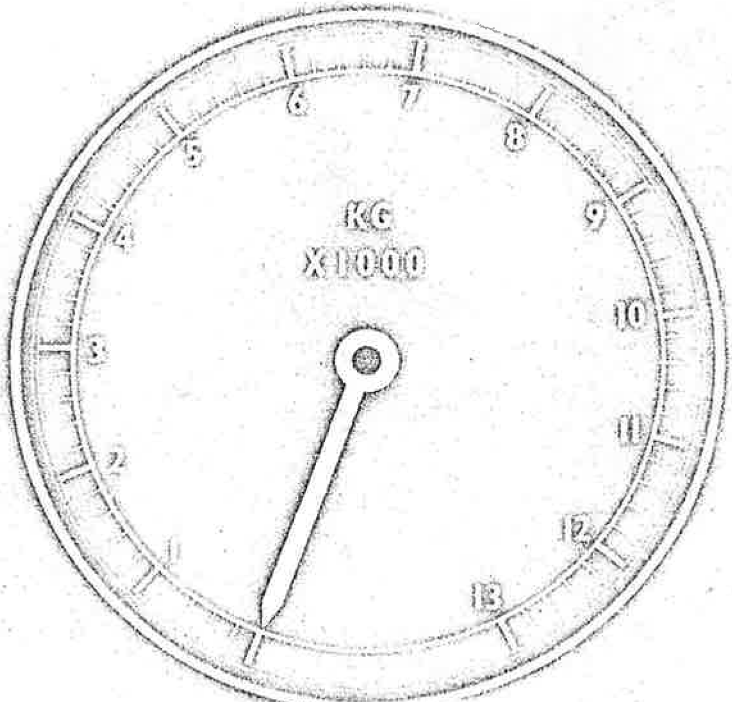
SMITHS

Compensated Fuel Contents Gauge

Type 4



SMITHS COMPENSATED FUEL CONTENTS GAUGE TYPE 4

SMITHS AVIATION DIVISION

The Aviation Division of

S. Smith & Sons (England) Ltd

Smiths, Kelvin Hughes, and Waymouth aviation instruments and systems.

K.L.G. aviation products.

Kelvin House, Wembley Park Drive, Wembley, Middlesex Telephone: Wembley 8888

Type 4 Introduction

The Smiths compensated fuel contents gauge TYPE 4 is the latest in a line of successful fuel gauges developed by Smiths Aviation Division. The gauge, similar to the Smiths Type 1 system, functions on precisely the same electrical principles. It possesses, to an enhanced degree, earlier system advantages such as increased accuracy, permittivity compensation, insensitivity to power supply variations, and independence of connecting cable lengths. The TYPE 4 gauge differs from the Type 1 gauge basically in the use of transistors in the place of thermionic valves. By using transistors, four main advantages follow in that there is a reduction in size, weight, power consumption and warming up time after switching on.

OUTLINE OF SYSTEM

Basic Principle FIGURE 1 depicts a simplified version of the TYPE 4 Fuel Contents Gauge which operates on the principle of a transformer ratio-arm impedance bridge.

The aircraft 115-volt A.C. 400 c.p.s. supply is connected to the primary of a transformer, the secondary of which is centre-tapped to provide sources of voltage of opposite phase at the terminals. The voltage appearing at one terminal is applied to the tank unit denoted by C_T, thus causing a current to flow equal to I_T in the direction indicated in the diagram. In the same way the voltage from the other terminal is applied to a capacitance denoted by C_B causing a current to flow equal to I_B. The value of this capacitance is so chosen as to balance out the air (or 'tank empty') value of the tank unit capacitance. Thus at tank empty condition, I_B will equal I_T and there will be no voltage at the input to the amplifier.

The effect of adding fuel to the tank will be to increase the value of the tank unit capacitance, and thus to increase the value of the current I_T. As a result, a small current will flow into the amplifier, whose impedence is small compared with that of the capacitor C_N. This current is amplified and used to drive a small two-phase motor. This motor drives, via a gear train, an indicator pointer across a scale calibrated in terms of fuel contents.

The gear train which drives the indicator pointer also drives the wiper arm of the potentiometer, which is connected across one section of the transformer. The value of the voltage on the potentiometer wiper will increase as the indicator pointer deflects towards full scale, and current will flow via the capacitance C_F. This current, denoted by I_F, will serve to balance the increased current in the tank unit thus effectively reducing to zero the current at the input to the amplifier. When this occurs there will be no output from the amplifier and the indicator pointer will come to rest. That this position will be a measure of the amount of fuel present will be appreciated when it is considered that the greater the change of capacitance in the tank unit the further the wiper of the potentiometer must travel to provide the necessary balancing current. In fact it can be shown that the fraction of the voltage at the potentiometer wiper (shown as p in FIGURE 1) is directly proportional to the fraction of total tank volume actually occupied by fuel.

The property of the fuel which causes an increase in tank unit capacitance is termed the permittivity and this, unfortunately, varies among samples of different fuels. Therefore, the simple gauge as described would be subject to inaccuracies if it were used to gauge different fuels. Thus some form of compensation against this variation of fuel permittivity is mandatory if the highest accuracies are to be achieved. An outstanding advantage of the bridge-type fuel gauge is the ease with which permittivity compensation can be applied.

FIGURE 2 shows an extra capacitance, denoted by kC_R, connected in parallel with C_F. This additional capacitance is the so-called reference capacitance, and is so physically disposed in the tank as to be totally immersed in fuel for the longest possible time. The symbol kC_R demonstrates that the capacitance value of this unit is wholly dependent upon the value of k, the permittivity of the fuel. The diagram shows that the effect of this capacitance is to cause an extra current I_R to flow into the balance point of the bridge, This means that the position taken up by the indicator pointer, and hence the wiper arm of the potentiometer, will take into account the value of permittivity of the fuel under measurement; this is what is meant by compensation. This feature can be treated in a little more detail as follows.

k-Function or Inferred-Density Compensation It is possible to show that the position of the indicator pointer, which is the fraction p of the transformer voltage, is equal to the tank empty capacitance multiplied by the mass of the fuel present multiplied by a known factor. This can be written:

$$P = C_E \times m \times (k-1)/d.$$

The factor $(k-1)/d$ is known as the capacitance index of the fuel; k being the permittivity of the fuel and d the density.

The equation shows that the gauge would give an accurate reading of mass of fuel if the capacitance index were a constant. Unfortunately, this is not strictly true although the capacitance index varies less than permittivity or density considered separately; that is to say, heavier fuels tend to have higher values of permittivity. Tests carried out in our laboratories on several hundreds of samples of fuels, have demonstrated that the capacitance index is a linear function of the permittivity. This is illustrated in FIGURE 3, and the diagram also shows that the fuel samples tend to cluster round a straight line relating $(k-1)/d$ to k.

The values of C_F and C_R are so chosen that the gauge will read with zero error when gauging a fuel whose measured properties lie on this straight line. This is because the gauge, in effect, divides the right-hand side of the equation by an expression which is a linear function of k, thus cancelling out the capacitance index. Hence the name 'k-function' compensation.

This type of compensation is also known as 'Inferred-Density' compensation, since the gauge, by utilising a component which measures the permittivity of the

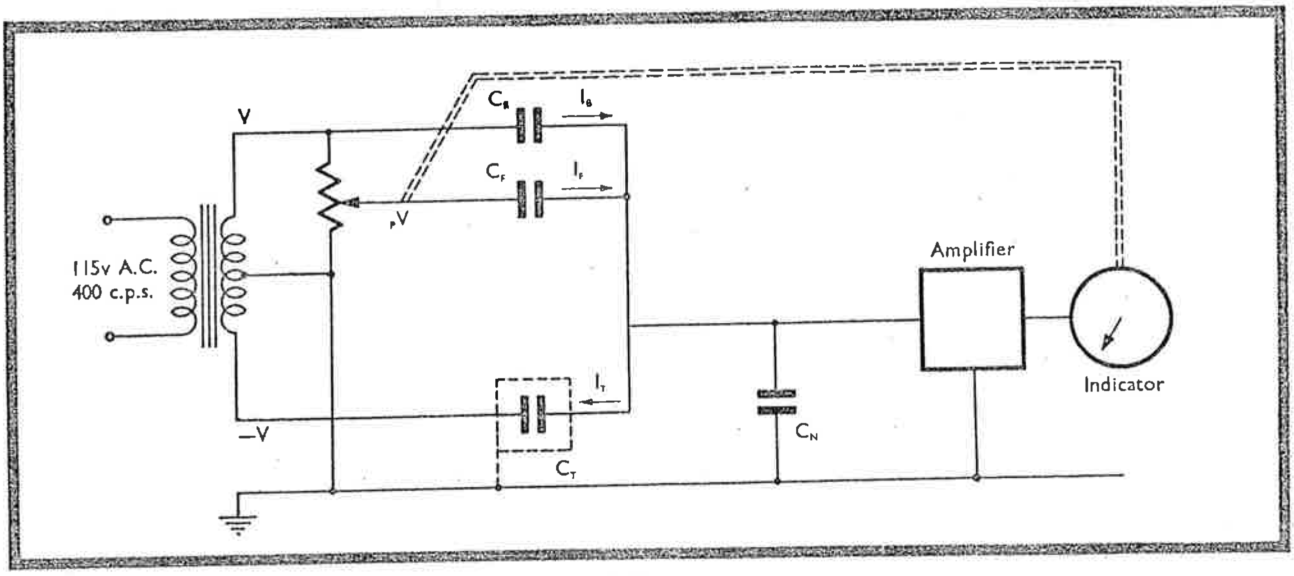


FIG 1 *Basic Circuit of simple type 4 Fuel Contents gauge.*

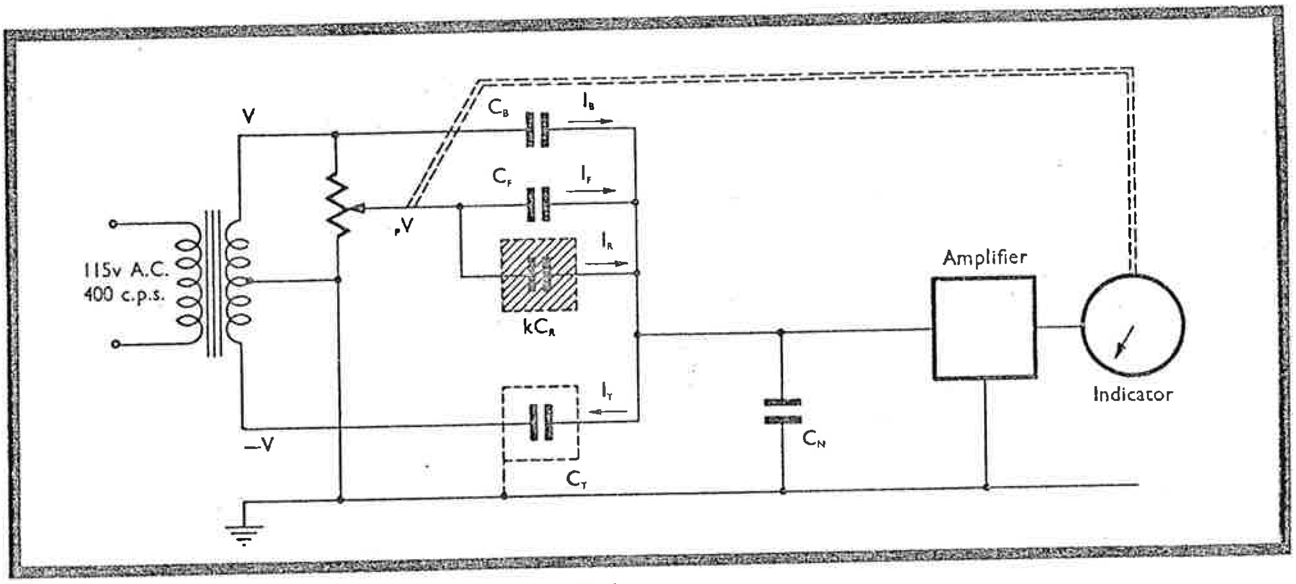


FIG 2 *Basic Circuit with reference capacitance added.*

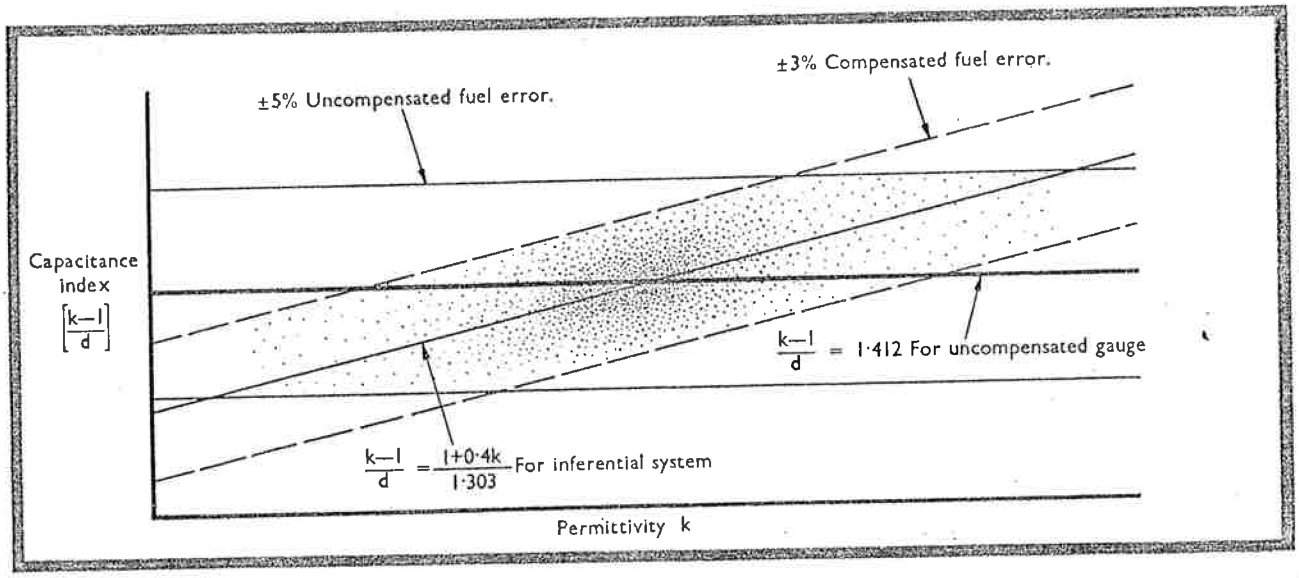


FIG 3 *Distribution of fuel errors, type 4 fuel gauge.*

fuel, infers the density. How correct this inference is will depend on how close the plotted fuel properties lie to the line illustrated in FIGURE 3.

For fuels whose properties do not lie on this straight line an error will be introduced, known as the fuel error; but which will never be greater than ±3% of the quantity present in the extreme instance. In fact, for 95% of fuel samples tested the results have shown that the error will be not greater than ±2%. In an uncompensated system, however, the fuel error can rise to as much as $\pm 5\frac{1}{2}\%$.

ELEMENTARY APPLICATION

The arrangement of the units of the system can best be illustrated by means of a block diagram, see FIGURE 4.

Installed in a fuel tank are a number of capacitance probes which will be described in detail later. The capacitances of these probes vary, of course, with the quantity of fuel present in the tank and these varying values of capacitance are fed to a bridge unit. Any error signal resulting from unbalanced conditions in this circuit is fed to the input of the amplifier which in turn drives the indicator. It must be stressed that this description is merely functional in the most elementary sense and gives no indication of the actual disposition of the units. As will transpire later, one of the features of the TYPE 4 gauging system is its flexibility in that various combinations of units can be offered to suit a customer's particular requirements.

Provision can be made for gauging single tanks continuously, or selecting individual tanks in a group, or for gauging the total contents of a number of tanks.

It sometimes becomes necessary to arrange for the tank contents to be presented on more than one indicator. For example, the fuel quantity present could be of interest to both the pilot and the navigator, or it could be needed to give a gauge reading in the wheel-well for refuelling purposes. Simultaneous, or alternative, presentation in these and similar instances can be readily provided by the Smiths TYPE 4 gauging system.

DESCRIPTION OF UNITS

Tank Units This name is given to the units of the gauging system which are concerned with the measurement of the properties of the fuel. There are two types of unit. The probes measure the height of the fuel, and hence the volume and the premittivity compensator or reference unit takes into account variations in fuel permittivity.

Probes These units consist of two or more concentric tubes of lightweight alloy. The spacing between the tubes is accurately maintained by means of pairs of insulators. For short units, a single pair of insulators at each end is sufficient to maintain the desired spacing, but in some instances additional insulators are fitted at intermediate points along the tubes.

The form of construction of the probes is such that the weight is kept to an absolute minimum, and the fraction of the total capacitance which is unaffected by the fuel is also kept very small.

Probes can be either externally flange-mounted to the skin of a fuel tank or they can be internally mounted with electrical connections made by wiring in parallel with a tank terminal. Units are terminated with pairs of miniature coaxial connectors. All internal tank wiring is carried out by means of sub-miniature coaxial cable whose insulating medium is strongly resistant to the chemical action of modern fuels.

PERMITTIVITY COMPENSATORS (Reference Units)

These components consist essentially of small precision-made parallel-plate or concentric tube capacitors. As their function is to provide a value of capacitance which depends only upon the value of permittivity, it will be obvious that these components must be so placed in the tank as to be fully immersed in fuel. If this condition is not obtained the gauge will be subject to error; but provided incomplete immersion occurs only at low fuel levels the magnitude of the error will be negligible.

The compensator unit comprises a number of flat plates mounted in a small rectangular box. This type of unit facilitates accurate siting at the lowest point of the fuel tank, and is in no way dependent upon the disposition of the capacitance probes. A reference unit, like a probe, is terminated with two coaxial connectors; a third connector may be added for convenience in interconnecting the common electrodes of the reference unit and probes.

Where it is difficult to mount a separate reference unit in an accessible position, an alternative type is available in the form of short concentric tubes fixed around the lower end of a probe. Such a composite unit will have a total of three terminating connectors, since one electrode of the reference unit is connected in parallel with one of the probe electrodes.

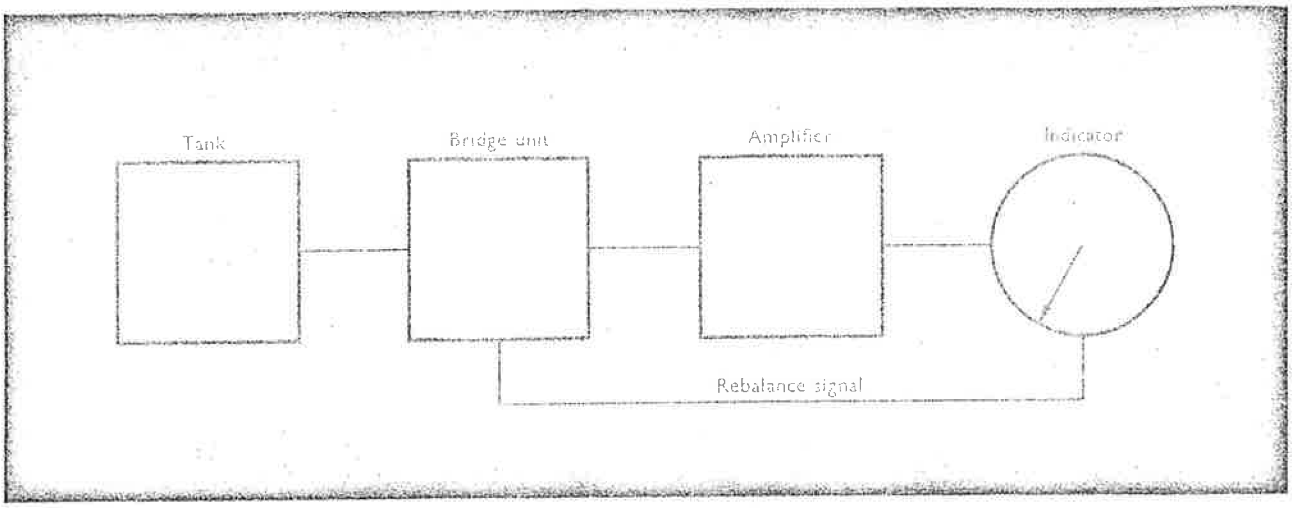


FIG 4 *Block diagram showing basic type 4 system.*

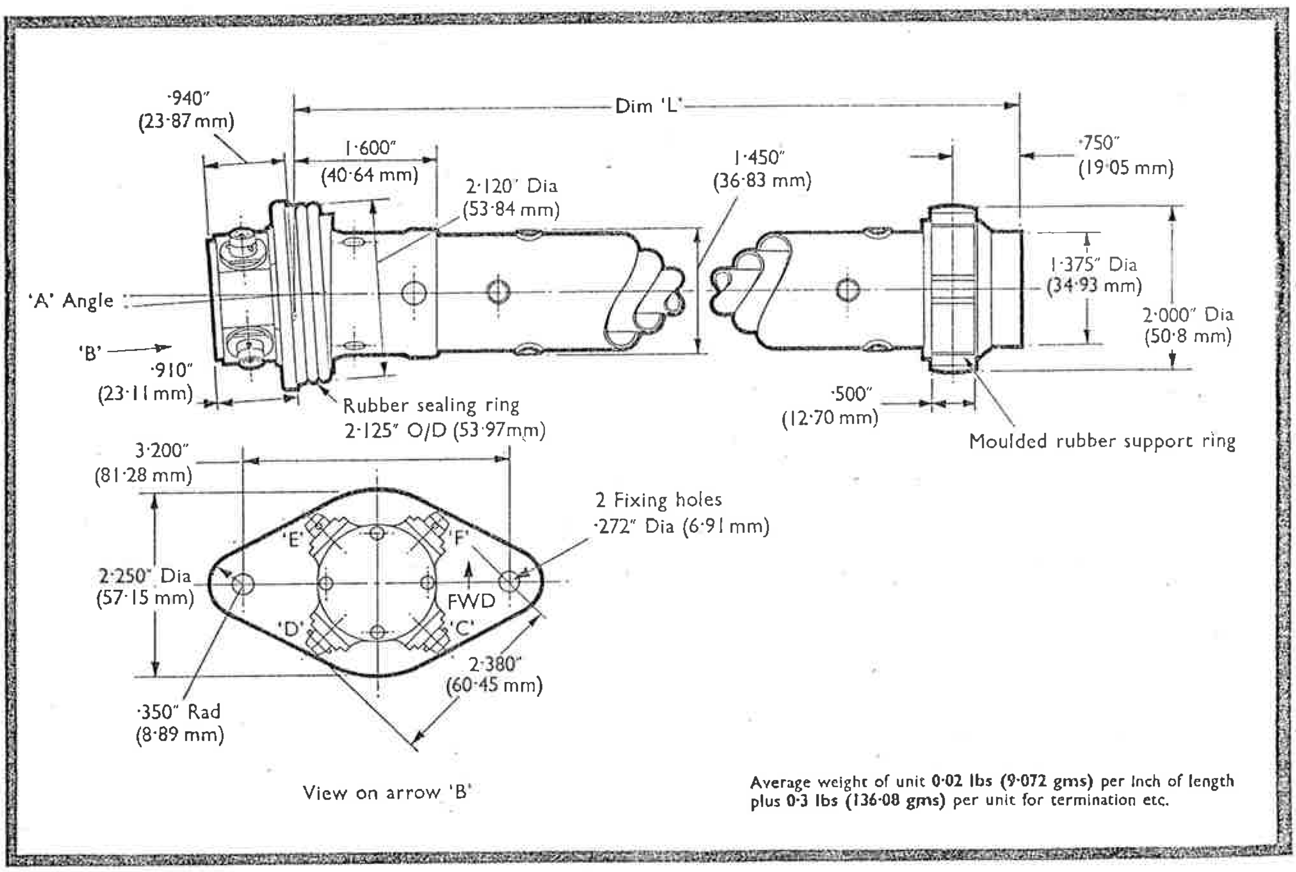


FIG 5 *Tank unit.*

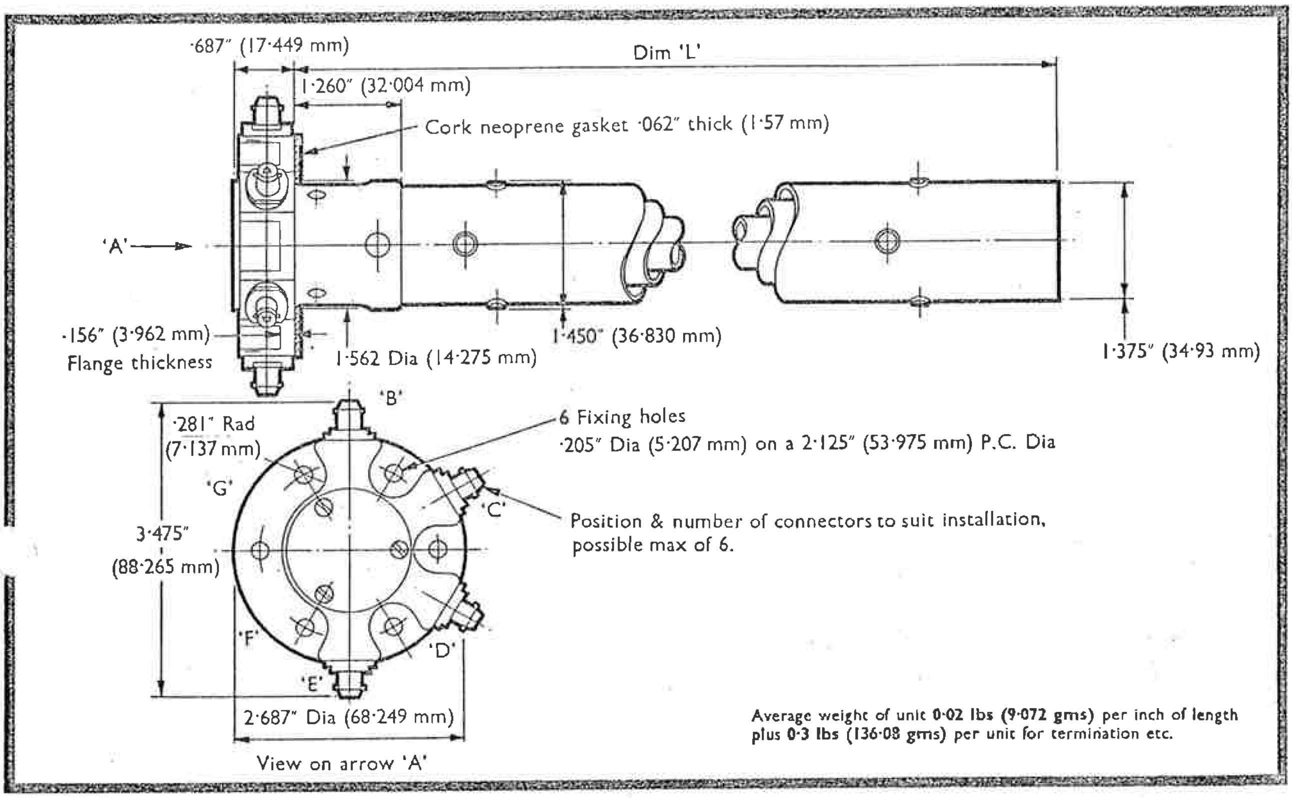


FIG 6 *Tank unit.*

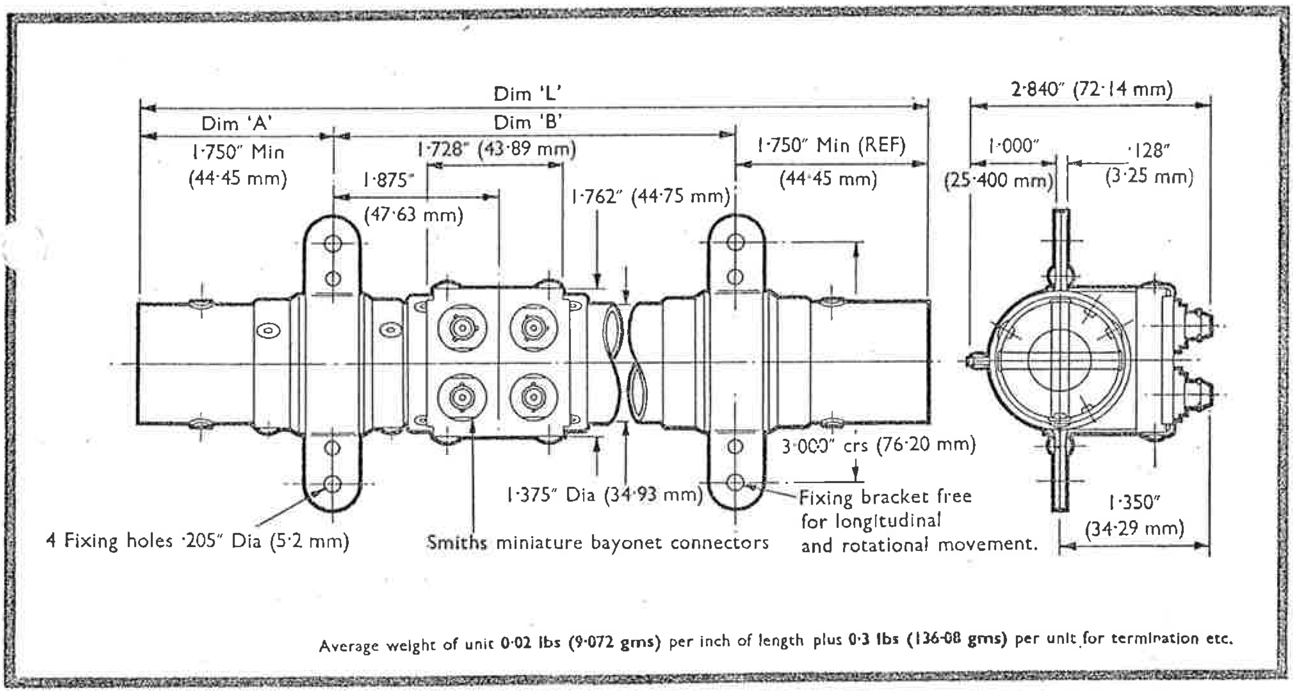


FIG 7 *Tank unit.*

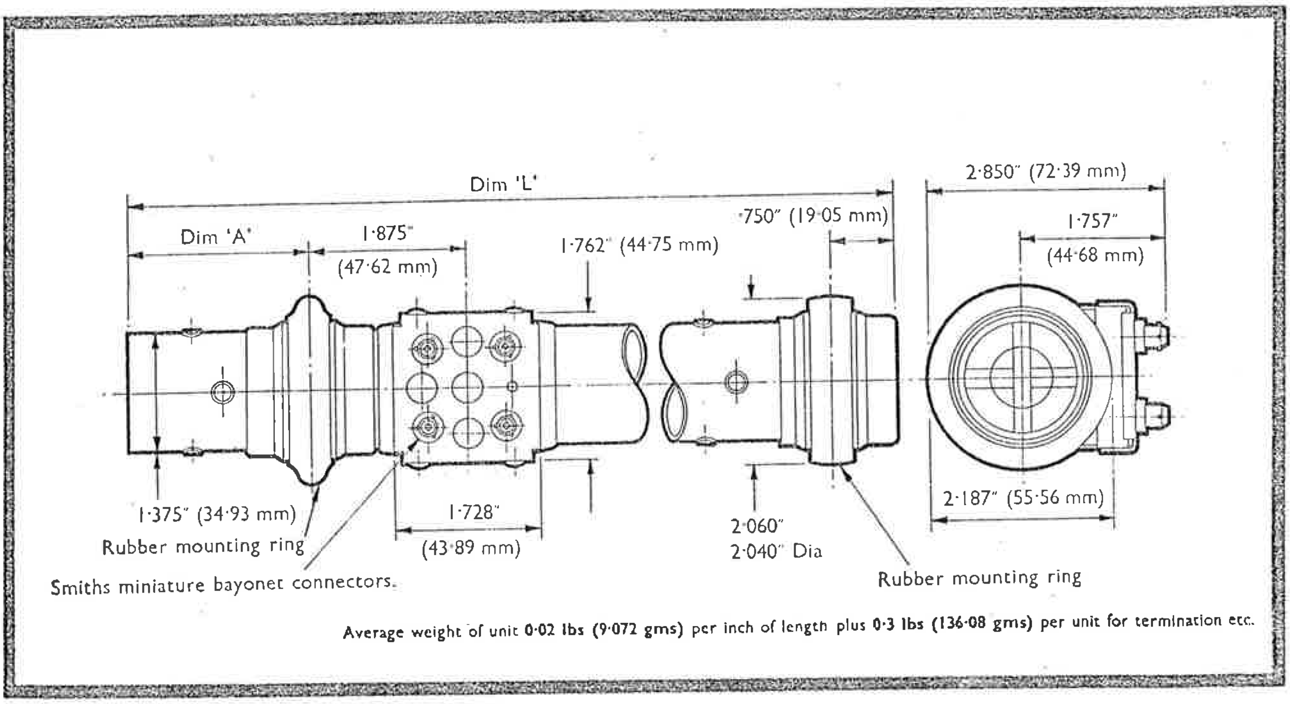


FIG 8 *Tank unit.*

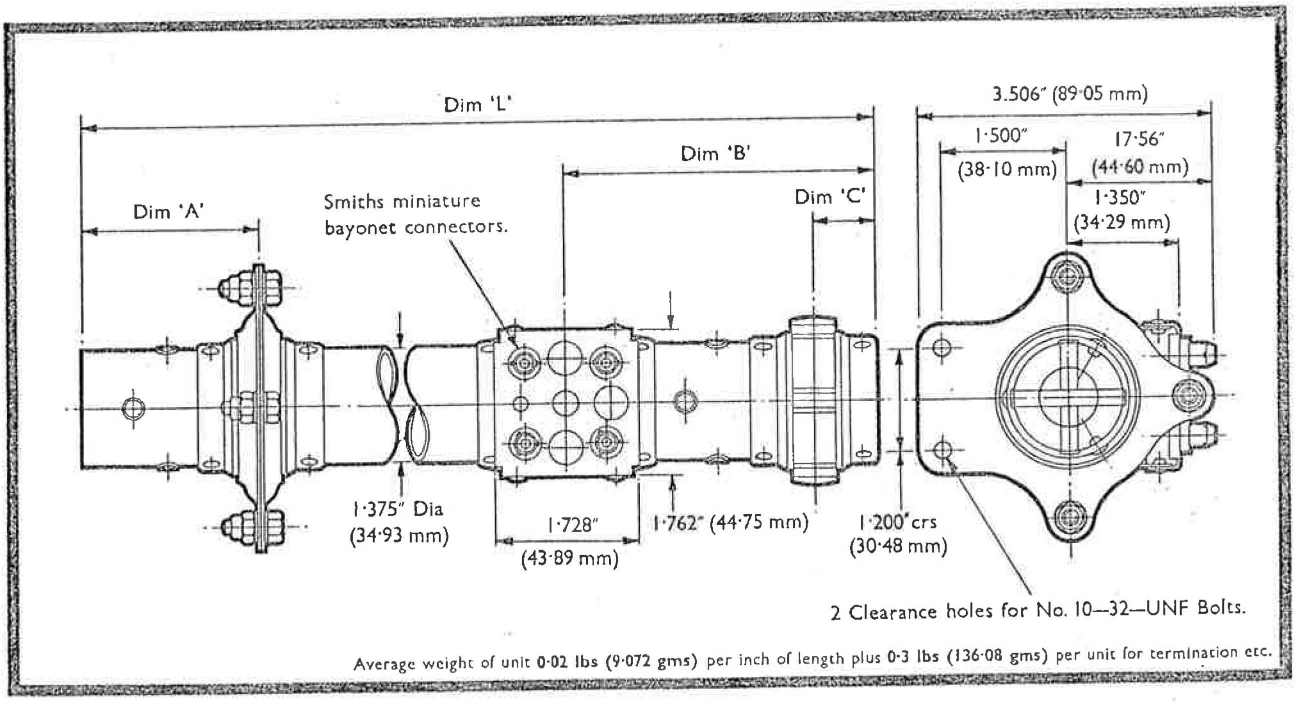


FIG 9 *Tank unit.*

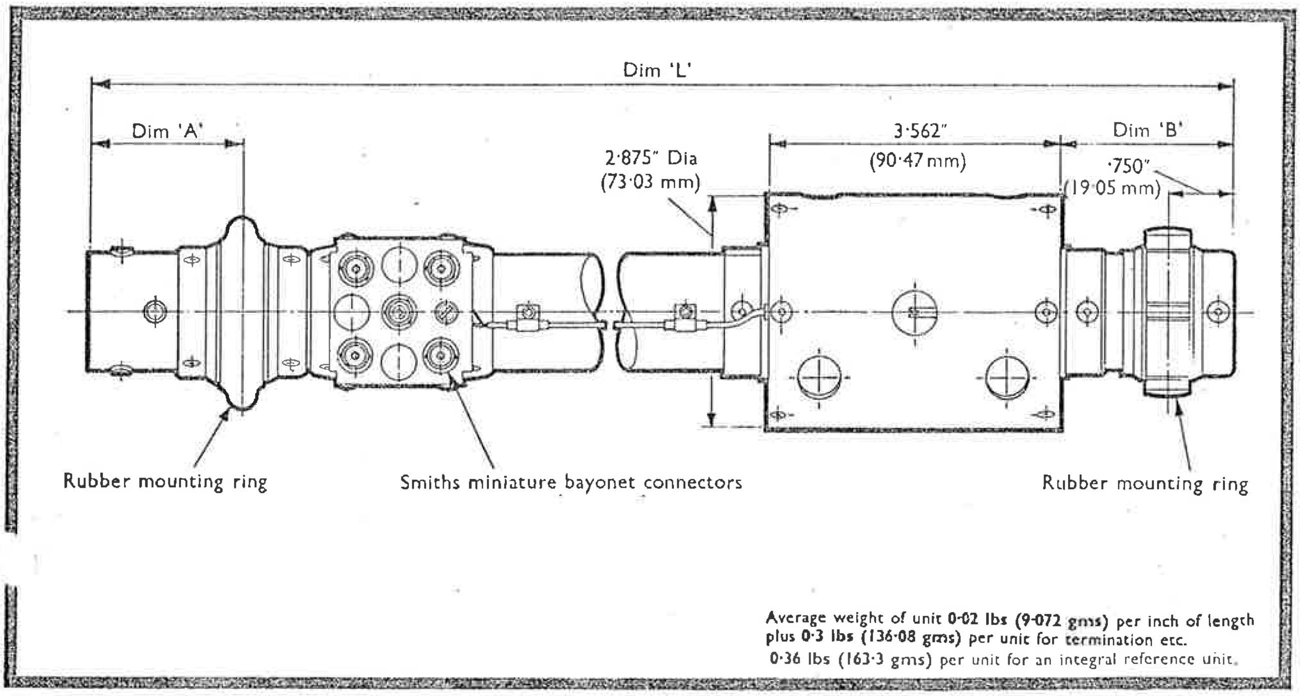


FIG 10 *Combined reference and tank unit.*

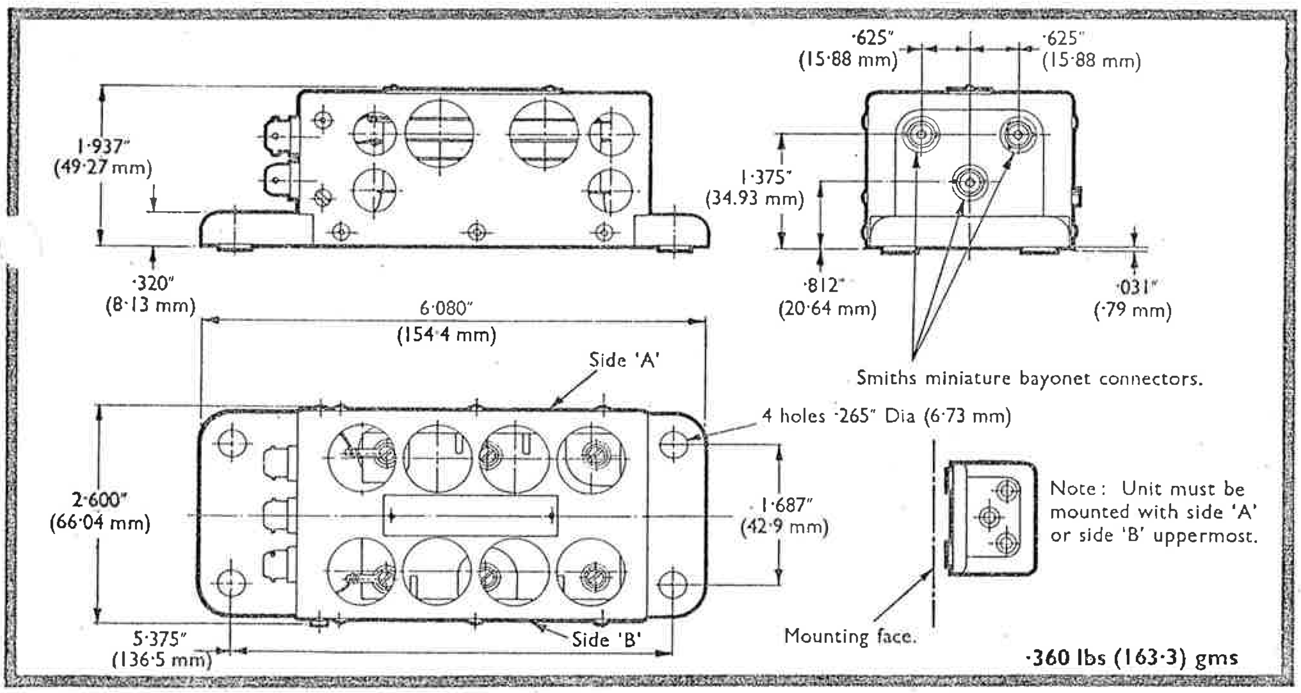


FIG 11 *Reference Unit*

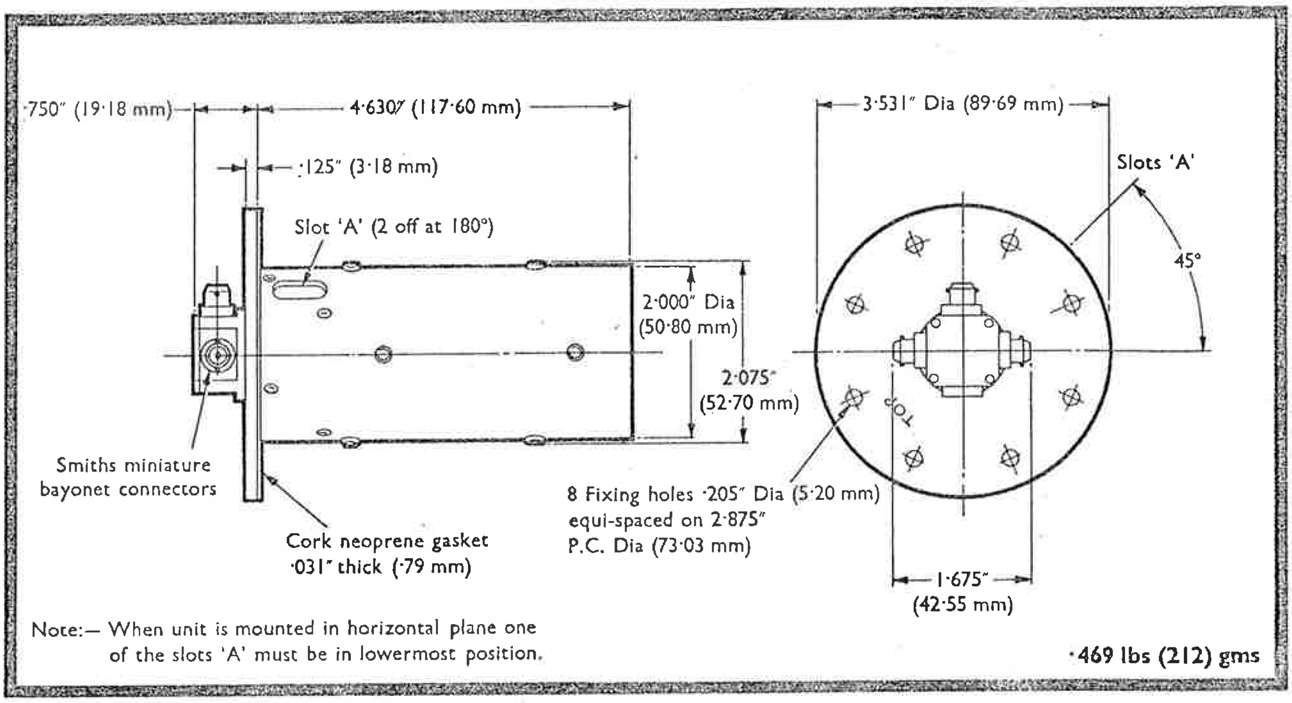


FIG 12 *Reference Unit*

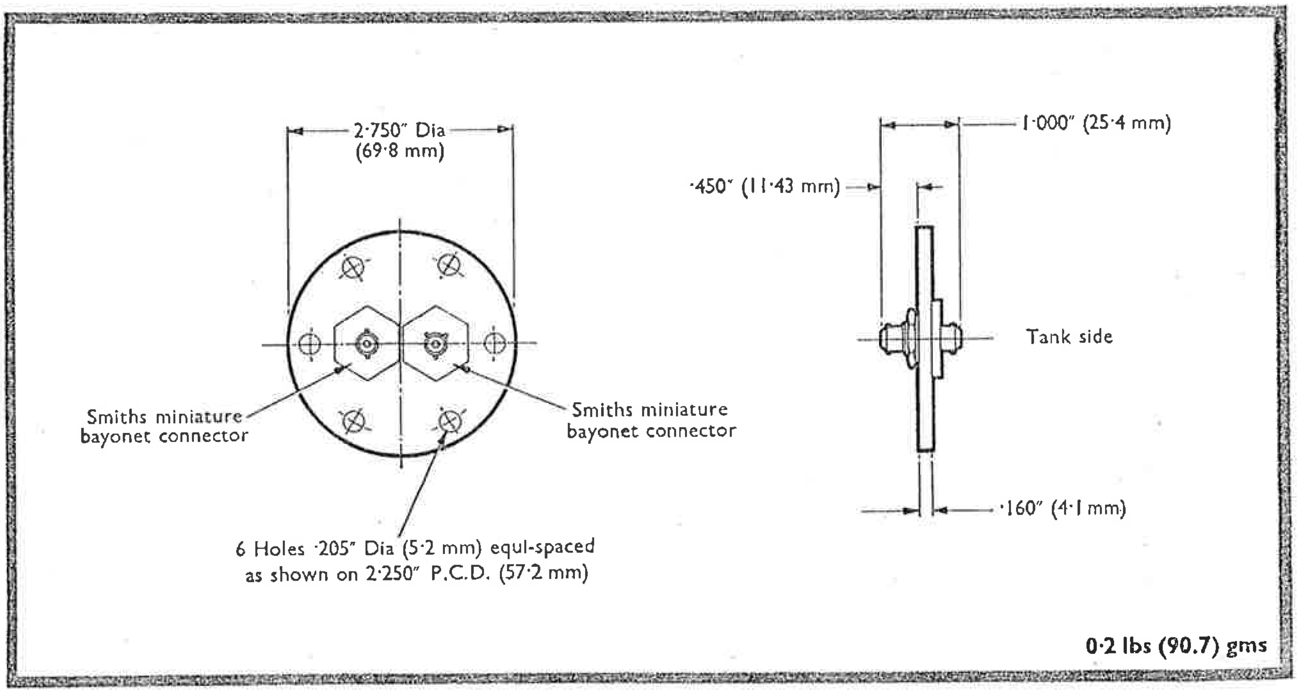
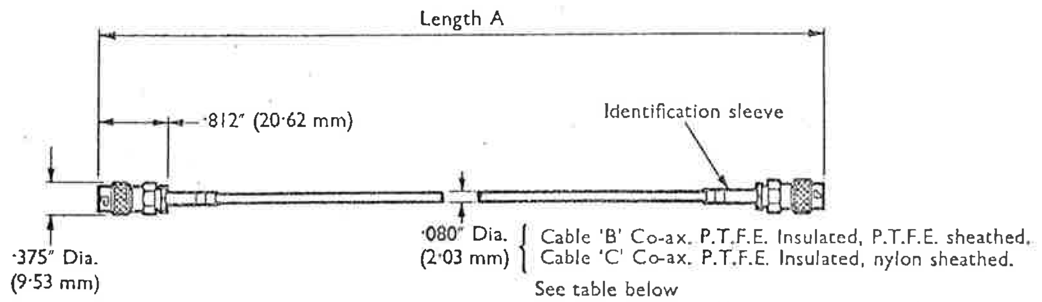


FIG 13 *Tank Terminal.*

CABLES AND CONNECTORS

In keeping with the policy on miniaturisation a range of small coaxial connectors has been developed which are known as the Smiths Miniature Bayonet Series, abbreviated to MB-Series. Complementary to these connectors is the use of a subminiature coaxial cable for all wiring in the TYPE 4 system between the probes, reference unit and bridge. As an installation is thus fully screened, it enjoys a complete freedom from all spurious voltages which otherwise would be generated by interference fields within an aircraft. This is one of the ways in which the high accuracy of the gauge is safeguarded. Also, a feature to be borne in mind in this context is that the wide variations in self capacitance of coaxial cables in no way affects the operation of the gauge.



Insulator type.	Connector code.	Contact.	Pin positions.
*Non shroud	MB 7–1	Plug.	180°
Shroud	MB 34–1	Plug.	
Shroud	MB 8–1	Socket.	
*Non shroud	MB 9–1	Plug.	120°
Shroud	MB 35–1	Plug.	
Shroud	MB 10–1	Socket.	
*Non shroud	MB 11–1	Plug.	90°
Shroud	MB 36–1	Plug.	
Shroud	MB 12–1	Socket.	

Notes.

1. To obtain a code for a complete cable assembly, select cable code from table on the right and add numerical suffix corresponding to length required ('A') in inches, i.e. using connector MB 7–1 at one end of cable and connector MB 8–1 at other, required length being 120″, complete cable assembly code would be MBE 120.
   Suffix ' S ' on cable assy. code denotes one end supplied loose and cable 1·0″ longer.
2. Limits on length 'A' : 9″–100″ $^{+1''}_{-0''}$
   101″–200″ $^{+1.5''}_{-0''}$
   201″–300″ $^{+2''}_{-0''}$
   Minimum bend radius : 1·0″
3. Weight of one connector (any type) : ·0123 lb. (5·6 gms.).
   Weight per 100″ of cable : ·0468 lb. (21·25 gms.).

Cable assy. code	Connectors one end	Connectors other end	Cable
MBD	MB 8–1	MB 8–1	B
MBH	MB 10–1	MB 10–1	B
MBJ	MB 12–1	MB 12–1	B
MBK	MB 34–1	MB 34–1	B
MBL	MB 10–1	MB 34–1	B
MBM	MB 10–1	MB 35–1	B
MBN	MB 8–1	MB 36–1	B
MBS	MB 8–1	MB 8–1	C
MBV	MB 10–1	MB 10–1	C
MBX	MB 12–1	MB 12–1	C
MBY	MB 34–1	MB 34–1	C
MBZ	MB 10–1	MB 34–1	C

FIG 14 *Miniature co-axial cables.*

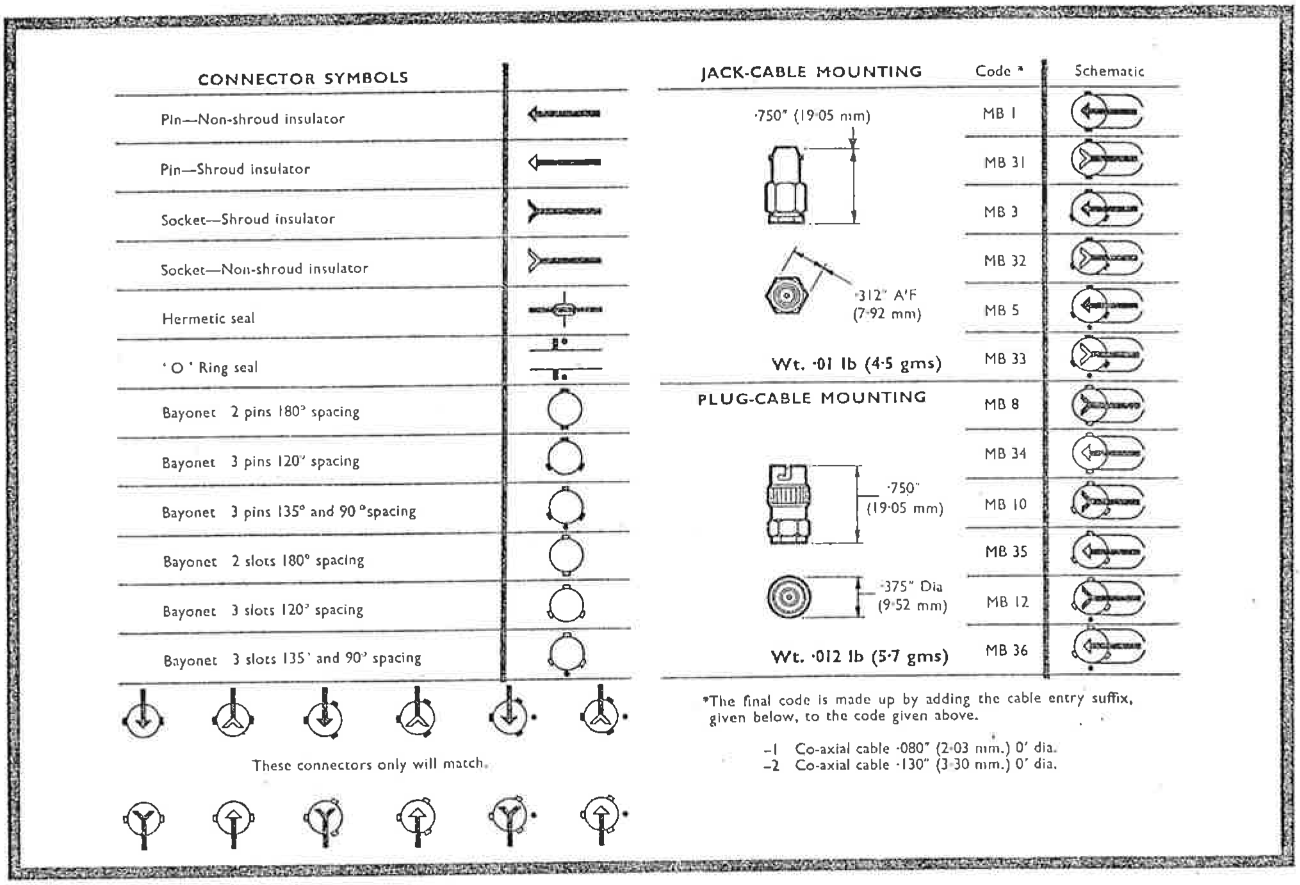


FIG 15 *Smiths miniature bayonet connectors.*

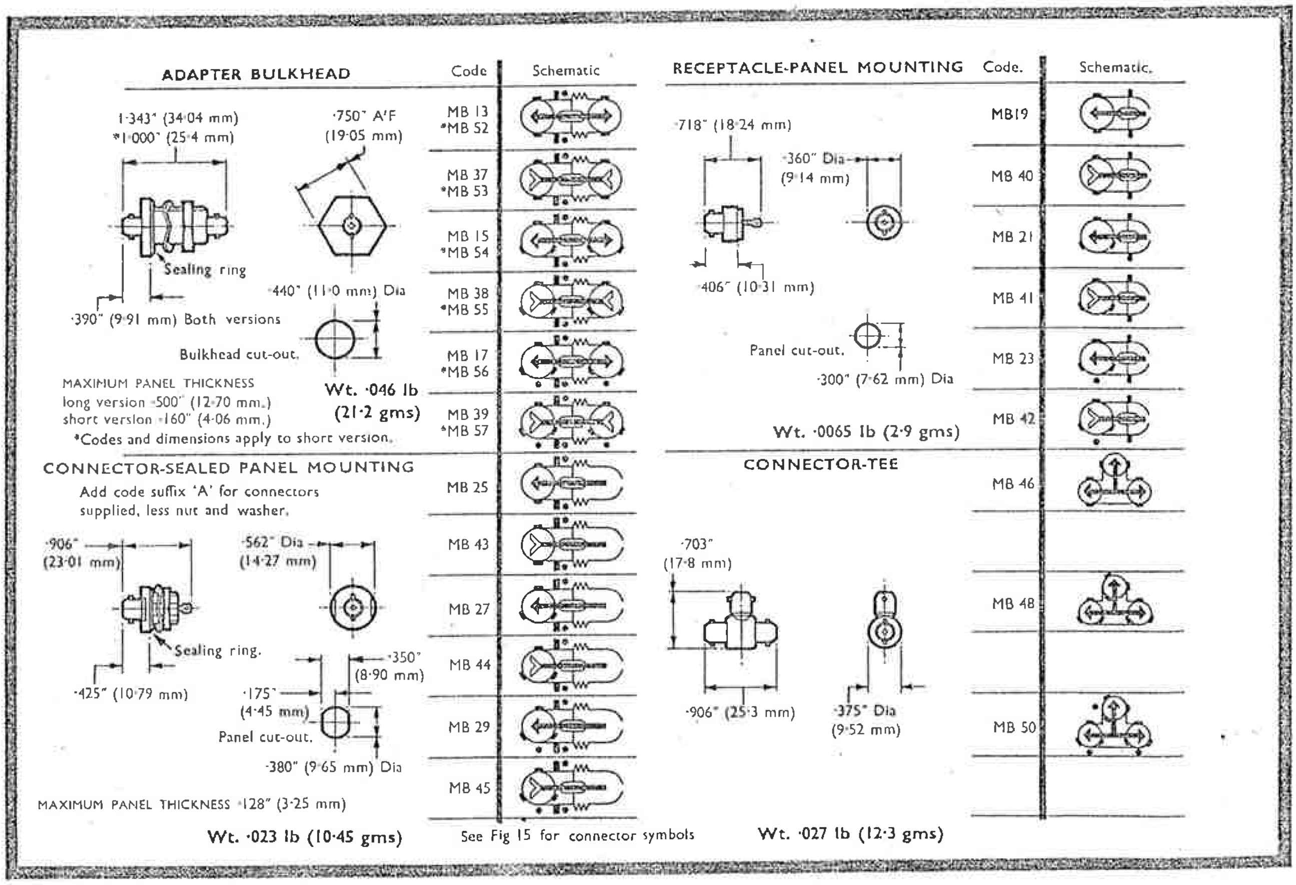


FIG 16 *Smiths miniature bayonet connectors.*

BRIDGE AMPLIFIER UNITS

In certain types of installation the Bridge and Amplifier Units are contained in a common case, purely as a matter of physical convenience.

BRIDGE UNITS

As the title implies, these units contain the bridge components comprising the supply transformer, reference and phase correcting networks, together with relays for switching tank circuits where necessary. Also fitted in the Bridge Unit are two adjustable components for trimming the Tank Empty and Tank Full indicator readings.

AMPLIFIER UNITS

A standard amplifier unit is used even though the capacitance values of the tank units differ between one installation and another.

The amplification of the small current appearing at the balance point of the bridge is achieved by a four-transistor circuit of advanced design. The output drives the control phase of the indicator motor, and the sensitivity is such that full-speed rotation is achieved for a balance point current of the order of 0·1 microampere. The direct voltage supplied to the transistors is obtained from a conventional half-wave rectifier fed from the aircraft power supply. It is here that the use of transistors shows a distinct advantage over thermionic valves. The power consumption of a TYPE 4 amplifier unit is only 5 watts, whereas the TYPE 1 amplifier consumes 20 watts. The primary reason for the reduced power consumption is that transistors have no heaters and the consequent saving amounts to at least 8½ watts.

INDICATOR UNITS

An indicator unit consists of a small two-phase motor driving, through a gear train, both the indicator pointer and the potentiometer wiper, which latter serves to rebalance the bridge. One phase of the motor,

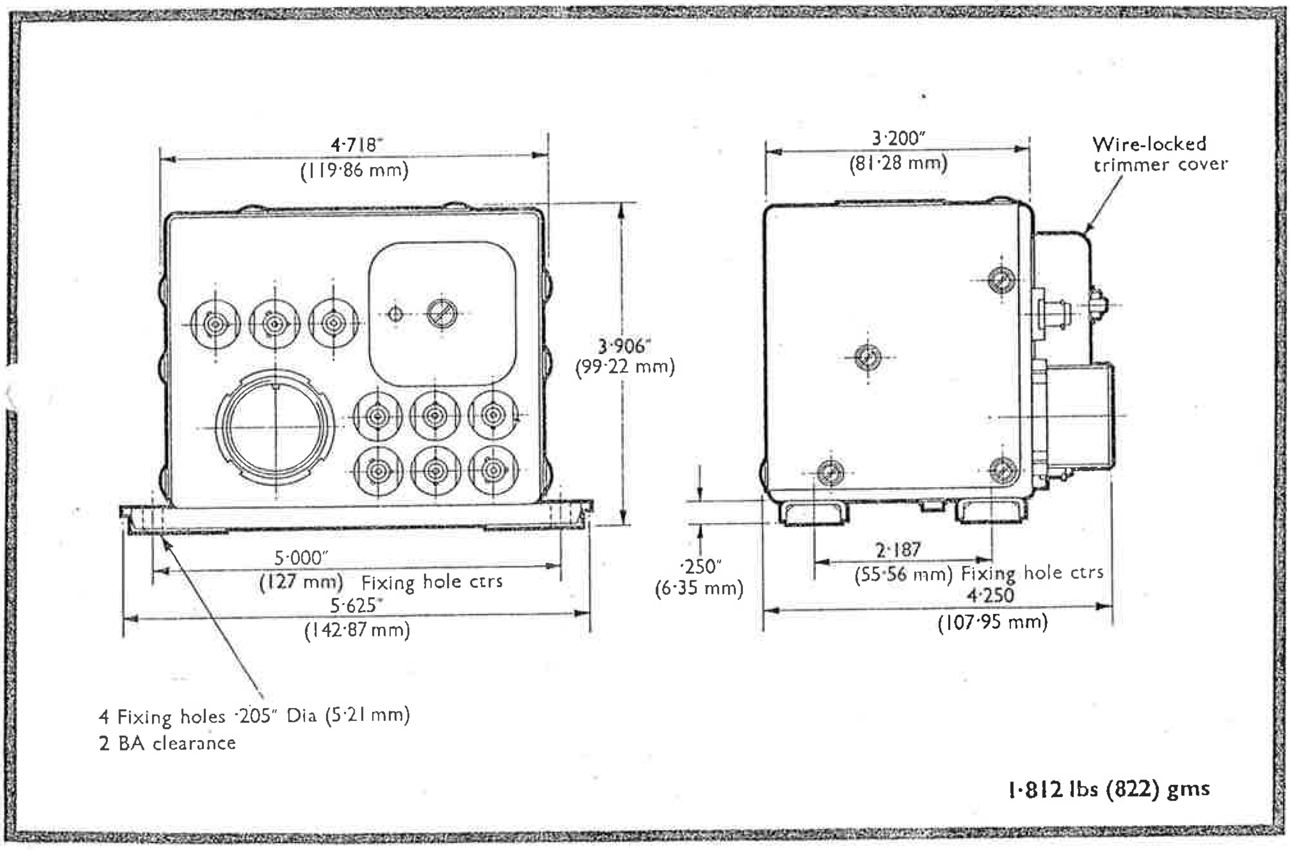


FIG 17 *Bridge amplifier unit.*

the reference phase, is driven from an output of the transformer in the bridge unit. The other phase, known as the control phase, is supplied with output power from the amplifier unit. By this means the indicator motor is caused to rotate in either direction depending on the phase of the voltage at the balance point of the bridge. A very important feature of the indicator is the precaution taken to ensure that it fails safe; in other words, in the event of an amplifier failure the indicator pointer will come to rest at a definite position off the calibrated scale. This is achieved in the following way. By means of a capacitor in series with the aircraft power supply, a small current is continuously fed to the control phase. In normal operation, this current is so small as to have a negligible effect upon the gauge's performance. If, however, the output from the amplifier fails, then the indicator will be driven slowly anticlockwise by the small current until the pointer comes to rest at a position off the scale.

ANCILLARY UNITS AND FUNCTIONS

In many modern aircraft installations, except the most simple, the fuel contents gauging system is required to perform functions other than merely fuel contents indication. Examples of such additional functions are, centre-of-gravity control by means of automatic adjustment of fuel distribution, proportioning, high and/or low level warning and fuel loading control. In common with earlier Smiths systems, the TYPE 4 system can be easily adapted to provide any or all of the ancillary services mentioned.

A complete range of such devices as repeater indicators, balancing relays, and loading control switches – both electro-mechanical and purely electrical – is under development and will serve to increase the flexibility and usefulness of the Smiths TYPE 4 gauging system.

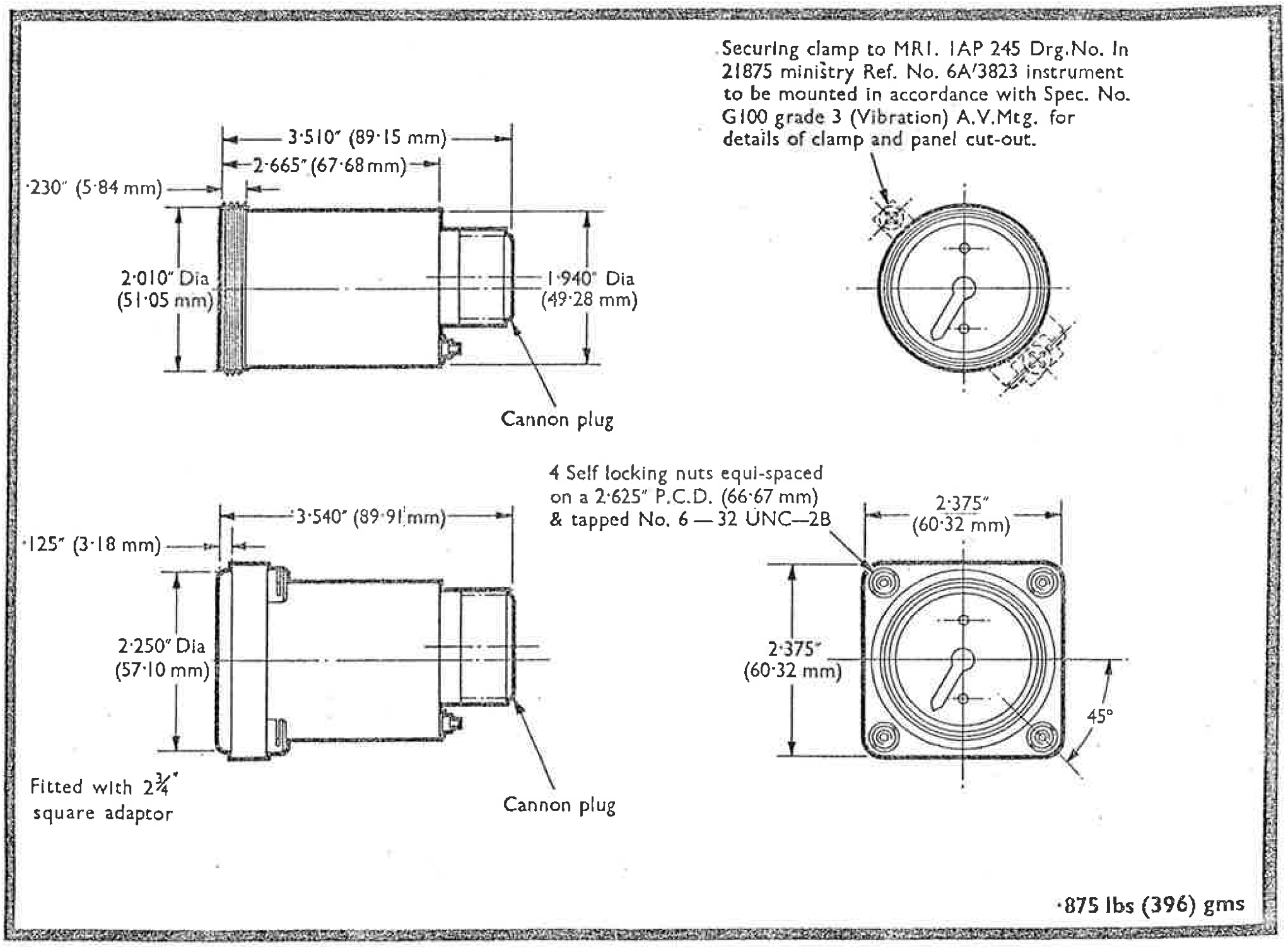


FIG 18 *Indicator, 2" & 2⅝" frontage.*

It has already been mentioned that one advantage of the TYPE 4 system lies in its flexibility, this feature now can be described in more detail. Three arrangements will be discussed; a simple installation for a single fuel tank, a more complicated one for a number of tanks, and an installation in which balancing and fuel control are also incorporated.

Combined Amplifier/Indicator Units In the simple system illustrated in FIGURE 20 the amplifier and bridge components are disposed in the same case as the indicator, thus reducing the installation to two units – the tank unit and the combined amplifier/ indicator.

The installation can be trimmed at the tank empty and tank full conditions in the normal manner, by means of two potentiometers at the rear of the indicator case.

Separate Units A more complicated system is that shown in FIGURE 21. In this instance there are four tanks, each feeding into a bridge unit. Within the Bridge Unit are switch-selected relays which are so arranged as to give individual tank contents or summated contents of all tanks as desired.

It will be noted that the bridge unit and the amplifier are shown as being separate units even though enclosed in the same case. This symbolises the fact that the amplifier is a standard unit whose physical dimensions are so small that it is convenient to construct it as an easily removable unit for fitment in the bridge unit. In this way, although they are separate units electrically, their juxtaposition enables a saving in complexity and interconnection.

FIGURE 22 demonstrates the application of the TYPE 4 system to an installation which is complicated by the addition of ancillary functions.

Two tanks on each side of the aircraft are shown and their outputs are combined in the bridge units. Thus the total contents of port and starboard wing tank groups are separately presented. Outputs from auxiliary potentiometers controlled by the indicator mechanisms are fed to a differential relay where they are compared. So long as the outputs are equal, indicating that the relative tank contents are also equal, then no signal is sent from the output of the differential relay. If however, one of the tank groups is drained (or filled) more quickly than the other, then the differential relay senses the difference between the outputs of the contents bridges and accordingly transmits a signal to the fuel pumps.

An adaptation of the same principle is known as the refuelling control system. In this instance the indicator outputs are compared with a voltage derived from a potentiometer calibrated in terms of tank contents. Thus the actual contents of the tank are compared electrically with the desired tank contents, and the differential or defuelling relay signals to the refuelling pumps when equality is achieved. By this means any desired quantity of fuel can be automatically attained by on- or off-loading.

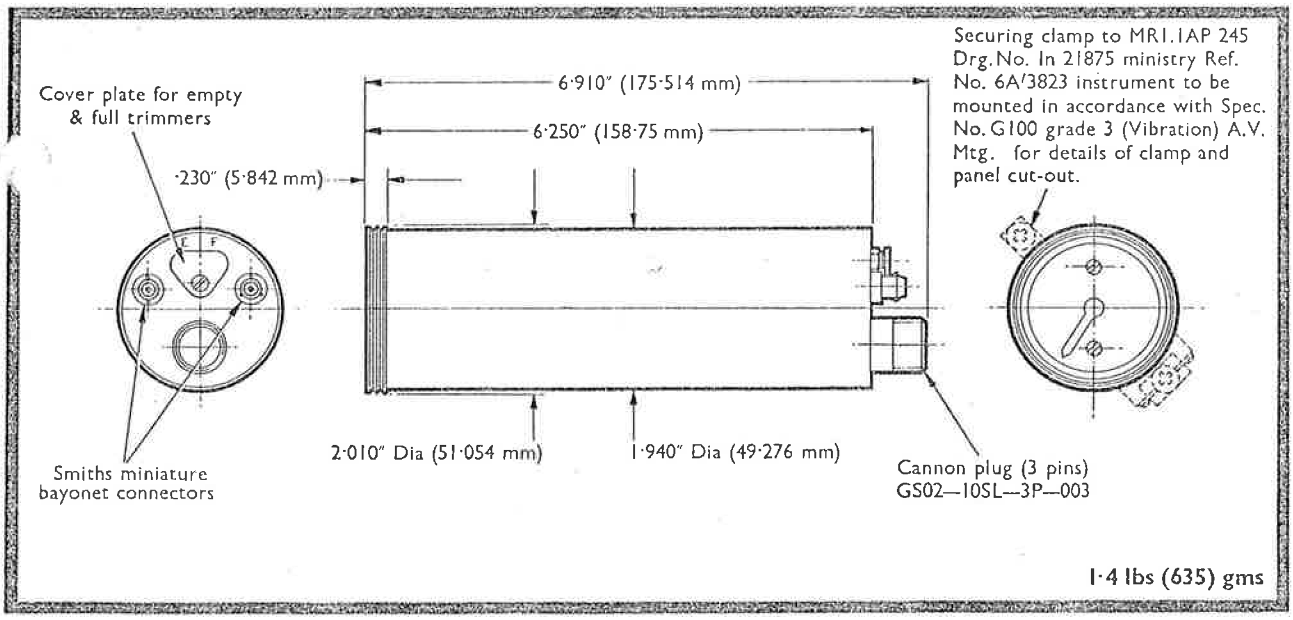


FIG 19 *Indicator-Amplifier 2″ frontage.*

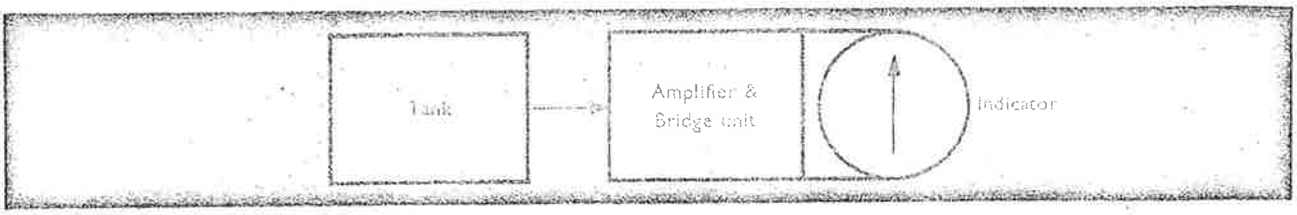


FIG 20 *Block diagram showing use of combined amplifier/indicator.*

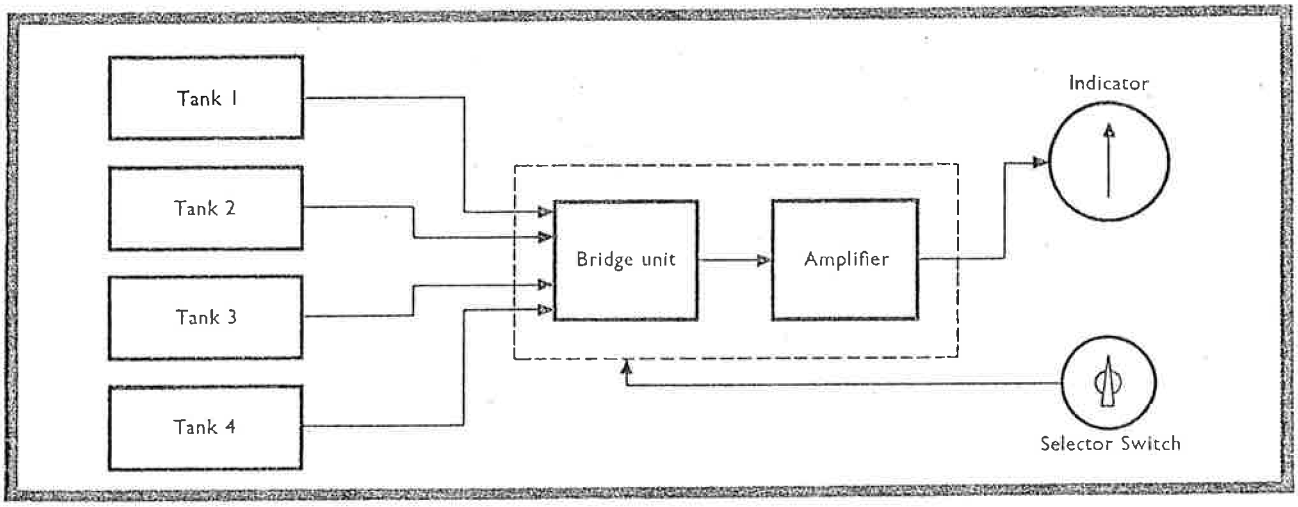


FIG 21 *Block diagram showing more complex system with the use of separate Bridge/Amplifier and indicator unit.*

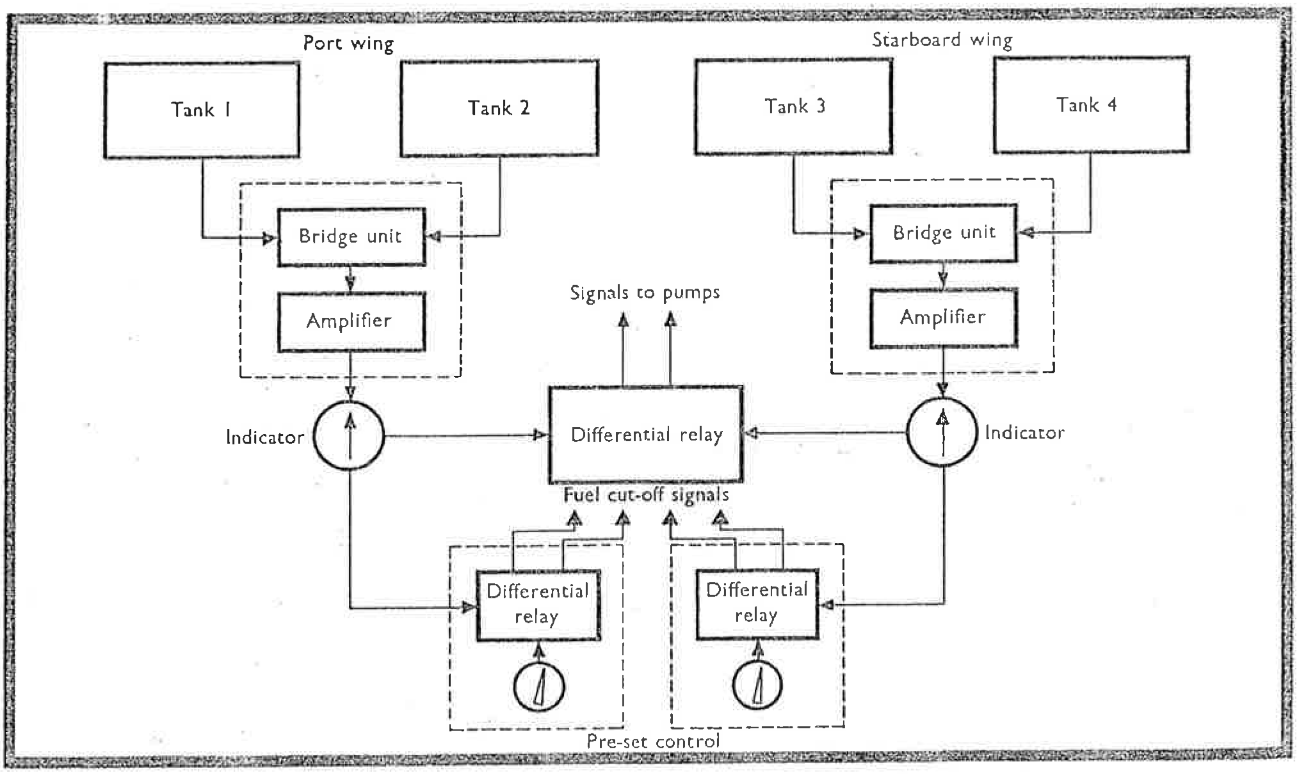


FIG 22 *Block diagram showing more complex system and use of ancillary functions.*

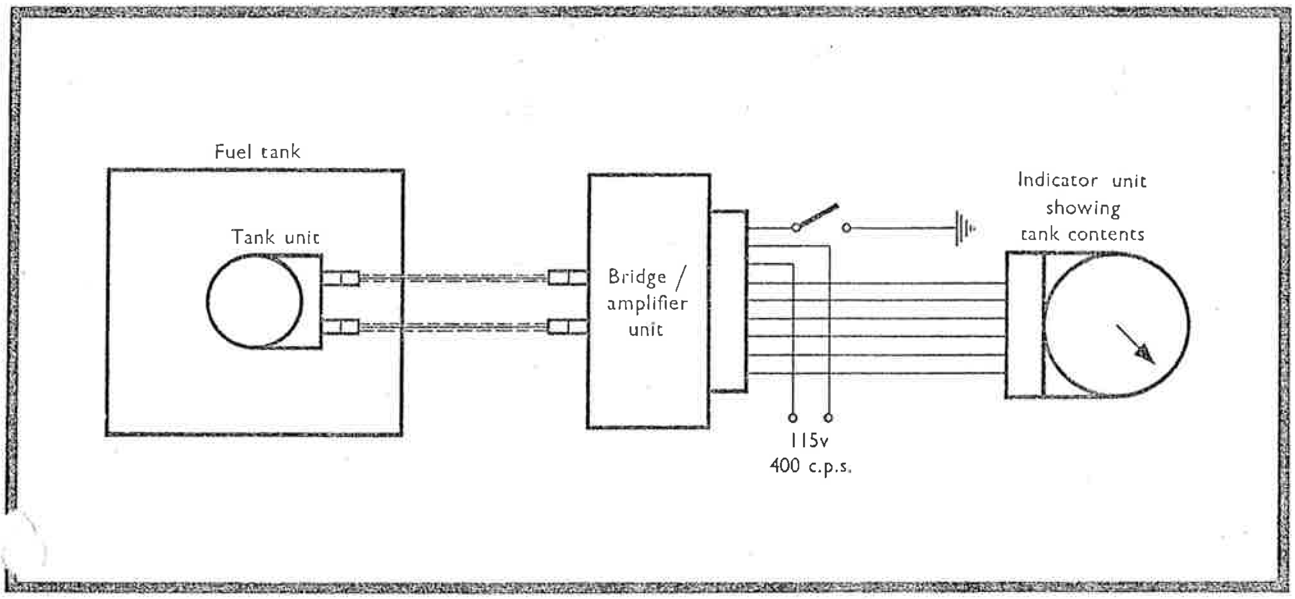


FIG 23 *Typical simple installation diagram.*

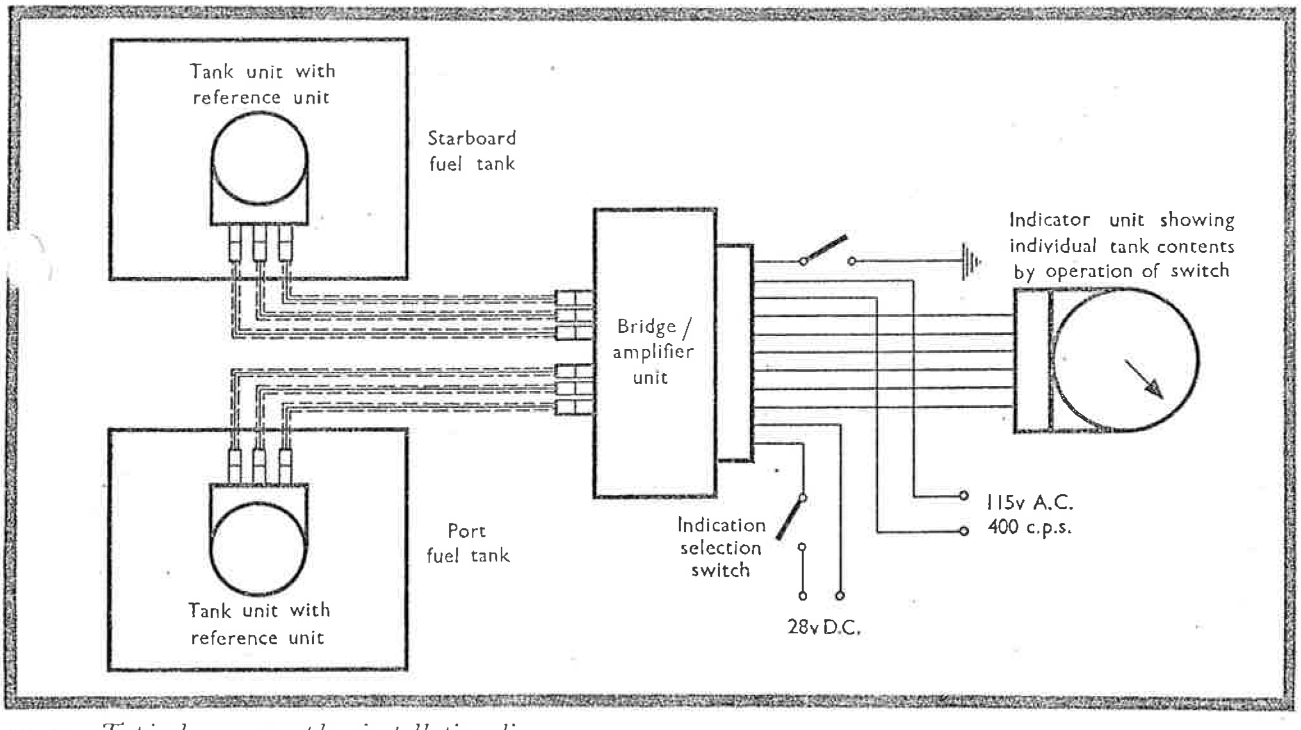


FIG 24 *Typical more complex installation diagram.*

COMBINED INDICATOR/ PRE-SELECTOR

In some systems it is desirable to have simultaneous indication and control of the fuel uplift at the re-fuelling station, and for this purpose the combined indicator-preselector has been developed. This is a motor-driven indicator, similar to the normal instrument already described, but having an additional pointer concentric with the indicator pointer controlled manually by a knob; the knob being located in one corner of the instrument face. A mechanism linking the two pointers causes two switches to open and close alternately according to the angular difference between the indicator and preselector pointers; when the two pointers coincide both switches are open circuited. By connecting one switch to a refuelling valve and the other to a defuelling valve it is possible to control the contents of a tank to attain any final fuel level according to the setting of the preselector. A combined indicator/preselector can be made to repeat a flight-deck indicator reading by means of an auxiliary bridge/amplifier; or it can be made to alternate with the flight/deck indicator by means of a changeover relay located in the bridge/amplifier unit.

OPERATING CONDITIONS

Power supply can be either 115v or 200v at 400 c.p.s. with a voltage and frequency to be within ±10% of nominal. Both terminals of the power input may be isolated from airframe. Consumption is 5 watts at 0.7 lagging power factor.

PERFORMANCE UNDER ENVIRONMENTAL CONDITIONS

Production units of the Smiths TYPE 4 Fuel Contents Gauge will be submitted to the M.O.A. for type approval in accordance with our specifications which are summarised as follows:—

FINISH AND PROTECTIVE TREATMENT

All surface treatment will be in accordance with DEF.5000.

EXTERNAL CONTAMINATION

All units will be unaffected by external contamination with all fluids with which they are liable to come into contact.

RADIO INTERFERENCE

The system will conform to M.O.A. Specification EL.1716.

TEMPERATURE

The complete system will operate satisfactorily at all temperatures between −20°C and +55°C, and will not be damaged or permanently deranged by prolonged exposure to temperatures between −40°C and +75°C and short term periods in the range −65°C to +100°C both operative and non-operative.

ALTITUDE

The complete system will be capable of operation at all altitudes between sea level and 100,000 feet.

VIBRATION

The complete system will meet the requirements of specifications Av.P24 and BSG.100. All units will be suitable for rigid mounting in extreme regions; tank units are suitable for vertical mounting.

ACCELERATION

The complete system will meet the requirements of specifications Av.P24 and BSG.100 for mounting in any part of an aircraft of high manoeuvrability, in attitudes specified under 'Vibration'. Units will not break loose from their mountings when a fore-and-aft shock load of 25 g. is applied.

CLIMATIC

In accordance with M.O.A. Specification DTD.1085B for protected equipment mounted in aircraft flying in all parts of the world at altitudes above and below 30,000 feet.

COMPASS INTERFERENCE

In accordance with M.O.A. Specification EL.1684.

INTRINSIC SAFETY.

Circuits associated with the tank will be tested for intrinsic safety with respect to the Pentane class of vapour in accordance with BS.1259.

ACCURACY

Comparative Accuracies of Uncompensated and Inferred Density Type 4 Gauging Systems

In the following paragraphs the limitations of the capacitance-type probe as a 'fuel dip-stick' are assessed and details are given of the effects that the physical and electrical properties may have on the accurate measurement of fuel quantity. Finally the errors are tabulated to show how the properties of the fuel and/or compensating equipment affect the basic system accuracy in an uncompensated and an inferentially compensated, mass-reading TYPE 4 gauge. Overall errors for uncompensated and inferred-density systems are also illustrated in FIGURES 25 and 26, where the proposed accuracy limits of Av.P970 are also shown for reference.

Tank Unit Capacitance as a Function of Fuel Quantity In any dielectric-type fuel contents gauge the result of adding a certain volume of fuel to the tank contents will cause a proportion of the dielectric between the probe electrodes to change from air to fuel. If the probes are designed for linear capacitance/volume response this change in capacitance will be proportional to the change in volume v; but it will also be proportional to the change in permittivity between air and fuel, which may be written $(k-1)$. Expressed as equation (1), where C is the change in capacitance and A is a constant indicating proportionality – $C=Av(k-1)$.

If the gauge is a simple system the indicator pointer deflection will be directly proportional to the change in capacitance and therefore to the product of the volume and the change in permittivity between air and fuel $(k\text{-}1)$. As a volume-measuring device, therefore, an uncompensated system suffers from errors due to variations in $(k\text{-}1)$ between samples and grades of fuels, and in any one fuel when subjected to changes of temperature.

most modern aircraft, however, fuel mass measurement is for various reasons preferred to volume measurement. The mass of fuel actually present in the tank is equal to the product of its volume v and density d: $m=vd$ or by re-arrangement giving equation (2) $v=m/d$.

The relationship between capacitance change and actual mass is therefore found by combining equations (2) and (1), thus $C=Am.\ (k\text{-}1)/d$, to give equation (3).

FUEL PROPERTIES AND INDICES

The ratio $(k\text{-}1)/d$ is known as the capacitance index of the fuel. If this factor were constant for all fuels under all conditions a simple capacitance gauge could be de- ·gned to read the mass of fuel as accurately as its ·sign limits would allow. Unfortunately the capacitance index varies from sample to sample and also with changes in temperature; the gauging errors due to these variations are known as 'fuel errors'. These errors have been measured at 20°C for about 400 samples of a wide variety of aviation kerosines and gasolines and have been found to have an approximate normal distribution within the limits of ±5%; while 95% of all the samples tested had fuel errors not exceeding ±3·5%, refer to FIGURE 3. A further discovery has been made in that an additional fuel error of ±1·1% will be incurred for every 40°C fall in fuel temperature from a 20°C datum, and −1·1% for every 40°C rise. Thus for an aircraft whose fuel temperatures may range between −20°C and +55°C the limits of fuel error will be ±6·1% of quantity present.

Uncompensated Capacitance Index The study of fuel properties has also shown that, while the capacitance index $(k\text{-}1)/d$ varies from fuel to fuel, this variation is not entirely random but tends to follow the permittivity. The tendency is for the variation to take the form of $(k\text{-}1)/d=B(1+0{\cdot}4k)$, which may also be stated $(k\text{-}1)/d\ (1+0{\cdot}4k)=B$ giving equation (4). The constant B is termed the '*k*-function index' of the fuel. This index is not subject to the same degree of variation as the simple capacitance index; the limits of variations, so far measured, are in fact ±3% about a mean value, while 95% of samples tested have indices within ±2% of the mean. Furthermore these limits are not exceeded at extreme temperatures. Refer to FIGURE 3.

By rearranging equation (4) – $d=(k\text{-}1)/B(1+0{\cdot}4k)$ giving equation (5). This rearrangement indicates that by a measurement of the permittivity, the density may be inferred to an accuracy limited by the possible variations in the *k*-function index B. Any form of compensation which takes advantage of this property of aircraft fuels is therefore known as the *k*-function, or inferential, compensation; a gauge constructed on this principle is termed an inferred-density gauge.

INFERRED-DENSITY COMPENSATION

Compensation in an inferred-density gauge is performed by a reference capacitor totally immersed in the fuel, for as long as is practical, so as to be dependent only on the fuel permittivity. The reference unit, in parallel with a fixed capacitor provides a total capacitance proportional to the factor $(1+0{\cdot}k4)$. The angular pointer deflection M is proportional to the ratio of the probe capacitance to the compensating capacitance. Thus by an extension of equation (3) – $M=Am.(k\text{-}1)/d(1+0{\cdot}4k)$. Then by combination with equation (4) – $M=m.AB$ giving equation (6). Thus by choosing a value of A to make $AB=1$ for a mean value of B the indicator reading is equal to the actual mass, within the limits of variation of the *k*-function index B of the particular fuel.

Apart from the *k*-function fuel error already mentioned, an inferred-density gauge is subject to a source of error which does not affect an uncompensated gauge: namely manufacturing variations in the basic capacitance of the reference unit; the limit of error due to these variations does not exceed ±0·3% of quantity present.

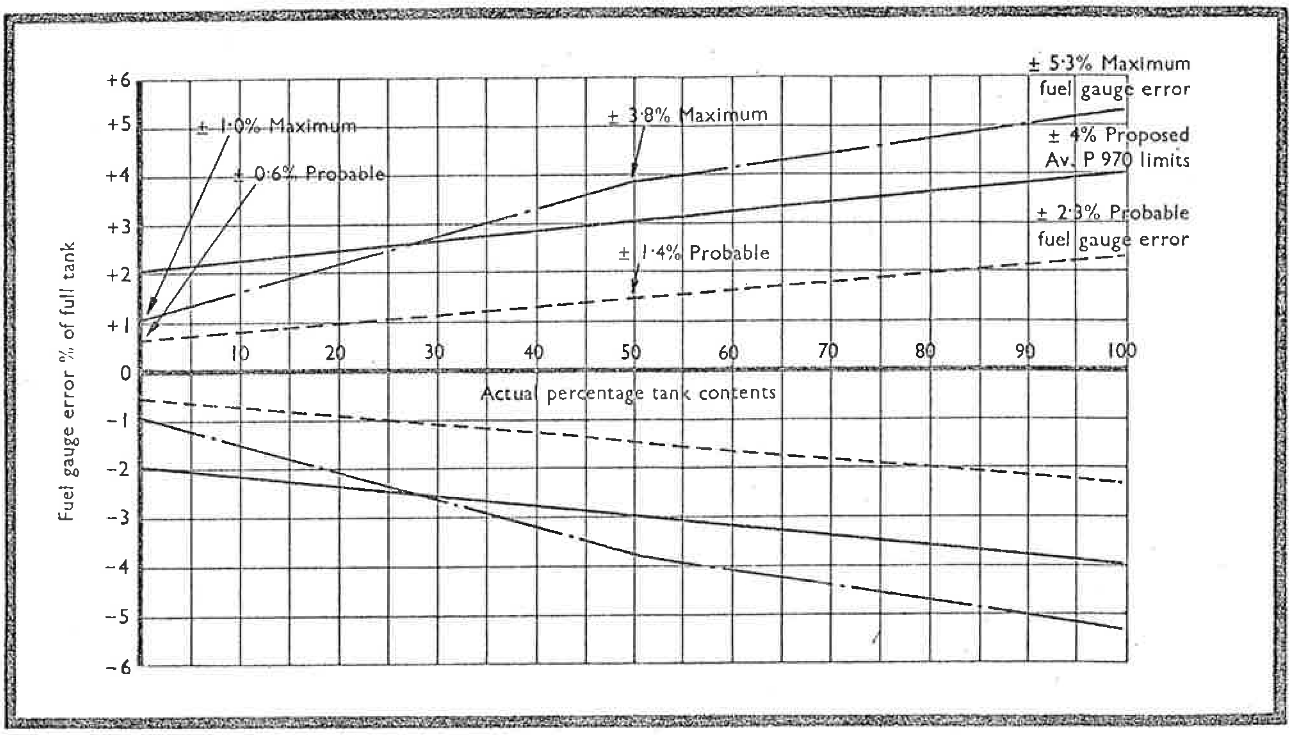


FIG 25 *Graph showing gauge error limits with inferred density compensation.*

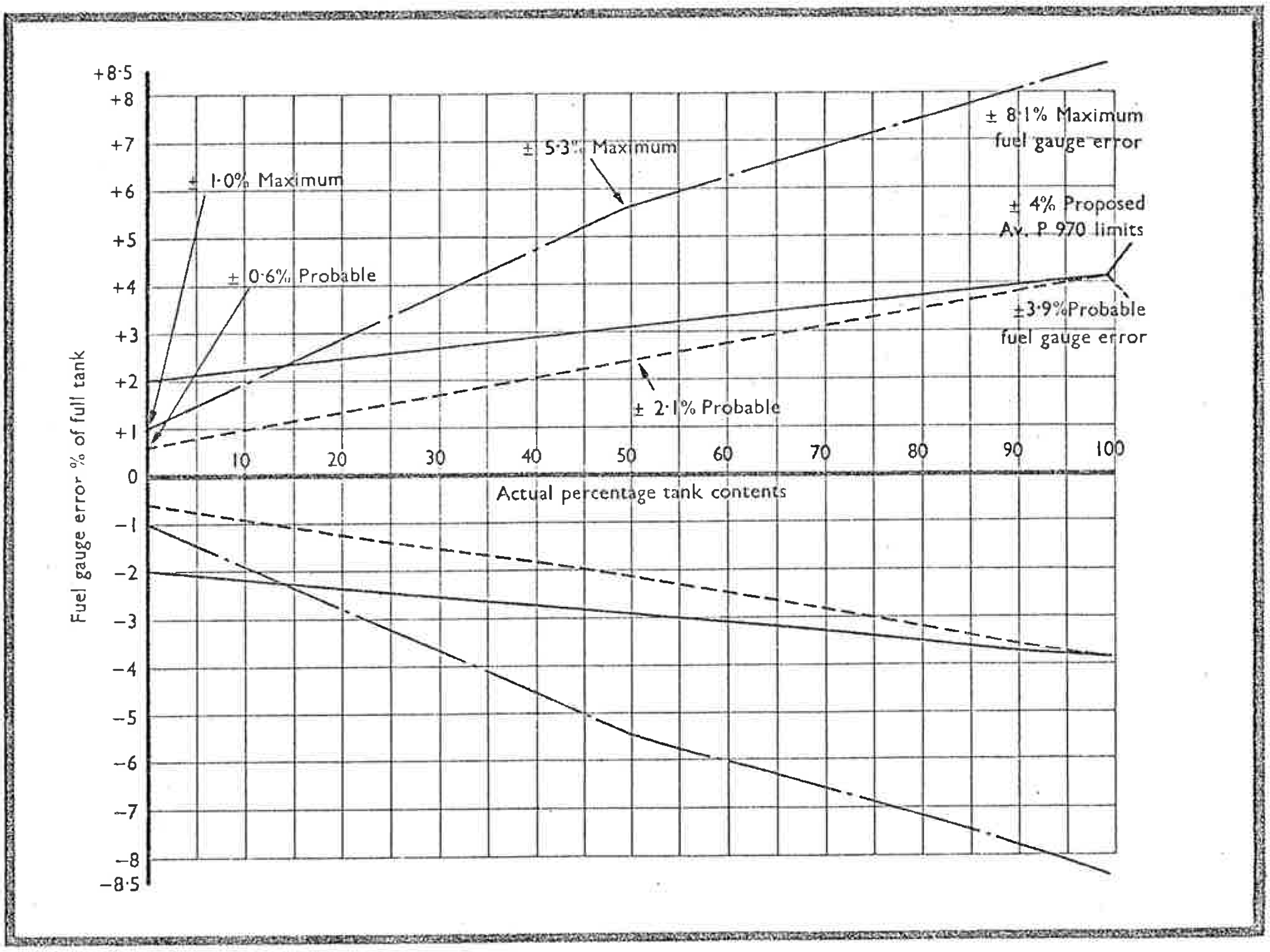


FIG 26 *Graph showing uncompensated gauge error limits.*

TABLE 1 *Basic Type 4 Gauge System Errors*

TANK CONDITION	EMPTY		HALF FULL		FULL	
description of error	*error limits*	*square of probable*	*error limits*	*square of probable*	*error limits*	*square of probable*
Tank Unit Tolerance	0	0	0·25	0·06	0·5	0·25
Tank Unit Linearity	0	0	0·25	0·06	0	0
System Trimming	0·2	0·04	0·2	0·04	0·2	0·04
Indicator Friction	0·1	0·01	0·1	0·01	0·1	0·01
Indicator Linearity	0	0	0·5	0·25	0	0
Power Supply Variations	0·2	0·04	0·2	0·04	0·2	0·04
Temperature	0·5	0·25	0·75	0·56	1·0	1·0
MAXIMUM POSSIBLE ERROR	1·0	—	2·25	—	2·0	—
PROBABLE ERROR	0·6	0·34	1·0	1·02	1·2	1·34

TABLE 2 *Overall Errors – Uncompensated Type 4 Gauge*

TANK CONDITION	EMPTY		HALF FULL		FULL	
description of error	*error limits*	*square of probable*	*error limits*	*square of probable*	*error limits*	*square of probable*
Basic System Error { Probate	0·6	0·34	1·0	1·02	1·2	1·34
Basic System Error { Max.	1·0	—	2·25	—	2·0	—
Fuel Error	0	0	2·50	3·06	5·0	12·25
Fuel Temperature	0	0	0·55	0·30	1·1	1·21
OVERALL—MAX. POSSIBLE ERROR	1·0	—	5·3	—	8·1	—
PROBABLE ERROR	0·6	0·34	2·1	4·38	3·9	14·80

TABLE 3 *Overall Errors – Inferred-Density Compensated Type 4 Gauge*

TANK CONDITION	EMPTY		HALF FULL		FULL	
description of error	*error limits*	*square of probable*	*error limits*	*square of probable*	*error limits*	*square of probable*
Basic System Error { Probable	0·6	0·34	1·0	1·02	1·2	1·34
Basic System Error { Max.	1·0	—	2·2	—	2·0	—
Fuel Error	0	0	1·5	1·0	3·0	4·0
Reference Unit Tolerance	0	0	0·15	0·02	0·3	0·09
OVERALL—MAX. POSSIBLE ERROR	1·0	—	3·8	—	5·3	—
PROBABLE ERROR	0·6	0·34	1·4	2·04	2·3	5·43

SUMMARY OF OVERALL ERRORS

In the following tables the errors due to the basic capacitance-measuring system under all flight conditions (except changes of aircraft attitude) are stated; the effects of fuel error and reference-unit error are then added separately.

The probable overall error is stated as the square root of the sum of squares of the probable values of the contributory errors. In most cases, where the errors vary randomly between tolerance limits, the probable value is assumed to be sufficiently close to the limit itself; but for normal fuel errors which are more sharply distributed, the probable error is taken as ±3·5% uncompensated or ±2% compensated.

All the errors in the table are expressed as percentages of full-scale indicator deflection.

Summary of Errors The improvement in accuracy offered by an inferred-density gauge over an uncompensated system is about ±2·8% of quantity present in respect of the maximum error limits, and about ±1·5% of quantity present in respect of the probable error. The weight penalty for this improvement is 0·36 lb. for the reference unit and 0·006 lb. per foot for the extra length of coaxial cable between the tank and the bridge unit.

SERVICE AND SHELF LIFE

The units will be capable of withstanding all conditions of service use, including handling, transportation and storage. The service life of all units will be not less than 3,000 hours of operation or 2 years installed-life, whichever is completed sooner. Shelf life for all units will be 2 years.