns whose baselines intersect at or near right angles. In fig. 3, the same four stations are shown in the conventional common-master layout and as separate pairs; plotting an accuracy contour of the same nominal value (2 m) for each shows the large improvement gained, given a concave coastline, from the crossed-baseline layout. The phase-locking of a pair of stations by a third, remote transmitter, is closely analogous to deriving the hyperbolic difference-pattern between, say, the red and green slaves in the Decca Navigator system by taking the difference between the red and green pattern readings. This is done, for example, in auxiliary equipment used with the Holland Decca chain in order to maximise the position line sensitivity across one of the Europoort harbour approach channels, but exercising such an option with Hi-Fix/6 entails only a simple switch setting and no extra equipment.

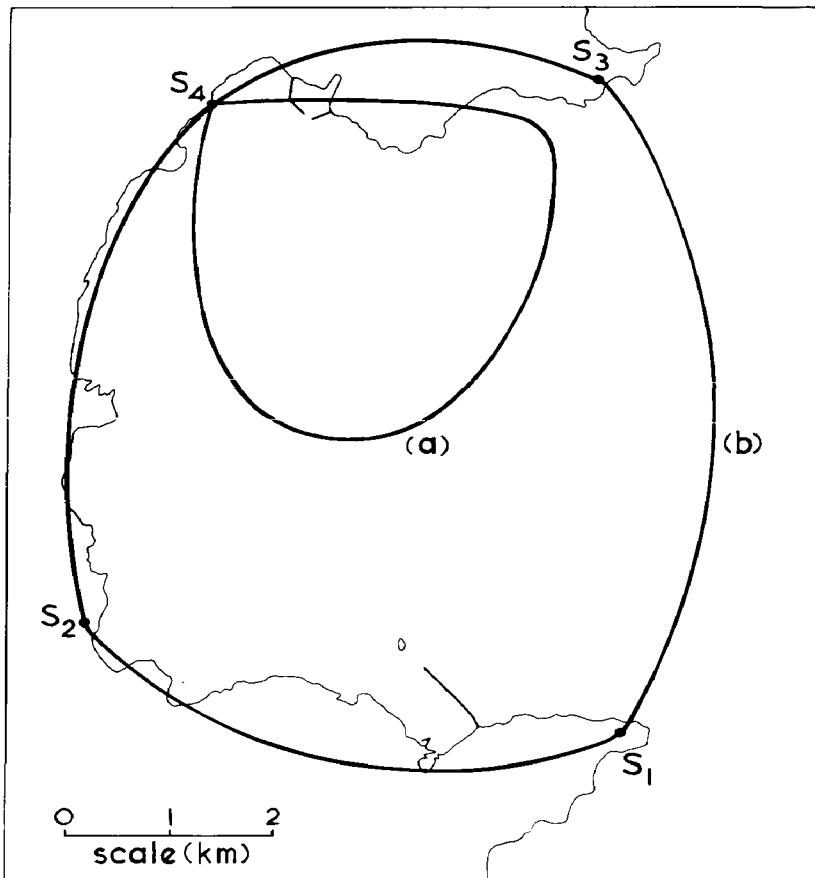


FIG. 3. — Use of crossed baselines to improve geometrical precision. Curves (a) and (b) are the respective 2-metre (67%) accuracy contours for the common-master layout S2-S4-S3 and the crossed baselines S1-S4 and S2-S3.

### CIRCULAR WORKING

Like its predecessors, the new system can be used in the circular (range/range) mode in which the user craft carries a transmitter as well as a receiver. The receiver readouts then correspond to the direct distance to two or more shore stations, giving a fix by the intersection of range circles. Here it is worth recalling that this is a true distance-measuring technique, similar in principle to secondary radar or a transponder, as opposed to the type of circular system in which the stations and the user craft are equipped with stable oscillators and the basic measurement is that of velocity, giving distance by a process of integration from a known start point. Through the time-sharing of the Hi-Fix/6 transmissions, more than one ship at a time can use the same pair of stations for circular

fixing, and two of the stations of a hyperbolic chain can be used simultaneously in the circular mode.

Referring again to the table, systems 5-9 show five of the options available for circular working. Up to four craft (A, B, C, D) can be accommodated at a time, although with three simultaneous users the provision of coarse patterns for ambiguity resolution has to be confined to one craft only. With four craft, only the fine patterns can be generated. The lower-case a, b, c and d in the table refer to the corresponding shore station signals which (to use the transponder analogy) "reply" to the respective transmissions from the ships. In some instances, denoted by an asterisk, the time slot normally reserved for the f2 signals from a particular station is used for a signal generating a fine pattern and hence would be allocated the frequency value f1. The final example in this group, system 9, provides a single craft with up to five circular position lines, each with a coarse as well as a fine reading: such a layout would be the probable choice for a highly critical operation in which the maximum accuracy of position-fixing was the paramount requirement.

It was stated above, in relation to the hyperbolic mode of operation, that the prime station must occupy a fixed position. In the circular mode, this limitation does not apply since the transmitter that has in previous systems been called the master is placed on the user ship as a fundamental requirement of the system. In Hi-Fix/6 it is convenient for the prime station to be so placed, and to act as master (on board craft A in the table) but it should be noted that the prime still controls the timing of all the stations in a multi-user circular layout such as system 9 in the table. In this layout, the transmitters on ships B, C and D radiate during the time slots shown and act as masters so far as the "responding" transmissions from the shore stations are concerned. The three ship-borne secondary transmitters in system 9 are phase-locked to the prime, simply in order to implement the important measure described below under the heading of Trigger Interference Protection; in principle, the distance measurements would still be valid if these three transmitters were free-running.

### COMPOUND WORKING

Systems 10, 11 and 12 in the table are examples of "compound" working, in which a three-station hyperbolic layout (which, of course, serves an unlimited number of users) is used in addition by up to three ships carrying secondary stations for circular working. In system 10, the hyperbolic users and the single "circular" ship all have the ambiguity resolution facility; with a pair of ships using the chain for circular fixing, the provision of coarse patterns is confined to the hyperbolic mode and three such craft preclude the generation of coarse patterns for either mode.

### RADIATED FREQUENCIES

As mentioned earlier, frequency synthesizers in the transmitting and receiving equipment enable any value to be selected within the band 1.6 MHz-5.0 MHz for the basic pattern frequency  $f_1$  and the coarse pattern frequency  $f_2$ , in 100 Hz steps. Under the conditions of frequency congestion now prevailing, it was considered essential to provide for virtually instant choice of radiated frequency values and to abandon the use of quartz crystals. The required frequency is selected simply by setting a thumbwheel switch to the corresponding heterodyne frequency value (the receiver and phase control units use superhet circuits). The intermediate frequency has the convenient round-figure value of 100 kHz so that to select  $f_1$  and  $f_2$  the user sets in values equal to  $f_1 + 100$  kHz and  $f_2 + 100$  kHz respectively.

The statement that the frequencies are continuously variable in 100 Hz steps requires one qualification, namely that this freedom of selection exists within a predetermined 10 kHz band. This is the passband of the r.f. filter; if, on changing chains, the new frequencies are outside the passband of the r.f. filter circuit board in use, it is necessary to substitute another board. This change takes a matter of seconds and presents no operational problem. At the transmitting stations, where changes of frequency will, in any case, be infrequent, a second circuit board in the output section of the control unit has to be changed if the new transmitted frequencies lie outside the 10 kHz band to which the equipment had previously been set.

Some restriction in the choice of frequency values will exist where two Hi-Fix/6 chains are closely adjacent, for example in a network covering a long coastline. While the engineering parameters governing the acceptable frequency separation are well defined, the calculation involves a number of variables especially in relation to the characteristics of the individual transmission paths: for example, the mutual interference conditions would differ in the respective cases of a straight and a convex coastline. As a first approximation, however, a frequency separation not less than 1000 Hz should be assumed for adjacent chains.

### AMBIGUITY RESOLUTION

As in previous Hi-Fix systems, the lane patterns are produced by comparing the phase of the transmissions at the radiated frequencies. Within the stated frequency band for Hi-Fix/6 the lane width varies from 30 m at the highest frequency to 94 m at the lowest, and it will often be desirable to resolve, at least to some degree, the closely-spaced ambiguities that these figures imply, without depending upon the lane-counting



action of the displays. Accordingly, the transmission format provides for superimposing a coarse pattern upon each fine pattern. This is done by radiating from each station a phase-locked signal on a second frequency  $f_2$ ; in effect, the receiver subtracts  $f_2$  from  $f_1$  and thus obtains from each station a relatively low frequency which is the basis of the coarse pattern to which the ambiguity-resolution readings refer.

The value of  $f_2$  can in principle lie between 80 % and 98 % of  $f_1$ , resulting respectively in coarse lanes 5 and 50 times wider than the fine lanes. In practice, a resolution factor of 50/1 would require extremely stable propagation conditions for acceptable reliability, and at the other end of the scale there would be little advantage to be gained from a factor smaller than 5/1. Values between 10/1 and 20/1 will probably become typical. The choice of suitable frequency values is simplified by the fact that the coarse lane width need not be an exact multiple of the fine (although charting draughtsmen will generally find a simple relationship easier to present). The receiver displays the coarse readings on a numerical indicator as described below, but it does not provide a binary-coded-decimal output of these readings: this limitation is deliberately imposed in order to enlist the user's judgment as to the validity of the coarse pattern readings when operating near the limit of range, rather than feeding them "raw" into an associated data processing system.

### TRIGGER INTERFERENCE PROTECTION

The Hi-Fix family of systems employs the principle of time-shared transmissions which has hitherto necessitated the reception, at the start of every sequence, of a synchronizing signal from the master station. This "trigger" signal enables the gating circuits in the receivers and transmitters to control the processing of the signals in step with the transmitted sequence. The trigger signal has to be of an accurately predetermined waveform in order to perform its timing function effectively and this in turn entails a wider receiver bandwidth for the trigger function (and hence a greater exposure to possible interference) than for reception of the pattern-generating signals. An important feature of Hi-Fix/6 is that a timing method is employed which dispenses with the need to receive the trigger before every sequence, and which enables that section of the receiver which handles the trigger signal to be kept turned off virtually all the time, except momentarily during initial setting up or when making an occasional check. By this means, the protection of the system against interference, and its overall integrity, has been greatly enhanced and the equipment can continue normal operation for a period of hours even under noise conditions that would wholly inhibit reception of the trigger signal.

Each secondary station and each receiver contains its own internal timer which controls the commutation of the circuits to correspond with the successive transmissions in the sequence, and here it is convenient to consider the action of this timer in terms of an ordinary domestic clock.

The "clock" mechanism is driven by the divided-down output from an oscillator whose phase is controlled by the prime station's pattern-generating signal (not the trigger signal) on frequency  $f_1$ ; the oscillator also has the function of memorising the phase of the prime signal between transmissions as part of the general operation of the equipment. So long as the  $f_1$  signal controlling the phase of the oscillator continues to be received, therefore, the clock will run at the required rate and with extremely high stability; there remains only the need to "set its hands" initially so as to bring the internally generated sequence precisely into step with the transmitted sequence, and this is the function assigned to the trigger signal from the prime station. The setting process is performed automatically when the user presses a button to activate the receiver circuits that detect the trigger signal, but he only has to do this when setting up the receiver or secondary station at the start of a day's work or when making periodic checks. The trigger channel in the receiving equipment is inoperative, and hence not open to interference, at all other times.

The trigger signal itself takes the form of a 20 ms burst of the carrier frequency  $f_1$ , modulated by two successive  $72^\circ$  phase shift pulses each lasting 5 ms with a 5 ms interval between them. The first of these pulses starts 5 ms after the start of the signal. The two nominally square wave phase shift pulses are thus 10 ms apart (taking either edge) and the receiver circuit is arranged to inhibit the trigger function if random noise pulses should occur during a 10 ms correlation period. The trigger pulse itself is thus assured a high degree of integrity at long ranges.

## RECEIVER

The receiver is housed in a single container identical in size and construction to those used for the transmitter control units, measuring 483 mm wide, 177 mm high and 417 mm deep. The unit is detachable for mounting in standard racking and consists of a card frame with the power supply assembly fitted at the rear. Plug-in circuit cards are used throughout and the front panel with its complement of readouts and controls is also a plug-in item. The receiver is designed for a 24 volt DC supply (as are all the other units in the system) consuming approximately 10 A during the first two minutes of operation and 5 A thereafter.

Referring to fig. 4, there are three identical readouts on the front panel, one for each of the three selected position-line patterns. Each readout incorporates a pattern-selector thumbwheel which, when set to 24, for example, would result in the display of readings for the patterns generated by stations S2 and S4 with the readings increasing in the direction of S4. The in-line numerical display gives the integrated whole-lane reading and the fractional value in hundredths, on the upper of two rows, and the ambiguity-resolution reading as a three-digit fraction of a coarse lane on the lower row. Light-emitting diodes were used for the numerals in the

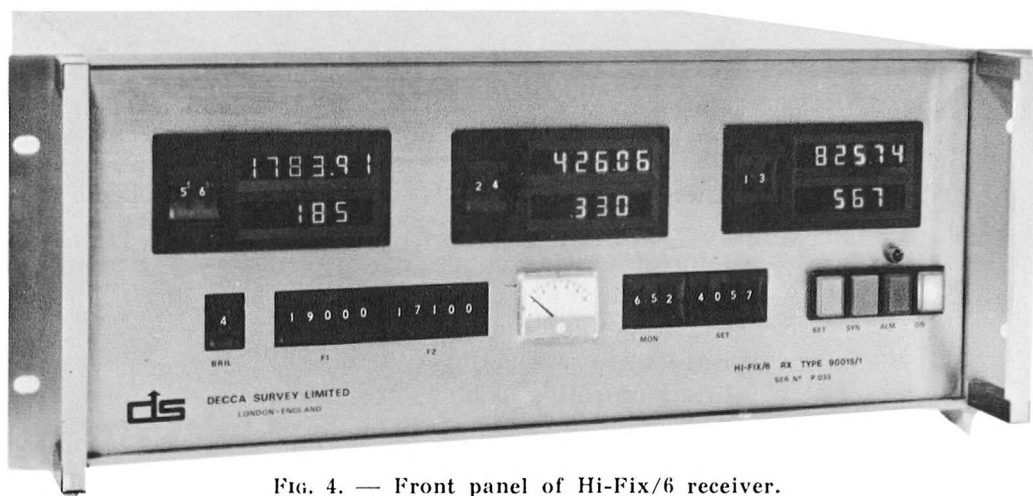


Fig. 4. — Front panel of Hi-Fix/6 receiver.

prototype but these proved unsatisfactory especially under high ambient temperatures and have been replaced by filament-type 7-bar number tubes. In parallel with the fine readouts the receiver delivers the integrated lane number and fraction in BCD form as an output for data processing, together with numbers defining the identity and sense of the patterns selected by the thumbwheels mentioned above.

Below the left-hand of the three displays are thumbwheels for setting in the frequency values, as described earlier under Radiated Frequencies, and to the right of these is the monitor meter and its associated three-section thumbwheel control. The meter can be switched at will to provide any one of 65 different indications ranging from basic quantities such as the power supply voltage to parameters such as the signal level from a specific station or the voltages obtaining at key points in the receiver circuits; with the aid of a check-list of the monitor readings and switch settings, an unskilled user can trace any fault to the individual circuit board containing the malfunction. The same thumbwheel panel contains four switches for adjusting the whole lane numbers on the three displays which are set-in, in turn, by pressing the "set" button.

Four push-buttons, which incorporate indicator lamps, are grouped at the bottom right-hand corner of the panel. From left to right, these comprise the lane-setting and timer-synchronizing buttons already mentioned and the alarm and power on-off buttons. The alarm button is of the alternate-action type and enables either of two different alarm modes to be selected. In one mode the lamp lights if any of the monitored parameters goes outside prescribed limits. The other alarm mode gives warning of a power supply fault or breakdown in any of the chain stations; at any station, one transmission in every 10 is automatically suppressed if the power supply voltage should fall below a predetermined level, and this serves to flash the a.g.c.-operated alarm lamp on the receiver. The faulty station can then immediately be identified by reference to the monitor meter in conjunction with the lamp indication. A station "off the air" would produce a flash recurring at the basic repetition rate (normally 260 ms) and would be identified in a similar way.

### TRANSMITTING STATIONS

Each station, whether the prime or a secondary, consists of the following items :

- Control unit
- Power amplifier
- Antenna matching unit
- Antenna and ground system
- Interconnecting cables

The control unit is the signal source for the station and, on secondary stations, performs the phase-locking functions. The circuit board complement in the control unit differs as between prime and secondary stations, but the power amplifier, matching unit and antenna/ground system are identical at all stations. By virtue of the time-shared transmissions, the one antenna serves for reception at the secondary stations as well as for transmission.

The antenna is engineered for maximum speed and ease of erection and dis-assembly, and is available in 10 m and 30 m heights giving maximum radiated powers for the transmission in the order of 40 W and 75 W respectively. The level of radiated power is continuously variable, by means of a pre-set control, from zero to the full output : this is an important provision in relation to requirements of frequency clearance. At full transmitter output the station units consume a total average current of about 12 A.

The transmitter units, other than the antenna matching unit, are constructed in the same modular form as the receiver and are housed in the same type of container. The power amplifier has special front and rear panels of cast construction with cooling fins. Several circuit boards are common to the receiver and the transmitter control units and only 11 different types of board are used in the entire system. The stations are intended for unmanned operation, as has long been the practice with the Sea-Fix system.

### SUMMARY OF APPLICATIONS

Hi-Fix/6 is applicable to every type of project requiring position fixing with an accuracy of a few metres in the best areas of coverage. The maximum offshore ranges vary from a few kilometres to two or three hundred kilometres depending on the type of coverage required. On the maritime side, the system is intended in particular for use in hydrography, dredging, oil and gas search and exploitation, port control and pilotage, harbour construction, pollution studies, naval operations, ship's trials and

hovercraft navigation. Potential airborne uses include a variety of operations in agricultural aviation, and its use by ground vehicles is feasible within the limits imposed by propagation.

The system provides position fixing in the hyperbolic and circular modes, with multiple redundancy and widely adaptable chain layouts employing up to six stations per chain.

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- [1] Supplementary Paper 3 to Special Publication 39 : Radio Aids to Maritime Navigation and Hydrography, Chapter III. Published by the International Hydrographic Bureau, June 1961.

(Manuscript submitted in English).