RESTRICTED

BASIC PRINCIPLES AND EXAMPLES OF TIME DOMAIN REFLECTOMETRY

CENTRAL SERVICING DEVELOPMENT ESTABLISHMENT

**ROYAL AIR FORCE
SWANTON MORLEY
NORFOLK.**

RESTRICTED

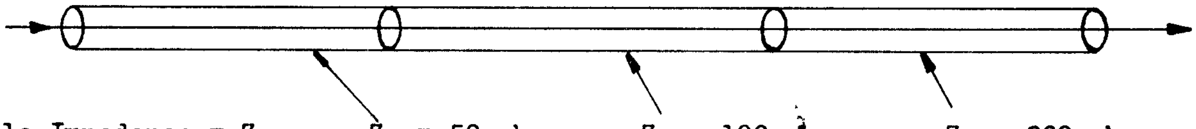
INTRODUCTION

1. The information contained in the following note is additional technical information to supplement the Hewlett Packard Handbooks issued with the 10S/4935-99-956-8468 OSCILLOSCOPE SET CT 552.

TYPICAL TDR DISPLAYS

1. Impedance Matching in co-ax. - Quarter Wave Transformers.

Zin = 50 ohms $\frac{1}{4}$ wave length   Z out = 200 ohms

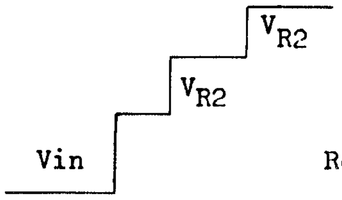


Cable Impedance = Zo.   Zo = 50 ohms.   Zo = 100 ohms.   Zo = 200 ohms.

VSWR at optimum frequency may be 1.08:1

VSWR at another frequency may be 1.3:1

TDR display

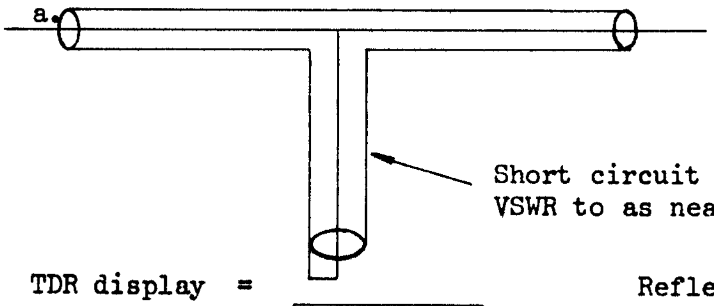


Total reflection co-efficient = +0.6

Reflection co-efficient = $\frac{V_{R1} + V_{R2}}{Vin}$

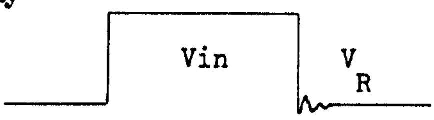
Tuned stubs in co-axial Lines.

a.



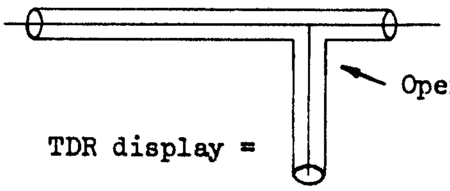
Short circuit stub used to reduce system VSWR to as near to 1:1 as possible.

TDR display =



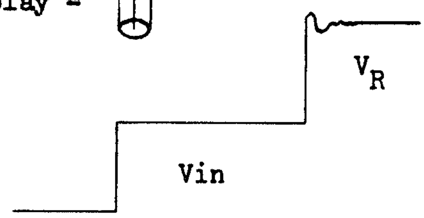
Reflection co-efficient = 1

b.



Open stub

TDR display =



Reflection co-efficient = +1

NOTE: The reflection co-efficient is always 1 and cannot be altered by adjusting the length of the stubs, but the VSWR at the operating frequency can be alter   ub length.

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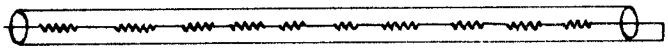
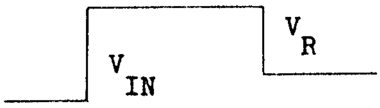
3. <u>Attenuation (Simple)</u>

a.

Input  Short circuit termination

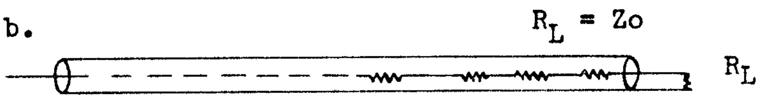
"Lossy" cable

TDR display = 

Two way attenuation = $20 \log \frac{V_{in}}{V_R} = 6db$

Therefore cable attenuation = 3db

b.



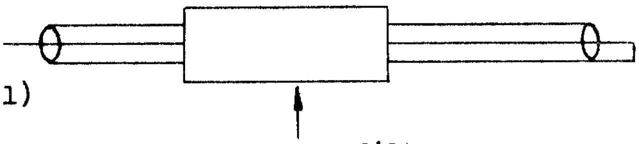
"Lossy" cable correctly terminated

TDR display 

The degree of attenuation is <u>NOT</u> displayed.

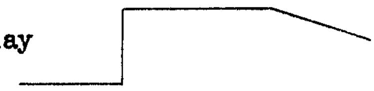
4. Attenuation (Frequency Conscious).

a.

(1)  Short circuit termination

Low pass filter

eg = 3db at 100 Mc/s and -30db at 200 Mc/s and above.

TDR display  Slope dependent on filter cut-off frequency.

(2)

 $R_L = Zo$

Low pass filter correctly terminated

TDR display 

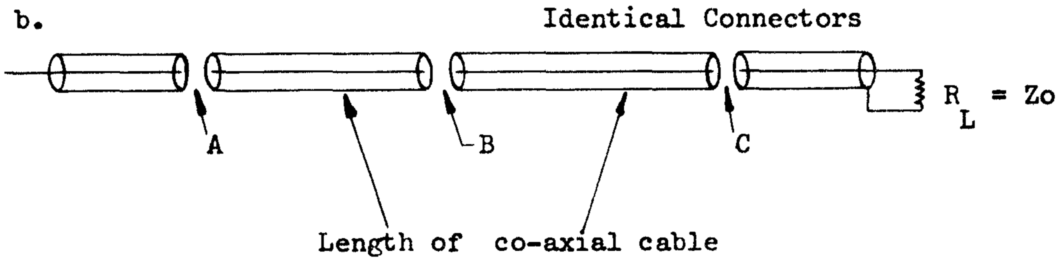
NOTE: A co-axial cable is eff ty low pass filter.

eg: Transradio RG-58 c/u co-axial cable, Attenuation per 100 ft:

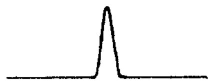
0.42 db at 1 Mc/s: 1.6 db at 10 Mc/s: 6.2 db at 100 Mc/s:

24 db at 1,000 M/cs: 45 db at 3,000 Mc/s.

b.



TDR displays: (1) reflection from A



reflection from small inductive mismatch in connector

(2) reflection from B

(3) reflection from C

Because the co-axial cable is an effective low pass filter the measurement bandwidth reduces throughout the system. Therefore the reflections from 'distant' components that cause high mismatch at SHF, may be smaller than the reflections from the strands of wire of the outer brading of the co-axial at the input end of a system.

5. The comments in this note should not be taken as criticisms of the Time Domain Reflectometer as a test instrument. It is a very effective instrument when used on LF to UHF co-axial systems. This note illustrates some of the differences between broad band and discrete frequency testing.

SOME THEORETICAL TIME DOMAIN REFLECTOMETER DISPLAYS

1. The Characteristic Impedance of any cable, can be computed in terms of the voltage of the step appearing on the TDR oscilloscope before, and after the cable has been connected, ie:

If: $E1$ = Incident voltage of step

$Z1$ = Characteristic Impedance of cable

Zo = Output Impedance of Step generator

Es = Voltage of step source.

Then: $E1 = \frac{ZL\ Es}{Zo+ZL}$ (See figs 1)

2. The incident step voltage is propogated down the co-axial cable and will be reflected from any discontinuities and from the cable termination.

The magnitude shape and sense of the reflection will depend on the nature of the discontinuities and will appear on the display screen of the TDR set, delayed from the incident step by a time equal to the propogation delay of the co-axial cable from the source to the discontinuity and return (Return path delay). The reflection is added algebraically to the incident step voltage. (fig 2).

3. If the co-axial cable is terminated by an open circuit the reflected step voltage will be equal in amplitude to the incident voltage and will be positive. If terminated by a short circuit the reflection will be negative.

If the termination is an impedance matching that of the cable at all frequencies, no reflection will result. The position of a perfectly matched termination will not be apparent. (fig 3).

4. Assume a cable with a perfectly matched load, but somewhere along its length is a component causing a small standing wave ratio (SWR), such as a co-axial plug/socket interconnection, this will cause a proportion of the incident step to be reflected back, and will show on the TDR screen as a small pulse, either positive or negative depending on whether it is caused by series Inductance or parallel capacitance. The amplitude of the reflection is proportional to the degree of SWR. (fig 4).

5. In the case of a resonant aerial, the arrival of the step at the aerial, will excite it into resonance. This resonance will be transmitted back to the TDR and displayed as an exponentially decaying sine wave. If the aerial has an impedance matching transformer, it will appear as a short circuit, after the disturbance due to its resonant excitation; if it is fed directly to the aerial, it will appear as an open circuit. (fig 5).

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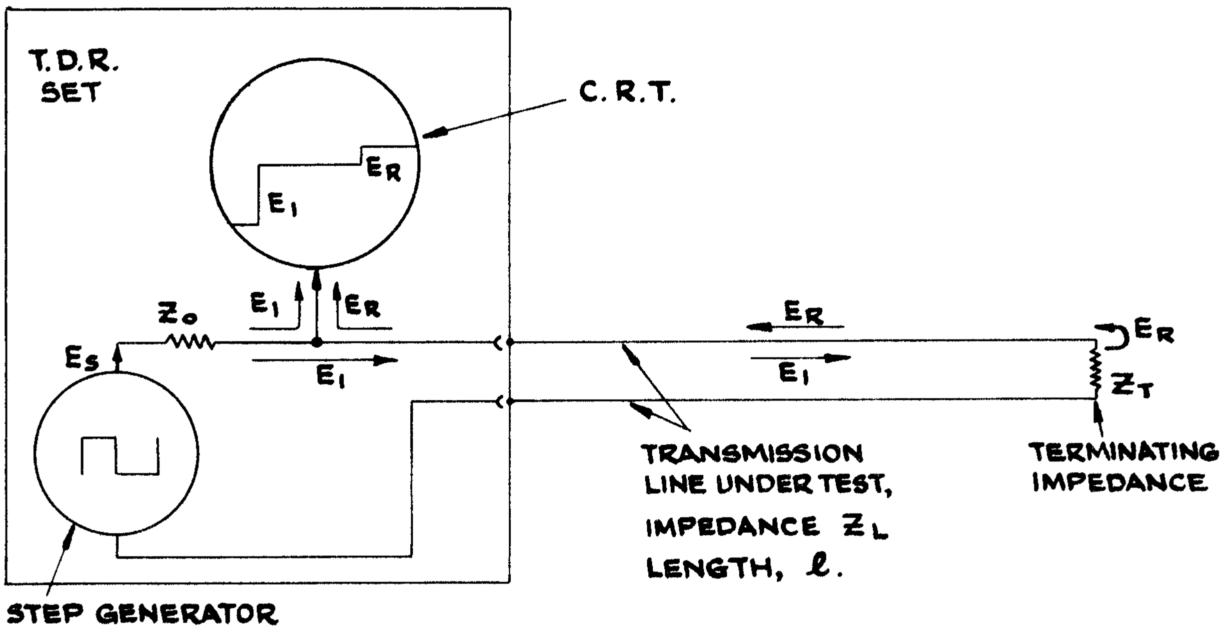
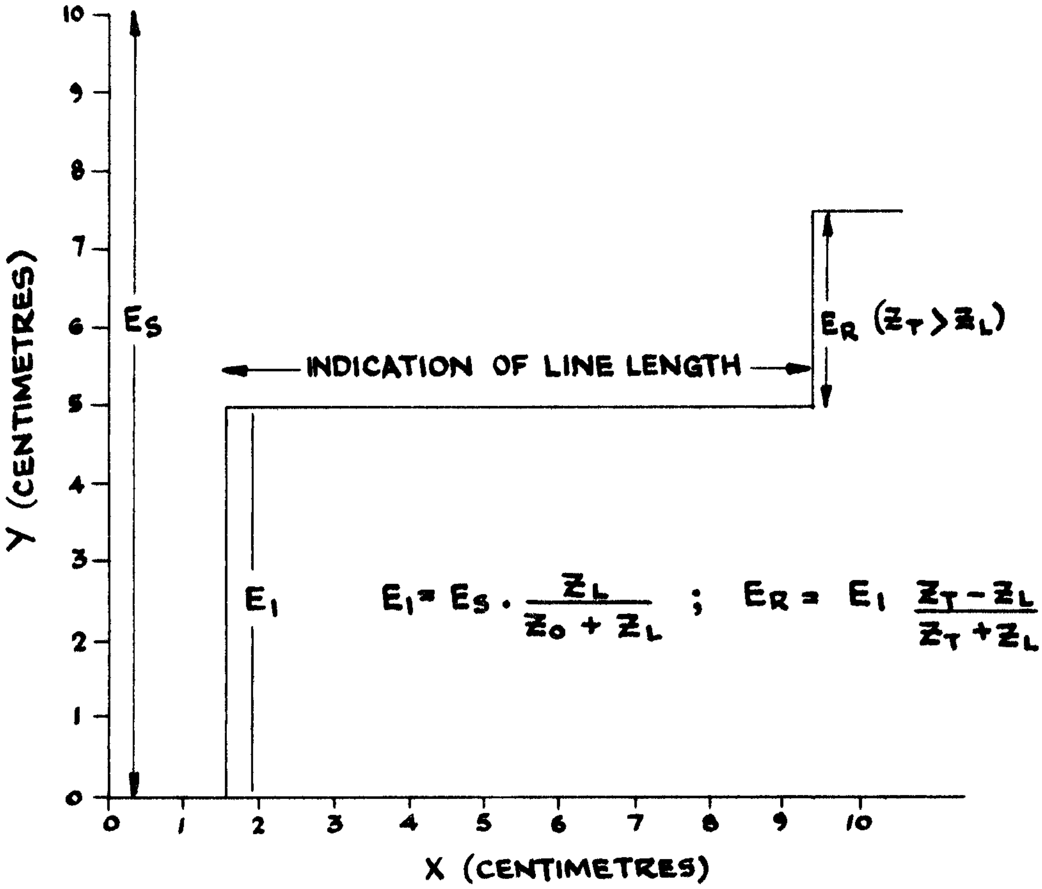
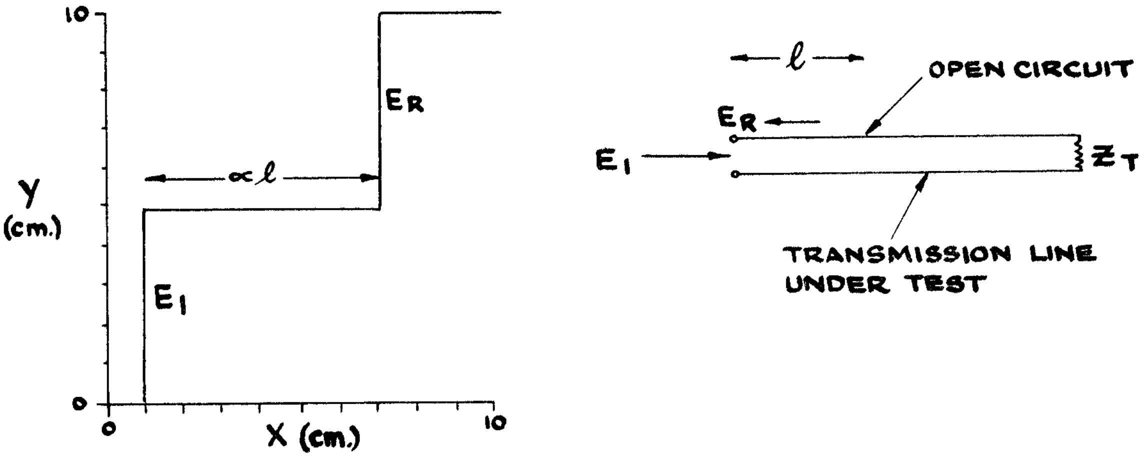


TIME DOMAIN REFLECTOMETER ~ BLOCK DIAGRAM. FIG. 1A.



$$E_1 = E_S \cdot \frac{Z_L}{Z_0 + Z_L} \; ; \quad E_R = E_1 \frac{Z_T - Z_L}{Z_T + Z_L}$$

T. D. R. DISPLAY. FIG. 1.B.



C.R.T. DISPLAY

FIG. 2.

DISPLAY

SYSTEM UNDER TEST

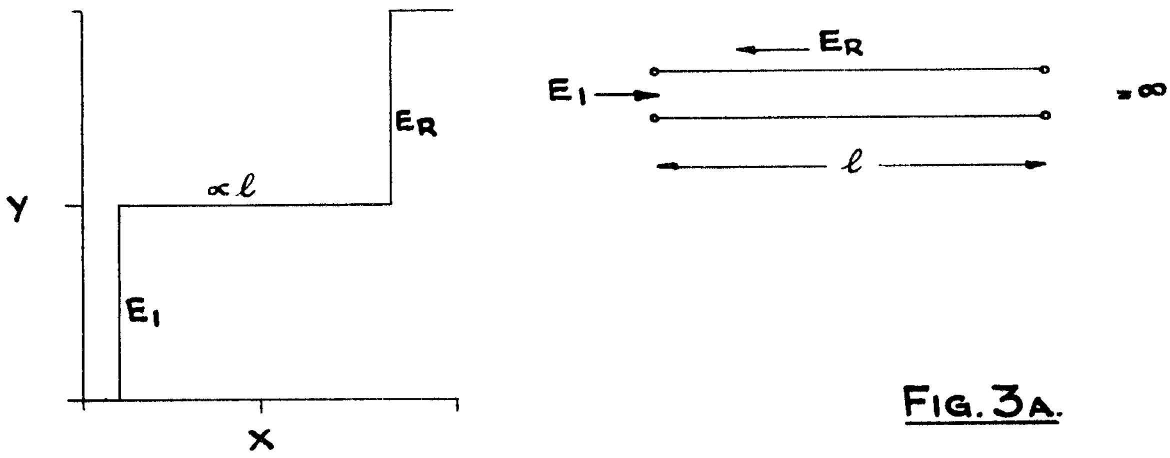


FIG. 3A.

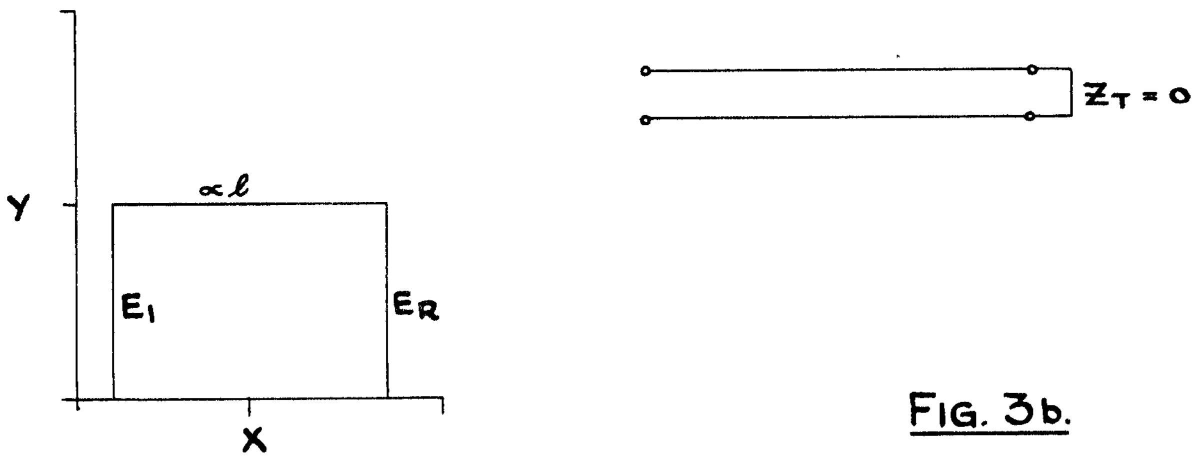


FIG. 3b.

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DISPLAY SYSTEM UNDER TEST

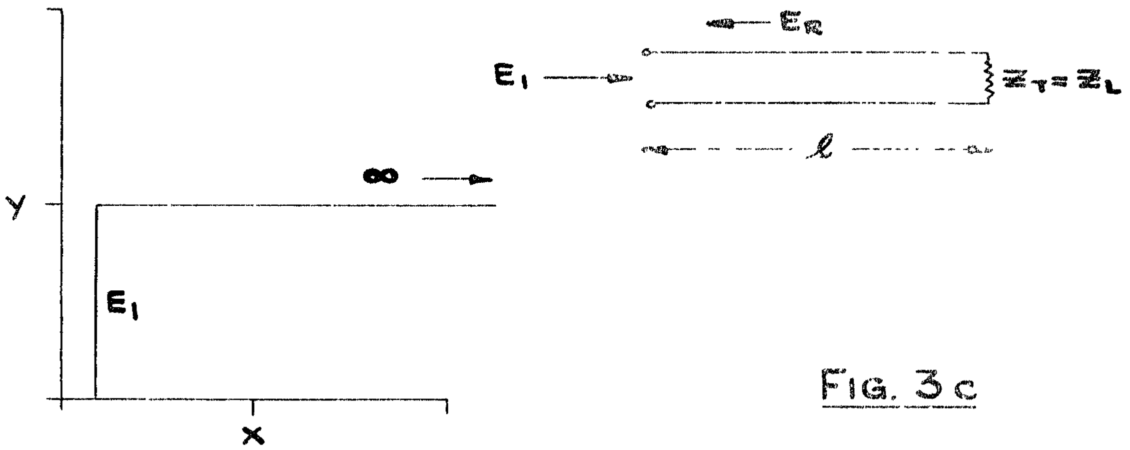

FIG. 3c

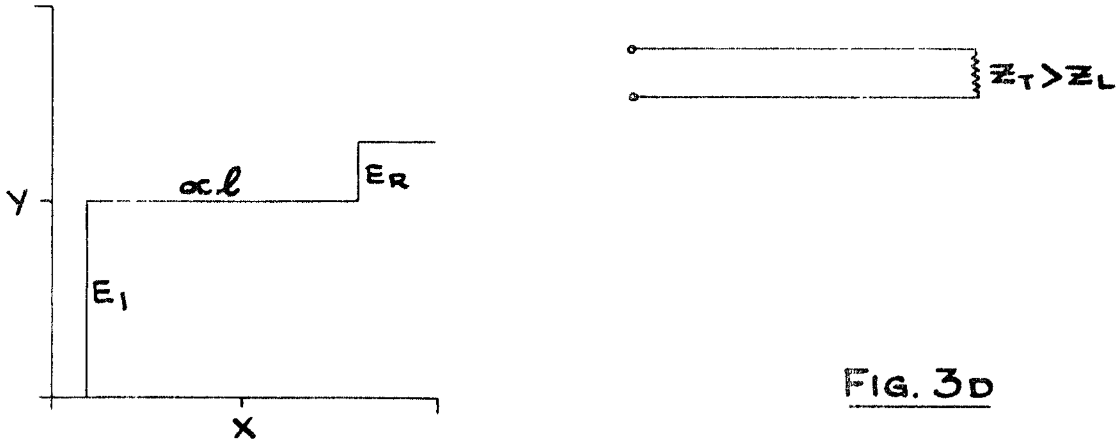

FIG. 3D

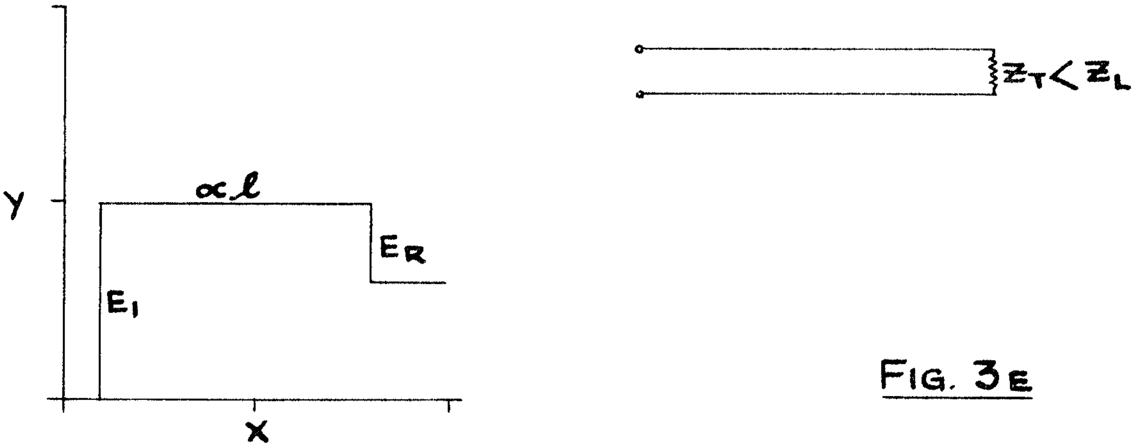

FIG. 3E

DISPLAY | SYSTEM UNDER TEST

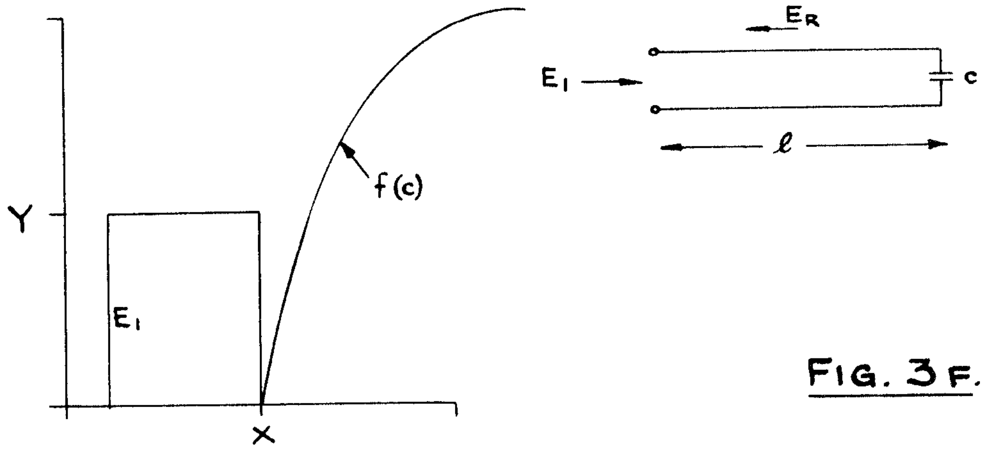

FIG. 3F.

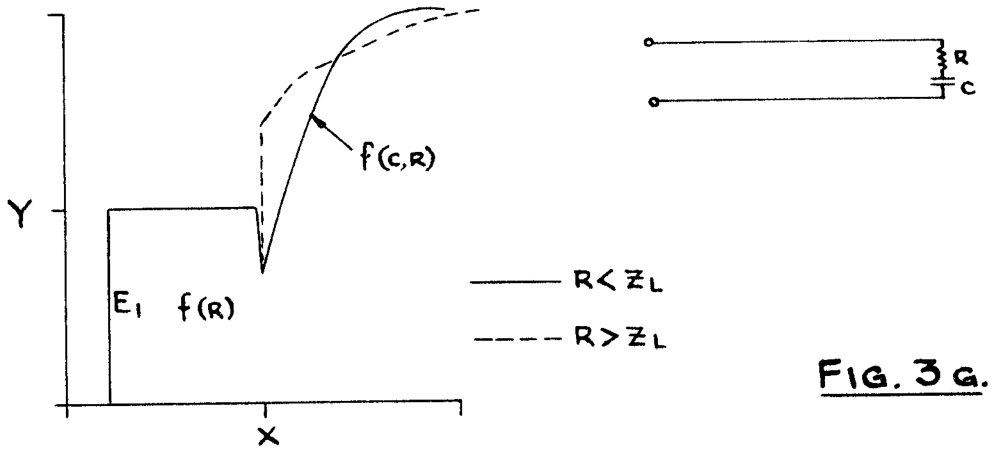

FIG. 3G.

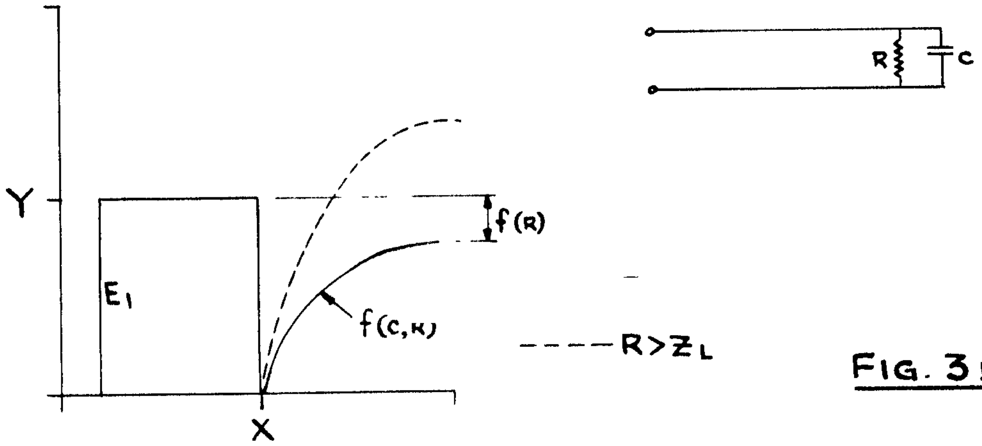

FIG. 3H.

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DISPLAY | SYSTEM UNDER TEST

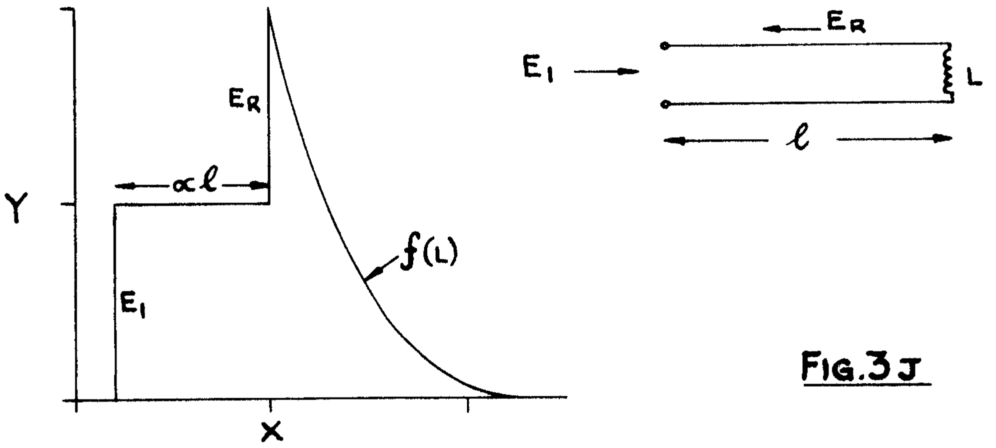

FIG. 3J

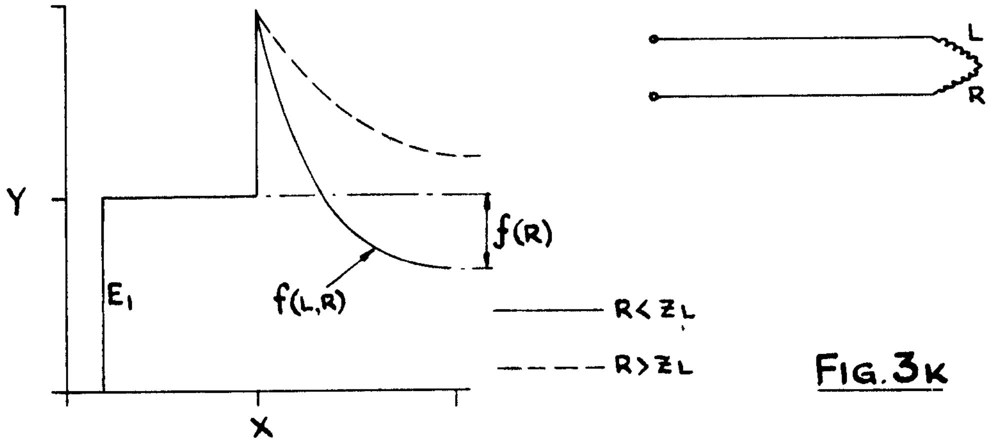

FIG. 3K

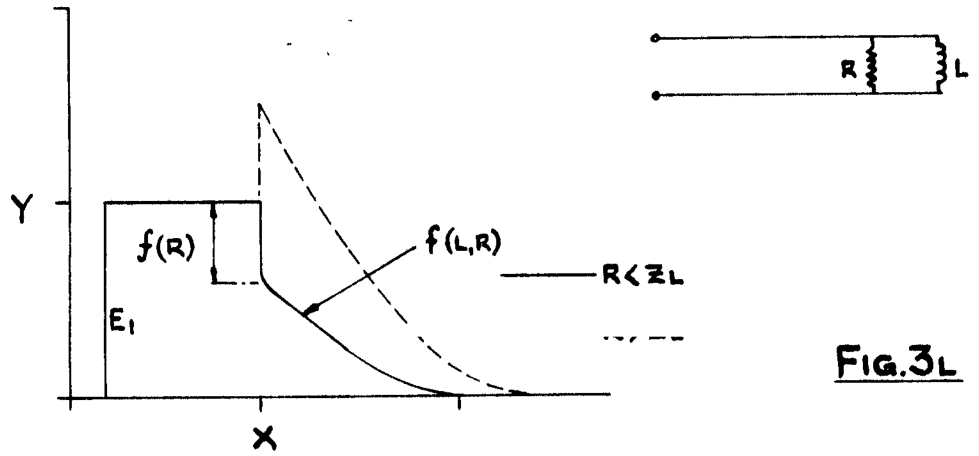

FIG. 3L

DISPLAY SYSTEM UNDER TEST

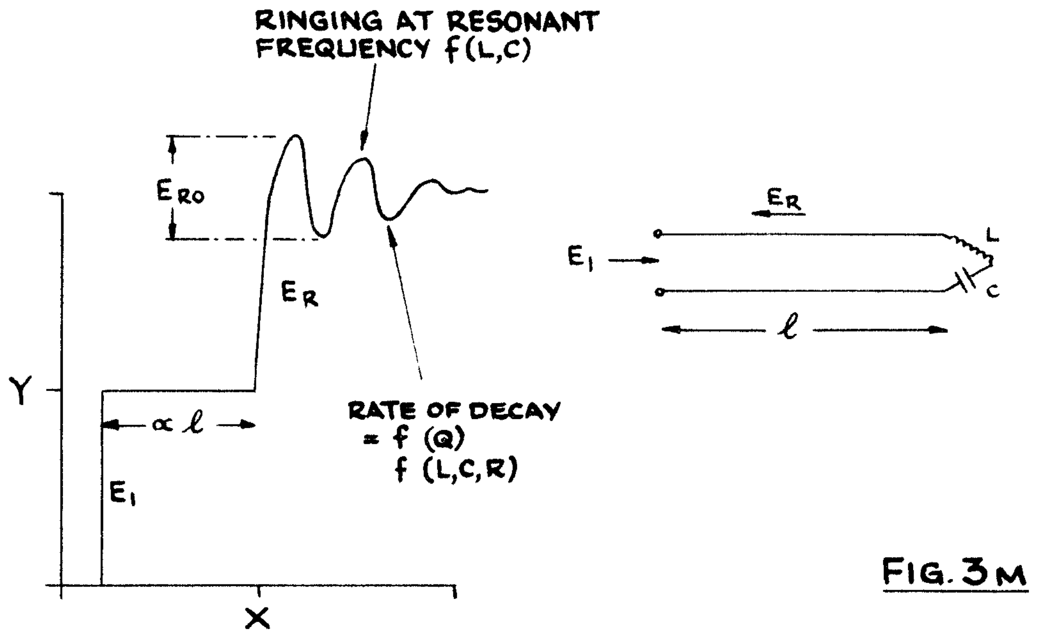

FIG. 3M

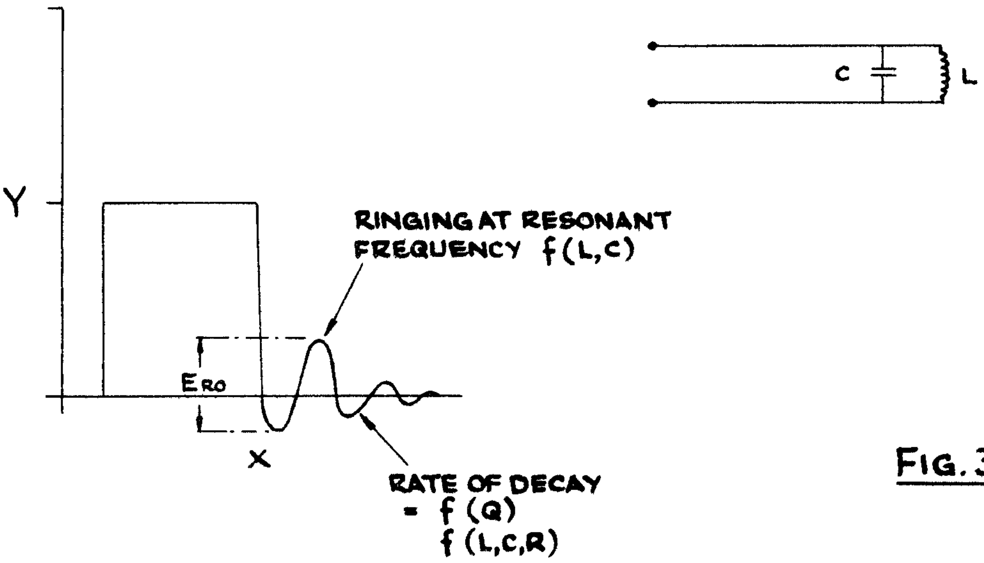

FIG. 3N.

THE AMPLITUDE OF THE RESONANT OSCILLATIONS, E_{Ro} IS DEPENDANT UPON:-

RESONANT FREQUENCIES, CIRCUIT IMPEDANCES, RESONANT CIRCUIT 'Q', CABLE CHARACTERISTICS, RISE TIMES, ETC.

MATHEMATICAL EQUATIONS FOR THE VARIOUS FUNCTIONS CAN BE FOUND IN:-

HEWLETT - PACKARD - APPLICATION NOTE 62
TIME DOMAIN REFLECTOMETRY

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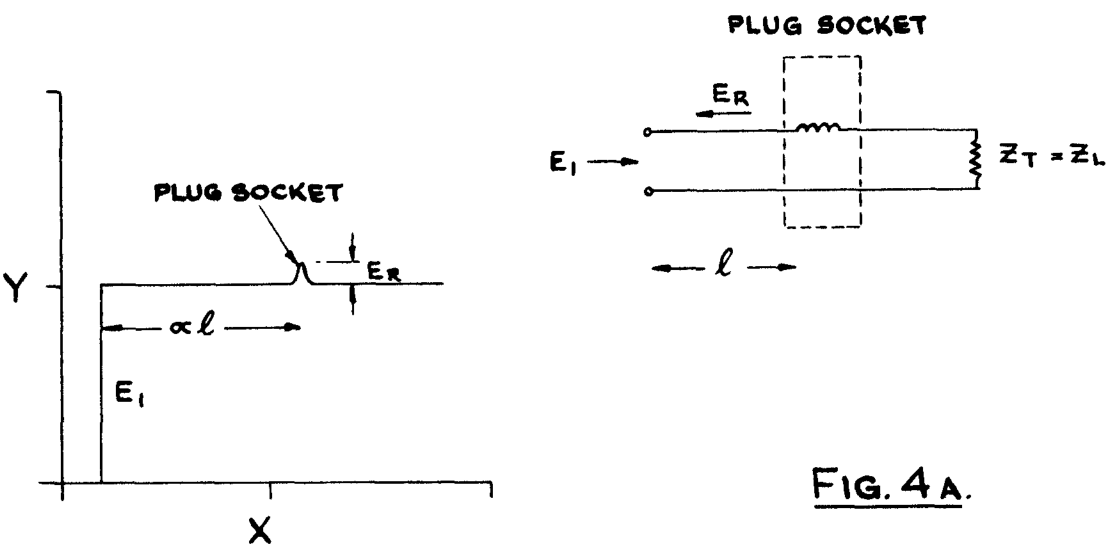

FIG. 4A.

REFLECTION COEFFICIENT, ρ:- $\rho = \frac{ER}{E1} = \frac{ZT - ZL}{ZT + ZL}$

STANDING WAVE RATIO (S.W.R.):-

$$S.W.R. = \frac{1+(\rho)}{1-(\rho)}$$

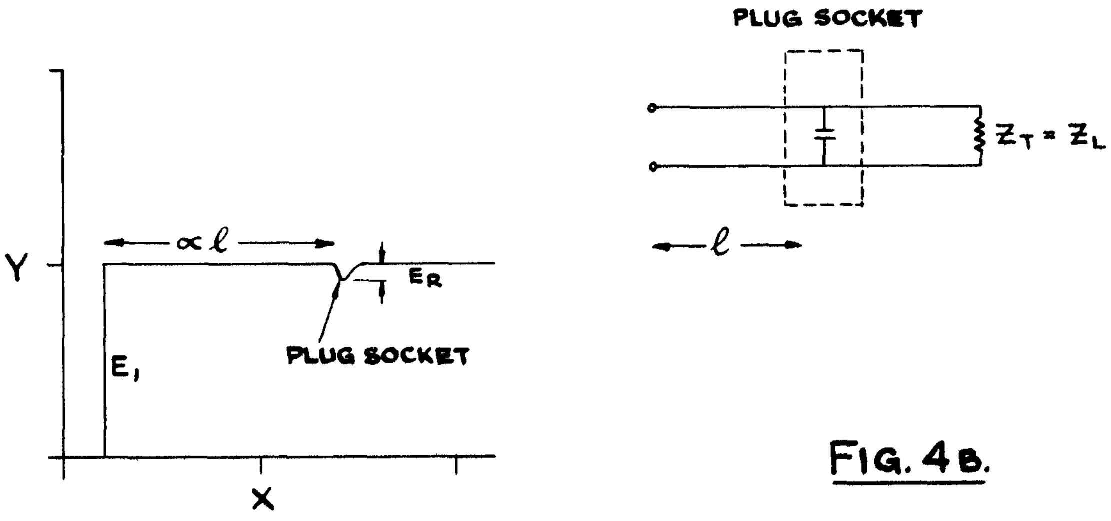

FIG. 4B.

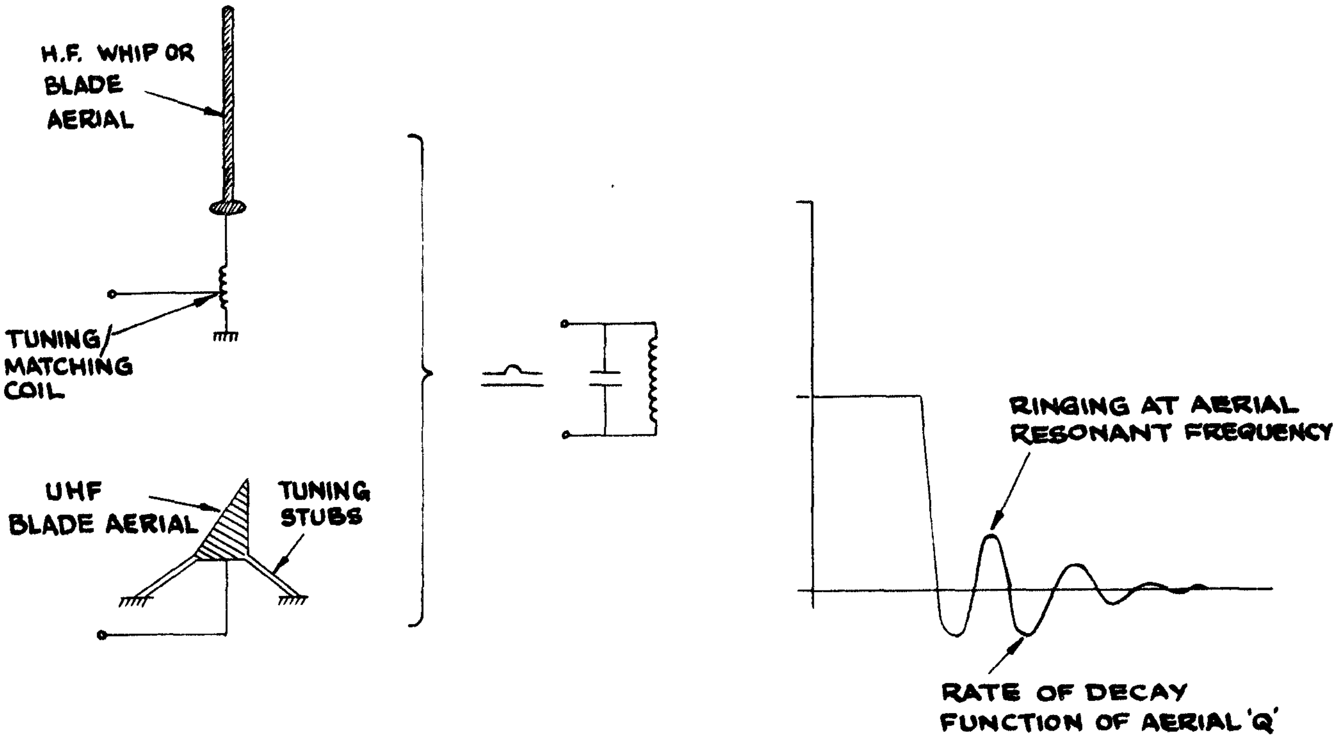
H.F. WHIP OR
BLADE
AERIAL
TUNING/
MATCHING
COIL
UHF
BLADE AERIAL
TUNING
STUBS
RINGING AT AERIAL
RESONANT FREQUENCY
RATE OF DECAY
FUNCTION OF AERIAL 'Q'

FIG. 5A.

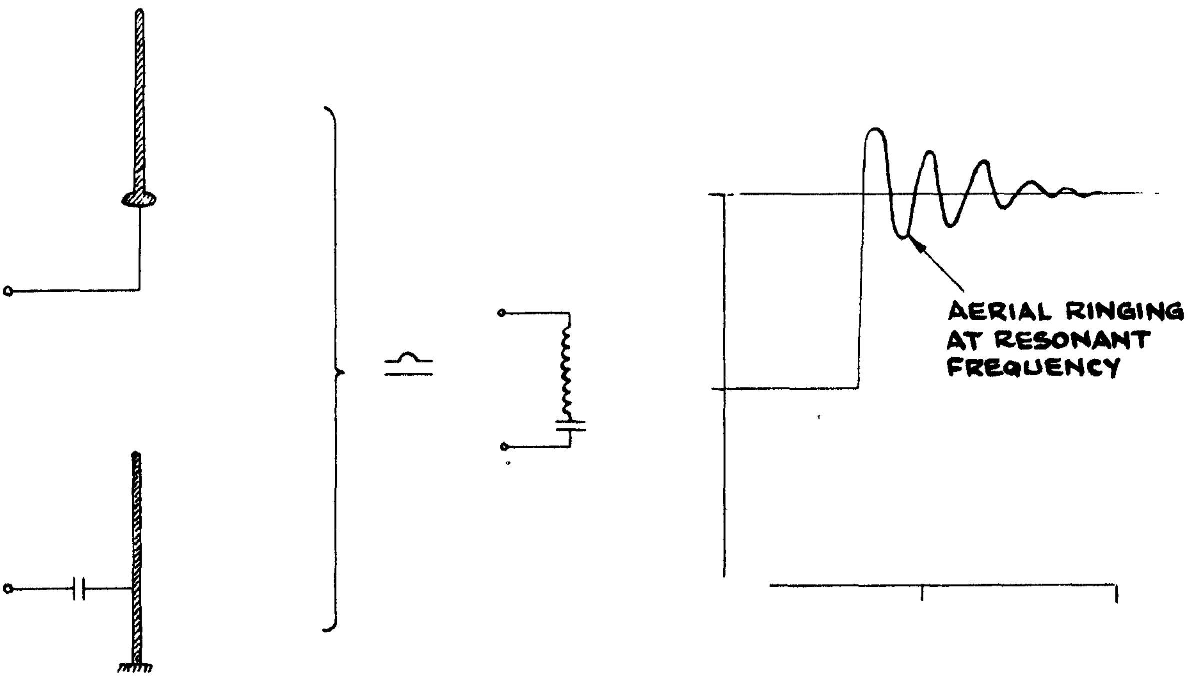
AERIAL RINGING
AT RESONANT
FREQUENCY

FIG. 5B.

BROAD BAND ATTENUATION MEASUREMENT

DISPLAY

SYSTEM UNDER TEST

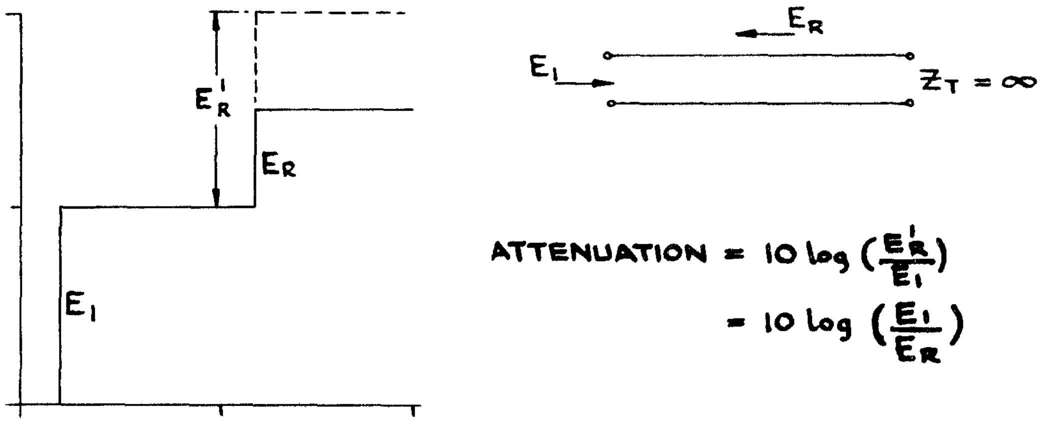

FIG. 6 A

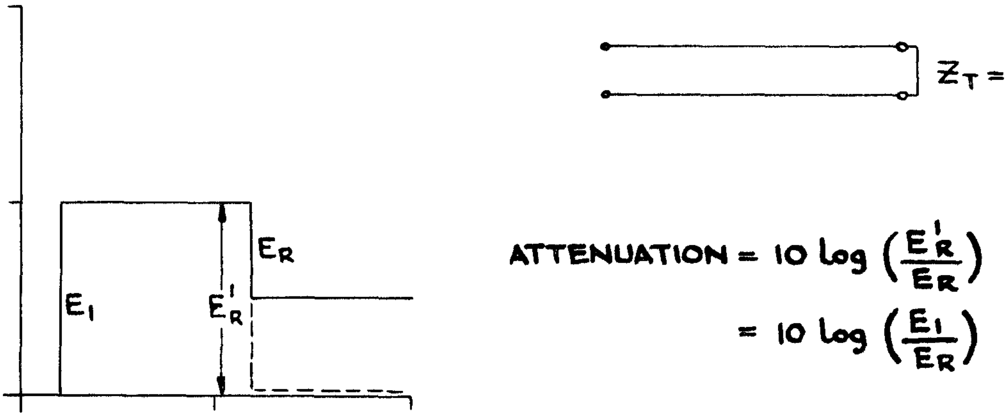

FIG. 6B.

BROAD BAND ATTENUATION IS CALCULATED

FROM:- $\frac{1}{2}\left[20 \text{ LOG} \left(\frac{ER'}{ER}\right)\right] = 10 \text{ LOG} \left(\frac{ER'}{ER}\right)$

WHERE E_R' IS THE VOLTAGE THAT WOULD HAVE BEEN REFLECTED THROUGH A CABLE OF ZERO LOSS, AND E_R IS THE ACTUAL VOLTAGE MEASURED.

MEASUREMENTS ARE USUALLY MADE WITH ZERO (SHORT CIRCUIT) OR INFINITE (OPEN CIRCUIT) IMPEDANCE TERMINATIONS, AS E_R' IS THEN KNOWN ($E_R' = E_1$)

BROAD BAND ATTENUATION IS DISPLAYED AS A RESISTING TERMINATION (SEE FIGS 3c, 3d, 3e). THEREFORE LOW LOSS CABLES AND GENERAL RADIO CONNECTORS MUST BE USED TO CONNECT T M UNDER TEST (SEE ANNEX C).

TYPICAL TDR DISPLAYS IN AIRCRAFT

AIRCRAFT	FIG	OBSERVATION EQUIPMENT AND ACTION TAKEN	SERVICEABILITY
Canberra IFF	1	Open circuit at junction of the upper aerial cable and switch unit. (Plug loose)	U/S
Canberra IFF	2	Plug tightened. Result satisfactory	'S'
Lightning IFF	3	Satisfactory	'S'
Lightning IFF	4	Upper aerial gave a slightly shorter reflection fall time.	'S'
Lightning IFF	5	Slight difference was noted in switch unit upper and lower positions.	'S'
Lightning ILS	6	Localiser	'S'
Lightning ILS	7	Marker. The aerial was dismantled to observe terminating inductance, it was found to be a feature of design.	'S'
Lightning ILS	8	Glidepath	'S'
Varsity	9	Radio Compass Loop Aerial	'S'
Varsity	10	Sense aerial via filter unit (filter unit blocked the step input waveform). Unsatisfactory	-
Varsity	11	Direct to snese aerial Satisfactory	'S'
Varsity	12	Gee III	'S'
Varsity	13	Rebecca Satisfactory	'S'
Varsity	14	Rebecca Satisfactory	'S'
Varsity	15	Rebecca Satisfactory	'S'
Varsity	16	Rebecca Satisfactory	'S'
Varsity	17	VHF Satisfactory	'S'
Varsity	18	VHF Satisfactory	'S'
Britannia	19	IFF 10 Unsatisfactory	U/S
Britannia	20	IFF 10 lower aerial connected to short lead, 3db attenuation in aerial was measured.	'S'
Britannia	21	Serviceable aerial connected to cable, tested.	'S'
Britannia	22	Serviceable aerial connected to aircraft	'S'
Britannia	23	Aerial switch to flight position. Display indicated that at some part of the switching cycle the t[illegible] [illegible] [illegible] [illegible] [illegible]allel. Lower aerial contacts were found not to be opening.	U/S
Britannia	24	VHF aerial	'S'
Britannia	25	STR 18 Aerial system Port High Z termination	U/S

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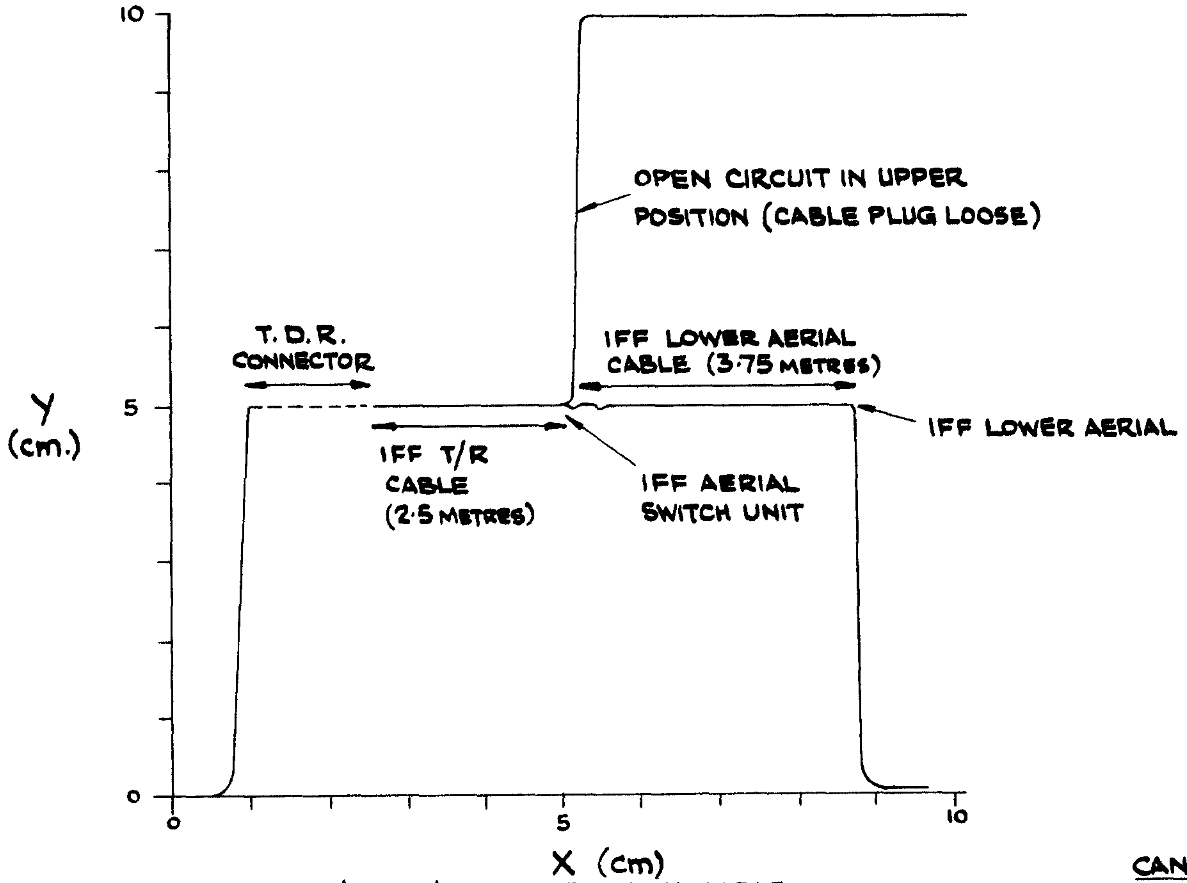
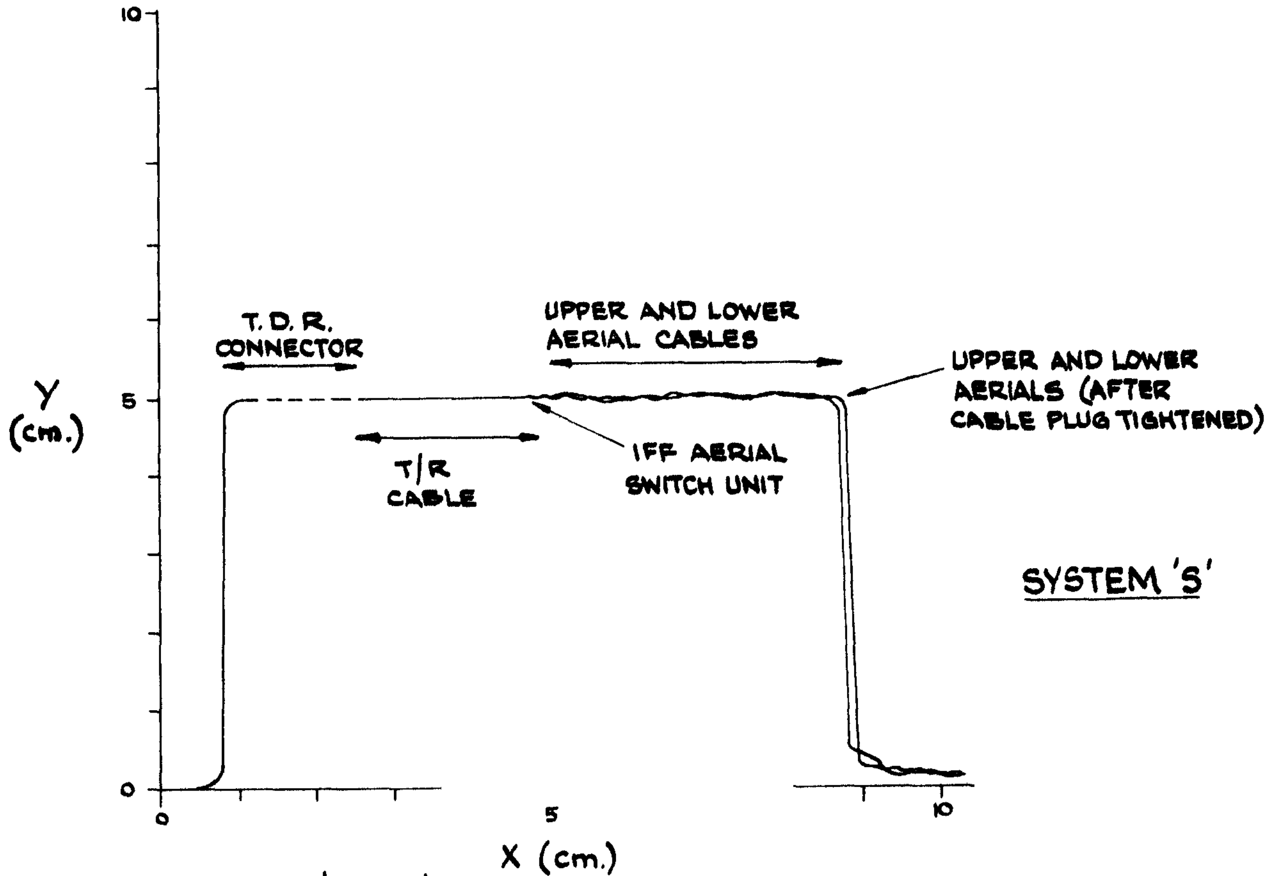
AIRCRAFT	FIG	OBSERVATION EQUIPMENT AND ACTION TAKEN	SERVICEABILITY
Britannia	26	STR 18 Aerial System	'S'
Britannia	27	STR 18 Aerial Wires Port Hing & Termination	U/S
Britannia	28	STR 18 Aerial Wires	'S'
Comet	29	ILS Glide Path	'S'
Comet	30	Localiser	'S'
Comet	31	Marker	'S'
Comet	32	UHF	'S'
Vulcan	33	IFF 10 Aerial System lower Aerial	'S'
Vulcan	34	IFF 10 Upper and Flight positions	U/S
Vulcan	35	IFF Satisfactory Display	'S'
Vulcan	36	IFF Satisfactory Display	'S'
Vulcan	37	IFF Satisfactory Display	'S'



1 cm = 1 METRE OF CO-AXIAL CABLE.
N.B. THE ACTUAL T.D.R. CONNECTOR LENGTH WILL DEPEND ON ACTUAL CABLE IN USE

CANBERRA

FIG. 1.



1 cm ≡ 1 METRE OF CO-AXIAL CABLE.

CANBERRA

FIG. 2.

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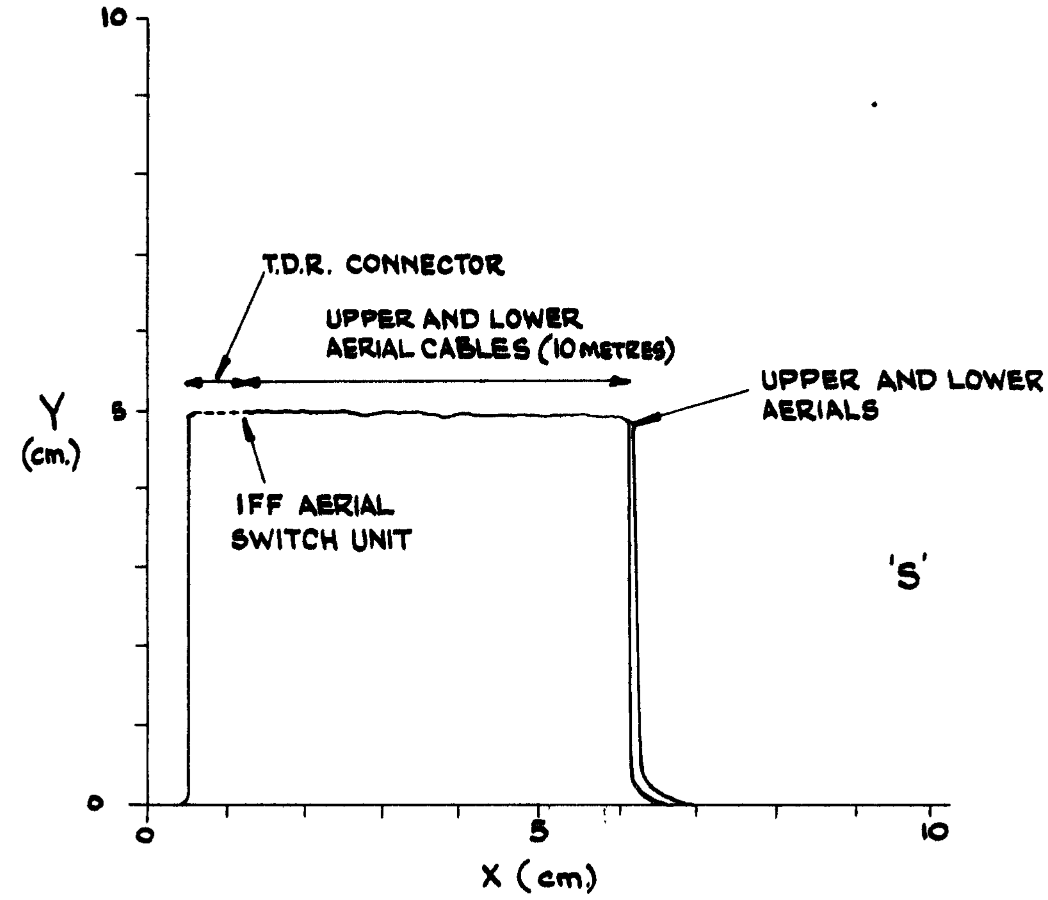
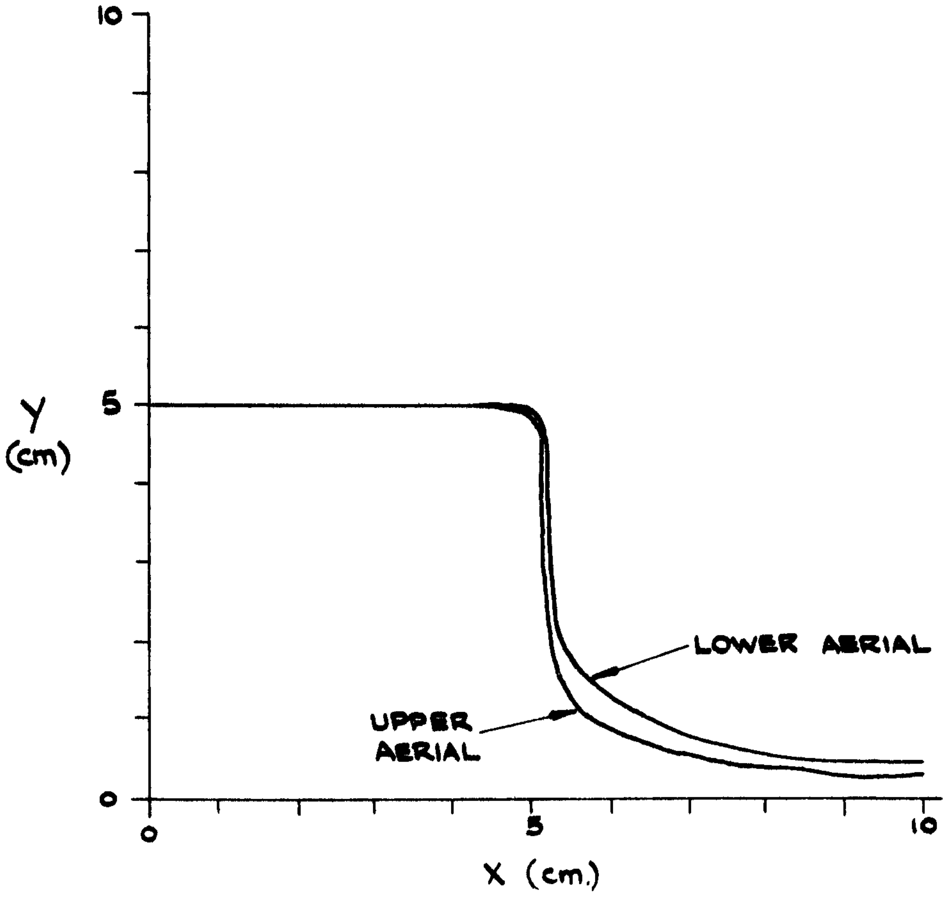


1 cm. ≡ 2 METRES OF CO-AXIAL CABLE

LIGHTNING F.MK.3

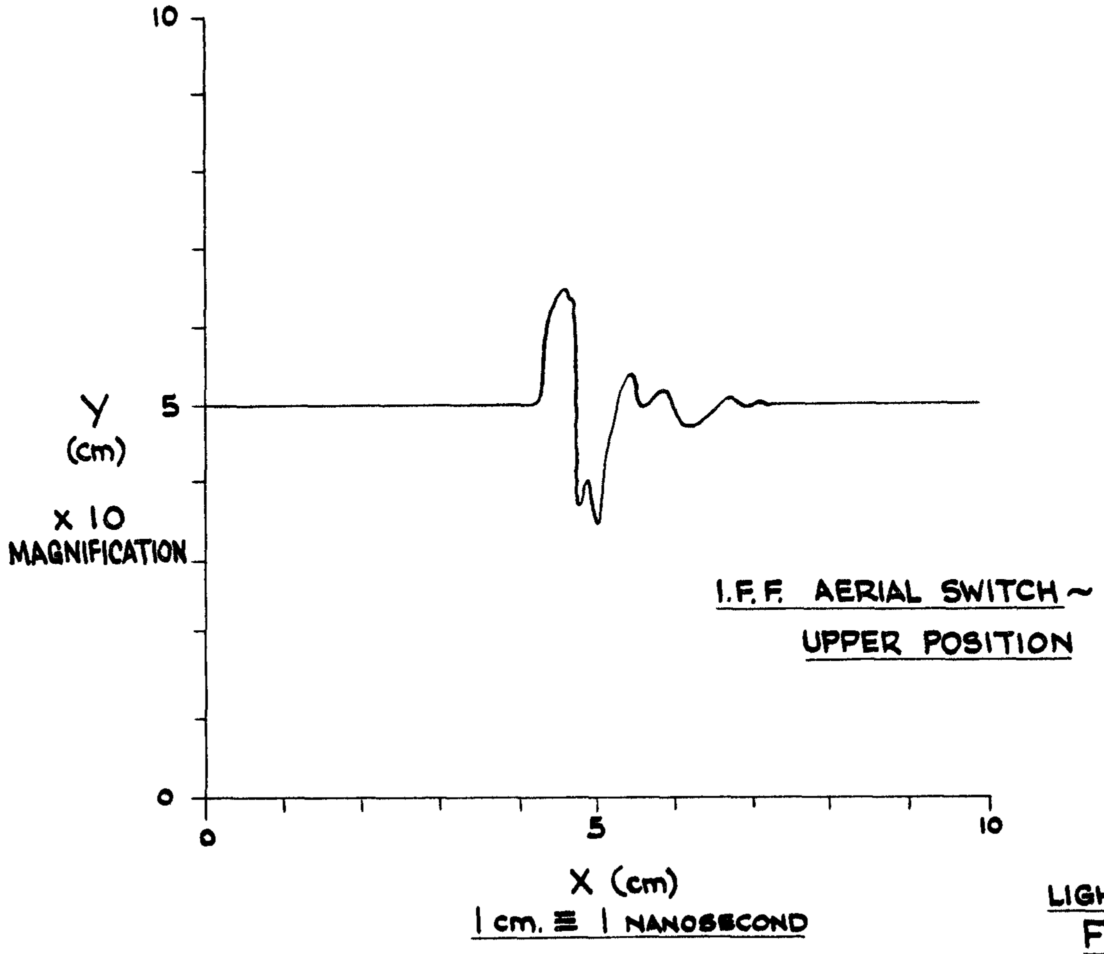
FIG. 3



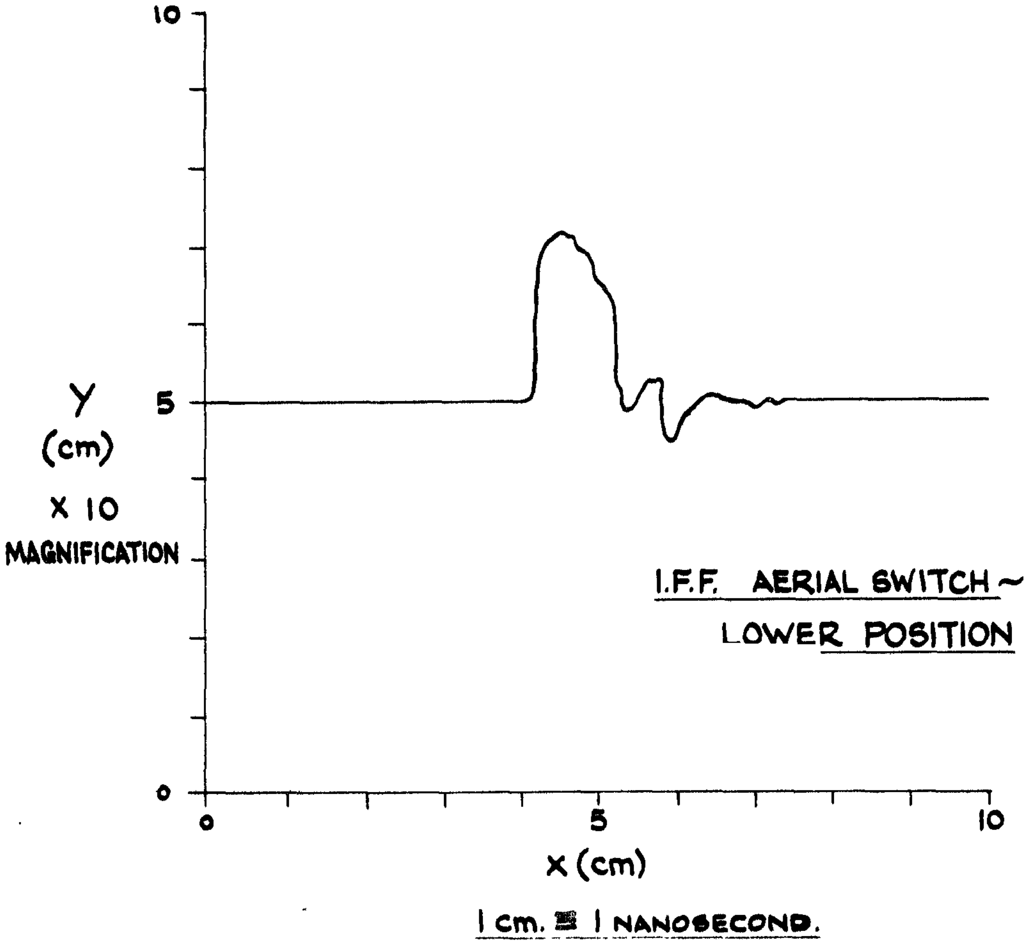
1 cm. ≡ 2 NANOSECONDS

LIGHTNING F.MK.3.

FIG. 4.



LIGHTNING F.MK.3
FIG. 5A.



LIGHTNING F.MK.3.
FIG. 5B.

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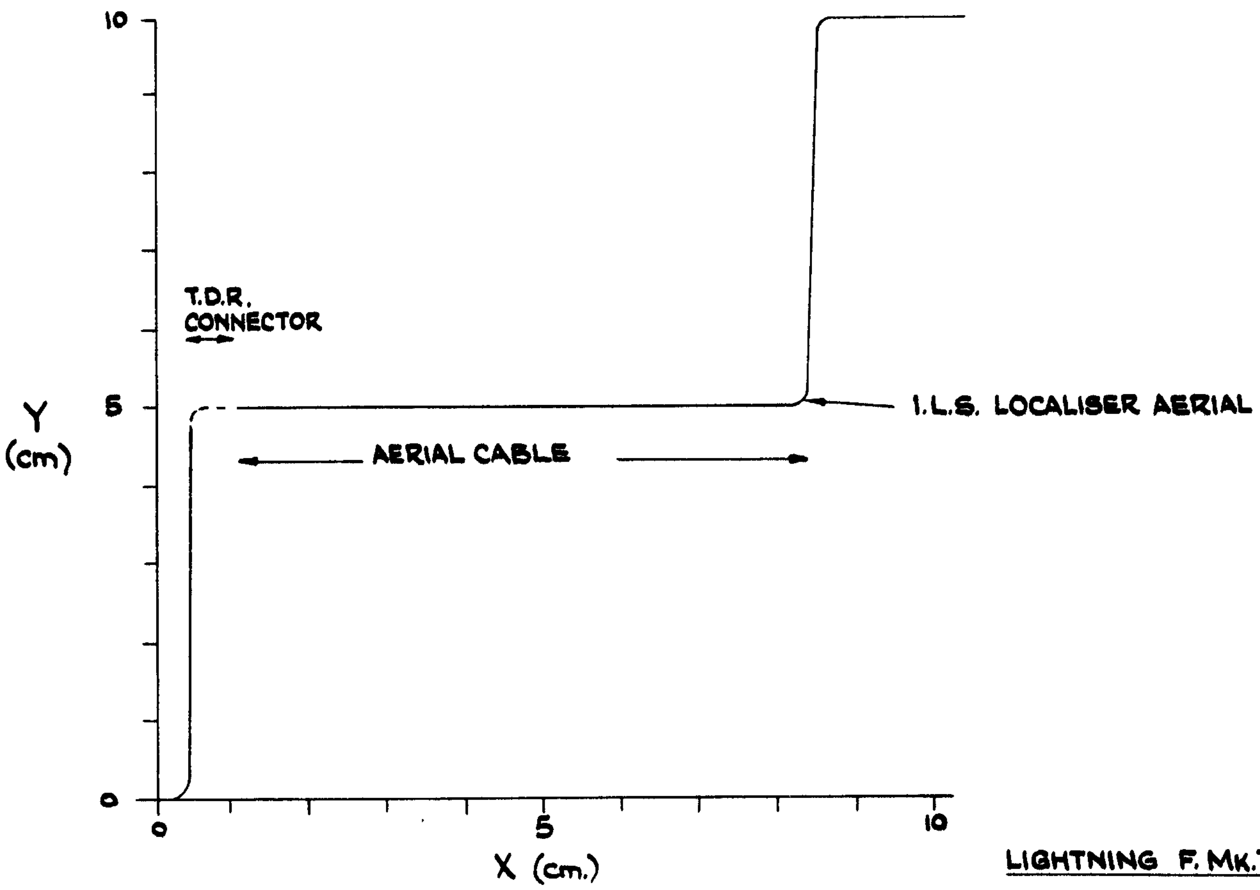
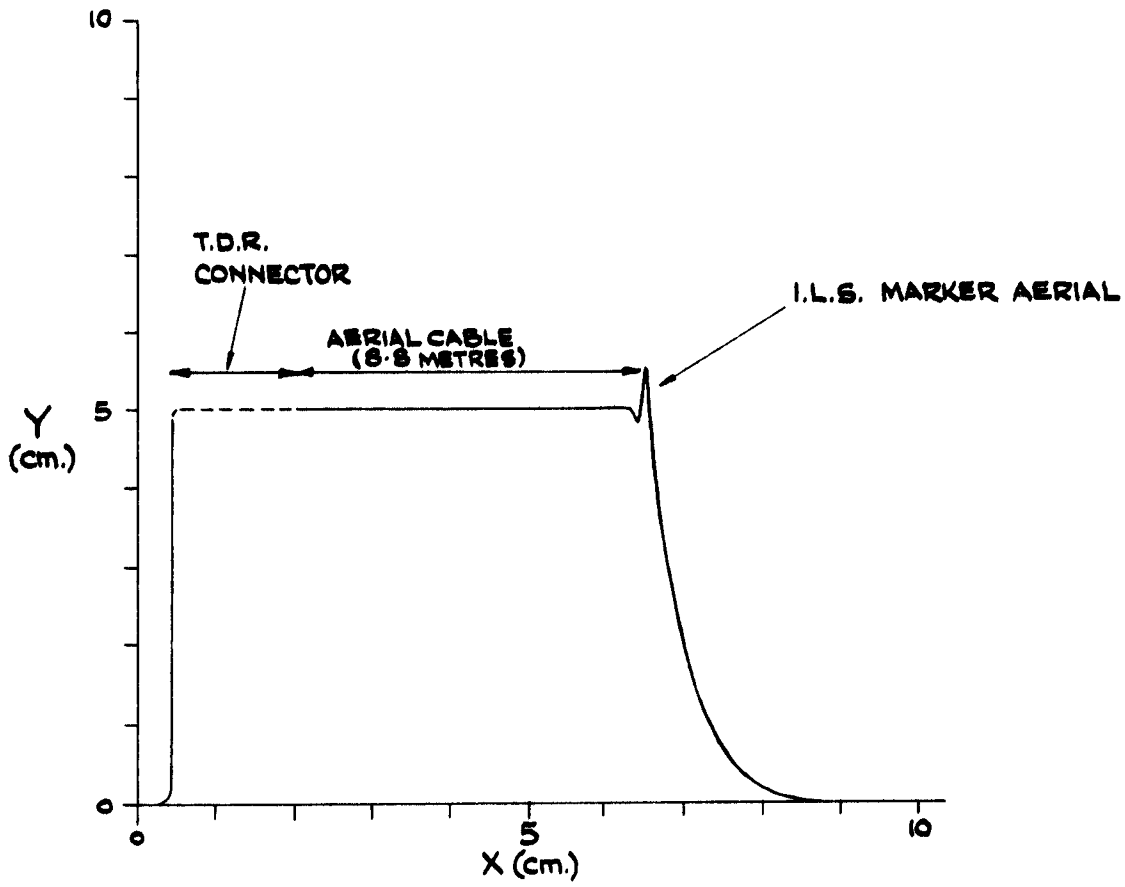


LIGHTNING F. MK.3

FIG. 6

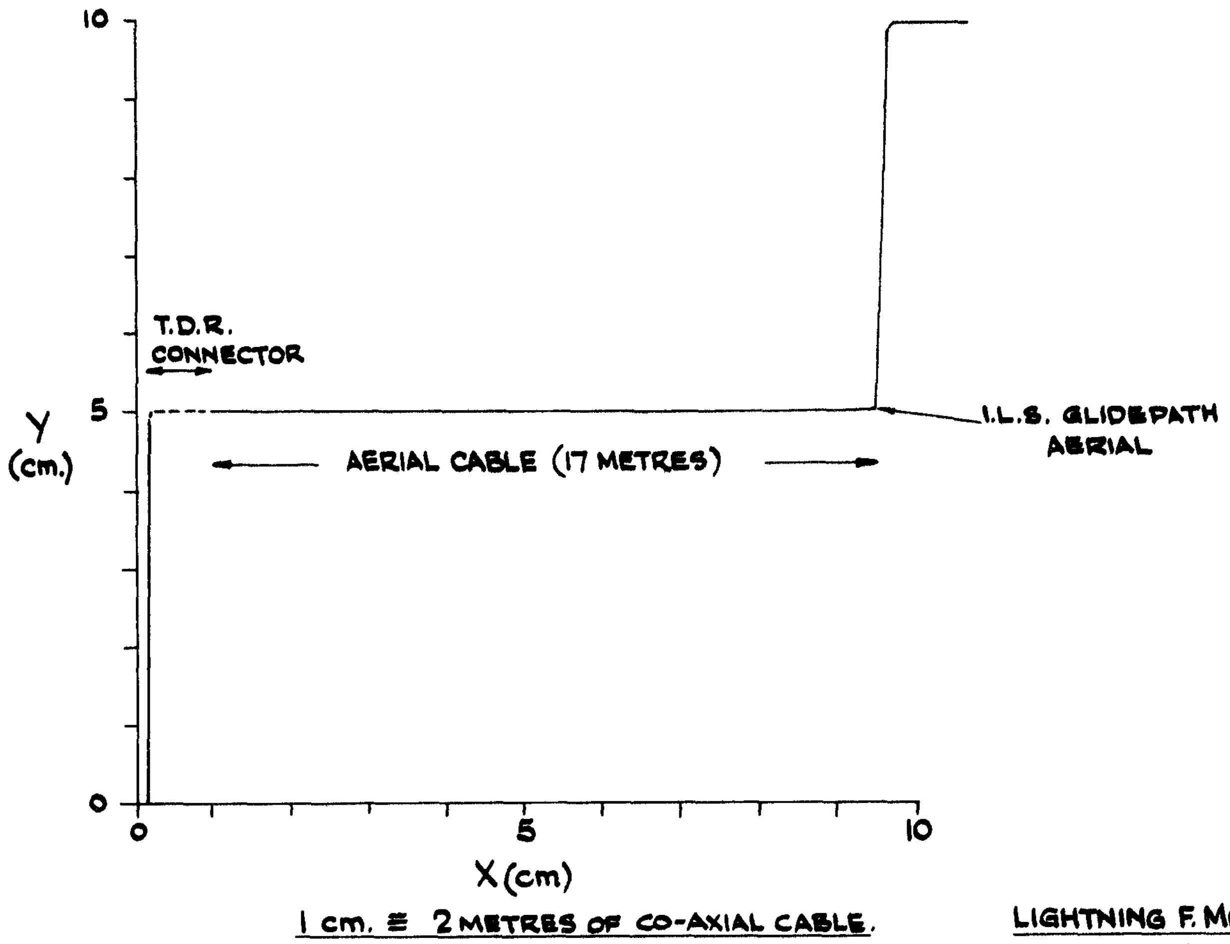


1 cm. ≡ 2 METRES OF CO-AXIAL CABLE.

LIGHTNING F. MK.3

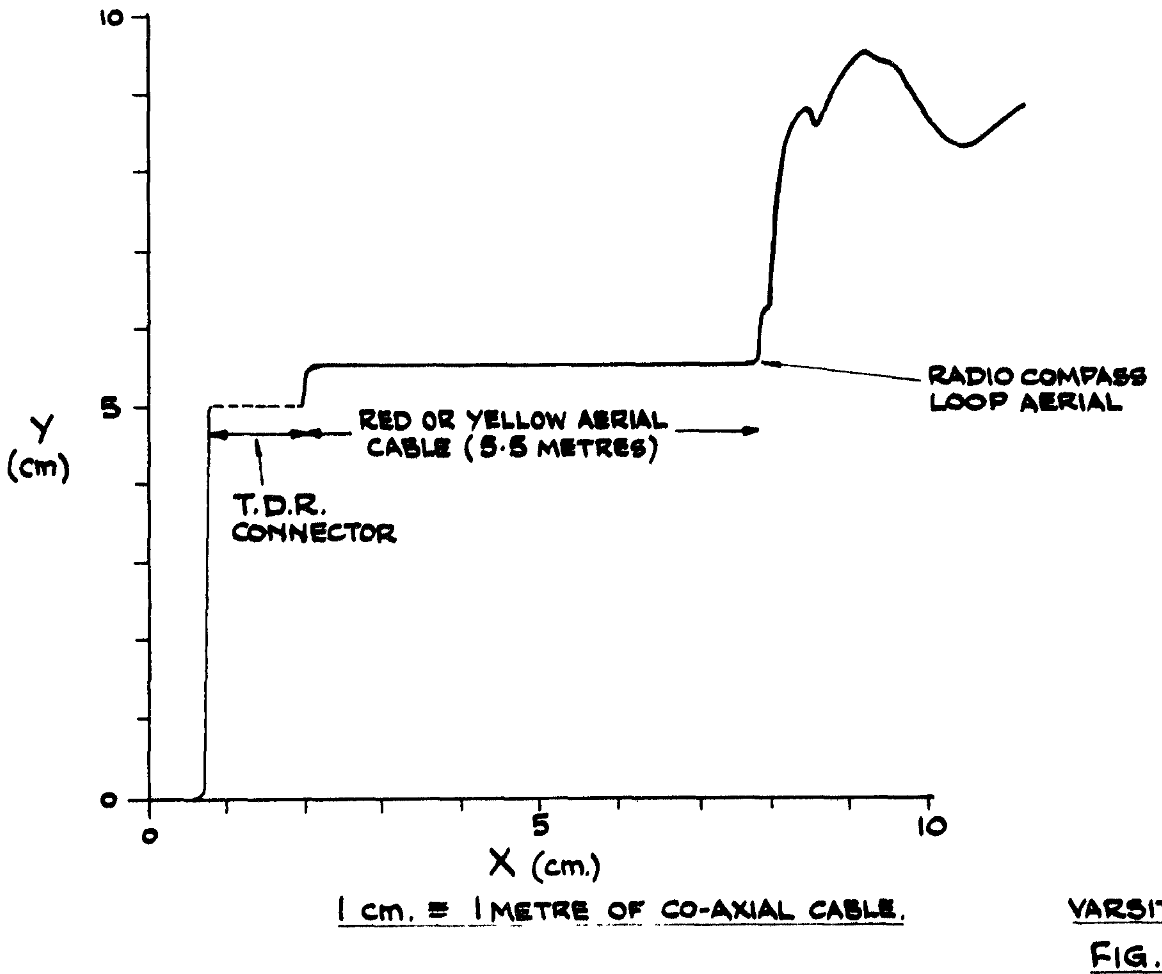
FIG. 7.

(12a)



LIGHTNING F. Mk.3

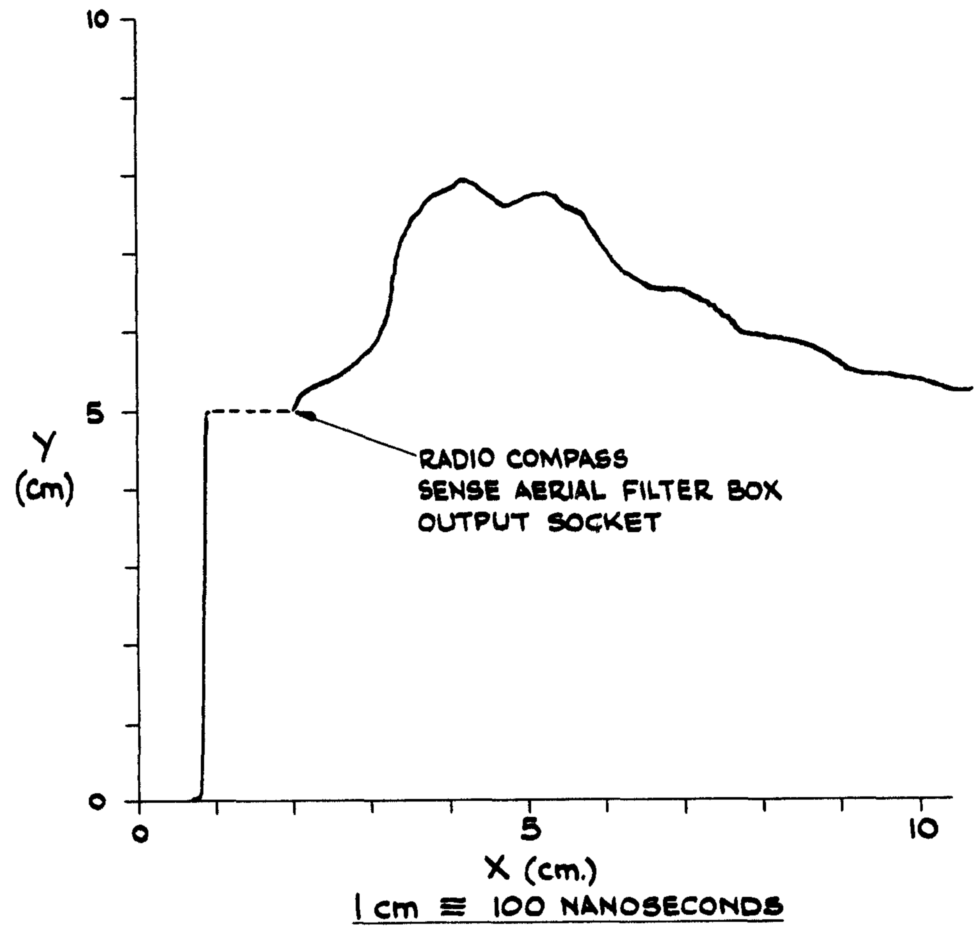
FIG. 8



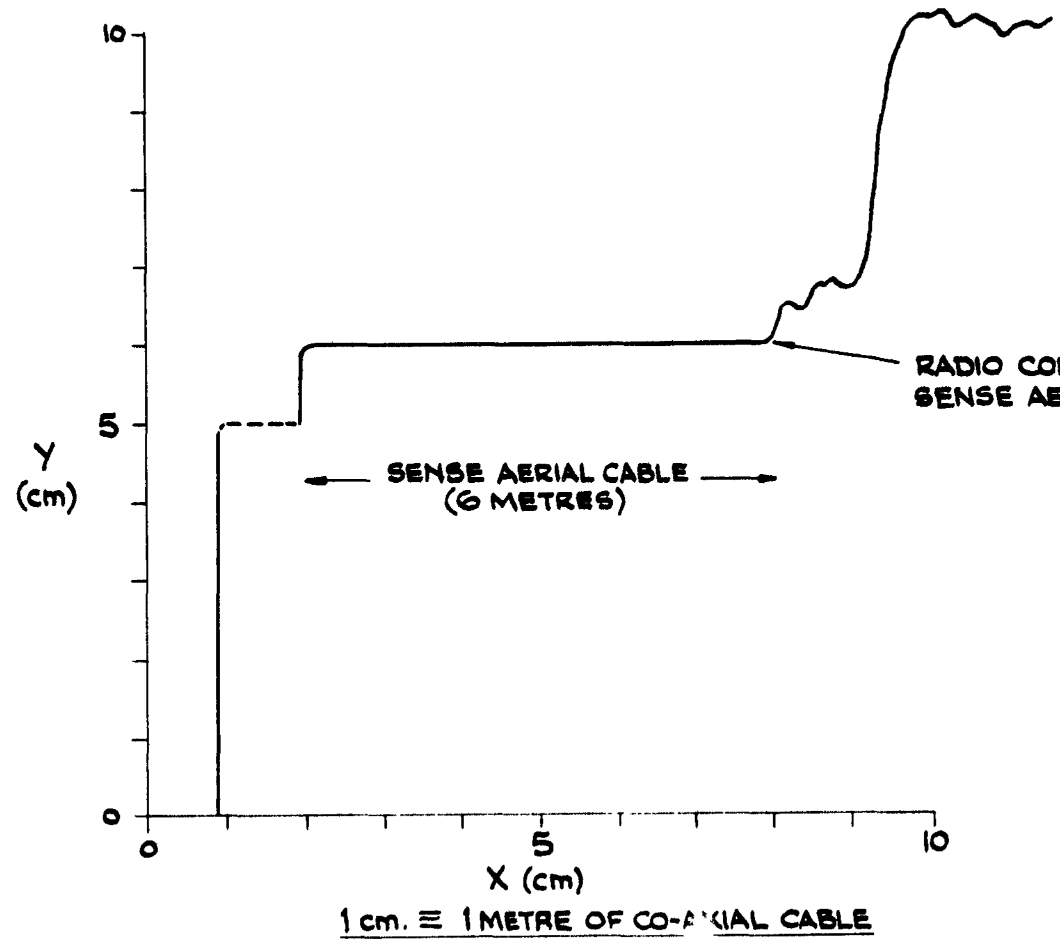
VARSITY

FIG. 9

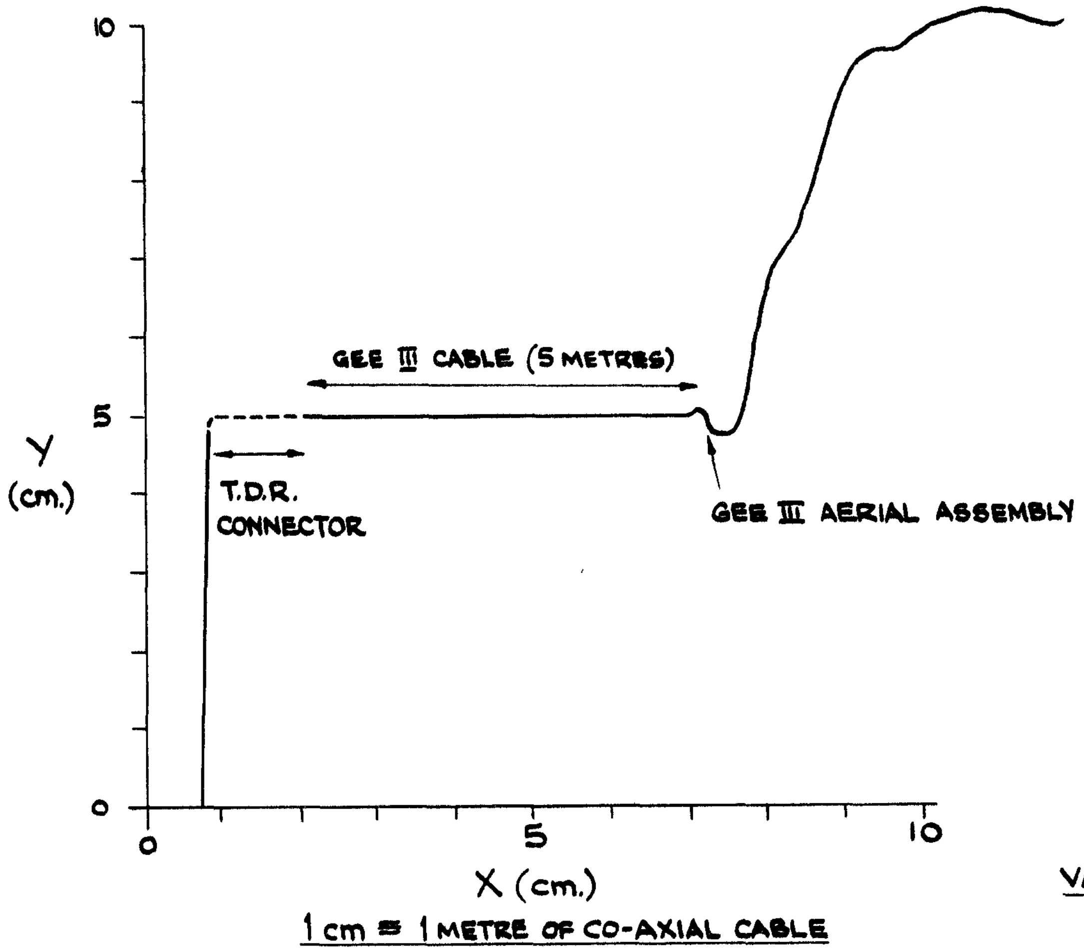
/Continued overleaf



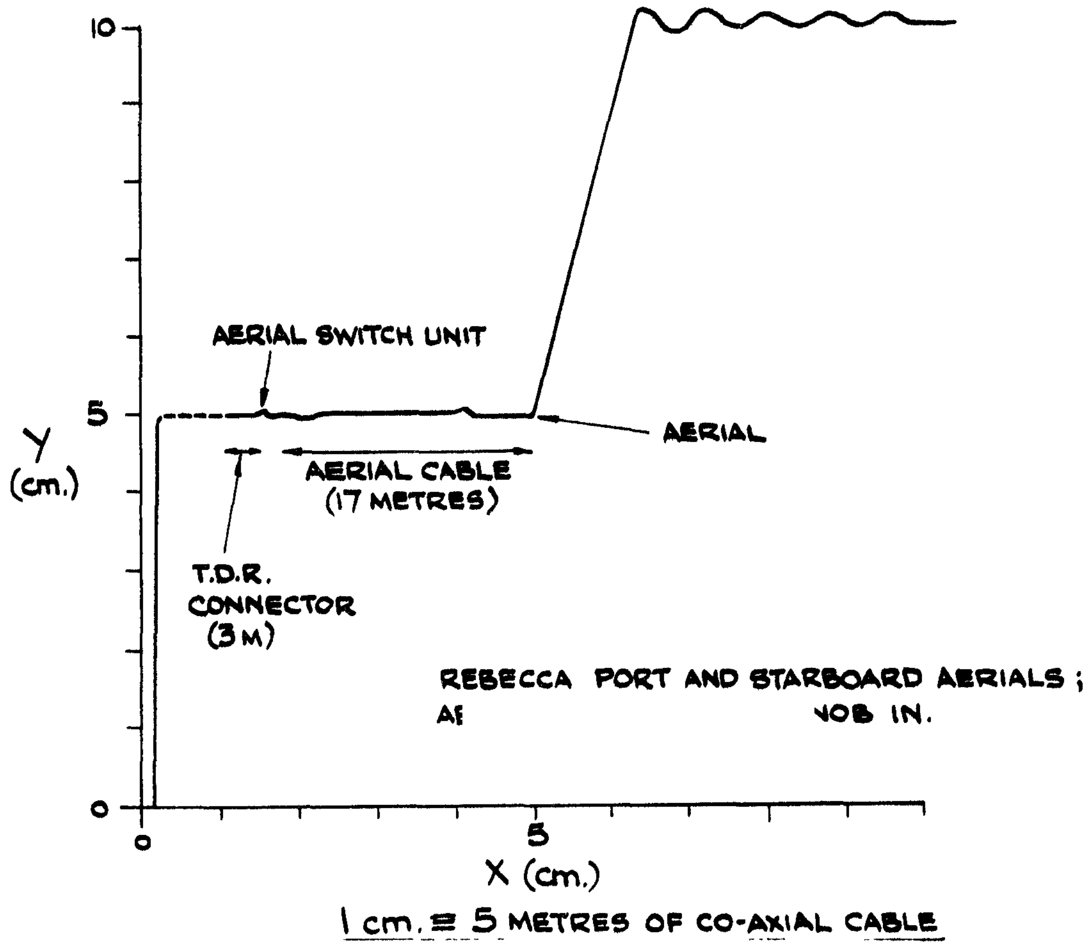
VARSITY
FIG. 10



VARSITY
FIG. 11

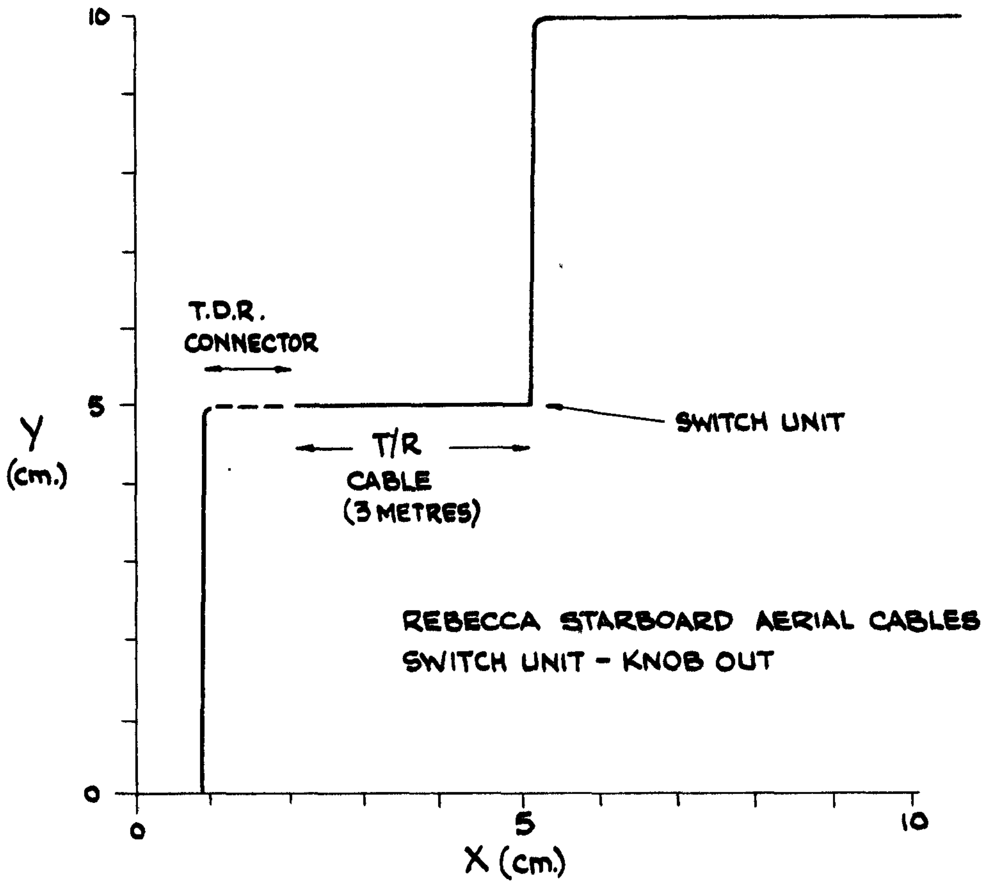


VARSITY
FIG. 12



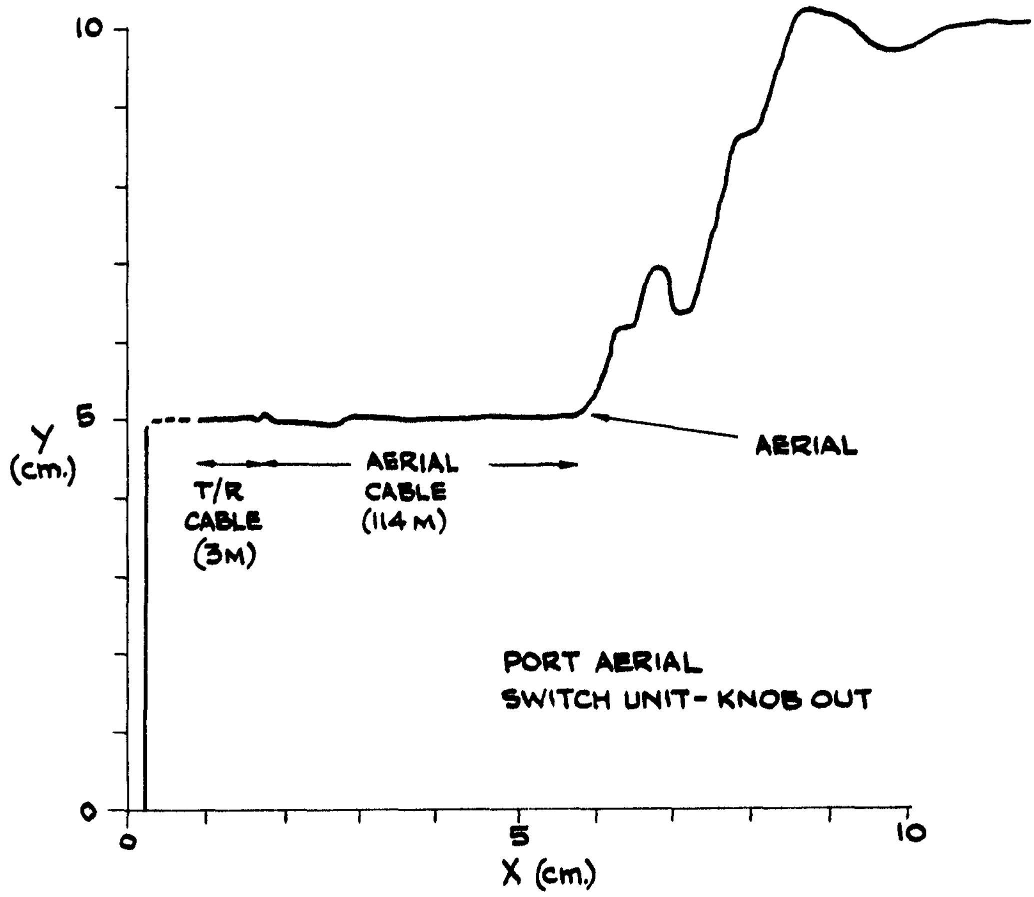
VARSITY
FIG. 13

/Continued overleaf



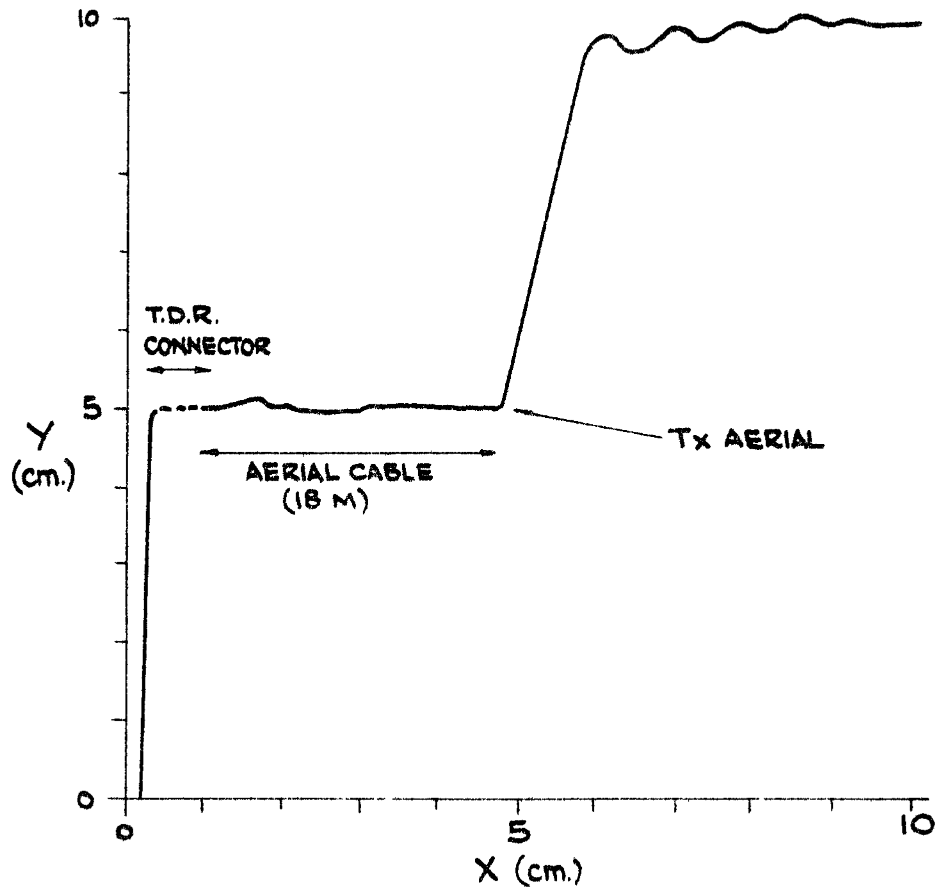
1 cm. ≡ 1 METRE OF CO-AXIAL CABLE

VARSITY
FIG. 14



1 cm ≡ 5 METRES OF CO-AXIAL CABLE

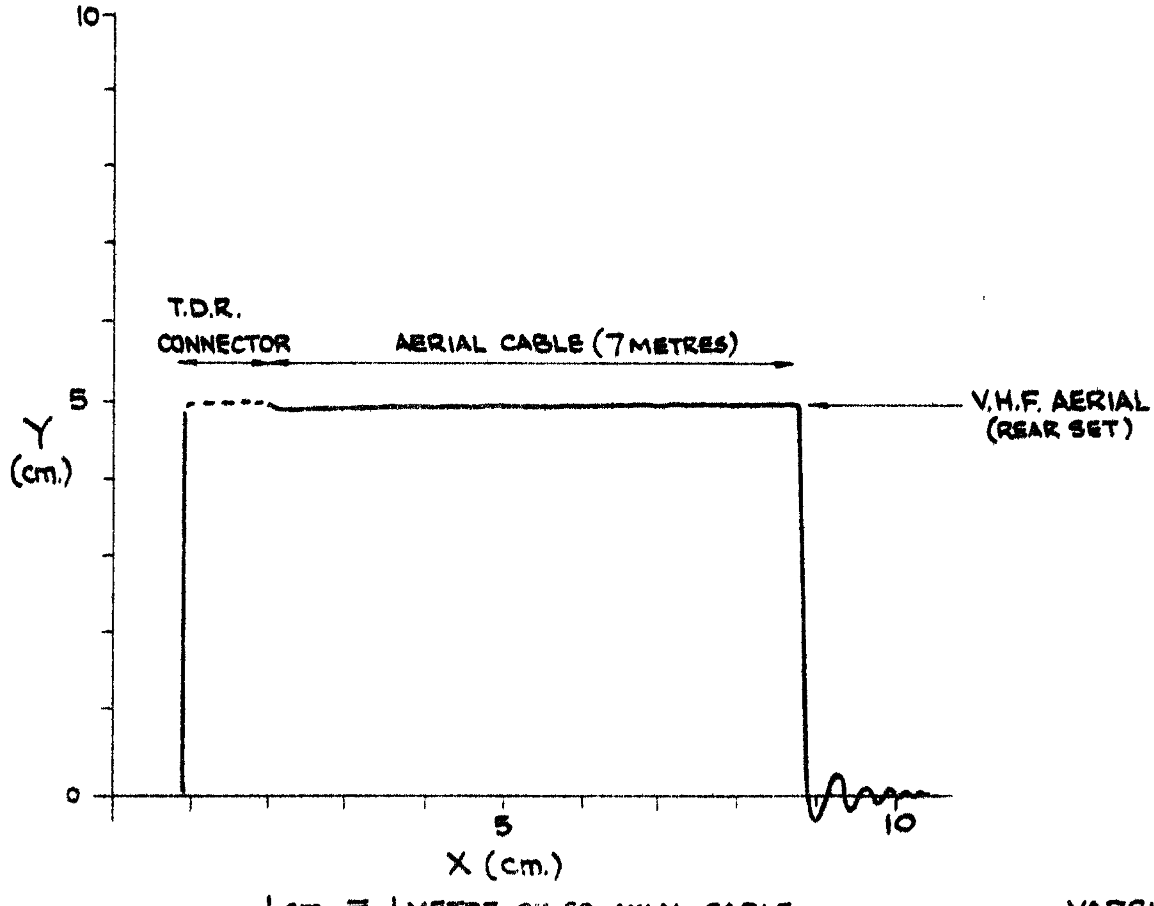
VARSITY
FIG. 15



1 cm. ≡ 5 METRES OF CO-AXIAL CABLE

VARSITY

FIG. 16

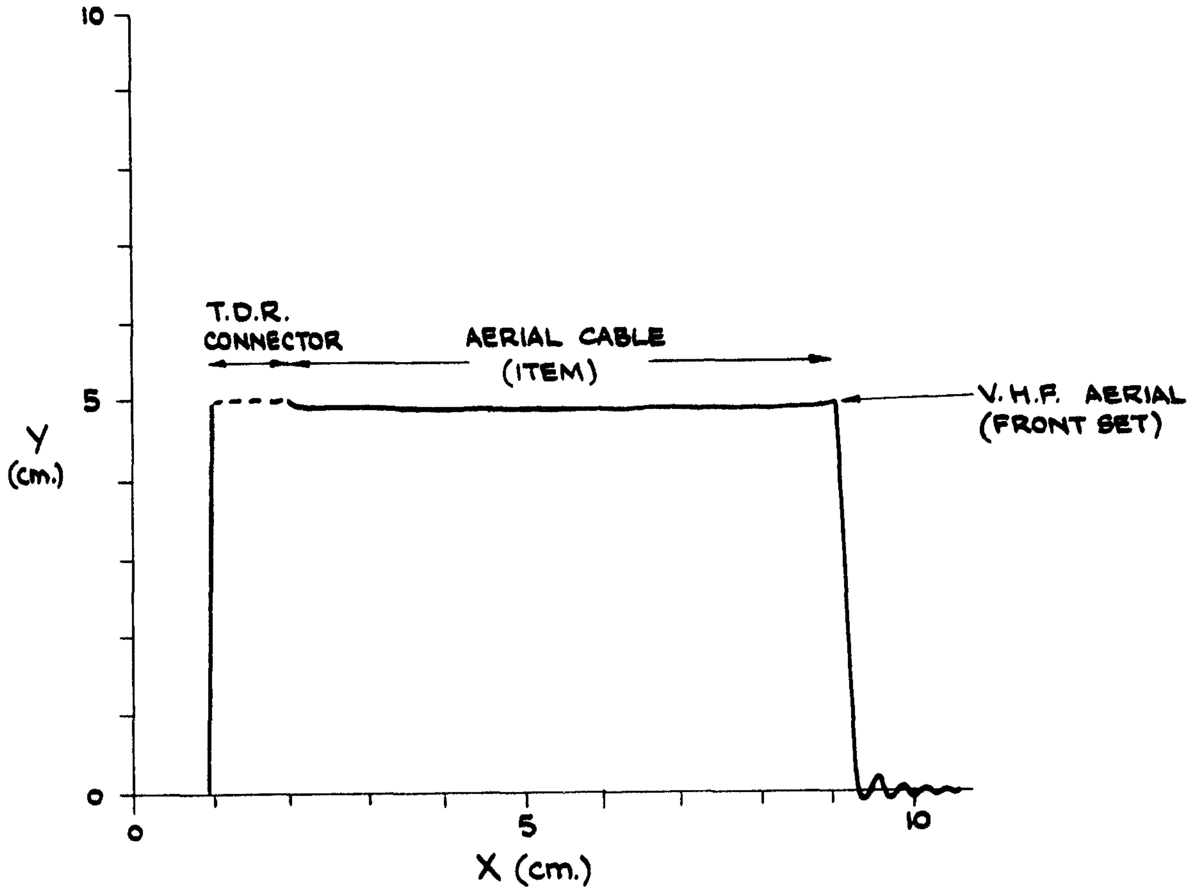


1 cm. ≡ 1 METRE OF CO-AXIAL CABLE

VARSITY

FIG. 17

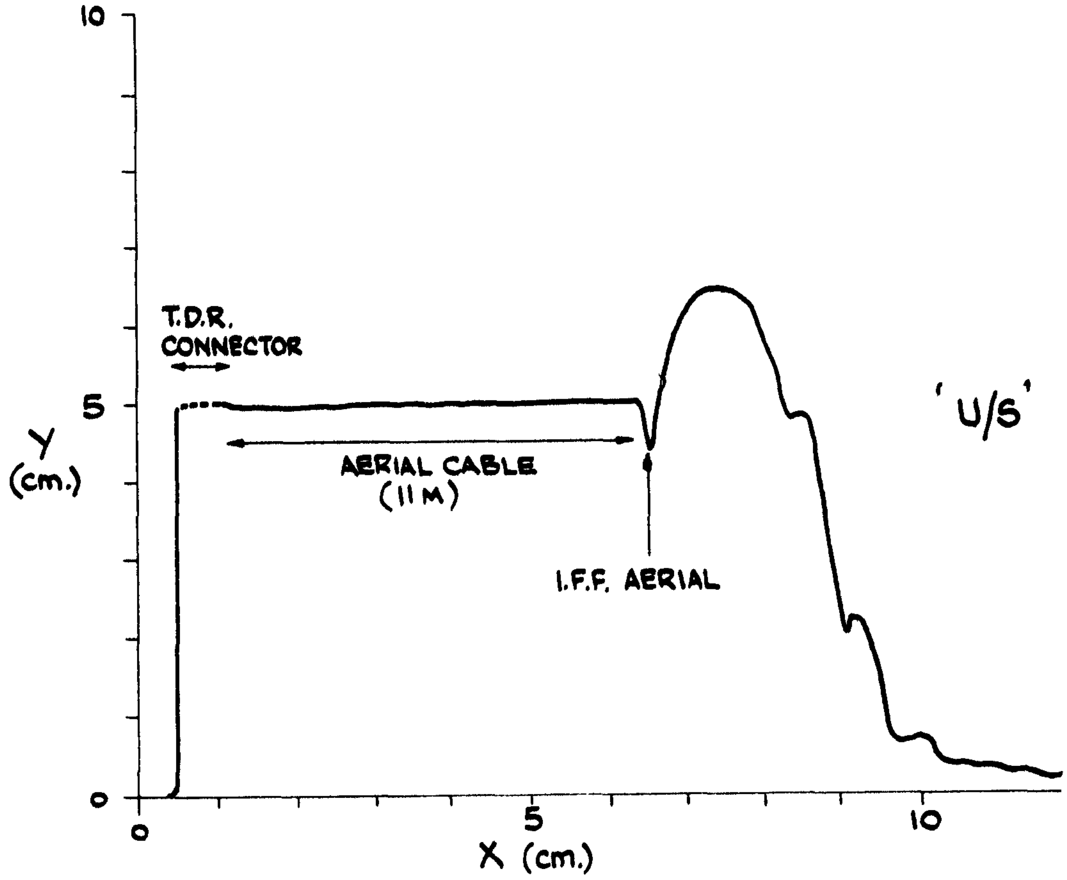
/Continued overleaf



1 cm. ≡ 1 METRE OF CO-AXIAL CABLE

VARSITY

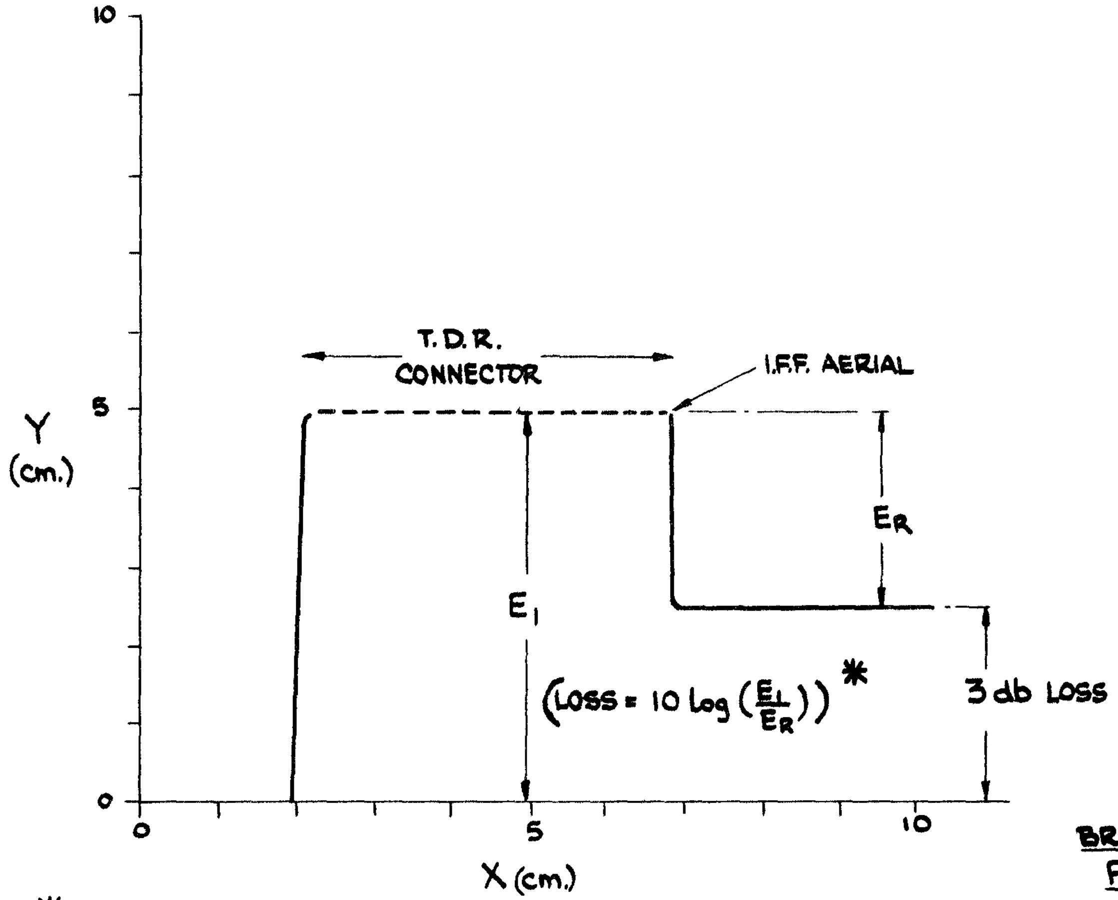
FIG. 18



1 cm. ≡ 2 METRES OF CO-AXIAL CABLE

BRITANNIA

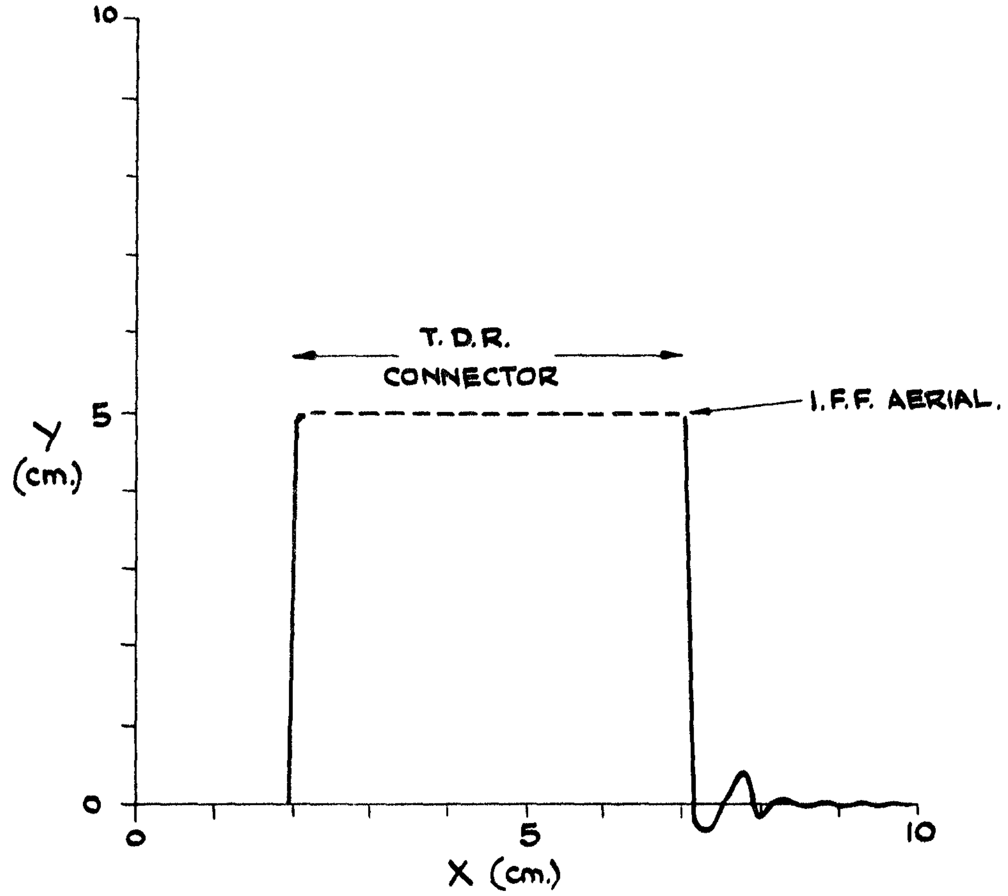
FIG. 19



BRITANNIA

FIG. 20

* BROAD-BAND ATTENUATION LOSSES CAN ONLY BE MEASURED DIRECTLY WITH OPEN OR SHORT CIRCUIT TERMINATIONS. (FIG. 20 – SHORT CCT.)

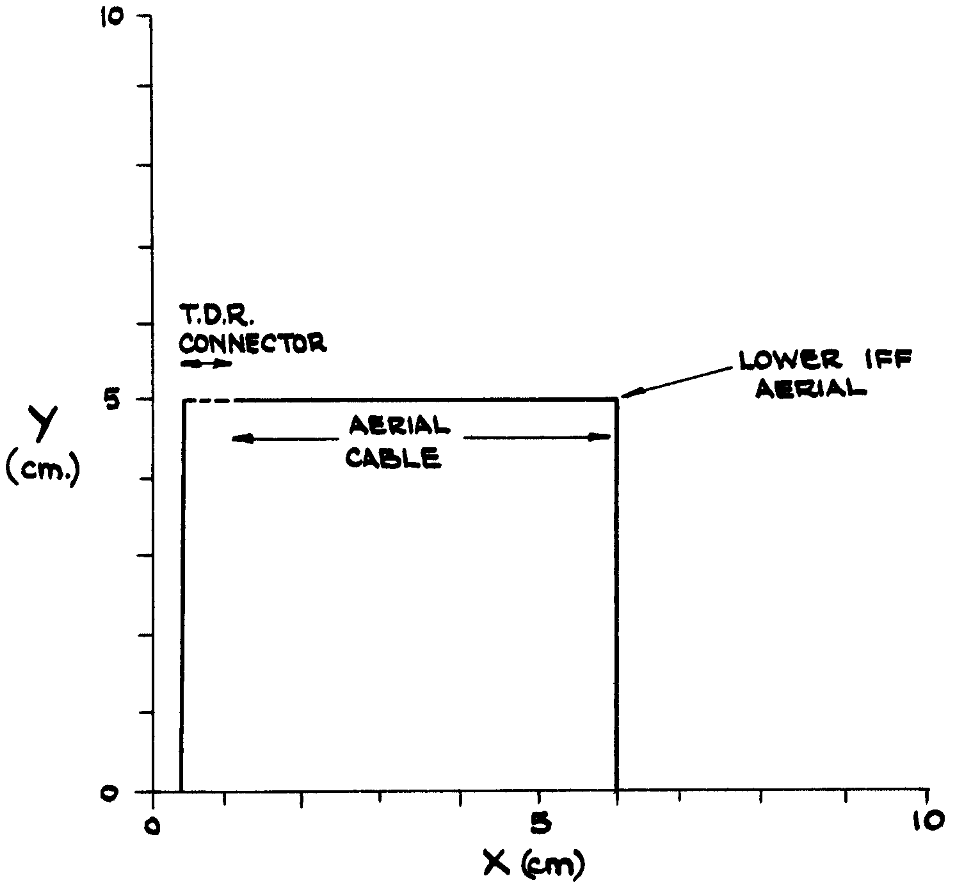


1 cm. ≡ 2 METRES OF CO-AXIAL CABLE.

BRITANNIA

FIG. 21

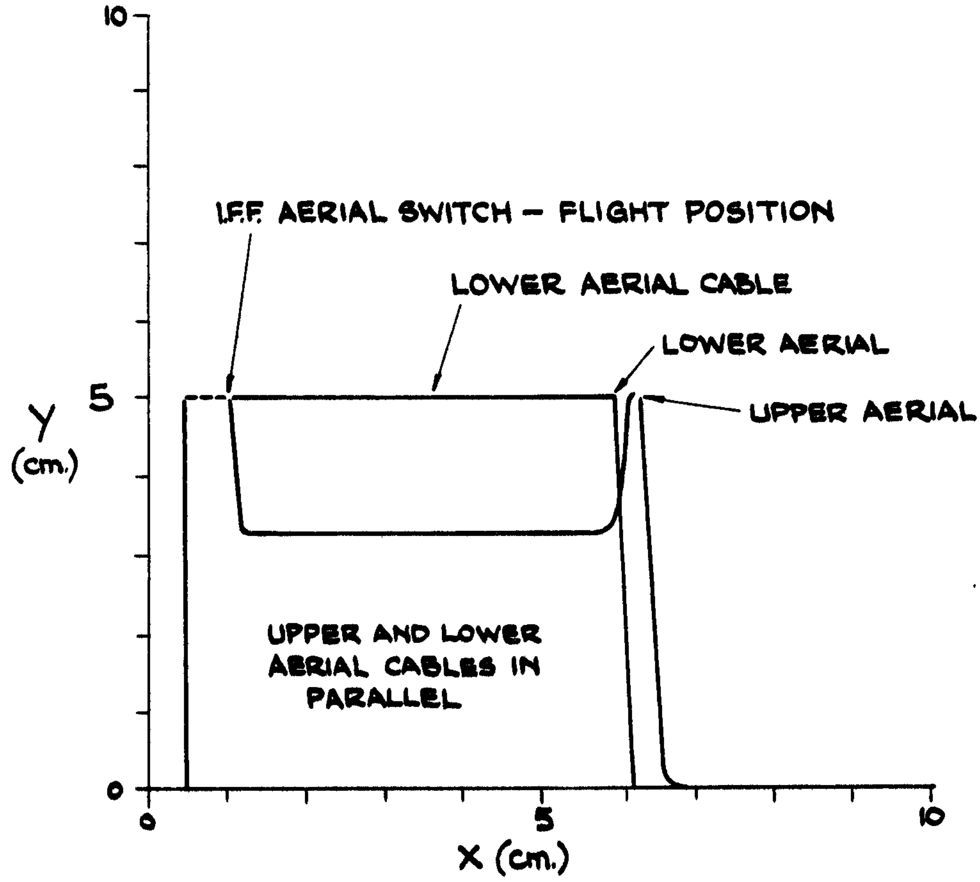
/Continued overleaf



1 cm. ≡ 2 METRES OF CO-AXIAL CABLE

BRITANNIA

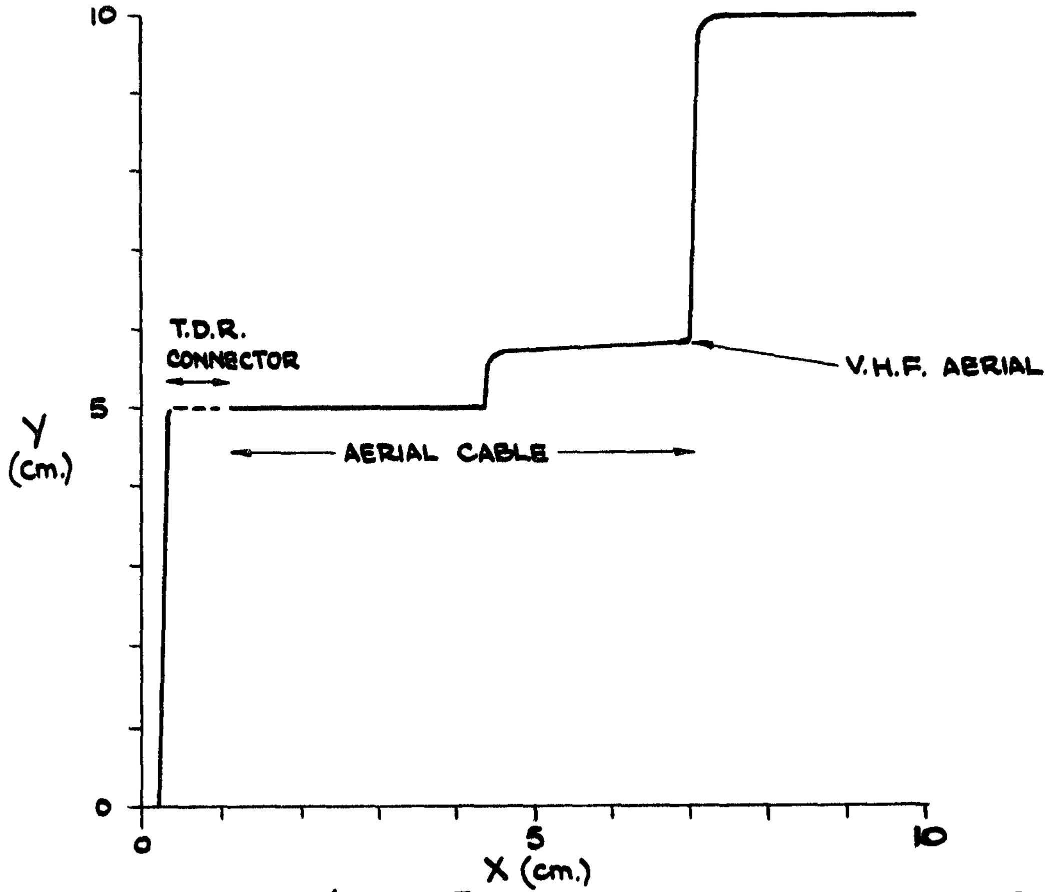
FIG. 22



1 cm. ≡ 2 METRES OF CO-AXIAL CABLE

BRITANNIA

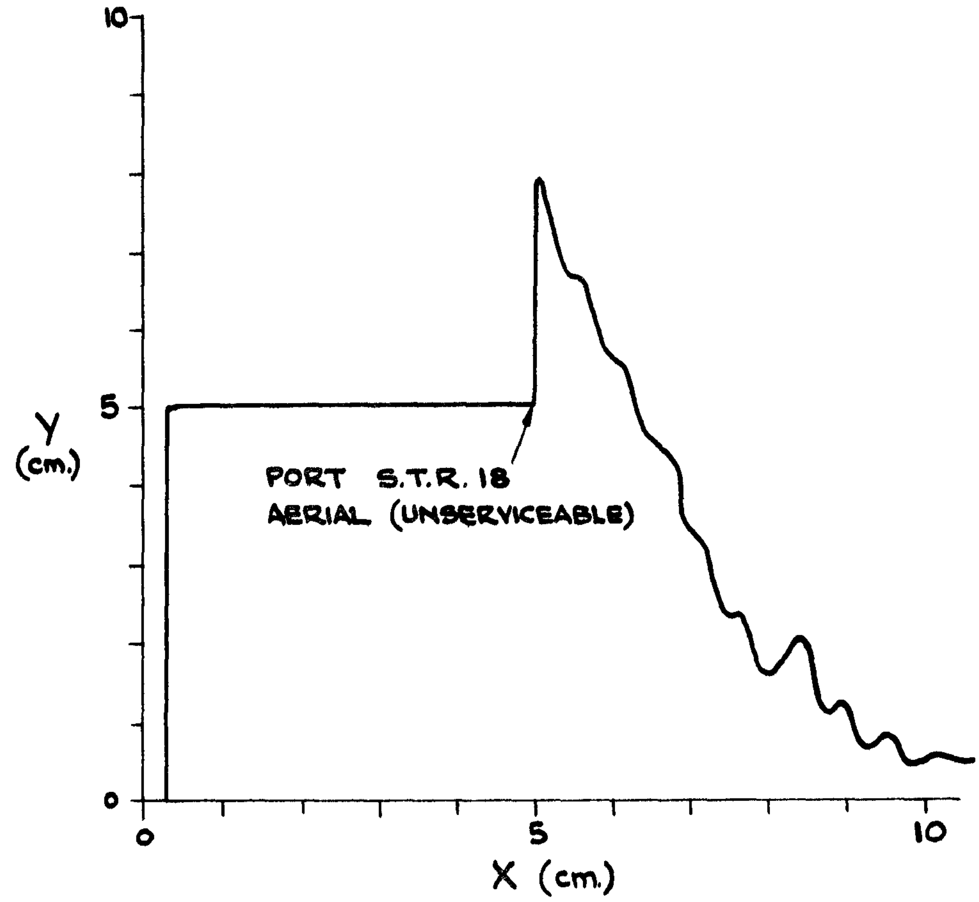
FIG. 23



1 cm. = 5 METRES OF CO-AXIAL CABLE

BRITANNIA

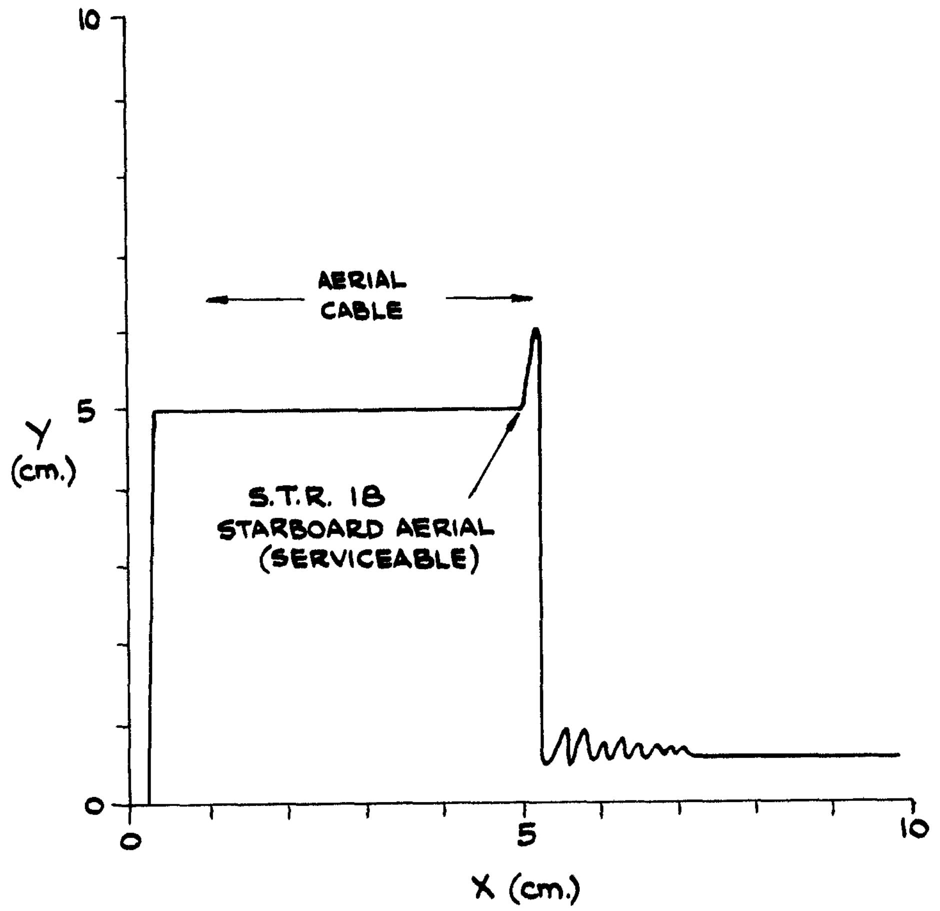
FIG. 24



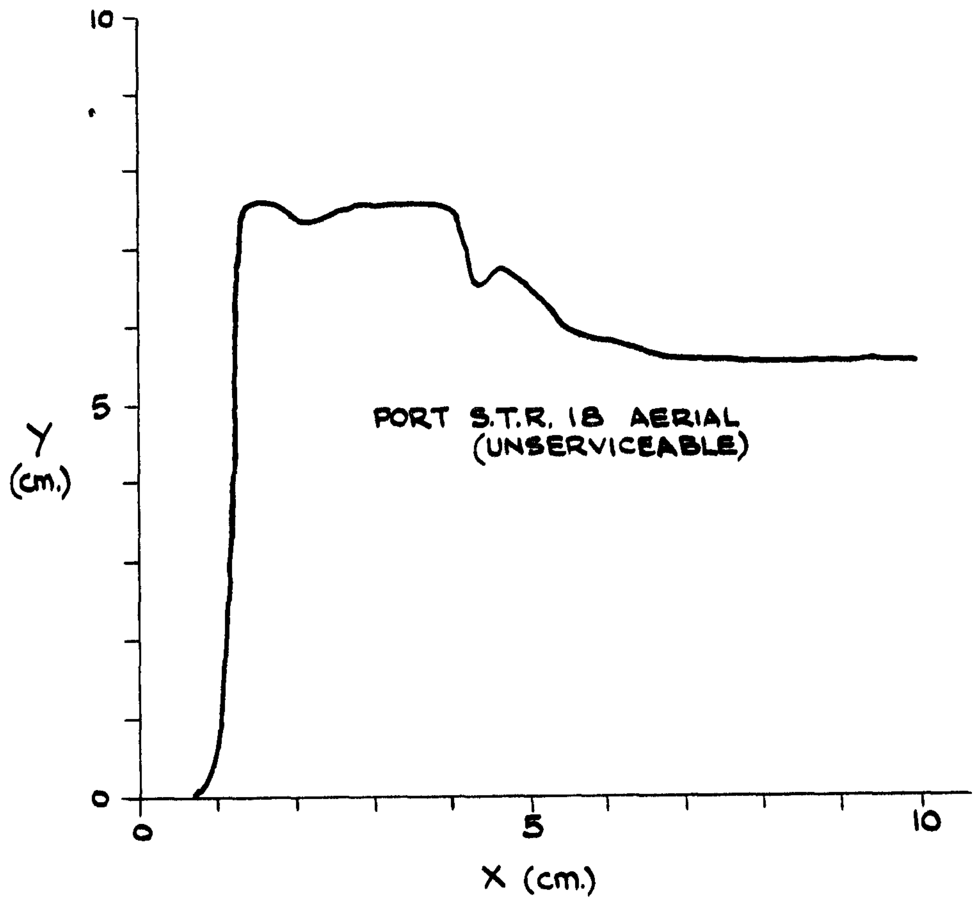
BRITANNIA

FIG. 25

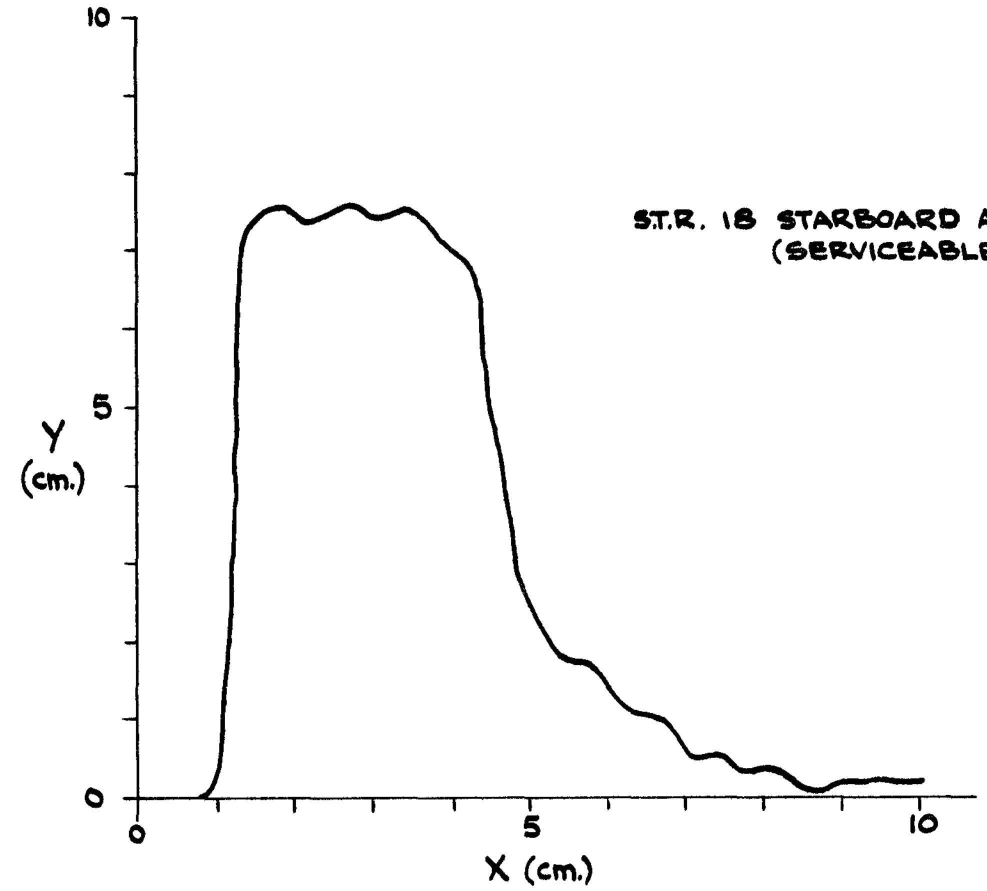
/Continued overleaf



BRITANNIA
FIG. 26

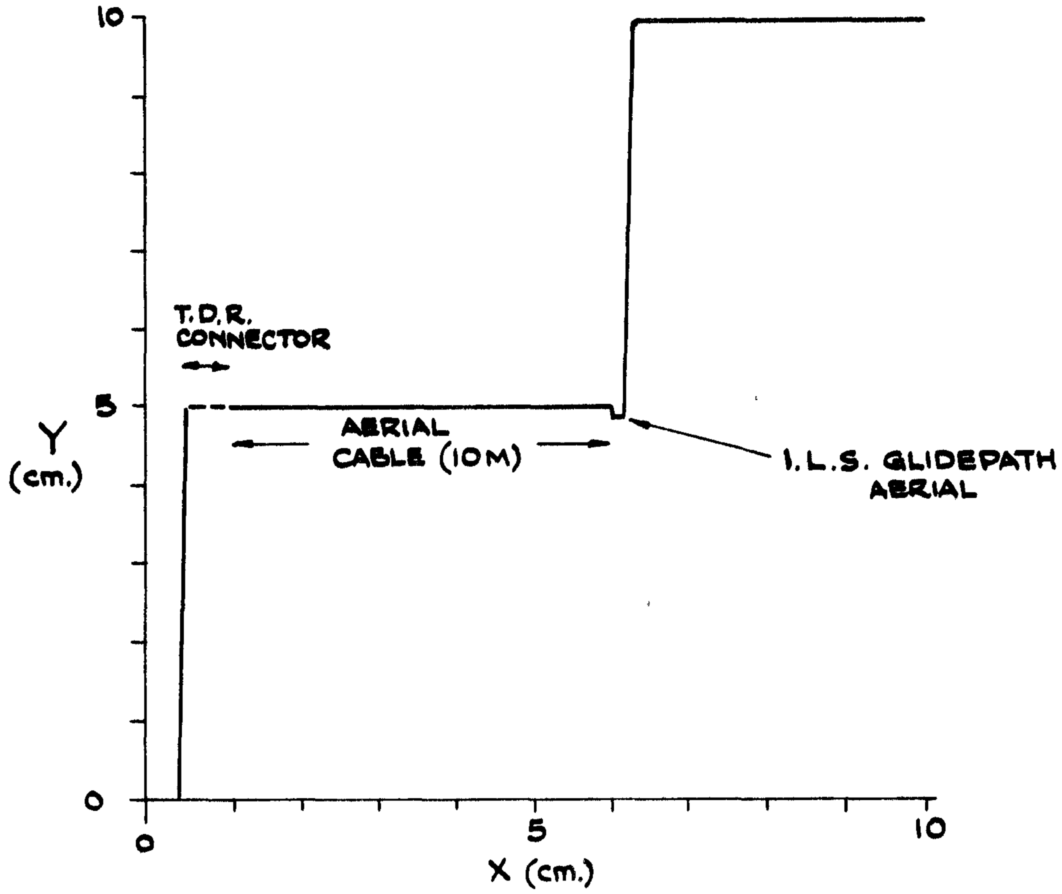


BRITANNIA
FIG. 27.



BRITANNIA

FIG. 28

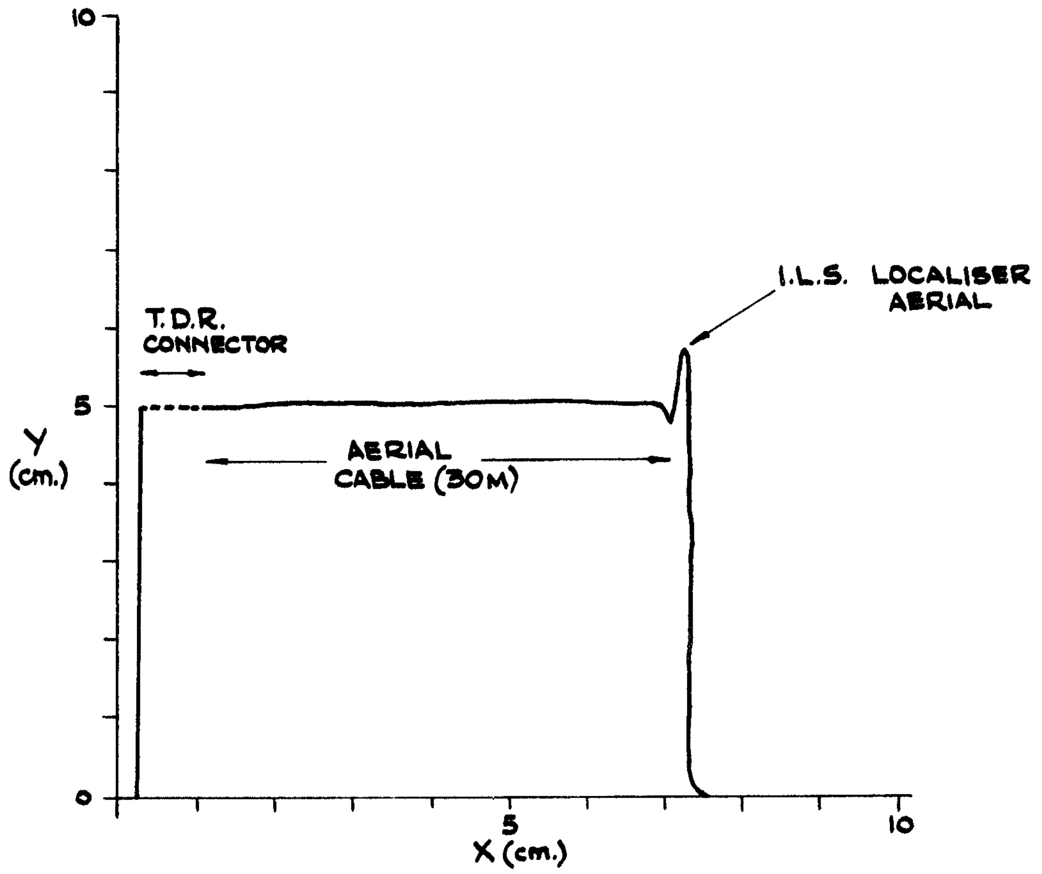


1 cm. ≡ 2 METRES OF CO-AXIAL CABLE

COMET

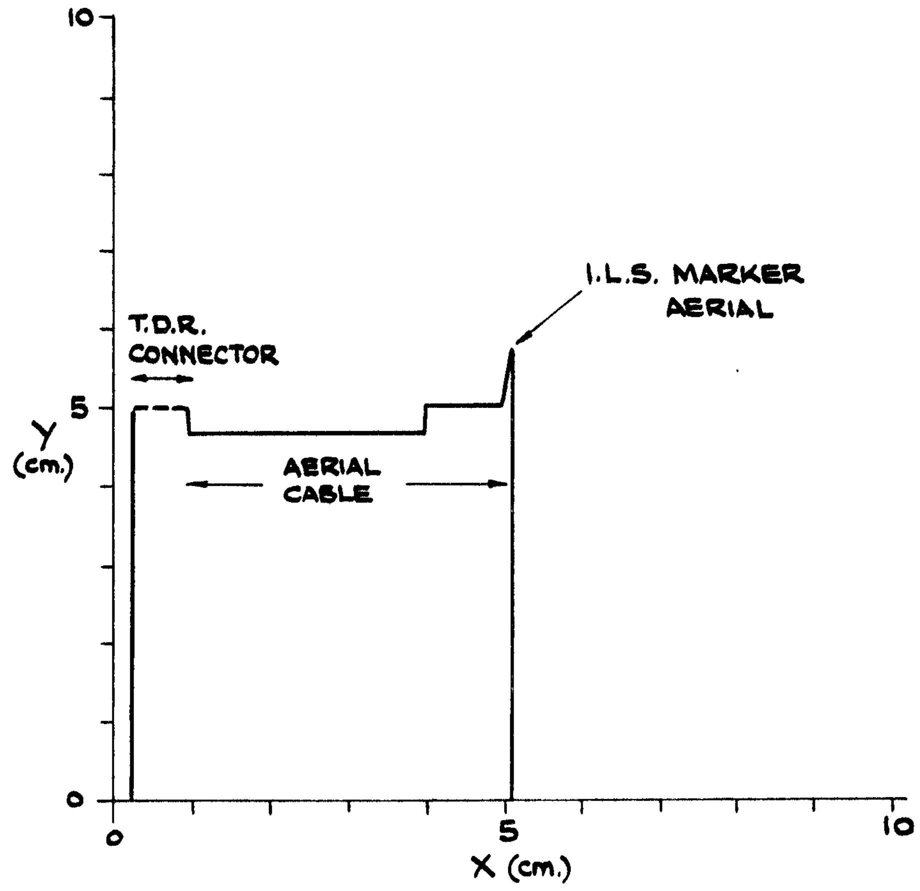
FIG. 29

/Continued overleaf



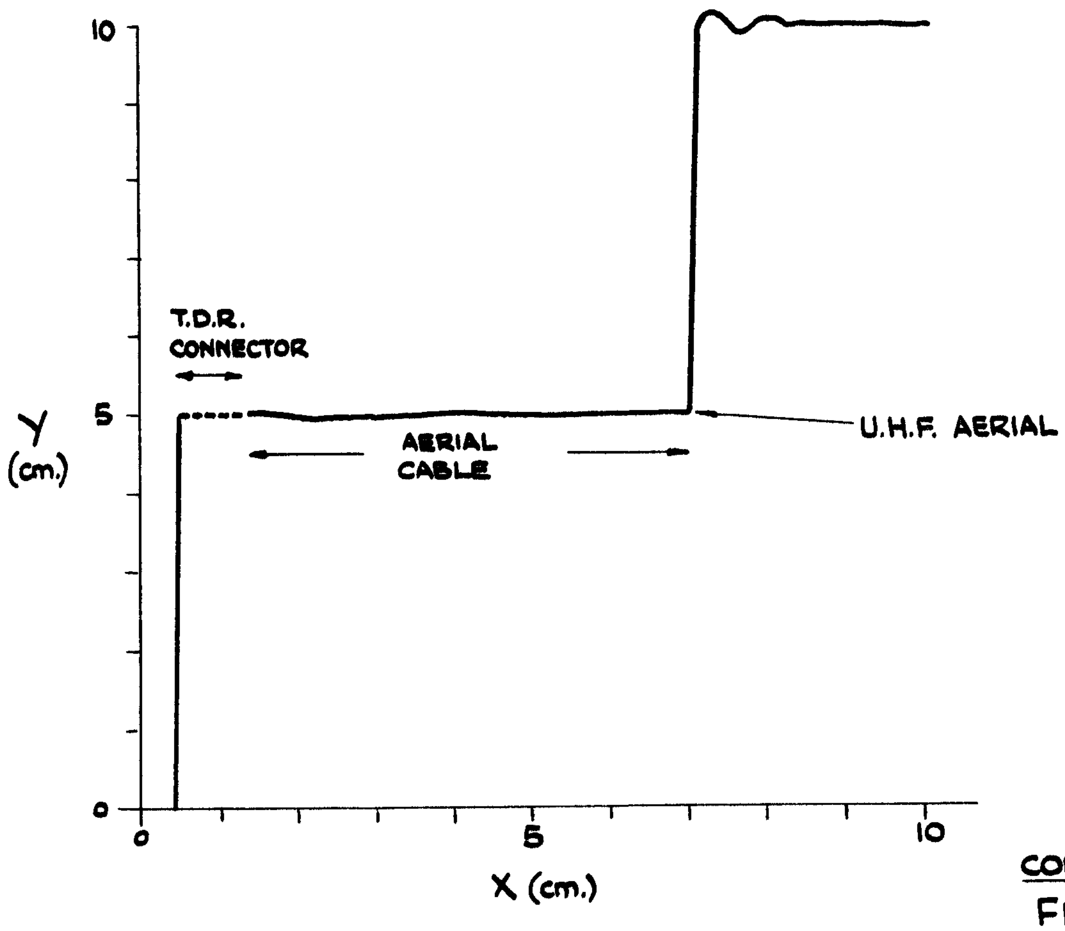
1 cm. ≡ 5 METRES OF CO-AXIAL CABLE

COMET
FIG.30

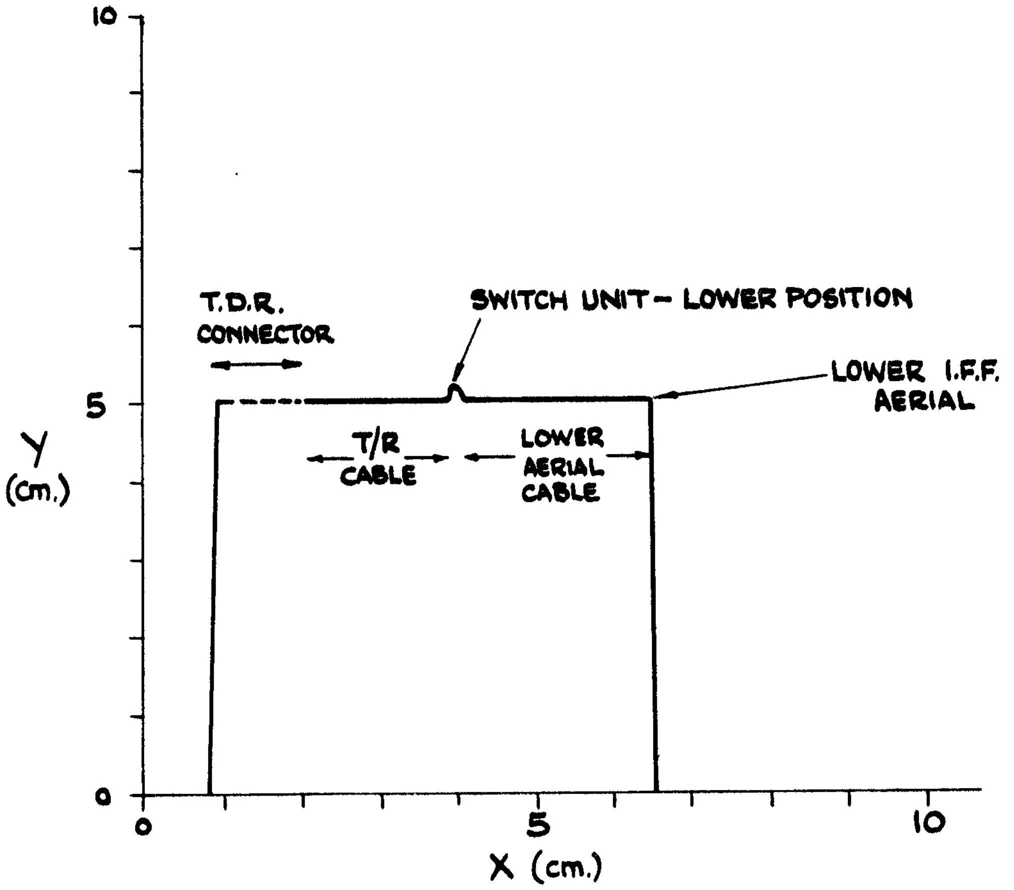


1 cm. ≡ 5 METRES OF CO-AXIAL CABLE

COMET
FIG.31.



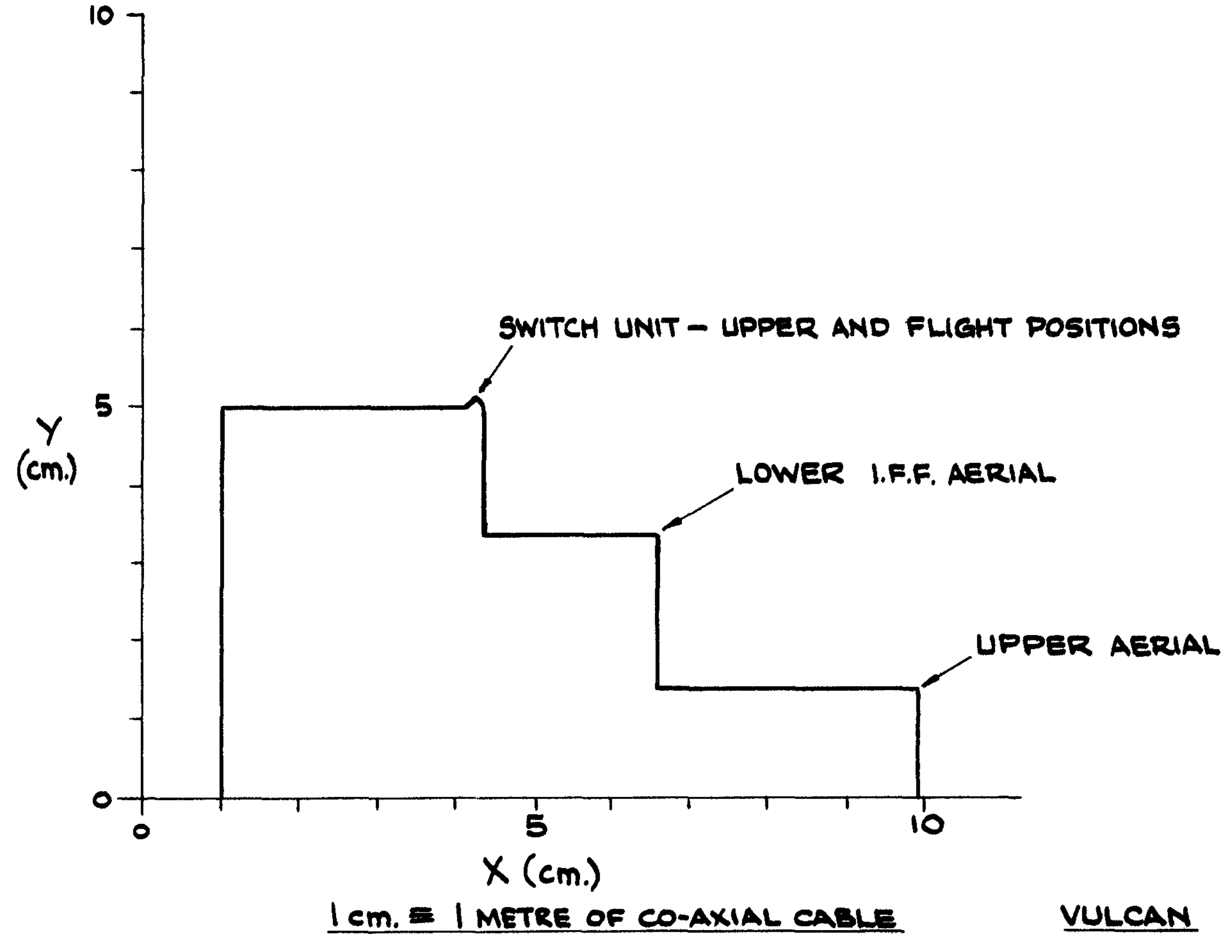
COMET
FIG. 32



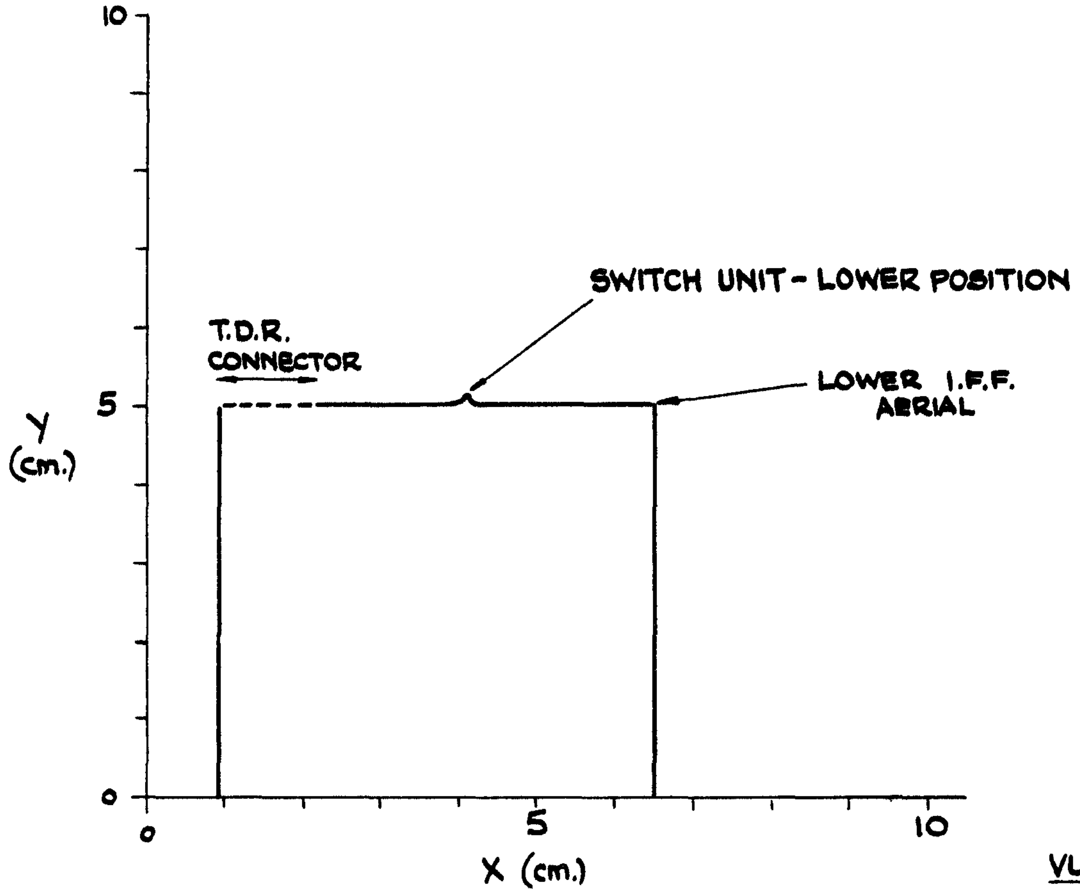
1 cm. ≡ 1 METRE OF CO-AXIAL CABLE

VULCAN
FIG. 33

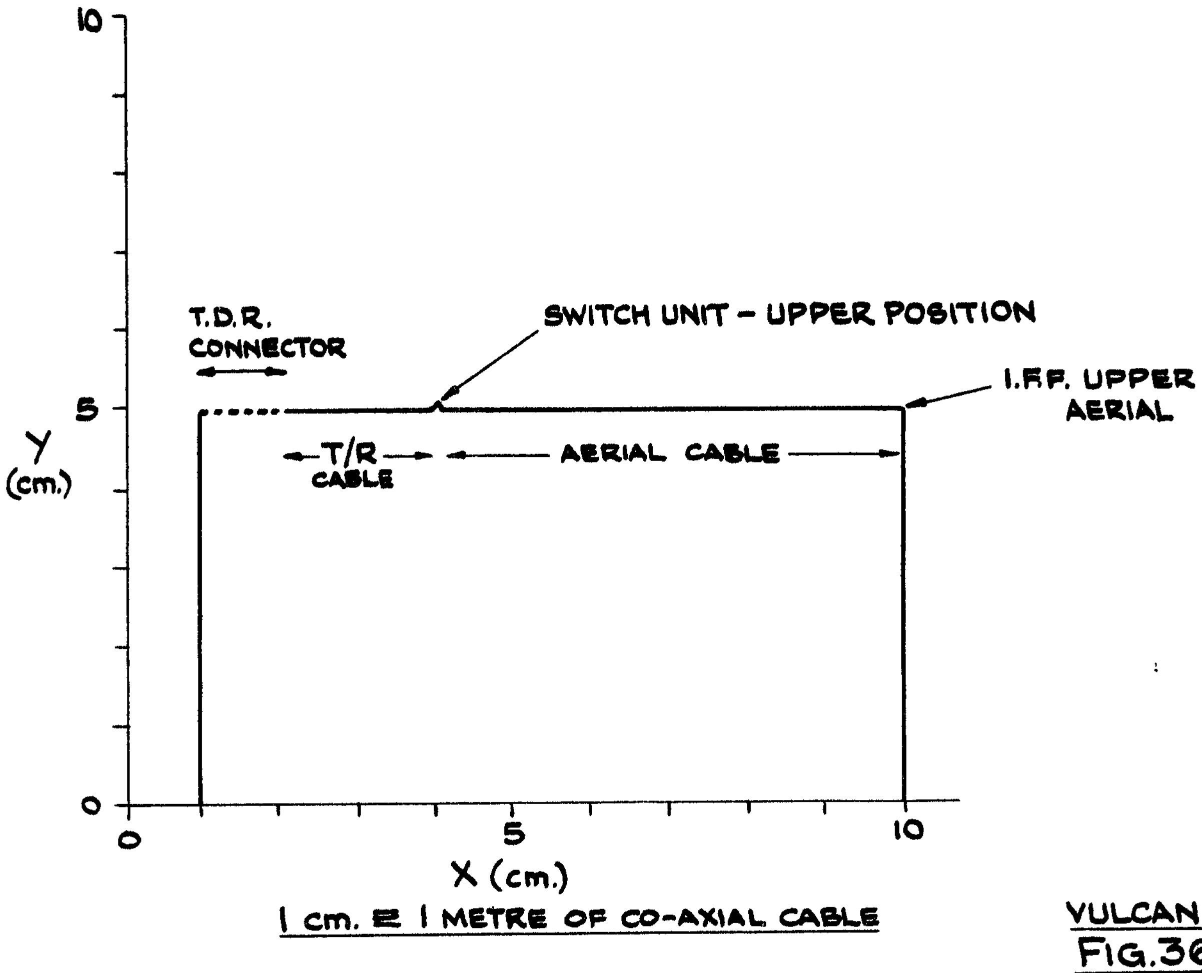
/Continued overleaf



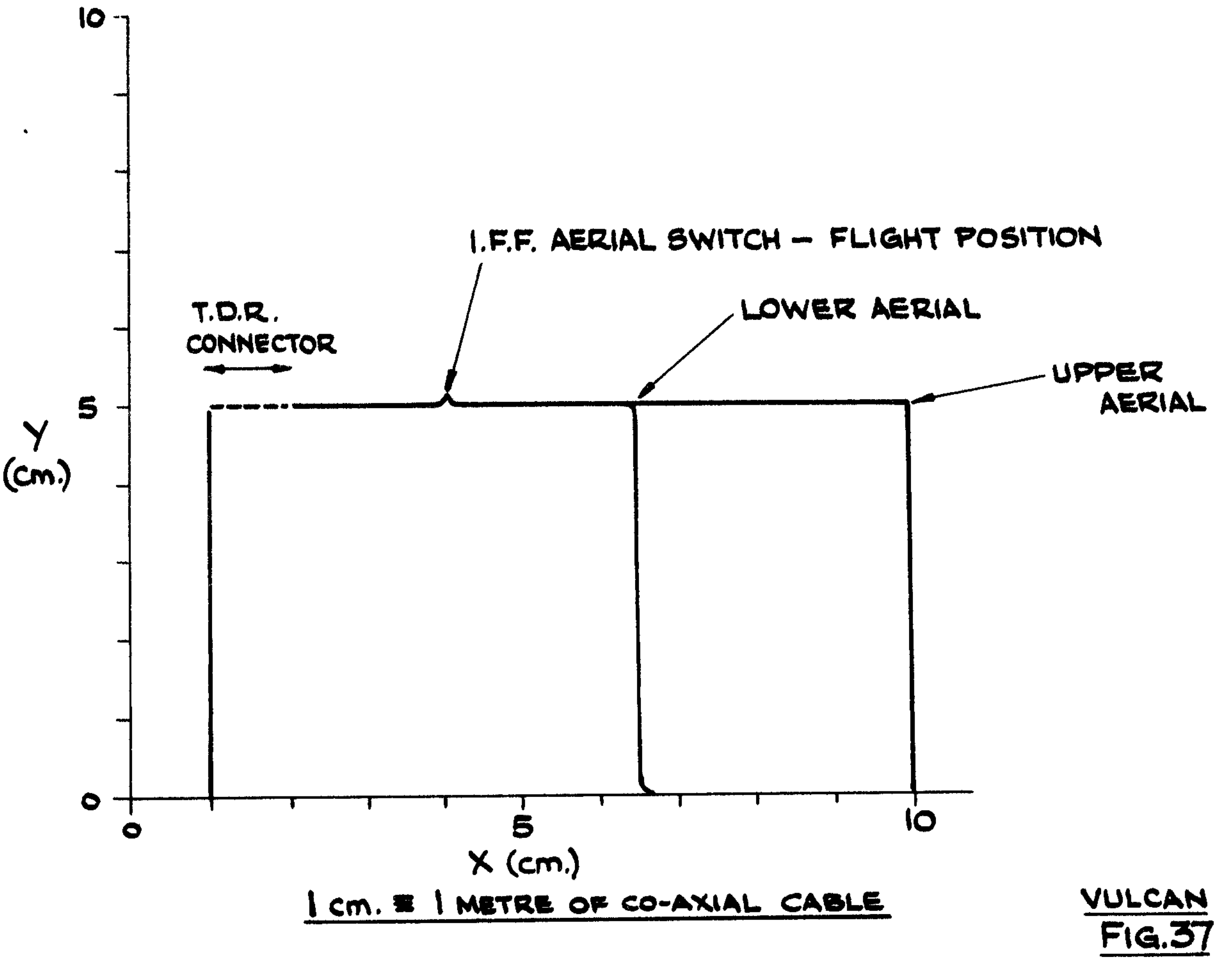
VULCAN
FIG. 34



VULCAN
FIG. 35



VULCAN
FIG.36



VULCAN
FIG.37