1 Hyperbolic navigation systems

1-1 Introduction

A navigation system in which two transmitting stations transmit
certain specified types of radio wave, according to the rated
time sequence, and in which a user of the system finds his position
by measuring the difference in distance between him and the two
transmitting stations, is called a "hyperbolic navigation system".
Under such system, the locus of the points having a certain
difference in distance forms a hyperbola, and the user determines
two of such hyperbolas (which are referred to as "line of position")
from the two pairs of transmitting stations he selects, to fix
his position at the point of intersection between these two hyper-
bolas.

The Decca Navigator system, Loran A system and Loran C system are
representative of the hyperbolic navigation systems.

1) Phase difference and difference in distance

Supposing that the frequency of the radio wave transmitted
from the transmitting station is 100 KHz and the propagation
speed of the radio wave is 3×10^8m (in actual cases this
speed alters according to the condition of propagation path),
the wave length of this radio wave would be 3000 metres, that
is, the radio wave of 100 KHz would propagate 3,000m during
one cycle. Since the phase angle changes from 0° through
to 360° during the one cycle, the radio wave of 100 KHz would
propagate 3,000m during the time the phase angle of 360°
changes. Figure 1-1 shows the state of this propagation.
If the frequency and propagation speed of a radio wave are
given, as in the above case, the distance may be replaced
by the wave length or phase of radio waves. A difference in
the distance from the two transmitting stations can be measured
as phase difference of the radio wave transmitted by the trans-
mitting stations.

Suppose radio waves are transmitted continuously on the same
frequency and at the same time from Point A and Point B in
Fig. 1-2 so as to make the phase of the transmitted waves
from A and B identical (this is called "phase synchroni-
sation), the phase of the radio waves from both stations would
be completely identical at Point P which is situated at an
equal distance from points A and B. There is no phase differ-
ence and this indicates that no difference in distance at
this point. However, as seen from this figure, there are
many points other than Point P, at which the phase difference
becomes zero, and therefore some method should be worked
out to select a single point wanted (this will be explained
further in the paragraph of "Lane identification").

If point P in Fig. 1-2 moves to Point P', the phase of the
radio waves from Point A would be 270° and the phase from
Point B 90°, and since the phase difference is 180° in this
case, the difference in distance would be known to be 1,500m.
Further, the phase difference at Point Q is 360° and the
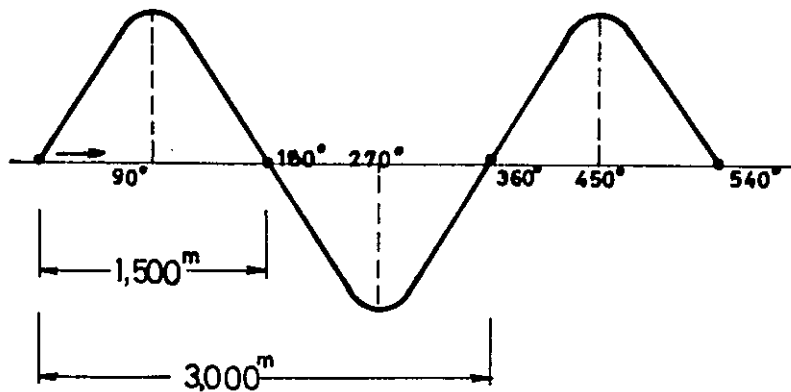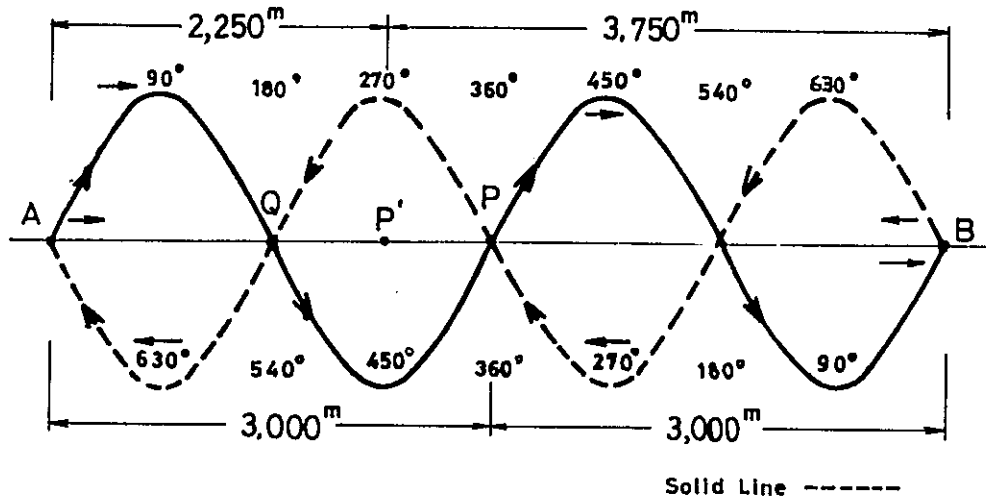difference in distance is therefore 3,000 m.

Fig. 1-1   Phase and Distance

Fig. 1-2   Difference in Distance and Phase Difference

Solid Line ------

1-2   Decca Navigator system

1-2-1   Principle of Decca system

The effect of transmitting signals of equal frequency from the master and slave is achieved by assigning harmonically-related values to the two frequencies so that multiplying circuits in the receiver can derive from each a common harmonic. Thus in the red hyperbolic pattern, for example, the master and slave signals are multiplied to a common frequency of 24f, where f is a non-transmitted fundamental value of about 14 kHz, and their phase is compared at this common frequency. The master transmits a signal of frequency 6f and the slave 8f, the respective channels in the receiver being followed by 4 and 3 multiplier stages; geometrically the system behaves as if the common frequency 24f (about 340 kHz) were radiated from the two sites. The purple and green hyperbolic patterns are generated in a similar manner by using different frequency values and multiplication factors as indicated in Table 1-1. The basic arrangement of the receiver is shown in Fig. 1-3.

Nearly all Decca navigational chains have three slave stations disposed around the central master and thus provide three inter-

Fig. 1-3   SIMPLIFIED   BLOCK   SCHEMATIC   OF   DECCA   RECEIVER

secting hyperbolic patterns; in practice the user selects the
two lines giving the best angle of cut at his location and re-
jects the third. Table 1-1 also shows typical values for lane
width on the interstation baselines. A lane is the name given
to the space bounded by two adjacent hyperbolic position lines
having the same phase-difference value, so that in crossing a
lane the receiver records one complete cycle of phase difference.
Interpolation of one-hundredth of a lane can be realized in
practice and corresponds to a change of position of the order
of 5 metres along the baseline where the lanewidth is narrowest.

Table 1-1 Typical values for radiated and comparison
frequencies and wavelength

(f = 14.16 kc/s)

Stations	Harmonic	Frequency kc/s	Wavelength m
		Radiated frequencies	
Master	6f	85.000	3521
Red slave	8f	113.333	2640
Green slave	9f	127.500	2347
Purple slave	5f	70.833	4225
		Comparison frequencies	
Red	24f	340.000	880
Green	18f	255.000	1174
Purple	30f	425.000	704

	Lane-width on baselines assuming a velocity of 299250 km/s	
	metres	yards
Red	440.074	481.28
Green	586.765	641.70
Purple	352.059	385.02

Fig. 1-4 is a drawing representing the position-line patterns produced by a chain of stations and showing the red and green decometer readings that will be obtained on board a ship at the position indicated. The lanes of each pattern are subdivided into zones, the latter being identified by letters of the alphabet. The lanes are numbered, using a notation which prevents confusion between the three patterns, and there are respectively 24, 18 and 30 red green, and purple lanes per zone. Each lane is numbered in such a way as 0 through 23 for the red station, 30 through 47 for the green station and 50 through 79 for the purple station. The zones have the same width for each pattern (approximately 10 km on the baseline) and their width is such as to correspond to a phasecomparison frequency of the fundamental value f. In each decometer the basic phase-meter drives a fraction pointer which makes one revolution per lane, and the successive lanes are counted by an appropriately geared pointer which makes one revolution per zone. The zone letters are indicated by a dial, viewed through an aperture below the centre of the instrument, which is driven by a further set of gearing.

The effectiveness of a Decca lane identification system proves that it will be sufficient if the ship's position is known within less than half a zone, when starting a journey or when entering the coverage, and then her precise position within this zone can be obtained from the LI meter and decometers. According to the aforesaid information, the lane and zone indicators on the deco-meters are then set in a manner similar to the adjustment of the hands of a clock, thereafter, so long as reception is uninter-rupted, the ship's movement through the patterns will be con-tinuously recorded by the decometers, and readings may be taken from them at any time and plotted on the hyperbolic chart.
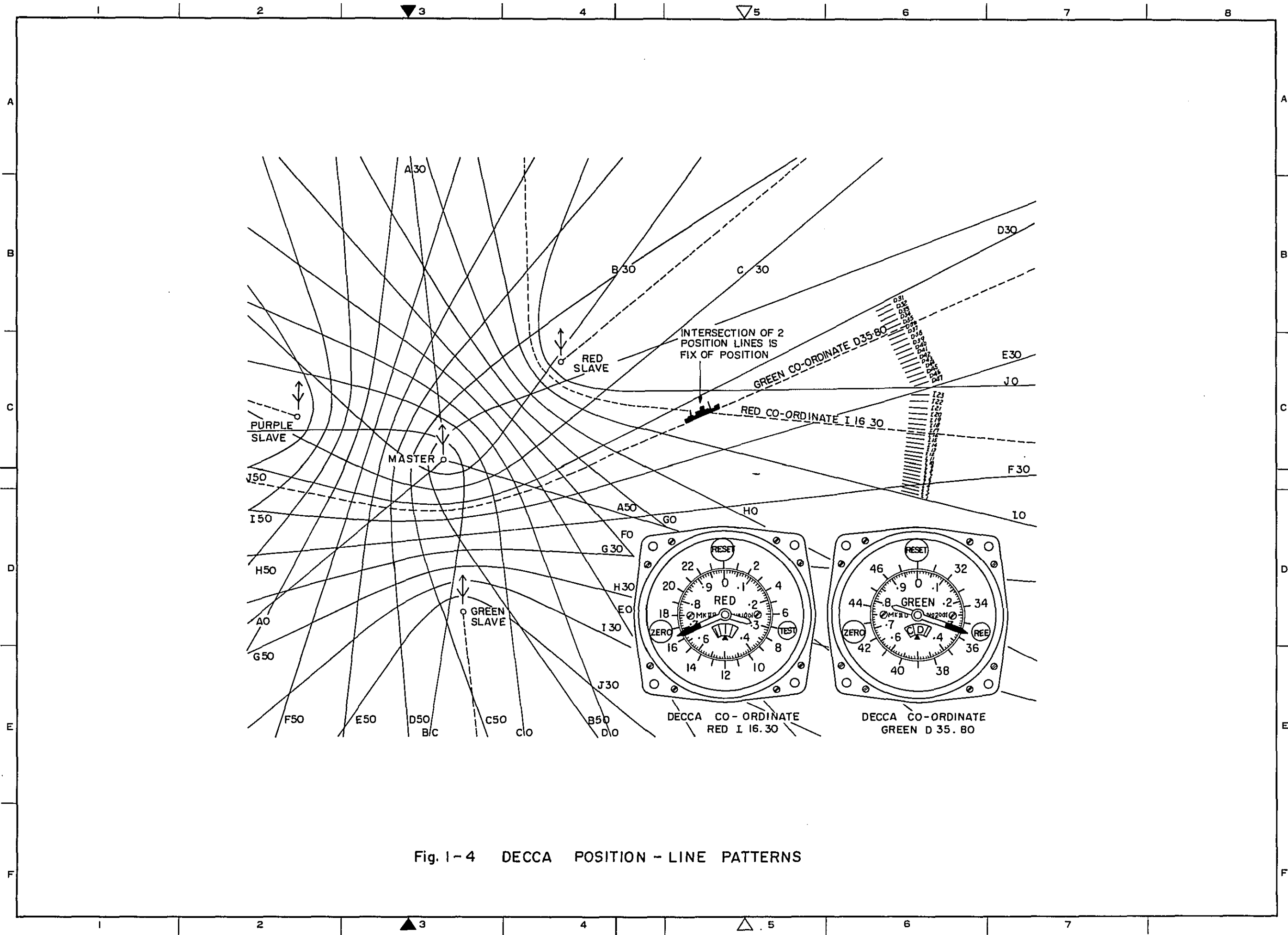
Fig. 1-4   DECCA   POSITION - LINE   PATTERNS

1-2-2   Decca charts

The Decca position lines are plotted on charts in the colours
accepted at standard for the patterns: red, green and purple.
The lines are numbered according to the convention adopted for
the decometer dials, i.e. the lanes in each zone are numbered
0 - 23 for red, 30 - 47 for green and 50 - 79 for purple as
shown in Fig. 1-4. A transparent rule carrying a number of
different-sized decimal scales is issued for the purpose of
interpolating fractional values within a lane. In a few charts
of very large scale, the lanes are subdivided into fractional
position lines, e.g. every 0.5 lane. The zone boundaries are
printed more boldly than the lanes and are lettered A - J.
In patterns containing more than ten zones, zone J is followed
A, B, etc.

1-2-3 Lane identification

The function of a Decca receiver in the Decca Navigator system is to accurately measure the phase difference between a pair of signals from the master and a certain specified slave station and display the phase difference on the decometer. There is a decometer for each of the combinations of master/red slave, master/green slave and master/purple slave, and they are called red decometer, green decometer and purple decometer respectively.

The decometer automatically displays, immediately upon the switch-on of the receiver, so long as it is within the effective area of a transmitting station, the width of a lane in a hundred equal parts. The Decca pattern produced by the master and a slave station includes many lanes and everytime the receiver crosses a lane within this pattern, the decometer's pointer records the number of lanes automatically. In normal use, the decometer continues to indicate correct value at all times during the equipment is in operation, if the value of the zone and lane is set, precisely prior to the starting of the decometer. If, for some reason, the action of the equipment is interrupted while the vessel is underway, the decometer will fail to indicate correct value, in which case the decometer should be reset. This resetting of the decometer at sea is called "lane identification".

The lane identification is necessary in order to:

1) Set the value of zone and lane to its original position;

2) Correct the decometer when service is interrupted for some reason.

In the Decca system, it is designed that the zone widths are so sufficiently wide that the navigator will find it unnecessary to carry out zone identification. The zone widths are more than 10 km long on the baseline. Accordingly, Decca marine receivers have no function for carrying out zone identification.

The widths of lanes are, on the other hand, not very wide
which makes it imperative for a vessel to know in which
lane she is.   To conduct lane identification is nothing
less than allowing the person who carries out such lane
identification to find at what point in a zone he is now
situated.   As stated before, the zone means an interval
between the two adjoining points where the phase difference
is zero, of the basic frequency 1f (about 14 KHz).   Lane
identification is thus possible by making a phase comparison
of 1f of the signal from the master station and one of the
slave stations and indicating the value produced by the
comparison on the indicator.

The multipulse system (Mark 10 transmission system) is the
latest system for transmission capable of setting up automatic
lanes and providing zone identification for airborne receivers.
The lane identification pattern is a coarse 1f pattern which
is effectively superimposed on each of the three normal patterns
in turn.   The 1f pattern is generated by a brief transmission
of the normal pattern frequencies 5f, 6f, 8f and 9f from each
of the stations in turn, transmissions from the other three
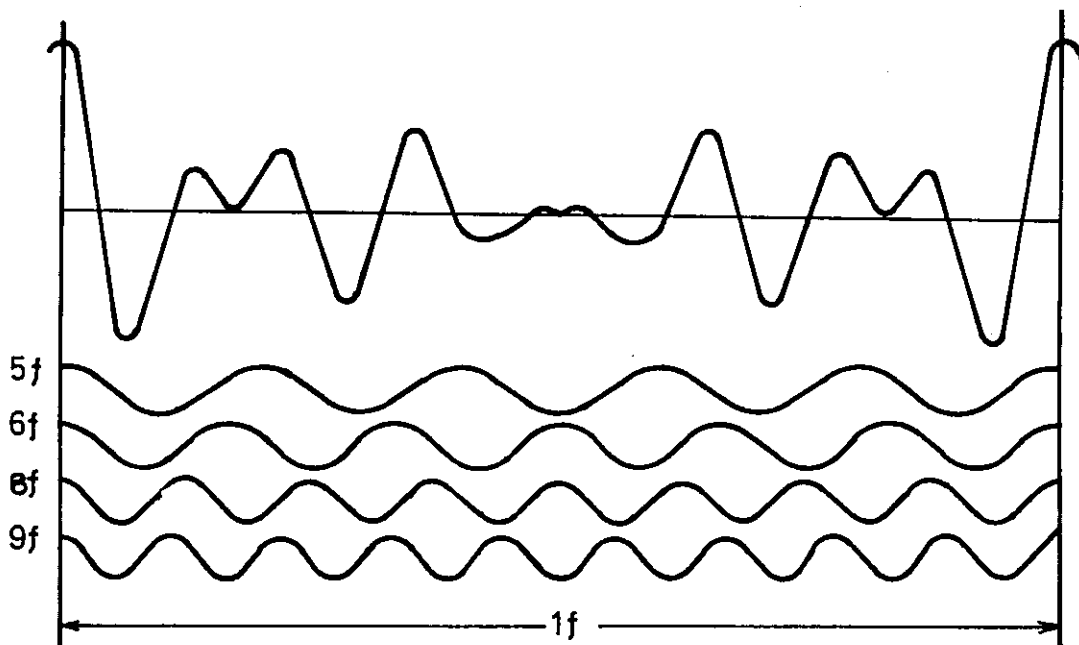stations being suppressed at these items.

Fig. 1-5   Identification Pulses of Mark 10 System

These "multipulse" transmissions are carefully phased at the
transmitting station, and the resultant waveform, shown in
Fig. 1-5, provides a 1f pulse component.   It can be shown
that individual variations in phase of the four component fre-
quencies forming the pulse will give rise primarily to ampli-
tude variations in the resultant phase signal and, only when
there are very large phase variations, to the production of a
false pulse displaced in phase with respect to the wanted one.

Just prior to the multipulse transmissions, each station radi-
ates a guard transmission for a short period on a frequency
of 8.2f to initiate switching in certain types of receivers in
the field.   The master guard transmission is also used a zero
time synchronising signal by the slave station.   The multipulse
transmission sequence is initiated three times a minute as shown
in Fig. 1-6.

1-2-4   Frequency channels

The frequency bands of 70 to 90 KHz and 110 to 130 KHz
are approved for the 3rd district for the Decca Navigator
system under the International Telecommunication Convention.

On the basis of this, sixty-three frequency channels are
provided for the Decca Navigator system under the standards
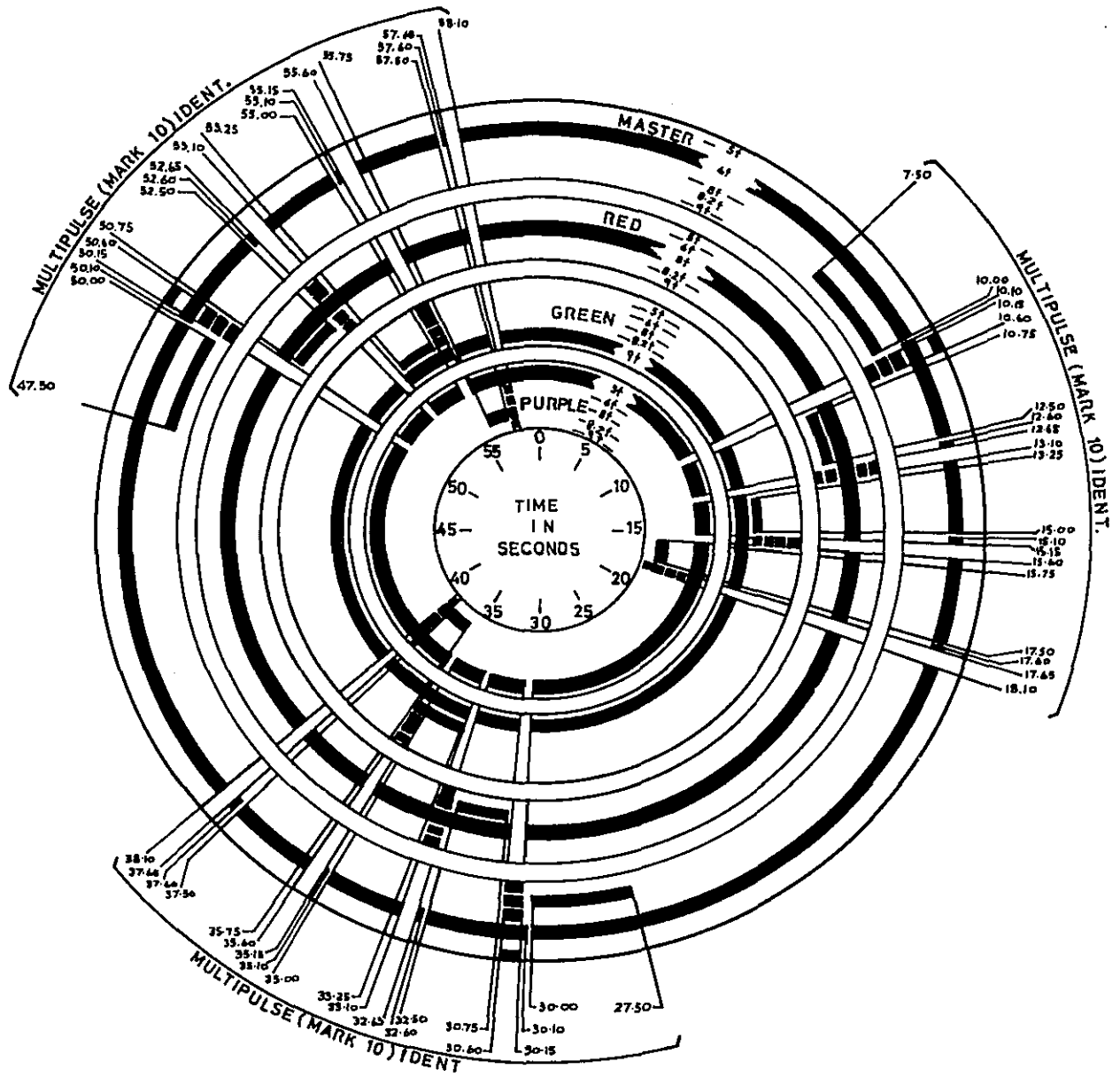shown in Tables 1-2 and 1-3 in the following pages:

Fig 1-6   60-second transmission cycle for 4-station chain

Table 1-2

Decca chain frequency grouping in kc/s

Nominal frequency (B) and 'half frequency' (E) groups

Decca Frequency Code	Master 6f	L.I. Signalling 6f + 60c/s	L.I. Signalling 6f − 60c/s	Red 8f	Green 9f	Purple 5f	Orange 8.2f
0 B	84.105	84.165	84.045	112.140	126.1575	70.0875	114.9435
0 E	84.195	84.255	84.135	112.260	126.2925	70.1625	115.0665
1 B	84.280	84.340	84.220	112.373	126.420	70.233	115.183
1 E	84.370	84.430	84.310	112.493	126.555	70.308	115.306
2 B	84.460	84.520	84.400	112.613	126.690	70.383	115.429
2 E	84.550	84.610	84.490	112.733	126.825	70.458	115.552
3 B	84.645	84.705	84.585	112.860	126.9675	70.5375	115.6815
3 E	84.735	84.795	84.675	112.980	127.1025	70.6125	115.8045
4 B	84.825	84.885	84.765	113.100	127.2375	70.6875	115.9275
4 E	84.915	84.975	84.855	113.220	127.3725	70.7625	116.0505
5 B	85.000	85.060	84.940	113.333	127.500	70.833	116.167
5 E	85.090	85.150	85.030	113.453	127.635	70.908	116.290
6 B	85.180	85.240	85.120	113.573	127.770	70.983	116.413
6 E	85.270	85.330	85.210	113.693	127.905	71.058	116.536
7 B	85.365	85.425	85.305	113.820	128.0475	71.1375	116.6655
7 E	85.455	85.515	85.395	113.940	128.1825	71.2125	116.7885
8 B	85.545	85.605	85.485	114.060	128.3175	71.2875	116.9115
8 E	85.635	85.695	85.575	114.180	128.4525	71.3625	117.0345
9 B	85.720	85.780	85.660	114.293	128.580	71.433	117.151
9 E	85.810	85.870	85.750	114.413	128.715	71.508	117.274
10 B	85.900	85.960	85.840	114.533	128.850	71.583	117.397

Table 1-3

Sample group of Decca frequencies

Showing relationship of A-B-C-D-E-F spot frequencies (in kc/s)
for one complete numerical group

Decca Frequency Code	Master 6f	L.I. Signalling 6f + 60c/s	L.I. Signalling 6f - 60c/s	Red 8f	Green 9f	Purple 5f	Orange 8.2f
5 A	84.995	85.055	84.935	113.327	127.4925	70.829	116.159
5 B	85.000	85.060	84.940	113.333	127.500	70.833	116.167
5 C	85.005	85.065	84.945	113.340	127.5075	70.837	116.1735
5 D	85.085	85.145	85.025	113.447	127.6275	70.904	116.283
5 E	85.090	85.150	85.030	113.453	127.635	70.908	116.290
5 F	85.095	85.155	85.035	113.460	127.6425	70.912	116.2965

1-2-5   Service area

The service area of the Decca Navigator system is
determined by the following two limitations:

(1) Limitations of effective range signal-to-noise ratio
     at a given receiving location

(2) Limitations of range by skywave at night

A detailed description of this is given in the paper
appended hereto.

The effective range of a Decca chain to be established in
the Southeast Asian area by the radiation power of 200W
(transmitter power 1.2 kw and umbrella type aerial 110m
tall will be used) stated in the present report, will be
400 km during both daylight periods and nighttime.

1.-3   Operation of Decca transmitting equipment

1-3-1   Phase control equipment

There are two types of phase control equipment, one is for the
master station and the other for a slave station. The systems
of their respective operation are shown in Fig. 5-4-19 and Fig.
5-4-20.

The phase control equipment for the master station produces the
signals that would become a frequency standard of a Decca chain,
by the crystal oscillator of the main oscillating unit of the
duty rack. To be more precise, the frequency of Rubidium
oscillator is divided up to $0.2f$ by the frequency synthesiser
to drive the transmitting driving unit of each radio wave. Then
the radio wave is transmitted from the aerial via the transmitter.
The aerial current is fedback to the transmitter's driving unit
and so controlled as to coincide the phase of the aerial current
with that of the $0.2f$ signal. Part of the fedback signal, on
the other hand, impresses even the transmitter's driving unit of
the spare rack and controls so as to make the phase of the $0.2f$
signal of the rack coincide with the phase of the duty rack.

The output signals of the driving unit of the transmitter are
in wave form switched by switch circuit of the transmitter's
driving unit by the signals consistent with time schedule of the
Mark-10 transmitting system in the time signal generating unit.

The phase control equipment for a slave station monitors by the
$6f$ receiver the phase of signals transmitted from own station
to insure that the phase coincide with that of the master station
at all times, and controls by difference of signal's output.
And the time sequence itself should be corrected by the zero time
signal of the $8.2f$ receiver's output because its reference point
must coincide with the master station. The operation of other
equipment for a slave station is similar to that of the master
station.

1-3-2   Switching equipment

The monitoring and switching equipment is a device by which to
monitor the operating conditons of the transmitting equipment,
to rate the serviceability of the three sets of phase control
equipment above-mentioned, and, immediately upon detection of
any abnormality, to switch over automatically to the phase control
equipment of high serviceability. The system of this equipment
is shown in Fig. 5-4-21.

Abnormalities of the three sets of phase control equipment in
the phase synchronisation, in the operation of the master oscil-
lator and in the time synchronisation are input in the fault ratio
detector to calculate the ratio of faults to time. The output
is then input in the automatic selector and led the selected
signal to the switching unit. The switching is performed by
sending out the switching signals to the control unit by command
from the switching unit. Switching can be done both automatically
and manually, and when it is done manually, artificial alarm is
produced from the test keyboard and an operational test of automatic
selection can be performed. The operational condition of the
phase control equipment by automatic selection can be monitored
by the display unit.

Each slave station has a receiver to monitor the phase synchronisation
between the master and slave stations in the basic frequencies
of 1f and 0.2f. This receiver is of superheterodyne system,
in which the monitoring of synchronisation is carried out by
the display of the decometer. If this phase synchronisation is
stepped out, phase control is done by the remote control from
the central monitoring equipment.

Following is an outline of the functions of the monitoring and
switching equipment:

> a) During its normal operation, the phase control
>   equipment is switched over to another phase control

equipment every 24 hours, and the switching over
is done in the order of No.1, No.2 and No.3 equip-
ment.

b) The amplitude, phase and time of the transmitted
    radio waves are compared with those of each phase
    control equipment and the automatic monitoring
    and switching equipment, and the serviceability
    of the equipment is classified into the following
    four stages in accordance with the number of troubles
    to time ratio of each phase control equipment.

    OK, Dubious, Suspect and No vote

    The "No vote" is a case where troubles are detected
    more than once during four minutes; the equipment
    is not in operable condition.

c) At a slave station, abnormalities caused by such
    factors outside the slave station as failures in
    the equipment at the master station and faults in
    radio wave propagation are discriminated by the
    anti-static circuit, thereby restricting the switch-
    ing of equipment in the receiving system in an
    abnormal condition.

d) With this monitoring and switching equipment, it
    is possible to cut the automatic switching system
    off and to switch over to manual handling and check
    the operating condition of the equipment by simulation.

1-3-3   Transmitter

The transmitter comprises five racks of equipment having identical
functions, and each rack has a different frequency. The system
of the transmitter is as shown in Fig. 5-4-22.

In the pre-input mixing circuit of the transmitter, the input from
three racks of phase control equipment is distributed and impressed
in four exciting units, opening the gate only for the rack

designated for the duty transmitter and amplified and divided
into eight parts by the coupling transformer. Then twelve pieces
of power amplifier units are excited. The output of each power
amplifier unit is 100W which is composed at the output trans-
former to make an output of 1.2kw. There are tap changers in
the output transformer, and the equipment can be operated by
half or low power output as occasion demands. In the event of
failure in the blower unit, the equipment can be operated,
reducing the power automatically to half power. And the output
voltage is fed back to the exciting unit, cause it to perform
ABC operation, and the output fluctuatuion is diminished. The
blower unit has a circuit separately incorporated to detect
troubles in the exciting unit, power amplifier and fan motor,
displays the abnormalities on its panel and outputs signals for
remote monitoring.

1-3-4   Aerial coil assembly

The aerial coil assembly is a device to feed the aerial with
power for five waves sent from the transmitter without mutual
interference and with high degree of efficiency.

Power for the five radio waves from the transmitter is supplied
through a feeder (coaxial cable) into the aerial coil assembly
normally 200m to 300m away from the transmitter. The power is
first supplied to the feeder collector unit, and after setting
the electric delay angle by the feeder at a certain degree $(\lambda/4)$
for the five waves, is input to an independent matching unit for
each frequency via the ATAM equipment. These high frequency
signals are adjusted to the impedance of the aerial tuning unit
by the matching unit, and the signals are effectively fed into
the aerial tuning unit, where the reactance parts of the aerial
impedance is compensated, and radio waves are transmitted on
five frequencies from the aerial.

The ATAM equipment (Automatic Tuning And Matching) is a system
to detect change in the phase and absolute value of load impedance
on the transmitter side to cope with the change in aerial
impedance caused by the change in the weather conditions, and
drive the aerial tuning system and matching unit to make the
optimum load automatically.

The return of the aerial tuning unit is earthed through the
phasing loop unit and aerial current meter. One of the signals
detected by the phasing loop is fed back to the phase control
equipment to control the phase of the signal and another signal
is sent to the monitoring and switching equipment to monitor
the aerial current.

1-3-5   Central monitoring equipment

The central monitoring equipment is a device set up in the
master station to monitor the phase and level of the radio waves
transmitted from the other stations. It also monitors the
operational condition of the equipment in the master and slave
stations. Remote control is carried out as occasion demands
in order to insure normal transmission of the radio waves at
all times.

The remote control console is composed from its functions of
a monitoring unit to monitor the radio waves transmitted from
the other stations and of a control unit to control the operation
of equipment at the stations. The radio waves from the master
and slave stations are received at the monitor site some dozen
kilometres away from the master station. The signals thus
received are made into codes and monitored via UHF link at the
monitoring unit of the remote control console.

This central monitoring equipment also has the data logger which
records the major state of performance in the overall system
operation, analysing the operation of a Decca chain as a whole
and which makes a detailed "diagnosis" of the troubles in the
equipment, etc. in the stations.

2 Outline of Loran C system

2-1 Loran C transmitting equipment

2-1-1 Principle of Loran C system

Loran is the designation for a family of radio position fixing systems which operate on the principle of measuring the difference in time of arrival of pulse signals from a number of transmitting stations. A pair of loran transmitting stations produces a family of lines of position uniquely determined in space. These lines of position of lines of equal time difference are hyperbolae, hence the name hyperbolic for this type of system. The name Loran was derived from the words LOng RAnge Navigation.

Loran A is the standard Loran system operating on a frequency of about 2000. The difference readings are obtained by matching the envelopes of the transmitted pulses.

Loran C is the logical extension of Loran A; the two major characteristics by which they differ are transmission frequencies and time difference measurements.

To take advantage of the stable propagation characteristic and long range of the LF band, 90 - 110 kHz frequency band was chosen as allocated internationally for long distance radionavigation systems.

Time difference measurements are made by utilizing both the pulse envelope and the phase of the carrier within the envelope, and the envelope match produces a coarse time difference reading and the cycle match produces the fine time difference reading.

It is this additional fine reading and longer baseline between stations which give Loran C its increased coverage and higher accuracy compared with previous Loran A system.

(1) Configuration of transmitting stations

Loran C chains are comprised of master transmitting station, two or more secondary transmitting stations and, system area

monitor (SAM) stations.   In Fig.2-1 is shown a typical con-
figuration of Loran C stations.   The transmitting stations are
located such that the signals from the master and at least
two secondary stations can be received throughout the desired
coverage area.   For convenience, the master station is designated
by the letter "M" and the secondary stations are designated W,
X, Y, or Z.   Thus, a particular master-secondary pair and the
TD which it produces can be referred to by the letter designations
of both stations or just that of the secondary (e.g. MX time
difference or TDX.)
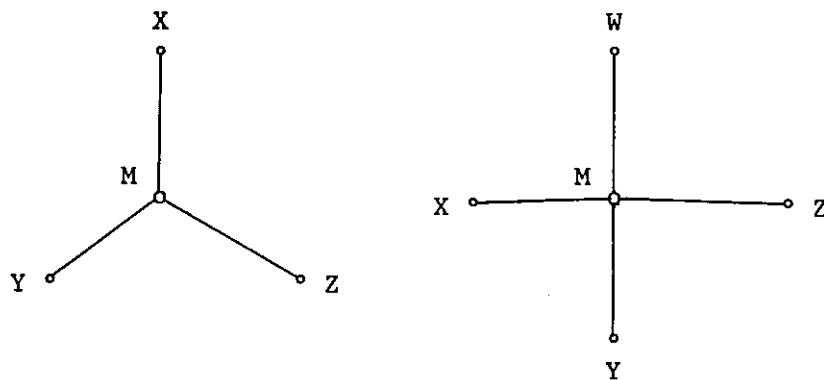
Fig. 2-1   Configuration of LORAN C stations

(2)   Method of transmitting radio waves

The transmitting stations of a Loran C chain transmit groups
of pulses at a specified group repetition interval (GRI).
Each pulse has a 100 kHz carrier and is of the shape described
in Figure 2-2.   For each chain a minimum GRI is selected of
sufficient length so that it contains time for transmission of
the pulse group from each station (10,000 microseconds for the
master and 8,000 microseconds for each secondary) pulse time
between each pulse group so that signals from two or more stations
cannot overlap in time anywhere in the coverage area.   (See
Figure 2-3.)   Thus, with respect to the time of arrival of the
master, a secondary station will delay its own transmissions
for a specified time, called the secondary coding delay.   The
minimum GRI is therefore a direct function of the number of
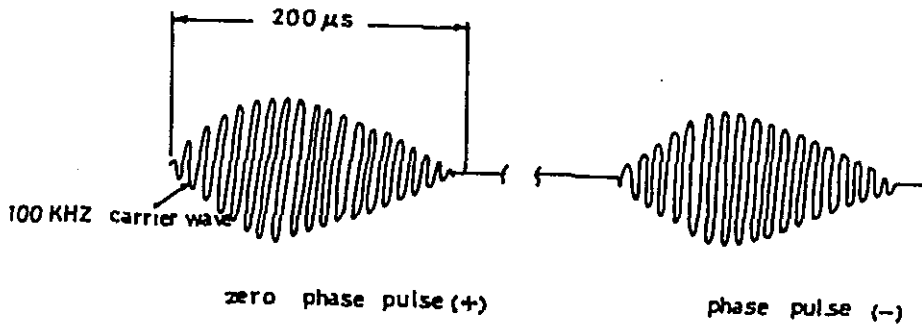
Fig. 2-2　Pulse waveform
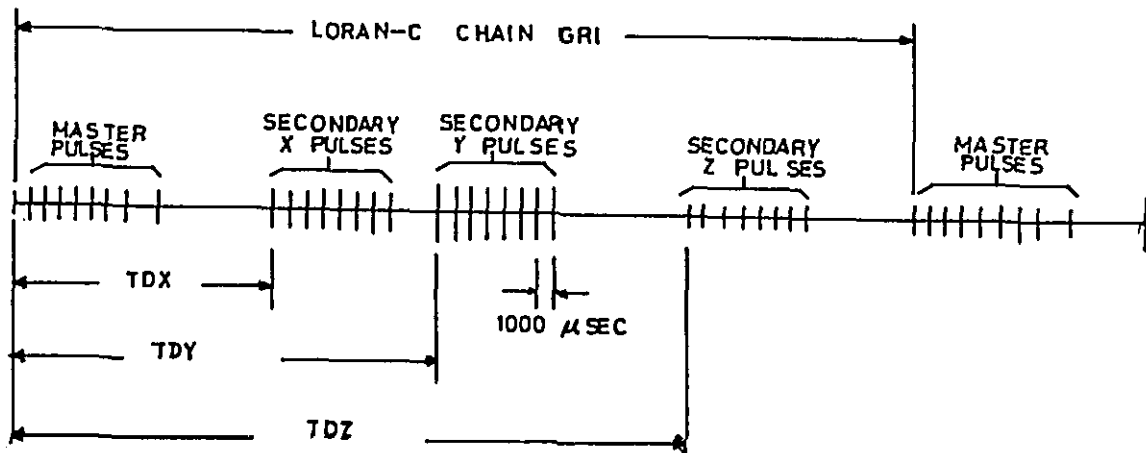
Fig. 2-3　Example of repetition synchronisation
of Loran-C system

stations and the distance between them.　A GRI for the chain
is then selected so that adjacent chains do not cause mutual
(cross-rate) interference.　Possible values for GRI are listed
is Table 2-1.　The GRI is defined to begin coincident with the
start of the first pulse of the master group.

Each station transmits one pulse group per GRI.　The master
pulse group consists of eight pulses speced 1,000 microseconds
apart, and a ninth pulse 2,000 miscroseconds after the eighth.
Secondary pulse groups contain eight pulse spaced 1,000 micro-
seconds spart.

As shown is Fig.2-2, there are two different types of pulse;
zero-phase pulse and　phase pulse.　Transmission of radio
waves is performed using the combination of these different
types of pulses as shown in Fig. 2-3.

	Stations	
GRI	Master	Secondary
A	+ + − − + − + − +	+ + + + + − − +
B	+ − − + + + + + −	+ − + − + + − −

Fig. 2-4 Phase code of Loran C pulse

Table 2-1 Pulse repetition period of Loran C

Special repetition period	Basic repetition period µs					
	SS	SL	SH	S	L	H
0	100,000	80,000	60,000	50,000	40,000	30,000
1	99,900	79,900	59,900	49,900	39,900	29,900
2	99,800	79,800	59,800	49,800	39,800	29,800
3	99,700	79,700	59,700	49,700	39,700	29,700
4	99,600	79,600	59,600	49,600	39,600	29,600
5	99,500	79,500	59,500	49,500	39,500	29,500
6	99,400	79,400	59,400	49,400	39,400	29,400
7	99,300	79,300	59,300	49,300	39,300	29,300

The phase pulses or codes are used in the receiver in identi-
fying the master and secondary stations and in automatic search
at the master station and automatic synchronisation to the
master station. An example of the phase code is shown in
Fig. 2-4, and pulse repetition synchronisation is given as
shown in Table 2-1.

(3) Loran C transmitting station equipment

Fig. 2-5 shows the composition of Loran C station equipment.
The Cesium oscillator is used as standard oscillator of
frequency to supply reference signal to the timer which
generates the standard repetition pulse of Loran C. The

pulse generators (PGEN's) are driven by the trigger pulse
the timer output, and thus the standard Loran C pulse signal
can be obtained. The PGEN can adjust manually the ampli-
fication of the eight cycles of 80 µs among the first
building-up time of the standard Loran C pulse. It can also
change the whole level of driving pulses of the transmitter.

As it is given the output of PGEN, the transmitter amplifies
the power of high frequency energy straight forwardly to produce
the required output at the final stage and feed the aerial
with it. There are two transmitters; one is s duty transmitter
and the other a stand-by equipment. In the event of failure
of the duty transmitter, the transmitter automatic controller(TAC)
can switch it over automatically to the stand-by equipment.

The aerial coupler has a loading coil which matches the aerial
with the transmitter, and the duty and stand-by transmitters
are so designed as to be switched over to each other as occasion
calls by the aerial/dummy change-over switch. Part of the
output fed into the aerial is picked up and led to the above-
mentioned TAC or electrical pulse analyser to perform the monitor-
ing of output wave form and the measurement of required para-
meters, and to display the operational condition of the trans-
metter by means of the alarm unit.

There is in the Loran C system a monitor station to monitor
the transmitted wave form from the master and secondary stations
in order to ensure the normal operation of the system. Should
any abnormality be detected in the transmitting station, such
abnormality is controlled by the teletypewriter placed in the
monitor station. The remote control interface is a device to
perform this and other functions.

At a secondary station the radio wave should be made synchronised
to that of the master station set at the required coding number
and for this reason signals from the master station is received
by the Austron timing receiver to set the timer of the secondary
station or blinking at the master station is detected here to
produce alarm signal.

2-1-2   All functions and features of the transmitter equipment

(1) Dual transmitter configuration: Automatic switchover to the standby transmitter in the event of a failure of the duty transmitter.

(2) Water-cooled amplifier for the final output stage of transmission

(3) Solid state high voltage power supply utilises SCR regulation

(4) Features of all solid-state LRE

  1) Control of Loran C pulse shape and amplitude

  2) Automatic switching of Loran C transmitter

  3) Loran C alarm indications centralised

  4) Digital Loran C pulse shape analysis

  5) Remote control of important matters relating to power source, transmitting equipment, sending of unusable signal

2-1-3   Composition of transmitting equipment

The composition of the transmitting equipment is as shown
in the following table:

Table 2-2   Components of Loran C transmitting equipment
(In the case of 3 secondary stations)

Name of unit	Master station	Secondary station (each station)	Monitor station	Remarks
Transmitter	2 sets	2 sets	-	
Aerial coupler	1 set	1 set	-	
Dummy load	1 set	1 set	-	
Cesium frequency standard rack	1 set	1 set	-	One set consists of 3 Cs standard OSC's
Timer set	1 set	1 set	-	Pulse monitor, Pulse generator,etc.
Transmitter control set	1 set	1 set	-	
Auxiliary rack	1 set	1 set	-	Status alarm unit,Austrom timing receiver,etc.
Recorder rack	1 set	1 set	-	
Remote control interface unit	1 set	1 set	1 set	
Teletypewriter	1 set	1 set	1 set	
Monitor station receiver	-	-	1 set	

The whole figure of the system, an outer appearance of each
component and the system drawing are shown in Fig. 2-5 through
2-12.

2-1-4   Main ratings of the transmitting equipment

(1) Transmitting frequency: 100 KHz

(2) Band width: 20 KHz (90 ~ 110 KHz)

A-24

(3)   Type of emission: Pulse

(4)   Emission power: 400 Kw   (Peak value)

2-1-5   Cesium frequency standard oscillator

This constitutes the frequency (phase) standard of a Loran C
transmitting station and is composed of the following components:

(1)   Cesium oscillator   3 units

(2)   Phase microstepper

(3)   Phase adjuster

(4)   Distributing amplification

(5)   Phase recorder

2-1-6   Timer equipment

This is a unit to generate Group repetition interval that is most
important in the Loran C equipment, and is composed of the follo-
ing equipment:

(1)   Loran timer   2 units

(2)   Timer switching unit 1 set

(3)   Power unit

2-1-7   Transmitter control set

This is a device to produce standard Loran C signals to drive the
transmitter by the trigger signals of the timer.   In addition,
it has such other functions as the monitoring of output wave form
of the transmitter and the switching over to the stand-by trans-
mitter in the event of failure of the duty equipment.
Main functions of transmitter control set are as follows:

(1)   Pulse generator (PGEN)

1) The PGEN develops a transmitter drive wave form (TDW)
   from the timing pulse received form the timer set.

2) Generation of standard pulse wave form $\left(t^2 \exp\ (-2^t/65)\right)$

3) Correction of distortion of transmitting pulse wave form

A-25

(2) Transmitter automatic controller (TAC)

This is a controlling equipment to monitor the wave form of "On air", and in case of a fault in the duty transmitter, switch it over automatically to the stand-by equipment.

(3) Electrical pulse analyser (EPA)

1) Precise and unambiguous Loran C pulse shape and amplitude measurements

2) The measurements of envelope-to-cycle difference (ECD) of the first pulse

3) The EPA generates a "reference envelope wave form", $t^2 \exp (-2^t/65)$, which is used in conjunction with an oscilloscope.

(4) Components of transmitter control set are as shown in the following table:

Table 2-3   Transmitter control set components

Name of unit	Quantity	
	Master station	Secondary station (each station)
Emergency stop panel	1 set	1 set
Transmitter automatic controller	1 set	1 set
Electrical pulse analyser	1 set	1 set
Pulse generator No.1	1 set	1 set
Pulse generator No.2	1 set	1 set

2-1-8   Auxiliary rack

This incorporates status display and alarm of the transmitting
equipment and an Austron timing receiver for setting the
"control number" of secondary stations.

Main functions of auxiliary rack are as follows:

(1) Status alarm unit (SAU)

When the equipment is in normal operation, only the green
light shows. In the event of any abnormality, the location
of trouble is indicated in red letters and at the same
time the emergency buzzer rings. That is to say, the red
colour display indicates that the equipment is in some sort
of troubles.

(2) Austron timing receiver

1) This is a controlling receiver for synchronisation to
    the master station and setting of the "control number"
    of a neighbouring station.

2) To detect unusable signal of the master station and
    transmit warning signal

3) To monitor other pair of a master and secondary stations.

2-1-9   Composition of the auxiliary rack

The composition of the auxiliary rack is as shown in the follow-
ing table (This is a case where the number of secondary stations
is three)

Table 2-4   Composition of auxiliary rack

Name of unit	Quantity	
	Master station	Secondary station (each station)
Austron timing receiver	–	1 set
Status alarm unit	1 set	1 set
Digital voltmeter	1 set	1 set
Synchro scope	1 set	1 set

2-1-10   Remote control interface unit

The Loran Replacement Equipment (LRE) is controlled by the
system monitor station by teletypewriter through this remote
control interface unit.

The main features of remote control interface are as follows:

(1) Interface to perform local phase adjustment through
     remote control

(2) Instruction and stoppage of blinking for the master and
     secondary stations

(3) Cabling out of and instructions to transmitting station
     monitoring personnel

2-1-11   Main actions of the transmitter

(1) The peak current of 700A and peak radiated power of
     400 KW are fed into the 625 foot toploaded monopole
     aerial (TLM).

(2) At the final stage, the equipment is operated as forced
     water cooling system and B-class straight line amplifier,
     and the second intermediage amplifier drives with cathod
     follower at the final stage.

(3) Ample band width is provided for each stage so that the
     standard Loran C pulse signals may be amplified without
     ·any distortion.

(4) Since the building-up waveform of the transmitter out-
     put gets blunted usually because of the high quality
     factor of the aerial system circuit, the transmitter
     input from the pulse generator is pre-emphasised.

2-1-12   Components of the transmitter

The transmitter is composed of the following units:

Table 2-5   Transmitter components

Name of unit	Quantity		Remarks
	Master station	Secondary station (each station)	
First stage power amplifier	1 set x 2	1 set x 2	
1st & 2nd intermediate power amplifier	1 set x 2	1 set x 2	
Final power amplifier	1 set x 2	1 set x 2	AC 208V: 225 KVA
Power supply	1 set x 2	1 set x 2	AC 460V: 300 KVA

2-1-13   Aerial coupler

The main part of an aerial coupler is a loading coil unit for matching of the aerial with the transmitter.

(1)   The aerial loading coil network is provided to perform matching the aerial base impedance with the required feeder line impedance on the side of the transmitter output.

(2)   The aerial current transformer is provided on the earth side of aerial circuit to measure the input signals of the transmitter automatic controller (TAC) circuit and aerial current.

(3)   There is a high tension vacuum switch to change No.1 and No.2 transmitter over to the aerial and dummy equipment.

2-1-14   Composition of aerial coupler

The components of the aerial coupler are as shown in the following table:

Table 2-6   Aerial coupler components

Name of unit	Quantity	
	Master station	Secondary station
Aerial loading coil	1 set	1 set x 3
Aerial current transformer	1 set	1 set x 3
Vacuum tube relay for aerial dummy changing	1 set	1 set x 3

2-1-15   Electrical aerial dummy load

This is used as dummy load for adjusting the stand-by transmitter and its main features of Electrical aerial dummy load are as follows:

(1)   This dummy load is connected to the stand-by transmitter, which can be operated by full rated continuous load. Cooling is done by the forced air cooling system.

(2)   Non-inductive resistance units are connected series-parallel, which are of the value equivalent to the aerial base resistance at the dimmy input extremity.

2-1-16   Composition of electrical aerial dummy load

The components of the electrical aerial dummy load are as shown in the following table:

Table 2-7 Electrical aerial dummy load components

Name of unit	Quantity	
	Master station	Secondary station (each station)
Non-inductive resistor	1 set	1 set
Blower for cooling	1 set	1 set

Reference literatures

1. G.R. Goodman and R.P. Oswitt: "Loran C Replacement
    Equipment (LRE)", Navigation, Vol.23, No.3, P.228
    (Fall 1976)

2. H.T. Sherman and V.L. Johnson, "The Loran C Ground
    Station", Navigarion, Vol.23, No.4, P.349
    (Winter 1976-77)

Loran C receiver

There is at present a wide variety of Loran C receivers
for general (non-military) use, and those which are in-
expensive ones are of the type utilising, just the pulse
envelope curves and the accuracy they provide is not
better than that of Loran A.

The receivers which conduct measurement by matching the
carrier waves contained in the pulse, and this is a primary
way of utilising the Loran C system, are rather expensive.
and those sophisticated receivers for military use are
extremely expensive, whose prices now amount to 100,000
US dollars.

There are no clear classifications or standards for both
expensive and inexpensive ones, and the difference in the
functions and other factors among the various types of
receiver is very big.   It is no easy matter at the present
time to bring all of these under complete control and
standardisation.

In Table 2-8 are shown some examples of high-class receivers
for public use and in Table 2-9 is shown a comparison of
their performance.

As seen from these tables, there is a considerable difference
among the receivers in, for example, the time required for
them to be stabilised, alone.   According to the data pub-
lished by the National Technical Information Service, some
receivers could make correct selection only after 17 minutes
of warm-up.

Table 2-8 Example of high-class Loran C receivers

Name of manufacturer and equipment	Automatic or semi-automatic	Display of hyperbola	Price	Remarks
EPSCO 4010-60	Semi-auto	by a pair	$4,500	
SIMRAD LC-201	"	"	$3,595	
SIMRAD LC-201	Auto	By two pairs simultaneously	$4,650	
MICROLOGIC MC-200	"	"	$4,195	
Decca DL-91	"	"	$4,995	
TELEDYNE 601	"	by a pair	$4,750	

Table 2-9 Comparison on performance of various types of high-class Loran C receivers

Classification \ Name of equipment	INTERNAV 204	Decca DL-91	MICROLOGIC ML-200
Range-ground wave	1200 n.m.	1000 n.m.	1400 miles
Range-skywave	2500 n.m.	Not specified	
Acquistition time	30 seconds	30 sec 0 db S/N 90 sec -6 db S/N	30 sec 10 db 90 sec -8 db
Setting time	5 seconds	400 sec 0 db S/N 600 sec -6 db S/N	200 sec 10 db 800 sec -8 db
Notch filter	2 systems incorporated	2 waves between 70 and 130 KHz. Capable of incorporating 4 waves in outer portion	4 waves between 65 and 155 KHz Depression: 26 db
R.F. Selectivity	6~7 KHz search 26KHz tracking	5 KHz search 23 KHz tracking	3 KHz search 16 KHz tracking

MONITOR STATION

MONITOR RECEIVER
RECORDER RACK
RX ANT
COMMUNICATION TERMINAL
TELETYPE CONSOLE

MONITOR STATION

SECONDARY STATION

MASTER STATION

REMOTE CONTROL INTERFACE
TX CONTROL SET
TIMER SET
AUXILIARY RACK
TELETYPE CONSOLE
NO.2 TRANSMITTER
RECORDER RACK
FREQ. STAND RACK
POWER SUPPLY DISTRIBUTION BOARD
ANT. COUPLER
NO.1 TRANSMITTER
DUMMY
ENGINE GENERATOR
BATTERY FOR EMERGENCY

LORAN C RECEIVER

SECONDARY STATION

Fig. 2-5   LORAN-C SYSTEM CONFIGU-
RATION

WATER INLET   TO ANT COUPLER

WATER
OUTLET   PA. WATER
            SUPPLY
                        EARTH

BLOWER &
AIR INTAKE   CONTROL

        PA   DRIVER   POWER SUPPLY

ANT MATCHING CIRCUIT &
HARMONIC FILTER

DUMMY LOAD

400 KW TRANSMITTER

H x W x D ≒ 100 x 144 x 280 INCHES

ANTENNA COUPLER   H x W x D ≒ 82 x 60 x 60 INCHES

TIMER & CONTROL

H x W x D ≒ 71 x 24 x 24 INCHES (x3)
TIMER & CONTROL RACK

H x W x D ≒ 78 x 24 x 24 INCHES (x 2)
Cs STANDARD OSC & RECORDER RACK

H x W x D ≒ 78 x 24 x 24
MONITOR & RECORDER RACK

H x W x D ≒ 32 x 40 x 24 INCHES
REMOTE CONTROL INTERFACE

H x W x D ≒ 32 x 40 x 32
TELETYPE CONSOLE

Fig . 2-6   OUTER   VIEW FOR LORAN-C EQUIPMENT
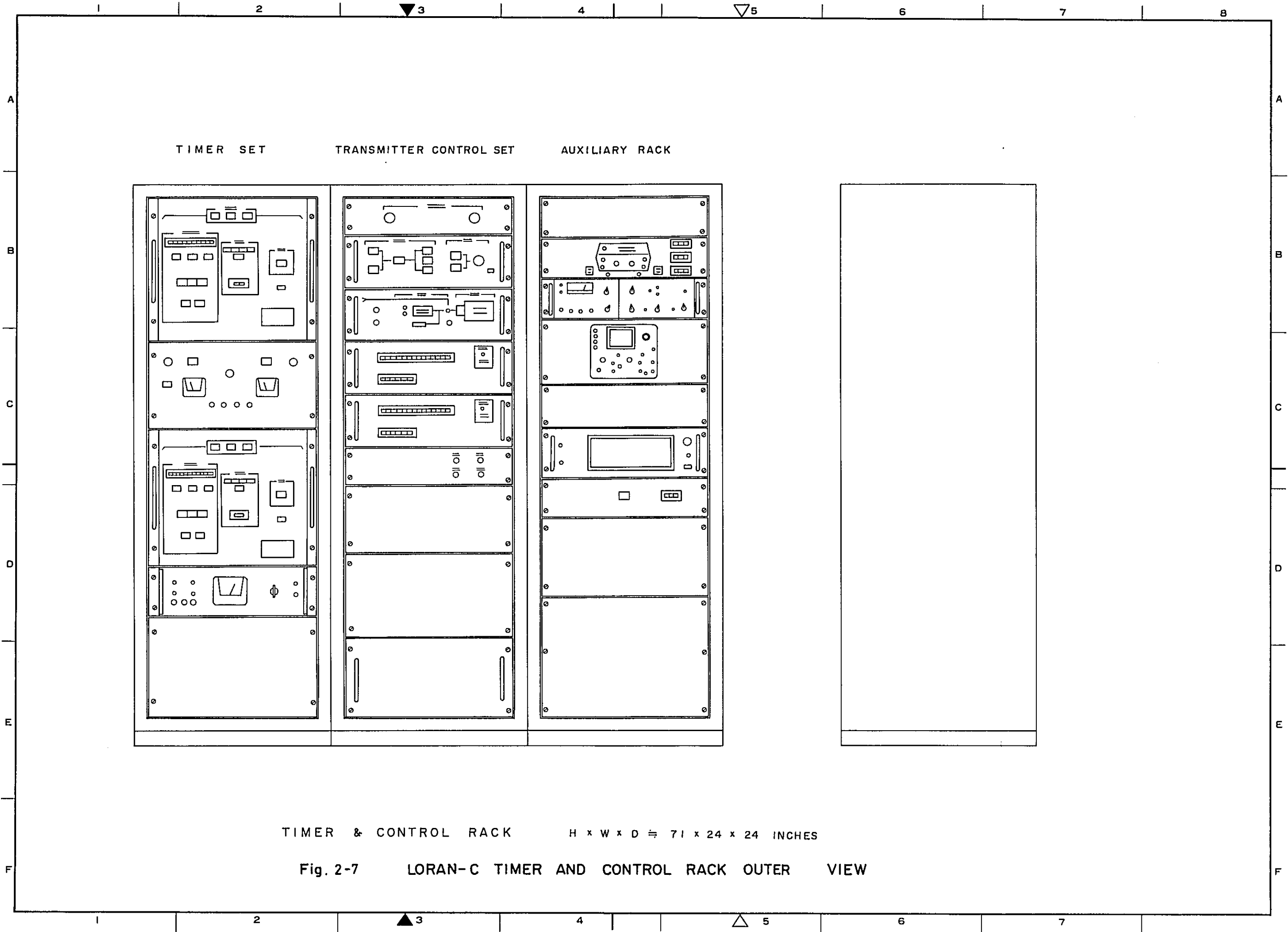
TIMER SET   TRANSMITTER CONTROL SET   AUXILIARY RACK

TIMER & CONTROL RACK   H x W x D ≒ 71 x 24 x 24 INCHES

Fig. 2-7   LORAN-C TIMER AND CONTROL RACK OUTER   VIEW

WATER INLET   PA WATER SUPPLY

WATER OUTLET   TO ANT COUPLER   EARTH   BLOWER & AIR INTAKE

PA   DRIVER   CONTROL   POWER SUPPLY

400 KW   TRANSMITTER   H x W x D = 100 x 144 x 280   INCHES

Fig. 2-8   LORAN - C   TRANSMITTER (400 KW)   OUTER   VIEW
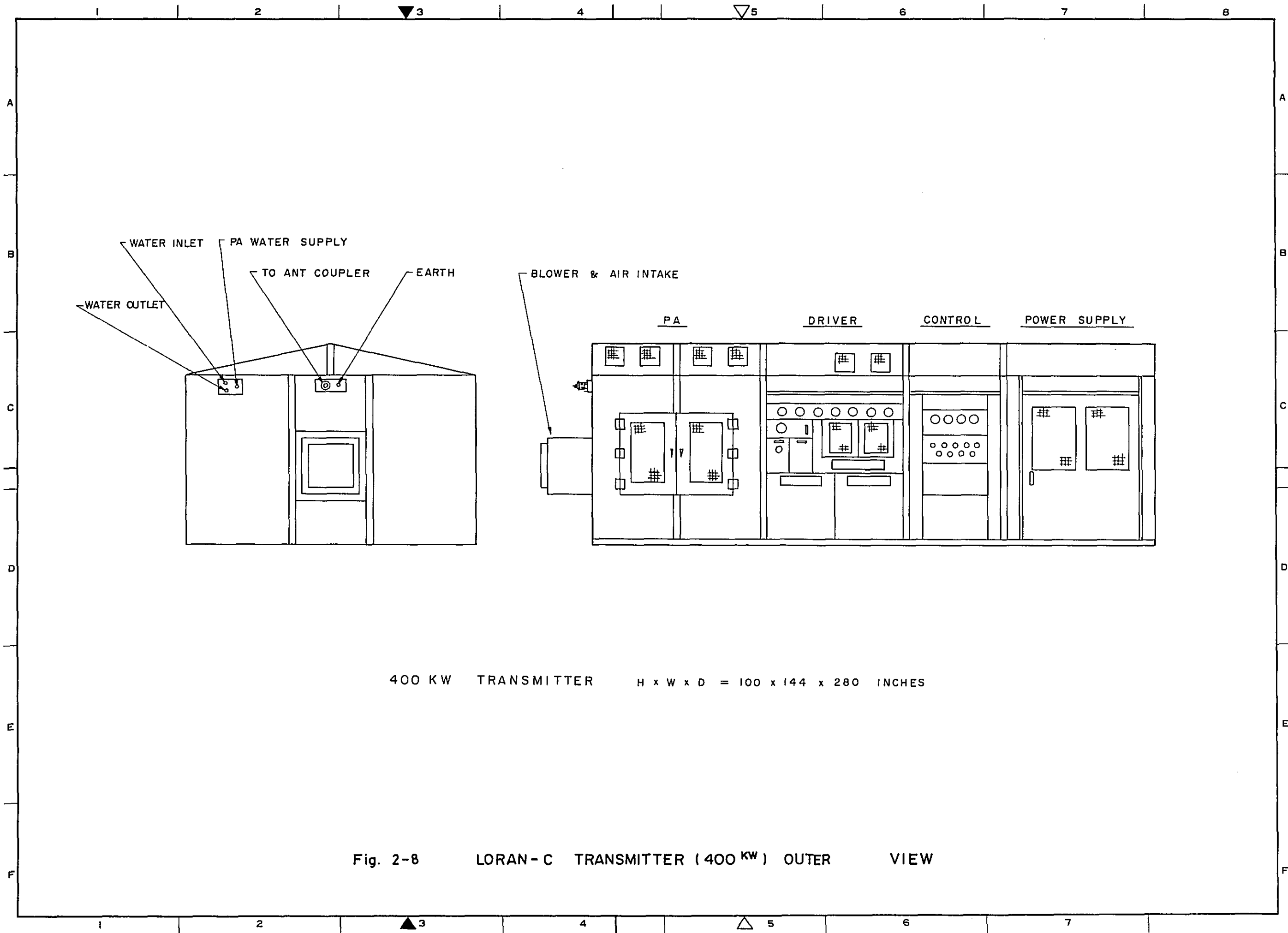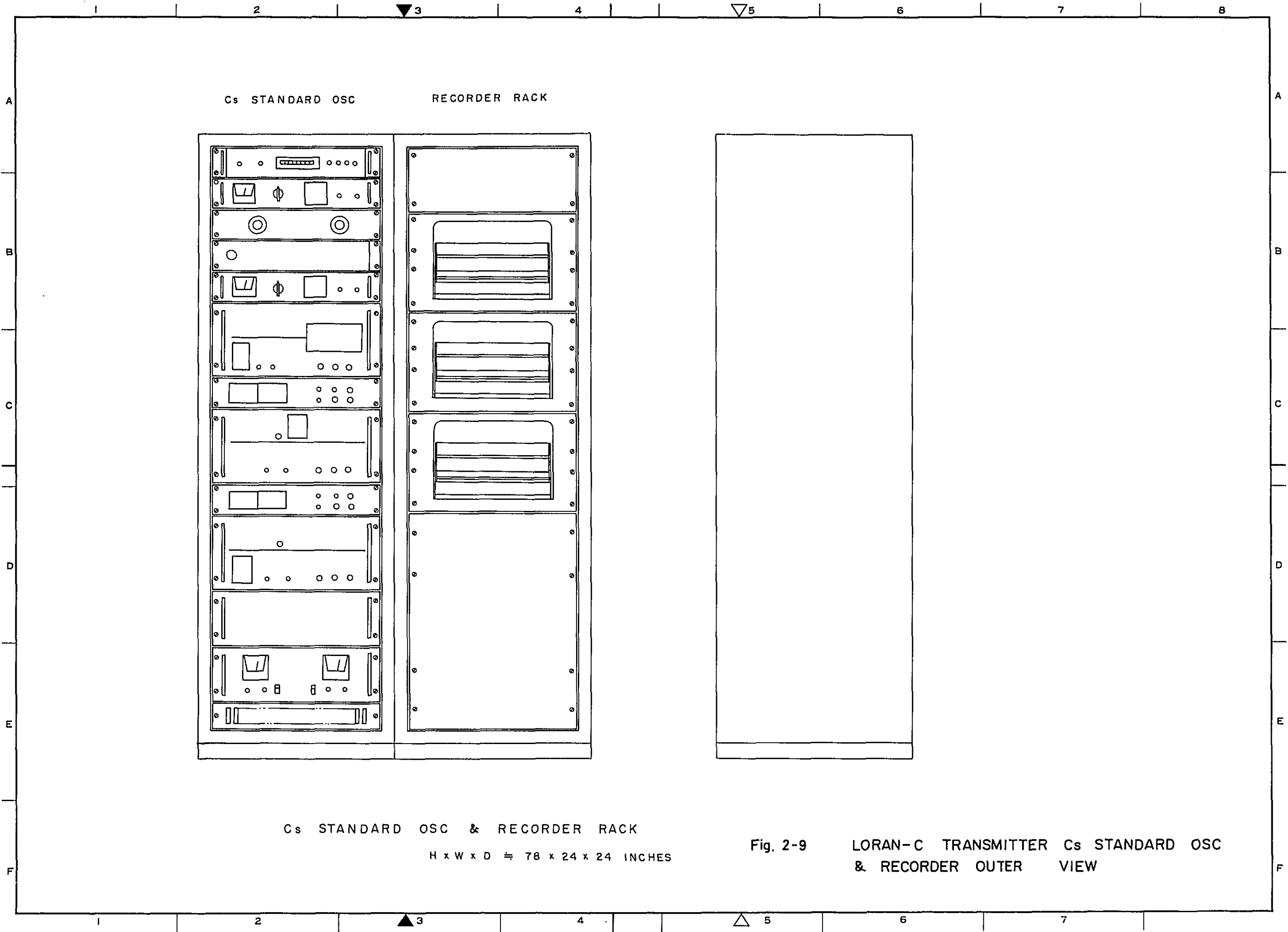
Cs STANDARD OSC   RECORDER RACK

Cs STANDARD OSC & RECORDER RACK

H x W x D ≒ 78 x 24 x 24 INCHES

Fig. 2-9   LORAN-C TRANSMITTER Cs STANDARD OSC
& RECORDER OUTER VIEW
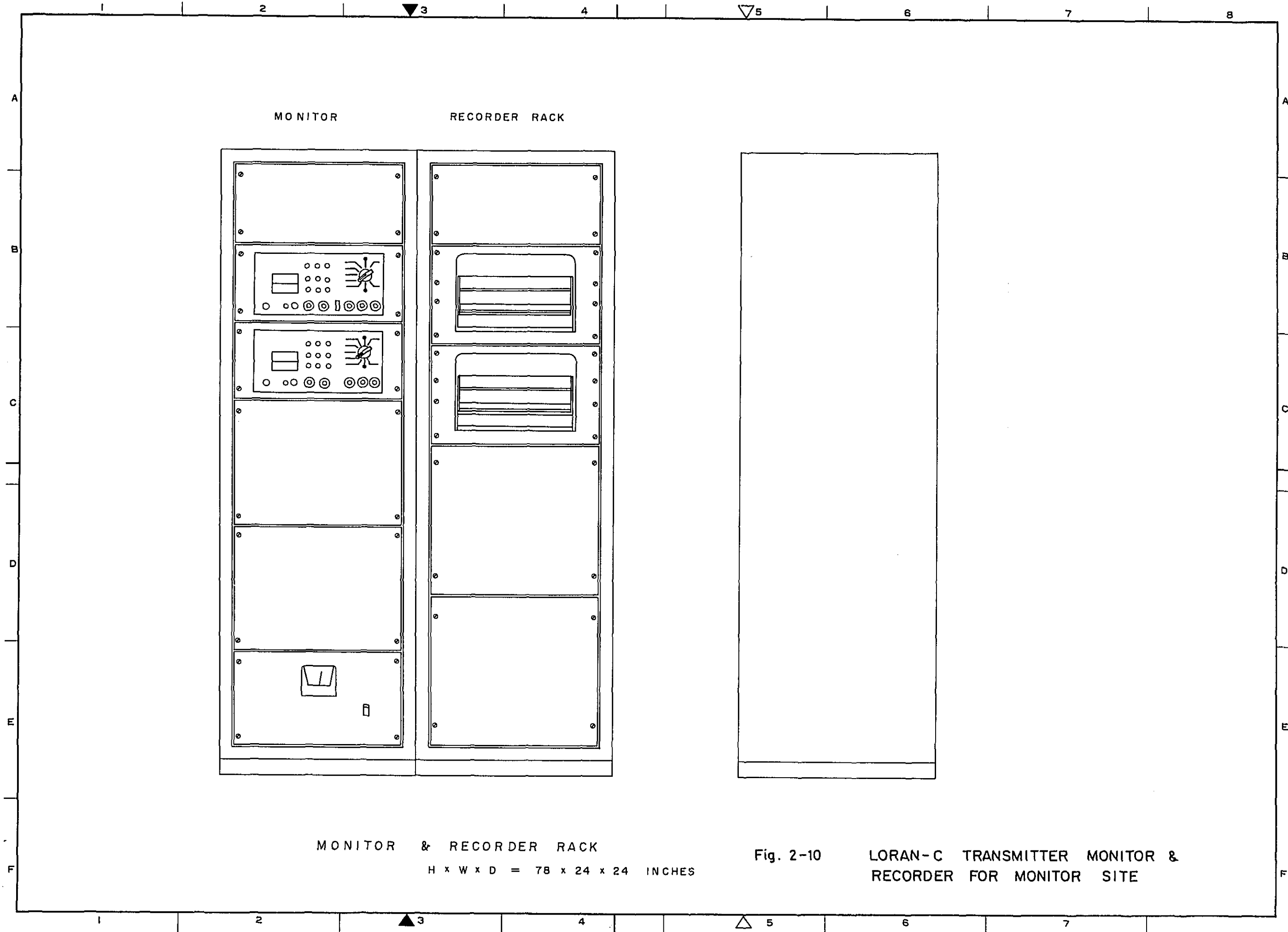
MONITOR   RECORDER RACK

MONITOR & RECORDER RACK

H x W x D = 78 x 24 x 24 INCHES

Fig. 2-10   LORAN-C TRANSMITTER MONITOR &
RECORDER FOR MONITOR SITE
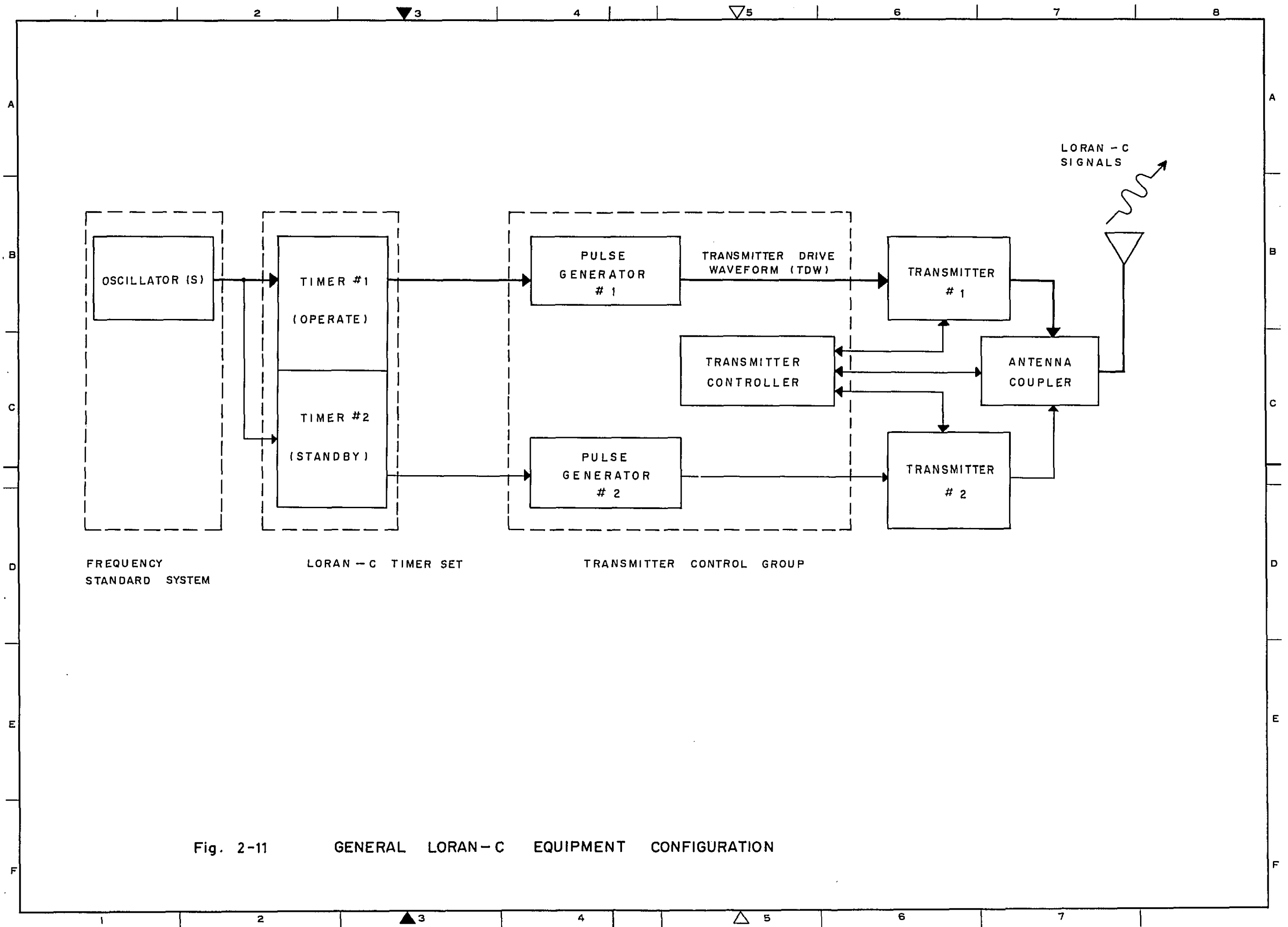
Fig. 2-11   GENERAL LORAN-C EQUIPMENT CONFIGURATION
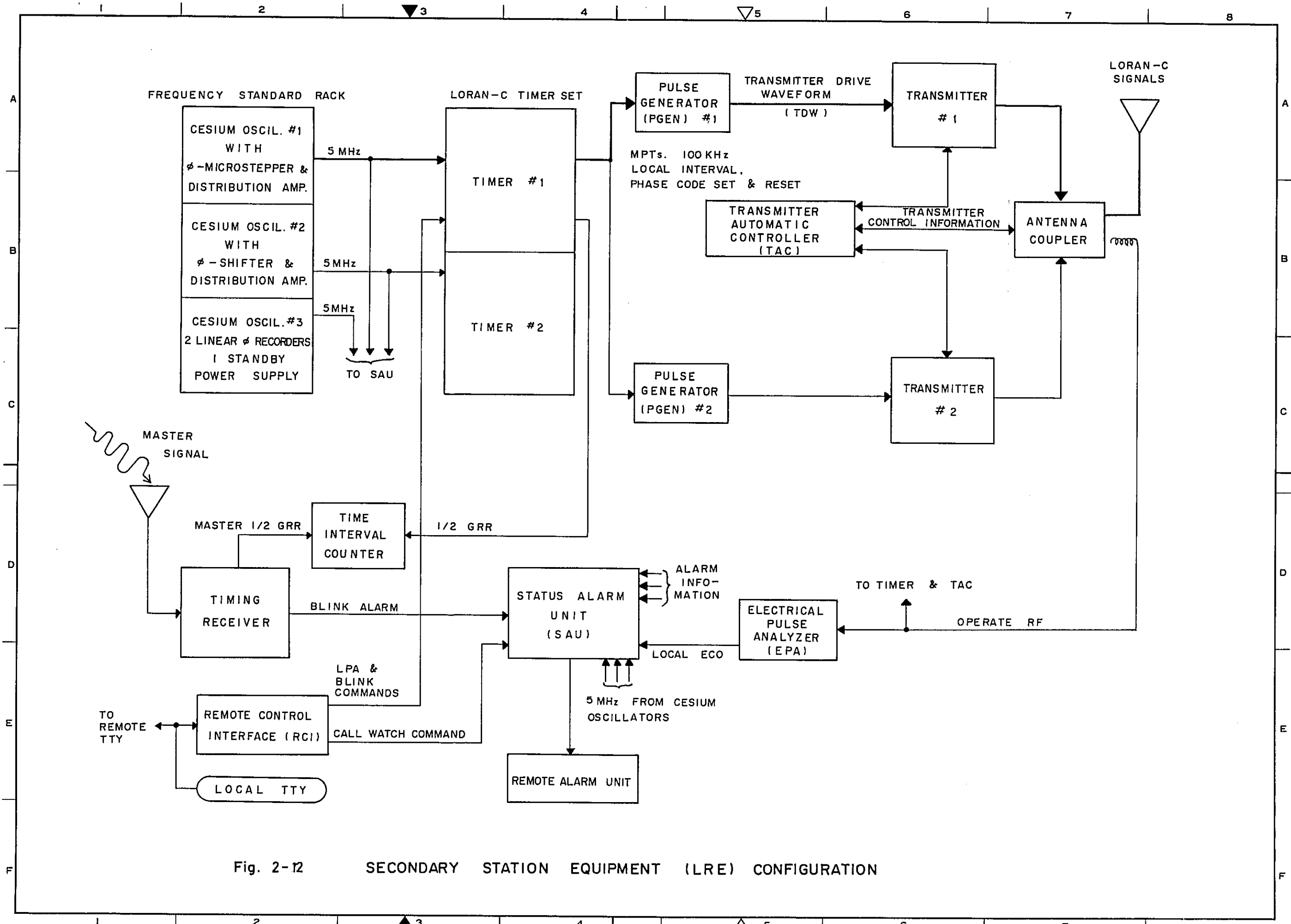
Fig. 2-12   SECONDARY STATION EQUIPMENT (LRE) CONFIGURATION

2-3   Power supply equipment for Loran C navigation system

2-3-1   Introduction

This power supply equipment is a device to supply power to
the transmitting equipment, its ancillaries and other units
for use with the Loran C station.

(1)   The standards to be followed are as follows:

        1)   JIS   Japanese Industrial Standards

        2)   JEC   Standard of the Japanese Electrotechnical
                     Committee

        3)   JEM   Standards of the Japan Electric machine
                     Industry Association

(2)   The Environmental conditions are as follows:

        1)   Ambient temperature: 10 - 45°C

   2)   Relative humidity: 40 - 95%

2-3-2   Composition

This power supply equipment comprises the units enumerated
below and the connection diagram is shown in Fig. 2-13.
The skeleton diagrams are as shown in Figs. 2-14 and 2-15.
The number of sets given below for a Loran C station.

(1)   Engine generator   3 sets (Fig. 2-18)

        A set of engine generator consists of the following units:

                AC generator   1
                Diesel engine   1

(2)   Engine ancillary   1 set

(3)   Generator control panel   1 set (Fig. 2-16)

        The control panel composed of eight panels as follows:

Output switching panel   3

                    Automatic starter panel   3

                    Automatic change over panel 1

                    DC source panel   1

    (4) Power distribution panel   1 set (Fig. 2-17)

    (5) Spares and repair tools   1 set

2-3-3   Functions and ratings

    (1) Engine generator

        1) AC generator

            ° Type of protection: Protected type
            ° System of excitation: Brushless
            ° Output power: 300 KVA
            ° Voltage: 200 V
            ° Frequency: 50 Hz
            ° Phase: 3
            ° Revolutions: 1,000 rpm
            ° Poles: 6
            ° Power factor: 0.8 (lag)
            ° Rated: Continuity
            ° Type of insulation: Type F

        2) Diesel generator

            ° Type: Vertical,single acting,
                                     4-cycles, pre-combustion
                                     chamber,water cooled type.
            ° Output: 300 PS
            ° Revolutions: 1,000 rpm
            ° members of cylinder: 6
            ° Starter: Air starting
            ° Cooling system: Water cooling with radiator
            ° Fuel: Diesel oil or heavy oil
            ° Fuel consumption rate: 195g/PS/hr

(2) Generator control panel

    1) Type of panel: Self stand, metal enclosed type

    2) Functions of panel:

    Functions of each panel are as follows:

        i) Output switching panel: On-off of output

                                      Automatic regulation of output voltage

                                      Monitering of output

       ii) Automatic starter panel: Starting and stopping of the engine generator and other controls

      iii) Automatic chane over panel: It performs automatic change over of three engine generator sets by parallel operation of the engine generator

       iv) DC source panel: It has two sets of storage battery 600AH – 12 cells and two sets of charger for use as control power source for the engine generator

(3) Power distribution panel

    1) Type of panel: Self stand, metal enclosed type

    2) Functions of panel: It receives output from automatic change over panel and supplies power to each load

2-4   Reliability of Loran C system

The Loran C system is extremely useful as a navigation system to cover a wide area, but it involves numerous problems when it is applied as it is in narrow channels where high degree of accuracy is required.

The factors or elements to influence the reliability of a system can be roughly divided into the following three items; radio wave propagation paths, transmitting equipment and receiving equipment. It is desirable that there is good harmony among these elements. In other words, it would be utterly meaningless if just the receiving equipment could be improved to almost perfection while the two other factors are dominant in lowering the reliability of the system. In the following paragraphs study will be made on the reliability according to the classified elements.

2-4-1   Propagation path

(1)   Length of base line

The stability of propagation path is the key to determining the accuracy of a system. In order to maintain this stability, the base line should be as short as possible. In the case of the Loran C system which adopts transmission of pulses, high power and long base lines are inevitably required, and this gives rise to disturbances in the sky-wave. This danger increases when the length of the base line exceeds 1000 km.

Referring to this point, Mr. C.B.Jeffery of the Canadian Coast Guard indicates that when signal from the transmitting stations on the east coast of the United States was received, lane slip had already occurred at a point 300 miles away on the mixed land and sea propagation path (One lane slip corresponds to an error of $10\mu^{\Delta}$ = 1500m).

In other words, it can be said a system which cannot guarantee high reliability in the area 300 miles on more away. According to a report published by the Natural Techinical Information Service (NTIS), the envelope-to-

cycle difference (ECD) sometimes changes by $\pm 2.5 \mu S$ depending upon the difference of the propagation path. Further, it may change up to $\pm 3 \mu S$ (error ± 450m) if the effect of the skywave is also taken into consideration. Unless Loran C adopts the differential system, the absolute accuracy (or geographic accuracy) would never be obtained in essence.

(2) Impulsive noise

The exclusive band width of the Loran C system is 20 KHz and therefore is susceptible to the influence of external noise. Particularly, the lightning impulsive noise at the time of thunderstorm falls completely in many cases from its energy distribution to within the Loran C transmission band width, and this is a defect in the L.F. band pulse transmission system.

(3) Inductive noise

In the cycle matching of the Loran C system the system is greatly affected by various noise sources in the vicinity of the receiving point. Noises from fluorescent lights, shipborne generators, radars, fish detectors, etc. all constitute causes of interference. Noises from cranes or other sources ashore while the vessel is getting alongside the wharf also become main causes of inductive noise, resulting in increasing lane slip.

(4) Interference of cross chain

According to a study made by Mr. D.A. Feldman and other Loran C experts of the U.S. Coast Guard, there is mutual interference between the existing chains. The South California Chain, for example, is seriously interfered by the Bering Sea Chain. This phenomenon will present itself all the more strikingly as Loran C chains increase in number. They warn that measures to counter such situation are urgently needed. The meer change of the

tracking rate is not sufficient as a counter-measure.
Both phase code function (PCF) and group repetition
interval (GRI) must be improved. This, however, will
involve a large-scale improvement of transmitting chains,
receivers and other equipment of the system, which
will, in turn, present extremely serious problems, such
as the obtaining of agreement on the part of the
Governments, manufacturers and users, to say nothing
of the international collaboration.

2-4-2   Transmitting equipment

(1)   Reliability of high power station

The scale of output of Loran C is a few figures larger
than that of the Decca Navigator system. The base
current of Loran C aerial amounts to as much as several
hundred amperes at the peak value, making the base
voltage go up, and this makes it necessary to work out
measures to counter the corona discharge, thunderstroms
and weather-proof peculiar to the tropical zone. This
is a major factor to cause the deterioration of the
system.

The operating hour percentage of the Decca chains in
Japan attains over 99.9% throughout the year, and the
system has been off-air just for a few minutes on an
annual average. In the case of Loran C in the tropical
zone, the percentage of operating hours is presumed to
be very low, judging from the various factors mentioned
above.

The mean time between failures (MTBF) and mean time to
repairs (MTTR) in the modern Loran C station have already
been published and are as shown in the table below.
As seen from the figures, the off-air state should not
take place even for a moment. The system can be said
too coarse to be applied in the area in question.

Name of system	Fiscal year	MTBF (hour)			MTTR (minute)			Remarks
		Maximum	Minimum	Average	Maximum	Minimum	Average	
Loran C	'74	805	180	340	100	60	68	@ chain
	'75	1,913	180	366	510	60	134	@ chain

Note: Literature cited: "LF/VLF Navaid Signal Reliability in airborne applications "(Navigation,1976 Fall Vol 23, No.3)

In the above table the time of "off-airs" includes only that of unexpected one, not off-air for the purpose of periodical maintenance check-up.

Failure occurs once every two weeks on an average.

(2) Pulse waveform of radiated power

In general, the height of a transmitting aerial in low frequency band is small as compared with the working wave length and therefore the radiation resistance is extremely low, quality factor (Q) is big and the band is spt to become narrow. For the Loran C system which uses pulse transmission, it is necessary to have matching circuit to conform to such type of transmission. In such cases,the aerial system can be easily affected by meteorological conditions by the fluctuation of various constants of Q, band width and the aerial of the aerial system due to the changes in earthing resistance and dielectric loss of the insulator. Particularly in the tropical zone where squalls or other sudden change in weather occur almost everyday, this presents a serious problem. With the fluctuation of the band width of radiation power comes the change in "rising time' of the pulse. To trim the rising waveform of pulses between the master and secondary stations in a chain, some special device would be needed not only in the aerial system, but in the whole transmitting system as well. It is however difficult for the system to maintain a high degree of accuracy.

(3) Control of envelope-to-cycle difference (ECD)

According to the date obtained from the U.S. Coast
Guard, the width of $\pm 5\mu S$ (error of approx. $\pm 750m$) is
accepted as the tolerance of ECD which constitutes
the phase standard of transmitted wave. This means
that the competent authorities themselves admit the
extremely coarse and careless operation of their
existing system. This problem has not been solved
as yet. As compared with the Decca Navigator system,
Loran C is originally a wide area oriented system,
and it has frequency characteristics in the propagation
path itself due to the difference by frequency of
electric conductivity of the propagation path.
Accordingly, the pulse waveform emitted from the
transmitting point cannot be transmitted to the
receiving point with accuracy, but is displayed in
the form of ECD abnormality. This is a problem which
affects the whole system and cannot be solved easily.
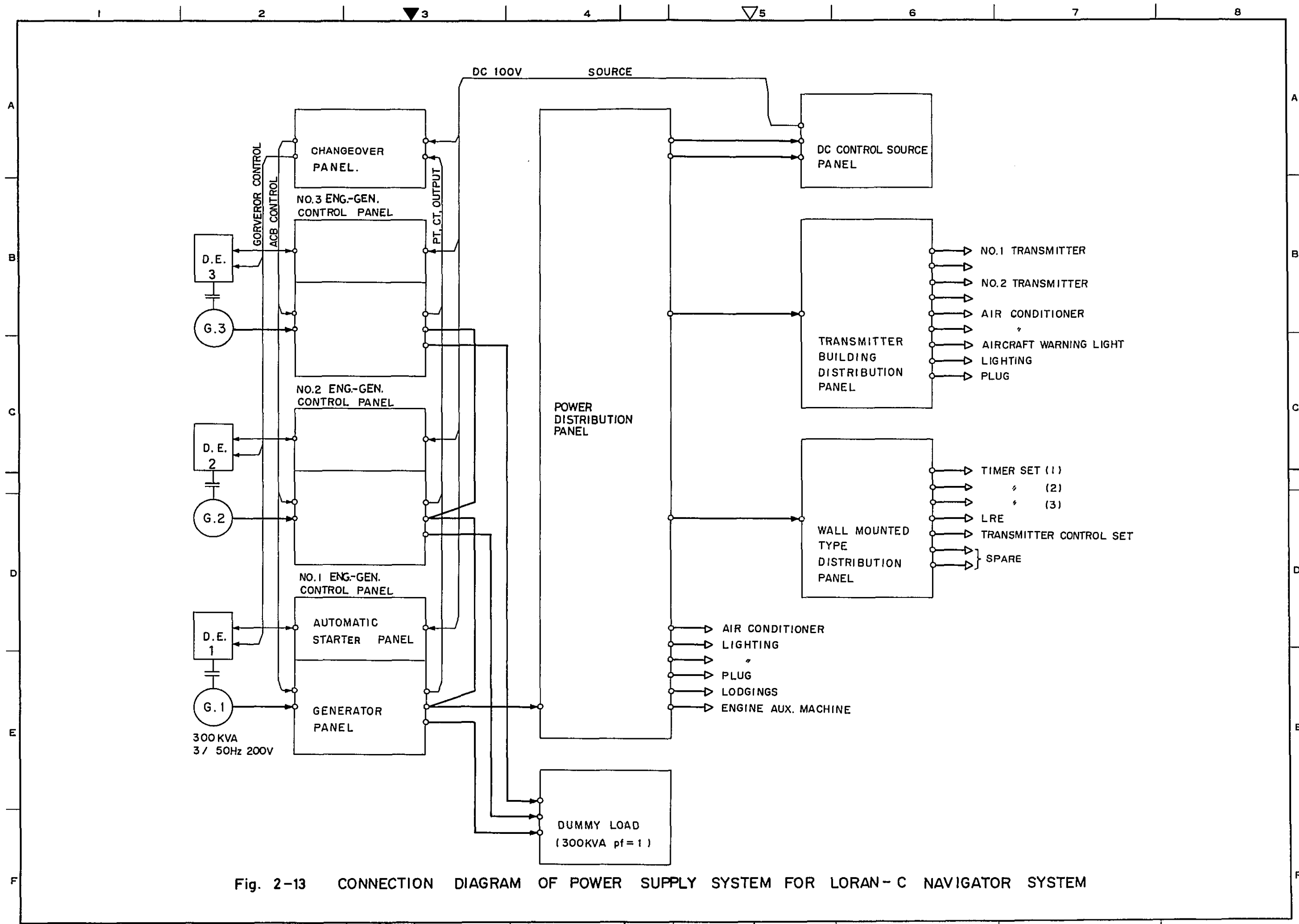
Fig. 2-13 CONNECTION DIAGRAM OF POWER SUPPLY SYSTEM FOR LORAN-C NAVIGATOR SYSTEM
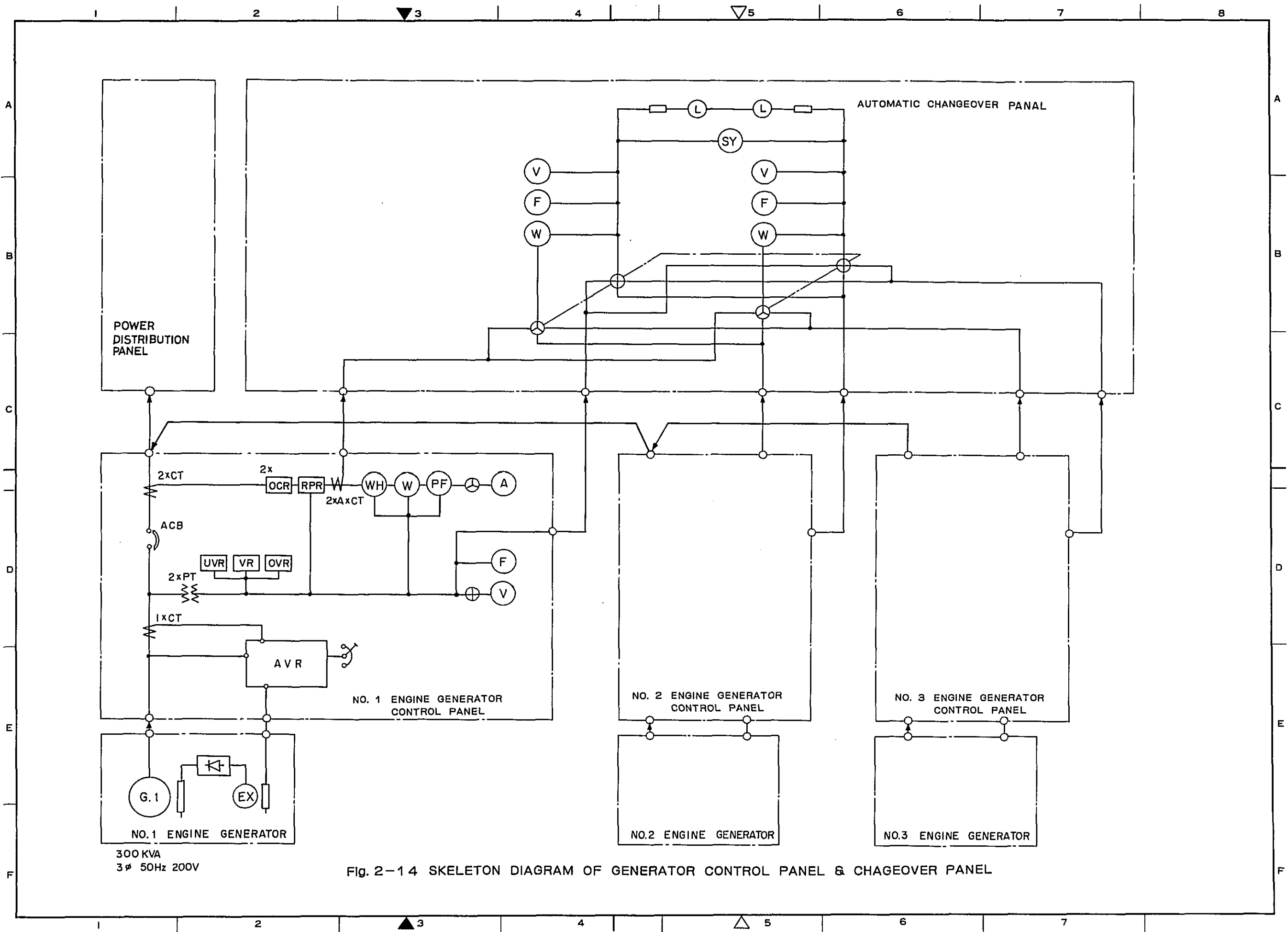
Fig. 2-14 SKELETON DIAGRAM OF GENERATOR CONTROL PANEL & CHAGEOVER PANEL
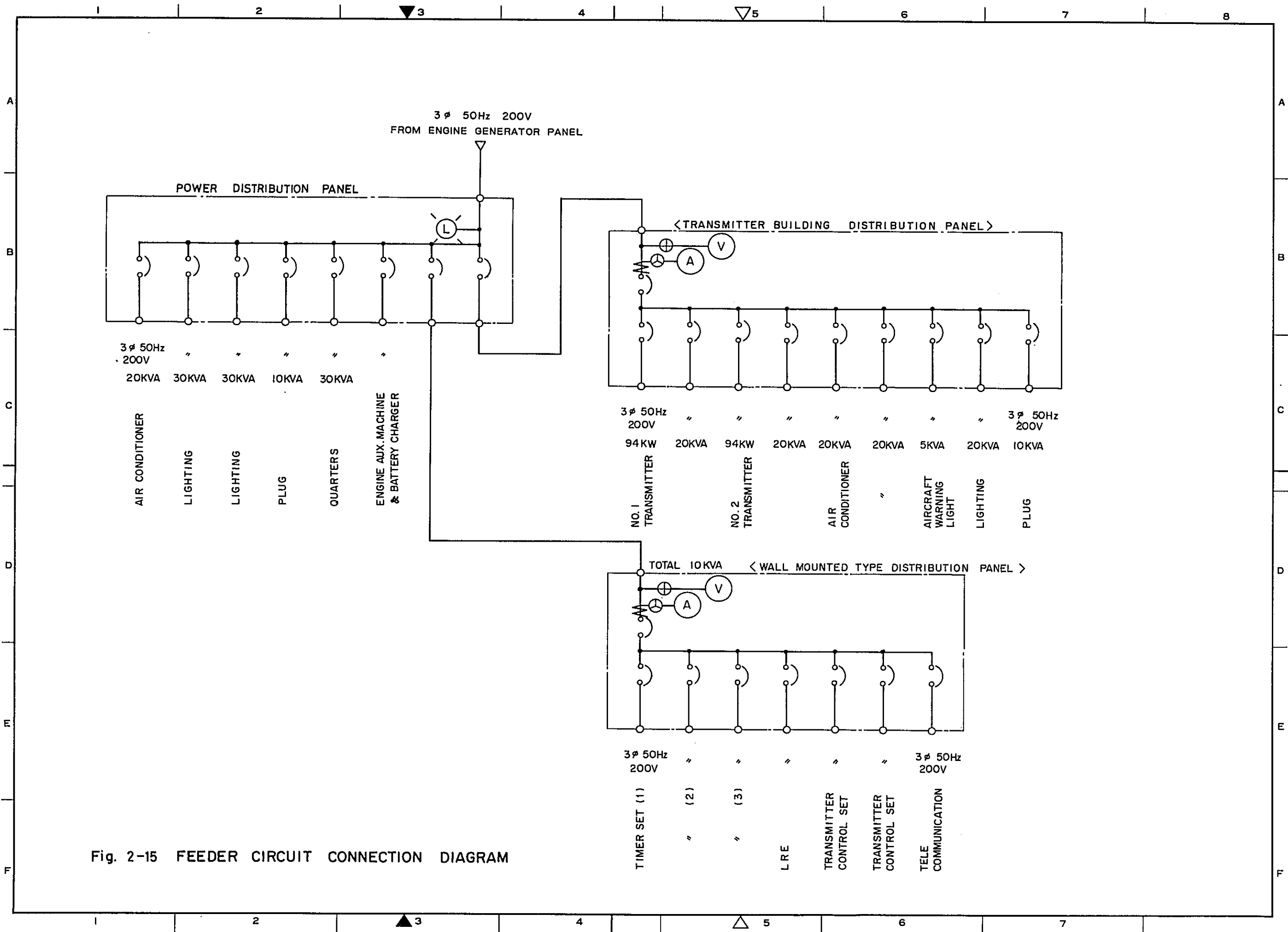
Fig. 2-15 FEEDER CIRCUIT CONNECTION DIAGRAM

3 φ 50Hz 200V
FROM ENGINE GENERATOR PANEL

POWER DISTRIBUTION PANEL

3 φ 50Hz
200V

20KVA	30KVA	30KVA	10KVA	30KVA	"

- AIR CONDITIONER
- LIGHTING
- LIGHTING
- PLUG
- QUARTERS
- ENGINE AUX. MACHINE & BATTERY CHARGER

⟨TRANSMITTER BUILDING   DISTRIBUTION PANEL⟩

3 φ 50Hz   3 φ 50Hz
200V   200V

94KW	20KVA	94KW	20KVA	20KVA	20KVA	5KVA	20KVA	10KVA

- NO.1 TRANSMITTER
- NO.2 TRANSMITTER
- AIR CONDITIONER
- "
- AIRCRAFT WARNING LIGHT
- LIGHTING
- PLUG

TOTAL 10KVA   ⟨WALL MOUNTED TYPE DISTRIBUTION PANEL ⟩

3 φ 50Hz   3 φ 50Hz
200V   200V

- TIMER SET (1)
- (2)
- (3)
- L R E
- TRANSMITTER CONTROL SET
- TRANSMITTER CONTROL SET
- TELE COMMUNICATION

NO.	NAME
1	DC CONTROL SOURCE PANEL
2	POWER DISTRIBUTION PANEL
3	AUTOMATIC CHANGEOVER PANEL
4	NO.1 GENERATOR MAIN CIRCUIT PANEL
5	NO.1 AUTOMATIC STARTER PANEL
6	NO.2 GENERATOR MAIN CIRCUIT PANEL
7	NO.2 AUTOMATIC START PANEL
8	NO.3 GENERATOR MAIN CIRCUIT PANEL
9	NO.3 AUTOMATIC STARTER PANEL

NO.	1	2	3	4	5	6	7	8	9

1000	800	800	800	800	800	800	800	800

7 400

2 300　　2 350

1 300

Fig. 2-16 OUTER VIEW OF GENERATOR CONTROL PANEL & FEEDER PANEL

TRANSMITTER BUILDING DISTRIBUTION PANEL

1 900

1 950

1 000

900

WALL MOUNTED TYPE DISTRIBUTION PANEL

800

600

400

Fig. 2-17 OUTER VIEW OF DISTRIBUTION PANEL
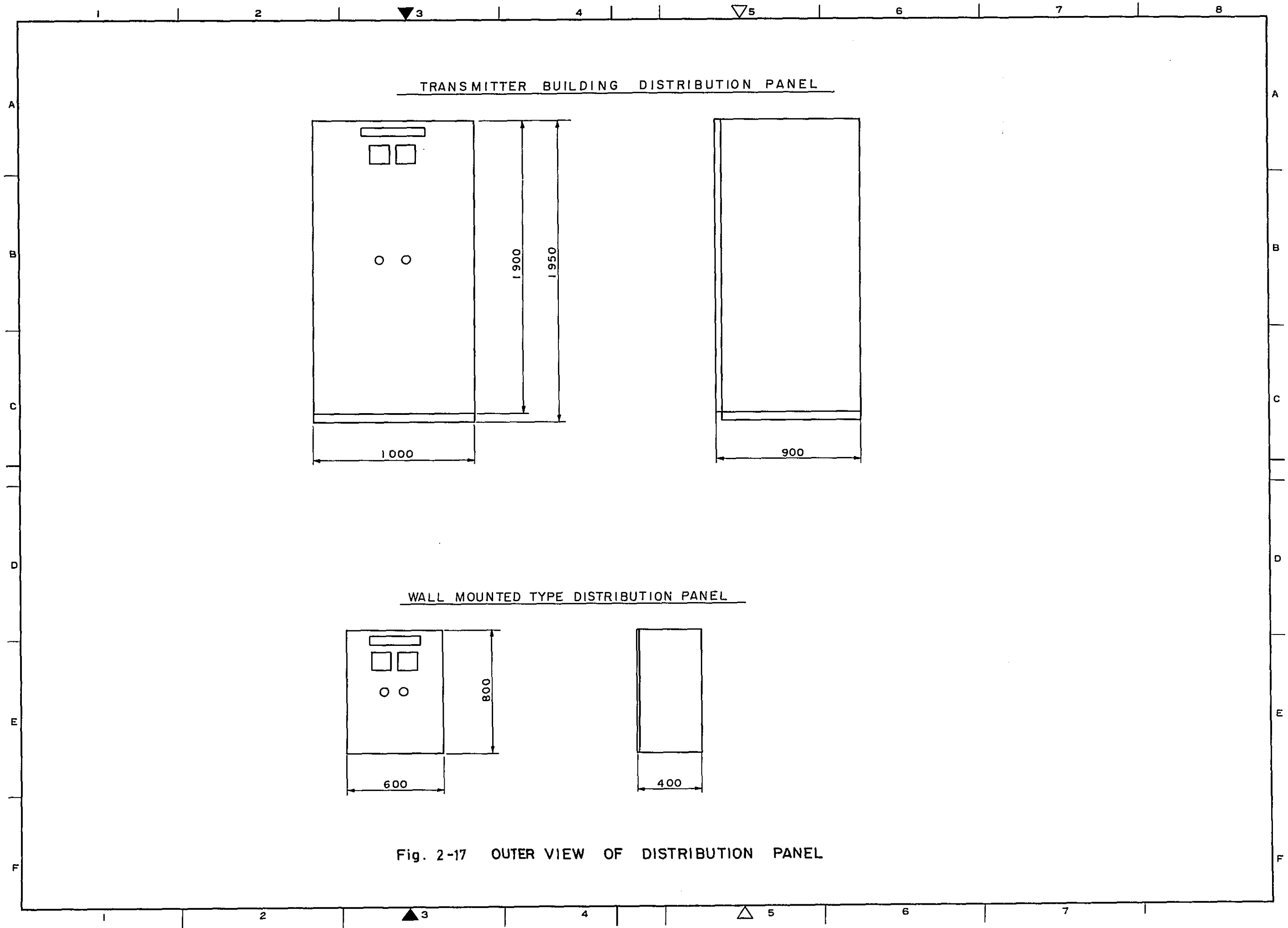
DIESEL ENGINE		A.C. GENERATOR	
TYPE	4 – CYCLES	TYPE	SYNCRONOUS
NO. OF CYL	6	PHASE	3 ∅
BORE	180 m/m	VOLTAGE	200 V
STROKE	230 m/m	CURRENT	866 A
REVOLUTION	1 000 r.p.m.	REVOLUTION	1 000 r.p.m.
B.H.P.	450 P.S.	OUT PUT	300 KVA
B.M.E.P.	11.54 Kg/cm²	POWER FACTOR.	80 %
MAX. PRESS.	115 Kg/cm²	CYCLE	50 Hz
PISTON SPEED	9.2 m/s	NO. OF POLES	6
STARTING	COMP. AIR	EXCITING	
COOLING	WATER	RATING	CONTINUITY
WEIGHT	5 450 Kg	WEIGHT	2000Kg
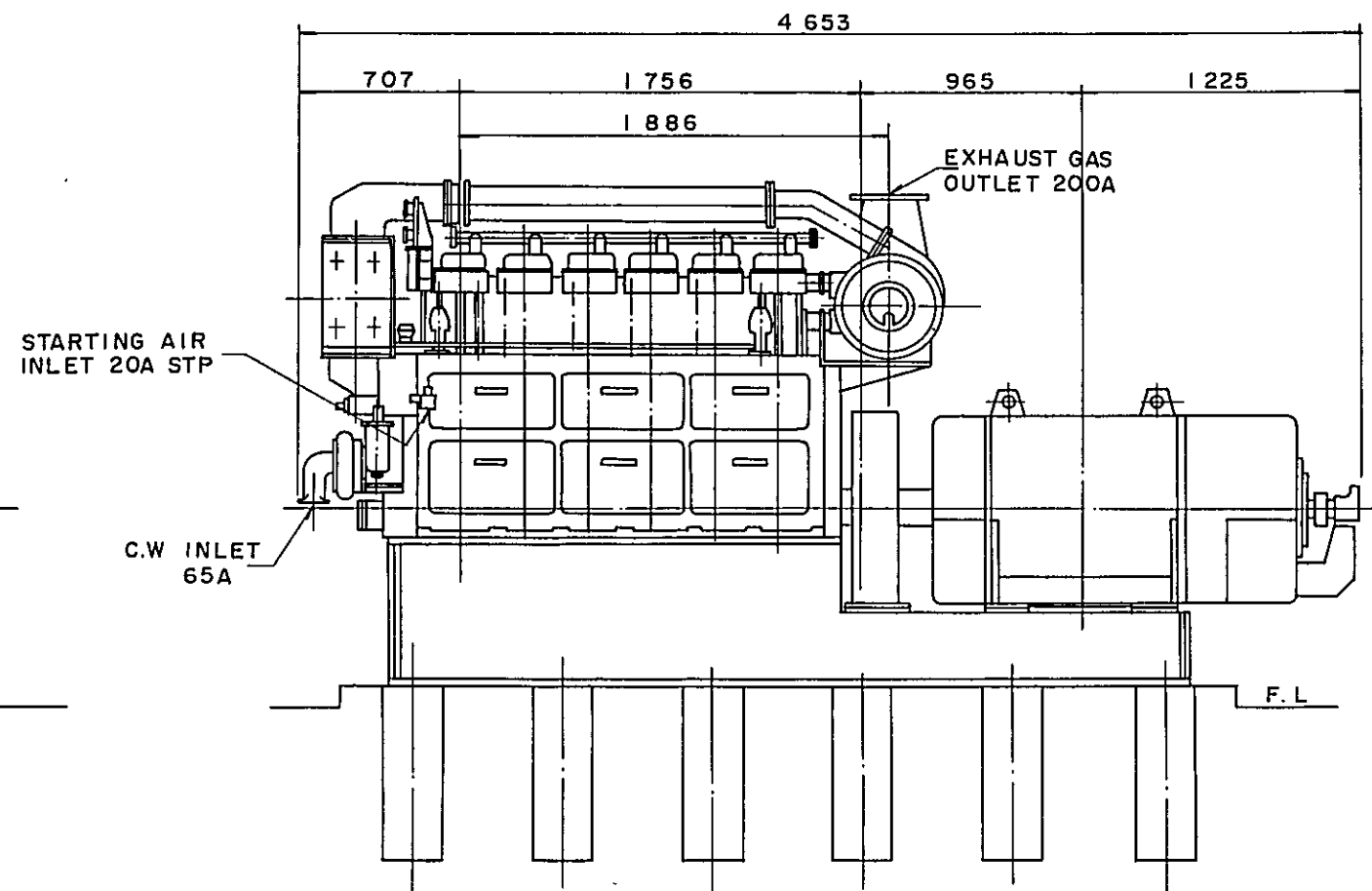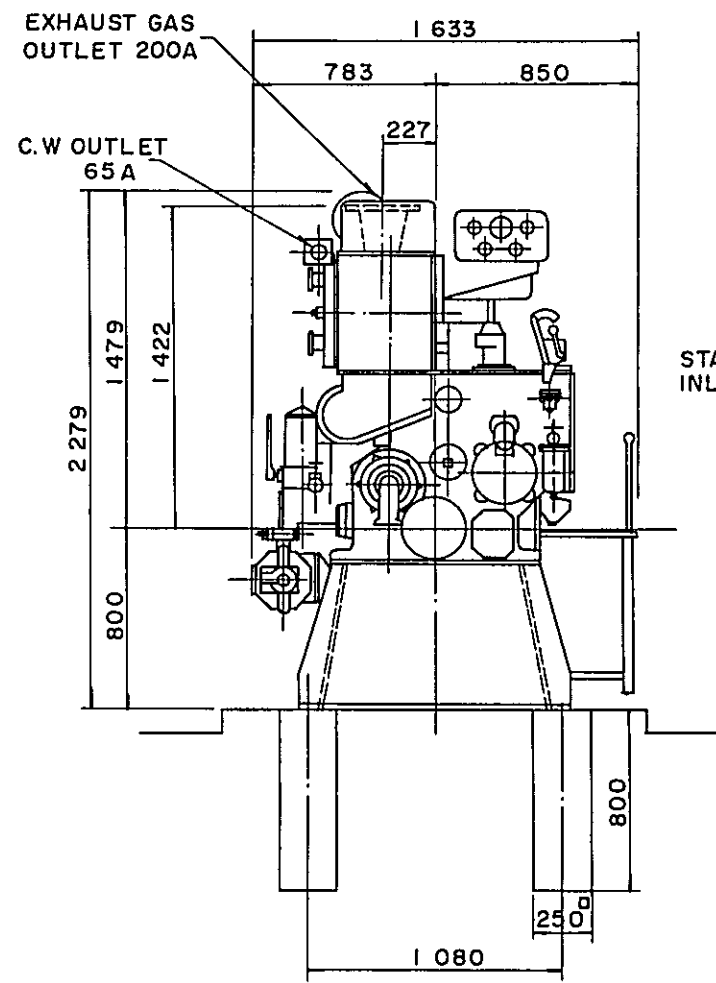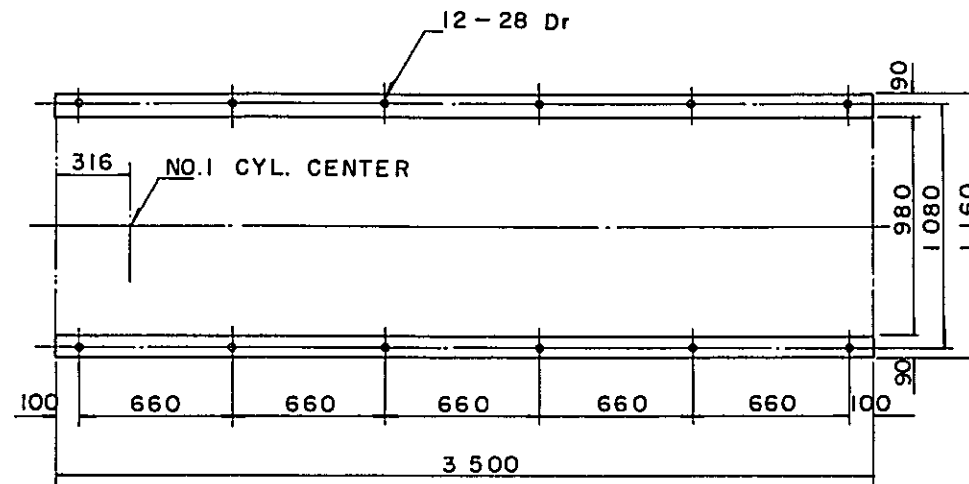
Fig. 2-18A OUTER VIEW OF ENGINE – GENERATOR
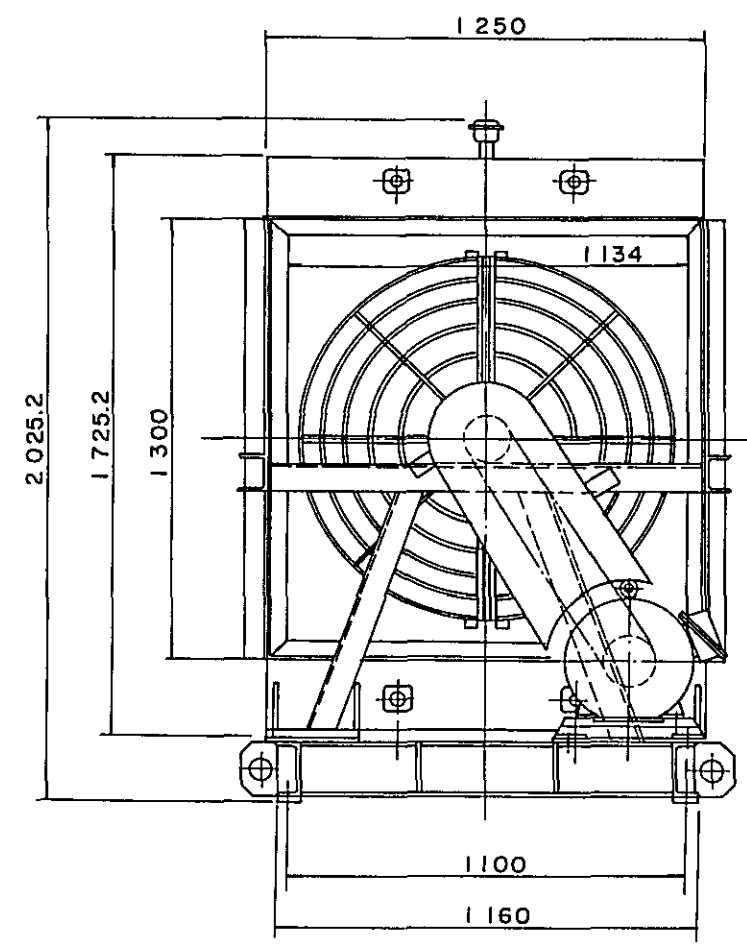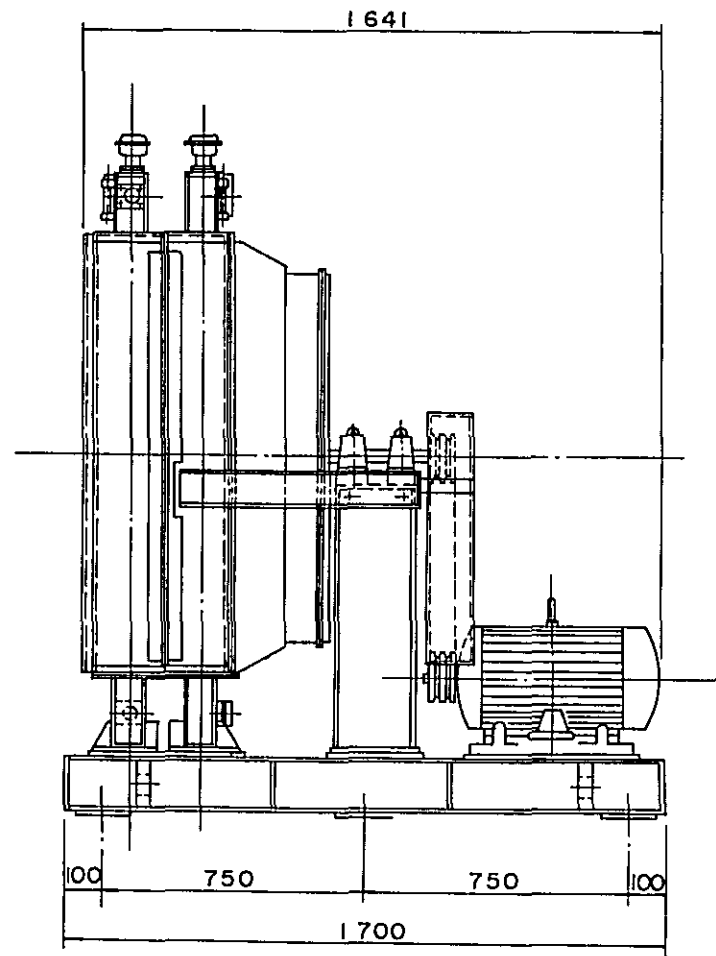
	JACKET COOLER	WATER COOLER	FAN & MOTOR	
RADIATION AREA	124.43 m^2	66.47 m^2	OUTER DIA.	1016 ø mm
FIN	98.61 m^2	49.27 m^2	AIR FLOW RATE	680 m^3/min
TUBE	25.82 m^2	17.20 m^2	REVOLUTION	1355 RPM
			MOTOR OUT PUT	18.5 KW

Fig. 2-18B RADIATOR FOR ENGINE GENERATOR

1 275
430   600   245

INTER COOLER

HIGH PRESS SAFETY VALVE

CHECK VALVE

AIR OUTLET 25 ϕ CUT

OIL LEVEL GAUGE

552

MAGNETIC UNVOASER VALVE

180
100   400   400   100
1 000

65
177
100

MANUAL UNLOADER

PANEL BOARD

OIL INLET

OIL PRESSURE CONTROL VALVE

OIL PUMP

565
250   278   37

LOW PRESSURE SAFETY VALVE

1060

533 ϕ

388

320
380
420
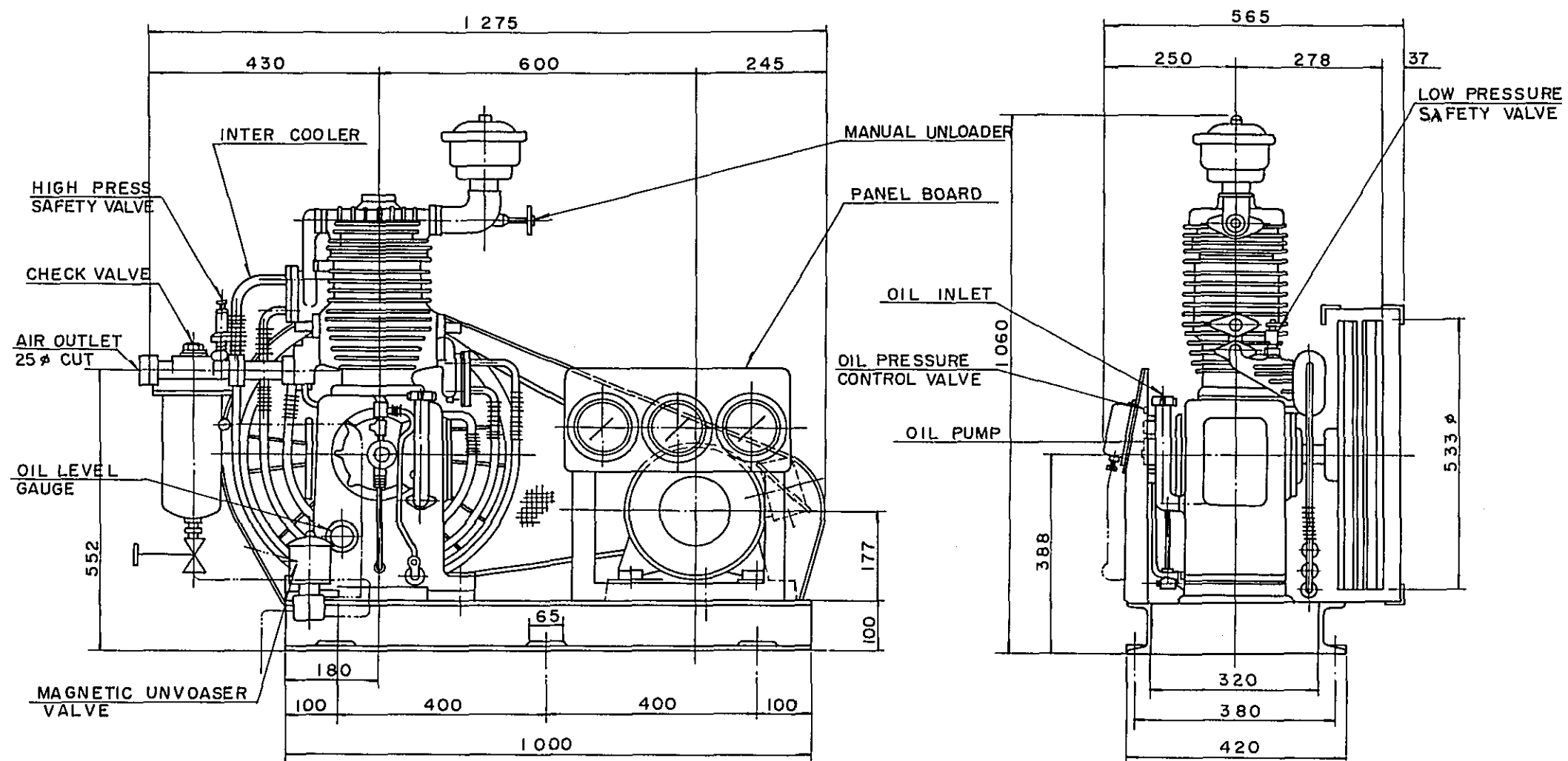
AIR	COMPRESSOR	A · C	MOTOR	
TYPE	AIR COOLER DOUBLE STAGE COMPRESSION	OUT PUT	5.5	kw
BORE	HIGH PRESS 107.95 m/m LOW PRESS 127 m/m	NO. OF POLE	4	P
STROKE	101.6 m/m	CYCLE	50	Hz
PRESS	30 kg/cm²	REVOLUTION	1 500	RPM
REVOLUTION	620 RPM			
CAPACITY	47.7 M³/Hr			

Fig. 2 -18C   AIR   COMPRESSOR

SPECIFICATIONS

MAX. OPERATING PRESS.	30	Kg/cm^2
DESIGN PRESS	32	Kg/cm^2
SAFETY VALVE	32	Kg/cm^2
HYDROLIC TEST		
BOTTLE	48	Kg/cm^2
HEADER	64	Kg/cm^2
PRESSURE SWITCH SET PRESS.		
AUTO-CHARGE	22 $\frac{ON}{OFF}$ 30	Kg/cm^2
ALARM	18	Kg/cm^2

1500

500

PRESS SWITCH FOR
AUTO-CHARGE

PRESS SWITCH FOR
LOW PRESS ALARM

AIR RECEIVER
COONNECTOR

SEFETY VALVE

PRESSURE GAUGE

CHECK VALVE

AIR INLET
15 ∅ Cu.T

AIR RECEIVER
CONNECTOR

AIR OUTLET
20A ST.P

249

2.029

1780

355.6 ∅

L - 65 x 65 x 6

F.L

355.6 ∅

Fig. 2-18D   (3-150ℓ) AIR TANK

3. Accuracy of Decca system and Loran C system

3-1 Accuracy of Decca system

3-1-1 Introduction

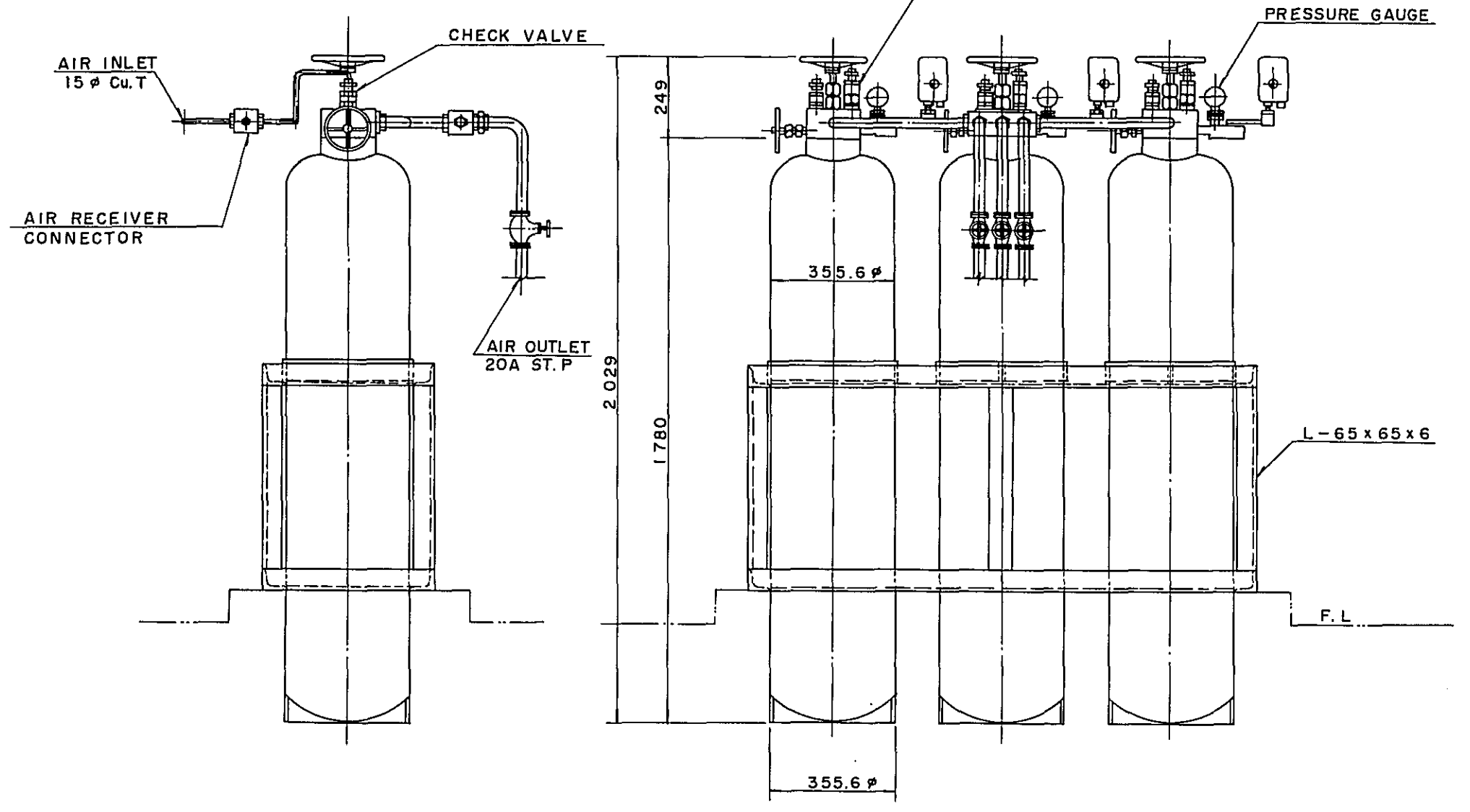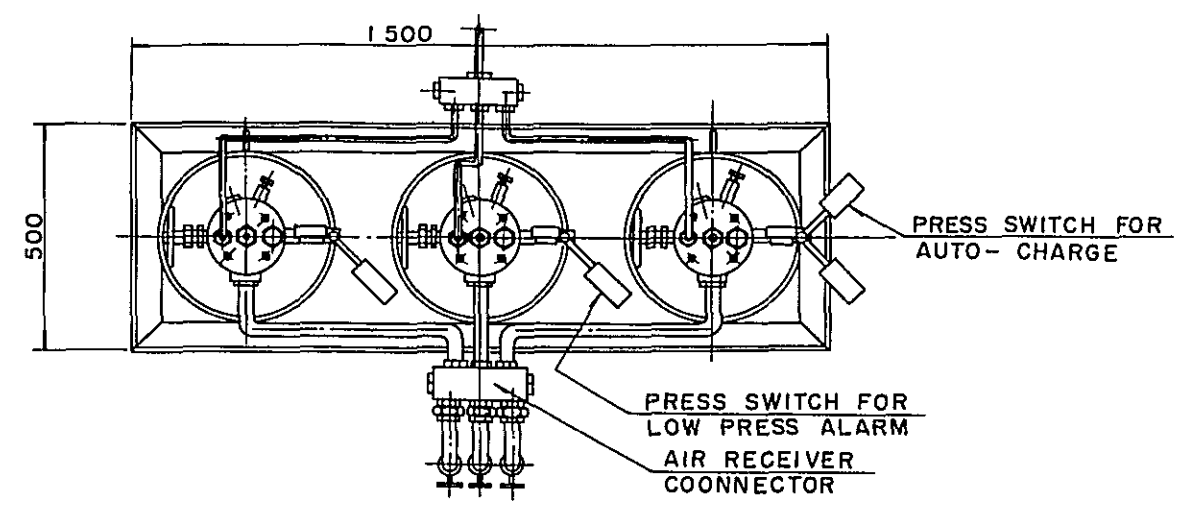The errors of the Decca Navigator system can be roughly classified into two groups: those caused by alterations in the state of radio wave propagation and those others which are indigenous to the system itself.

The first group of errors are random errors caused chiefly by changes in time of atmosphere in radio wave propagation path, while those of the latter group are errors caused from configuration of the transmitting station and performance of the equipment, and the value of these latter errors could be reduced by efforts of the operator.

3-1-2 Random errors

Random errors are caused by changes in time of atmospheric condition in radio wave propagation path, changes to Decca equipment for a short time, or by errors in reading numerical valve. The biggest cause of all these is the changes in time of atmospheric condition in the radio wave propagation path, and the influence is big particularly at night.

In the Decca Navigator system it is always necessary to ensure that the synchronised radio waves from the master and slave station arrive at the receiving point, maintaining a certain phase relationship.

Most of the radio wave propagation is the ground wave that propagates along the surface of the earth during daytime. The reflecting energy of the radio wave radiated toward the sky (sky-wave) is extremely small (The reflection factor at E-layer in the sky 70km high is approximately 2%) and therefore negligible. The phase deviation is also small, and errors caused by the propagation conditon do not present any problem. During nighttime,

however, the activities of the E-layer about 100km high up
in the sky and the ionosphere called F-layer, 200 to 400km
high are remarkable, and the radio wave radiated toward to
sky are refracted as it travels through the ionosphere and,
reflested, return to the surface of the earth. The reflection
factor at 95km high up in the sky is approximately 25%. This
is because the ionosphere comprises free electron and positive
and negative ionospheric layer, and its character is unstable,
and the degree of reflection changes every moment, with which
the phase and amplitude of the skywave that has returned to the
ground also change every moment. Since the Decca system adopts
continuous wave system, unlike the Loran C system which employs
pulse wave, cannot utilise skywave and ground wave by distin-
guishing one from the other. Accordingly, as the power of
skywave at the receiving points becomes strong, the skywave
joins the ground wave to make composite wave, the amplitude and
phase of which fluctuate to cause errors in the fixed position.

(1) Errors by skywave
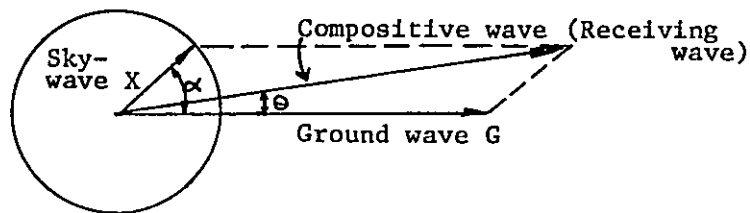
Fig. 3-1

The fluctuation of phase of the received radio wave, caused
by composite wave of ground wave and skywave may be obtained
in the following manner:

In Fig. 3-1   above, suppose

   G: Field intensity of the ground wave
   S: Square mean value (R.M.S.) of field intensity
       of the skywave
   X: Instanraneous valve of S.

Θ: Phase angle (radian) of the composite wave and ground wave

$\Theta1$: Instataneous valve (radian) of Θ

α: Phase angle of the skywave and ground wave,

and here X   G and (X/G)   0,

then

$$\sin\Theta1 \longrightarrow \Theta1 \fallingdotseq \frac{X. \sin\alpha}{G}$$

If this is expressed in cycle, the result will be:

$$\frac{X.\, \sin\alpha}{2X \cdot G}$$

Since the probabilities caused by all values of α are considered equal, if the square mean value of $\Theta1$, by the mixing of skywave S is set at σ,

$$\sigma^2 = \frac{\sum \Theta1^2}{n}$$

$$= \frac{1}{n}\sum (\frac{1}{2\pi} \cdot \frac{1}{G} \cdot X \; \sin\alpha)^2$$

Since again the square mean value of X is S and that of sin Θ is $1/\sqrt{2}$,

$$\sigma = \frac{1}{\sqrt{2}} \cdot \frac{1}{2\pi} \cdot \frac{S}{G} \fallingdotseq \frac{1}{9} \cdot \frac{S}{G} \;\text{(cycle)} \quad \ldots (3\text{-}1)$$

can be obtained.

Therefore, if the square mean value   of synchronisation errors between the master and slave stations is held at 0.01 cycle, S/G = 0.09 can be obtained. This indicates that the intensity of the skywave is made less than -21 db against the intensity of the ground wave.

(2) Lane errors

The Decca Navigator receiver receives radio waves transmitted from the master and slave station, multiplies the radio waves up to comparison frequency,

compares phases and displays phase difference on the decometer.

If the radio waves from both stations have undergone phase fluctuation by skywave, such waves are multiplied and phase compared, and the result is lane errors in the decometer, which becomes errors in fixing positions.

When two signals a and b are multiplied and phase compared ———— one signal has phase angle $\theta1$ of the composite wave of ground wave and skywave and the other signal has phase angle $\theta2$ of the ground wave ———— , the resultant phase difference θx will be:

$$\theta x = a. \ \theta1 - b. \ \theta2$$

Accordingly, the phase difference x

is: $\quad \sigma_x{}^2 = \dfrac{1}{n} \quad \theta_x^2 = \dfrac{1}{n} \quad (a\cdot\theta_1 - b\cdot\theta_2)^2$

$$= \dfrac{1}{n} \left\{ \sum a^2\cdot\theta_1^2 + \sum b^2\cdot\theta_2^2 - \sum 2ab \ \theta_1\cdot\theta_2 \right\}$$

Since θ_1 and θ_2 are considered to change orbitrarily and all their values are considered to be produced with the equal probability, the result will be:

$$\sum a \ \theta_1 \ . \ b \ \theta_2 = 0$$

Therefore:

$$\sigma x^2 = a^2\cdot\sigma_1{}^2 + b^2\cdot\sigma_2{}^2$$

Where σ_1 is square mean value of θ_1

σ_2 is square mean value of θ_2

(3) Application of the skywave error theory to Decca chains

The master and slave stations of the Decca Navigator system transmit radio wave of different frequencies having multiplying relationship, and it is therefore necessary to modify the frequency relation when sky-wave errors are considered.

M: Master station
R: Red slave station
G: Green slave station
P: Purple slave station
X: Receiving point
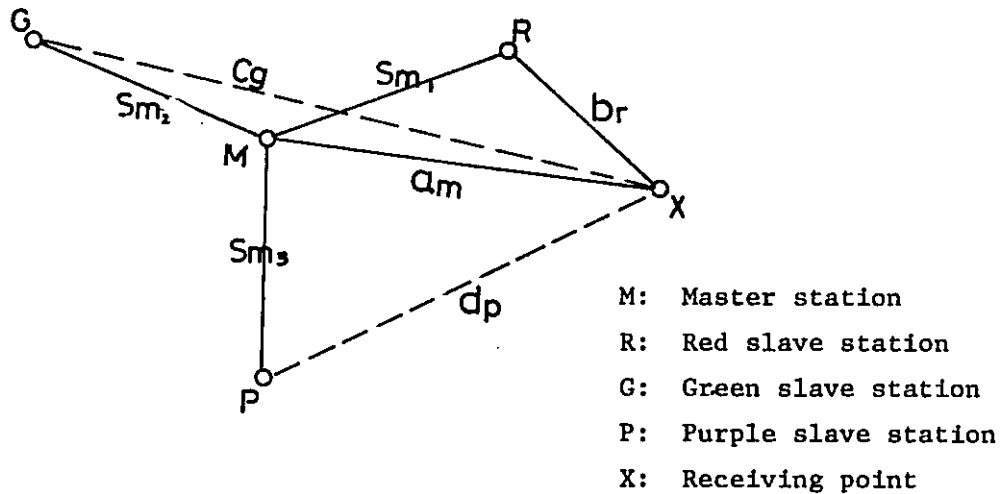
To take the pattern of the red slave station for
example, errors at the receiving point X are presumed
to be those by phase deviation as shown below.

Sml: Phase deviation of master station frequency
      (6f) in synchronisation path of master/slave

br : Phase deviation of red slave station frequency
      (8f) in path between red slave and receiving
      point

am : Phase deviation of master station frequency
      (6f) in the path between master and receiving
      point

When the phase deviation of signal from the master
station in the propagation path of master/slave stations
is Sml cycle, the deviation is converted into amount
four times that of the comparison frequency of the
control receiver of a slave station. The amount of
phase deviation is subject to 1/3 time conversion when
it is converted into the frequency of the red slave
station.

Accordingly, the phase of the signal from the red slave
station has a phase deviation of 4/3 Sml. Further,

the signal is subject to the phase deviation of br by
the time it reaches the receiving point. The phase
deviation of the red slave station at Point X is:

$$(br + \frac{4}{3} Sml) \text{ cycle}$$

On the other hand, the signal from the master station,
which has reached the receiving point through the
path of MX is subject to the phase deviation of Am.

The phase deviation Θ_R of the red decometer at the time
when the signal from both the master and slave stations
at the receiving point is taken into the receiver and
converted into comparison frequency, is indicated in
the following formula:

$$\Theta_R = 4Am - 3(br + \frac{4}{3} Sml)$$

$$= 4Am - 3br - 4Sml \quad \text{chcle or lane} \quad \ldots\ldots(3-2)$$

When a number of observation values of Θ_R have been
obtained, the following expression is possible as
dispersion of Θ_R:

$$\sigma_R{}^2 = \frac{\sum\limits_{i=1}^{N} \Theta_{Ri}^2}{N}$$

$$= \frac{\sum\limits_{i=1}^{N} (4Am-3br-4Sml)^2}{N} \quad \ldots\ldots\ldots(3-3)$$

Where N is amount of observation value

Both Am and br are clearly independent and employ
random distribution with zero as mean value, and have
no interphase for phase errors.

The term of cross product of Am and br under big
observation value, therefore, can be deemed as zero.
Accordingly, $_R$ is expressed as follows:

$$\sigma_R{}^2 = 16\sigma_{Am}{}^2 + 9\sigma_{br}{}^2 + 16\sigma_{Sm1} + (0.012)^2 \ldots (3-4)$$

The 0.012 in the above expression is an amount estimated
for uatomatic synchronisation error at a slave station
and follow-up error of the receiver.

Likewise, in the green pattern, we can obtain:

$$\theta_G = 3Am - 2 \left(\frac{3}{2} - Sm2 + Cg \right)$$

$$\sigma_G{}^2 = 9\sigma_{Am}{}^2 + 9\sigma_{Sm2}{}^2 + 4\sigma_{cg}{}^2 + (0.009)^2 \ldots (3-5)$$

In the purple slave station

$$\theta_P = 5Am - 6 \left(\frac{5}{6} Sm3 + d_p \right)$$

$$\sigma_P{}^2 = 25 \ Am^2\sigma + 25\sigma_{Sm3}{}^2 + 36\sigma_{d_p}{}^2 + (0.015)^2 \ldots (3-6)$$

can be obtained.

3-1-3   System error

When the Decca Navigator system is utilised in measuring phase
difference and the position obtained from the mean value of the
thus measured value differs from the actual position, it is
said that there is a system error.   There are several types
of system error as shown below.

(1)   Error by propagation speed of radio wave

The propagation speed of radio wave varies according to
the soil conductivity of propagation path.   Generally,
the speed is indicated in the following values:

In vacuum	299792 km/sec
At sea	299650 km/sec

In fresh water	299250 km/sec
Over farm	299400 km/sec
In mountain area	298800 km/sec

The propagation path between the transmitting point and the receiving point is not normally of a single property. It usually passes the partion where soil conductivity varies. In order to calculate an accurate position, the propagation speed is assumed with every classification of the conductivity, and distance is calculated also with each classification of propagation path, and thus the chart calculation is performed most effectively by the integral value of each phase value.

The chart calculation in the Decca Navigator system is carried out by dividing the propagation path into two types; that of the sea and that of land, or by futher dividing land propagation path into that of big conductivity and that of small conductivity, and by applying a suitable propagation speed to the propagation path. The length of base line is relatively short in this system and this contributes to the smallness of accumulation of errors and to the satisfactory result of the calculation.

The chart calculation in the Loran C system, on the other hand, is performed on the basis of a single propagation path which results in an increase in the accumulated errors caused by the large distance between two stations, and in big errors.

(2) Frequency stability and error of radio wave transmitted from the master and slave stations

The frequency deviation of radio wave transmitted from the master and slave stations is indicated as deviation of line of position and becomes a system error.

The deviation δ(m) caused by frequency deviation $\triangle f$
is expressed as follows, of the distance to the receiving
point is D(m):

$$\delta = \frac{a}{c} \cdot D \cdot \triangle f$$

Shere   C is propagation speed of radio wave
a is wave length

As explained in the following paragraph, this system
has a frequency osbillator of high degree of accuracy,
and the errors of this system referred to in this
paragraph are quite negligible.

(3)   Errors by phase synchronisation between the master
and slave stations

In the Decca Navigator system, the ground wave (Gf)
from the master station is received at a slave station,
which, in turn, transmits radio wave synchronised to
the one received from the master station.   If there
is an error in this synchronisation, it will become an
error in position fixing.   During the nighttime may
be mixed with skywave and affected by the fluctuation
of phases, which makes it difficult to maintain the
normal phase relations between the master and slave
stations.   This also causes an error in position fixing.
The synchronisation between the master and slave station
is performed by 6f transmitted from the master station,
but the synchronisation error at the time of synchroni-
sation is held within the sphere of 0.01 lane by the
decometer of the user's receiver, i.e. within 0.01 Hz
by comparison frequency, and this means the error is
held within 0.001 Hz by 6f.

(4)   Geometrical accuracy of line of position

1)   Deviation error

In the Decca Navigator system, the higher the

density of lines of position, the smaller the
deviation error of lines of position influenced by
indicating error of the decometer. The deviation
error is smallest when it is on the base line and
becomes larger as it falls out farther of the line.

Suppose the width of a lane on the base line is
denoted as W, the included angle between the master
and slave stations, measured from the measuring
point, as 4 and the error of measured value of the
lane as Δ 1, the deviation error Δ S at the point
can be expressed as follows:

$$\Delta S = \Delta 1. \ W. \ Cosec \ \frac{4}{2}$$

As clearly seen from this expression, at the point
where the included angle 4 becomes zero, i.e. on the
base line extension, deviation error will become
infinitely great and unusable, and on the base line
the indluded angle becomes 180 degrees and the error
becomes smallest.

2) Error by crossing angle

When accuracy of the lines of position is considered,
reference must be made to the random error contained
in the reading value of the decometer and the devia-
tion error determined by the position of measuring
point as described in the preceding paragraph.
Therefore, error band can be considered on both sides
of the line of position.

The position obtained as crossing point of the line
of position by the reading value of two decometers
is located within the parallelograms overlapped with
two error bands as shown in Fig. 3-2   below.
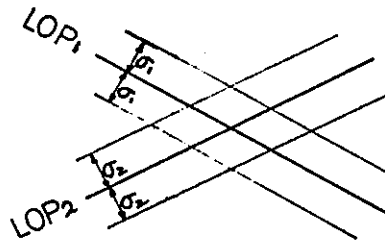
Fig. 3-2

It is, however, inconvenient to express the error
by such parallelograms, and the general practice
is denote the error by error circles.

Suppose the difference in distance between the
measured position of a vessel and the actual
position of the same vessel is expressed as d, and
the standard deviation of d as σd, and this is
denoted by the standard deviations $\sigma 1$ and $\sigma 2$ of
the measured value of the line of position and the
crossing angle Q of the line of position, σd is:

$$\sigma d = \text{Cosec } \theta \sqrt{\sigma_1{}^2 + \sigma_2{}^2}$$

The radius R of the error circle denoted by dis-
tance (68% circular error field) is indicated by
the following expression:

$$R = \text{Cosec } \theta \sqrt{(\sigma_1 W_1 \text{Cosec } \frac{\psi_1}{2})^2 + (\sigma_2 W_2 \text{Cosec } \frac{\psi_2}{2})^2}$$

$$\cdots \cdots (3-8)$$

Where Wi : Width of a lane on base line
            of LOPi

ψi : Included angle between master
        and slave stations
        Viewed from the measuring
        point

3-1-4 Estimated accuracy of Decca system in the low latitude zone

The propagation during the nighttime of the radio wave of long
wave band is subject to the magnetic field and latitude effect
of the earth. The Decca Navigator Co. and organisation in the

countries having the Decca system in operation have collected data and information on the propagation of radio wave in order to establish proper operation of the Decca Navigator system which utilises radio wave of long wave band. The data thus collected have been made available to general public.

The data on estimated accuracy of the system in such low latitude zone as Malacca/Singapore straits and Lombok/Makassar straits have been prepared by the Japanese survey team on the basis of the actual data and automatic drawing by computer under the following conditions:

1) The curve shown in Fig. 3-3 has been used as standard deviation curve of random phase error during nighttime.

   The data obtained from actual measurement at Decca stations in Japan on the distance-to-skywave intensity curve as shown in Fig. 3-4 have also been taken into consideration in slide calculation together with the latitudinal effect.

2) The curve has been added with the following frequency characteristics:

5f	+ 1.5 db (multiplied by 1.189)
6f	
8f	} Without any change
9f	-0.5 db (multiplied by 0.944)

3) The relative co-efficient of the line of position has been made at 0.75 during nighttime and 0 during daytime in calculating errors in position-fixing.

4) The following values have been added as fixed errors appearing on the decometer:

Red pattern	0.012 lane
Green pattern	0.009 lane
Purple pattern	0.015 lane

5) The daytime value of phase error has been − 9db (1/2.83) lower than the curve of 0° shown in Fig. 3-4.
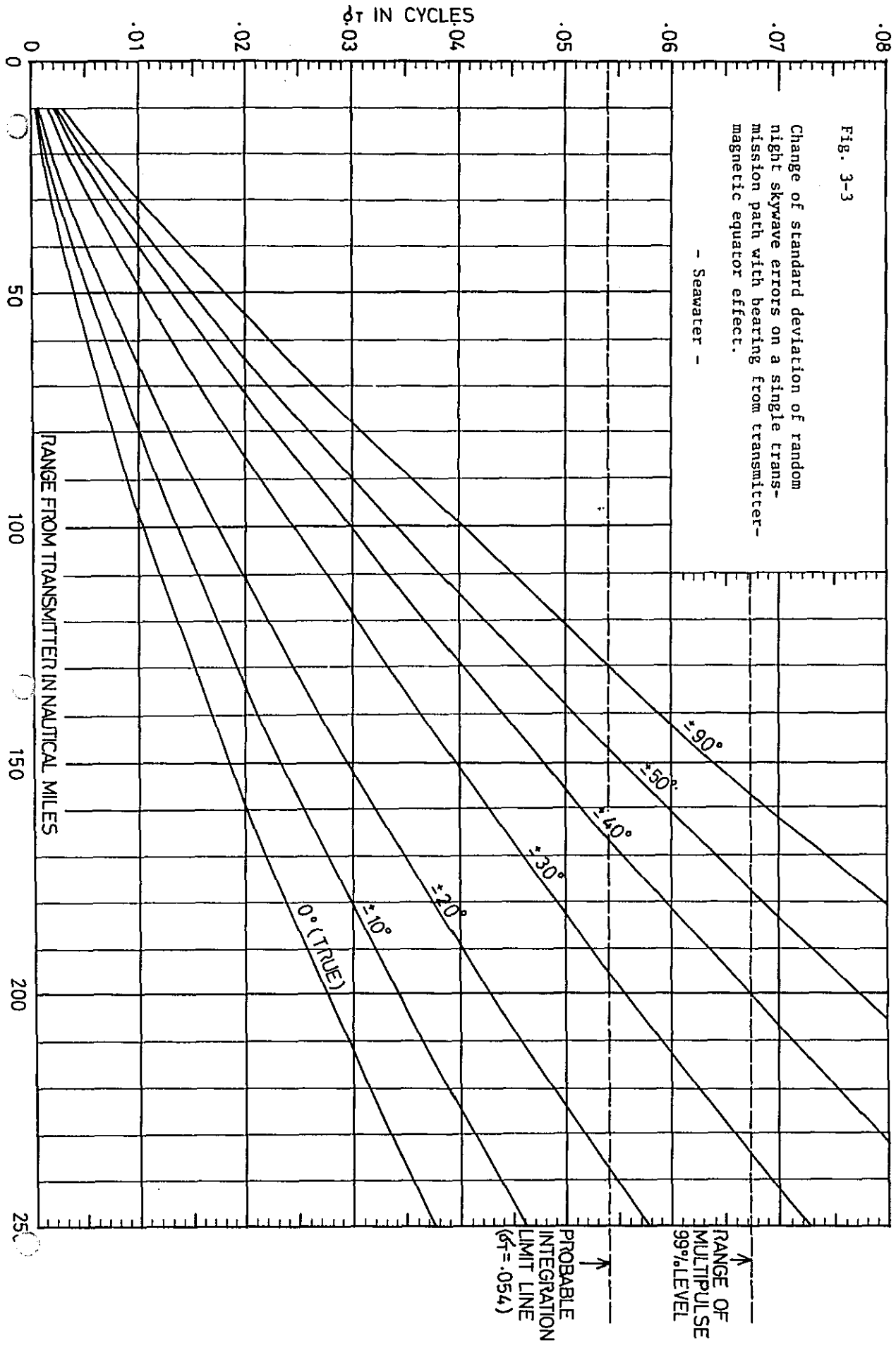
Fig. 3-3

Change of standard deviation of random night skywave errors on a single transmission path with bearing from transmitter-magnetic equator effect.

– Seawater –
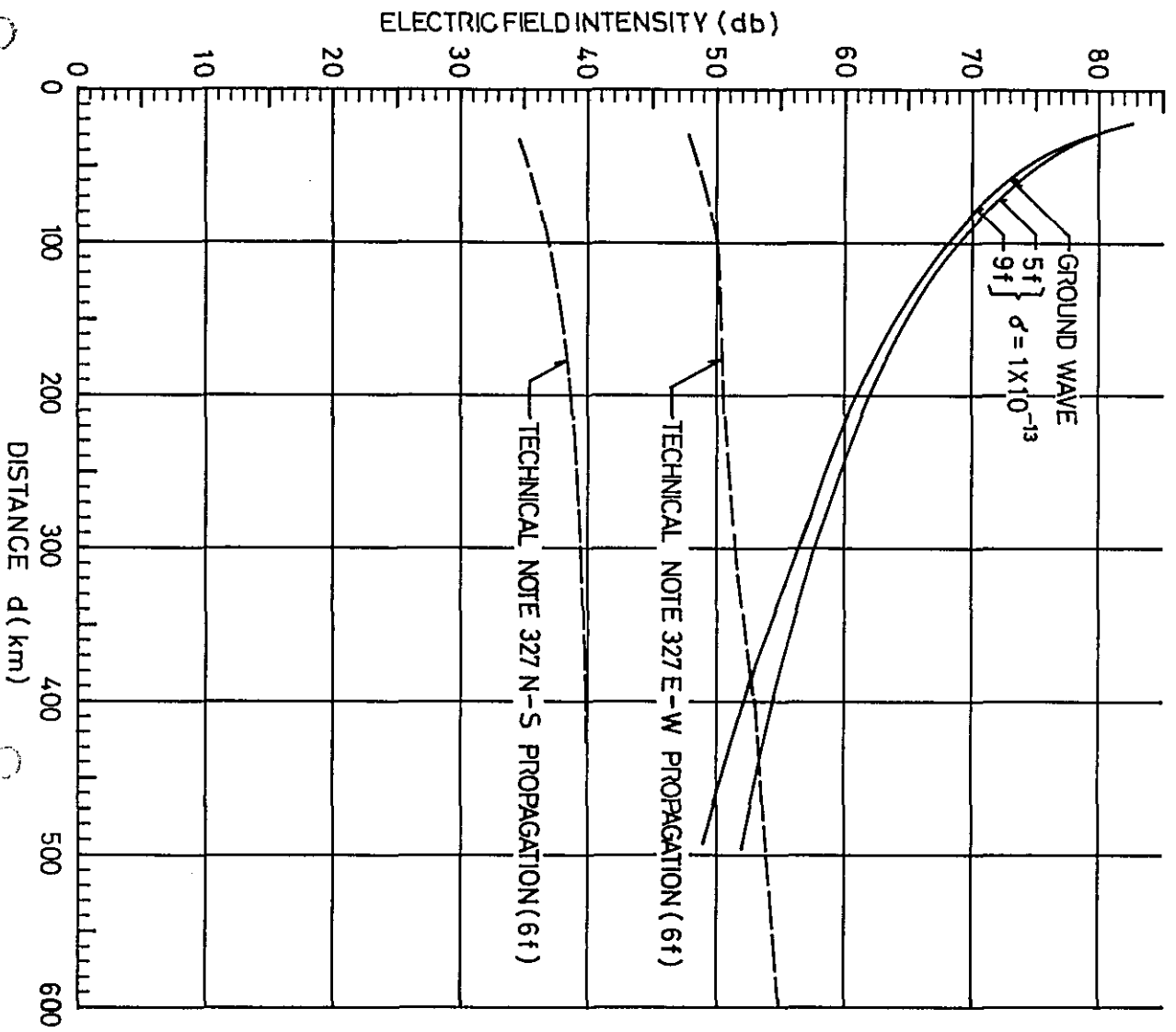
Fig. 3-4

Electric field intensity of ground wave and skywave

3-2   Accuracy of Loran C system

3-2-1   Introduction

The fundamental matters relating to the errors of the Loran C
system are similar to those of the Decca Navigator system.
The only difference should be that the selection of ground wave
and skywave is possible in the Loran C system which employs
pulses, by utilising the third rising-up cycle of the pulse.
However, transmitting stations throughout the world mingle in
a single channel of frequency band of 90 to 110 KHz and parti-
cularly at night these stations mutually beat signals from other
stations on many occasions.   This trend will become increa-
singly marked in the future.   This beating of signals is rated
in the similar way as an extremely big noise, which would bring
timing changes in the display of the receiver.   In the calcu-
lation of errors these are completely disregarded and the evalua-
tion is made in the quite ideal state which is far from the
actual situation.

3-2-2   Estimation of accuracy of Loran C system in low latitude zone

The estimation data on the accuracy of the Loran C system have
been indicated in automatic drawing by a computer taking the
following conditions into account:

a) Relation between signal-to-noise ratio and standard
   deviation (σ_{DT}) of received signal.

   The time fluctuation by noise of the secondary
   servo used in the Loran C receiver is, according
   to a report published by the National Technical
   Information Service (NTIS), expressed in the
   following expression:

$$\sigma = 1.25 \left(\frac{N}{S} \right) \frac{1}{\sqrt{n}} . Ka^{-\frac{1}{4}} \quad \cdots\cdots (3\text{-}9)$$

   Where σ :   r.m.s. error (μs)

N/S : r.m.s. noise-to-signal ratio
at input point of sampler

n : Number of samplings per second
(80 in normal Loran C chains)

Ka : Accelerating constant of servo
loop   (According to NTIS
report, ITT-make equipment Ka
is: Ka = 0.08 γad/sec^2)

b) Relation between distance and field intensity

According to the data published by ITT, the field
intensity of Loran C (field intensity of sampling
point (3rd cycle) from a transmitting station
having transmission power of 400 KW) is as shown
in Fig. 3-5.

Fig. 3-5
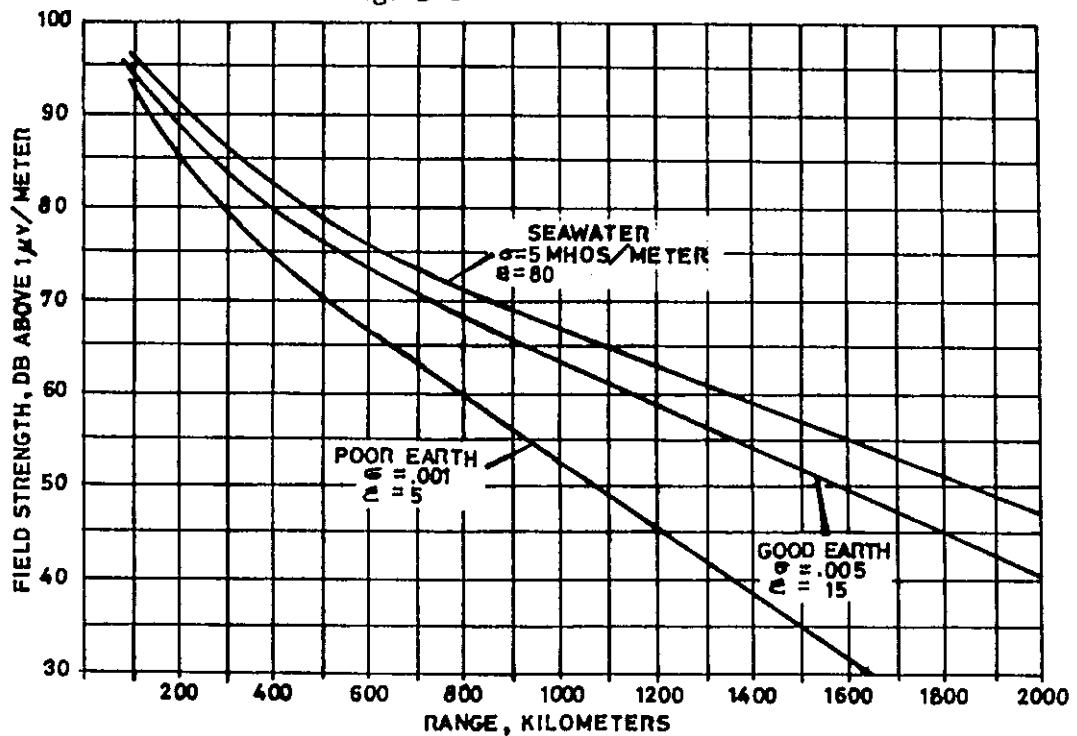
In the calculation, a curve of σ = 0.005 m
ε = 15 (land propagation) is used.

c) Noise in Southeast Asia

The atmospheric noise level in Southeast Asia is, according to the quotation in CCIR 322, considered to be M=62 db when the band width is 20 KHz, M being the worst value.

Fig. 3-6
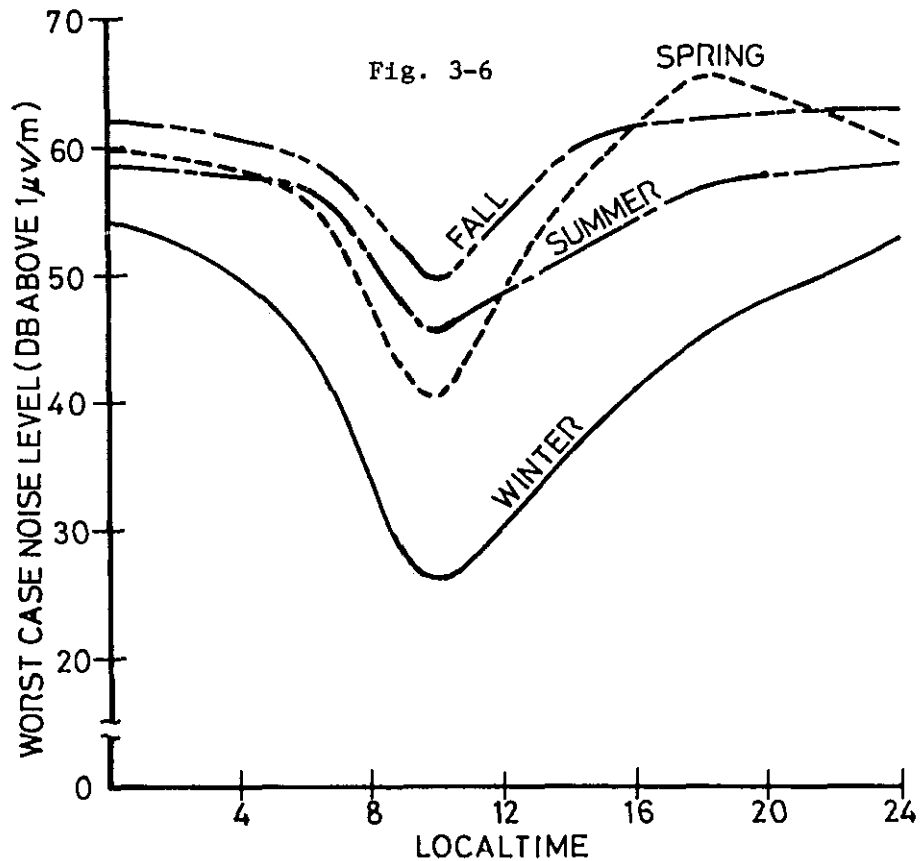
d) Other factors to cause errors

i)   Standard deviation value of synchronisation error of slave station   0.04 μs

ii) Errors in the hardware of the receiver   0.1 μs

The receiver having a resolution of less than 0.1 us is only for military use.   Public type receiver's error is 0.1 μs.

iii) Improvement of noise

The degree of improvement by the noise checking by limiter has been deemed as zero.

e) Signal-to-noise ratio at sampling point

S/N at sampler input point is denoted in the following expression:

$$(S/N) \ db = E - M + L \quad (db) \quad \ldots \ldots (3\text{-}10)$$

Where E : Field intensity of signal (db)

M : Noise level (db)

L : Improvement by limiter (db)

f) The timing changes caused in the receiver by noise in propagation path from the transmitting point to the receiving point

The timing changes in the above caption can be denoted by the following expression by using the relation of a) through e) above:

$$\sigma d = 1.25 \ (\ \frac{N}{S} \ ) \ \frac{1}{n} \ . \ Ka^{\frac{1}{4}}$$

$$= 1.25 \ x \ \frac{1}{10^{(\frac{E - M + L}{20})}} \ x \ \frac{1}{\sqrt{80}} \ x \ 0.08^{\frac{1}{4}} \quad \ldots (3\text{-}11)$$

g) Stability of lines of position
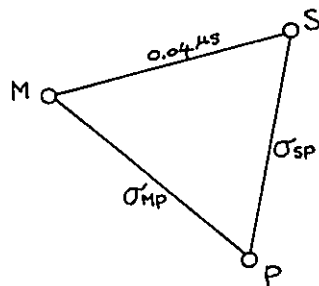
M : Master station

S : Slave station

P : Receiving point

As a result of a) through h), the standard deviation of timing fluctuation of each station is as shown in Fig.

The error of the line of position is expressed in the following expression:

$$\sigma_i = \sqrt{\sigma_{MP}^2 + 0.04^2 + \sigma_{SP}^2 + R^2} \quad \dots\dots (3\text{-}12)$$

Where the R value is an error on the hardware of the receiver (including resolution of LOP) and $0.2\,\mu s$ is given.

<p style="text-align:center">i : pair of stations</p>

h) Calculation of error circle

The error circle (probability 68%) dr.m.s. can be expressed as follows:

$$dr.m.s. = \frac{150}{Sin\left(\frac{\psi_1 + \psi_2}{2}\right)} \sqrt{\left(\frac{\sigma_1}{Sin\,\frac{\psi_1}{2}}\right)^2 + \left(\frac{\sigma_2}{Sin\,\frac{\psi_2}{2}}\right)^2}$$

$$\dots (3\text{-}13)$$
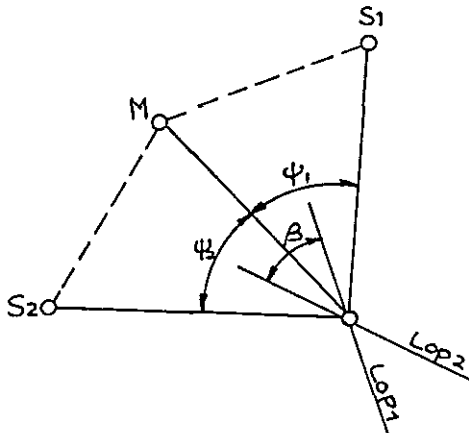
M : Master station
S1: Slave station 1
S2: Slave station 2
B : Angle between LOP's

$$= \frac{\psi_1 + \psi_2}{2}$$

Accuracy of Loran C : example of receiving

Expression (3) in the preceding paragraph indicates a case where the Loran C system is operated indeally, free from interference from others. In actual cases, particularly during the nighttime, interference by

mutual signals from the stations becomes very large because of the peculiarity of the Loran C system that it is operated in a single channel. This inevitably leads to the worsening of signal-to-noise ratio and the reduction in the number of samplings of signals and eventually to big timing changes.

Here is example of receiving signals from the Loran C stations in Japan.

Example 1 (Fig. 3-7) and Example 2 (Fig. 3-8) are Lissajous during 3 to 4 hours of receiving LOP value under the conditions shown in the following table:

Table 3-1.   Example of receiving signal
from Loran C stations

	Example 1	Example 2

Chain received
    LOP 1
    LOP 2
	SS3 - X
	SS3 - Y
		SS3 - X
		SS3 - W

Distance to receiving point from: Master station Slave 1 Slave 2	1300 km 1200 km 1200 km	1300 km 1200 km 2200 km
Lissajous Drawing	Fig. 3	Fig. 4

Fluctuation of LOP
        LOP 1
        LOP 2
	0.75 μs P-P
	0.75 μs P-P
		0.62 μs P-P
		7.63 μs P-P

Receiving point	Akashi, Japan 34°46' N 134°56' E
Receiver	DL 91 Loran C receiver made by Decca

Example 1 shows a case where the distance from the master and slave stations is both within 750 nautical miles.

Example 2 shows a case where the distance from a slave station is more than 750 n.m.

Example 1 is within the best coverage of SS3 chain and indicates a time fluctuation of peak-to-peak 0.75 μs, a big fluctuation quite different from the theoretical value.

Fig. 3-7

Loran C receiving data (SS-3)

    (by DL91 MK2 receiver)
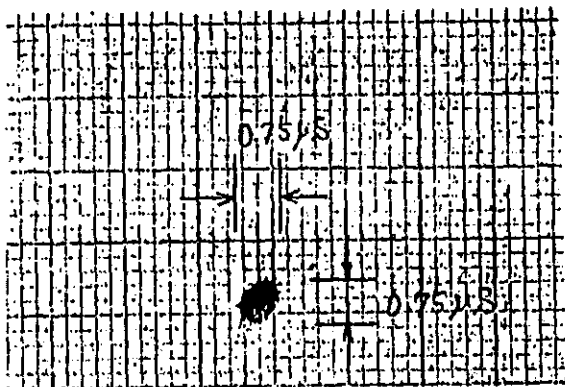
18th March, 1977.

Time of
  measurement: 08:45 - 20:37

Axis X (LOP 1): M-X (Tokachibuto)

Axis Y (LOP 2): M-Y (Okinawa)

Scale: 8cm/10 μs

LOP 1 Centre value 36412.0 μs

LOP 2   "   58594.4 μs

Receiving point: ϕ = 34° 46.056' N

                λ =134° 56.209' E

          (Fujitsu Akashi Factory)

Fig. 3-8

Loran C receiving data (SS-3)

25th March, 1977.
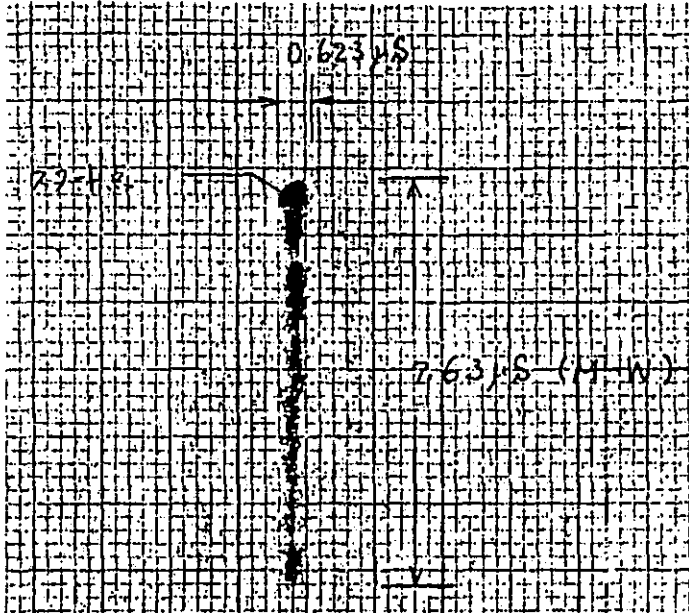
Time of
  measurement: 10:30 - 16:20

Axis X (LOP 1): M-X (Tokachibuto)

Axis Y (LOP 2): M-X (Marcus Is.)

Scale: 8cm/ 10 μs

Starting point:
 LOP 1 = 36411.8 μs
 LOP 2 = 18366.8 μs

Receiving point:

        ϕ = 34°46.056' N
        λ =134°56.209' E
     (Fujitsu Akashi Factory)

Appendix B

Analysis of guyed towers

1-1 Introduction

A method of analysis of high guyed towers under wind
loading, readily adaptable to electronic computer
solution, is presented herein. The method includes
the variable guy spring constants, effect of drag
and lift on the guys, and such secondary effects as
external moments produced at each guy level, and
those produced by the distortion of the shaft.
Effects of ice loads and insulators, or both, on
the guys are also examined.

The analysis presented for computing tower member
stresses includes the effects of web member strains,
initial eccentricities of tower shaft between guy
levels, and increase in shear caused by shaft dis-
tortion.

An examiniation of two-way bending of guyed towers
is also included and a method of solution presented.

1-2 Assumptions

The following assumptions are made concerning high
guyed towers under wind loading:

(a) Wind loads on tower shaft are known and are
assumed to be uniform between guy levels; (b) the
moment of inertia of the tower shaft is considered
to be uniform between guy levels; (c) dead load of
tower shaft for each span is concentrated, one-half
at each end for beam-column action only; (d) the
guys are uniformly loaded by the wind or by a com-
bination of wind and ice; (e) the velocity of the
wind acting on a guy is the velocity at its average
height; (f) guy curve is a parabola for all loading
conditions; (g) drag and lift coefficients for a

guy are as indicated by Diehl; and (h) wind is
blowing parallel to the ground.

1-3 Normal position of guy

Fig.1 shows a guy with no wind blowing and at normal
temperature, t_o. If the total weight of the guy is
W kips, its approximate length L, in feet, is given
by

$$L = a \left(\sec \omega + \frac{W}{24H^2 \sec^3 \omega} \right) \quad \ldots\ldots\ldots\ldots \text{(1)}$$

in which H is the horizontal component of the ten-
sion in the guy in kips.
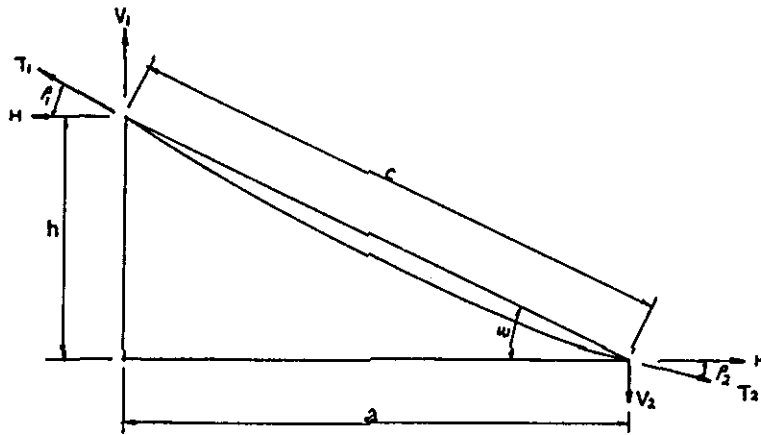
FIG. 1. - ELEVATION OF GUY IN NORMAL
          POSITION

For erection purposes, the tension at the anchorage,
T_2, is known and H can be computed from

$$H = \frac{\cos \omega}{2} \left[W \sin \omega + \sqrt{4 \, T_2^2 - W^2 \cos^2 \omega} \right] \quad \ldots\ldots \text{(2)}$$

It may be shown for a parabola that

$$\tan \beta_1 = \tan \omega + \frac{W}{2 \, H} , \quad \ldots\ldots\ldots \text{(3a)}$$

$$\tan \beta_2 = \tan \omega + \frac{W}{2 \, H} , \quad \ldots\ldots\ldots \text{(3b)}$$

$$\Delta_g = \frac{H a}{A_g E_g} \left(\sec^2 \omega + \frac{W^2}{12 H^2}\right) , \quad \dotfill \quad (3c)$$

in which Δ = stretch of the guy, in feet; A_g = the metallic area of the guy in square inches; and E_g = the modulus of elasticity of the guy in kips per square inch. The unstressed length of the guy, L_o, at normal temperature is then

$$L_o = L - \Delta_g , \quad \dotfill \quad (4)$$

At a temperature of t degrees C, the unstressed length, L_t, is

$$L_t = L_o [1.0 + .0000125(t - t_o)] \quad \dotfill \quad (5)$$

1-4 Effect of wind and tower motion on guy

Fig.2 shows the forces acting on a guy. The projection of these forces, on a horizontal plane, make an angle of ϕ with the direction of wind. Point B represents the point of attachment to the tower which, in this case, is assumed not to have moved. Positive directions of the forces are shown in Fig.2. The total weight, W, acts vertically down; the total drag, d_o, acts parallel to the y axis; and the lift, l_1, is parallel to BD and normal to d_o. θ, the true angle between the guy chord and the wind, is given by

$$\cos \theta = \cos \phi \cos \omega \quad \dotfill \quad (6)$$

Let l and l_h represent the components of the lift, l_1, in the z and x directions, respectively. Then

$$l = l_1 \sin \rho , \quad \dotfill \quad (7a)$$

$$l_h = l_1 \cos \rho , \quad \dotfill \quad (7b)$$

in which

$$\sin \rho = \frac{\sin \omega}{\sin \theta} , \text{ and } \quad \dotfill \quad (8a)$$

$$\cos \rho = \frac{\sin \phi \cos \omega}{\sin \theta} \quad \dotfill \quad (8b)$$

Assuming the volocity pressure to be given by

$$vp = 0.625 \ v^2 \times 10^{-6} \ \ldots\ldots\ldots\ldots\ldots \ (9)$$

the total drag, d_o, and lift, l_1, on a guy are approximately,

$$d_o = 2.133 \ (Cdv^2) \cdot C_D \cdot 10^{-7} \ \text{tons, and} \ \ldots. \ (10a)$$

$$l_1 = 2.133 \ (Cdv^2) \cdot C_L \cdot 10^{-7} \ \text{tons,} \ \ldots\ldots. \ (10b)$$

in which C = chord length of guy in feet, d = diameter of guy in inches, v = wind velocity in miles per hour, C_D = drag coefficient, and C_L = life coefficient.

It should be noted that l_1 is negative when ϕ is in the first or fourth quadrant. Hence, the sign of l_1 is opposite to that of cos ϕ.

Diehl[1] indicates values of C_D and C_L by curves for values of θ varying from 0° to 90°. For computer use, it is expedient to express the values of C_D and C_L in polynomial form as

$$C_D = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4$$
$$\ldots\ldots. \ (11)$$
$$C_L = b_0 + b_1 x + b_2 x^2 + b_3 x^3 + b_4 x^4$$
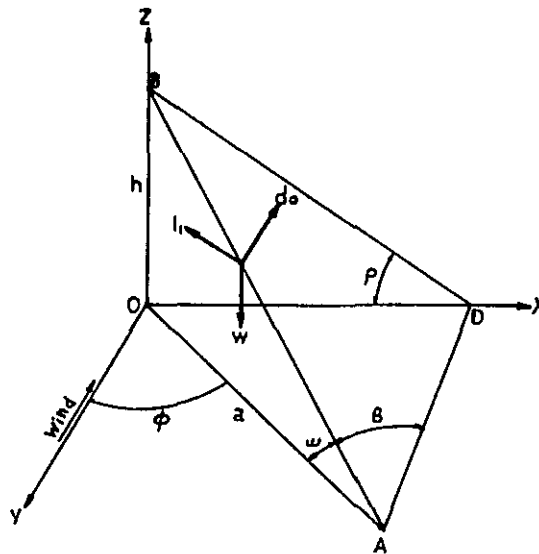
FIG. 2. - LOADS ON GUY
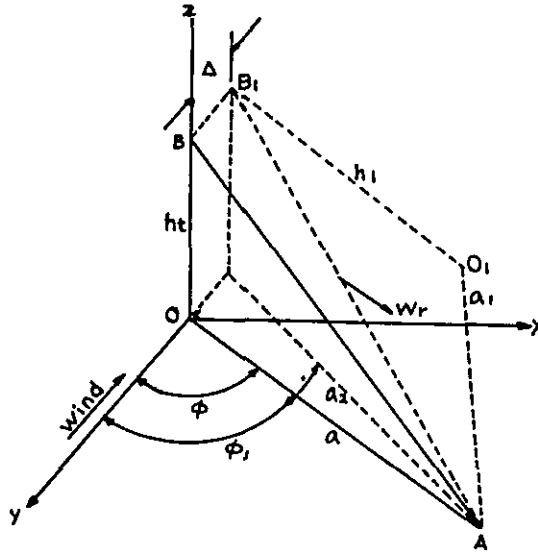
FIG. 3. - GEOMETRY OF GUY IN DEFLECTED
POSITION

in which $x = | \cos \theta |$

For $x \leqslant 0.575$: $a_0 = 1.18457$; $a_1 = 0.07816$; $a_2 =$
-1.51543; $a_3 = -1.73395$; $a_4 = 2.56634$; $b_0 = 0.00008$;
$b_1 = 1.45668$; $b_2 = -2.73481$; $b_3 = 5.36663$; and $b_4 =$
-4.75092.

For $x > 0.575$: $a_0 = 1.20931$; $a_1 = -0.08774$; $a_2 =$
-1.33619; $a_3 = -0.82684$; $a_4 = 1.06662$; $b_0 = 1.40075$;
$b_1 = -4.20644$; $b_2 = 6.00561$; $b_3 = -2.24738$; and $b_4 =$
-0.94991.

In Fig.3, the tower has deflected a distance Δ ft in
the direction of the wind at the point of guy attachment.
Because of the wind loads., the guy lies in a new plane
that contains the resultant, W_r, of all the forces
acting on the guy. This new guy plane is represented
by the triangle B_1 O_1 A in the figure. The guy is
assumed to be a parabola lying in this plane with B_1 O_1
parallel to W_r and O_1 A normal to W_r. W_r is given by

$$W_r = \sqrt{ l_h^2 + d_o^2 + (W-1)^2 } \quad \ldots\ldots\ldots\ldots\ldots (12)$$

Thus

$$a_2 = \sqrt{(a \sin \phi)^2 + (a \cos \phi + \Delta)^2} \quad \dots\dots\dots \text{(13a)}$$

$$\sin \phi_1 = \frac{a \sin \phi}{a_2} \quad \dots\dots\dots\dots\dots \text{(13b)}$$

and

$$\cos \phi_1 = \frac{a \cos \phi + \Delta}{a_2} \quad \dots\dots\dots\dots \text{(13c)}$$

It may be shown that

$$h_1 = \frac{(W-1)h_t - a_2(l_h \sin \phi_1 + d_o \cos \phi_1)}{W_r} \,, \quad \dots \text{(14a)}$$

$$a_1 = \sqrt{a_2^2 + h_1^2 - h_1^2} \,, \quad \dots\dots\dots\dots \text{(14b)}$$

and

$$\tan \omega_1 = \frac{h_1}{a_1} \,, \quad \dots\dots\dots\dots \text{(14c)}$$

in which h_t is the height of the guy at temperature, t.
The value of h_t is given by

$$h_t = h [1.0 + .0000125 (t-t_o)] \quad \dots\dots\dots\dots \text{(15)}$$

for steel structures.

The direction cosines of lines B_1O_1 and O_1A are

$$B_1O_1 \qquad\qquad\qquad O_1A$$

$$\cos \alpha_1 = \frac{l_h}{W_r} \,, \quad \cos \alpha_2 = -\tan\omega_1 \cos\alpha_1 + \frac{a_2}{a_1} \sin \phi_1 \,,$$

$$\cos \beta_1 = \frac{d_o}{W_r} \,, \quad \cos \beta_2 = -\tan\omega_1 \cos\beta_1 + \frac{a_2}{a_1} \cos \phi_1 \,, \quad \dots \text{(16)}$$

$$\cos \gamma_1 = -\frac{W-1}{W_r} \,, \quad \cos \gamma_2 = -\tan\omega_1 \cos\gamma_1 - \frac{h_t}{a_1}$$

Fig.4 shows the forces at the tower produced by a guy under wind load, and Fig.5 shows the forces at the anchorage. At the tower, the vertical load produced
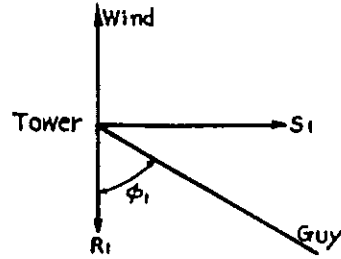
FIG. 4. - GUY FORCES
AT TOWER
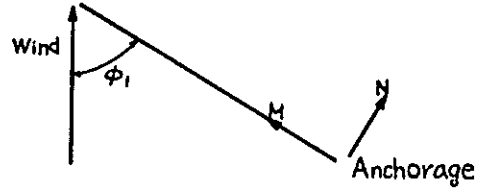
FIG. 5. - GUY FORCES
AT ANCHORAGE

by the guy is Z_1 and the tension in the guy is T_3. At the anchorage, the vertical uplift is Z_2 and the guy tension is T_4.

If H_1 is the tension in the guy of Fig.3 comparable to H of Fig.1, it is possible to write

$$\tan \rho'_1 = \tan \omega_1 + \frac{W_r}{2H_1} \quad \ldots\ldots\ldots\ldots (17a)$$

$$\tan \rho'_2 = \tan \omega_1 - \frac{W_r}{2H_1} \quad \ldots\ldots\ldots\ldots (17b)$$

$$V'_1 = H_1 \tan \rho'_1 \quad \ldots\ldots\ldots\ldots\ldots (17c)$$

$$V'_2 = H_1 \tan \rho'_2 \quad \ldots\ldots\ldots\ldots\ldots (17d)$$

$$T_3 = H_1 \sec \rho'_1 \quad \ldots\ldots\ldots\ldots\ldots (17e)$$

$$T_4 = H_1 \sec \rho'_2 \quad \ldots\ldots\ldots\ldots\ldots (17f)$$

$$R_1 = H_1 \cos \beta_2 + V'_1 \cos \beta_1 \quad \ldots\ldots\ldots\ldots (17g)$$

$$S_1 = H_1 \cos \alpha_2 + V'_1 \cos \alpha_1 \quad \ldots\ldots\ldots\ldots (17h)$$

$$Z_1 = H_1 \cos \gamma_2 - V'_1 \cos \gamma_1 \quad \ldots\ldots\ldots\ldots (17i)$$

$$M = H_1 (\sin \phi_1 \cos \alpha_2 + \cos \phi_1 \cos \beta_2)$$

$$+ V'_2 (\sin \phi_1 \cos \alpha_1 + \cos \phi_1 \cos \beta_1) \quad \dots \quad (17j)$$

$$N = H_1 (\sin \phi_1 \cos \beta_2 - \cos \phi_1 \cos \alpha_2)$$

$$+ V'_2 (\sin \phi_1 \cos \beta_1 - \cos \phi_1 \cos \alpha_1) \quad \dots \quad (17k)$$

and $$Z_2 = -H_1 \cos \gamma_2 - V'_2 \cos \gamma_1 \quad \dots \dots \quad (17l)$$

Note that V'_1 is parallel to W_r and H_1 is normal to W_r.

For any particular value of Δ and temperature, t, the value of H_1 is determined by trial as follows:

1. Assume a value for H_1,

2. Compute $$L_1 = a_1 \left(\sec \omega_1 + \frac{W_r^2}{24 H_1^2 \sec^3 \omega_1} \right) \quad \dots \quad (18)$$

3. Compute $$\Delta'_g = \frac{H_1 a_1}{A_g E_g} \left(\sec^2 \omega_1 + \frac{W_r^2}{12 H_1^2} \right) \quad \dots \dots \quad (19a)$$

4. Compute $$L'_t = L_1 - \Delta'_g \quad \dots \dots \dots \dots \quad (19b)$$

5. Compare the value of L'_t given by Eq. 19b with that given by Eq. 5. Because the unstressed length of the guy is invariant, these two values should be the same. If the values do not agree, assume a new value for H_1 and repeat the calculations until satisfactory agreement is reached.

Having obtained a value for H_1, forces at the tower, anchorage, and the guy tensions may be found by application of Eqs. 17c to 17l, inclusive.

This same procedure is applied to all the guys at one level. Having determined the forces at the tower for

each of the guys, resultants can be found by super-
position: Thus

$$R = \sum R_1, \quad \dots \dots \dots \dots \dots \dots \dots \dots \quad (20)$$

and
$$Z = \sum Z_1, \quad \dots \dots \dots \dots \dots \dots \dots \dots \quad (21)$$

in which R = the net guy reaction in a direction op-
posed to the wind at the guy level in question and
Z = the total vertical, down load produced by the guys
at the tower. Because the resultant, Z, of the Z_1
forces is eccentric to the centroid of the tower shaft,
an external moment, $\bar{M}$, will be introduced at the guy
level. If e is the distance of the application of
the load Z_1 to the centroid of the tower shaft in the
direction of the wind,

$$\bar{M} = \sum Z_1 e \quad \dots \dots \dots \dots \dots \dots \dots \dots \quad (22)$$

Because $\bar{M}$ is considered to be positive when it produces
compression on the windward side of the tower, windward
guys will have positive e values and lee guys, negative
values.

In Fig. 6, values of R are plotted for tower deflection
values Δ.
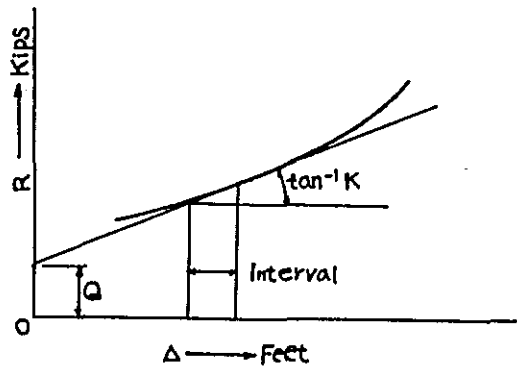
FIG. 6.   R-Δ CURVE FOR GUYS AT
         ONE LEVEL

If it is assumed that the change in R is linear for two successive values of Δ, then

$$R = K\Delta + Q \quad \dots\dots\dots\dots\dots\dots\dots \quad (23)$$

for the selected interval. The values of K and Q are simply computed from the values of R at the lower and upper bounds of the Δ interval. Thus, the two constants, K and Q, associated with each value of Δ, (e.g., the upper bound of the interval) define the value of R for that interval. Because the slope of the R- Δ curve changes from interval to interval, values of K and Q will vary with Δ.

Similarly,

$$\bar{M} = B\Delta + E, \quad \dots\dots\dots\dots\dots\dots \quad (24)$$

$$Z = O\Delta + J, \quad \dots\dots\dots\dots\dots\dots \quad (25)$$

1-5 Tower analysis

Fig.7 shows the forces acting on two spans of a multiguyed tower. W_n and W_{n+1} = uniformly distributed wind loads; M_{n-1}, M'_n, M_n, and M'_{n+1} = the internal resisting moments; $\bar{M}_n$ = the external moment produced by the guys; P_{n+1} = the total force acting down above guy level n+1 including the vertical Z loads at this guy level; and Pn = the similar load above guy level n. Positive directions of the loads and moments are shown.

To maintain continuity at joint n, Timoshenko established the relationship

$$M'_n \ \frac{1_n}{3EI_n} \ \psi \ (u_n) + M_{n-1} \ \frac{1_n}{6EI_n} \ \phi \ (u_n)$$

$$+ \ W_n \ \frac{1_n^2}{24EI_n} \ \chi \ (u_n) - \frac{\partial'}{1_n}$$

$$+ M_n \frac{1_{n+1}}{3EI_{n+1}} \psi (u_{n+1}) + M'_{n+1} \frac{1_{n+1}}{6EI_{n+1}} \phi (u_{n+1})$$

$$+ W_{n+1} \frac{1^2_{n+1}}{24EI_{n+1}} \chi (u_{n+1}) + \frac{\delta'_{n+1}}{1_{n+1}} = 0 \ldots \quad (26)$$

in which I_n, I_{n+1}, = the moment of inertia of beams of span n and n+1, and E = the modulus of elasticity of the tower shaft,

$$U = \frac{\ell}{2} \sqrt{\frac{P}{EI}} \quad \ldots \ldots \ldots \ldots \ldots \quad (27)$$

$$\phi (u) = \frac{3}{u} \left(\frac{1}{\sin 2u} - \frac{1}{2u} \right) \quad \ldots \ldots \ldots \quad (28)$$

$$\psi (u) = \frac{3}{2u} \left(\frac{1}{2u} - \frac{1}{\tan 2u} \right) \quad \ldots \ldots \ldots \quad (29)$$
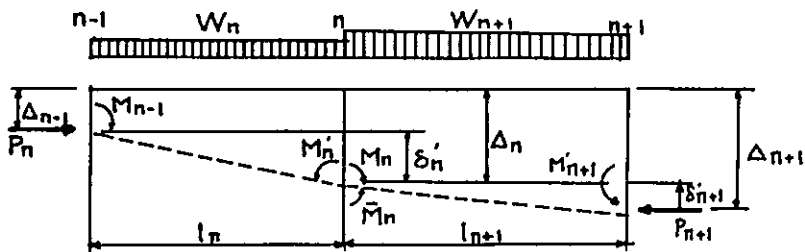
FIG. 7. FORCES ON TWO CONTINUOUS SPANS OF TOWER SHAFT

and
$$X(u) = \frac{3(\tan u - u)}{u^3} \quad \dots \dots \dots \dots \dots \dots \dots (30)$$

Because
$$\left. \begin{aligned} M'_n &= M_n + \bar{M}_n, \\ M'_{n+1} &= M_{n+1} + \bar{M}_{n+1}, \\ \delta'_n &= \Delta_n - \Delta_{n-1}, \quad \text{and} \\ \delta'_{n+1} &= \Delta_{n+1} - \Delta_n, \end{aligned} \right\} \quad \dots \dots \dots \dots \dots \dots (31)$$

Eq. 26 may be written

$$4M_{n-1} \frac{l_n}{I_n} \phi(u_n) + 8M_n \left[\frac{l_n}{I_n} \psi(u_n) + \frac{l_{n+1}}{I_{n+1}} \psi(u_{n+1}) \right]$$

$$+ 4(M_{n+1} + \bar{M}_{n+1}) \frac{l_{n+1}}{I_{n+1}} \phi(u_{n+1})$$

$$+ 8\bar{M}_n \frac{l_n}{I_n} \psi(u_n) + W_n \frac{l_n^2}{I_n} X(u_n) + W_{n+1} \frac{l_{n+1}^2}{I_{n+1}} X(u_{n+1})$$

$$= 24E \left[\frac{\Delta_n - \Delta_{n-1}}{l_n} - \frac{\Delta_{n+1} - \Delta_n}{l_{n+1}} \right] \quad \dots \dots \dots (32)$$

Eq. 32 is the typical continuity equation.

Fig.8 shows free body diagrams of the spans of Fig.7 with applied forces as indicated. For equilibrium, V'_n and V_n are given by

$$\left. \begin{aligned} V'_n &= \frac{W_n}{2} + \frac{M_{n-1} - M'_n}{l_n} + \frac{P_n}{l_n} (\Delta_n - \Delta_{n-1}), \\ V_n &= \frac{W_{n+1}}{2} + \frac{M'_{n+1} - M_n}{l_{n+1}} - \frac{P_{n+1}}{l_{n+1}} (\Delta_{n+1} - \Delta_n), \end{aligned} \right\} \quad \dots (33)$$

Because $R_n = V'_n + V_n$, and using the first two values of Eq. 32, the value of R_n is given by

$$R_n = \frac{1}{2} (W_n + W_{n+1}) + \frac{M_{n-1}}{l_n} - M_n(\frac{1}{l_n} + \frac{1}{l_{n+1}}) + \frac{M_{n+1}}{l_{n+1}} - \frac{\bar{M}_n}{l_n}$$

$$+ \frac{\bar{M}_{n+1}}{l_{n+1}} + \frac{P_n}{l_n} (\Delta_n - \Delta_{n-1}) - \frac{P_{n+1}}{l_{n+1}} (\Delta_{n+1} - \Delta_n) \quad ..(34)$$

Eq. 34 is the typical interior reaction equation.
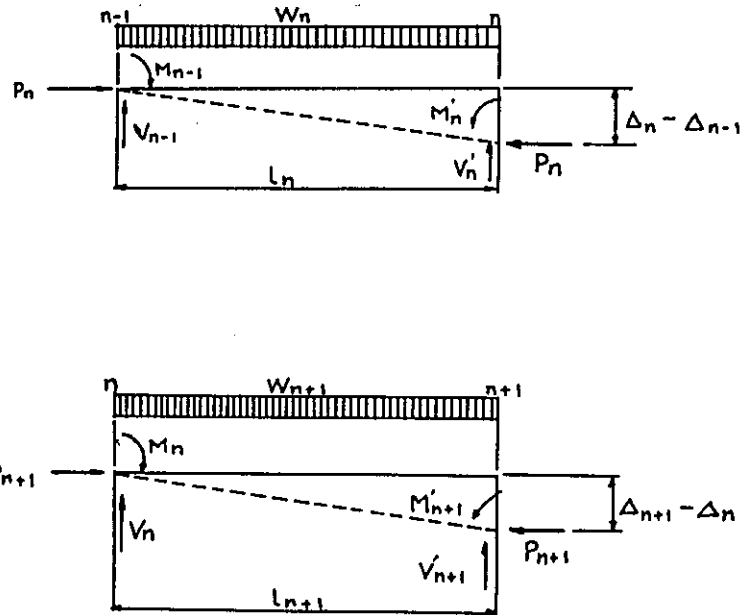
FIG. 8 . - FREE BODY DIAGRAMS OF TWO
CONTINUOUS SPANS OF TOWER SHAFT

For a tower with m spans, the continuity and reaction
equations, Eqs. 32 and 34 must be modified for the
end spans. For continuity at support 1, Eq.32 becomes

$$4M_o \frac{l_1}{I_1} \phi (u_1) + 8M_1 [\frac{l_1}{I_1} \psi (u_1) + \frac{l_2}{I_2} \psi (u_2)]$$

$$+ 4(M_2 + \bar{M}_2) \frac{l_2}{I_2} \phi (u_2) + 8\bar{M}_1 \frac{l_1}{I_1} \psi (u_1)$$

$$+ W_1 \frac{l_1^2}{I_1} \chi (u_1) + W_2 \frac{l_2}{I_2} \chi (u_2) = 24E [\frac{\Delta_1}{l_1} - \frac{\Delta_2 - \Delta_1}{l_2}] \quad ..(35)$$

and at support m-1, the term M_{m+1} is omitted. For the reaction at the first support, Eq. 34 becomes

$$R_1 = \frac{1}{2} (W_1 + W_2) + \frac{M_o}{l_1} - M_1(\frac{1}{l_1} + \frac{1}{l_2}) + \frac{M_2}{l_2} - \frac{\bar{M}_1}{l_1} + \frac{\bar{M}_2}{l_2}$$

$$+ \frac{P_1}{l_1}\Delta_1 - \frac{P_2}{l_2} (\Delta_2 - \Delta_1) , \quad \ldots\ldots\ldots\ldots \quad (36)$$

and for the reaction at m

$$R_m = \frac{1}{2} (W_m) + \frac{M_{m-1}}{l_m} - \frac{\bar{M}_m}{l_m} + \frac{P_m}{l_m} (\Delta_m - \Delta_{m-1}) \quad .. \quad (37)$$

If the tower is hinged at the base, $M_o = 0$ in the above equations. I the base is fixed there is no angle change and

$$M_o = \frac{l_1}{3EI_1} \psi (u_1) + M'_1 \frac{l_1}{6EI_1} \phi (u_1)$$

$$+ W_1 \frac{l_1^2}{24EI_1} \chi (u_1) + \frac{\Delta_1}{l_1} = 0 \quad \ldots\ldots\ldots\ldots \quad (38a)$$

or

$$8M_o + \frac{l_1}{I_1} \psi (u_1) + 4(M_1 + \bar{M}_1) \frac{l_1}{I_1} \phi (u_1)$$

$$+ W_1 \frac{l_1^2}{I_1} \chi (u_1) + 24E \frac{\Delta_1}{l_1} = 0 \quad \ldots\ldots\ldots\ldots \quad (38b)$$

For a tower with m guy levels, 2 m equations can be written for a fixed base and 2 m-1 equations can be written for a hinged base. The unknowns in these equations are M_o, M_1, ... M_{m-1}, and R_1, R_2, ... R_m.

The above equations contain values of the tower deflections Δ_1, Δ_2, etc., that are also unknown, thereby increasing the number of unknowns to 3 m for a fixed base and 3 m-1 for a hinged base. If

use is made of the constants K, Q, B, E, O, and J, the Δ values can be eliminated, thus reducing the number of unknowns to the same number of available equations.

From Eqs. 23, 24, and 25,

$$\Delta_1 = \frac{R_1 - Q_1}{K_1} \qquad \bar{M}_1 = \frac{B_1}{K_1}(R_1 - Q_1) + E_1$$

$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \ldots \ (39)$$

$$\Delta_2 = \frac{R_2 - Q_2}{K_2} \qquad \bar{M}_2 = \frac{B_2}{K_2}(R_2 - Q_2) + E_2$$

$$\qquad \text{etc.} \qquad\qquad\qquad\qquad \text{etc.}$$

in which Δ_1 = the deflection at guy level 1, Δ_2 = the deflection at guy level 2, etc. By means of Eqs. 39 and the first two of Eqs. 31 the general continuity equation, Eq. 32 becomes

$$4M_{n-1}\frac{l_n}{I_n}\phi\,(u_n) + 8M_n\,[\frac{l_n}{I_n}\psi\,(u_n) + \frac{l_{n+1}}{I_{n+1}}\psi\,(u_{n+1})]$$

$$+\ 4\,\frac{l_{n+1}}{I_{n+1}}\phi\,(u_{n+1})\,[M_{n+1} + \frac{B_{n+1}}{K_{n+1}}(R_{n+1} - Q_{n+1}) + E_{n+1}]$$

$$+\ 8\,\frac{l_n}{I_n}\psi\,(u_n)\,[\frac{B_n}{K_n}(R_n - Q_n) + E_n]$$

$$+\ W_n\,\frac{l_n^2}{I_n}\,\chi\,(u_n) + W_{n+1}\,\frac{l_{n+1}^2}{I_{n+1}}\,\chi\,(u_{n+1})$$

$$=\ 24E\left\{(\frac{1}{l_n} + \frac{1}{l_{n+1}})\,(\frac{R_n - Q_n}{K_n}) - \frac{1}{l_n}\,(\frac{R_{n-1} - Q_{n-1}}{K_{n-1}})\right.$$

$$\left. -\ \frac{1}{l_{n+1}}\,(\frac{R_{n+1} - Q_{n+1}}{K_{n+1}})\right\} \quad \ldots\ldots\ldots\ldots\ldots\ (40)$$

and the general interior reaction equation, Eq. 34, becomes

$$R_n = \frac{1}{2}(W_n + W_{n+1}) - M_n\left(\frac{1}{l_n} + \frac{1}{l_{n+1}}\right) + \frac{M_{n-1}}{l_n} + \frac{M_{n+1}}{l_{n+1}}$$

$$- \frac{1}{l_n}\left[\frac{B_n}{K_n}(R_n - Q_n) + E_n\right] + \frac{1}{l_{n+1}}\left[\frac{B_{n+1}}{K_{n+1}}(R_{n+1} - Q_{n+1}) + E_{n+1}\right]$$

$$+ \left[\frac{P_n}{l_n} + \frac{P_{n+1}}{l_{n+1}}\right]\left[\frac{R_n - Q_n}{K_n}\right] - \frac{P_n}{l_n}\left[\frac{R_{n-1} - Q_{n-1}}{K_{n-1}}\right] - \frac{P_{n+1}}{l_{n+1}}\left[\frac{P_{n+1} - Q_{n+1}}{K_{n+1}}\right]$$

$$\dots\dots\dots\dots \quad (41)$$

Guy constants O_1, J_1, etc., are used to determine
values of P_1, P_2, etc., as will be described hereafter.

In a similar manner, values of Δ can be eliminated
from the end span equations.

In many cases, the span above the top guy is canti-
levered and, in some instances, this cantilevered span
is loaded with an antenna pull-off with an additional
moment and vertical load applied at the top of the
tower. Assuming a cantilever above the mth guy level,
as indicated in Fig. 9 , and neglecting the effect
on the moments caused by the force T in span l_c, the
value of Δc is given by

$$\Delta_c = \Delta_m + \frac{1}{EI_c}\left[\frac{THl_c^3}{3} + \frac{W_c l_c^3}{8} + \frac{TMl_c^2}{2}\right] - l_c\theta_m \quad \dots \quad (42)$$

in which θ_m is the angle change at m and I_c is the
moment of inertia of the cantilevered span. In the
usual design cases, θ_m is small and will therefore
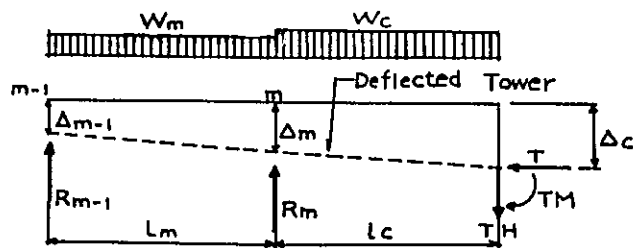
FIG. 9 . - LOADS ON CANTILEVERED SPAN OF TOWER
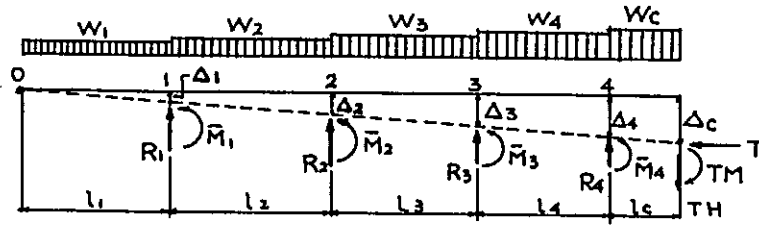
FIG. 10. - FOUR-SPAN TOWER WITH CANTILEVER

be considered herein to be = 0. A method for including the actual value of θm is presented subsequently.

For θm = 0, Eq. 42 becomes

$$\Delta_c = \Delta_m + \xi \quad \dots\dots\dots\dots\dots \quad (43)$$

in which

$$\xi = \frac{1_c^2}{24EI_c} \ [1_c(8TH + 3W_c) + 12TM] \ \dots \ (44)$$

The cantilever moment, G, at m is given by

$$G = W_c \frac{1_c}{2} + TH1_c + TM + \xi \ (T + 0.5D_c) \ \dots \ (45)$$

in which D_c is the total weight of the cantilever.

As an example, equations for a 4-span tower with a hinged base and cantilever with pull-off, as shown in Fig.10, are as follows:

$$R_1 = \frac{1}{2}(W_1 + W_2) - M_1(\frac{1}{1_1} + \frac{1}{1_2}) + \frac{M_2}{1_2} - \frac{1}{1_1}[\frac{B_1}{K_1}(R_1 - Q_1) + E_1]$$

$$+ \frac{1}{1_2}[\frac{B_2}{K_2}(R_2 - Q_2) + E_2] + (\frac{P_1}{1_1} + \frac{P_2}{1_1})(\frac{R_1 - Q_1}{K_1}) - \frac{P_2}{1_2}(\frac{R_2 - Q_2}{K_2}) \ \dots (46)$$

$$R_2 = \frac{1}{2}(W_2+W_3) - M_2(\frac{1}{I_2} + \frac{1}{I_3}) + \frac{M_1}{I_2} + \frac{M_3}{I_3} - \frac{1}{I_2}[\frac{B_2}{K_2}(R_2-Q_2)+E_2]$$

$$+ \frac{1}{I_3}[\frac{B_3}{K_3}(R_3-Q_3)+E_3] + (\frac{P_2}{I_2} + \frac{P_3}{I_3})(\frac{R_2-Q_2}{K_2})$$

$$- \frac{P_2}{I_2}(\frac{R_1-Q_1}{K_1}) - \frac{P_3}{I_3}(\frac{R_3-Q_3}{K_3}) \quad\dots\dots\dots\dots (47)$$

$$R_3 = \frac{1}{2}(W_3+W_4) - M_3(\frac{1}{I_3} + \frac{1}{I_4}) + \frac{M_2}{I_3} - \frac{G}{I_4} - \frac{1}{I_3}[\frac{B_3}{K_3}(R_3-Q_3)+E_3]$$

$$+ \frac{1}{I_4}[\frac{B_4}{K_4}(R_4-Q_4)+E_4] + (\frac{P_3}{I_3} + \frac{P_4}{I_4})(\frac{R_3-Q_3}{K_3})$$

$$- \frac{P_3}{I_3}(\frac{R_2-Q_2}{K_2}) - \frac{P_4}{I_4}(\frac{R_4-Q_4}{K_4}) \quad\dots\dots\dots\dots (48)$$

$$R_4 = \frac{W_4}{2} + W_c + TH + \frac{M_3+G}{I_4} - \frac{1}{I_4}[\frac{B_4}{K_4}(R_4-Q_4) + E_4]$$

$$+ \frac{P_4}{I_4}(\frac{R_4-Q_4}{K_4} - \frac{R_3-Q_3}{K_3}) \quad\dots\dots\dots\dots\dots (49)$$

$$8M_1[\frac{l_1}{I_1}\psi(u_1)+ \frac{l_2}{I_2}\psi(u_2)] + 4\frac{l_2}{I_2}\phi(u_2)[M_2+\frac{B_2}{K_2}(R_2-Q_2)] + E_2$$

$$+ 8\frac{l_1}{I_1}\psi(u_1)[\frac{B_1}{K_1}(R_1-Q_1)+E_1] + W_1\frac{l_1^2}{I_1}\chi(u_1) + W_2\frac{l_1^2}{I_2}\chi(u_2)$$

$$= 24E\left\{(\frac{1}{I_1} + \frac{1}{I_2})(\frac{R_1-Q_1}{K_1}) - \frac{1}{I_2}(\frac{R_2-Q_2}{K_2})\right\} \quad\dots (50)$$

$$4M_1\frac{l_2}{I_2}\phi(u_2)+8M_2[\frac{l_2}{I_2}\psi(u_2)+ \frac{l_3}{I_3}\psi(u_3)]+4\frac{l_3}{I_3}\phi(u_3)[M_3+\frac{B_3}{K_3}(R_3-Q_3)+E_3]$$

$$+ 8\frac{l_2}{I_2}\psi(u_2)[\frac{B_2}{K_2}(R_2-Q_2)+E_2] + W_2\frac{l_2^2}{I_2}\chi(u_2) + W_3\frac{l_3^2}{I_3}\chi(u_3)$$

$$= 24E\left\{(\frac{1}{I_2} + \frac{1}{I_3})(\frac{R_2-Q_2}{K_2}) - \frac{1}{I_2}(\frac{R_1-Q_1}{K_1}) - \frac{1}{I_3}(\frac{R_3-Q_3}{K_3})\right\} \dots (51)$$

and

$$4M_2 \frac{1_3}{I_3} \phi(u_3) + 8M_3[\frac{1_3}{I_3} \psi(u_3) + \frac{1_4}{I_3} \psi(u_4)]$$

$$+ 4 \frac{1_4}{I_4} \phi(u_4)[-G + \frac{B_4}{K_4}(R_4-Q_4) + E_4]$$

$$+ 8 \frac{1_3}{I_3} \psi(u_3)[\frac{B_3}{K_3}(R_3-Q_3) + Ec]$$

$$+ W_3 \frac{1_3^2}{I_3} \chi(u_3) + W_4 \frac{1_4^2}{I_4} \chi(u_4)$$

$$= 24E\left\{(\frac{1}{1_3} + \frac{1}{1_4})(\frac{R_3-Q_3}{K_3}) - \frac{1}{1_3}(\frac{R_2-Q_2}{K_2}) - \frac{1}{1_4}(\frac{R_4-Q_4}{K_4})\right\} \quad .. \quad (52)$$

The P values in the above equations are determined as follows: Let D_1 = dead load of span 1, D_2 = dead load of span 2, etc. Because $Z_1 = O_1\Delta_1 + J_1$, $Z_2 = O_2\Delta_2 + J_2$, etc. Then $P_4 = T + D_c + Z_4 + 5D_4$, $P_3 = P_4 + Z_3 + .5(D_3 + D_4)$, $P_2 = P_3 + Z_2 + .5(D_2 + D_3)$ and $P_1 = P_2 + Z_1 + .5(D_1 + D_2)$.

In Eqs. 46-52, the unknowns are R_1, R_2, R_3, R_4, M_1, M_2, and M_3. The values of the unknowns are found by a solution of the seven simultaneous equations. Having determined the reactions, the deflections and remaining moments can be computed by means of Eqs. 23, 24, and 25.

1-6   Notation

The following symbols have been adopted for use in this paper:

    a = horizontal projection of guy in normal position;

    a_1 = projection of guy normal to resultant of guy loads;

    a_2 = horizontal projection of guy chord with tower motion;

$a_0, a_1, \ldots$ = coefficients in polynomial expression for drag coefficient;

B_n = a constant for guys at guy level n;

$b_0, b_1, \ldots$ = coefficients in polynomial expression for lift coefficient;

C = chord length of guy;

C_D = coefficient for drag force on guy;

C_L = coefficient for lift force on guy;

D_c = dead load of cantilever span of tower shaft;

D_n = dead load of span n of tower shaft;

DI_n = weight of insulator strings at guy level n;

d = diameter of guy;

d_0 = total drag force on guy;

E = modulus of elasticity of tower shaft;

Eg = modulus of elasticity of guy;

E_n = a constant for guys at guy level n;

e = moment arm for vertical component of guy force about centroid of tower shaft;

H = horizontal component of tension in guy for guy in normal position;

H_1 = component of tension in guy parallel to a_1;

h = height of guy above anchorage at normal temperature, also panel height of web members of triangular tower;

h_t = height of guy above anchorage at temperature t;

h_1 = projection of guy parallel to W_r;

I_c = moment of inertia of cantilever span of tower shaft;

I_n = moment of inertia of span n of tower shaft;

J_n = a constant for guys at guy level n;

K_n = a constant for guys at guy level n;

L = stretched length of guy in normal position;

L_1 = stretched length of guy under wind load at temperature t;

L_o = no stress length of guy in normal position;

L_1 = no stress length of guy in normal position at temperature t;

L'_t = no stress length of guy under wind load at temperature t;

l = vertical component of lift on guy;

l_1 = total lift on guy;

l_h = horizontal component of lift on guy;

l_n = length of span n of tower shaft;

M = horizontal guy force at anchorage in guy direction under wind loading;

M_n = internal resisting moment in tower shaft immediately above guy level n;

M'_n = internal resisting moment in tower shaft immediately below guy level n;

m = top guy level of tower;

N = horizontal guy force at anchorage normal to M under wind loading;

n = guy level number;

O_n = a constant for guys at guy level n;

P_n = total vertical load on tower shaft at guy level n;

Q_n = a constant for guys at guy level n;

Q_1 = shear in triangular tower in direction 1;

Q_2 = shear in triangular tower in direction 2;

R_n = guy reaction at guy level n;

S_1 = component of guy force at tower normal to wind direction;

s = width of face of triangular tower;

T = vertical component of pull-off load at tower top;

T_1 = erection tension in guy at tower at normal temperature;

T_2 = erection tension in guy at anchorage at normal temperature;

T_3 = guy tension at tower under wind loading;

T_4 = guy tension at anchorage under wind loading;

TH = horizontal component of pull-off load at tower top;

TM = moment at tower top caused by pull-off load;

t = temperature;

t_o = normal temperature

V_n = shear immediately above guy level n;

$V'n$ = shear immediately below guy level n;

V_1 = vertical component of guy tension at tower, guy in normal position;

V'_1 = component of guy tension at tower parallel to W_r;

V'_2 = component of guy tension at anchorage parallel to W_r;

v = wind velocity;

vp = velocity pressure of wind;

W = total weight of guy;

DECCA 110 METERS TOWER

*** TOWER DATA (1) ***

SPAN	BASE H.	LENGTH	HEIGHT	I	SECT. AREA	WEIGHT	DRAG AREA	C
G-B	300.00							
1		2700.00	3000.00	77600.	46.56	4.05	46.460	
2		2700.00	5700.00	77600.	46.56	4.05	46.460	
3		2700.00	8400.00	77600.	46.56	4.05	46.460	
4		2600.00	11000.00	77600.	46.56	3.90	46.460	
5		0.00	11000.00	100.	1.00	0.00	0.000	

MODULUS OF ELASTICITY OF TOWER SHAFT = 2000.

TEMPERATURE = 30.0   NORMAL TEMP.= 30.0

B-23

DECCA 110 METERS TOWER

*** LOCATION DATA ***

GUY		ANGLE	VERT.	HORIZ.		...... REFERENCE		
LEVEL	SET	TRUE BEG.	HT	A		HANC	A₁	LEVER ARM
1	1	60.000	2950.0	6959.0		50.0	7000.0	41.0
1	2	180.000	2950.0	6959.0		50.0	7000.0	41.0
1	3	300.000	2950.0	6959.0		50.0	7000.0	41.0
2	1	60.000	5650.0	6959.0		50.0	7000.0	41.0
2	2	180.000	5650.0	6959.0		50.0	7000.0	41.0
2	3	300.000	5650.0	6959.0		50.0	7000.0	41.0
3	1	60.000	8350.0	6959.0		50.0	7000.0	41.0
3	2	180.000	8350.0	6959.0		50.0	7000.0	41.0
3	3	300.000	8350.0	6959.0		50.0	7000.0	41.0
4	1	0.000	10970.0	11929.0		30.0	12000.0	71.0
4	2	22.500	10970.0	11929.0		30.0	12000.0	71.0
4	3	45.000	10970.0	11929.0		30.0	12000.0	71.0
4	4	67.500	10970.0	11929.0		30.0	12000.0	71.0
4	5	90.000	10970.0	11929.0		30.0	12000.0	71.0
4	6	112.500	10970.0	11929.0		30.0	12000.0	71.0
4	7	135.000	10970.0	11929.0		30.0	12000.0	71.0
4	8	157.500	10970.0	11929.0		30.0	12000.0	71.0
4	9	160.000	10970.0	11929.0		30.0	12000.0	71.0
4	10	202.500	10970.0	11929.0		30.0	12000.0	71.0
4	11	225.000	10970.0	11929.0		30.0	12000.0	71.0
4	12	247.500	10970.0	11929.0		30.0	12000.0	71.0
4	13	270.000	10970.0	11929.0		30.0	12000.0	71.0
4	14	292.500	10970.0	11929.0		30.0	12000.0	71.0
4	15	315.000	10970.0	11929.0		30.0	12000.0	71.0
4	16	337.500	10970.0	11929.0		30.0	12000.0	71.0

DECCA 110 METERS TOWER

** GUY DIMENSION ***

| | | | WIRE WEIGHT (T/CM) | | | | | | BREAK-UP INSULATOR | | |
LEVEL	SET	TENSION	NO ICE	WITH ICE	DIAM.	SECT. AREA	E	NO.	LENGTH	WEIGHT
1	1	5.06	0.1163E-03	0.1163E-03	2.20	2.90	1600.00	0	0.00	0.00
1	2	5.06	0.1163E-03	0.1163E-03	2.20	2.90	1600.00	0	0.00	0.00
1	3	5.06	0.1163E-03	0.1163E-03	2.20	2.90	1600.00	0	0.00	0.00
2	1	4.03	0.1018E-03	0.1018E-03	2.20	2.90	1600.00	0	0.00	0.00
2	2	4.03	0.1018E-03	0.1018E-03	2.20	2.90	1600.00	0	0.00	0.00
2	3	4.03	0.1018E-03	0.1018E-03	2.20	2.90	1600.00	0	0.00	0.00
3	1	4.39	0.8810E-04	0.8810E-04	2.20	2.90	1600.00	0	0.00	0.00
3	2	4.39	0.8810E-04	0.8810E-04	2.20	2.90	1600.00	0	0.00	0.00
3	3	4.39	0.8810E-04	0.8810E-04	2.20	2.90	1600.00	0	0.00	0.00
4	1	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	2	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	3	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	4	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	5	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	6	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	7	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	8	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	9	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	10	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	11	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	12	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	13	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	14	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	15	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00
4	16	0.40	0.9650E-05	0.9650E-05	1.26	0.97	1600.00	0	0.00	0.00

DECCA 110 METERS TOWER

*** WIND DATA ***

```
BASIC WIND VELOCITY        =      35.0   M/S
STANDARD HEIGHT            =    1500.    CM
ESCALATION CUTOFF HEIGHT = 11000.    CM
ESCALATION EXPONENT        =       0.143000

WIND INJECTION ANGLE       =     180.000 DEG (TRUE BEARING)
```

MODIFICATION COEFFICIENT OF TOWER INPUT DATA BY CHANGE OF WIND ANGLE   I 1.000
                                                                                                                   CD 1.000

TOWER DATA (2)

SPAN	MOD. I	MOD. CD	WIND LOAD
1	0.7760E+05	1.820	1.863
2	0.7760E+05	1.820	2.362
3	0.7760E+05	1.820	2.718
4	0.7760E+05	1.820	2.869
5	0.1000E+03	1.000	0.000

*** LOCAL LOAD (AT GUY LEVEL) ***

LEVEL	...... LOCAL LOAD			...EXT. MOM. ...	
	VERT.	WINDWARD	NORMAL	WINDWARD	NORMAL
1	1.500	0.250	0.000	0.000	0.000
2	1.510	0.300	0.000	0.000	0.000
3	1.510	0.330	0.000	0.000	0.000
4	0.670	0.300	0.000	0.000	0.000

*** PULL OFF LOAD (AT TOWER TOP) ***

```
TH =     0.00    TM =     0.00    TN =     0.00    TH1 =    0.00    TM1 =    0.00
```

ERROR FUNCTION SQRT(-X)   RESULT=SQRT(ABS(X))   PN-000032 IC-64CF SFG02

ERROR FUNCTION SQRT(-X)   RESULT=SQRT(ABS(X))   PN-000032 IC-64CF SEG02

DECCA 110 METERS TOWER

*** GUY LENGTH ***

LEVEL	GUY SET	GUY ANGLE (TBG)	WITH WIND (CCW)	TENSION	GUY LENGTH UNSTRESSED	CATENARY	GUY TOTAL WEIGHT	WIND VEL. ON GUY
1	1	60.000	300.000	5.060	7557.5	7566.0	0.879	35.8
1	2	180.000	180.000	5.060	7557.5	7566.0	0.879	35.8
1	3	300.000	60.000	5.060	7557.5	7566.0	0.879	35.8
2	1	60.000	300.000	4.029	8965.6	8973.9	0.913	37.9
2	2	180.000	180.000	4.029	8965.6	8973.9	0.913	37.9
2	3	300.000	60.000	4.029	8965.6	8973.9	0.913	37.9
3	1	60.000	300.000	4.391	10866.1	10877.2	0.957	39.7
3	2	180.000	180.000	4.391	10866.1	10877.2	0.957	39.7
3	3	300.000	60.000	4.391	10866.1	10877.2	0.957	39.7
4	1	0.000	0.000	0.398	16246.6	16251.3	0.157	40.7
4	2	22.500	337.500	0.398	16246.6	16251.3	0.157	40.7
4	3	45.000	315.000	0.398	16246.6	16251.3	0.157	40.7
4	4	67.500	292.500	0.398	16246.6	16251.3	0.157	40.7
4	5	90.000	270.000	0.398	16246.6	16251.3	0.157	40.7
4	6	112.500	247.500	0.398	16246.6	16251.3	0.157	40.7
4	7	135.000	225.000	0.398	16246.6	16251.3	0.157	40.7
4	8	157.500	202.500	0.398	16246.6	16251.3	0.157	40.7
4	9	180.000	180.000	0.398	16246.6	16251.3	0.157	40.7
4	10	202.500	157.500	0.398	16246.6	16251.3	0.157	40.7
4	11	225.000	135.000	0.398	16246.6	16251.3	0.157	40.7
4	12	247.500	112.500	0.398	16246.6	16251.3	0.157	40.7
4	13	270.000	90.000	0.398	16246.6	16251.3	0.157	40.7
4	14	292.500	67.500	0.398	16246.6	16251.3	0.157	40.7
4	15	315.000	45.000	0.398	16246.6	16251.3	0.157	40.7
4	16	337.500	22.500	0.398	16246.6	16251.3	0.157	40.7

DECCA 110 METERS TOWER

*** GUYS FORCE LIST ***

LEVEL	GUY	TENSION	UPLIFT	AT ANCHORAGE M	N	WIND	AT TOWER NORMAL	VERT.	AT ANCHORAGE INITIAL TENSION
1	1	4.66	1.32	4.11	0.06	-2.11	3.54	2.17	5.06
1	2	7.53	2.41	6.77	-0.00	6.76	0.00	3.32	5.06
1	3	4.66	1.32	4.11	-0.06	-2.11	-3.54	2.17	5.06
2	1	3.72	1.72	2.63	0.09	-1.41	2.28	2.59	4.03
2	2	7.68	4.16	5.77	-0.00	5.71	0.00	5.13	4.03
2	3	3.72	1.72	2.63	-0.09	-1.40	-2.28	2.59	4.03
3	1	3.85	2.22	2.18	0.12	-1.22	1.90	3.12	4.39
3	2	9.51	6.48	5.93	0.00	5.80	0.00	7.54	4.39
3	3	3.85	2.22	2.18	-0.12	-1.22	-1.90	3.12	4.39
4	1	0.06	-0.03	-0.04	-0.00	-0.05	0.00	0.04	0.40
4	2	0.29	0.13	0.13	0.04	-0.21	0.05	0.20	0.40
4	3	0.57	0.30	0.34	0.08	-0.34	0.24	0.39	0.40
4	4	0.86	0.48	0.56	0.11	-0.33	0.52	0.59	0.40
4	5	1.07	0.60	0.74	0.13	-0.12	0.74	0.76	0.40
4	6	1.18	0.66	0.85	0.11	0.21	0.79	0.86	0.40
4	7	1.20	0.66	0.88	0.08	0.52	0.62	0.89	0.40
4	8	1.17	0.64	0.87	0.04	0.71	0.33	0.87	0.40
4	9	1.16	0.63	0.86	0.00	0.77	0.00	0.87	0.40
4	10	1.17	0.64	0.87	-0.04	0.71	-0.33	0.87	0.40
4	11	1.20	0.66	0.88	-0.08	0.52	-0.62	0.89	0.40
4	12	1.18	0.66	0.85	-0.11	0.21	-0.79	0.86	0.40
4	13	1.07	0.60	0.74	-0.13	-0.12	-0.74	0.76	0.40
4	14	0.86	0.48	0.56	-0.11	-0.33	-0.52	0.59	0.40
4	15	0.57	0.30	0.34	-0.08	-0.34	-0.24	0.39	0.40
4	16	0.29	0.12	0.13	-0.04	-0.21	-0.05	0.20	0.40

DECCA 110 METERS TOWER

*** TOWER OUTPUT LIST ***

WIND DIRECTION

LEV	PHI	REACTION		MOMENT		VERTICAL	
		SLOPE K	INTERCEPT Q	SLOPE B	INTERCEPT E	SLOPE O	INTERCEPT J
1	1.47697	0.3922	-0.4361	6.7754	-4.4708	0.0792	7.0648
2	1.34221	0.2344	-0.6541	7.7377	-12.8216	0.1202	8.4942
3	1.20745	0.1616	-0.3242	7.8612	2.8597	0.1152	11.1564
4	1.06821	0.0368	0.4014	2.4731	138.1644	0.0307	9.1029

LEVEL	DEFLECTION	REACTION	MOMENT	MOM.PRIME	P
1	7.6	2.55	-289.02	-241.99	60.99
2	15.0	2.87	-249.30	-145.78	47.78
3	22.7	3.34	-316.83	-135.82	31.90
4	30.1	1.57	0.00	212.49	12.65

MOMENT AT BASE =   0.00   SHEAR AT BASE =   0.67   TOTAL CANTILEVER DEFLECTION = 30.055

DECCA 110 METERS TOWER

NORMAL DIRECTION

		REACTION		MOMENT		VERTICAL	
		SLOPE	INTERCEPT	SLOPE	INTERCEPT	SLOPE	INTERCEPT
LEV	PHI	K	Q	B	E	O	J
1	1.47697	0.2133	-0.0002	3.6695	-0.0033	0.0046	7.6640
2	1.34221	0.0900	-0.0005	2.9426	-0.0160	0.0056	10.3144
3	1.20745	0.0692	0.0003	3.3327	0.0171	0.0084	13.7721
4	1.06821	0.0390	-0.0001	2.4966	-0.0087	0.0019	10.0251

LEVEL	DEFLECTION	REACTION	MOMENT	MOM.PRIME	P
1	0.0	0.00	-0.06	-0.05	60.99
2	0.0	-0.00	0.25	0.24	47.78
3	-0.0	0.00	-0.29	-0.28	31.90
4	0.0	-0.00	0.00	-0.01	12.65

MOMENT AT BASE =　　0.00　　SHEAR AT BASE =　-0.00　　TOTAL CANTILEVER DEFLECTION =　0.001

Appendix C

Limitation of Decca service area due to noise

1   ## Origin and nature of noise

Most of the atmospheric noise in the world originates in thnder-
storms. At a given receiving location the atmospheric noise is
made up of noise from nearby centres of noise, such as local
thunderstorms whose distance from the receiving location may
vary from a few miles to hundreds of miles, plus noise which
has been propagated from one or more of the principal centres
of noise generation, such as the active thunderstorm areas in
equatorial Africa, Central America and the East Indies. The
location and activity of the various centres vary with time
of day and season. The determination of atmospheric noise at
a given receiving location is thus a series of radio propa-
gation problems, in which the noise originating in each centre
of storm activity produces a definite field intensity at the
receiving locations.

2   ## Interpretations of coverage diagrams
     ## based on noise limitations

Too rigid an interpretation should not be made of diagrams
intended to show coverage due to noise limitations, owing to
the wide range over which the noise level may vary from day
to day and hour to hour. Such diagrams must be regarded as
presenting an overall picture of the general experience of
the System over a period. For this reason the useable range
will be considerably greater than that indicated during quiet
periods and for certain projects, when advantage can be taken
of such quiet periods to fly in areas normally beyond the
limiting range, the effective cover of a system may be consi-
derably enlarged. On the other hand, in tropical regions
the noise intensity over a small area may on occasions be so
great that signals will be blotted out temporarily at points
well within the nominal cover.

3   Determination of effective range
of a Decca transmitter under given conditions

The factors controlling the effective range of a Decca
transmitter are:-

(i)   The mean noise level.

(ii)   The percentage serviceability required and
       the amount by which the mean noise level may
       be exceeded during this percentage of the
       total time.

(iii) The power radiated by the transmitter.

(iv)   The conductivity of the soil over which the
       transmission path lies.

(v)   The type of Decca receiver to be used.

A method has been evolved of denoting the value of each
factor by a number so that the effective range of a trans-
mitter can be quickly obtained from the sum of the numbers.

The procedure is as follows:-

(a)   From CCIR Figures find the noise zone
       corresponding to the location of the Decca Chain.
       For 24 hours main chains use figures for periods
       2000 - 2400 and 0000 - 0400.

(b)   From Table I determine the noise level factor for
       the location and conditions required.

(c)   From Table II find the serviceability factor.

(d)   From Table III find the transmitter power factor.

(e)   From Table IV find the requirement factor.

Add all these together to obtain the Performance Factor and
against the line with this total value in the left hand
column of Table VI read (in the column headed with the appro-
priate soil conductivity letter) the effective range. Soil
conductivities for various types of terrain are given in
Table V.

It is the practice to use 85 kc/s as appropriate to the problem for planning purposes.

Example

What is the effective range of transmitter radiating 200 watts on 85 kc/s by daylight in Maracca Strait to give 98% serviceability of integration of a Mark 10 receiver over

5×10^{-14} e.m.u.

From C.C.I.R Noise Figures derive mean noise zone as 80.

Table I	Noise factor for day working	= 26
Table II	Serviceability factor for 98% service	= 11
Table III	Transmitter power for 200 watts (see table VII)	= 7
Table IV	Requirement factor for Mark 10 integration (Automatic Lane Setting)	= 9
	Performance factor = Total of above	= 53

From Table V it will be seen that the soil conductivity is Group C and looking in column C under 85 kc/s against entry 53 in the performance factor column in Table VI we find a range of 400 kms.

For survey work in choosing the "Requirement factor" it is of interest to note that (for given noise conditions) if the Decca field strength is gradually raised until there is just sufficient torque to operate the decometer, a further increase in level of 6 db will limit the decometer needle kicks to about 0.02 lane, the extent of the kicks being halved each time the field strength is doubled.

If a 95% serviceability level is adopted (requirement factor as given) torque will be maintained for 99.9% of the time and kicks of less than 0.01 lanes will be experienced at 75% of the time.

4   <u>Limitation of range by skywave at night (Mark 10)</u>

The effective range at night may be limited by cancellation or weakening of the groundwave signals reflected from the ionosphere.

For this reason the limit of night range is almost independent of the radiated power and depends only on the ground conductivity. The night skywave range limits are approximately as follows:-

Conductivity Group	Limiting Range (kms)
A	540
B	480
C	430
D	370
E	300

The effective range at night should be taken as the skywave limit or noise limit whichever is the lower.

5   <u>Graph   of typical conditions</u>

Graph   for the rapid solution of typical requirements is   appended.

Drawing Number   F.281   For 24 hour operation.

Note that in drawing F.281 during daylight periods, the coverage will be very considerably greater, as can be seen by full computation.

<u>Table I</u>

<u>50% level of atmospheric noise in db</u>
<u>above 1 μv/metre for ± 30 c.p.s. bandwidth</u>

Period 0800 - 1200 and 1200 - 1600 All Seasons		
Period 0400 - 0800 and 1600 - 2000 Spring and Summer		
C.C.I.R Noise Zone	Kc/s	
	85	127.5
90	37	33
80	31	27
70	25	21
60	20	15
50	14	8
40	8	2
30	3	- 4
20	- 2	- 9
10	- 6	- 15
0	- 10	- 20
Period 0000 - 0400 and 2000 - 2400 All Seasons		
Period 0400 - 0800 and 1600 - 2000 Autumn and Winter*		
C.C.I.R Noise Zone	Kc/s	
	85	127.5
100	40	37
90	31	28
80	23	20
70	16	12
60	9	3
50	2	- 5
40	- 4	- 12
30	- 10	- 20
20	- 15	- 29

*See note under Section 6-3 (a)

Note: For Mark 10 operation having ± 10 c.p.s. bandwidth lower the figures
above by 5 db i.e. for 40 read 35

Table II

Serviceability factor

(Difference in level between average amplitude of noise and amplitude not exceeded for given percentage of time)

Required Serviceability as Percentage of Operating Time	Serviceability Factor	
	85 Kc/s	127 Kc/s
50%	0	0
75%	4	5
90%	7	10
95%	$8^{1/2}$	12
98%	11	15
99%	$12^{1/2}$	17

Table III

Transmittor power factor
(db below 1 kw radiated power)

Radiated Power (watts)	Power Factor	Radiated Power (watts)	Power Factor
1	30	40	14
1.5	28	50	13
2	27	60	12
2.5	26	80	11
3	25	100	10
4	24	150	8
5	23	200	7
6	22	250	6
8	21	300	5
10	20	400	4
15	16	500	3
20	17	600	2
25	16	800	1
30	15	1,000	0

Table IV

Requirement factor

			REMARKS
Mark 10 Receiver	($\pm$ 10 c.p.s. bandwidth with locked oscillators)		
	Integration	0	
	Automatic Lane Setting	9	
	8.2f triggering	9	

Table V

Table of soil conductivity

Nature of Terrain	Column to be used in Table VI	Assumed Conductivity(e.m.u.)
Sea Water	A	5×10^{-11}
Good Soil	B	10^{-13}
Poor Soil	. C	5×10^{-14}
Sandy dry flat country and rocky soil, fresh water	D	2×10^{-14}
Desert and Mountainous	E	10^{-14}

Table VI

Performance factor

	(Field strength of groundwave in db above 1 μv/metre for transmitter radiating 1 kw)									
	85Kc/s					127 Kc/s				
*	A	B	C	D	E	A	B	C	D	E
80	32	32	32	32	32	32	32	32	32	32
78	37	37	37	37	35	37	37	37	37	35
76	45	45	43	42	40	45	45	42	40	39
74	58	56	56	52	48	58	56	53	50	46
72	72	71	71	64	58	72	71	66	60	55
70	90	90	88	80	72	90	90	83	75	67
69	103	101	98	90	80	102	100	90	80	72
68	116	114	109	100	88	115	113	100	90	78
67	130	128	122	111	100	128	126	110	100	85
66	140	137	131	125	120	137	134	120	110	95
65	155	152	145	137	130	151	148	135	120	105
64	180	176	168	154	140	176	172	155	135	115
63	190	184	175	162	150	185	179	165	145	125
62	205	200	190	177	165	200	195	180	155	130
61	230	225	215	195	175	225	220	200	170	140
60	250	245	235	215	190	245	235	215	185	155
59	270	264	249	226	204	265	250	225	195	165
58	290	284	269	244	219	285	270	240	210	175
57	320	313	293	263	233	310	295	260	225	185
56	350	343	323	290	258	340	325	285	240	195
55	380	373	343	308	273	365	345	300	255	205
54	410	403	373	335	298	385	370	320	270	220
53	430	423	383	343	303	415	400	345	285	230
52	460	452	412	370	327	445	425	365	302	240
51	500	492	442	397	352	470	450	390	320	250
50	540	532	480	430	380	500	480	420	340	265
49	570	562	507	452	397	525	500	440	355	275
48	600	592	537	477	417	555	530	465	375	285
47	640	632	572	507	442	590	560	490	395	300
46	675	666	606	536	466	625	590	515	415	315
45	710	701	636	561	486	655	625	540	435	330
44	750	740	675	595	515	690	660	565	455	345
43	790	780	710	625	540	725	690	590	475	360
42	825	825	755	665	575	760	725	620	498	375
41	865	855	775	680	585	795	755	650	520	390
40	900	890	810	710	610	825	785	680	545	410

*   Performance Factor   A 5×10^{-11} e.m.u.

B 10^{-13} e.m.u.

C 5×10^{-14} e.m.u.

D 2×10^{-14} e.m.u.

E 10^{-14} e.m.u.

All ranges in Kilometres

Table VII

Table for estimating radiated power in
watts of a Decca station with an input
power of 1.2 kilowatts.

Type and Physical Height of Aerial (in feet)	Frequency 85 Kc/s			
	Good Earth		Poor Earth	
	Single Tuned	Double Tuned	Single Tuned	Double Tuned
Umbrella 70	4	3	2	2
100	7	6	3	3
150	30	24	13	12
168	36	30	18	15
200	60	48	28	24
300	175	150	85	78
500	525	480	320	300
650	750	700	525	500

Notes:

(1)   To obtain radiated power for other input powers multiply the figures shown by the ratio of required input power to 1.2 K/Watts. e.g. If input is 600 watts halve the figures shown.

(2)   To obtain radiated powers for the other main Decca chain frequencies multiply the figures derived from the Table by the following factors:

Purple 0.7   :   Red 1.7   :   Green 2.2

(3)   All Mark 10 Chains are 1.2 kilowatt input power at this time and radiated about 70% of the power shown in the "Double Tuned" column.

Coverage for daylight – 85 Kc/s
Conditions 0800–1600 local time
98% serviceability – bandwidth ± 30 c.p.s.
10 db S/N requirements
—— Good land and sea
– – – Poor land

CCIR NOISE GRADE

RADIATED POWER IN WATTS

db ABOVE 1μ/VOLT PER METRE

F 280

C–10
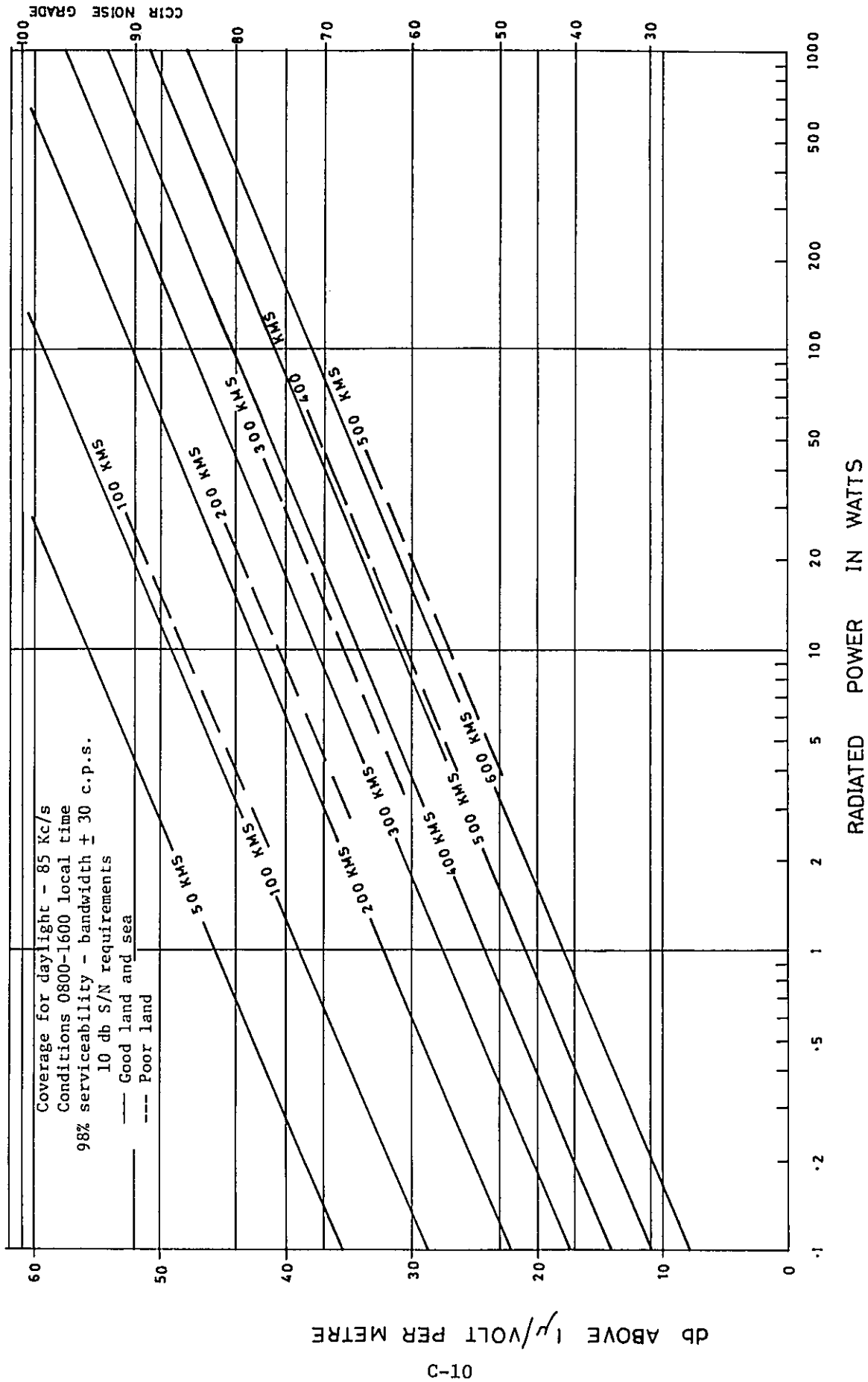
APPENDIX D: Present and Future Maritime Traffic on Malacca/
Singapore Straits and Lombok/Makassar Straits

APPENDIX D: Maritime Traffic on Malacca/Singapore Straits and
Lombok/Makassar Straits

1.   Analysis of Existing Maritime Traffic

The maritime traffic in the peripheral water area around
Indonesia, Singapore and Malaysia (called "the Countries" herein-
after) can be stratified into two groups. One is the traffic with
origin and/or destination in the Countries (the generated traffic
including attracted traffic), and the other is the traffic passing
through the seas concerned (the passing through traffic).

1-1   The Generated Traffic

The volume of generated traffic can be estimated by the following
method of:

a)   preparation of the inter-regional O-D matrices of seaborne
cargo tonnage in the years of 1972 and 1973

b)   traffic assignment to typical sea routes

c)   classification of seaborne cargoes by petroleum/petroleum
products and general cargoes

d)   estimation of the conversion rates from cargo tonnage to
vessel traffic based on the data from Belawan Port Master
Plan to derive the total volume of generated traffic.

The O-D matrix of seaborne cargo tonnage in 1973 gives the overall
cargo movement in the water areas concerned. (See the attached
O-D matrix) From this, the general trading pattern is analysed,
and is shown below:

GENERAL TRADING PATTERN OF THE REGION

(x 1000 ton)

1973	Foreign Trade	* Domestic Trade	Total
Petroleum & Petroleum Products	76,620	15,430	92,050
General cargo	6,830	8,790	15,620
Total	83,450	24,220	107,670

* Including trade between Indonesia and Singapore, West Malaysia.

The domestic cargo flow was also roughly assigned to sea routes.

In consequence the cargo flow for 1973 on each of the Straits was estimated as follows:

ESTIMATED DOMESTIC CARGO FLOW FOR 1973

| Malacca/Singapore Straits	6.50 million ton/year
Lombok/Makassar Straits	2.50 million ton/year

TOTAL DRY CARGO FLOWS (1973)   *100 TON

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	TOTAL
01	10	135	13	112	26	109	6	749	10	142	2	6	3	0	1	0	849	361	281	2815
02	103	69	41	167	27	52	5	0	0	0	0	0	0	0	0	0	472	1	290	1227
03	0	2	63	54	4	0	0	6	7	0	0	0	5	0	0	0	351	0	16	508
04	4	49	68	169	35	123	1	104	85	60	0	0	0	0	0	0	2467	21	660	3846
05	15	52	0	5	2186	175	4	5	323	0	0	0	0	0	6	48	855	2	134	3816
06	34	15	0	0	33	2	122	145	323	209	0	0	22	0	0	0	2013	0	564	3586
07	6	6	1	138	1	12	165	104	823	74	45	6	3	0	7	0	230	76	59	1567
08	604	13	25	155	9	76	102	7	0	11	1	325	91	45	282	0	418	3	1261	3388
09	477	1	8	252	218	543	503	0	1	17	0	325	3	0	8	0	2	1	943	3471
10	1455	15	0	259	4	496	135	175	5	17	757	163	1001	200	521	70	1738	12	4547	11571
11	587	37	0	12	7	132	8	43	64	587	451	57	67	0	21	2376	109	0	788	5576
12	0	0	0	0	0	9	1	12	166	7	2	73	0	0	0	0	1726	38	106	2152
13	0	0	0	0	0	4	0	101	25	254	4	0	178	0	24	14	1190	44	213	2051
14	0	0	0	6	0	0	0	155	5	144	0	38	0	2	8	0	129	0	495	933
15	198	0	0	0	0	168	1	796	0	437	576	0	196	207	9	10	104	0	35	647
16	0	0	0	0	0	4	0	3	48	19	2	137	2	43	134	3	0	1	1846	4063
17	2066	379	457	78	65	1241	47	3426	1	898	0	677	1235	0	0	43	—	0	2958	13157
18	98	50	64	8	0	1	0	96	822	42	33	1987	1	313	465	81	7769	442	77	393
19	150	122	23	163	162	453	29	1306	2700	3413	1875	—	134	010	1486	2645	20427	1000	6682	23147
TOTAL	5807	828	748	1637	2777	3500	1129	7233	2700	6331	1875	1987	2941	010	1486	2645	20427	1000	22045	87914

TOTAL DRY CARGO FLOWS (1972)   *100 TON

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	TOTAL
01	4	99	17	93	6	62	0	617	0	145	0	0	0	0	5	0	477	338	130	1993
02	94	93	44	157	17	44	7	1	1	0	0	0	0	0	0	0	108	3	199	765
03	0	3	28	53	0	1	1	4	23	44	0	25	52	0	0	0	92	41	23	308
04	11	46	1075	143	22	20	2	152	122	1	1	0	0	0	3	0	1376	11	397	3451
05	35	80	3	52	1501	147	6	177	369	400	321	1	0	3	0	210	373	10	100	2689
06	167	19	22	14	23	3	270	33	270	84	0	49	32	0	4	3	151	0	1628	4449
07	6	3	0	1	0	21	156	1	1208	108	32	614	0	0	2	0	505	0	49	1525
08	711	11	50	17	6	63	10	48	0	271	26	171	109	51	249	82	0	6	664	2655
09	4	0	16	112	100	451	1057	44	1	2	10	45	112	0	0	864	1083	0	717	3365
10	1160	9	3	36	7	534	123	24	87	431	666	0	755	168	435	0	72	0	3677	9016
11	276	11	1	186	4	122	15	46	150	175	045	0	41	10	20	2	2204	170	703	3768
12	0	0	0	0	0	2	0	124	62	43	0	0	122	1	21	0	280	0	34	2664
13	0	0	1	0	0	1	0	254	8	126	23	23	107	48	7	3	102	19	86	805
14	17	1	0	0	0	0	0	2	0	46	409	0	3	95	2	4	71	0	446	750
15	4	164	165	80	46	698	45	3071	0	1462	0	130	167	0	35	46	0	1	812	1497
16	852	16	45	44	0	1	2	36	0	11	0	3	2	0	3	0	—	0	65	541
17	103	122	23	213	46	559	71	1314	2114	5052	100	558	429	419	673	63	5057	185	1510	8566
18	165	677	1493	1201	149	2601	1770	5958	4503	8412	2123	1624	1831	787	1457	1088	13313	785	11	277
19	3609				1881														8247	25216
TOTAL	3609	677	1493	1201	1881	2601	1770	5958	4503	8412	2123	1624	1831	787	1457	1088	13313	785	19567	74600

D-3

MARITIME REGION MAP
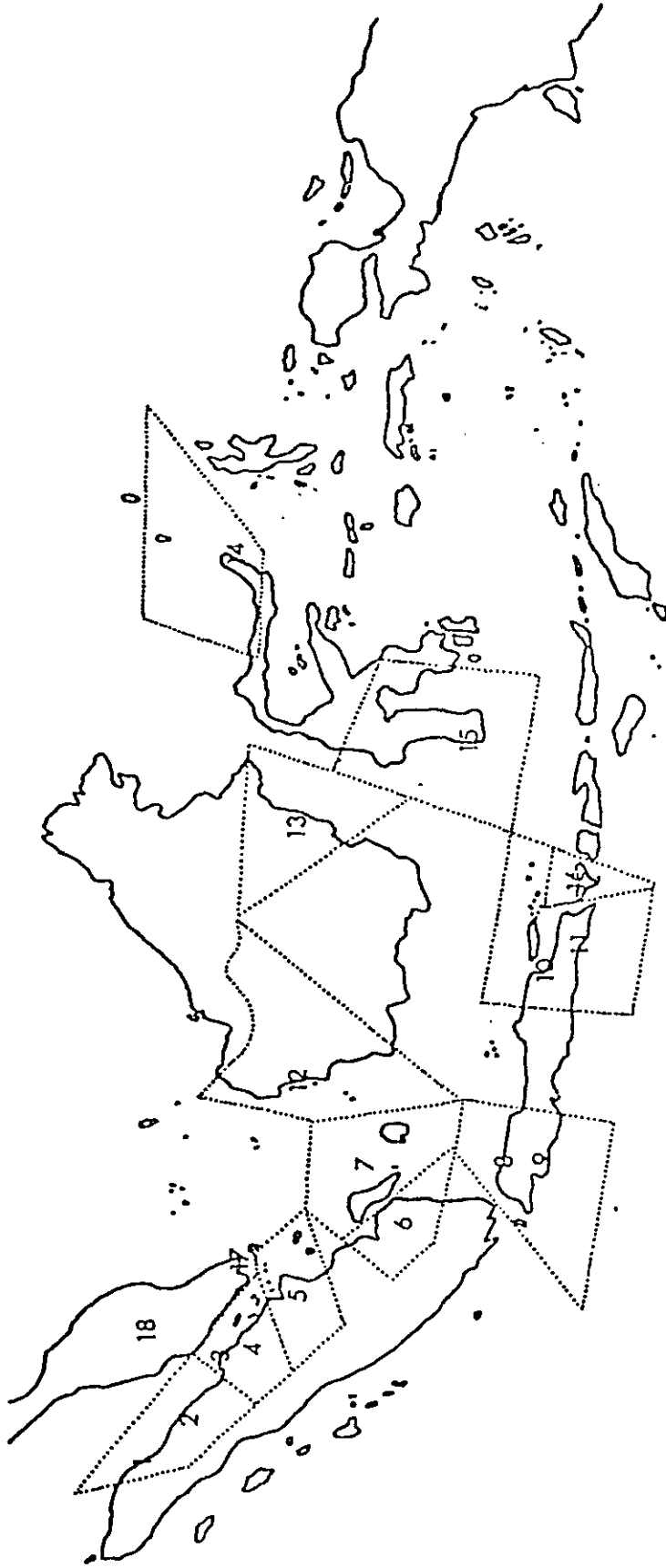
1 Belawan	6 South Sumatera I	11 East Java	16 Bali
2 North Sumatera	7 South Sumatera II	12 West Kalimantan	17 Singapore
3 Dumai	8 DKI JAKARTA	13 East Kalimantan	18 West Malaysia
4 Riau I	9 West Java	14 Bitung	19 Others
5 Riau II	10 Surabaya	15 Makassar	

The international seaborne cargo in 1973 (except for Singapore and Malaysia) was 83.45 million ton/year. The exports accounted for 90.6% or 75.61 million ton/year of a total foreign trade and the imports 9.4% or 7.84 million ton/year.

The orientation and distribution are roughly given below.

East Asia	74.6%
Philippines	4.1%
Others	21.3%

As a result of the traffic assignment to the sea routes the cargo movements for foreign trade on each of the Straits in 1973 was estimated as follows:

ESTIMATED FOREIGN CARGO FLOW FOR 1973

Malacca/Singapore Straits	60.0 million ton/year
Lombok/Makassar Straits	15.0 million ton/year

By using the statistics of the seaborne cargo flow of Indonesia, 1973, a total cargo flow on both Straits can be itemized by type of trade and cargo.

ESTIMATED TOTAL CARGO FLOWS FOR 1973

Malacca/Singapore Straits	Domestic Trade	Foreign Trade	Total (Million ton)
General Cargo	1.10	5.60	6.70
Petroleum & Petroleum Products	5.40	54.40	59.80
Total (Million ton)	6.50	60.00	66.50

Lombok/Makassar Straits	Domestic Trade	Foreign Trade	Total (Million ton)
General Cargo	0.61	1.50	2.11
Petroleum & Petroleum Products	1.89	13.50	15.39
Total (Million ton)	2.50	15.00	17.50

Although vessels carrying the above cargo vary in size and type, an average size and a loading factor were derived from the actual data observed for the Belawan Port. This is summarized as follows:

Items	Average vessel size (dead weight tonnage)	Average loading factor (percentage of capacity)
General Tankers	27,000	35%
General Cargo Vessels	4,500	30%

D-6

Therefore, total generated traffic (with origin and/or destination in the Countries) in 1973 on both Straits is estimated as shown in the Table 1-1.

Table 1-1:   Total Generated Traffic in 1973 on the Straits

(unit: Vessels/year)

Items	Malacca/Singapore Straits	Lombok/Makassar Straits	Total
Gereral Tankers	6,330 (6,580)	1,630 (1,718)	11,290 (11,840)
Gereral Cargo Vessels	4,960 (5,260)	1,560 (1,792)	3,190 (3,510)
Total	11,290 (11,840)	3,190 (3,510)	14,480 (15,350)

Note: Figures in parentheses show the estimated generated
        traffic in 1974.

1-2   The Passing Through Traffic

For the analysis of passing through traffic, the following approach was adopted.

a)   the through traffic on the Malacca/Singapore Straits is
     obtained by deduction of the generated traffic derived in the
     previous section from a total traffic volume observed by the
     Port of Singapore Authority.

b)   an assumption is made that on the Lombok/Makassar Straits
     there is no passing through traffic except for large tankers.

<Passing Through Traffic on Malacca/Singapore Straits>

According to the data collected by the Port of Singapore Authority,
the maritime traffic observed during each 28-day traffic survey in
1969, 1973 and 1974 is as follows:

Table 1-2: Maritime Traffic Observed by PSA

(Vessels/28 days)

1)	Year	1969 Oct.	1973 Feb./Mar.	1974 Oct.
	Total traffic	3,623	4,019	3,940

2)	By type of Vessel	1969 Oct.		1973 Feb./Mar.		1974 Oct.	
			(%)		(%)		(%)
	Tankers & Bulk Carriers	1,231	(34.0)	1,115	(27.7)	1,249	(31.7)
	Cargo Ships	1,961	(54.1)	2,595	(64.6)	2,170	(55.0)
	Passenger Ships	27	(0.7)	38	(1.0)	52	(1.4)
	Others	404	(11.2)	271	(6.7)	469	(11.9)

3)	By class of Gross Tonnage	1969 Oct.		1973 Feb./Mar.		1974 Oct.	
			(%)		(%)		(%)
	Above 30,000 ton	162	(4.5)	276	(6.9)	540	(13.7)
	5,000 ~ 30,000 ton	2,344	(67.7)	1,857	(4.62)	1,377	(33.9)
	75 ~ 5,000 ton	940	(25.9)	1,882	(4.68)	2,019	(51.3)
	Below 75 ton	177	(4.9)	4	(0.1)	4	(0.1)
				more than 180,000 ton Class Vessels in the above are:		more than 150,000 ton Class Vessels in the above are:	
				46	(1.1)	39	(1.0)

The same statistical data also indicates that tanker traffic accounts for 22.2% of the total maritime traffic in 1974.

Combining the data presented so far, the total annual vessel traffic, the generated traffic and the passing through traffic are estimated as following Table 1-3.

Table 1-3: Estimated Distribuion of Total Traffic
on Malacca/Singapore Straits in 1974

(Vessels/year)

Items	Total traffic	Generated traffic	Passing through traffic
Large tankers	508	0	508
General tankers	10,894	6,751	4,134
General Cargo Vessels and Others	39,958	5,475	34,483
Total	51,360	12,226	39,134

<Passing Through Traffic on Lombok/Makassar Straits>

The maritime traffic in 1974 on the Lombok/Makassar straits is summarized in the Table 1-4.

It is assumed that there is no passing through traffic except large tankers on the straits.

Table 1-4:   Estimated Distribution of Total Traffic
on Lombok/Makassar Straits in 1974

(Vessels/year)

Items	Total traffic	Generated traffic	Passing Through traffic
Large tankers	30	0	30
General tankers	1,718	1,718	0
General cargo vessels and others	1,792	1,792	0
Total	3,540	3,510	30

Table 1-5: Summary of Maritime Traffic on Malacca/Singapore Straits

(Vessels/year)

Items	1974			1975			1976		
	Generated traffic	Passing through traffic	Total	Generated traffic	Passing through traffic	Total	Generated traffic	Passing through traffic	Total
Large tankers	-	508	508	-	528	528	-	549	549
General tankers	6,580	4,314	10,894	6,840	4,486	11,326	7,111	4,666	11,777
General cargo vessels and others	5,260	34,698	39,958	5,578	36,086	41,664	5,915	37,529	43,444
Total	11,840	39,520	51,360	12,418	41,100	53,518	13,026	42,744	55,770

Note: Annual Growth Rates referred to in Section 2 are used to derive 1975 and 1976 flows.

Table 1-6: Summary of Maritime Traffic on Lombok/Makassar Straits

(Vessels/year)

Items	1974			1975			1976		
	Generated traffic	Passing through traffic	Total	Generated traffic	Passing through traffic	Total	Generated traffic	Passing through traffic	Total
Large tankers	-	30	30	-	31	31	-	32	32
General tankers	1,718	-	1,718	1,811	-	1,811	1,909	-	1,909
General cargo vessels and others	1,792	-	1,792	2,058	-	2,058	2,365	-	2,365
Total	3,510	30	3,540	3,869	31	3,900	4,274	32	4,306

Note: Annual growth rates referred to in Section 2 are used to derive the 1975 and 1976 flows

2. Forecast of Future Maritime Traffic on the Straits

A frame of reference for the prediction of the future maritime traffic comprises the following items.

A. <Malacca/Singapore Straits>

(a) to built a correlated model equation to estimate total seaborne cargo volume (a total of general cargo and petroleum/petroleum products) loaded and/or unloaded in Indonesia, Singapore and Malaysia in relation with Gross Domestic Product (GDP) of the respective countries.

(b) to estimate the future movements of petroleum/petroleum products by extrapolation using a trend model.
for Indonesia, the estimated growth rate derived from the above model can be compared with the projected growth rate given in the Tg. Priok Port Master Plan.

(c) to estimate the general cargo movements (which have at least a destination or an origin in the Countries) by deducting the movements of petroleum and petroleum products from the total cargo movements estimated in the items (a) and (b) above.

(d) to estimate a future average size and loading factor for vessels carrying general cargo and petroleum/petroleum products and subsequently to estimate the growth rates of the maritime traffic by type of vessel.

(e) to estimate the passing through traffic including large tankers on the basis of the analysis of international oil movements and their growth rates.

B.   <Lombok/Makassar Straits>

(f)   to built a regression model explaining total Indonesian
       cargo movement by the annual per capita GDP in
       Indonesia, subsequently to forecast total cargo movement
       for future traffic.

(g)   to estimate the general cargo and oil movements in
       Indonesia using the results derived from the above items
       (b) and (f).

(h)   to estimate the future maritime traffic by the same
       approach adopted in the items (a) ∿ (e) above.

2-1   The Generated Maritime Traffic on Malacca/Singapore Straits

2-1-1 Forecast of Future Seaborne Cargo Movements Relating to Indonesia,
       Malaysia and Singapore.

       The seaborne cargo which has at least an origin or a destination
       in the Countries is estimated by a multiple regression model with
       the independent variables of the GDP in each country and the
       dependent variable of a total cargo handled at ports of the
       Countries.

       The future projected GDP in the respective countries are extracted
       from various national plans and government publications.

       Both the future GDP and the estimated regression equation are used
       to forecast the future cargo volume handled in the Countries.

       The data for the multiple regression model, cargo handled in each
       country and its GDP is collated and summarized in the following
       tables:

Table 2-1: Cargo Loaded and Unloaded at Ports in the Countries

Year	1968	1969	1970	1971	1972	1973	1974
Indonesia	46.0	55.6	64.4	74.1	94.4	113.9	108.5
Malaysia	24.8	26.3	28.2	27.7	27.9	29.4	28.2
Singapore	36.8	39.2	43.6	49.7	57.1	61.3	60.4
Total	107.6	121.1	136.2	151.5	179.4	204.3	197.1

Note: 1) Iron ore loaded from the Peninsular Malaysia is excluded.

2) Crude petroleum transported from Brunei to Sarawak by pipes is excluded.

Table 2-2: Gross Domestic Product of the Countries

Year	1968	1969	1970	1971	1972	1973	1974
Indonesia (Bil. Rp. at 1969 Const. Price)	2,544	2,718	2,923	3,128	3,348	3,620	3,880
Malaysia (Mil. M$ at 1970 Const. Price)	9,310	10,282	10,708	11,589	12,349	13,867	14,797
Singapore (Mil. S$ at 1968 Const. Price)	3,971	4,502	5,107	5,747	6,514	7,239	7,731
Malaysia plus Singapore	13,281	14,784	15,815	17,336	18,863	21,106	22,528

Based on the above data, analysis of a multiple regression model was carried out and the most significant model and equation was selected as follows:

$$Y = 0.02835\ X_1 + 0.00877X_2 - 84.30396 \quad (R:\ 0.996)$$

where, Y : cargo handled at ports in the Countries (Mil. ton)

X_1 : GDP of Indonesia

X_2 : total GDP of Malaysia and Singapore

The future GDP projected for Indonesia is taken from the "Indonesia Second Five Year Plan (PELITA II)" and for Malaysia, from the "Third Malaysia Plan". With regard to Singapore such authorized data could not be obtained, so that the future GDP of Singapore was estimated from the data used in the brief report of "Mass Transit Study, 1974".

Based on these publications the projected GDP is assumed to be as follows:

Table 2-3:   Future Growth Rate of GDP in the Countries

Country	Years	Annual Growth Rate of GDP
Indonesia	1974 $\sim$ 1979	7.5%
Malaysia	1971 $\sim$ 1975	7.4%
	1976 $\sim$ 1980	8.5%
	1981 $\sim$ 1990	8.1%
Singapore	1972 $\sim$ 1976	7.1%
	1977 $\sim$ 1981	6.1%
	1982 $\sim$ 1992	5.1%

Accordingly, the value of the projected GDP in the respective countries is estimated as in the Table 2-4.

Table 2-4: Projected GDP of the Countries

Year	1975	1980	1985	1990	1995	2000	2010
Indonesia (Bil. Rp. at 1969 Const. Price)	4,086	5,866	8,421	12,090	17,357	24,918	51,357
Malaysia (Mil. M$ at 1970 Const. Price)	15,315	23,073	34,059	50,097	73,950	109,161	237,862
Singapore (Mil. S$ at 1968 Const. Price)	8,048	11,290	14,590	18,675	23,902	30,593	50,118

By the estimated regression equation presented earlier the future total cargo volume handled in these coutries can be estimated as follows:

Table 2-5: Total Maritime Cargo Volume Handled in the Countries

Year	1975	1980	1985	1990	1995	2000	2010
Total Cargo Volume handled (Mil. ton)	236.4	382.7	581.1	861.6	1265.9	1847.8	3897.3

The assumption was made that the intra-regional cargo movement which is double counted in the above table, is 10% of the total cargo handled at ports in the Countries.

Therefore, the estimated total seaborne cargo handled in the Countries has been adjusted as given in the Table 2-6 to derive the total cargo movement.

Table 2-6:   Total Maritime Cargo Movement with Origin
and/or Destination in the Countries

Year	1975	1980	1985	1990	1995	2000	2010
Total Cargo Movement (Mil. ton)	212.8	344.4	523.0	775.4	1,139.3	1,663.0	3,507.6

2-1-2   Forecast of Future Movement of Petroleum and Petroleum Products
Relating to the Countries

For the estimation of the future movement of petroleum and
petroleum products, a trend model was built using data of the past
annual increases of oil volume handled at ports in each country
as listed in the Table 2-7.

Table 2-7:   Petroleum and Petroleum Products
Handled at Ports in the Countries

(Unit: Million ton.)

Year	1968	1969	1970	1971	1972	1973	1974
Indonesia [1]	23.0	29.8	34.5	37.2	45.9	59.0	62.2
Malaysia [2]	11.7	11.9	12.7	14.7	11.6	11.6	11.0
Singapore [3]	27.5	29.2	32.5	37.5	45.4	47.0	45.7

Note: 1)   The figures for Indonesia are quoted from the Export-Import data.

2)   The figures for Malaysia represent a total amount of handled
in Peninsular Malaysia, Sarawak and Sabah.
The piped from Brunei to Sarawak is excluded.

3)   The figures for Singapore are quoted from the data on loading-
unloading at ports in Singapore.

The future seaborne oil movement of the Countries is extrapolated by a simple regression model in the case of Indonesia and, with regard to Singapore and Malaysia the total sum of the seaborne oil handled in both countries is used to obtain better correlation coefficient.

The parameters in the regression models are estimated as follows:

Indonesia : $Y_1 = 6.693X_1 - 13,150$ (R = 0.982)

where, Y_1 : Petroleum and petroleum products handled at ports in Indonesia (Million ton.)

      X_1 : Calendar year

Malaysia and Singapore : $Y_2 = 3.546X_1 - 6,940$ (R = 0.948)

where, Y_2 : Petroleum and petroleum products handled at ports in both Malaysia and Singapore

      X_1 : Calendar year

Thus, the future handling volume of oil at ports in the Countries is calibrated, and summarized in the Table 2-8.

Table 2-8: Forecast of Future Oil Volume Handled at Ports in the Countries

(Unit: 1000 ton)

Year	1975	1980	1985	1990	1995	2000	2010
Indonesia	68.7	102.1	135.6	169.1	202.5	236.0	302.9
Manaysia & Singapore	63.4	81.1	98.8	116.5	134.3	152.0	187.5
Total	132.1	183.2	234.4	285.6	336.8	388.0	490.4

For Indonesia, comparison of the growth rate can be made with the annual growth rate of the oil handling volume at Tg. Priok which is projected in its Port Master Plan.

Table 2-9: Oil Handling Volume Projected at Tg. Priok
and that Estimated from the Model

(Unit: 1000 ton)

Year	1980	1985	1990
From the Master Plan	4,250	6,000	7,500
annual growth rate		7.1%	4.6%
From the estimated regression equation	102,100	135,000	169,000
annual growth rate		5.8%	4.5%

As seen in the above table, the annual growth rate derived from the Tg. Priok Port Master Plan is a little higher than that derived from the estimated regression equation for whole Indonesian ports. However, it is conceivable that the estimate for the latter should be lower in consideration of the scale of Tg. Priok Port. Therefore, the volume estimated from the equation is adopted to forecast future overall oil handling volume at ports in Indonesia.

Furthermore, in recognition of the fact that the intra-regional seaborne oil cargo movement is double counted in the total oil handling volume at ports in the Countries, it is assumed that the intra-regional oil cargo movement accounts for 10% of the total oil handling volume at ports in the Countries.

Consequently, the future oil movement which has destination and/or origin in Indonesia, Malaysia and Singapore is estimated as follows:

Table 2-10: Forecast of Future Oil Cargo Movement

Year	1975	1980	1985	1990	1995	2000	2010
Oil cargo movement (Mil. ton)	118.9	164.9	211.0	257.0	303.1	349.2	441.4

2-1-3   Forecast of the Future General Cargo Movement Relating to the Countries

The future general cargo movement is estimated by deducting the oil cargo movement from the total seaborne cargo movement forecasted in the previous sections 2-1-1 and 2-1-2. The subtraction is summarized below.

Table 2-11: Forecast of the Future General Cargo Movement

Year	1975	1980	1985	1990	1995	2000	2010
General cargo movement (Mil. ton)	93.9	179.5	312.0	518.4	836.2	1,313.8	3,066.2

2-1-4   Forecast of Future Average Vessel Size and Loading Factor

The Indonesia Five Year Plan (PELITA II) depicts the number of vessels necessary for Regular Liner Service (RLS) routes. It anticipates slightly change in ship size as indicated in the Table 2-12.

Table 2-12: Future Change in Vessel Size for RLS by PELITA II

Year	1974	1975	1976	1977	1978	1979
No. of Vessels	191	203	215	226	237	250
D.W.T.	227,500	239,250	250,000	263.500	273,750	287.750
Av. D.W.T./ Vessel	1,191	1,179	1,165	1,166	1,155	1,151

The Tg. Priok Port Master Plan indicates the future cargo volume
and number of vessels as presented in the following table.

Table 2-13: Projected Number of Vessels and Cargo Volume

Year	1980	1985	1990
No. of Vessels	3,284	4,020	4,830
Cargo Tonnage (x 1000)	7,020	11,135	14,800
Av. Cargo Ton/Vessel	2,138	2,770	3,064

The Balawan Port Master Plan Report predicts that loading factor
of general cargo vessels will increase on average to 50% in the
future.

Therefore for general cargo vessels, the average loading factor,
average cargo tonnage and average vessel size in the future
are estimated as follows:

Table 2-14: Estimated Future Mutation in Items of General
Cargo Vessels Relating to the Countries

Year	1975	1980	1985	1990	2000	2010
Av. Cargo Tonnage (ton/Vessel)	1,500	2,138	2,770	3,064	3,735	4,553
Av. Loading Factor (%)	30	35	40	43	45	50
Av. Vessel Size (D.W.T.)	4,500	6,110	6,925	7,125	8,300	9,100

The future loading factor of general tankers is also estimated
to increase from 35% in 1975 up to 50% in the future and the
size is assumed to remain constant at 27,000 DWT. The following
table represents the estimated future mutation in items of
general tankers.

Table 2-15: Estimated Future Mutation in Items of General
Tankers Relating to the Countries

Year	1975	1980	1985	1990	2000	2010
Av. Cargo Tonnage (ton)	9,450	10,800	10,800	12,150	13,500	13,500
Av. Loading Factor (%)	35	40	40	45	50	50
Av. Vessel Size (D.W.T.)	27,000	27,000	27,000	27,000	27,000	27,000

2-1-5 Growth Rate of the Sea Transport Relating to the Countries

The generated vessel traffic in the peripheral seas of Indonesia, Malaysia and Singapore has been estimated in accordance with the analysis on future cargo movement and changes in characteristic of vessels as explained in the preceding sections.

Based on these assumptions, the calculation of the growth rate of the sea transport which at least has an origin and/or a destination in the Countries has been carried out and the result is given in the Table 2-16 by type of vessels.

Table 2-16: Growth Rate of the Sea Transport   (1975 = 1.000)

Year	1975	1980	1985	1990	2000	2010
General Tanker	1.000	1.214	1.553	1.681	2.056	2.559
General Cargo Vessel	1.000	1.341	1.799	2.703	5.619	10.758

2-2-1　Forecast of Future Seaborne Cargo Movements Relating to Indonesia

The Table 2-17 gives the seaborne cargo volume dealt with in the inter-island and the international trades of Indonesia.

Table 2-17:　Cargo Volume Moved for the Inter-island and International Trades

(Mil. ton)

Year	1969	1970	1971	1972	1973	1974
Inter-island Trade	31.2/2	22.9/2	26.2/2	27.6/2	33.9/2	33.0/2
International Trade	24.4	38.2	48.0	67.1	79.6	76.2
Total	40.0	49.7	61.1	80.9	96.6	92.7

"Cargo loading and unloading at Ports in Indonesia"

Source:　Biro Pusat Statistik

During the same period per capita GDP of Indonesia shows the following growth.

(X1000R.P)

Year	1969	1970	1971	1972	1973	1974
Per Capita GDP at 1969 cost. Price	23.9	25.2	26.2	27.4	28.7	30.0

Making use of the above data a regression model was built relating per capita GDP to sea cargo movement.

If the figures in 1974 are precluded, to obtain a better
correlation coefficient, then the following regression equation
can be established.

$$Y = 12.232X - 255.797 \qquad (R = 0.991)$$

where, Y : seaborne cargo movement (mil. ton)
       X : per capita GDP (x 1000 R.P.)

The future per capita GDP in Indonesia is projected as in the
table 2-18, so that the above equation affords the future seaborne
cargo movement of Indonesia as listed in the Table 2-19.

Table 2-18: Projected Future per Capita GDP of Indonesia

(x 1,000 Rp)

Year	1975	1980	1985	1990	2000	2010
Per Capita GDP at 1969 Price	30.9	42.5	53.9	71.7	124.6	217.1

Table 2-19: Forecast of Future Seaborne Cargo Movement
             of Indonesia

(Mil. ton)

Year	1975	1980	1985	1990	2000	2010
Seaborne Cargo Movement	122.2	264.1	403.5	621.2	1,268.3	2,399.8

The future oil movement by vessels has been already estimated in
the section 2-1-2 and listed in the Table 2-8.

Therefore, the seaborne cargo movement for Indonesia is
stratified by cargo type as follows:

Table 2-20:   Seaborne Cargo Movement by Cargo Type for Indonesia

Year	1975	1980	1985	1990	2000	2010
Oil Cargo Movement (Mil. ton)	61.8	91.9	122.0	152.2	212.4	272.6
General Cargo Movement (Mil. ton)	60.4	172.2	281.5	469.0	1,055.9	2,127.2

By using the loading factor and the size of vessels estimated in 2-1-4, Tables 2-14 and 2-15, the generated vessel traffic can be estimated, while the growth rate is summarized as follows:

Table 2-21:   Growth Rate of the Generated Vessel
Traffic Related to Indonesia

(1975 = 1.000)

Year	1975	1980	1985	1990	2000	2010
General Tankers	1.000	1.301	1.727	1.915	2.406	3.088
General Cargo Vessels	1.000	2.000	2.524	3.801	7.021	11.603

2-3   Summary of the Generated Maritime Traffic on Malacca/Singapore Straits and Lombok/Makassar Straits

The future growth rates have been estimated in the Tables 2-16 and 2-21 with regard to the maritime traffic generated and/or attracted in the peripheral seas of Indonesia, Singapore and Malaysia.

In order to predict the future generated traffic on each of the Straits, the present vessel traffic in 1975 listed in the Tables 1-3 and 1-4 is multiplied by the growth rates above.

The summary of such traffic is then given below.

Table 2-22:   The Generated Maritime Traffic on the Straits

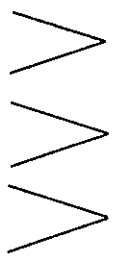|	Type of Vessel	1975	1980	1985	1990	2000	2010
M/S Straits	General Tankers	6,840	8,304	10,623	11,498	14,063	17,504
	General Cargo Vessels	5,578	7,480	10,035	15,077	31,343	60,008
	Total	12,418	15,784	20,658	26,575	45,406	77,512
L/M Straits	General Tankers	1,811	2,356	3,128	3,468	4,357	5,447
	General Cargo Vessels	2,058	4,116	4,635	7,822	14,449	23,879
	Total	3,869	6,472	7,763	11,290	18,806	29,326

(Vessels/year)

2-4   Forecast of Passing Through Traffic on the Straits

2-4-1   Forecast of Passing Through Traffic of Large Tankers

The recession which started towards the end of 1973 had a direct impact on the world economy and on the world wide movement of crude oil and oil products. However the annual growth rate of seaborne oil in the world has been in a gradual decline as shown in the Table 2-23.

Table 2-23:   Crude Oil Movement in the World

Year	Crude Oil Movement	Annual Average Rate of Growth	
1965	730 x 10^6 ton		
		11.0%	
1970	1,228 x 10^6 ton		
		9.8%	
1973	1,627 x 10^6 ton		
		7.8%	
1974	1,656 x 10^6 ton		

It is estimated that the growth rate of seaborne oil will also be lower in the future. Assuming that the average size and loading ratio of large tankers are hardly changed in future the growth rate of their traffic is estimated as follows:

Table 2-24: Annual Growth Rate of Large Tanker's Traffic

Years	Annual Growth Rate	Growth Rate against 1975 Traffic
1975 ∿ 1980	4%/year	(1.217)
1980 ∿ 1985	4%/year	(1.480)
1985 ∿ 1990	6%/year	(1.981)
1990 ∿ 2000	6%/year	(3.547)
2000 ∿ 2010	4%/year	(5.250)

2-4-2 Forecast of Future Passing Through Traffic of General
Cargo Vessels and General Tankers

For lack of adequate data on through traffic of such vessels the
annual growth rates of large tankers are also applied to general
tankers and general cargo vessels. Furthermore, it is assumed
that the future through traffic of general tankers will be of the
same ship size and loading factor as the corresponding generated
traffic referred to in Table 2-15, while that of general cargo
vessels remains constant in either size or loading factor, 13,000
D.W.T. and 50% respectively.

The summary of the through vessel traffic on each of the Straits
is shown in the Tables 2-25 and 2-26.

Table 2-25:   Forecast of Future Through Traffic
on Malacca/Singapore Straits

(Vessels/year)

Year	1975	1980	1985	1990	2000	2010
Large Tankers	528	643	781	1,046	1,873	2,772
General Tankers	4,486	5,459	6,639	8,887	15,912	23,552
General Cargo Vessels	36,086	43,917	53,407	71,486	127,997	189,452
Total	41,100	50,019	60,827	81,419	145,782	213,004

Table 2-26:   Forecast of Future Through Traffic
on Lombok/Makassar Straits

(Vessels/year)

Year	1975	1980	1985	1990	2000	2010
Large Tankers	31	38	46	61	110	163
General Tankers	-	-	-	-	-	-
General Cargo Vessels	-	-	-	-	-	-
Total	31	38	46	61	110	163

2-5   Total Vessel Traffic Forecasted on the Straits

Through the section 2-1 to 2-4, the generated and through vessel
traffic on each of the Straits has been estimated by type of
vessel.   This data is now summarized in Tables 2-27 and 2-28.

Table 2-27:   Future Vessel Traffic on Malacca/Singapore Straits

(Vessels/year)

Year	1975	1980	1985	1990	2000	2010
Large Tanker	528	643	781	1,046	1,873	2,772
General Tankers	11,326	13,763	17,262	20,385	29,975	41,056
Generated traffic	6,840	8,304	10,623	11,498	14,063	17,504
Through traffic	4,486	5,459	6,639	8,887	15,912	23,552
General Cargo Vessels	41,664	51,397	63,442	86,563	159,340	249,460
Generated traffic	5,578	7,480	10,035	15,077	31,343	60,008
Through traffic	36,086	43,917	53,407	71,486	127,997	189,452
Total	53,518	65,803	81,485	107,994	191,188	290,516
Generated traffic	12,418	15,784	20,658	26,575	45,406	77,512
Through traffic	41,100	50,019	60,827	81,419	145,782	213,004

Table 2-28: Future Vessel Traffic on Lombok/Makassar Strait

(Vessels/Year)

Year	1975	1980	1985	1990	2000	2010
Large Tankers	31	38	46	61	110	163
General Tankers	1,811	2,356	3,128	3,468	4,357	5,447
Generated traffic	1,811	2,356	3,128	3,468	4,357	5,447
Through traffic	–	–	–	–	–	–
General Cargo Vessels	2,058	4,116	4,635	7,822	14,449	23,879
Generated traffic	2,058	4,116	4,635	7,822	14,449	23,879
Through traffic	–	–	–	–	–	–
Total	3,900	6,510	7,763	11,351	18,916	29,489
Generated traffic	3,869	6,472	7,763	11,290	18,806	29,326
Through traffic	31	38	46	61	110	163

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1978