APPENDIX E

LISTINGS OF THE ANALYTICAL AND SYNTHESIS PROGRAMS DEVELOPED TO STUDY AND DESIGN THE MULTIBAND ANTENNA

```
0010 PRINT "PROGRAM FOR CALCULATING VSWR ON G5RV-TYPE ANTENNAS"
0020 PRINT
0030 PRINT "UPDATED 12 JUNE 1985"
0040 PRINT
0050 PRINT "STORED ON DISC AS G5RV "
0060 PRINT "******************************************************"
0070 DIM B(1000),B2(1000),B3(1000),Z(256,2),S$(100)
0080 PRINT "DO YOU WANT A FREQ. SWEEP (Y/N)?"
0090 INPUT X$
0100 IF X$="Y" THEN GOTO 0190
0110 PRINT "ENTER THE NUMBER OF FREQUENCIES TO BE TESTED"
0120 INPUT M
0130 PRINT "ENTER THE REQUIRED FREQUENCIES AND THEN 0 AS THE LAST VALUE"
0140 PRINT "AFTER EACH FREQUENCY TYPE NEW LINE"
0150 FOR I=1 TO (M+1)
0160   INPUT B(I)
0170   IF B(I)=0 THEN GOTO 0310
0180 NEXT I
0190 PRINT "ENTER LOWEST FREQ."
0200 INPUT A
0210 PRINT "ENTER HIGHEST FREQ."
0220 INPUT B
0230 PRINT "ENTER STEPSIZE"
0240 INPUT T
0250 LET M=1+(B-A)/T
0260 LET F=A
0270 FOR I=1 TO M
0280   LET B(I)=F
0290   LET F=F+T
0300 NEXT I
0310 OPEN FILE (3,3),"IMPEDANCES",16
0320 FOR I=1 TO 250
0330   READ FILE (3,I-1),R,X
0340   LET Z(I,1)=R
0350   LET Z(I,2)=X
0360 NEXT I
0370 PRINT "**********BOTH L1 AND L2 ARE PHYSICAL LENGTHS ***********"
0380 PRINT "ENTER L1"
0390 INPUT L1
0400 PRINT "ENTER L2"
0410 INPUT L2
0420 PRINT "ENTER VELOCITY FACTOR OF Z2"
0430 INPUT V
0440 LET L=L2/V
0450 PRINT "ENTER Z2"
0460 INPUT Z2
0470 PRINT "ENTER Z4"
0480 INPUT Z4
0490 LET B1=0
0500 FOR I=1 TO M
0510   LET F=B(I)
0520   IF F=0 THEN GOTO 0800
0530   LET K=(SYS(15)*L1*F)/300
0540   IF K<1 THEN GOTO 0790
0550   LET K1=(K-1)*10
0560   LET K2=INT(K1)
0570   LET R=Z(K2+1,1)
0580   LET X=Z(K2+1,2)
0590   LET R6=R
0600   LET X6=X
0610   LET R=Z(K2+2,1)
0620   LET X=Z(K2+2,2)
0630   LET R7=R
```

```
0640   LET I7=X
0650   LET K4=K1-K2
0660   LET R1=((R7-R6)*K4)+R6
0670   LET I1=((X7-X6)*K4)+X6
0680   LET B=(SYS(15)*F)/150
0690   LET T2=TAN(B*L)
0700   LET D=((1-(X1/Z2)*T2)^2+((R1/Z2)*T2)^2)
0710   LET R3=R1*(1+(T2)^2)/D
0720   LET N=(X1*(1-(T2)^2)+Z2*(1-(R1/Z2)^2-(X1/Z2)^2)*T2)
0730   LET X3=N/D
0740   LET P=SQR(((R3-Z4)^2+(X3)^2)/((R3+Z4)^2+(X3)^2))
0750   LET S=(1+P)/(1-P)
0760   LET B1=B1+1
0770   LET B2(B1)=F
0780   LET B3(B1)=S
0790 NEXT I
0800 PRINT "L1=";L1;"M"
0810 PRINT "L2(PHYSICAL)=";L2;"M"
0820 PRINT "Z2=";Z2;"OHMS"
0830 PRINT "Z4=";Z4;"OHMS"
0840 PRINT "VELOCITY FACTOR =";V
0850 PRINT
0860 PRINT
0870 FOR I=1 TO B1
0880   PRINT "F=";B2(I);"MHZ","VSWR=";B3(I)
0890   PRINT
0900 NEXT I
0910 PRINT "ENTER HIGHEST VALUE OF VSWR TO BE PLOTTED"
0920 INPUT S2
0930 LET S1=S2-1
0940 PRINT "FREQ(MHZ)"; TAB(10);"1"; TAB(40);1+S1/2; TAB(70);1+S1; TAB(73);"VSWR
0950 PRINT  TAB(10);"I-----------------------------I-----------------------------
0960 FOR I=1 TO B1
0970   IF B3(I)>S2 THEN GOTO 1000
0980   PRINT B2(I); TAB(10);":"; TAB(40);":"; TAB(10+(B3(I)-1)*60/(S2-1));"*"
0990   PRINT
1000 NEXT I
1010 PRINT " DO YOU WANT HARD COPY?"
1020 REM************HARD COPY ONLY FOR TABLE NOT GRAPH
1030 INPUT S$
1040 IF S$="NO" THEN GOTO 1160
1050 OPEN FILE (4,2),"#LPT"
1060 PRINT FILE (4),"LISTING OF VSWR VS FREQ FOR ANTENNA AS SPECIFIED"
1070 PRINT FILE (4),"L1=";L1;"M"
1080 PRINT FILE (4),"L2(PHYSICAL)=";L2;"M"
1090 PRINT FILE (4),"Z2=";Z2;"OHMS"
1100 PRINT FILE (4),"Z4=";Z4;"OHMS"
1110 PRINT FILE (4),"VELOCITY FACTOR =";V
1120 FOR I=1 TO B1
1130   PRINT FILE (4),"F=";B2(I);"MHZ","VSWR=";B3(I)
1140 NEXT I
1150 CLOSE FILE (4)
1160 CLOSE FILE (3)
1170 END
```

```
0010 PRINT "MULTIFREQUENCY ANTENNA ANALYSIS"
0020 PRINT "*********************************"
0030 PRINT
0040 PRINT "STORED ON DISK AS  ZS6BKW "
0050 PRINT
0060 PRINT "BASED ON THE G5RV PRINCIPLE WITH IMPEDANCE DATA FROM KING/HARRISON"
0070 PRINT "ANTENNAS AND WAVES -A MODERN APPROACH"
0080 PRINT
0090 PRINT
0100 PRINT
0110 PRINT "ANTENNA LENGTH IS L1"
0120 PRINT "MATCHING STUB LENGTH IS L2"
0130 PRINT "STUB IMPEDANCE IS Z2"
0140 PRINT "TRANSMISSION LINE IMPEDANCE IS Z4"
0150 PRINT "ALL LENGTHS IN METRES"
0160 PRINT "FREQUENCY IN MHZ"
0170 PRINT
0180 PRINT
0190 PRINT
0200 DIM B(20),B2(20),B3(20),Z(256,2),S$(100)
0210 PRINT "ENTER THE NUMBER OF FREQUENCIES TO BE TESTED"
0220 INPUT M
0230 PRINT "WHAT IS THE MINIMUM NUMBER ACCEPTABLE FOR THE ANTENNA SYSTEM?"
0240 INPUT Q
0250 PRINT "WHAT IS THE MAXIMUM ACCEPTABLE VSWR?"
0260 INPUT W
0270 PRINT "ENTER THE REQUIRED FREQUENCIES AND THEN 0 AS THE LAST VALUE"
0280 PRINT "AFTER EACH FREQUENCY TYPE NEW LINE"
0290 FOR I=1 TO (M+1)
0300   INPUT B(I)
0310   IF B(I)=0 THEN GOTO 0330
0320 NEXT I
0330 OPEN FILE (3,3),"IMPEDANCES",16
0340 FOR I=1 TO 250
0350   READ FILE (3,I-1),R,X
0360   LET Z(I,1)=R
0370   LET Z(I,2)=X
0380 NEXT I
0390 PRINT "ENTER L1(MIN)"
0400 INPUT A
0410 PRINT "ENTER L1(MAX)"
0420 INPUT C
0430 PRINT "ENTER L1 STEP-SIZE"
0440 INPUT E
0450 PRINT "ENTER L2(MIN)"
0460 INPUT H
0470 PRINT "ENTER L2(MAX)"
0480 INPUT J
0490 PRINT "ENTER L2 STEP-SIZE"
0500 INPUT U
0510 FOR L1=A TO C STEP E
0520   FOR L2=H TO J STEP U
0530     FOR Z2=300 TO 600 STEP 50
0540       FOR Z4=50 TO 72 STEP 22
0550         LET B1=0
0560         FOR I=1 TO M
0570           LET F=B(I)
0580           IF F=0 THEN GOTO 0870
0590           LET K=(SYS(15)*L1*F)/300
0600           IF K<1 THEN GOTO 0860
0610           LET K1=(K-1)*10
0620           LET K2=INT(K1)
0630           LET R=Z(K2+1,1)
```

```
0640          LET X=Z(K2+1,2)
0650          LET R6=R
0660          LET X6=X
0670          LET R=Z(K2+2,1)
0680          LET X=Z(K2+2,2)
0690          LET R7=R
0700          LET X7=X
0710          LET K4=K1-K2
0720          LET R1=((R7-R6)*K4)+R6
0730          LET X1=((X7-X6)*K4)+X6
0740          LET B=(SYS(15)*F)/150
0750          LET T2=TAN(B*L2)
0760          LET D=((1-(X1/Z2)*T2)^2+((R1/Z2)*T2)^2)
0770          LET R3=R1*(1+(T2)^2)/D
0780          LET N=(X1*(1-(T2)^2)+Z2*(1-(R1/Z2)^2-(X1/Z2)^2)*T2)
0790          LET X3=N/D
0800          LET P=SQR(((R3-Z4)^2+(X3)^2)/((R3+Z4)^2+(X3)^2))
0810          LET S=(1+P)/(1-P)
0820          IF S>W THEN GOTO 0860
0830          LET B1=B1+1
0840          LET B2(B1)=F
0850          LET B3(B1)=S
0860        NEXT I
0870        IF B1<Q THEN GOTO 1100
0880        PRINT "THE FOLLOWING  VALUES MEET THE SPECIFICATION VSWR<=",W
0890        PRINT "L1=";L1;"M"
0900        PRINT "L2=";L2;"M"
0910        PRINT "Z2=";Z2;"OHMS"
0920        PRINT "Z4=";Z4;"OHMS"
0930        FOR I=1 TO B1
0940          PRINT "F=";B2(I);"MHZ","VSWR=";B3(I)
0950          PRINT
0960        NEXT I
0970        PRINT " DO YOU WANT HARD COPY?"
0980        INPUT S$
0990        IF S$="NO" THEN GOTO 1100
1000        OPEN FILE (4,2),"#LPT"
1010        PRINT FILE (4),"THESE VALUES MEET THE SPECIFICATION VSWR<=";W
1020        PRINT FILE (4),"L1=";L1;"M"
1030        PRINT FILE (4),"L2=";L2;"M"
1040        PRINT FILE (4),"Z2=";Z2;"OHMS"
1050        PRINT FILE (4),"Z4=";Z4;"OHMS"
1060        FOR I=1 TO B1
1070          PRINT FILE (4),"F=";B2(I);"MHZ","VSWR=";B3(I)
1080        NEXT I
1090        CLOSE FILE (4)
1100      NEXT Z4
1110     NEXT Z2
1120    NEXT L2
1130 NEXT L1
1140 CLOSE FILE (3)
1150 PRINT "NO LENGTHS WITHIN RANGE MEET THE SPECIFICATION"
1160 END
```

```
0010 PRINT "                              FEED3"
0020 PRINT "::::::::::::::::::::::::::::::::::::::::::::::::::::::::"
0030 PRINT "FEED3 TO FIND Z1 GIVEN Z3"
0040 PRINT
0050 PRINT
0060 DIM B(100),B2(100),B3(100),B4(100),S$(100)
0070 DIM B1(100),B5(100),B6(100)
0080 PRINT "ENTER THE NUMBER OF FREQUENCIES AND IMPEDANCES TO BE TESTED"
0090 INPUT M
0100 PRINT "ENTER THE REQUIRED FREQUENCIES AND THEN 0 AS THE LAST VALUE"
0110 PRINT "AFTER EACH VALUE TYPE NEW LINE"
0120 FOR I=1 TO (M+1)
0130   INPUT B(I)
0140   IF B(I)=0 THEN GOTO 0160
0150 NEXT I
0160 PRINT "ENTER VALUES OF Z3 AND THEN 0 AS LAST VALUE"
0170 FOR I=1 TO (M+1)
0180   INPUT B1(I)
0190   IF B1(I)=0 THEN GOTO 0210
0200 NEXT I
0210 PRINT "ENTER VALUES OF A3 AND THEN 360 AS LAST VALUE"
0220 FOR I=1 TO (M+1)
0230   INPUT B5(I)
0240   IF B5(I)=360 THEN GOTO 0260
0250 NEXT I
0260 PRINT "ENTER PHYSICAL LENGTH OF ANTENNA L1"
0270 INPUT L1
0280 PRINT "ENTER PHYSICAL LENGTH L OF STUB"
0290 INPUT L
0300 PRINT "ENTER VELOCITY FACTOR V OF STUB"
0310 INPUT V
0320 LET L2=L/V
0330 PRINT "ENTER CHARACTERISTIC IMPEDANCE OF STUB = Z2"
0340 INPUT Z2
0350 PRINT "WHAT IS ANTENNA HEIGHT?"
0360 INPUT H5
0370 PRINT "DO YOU WANT ABSOLUTE OR NORMALISED VALUES OF Z1 W.R.T. Z2"
0380 PRINT "TYPE A OR N"
0390 INPUT A$
0400 IF A$="A" THEN GOTO 0450
0410 LET N1=Z2
0420 LET P5=1
0430 REM N1 AND P5 ARE MERELY MARKERS TO INDICATE ABS. OR NORM. VALUES
0440 GOTO 0460
0450 LET N1=1
0460 LET B1=0
0470 FOR I=1 TO K
0480   LET F=B(I)
0490   LET A3=B5(I)
0500   LET A3=(SYS(15)*A3)/180
0510   LET Z3=B1(I)
0520   LET R3=Z3*COS(A3)
0530   LET X3=Z3*SIN(A3)
0540   LET B=(SYS(15)*F)/150
0550   LET T2=TAN(B*L2)
0560   LET D=(Z2+X3*T2)^2+(R3*T2)^2
0570   LET R1=((R3*Z2)*(Z2+(X3*T2))-(X3*Z2-(Z2)^2*T2)*(R3*T2))/D
0580   LET R1=R1/N1
0590   LET X1=((R3*Z2)*(R3*T2)+(X3*Z2-(Z2)^2*T2)*(Z2+X3*T2))/D
0600   LET X1=X1/N1
0610   LET K9=SYS(15)*L1*F/300
0620   LET B1=B1+1
0630   LET B2(B1)=F
```

```
0640   LET B3(B1)=R1
0650   LET B4(B1)=X1
0660   LET B6(B1)=INT(X9*100)/100
0670 NEXT I
0680 PRINT "L1=";L1;"M (PHYSICAL)"
0690 PRINT "L2=";L2;"M  (ELECTRICAL)"
0700 PRINT "Z2=";Z2;"OHMS"
0710 PRINT "VELOCITY FACTOR =";V
0720 PRINT "ANTENNA HEIGHT=";H5;"M"
0730 PRINT
0740 PRINT
0750 PRINT
0760 PRINT
0770 PRINT "THESE VALUES ARE NORMALISED W.R.T. Z2"
0780 PRINT "*************************************"
0790 PRINT
0800 PRINT
0810 PRINT
0820 FOR I=1 TO B1
0830   PRINT "F=";B2(I);"MHZ","R1=";B3(I);"OHMS","X1=";B4(I);"OHMS","XOH=";B6(I)
0840   PRINT
0850 NEXT I
0860 PRINT " DO YOU WANT HARD COPY?"
0870 INPUT S$
0880 IF S$="NO" THEN GOTO 1070
0890 OPEN FILE (4,2),"@LPT"
0900 IF P5=1 THEN GOTO 0930
0910 PRINT FILE (4),"LISTING OF R1 AND X1 VS FREQ FOR ANTENNA AS SPECIFIED"
0920 GOTO 0940
0930 PRINT FILE (4),"NORMALISED VALUES OF R1 AND X1 W.R.T. Z2 VS FREQ."
0940 PRINT FILE (4),"L1=";L1;"M (PHYSICAL)"
0950 PRINT FILE (4),"L2=";L2;"M  (ELECTRICAL)"
0960 PRINT FILE (4),"Z2=";Z2;"OHMS"
0970 PRINT FILE (4),"VELOCITY FACTOR =";V
0980 PRINT FILE (4),"ANTENNA HEIGHT=";H5;"M"
0990 PRINT FILE (4)
1000 PRINT FILE (4)
1010 PRINT FILE (4)
1020 PRINT FILE (4)
1030 FOR I=1 TO B1
1040   PRINT FILE (4),"F=";B2(I);"MHZ","R1=";B3(I);"OHMS","X1=";B4(I);"OHMS","XO
1050 NEXT I
1060 CLOSE FILE (4)
1070 END
```

APPENDIX F

LISTING OF L_1, L_2 AND Z_2 VALUES WHICH YIELDED VSWR ≤ 2:1 ON 7; 14; 18; 24 AND 29 MHz BANDS

L_1 (m)	L_2 (m)	Z_2 (Ω)
27,7	13,7	400
27,9	13,6	400
28,0	13,6	400; 375;
28,1	13,5	400;
28,2	13,5	400; 375;
28,3	13,5	400; 375; 350
28,3	13,4	400
28,4	13,5	400; 375;
28,4	13,4	400; 375; 350;
28,5	13,4	400; 375; 350; 325;
28,5	13,3	375;
28,6	13,3	400; 375; 350
28,6	13,4	400; 375; 350;
28,6	13,2	400
28,7	13,4	400; 375; 350
28,7	13,3	400; 375; 350; 325
28,7	13,2	400; 375; 350
28,8	13,3	400; 375; 350; 325
28,8	13,2	400; 375; 350; 325
28,8	13,1	400; 375
28,9	13,3	375,250,300
28,9	13,2	400; 375; 350; 325; 300
28,9	13,1	400; 375; 350; 325
28,9	13,0	375; 350
29,0	13,3	350; 325
29,0	13,2	375; 350; 325; 300
29,0	13,1	400; 375; 350; 325; 300
29,0	13,0	400; 375; 350; 325
29,1	13,2	350; 325
29,1	13,1	375; 350; 325
29,1	13,0	375; 350; 325
29,1	12,9	375; 350
29,2	13,1	325; 300
29,2	13,0	375; 350; 325; 300
29,2	12,9	400; 375; 350; 325
29,2	12,8	375; 350
29,3	13,1	300
29,3	13,0	325; 300; 275
29,3	12,8	375; 350; 325
29,4	13,0	275
29,4	12,9	350; 300
29,4	12,8	300

APPENDIX G

LEAST SQUARES FITS OF L_1f AND L_2f DATA - FROM FIGS. 5.7 AND 5.8

L_1f vs Z_2 (Using mean value of each column of data)

Z_2	L_1f	Z_2^2	$Z_2.L_1f$
275	205,4	75625	56485
300	203,8	90000	61140
325	202,9	105625	65943
350	202,2	122500	70770
375	200,6	140625	75225
400	199,2	160000	79680
$\sum$: 2025	$\sum$: 1214,1	$\sum$: 694375	$\sum$: 409243

(n = 6)

$$\Delta_o = \begin{vmatrix} n & \sum Z_2 \\ \sum Z_2 & \sum {Z_2}^2 \end{vmatrix} = 65625$$

$$\Delta_1 = \begin{vmatrix} \sum Z_2 & -\sum L_1 f \\ \sum Z_2^2 & -\sum Z_2.L_1 f \end{vmatrix} = 14323613$$

$$\Delta_2 = \begin{vmatrix} n & -\sum L_1 f \\ \sum Z_2 & -\sum Z_2.L_1 f \end{vmatrix} = 3094,5$$

Now $\quad a/\Delta_1 = -b/\Delta_2 = 1/\Delta_o$

therefore $\quad a = -\Delta_1/\Delta_o = 218,26$

$\quad b = -\Delta_2/\Delta_o = -0,0472$

thus $\boxed{L_1.f = a+bZ_2 = 218,26 - 0,0472\ Z_2}$

L_2f vs Z_2

Z_2 : 275 300 325 350 375 400

L_2f : 91,0 91,35 91,7 92,05 92,4 93,1

$\sum Z_2 = 2025$; $\sum L_2f = 551,6$; $\sum Z_2^2 = 694375$; $\sum Z_2.L_2f = 186340$;

$\Delta_o = 65625$; $\Delta_1 = 5678750$; $\Delta_2 = 1050$

therefore a = 86,5 and b = 0,016

thus $\boxed{L_2.f = 86,5 + 0,016\ Z_2}$

CALCULATED IMPEDANCE DATA FOR A PARTICULAR ANTENNA CONFIGURATION (REFER TO FIG. 5.12)

$L_1 = 204,19m; \quad L_2 = 93,59m; \quad Z_2 = 350\Omega$

$k_o h = \pi L_1 f/c = 2,1383\, f_{MHz}$

f (MHz)	N	L_2/λ	$k_o h$	Z_1(K-H) (Ω)	$Z_{1N} = Z_1/350$
1	1	0,312	2,1383	289+j755	0,83+j2,16
2,01	2	0,627	4,298	91-j344	0,26-j0,98
2,54	3	0,792	5,431	577+j932	1,65+j2,66
3,52	4	1,098	7,527	110-j237	0,31-j0,68
4,09	5	1,276	8,746	1110+j1049	3,2+j3
5,03	6	1,569	10,76	122-j148	0,35-j0,42
5,65	7	1,760	12,08	1860+j703	5,31+j2
6,53	8	2,037	13,96	134-j93	0,38-j0,27
7,20	9	2,256	15,39	2092-j219	6-j0,63
8,04	10	2,508	17,19	151-j18	0,43-j0,05
8,76	11	2,733	18,73	1555-j879	4,44-j2,5
9,54	12	2,976	20,40	169+j37	0,48+j0,11
10,32	13	3,220	22,07	973-j970	2,78-j2,8
11,04	14	3,440	23,61	191+j90	0,55+j0,26
11,88	15	3,706	25,40	620-j879	1,77-j2,51

Smith Chart TA limits:

$MAX = S\, Z_4/Z_2 = 2(50)/350 = 0,286$

$MIN = Z_4/S\, Z_2 = 50/(2)(35) = 0,071$

EXPERIMENTAL RESULTS FROM THE HORIZONTAL ANTENNA ABOVE GROUND

L1=26,51m (Phys) L2=12,2m (Phys) Z2=400 ohms at velocity factor 0,897 Z4= 50 ohms

Frequency (MHz)	Z_3 (Ω)	$Ø_3$(deg)	VSWR (50Ω)
2,874	7,5	-30	7,742
3,170	68	-83	17,135
3,398	22	-89	155,5
3,500	39	-30	1,836
3,534	34	0	1,471
3,650	47	70	5,683
3,800	35	67	5,257
4,263	255	72	17,080
5,376	1500	-28	33,985
5,640	870	-55	30.403
6,288	290	-65	14,061
6,996	95	-40	2,812
7,049	87	-34	2,370
7,104	79	-31	2,107
7,261	80	0	1,600
7,877	160	45	4,757
8,783	255	29	5,885
10,054	760	57	27,993
10,097	760	58	28,773
10,157	830	55	29,012
10,753	2000	20	42,570
11,030	2150	-23	46,717
12,448	430	-69	24,281
13,246	270	-77	24,788
14,000	91	-80	13,571
14,198	51	-63	4,166
14,348	45	-22	1,504
14,458	53	2	1,070
14,521	75	21	1,749
15,306	190	33	4,629
16,129	880	24	19,276
17,064	410	58	15,640
18,095	85	-35	2,372
18,168	78	-28	1,990
18,372	71	1	1,421
18,931	160	42	4,505
20,388	420	34	10,178
21,000	640	31	14,957
21,259	760	28	17,232
21,455	910	23	19,781
21,504	930	20	19,800
22,059	1225	-21	26,249
23,825	290	-65	14,061
24,835	120	-54	4,573
24,940	100	-52	3,797
25,365	52	0	1,040
26,883	730	34	17,637
28,003	310	-52	10,235
28,500	620	-55	21,713
28,975	350	-37	8,831
29,383	280	1	5,601
29,985	170	41	4,681

APPENDIX J

MEASUREMENT OF TRANSMISSION LINE CHARACTERISTIC IMPEDANCE

A 4,68 m length of nominally 300Ω "tape" transmission line was measured using the configuration shown below.

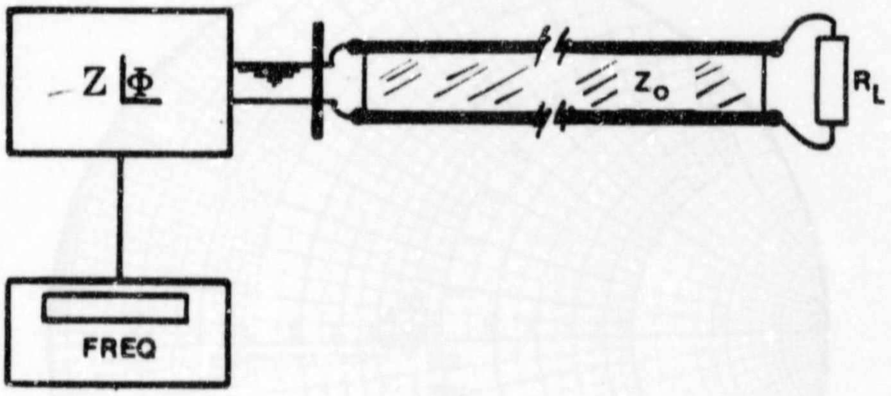

Figure J.1 : The measurement of cable characteristics

Two sets of measurements were made: the first with the equipment configured as above with a R_L = 300Ω non-inductive resistor; the second set with a 1:1 Balanced-to-Unbalanced Transformer (BALUN) inserted between the probe and the transmission line (in view of the fact that the line is a balanced configuration while the Vector-Impedance meter Z|Ø is unbalanced).

<u>Case 1</u>: $R_L = 300\Omega$

Frequency (MHz)	Z_{in} (Ω)
2	$300\angle -4$
5	$300\angle -10$
10	$250\angle 5$
20	$250\angle 0$
30	$240\angle -15$

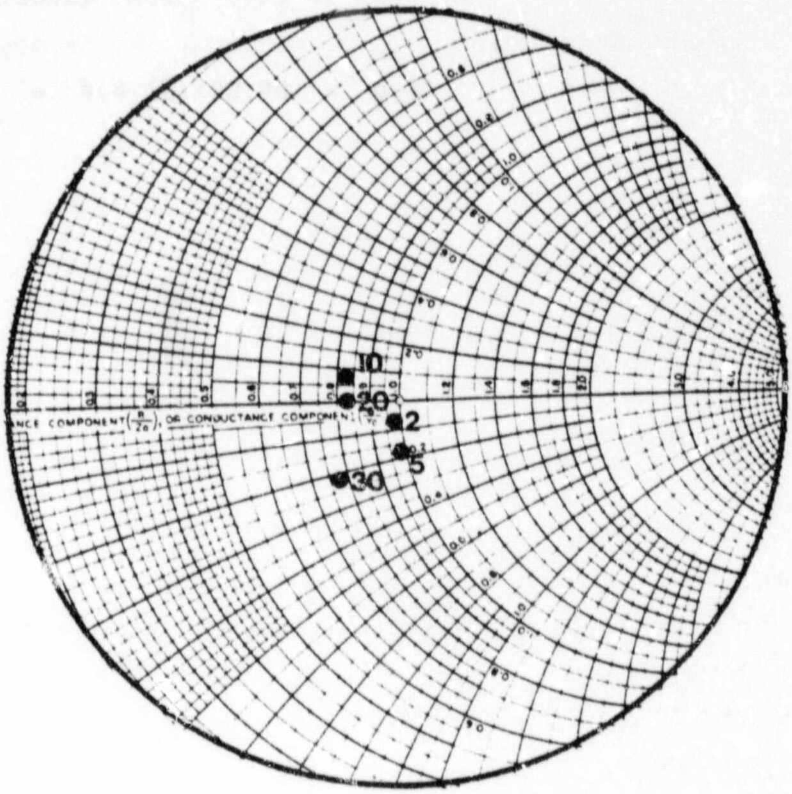

Figure J.2 : Data from the Table plotted on the Smith Chart normalized with respect to 300Ω

Case 2: Quarterwave Transformer

Terminating the line with 1800Ω and 1:1 Balun between Z|Ø meter and line:-

At f = 13,056 MHz Z_{in} = 70+j0Ω

therefore $L_{(elec)} = \lambda/4 = 4{,}68$ m

hence $Z_o = \sqrt{Z_{in} Z_L} = \sqrt{(70)(1800)} = 355\Omega$

which confirms the above result in Case 1.

Now the freespace wavelength, λ_o, is

$$\lambda_o = 300/13{,}056 = 22{,}98 \text{ m}$$

therefore Velocity Factor (VF) of line is

$$VF = \lambda/\lambda_o = 4(4{,}68)/22{,}98 = 0{,}81$$

APPENDIX K

THE OPTIMISATION OF THE LINEAR DESIGN EQUATIONS FOR THE MULTIBAND WIRE ANTENNA

We commence with the equations obtained by means of the linear regressions in Appendix G:

$$L_1 f_{min} = 218,26 - 0,0472 Z_2 \qquad (K.1)$$

$$L_2 f_{min} = 86,5 + 0,016 Z_2 \qquad (K.2)$$

and use f_{min} = 9,4 MHz and L_1 = 22,0 m wit! Z_2 = 355Ω, from the experimental results in section 6.1.4.

From (K.1) $\qquad k_1 = [218,25 - (22)(9,4)]/Z_2$

where k_1 is the corrected slope of the defining equation.

$$\text{Now } Z_2 = 355\Omega$$

$$\text{therefore } k_1 = 0,0323$$

Likewise (K.2), with L_2 = 9,95 m, becomes,

$$L_2 f_{min} = 86,5 + k_2(355)$$

$$\text{thus } k_2 = 0,0198$$

From which the three design equations are now given as,

$$L_1 f_{min} = 218,26 - 0,0323 Z_2 \qquad (K.3)$$

$$L_2 f_{min} = 86,5 + 0,0198 Z_2 \qquad (K.4)$$

and, after eliminating Z_2, and solving simultaneously,

$$L_1 f_{min} = 359{,}19 - 1{,}631 L_2 f_{min} \qquad (K.5)$$

Likewise, instead of correcting the slopes of (5.4) and (5.5) we could have adjusted their points of intercept on their respective ordinates.

Thus from (5.4)

$$L_1 f_{min} = A - 0{,}0472 Z_2$$

while from (5.6)

$$L_2 f_{min} = B + 0{,}016 Z_2$$

Using $Z_2 = 355\Omega$ we obtain

$$A = 223{,}56 \text{ and } B = 87{,}85$$

hence

$$L_1 f_{min} = 223{,}56 - 0{,}0472 Z_2 \qquad (K.6)$$

$$L_2 f_{min} = 87{,}85 + 0{,}016 Z_2 \qquad (K.7)$$

and $$L_1 f_{min} = 482{,}72 - 2{,}95 L_2 f_{min} \qquad (K.8)$$

Now equating (K.3) and (K.6) we obtain

$$L_1 f_{min} = 206{,}44 \qquad (K.9)$$

and $$L_2 f_{min} = 93{,}65 \qquad (K.10)$$

which define L_1 and L_2 for given f_{min} on the assumption that L_1 and L_2 can be chosen independently of Z_2. This is basically only true over a narrow range of Z_2. As Fig. 5.3 shows however, for $350 \leq Z_2 \leq 400\Omega$ this assumption is reasonable.

The relationship between the frequencies on which the best match occurs is obtained from the program "G5RV" with f_{min} = 1 MHz. Thus from (K.9), L_1 = 206,44 m and from (K.10), L_2 = 93,65 m:

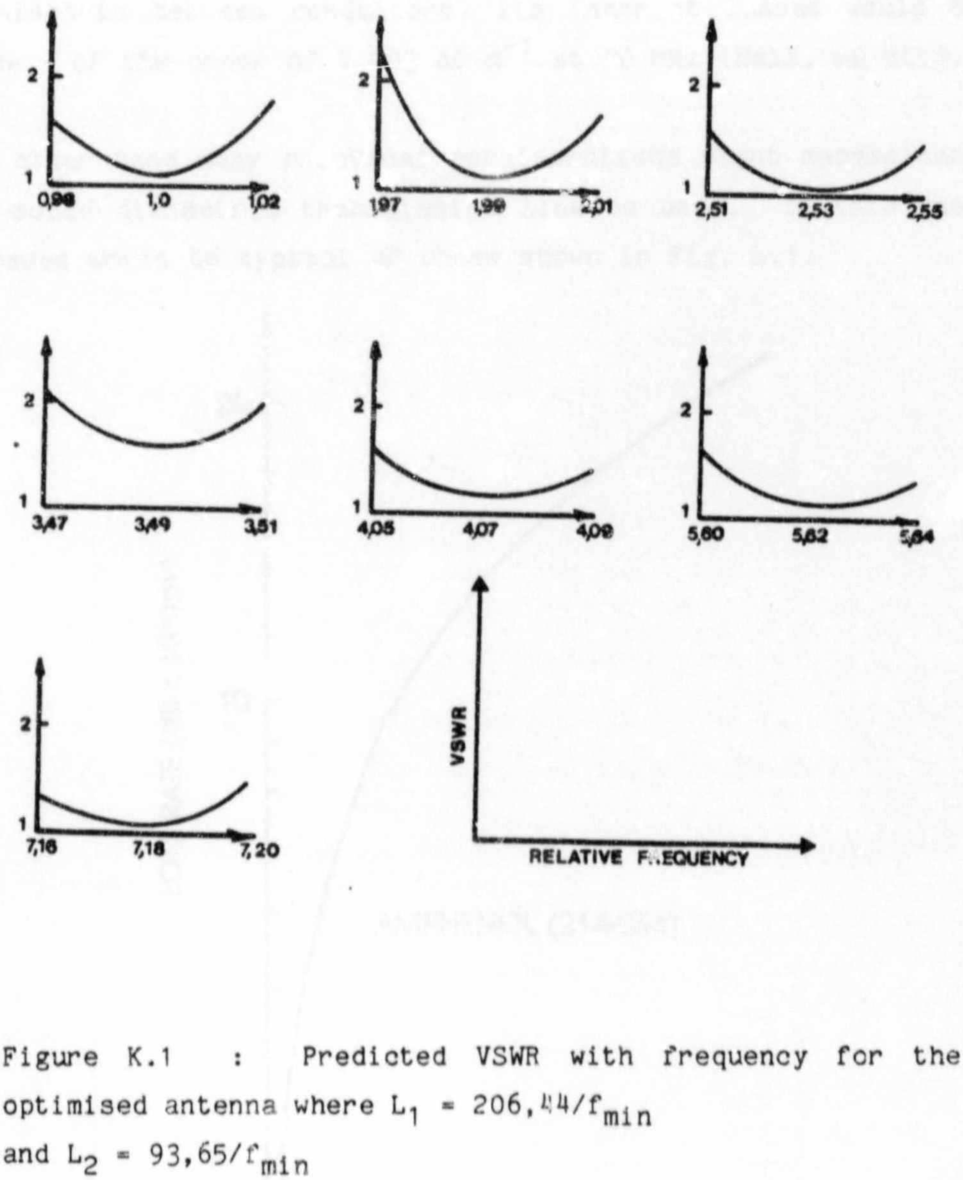

Figure K.1 : Predicted VSWR with frequency for the optimised antenna where $L_1 = 206,44/f_{min}$ and $L_2 = 93,65/f_{min}$

From Fig. K.1 the frequencies at which VSWR minima occur are related by

f_N = 1 : 1,99 : 2,53 : 3,49 : 4,07 : 5,62 : 7,18 : ....

APPENDIX L

THE EFFECT OF TRANDMISSION LINE (L_2) LOSS ON THE IMPEDANCE MATCHING MECHANISM

Any loss in the particular type of transmission line used for L_2 will affect its performance as an impedance matching transformer. If L_2 were constructed of "open-wire" line (ie. with air dielectric between conductors) its inherent losses would be very low - of the order of 0,003 dB m^{-1} at 30 MHz (Hall, op cit).

On the other hand many practical considerations might necessitate that a solid dielectric transmission line be used. In this case line losses would be typical of those shown in Fig. L.1.

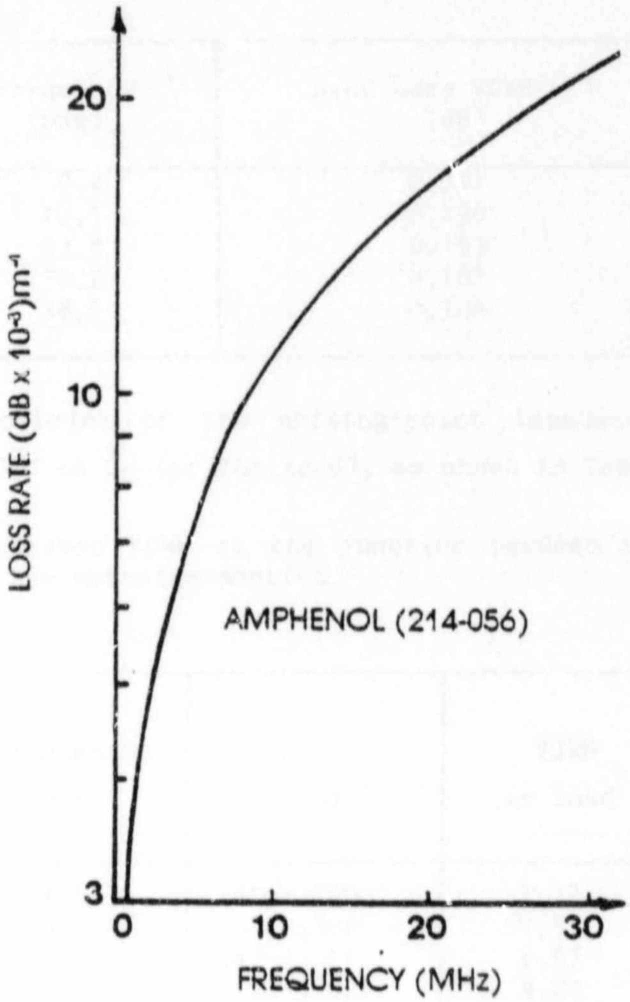

Figure L.1 : Typical loss with frequency for a solid-dielectric parallel conductor transmission line.

The fact that standing waves exist on L_2, because of its specific role as an impedance transformer, means that the intrinsic line losses given in Fig. L.1 will be increased because of the greater voltages and currents on the line compared to the matched case. These increased losses can be determined easily.

Considering the optimised antenna design (Fig. 6.14) as a working example, we proceed as follows:-

From Fig. L.1 the (typical) intrinsic losses, the frequencies on which the antenna is to operate are obtained and listed in Table L.1.

Table L.1 Intrinsic loss in L_2 if matched

Frequency (MHz)	Line Loss VSWR = 1 (dB)
9,4	0,094
18,7	0,136
23,8	0,153
32,9	0,187
38,5	0,204

Now from a knowledge of the driving-point impedance, Z_1, we calculate the VSWR on L_2 (at the load), as shown in Table L.2.

Table L.2 Calculated VSWR at the junction between the antenna and the matching section

Frequency (MHz)	Z_1 (Ω)	VSWR at load
9,4	310+j800	7,77
18,7	91-j336	7,59
23,8	667+j1016	6,67
32,9	110-j192	4,22
38,5	1589+j1065	6,57

The total loss, L_t, as a result of the standing waves are then obtained from (Hall, op cit, p.3-12):-

$$L_t = 10 \log \left| (B^2 - C^2)/B(1 - C^2) \right| \quad dB$$

where $B = 10^{Lm/10}$

L_m = line loss (dB) when matched (Table L.1)

$C = (S_\ell - 1)/(S_\ell + 1)$

S_ℓ = VSWR at load (Table L.2)

Table L.3 Calculated total loss on L_2

Frequency (MHz)	L_t (dB)
9,4	0,36
18,7	0,50
23,8	0,497
32,9	0,402
38,5	0,64

Note that within the HF band (3 to 30MHz) the loss on L_2 never exceeds 0,5 dB.

By using the Smith Chart we show the effect of this loss on L_2 and plot the point to which Z_{1N} at 18,7 MHz is transferred. This is shown in Fig. L.2, where the new value is Z_3'. It will be noted that this is still within the TA hence a suitable match will occur. We therefore conclude that line losses on L_2, under the conditions encountered in this antenna configuration can be ignored at HF.

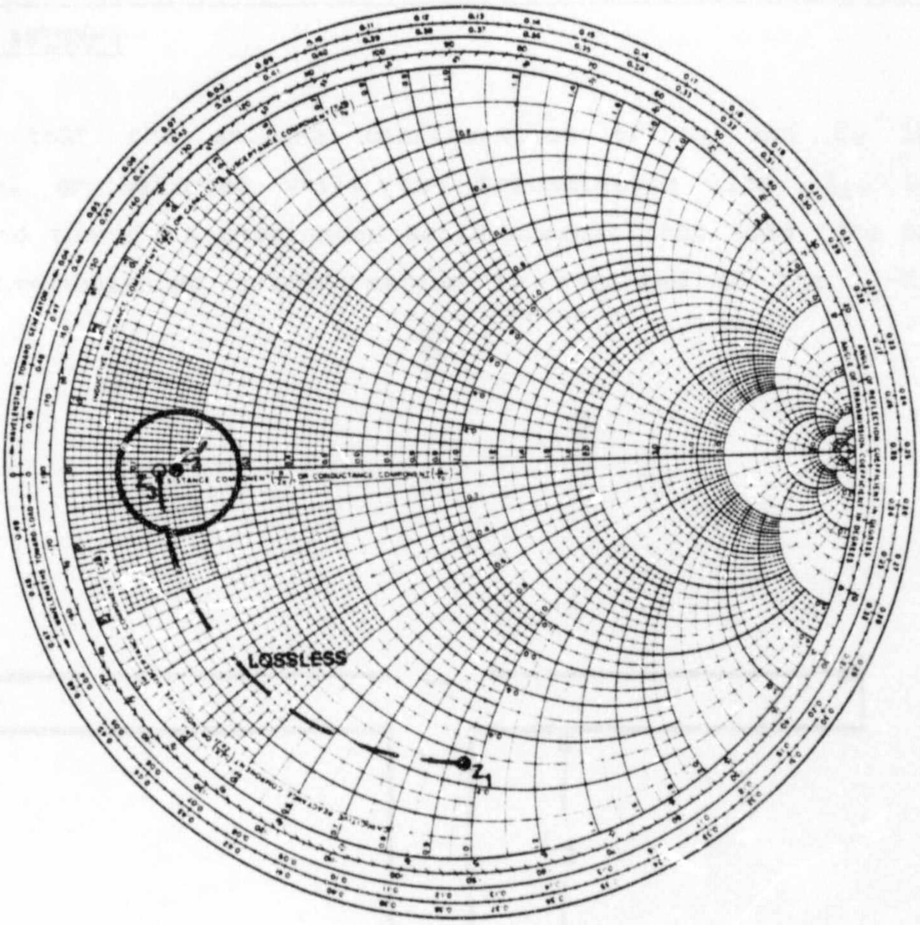

Figure L.2 : The effect of line losses at 18,7 MHz on the performance of the multiband antenna

APPENDIX M

THE USE OF A BALANCED-TO-UNBALANCED (BALUN) TRANSFORMER WITH THE MULTIBAND ANTENNA

The fact that the antenna configuration of L_1 and L_2 is symmetrical or balanced while the transmission line, Z_4, is coaxial and therefore unbalanced would suggest that some form of balanced-to-unbalanced transformation is required at the L_2-Z_4 junction.

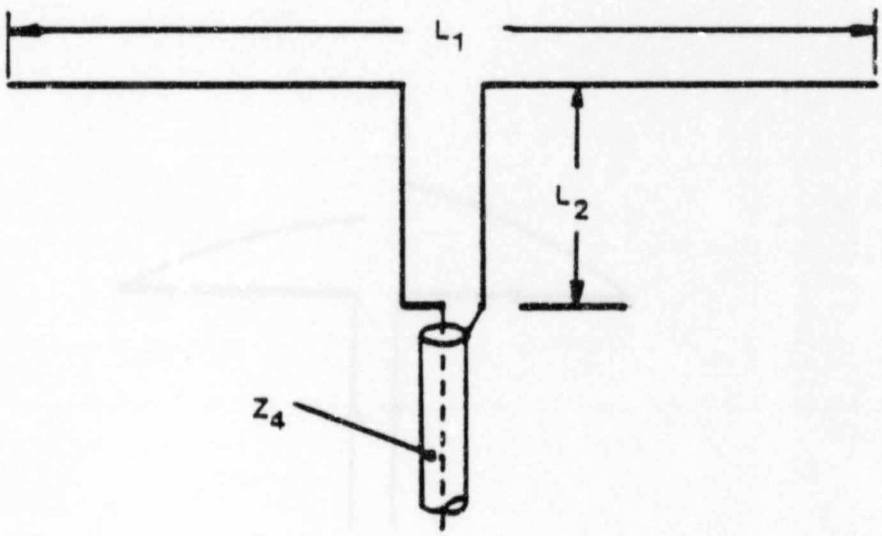

Figure M.1 : The junction between the balanced antenna system and the unbalanced transmission line.

The inherent symmetry means that equiamplitude, opposite-phase currents exist on both L_1 and L_2, whereas at the junction with Z_4 a third current path, <u>on the outside</u> of the coaxial cable br now exists. This is shown diagrammatically in Fig. M.2.

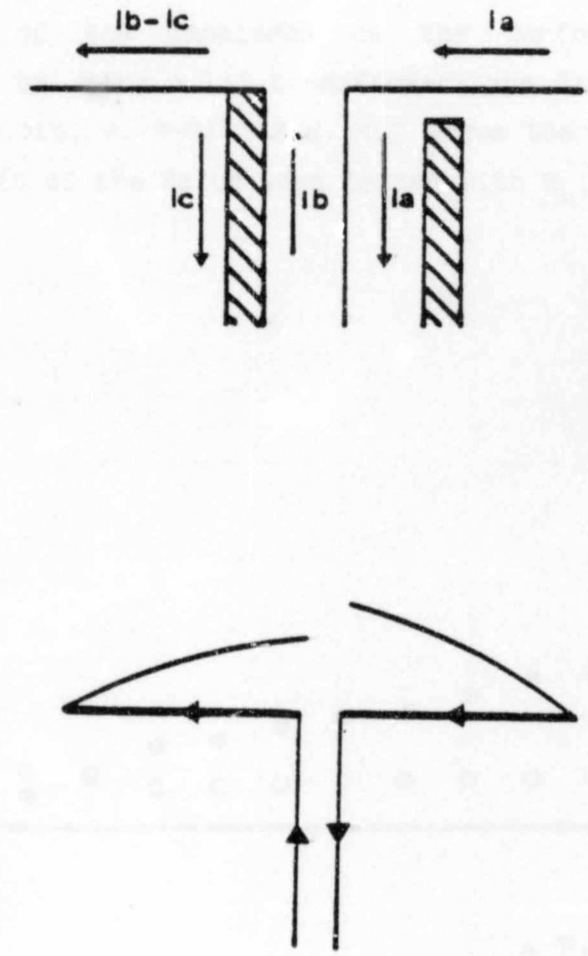

Figure M.2 : The unbalanced current distribution on the antenna caused by an unsymmetrical feed system (after Balanis, op cit, pp 216-217).

This lack of balance has two main consequences (Maxwell, 1983):-

- it causes distortion of the radiation pattern of the antenna;

- it can affect the impedance (and hence the VSWR) presented to the terminal equipment;

The first of these is really of no consequence at HF with low directivity wire antennas close to both the ground and, in many cases, other undefined conducting objects likely to couple with the antenna and so alter its performance (Belrose, op cit; 1981).

The effect of the imbalance on the performance of L_2 is investigated by using a 1:1 transformer-type Balun between Z_2 and Z_4 (Hall, op cit, p. 4-9). Fig. M.3 shows the measured impedance characteristic of the Balun when loaded with $R_L = 50|\underline{0^o}\Omega$.

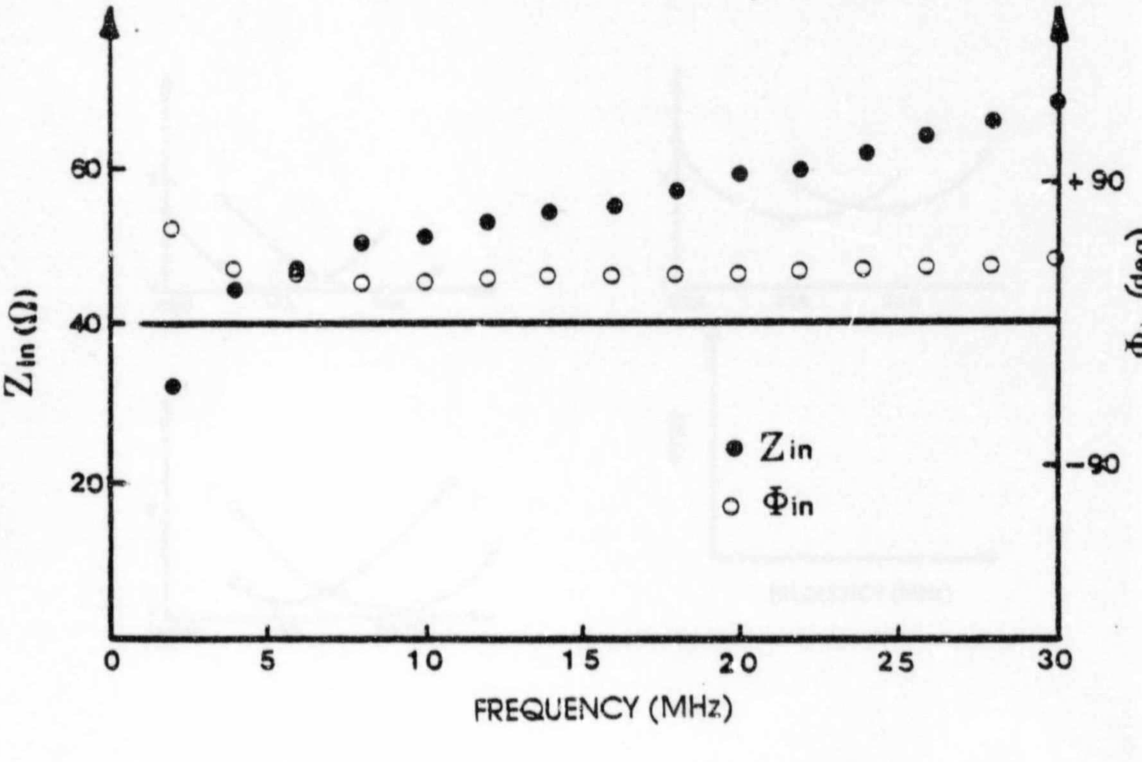

Figure M.3 : The measured performance of the 1:1 Balun when loaded with 50Ω.

These Balun characteristics are not ideal, in that the impedance transformation changes with frequency from about 0,8:1 at 3 MHz to nearly 1,4:1 at 30 MHz, while presenting about 24Ω of inductive reactance across the band. However, by its construction, the inherent balanced-to-unbalanced transformation characteristic, though not quoted nor measured, should be good.

The measured VSWR on five bands is shown in Fig. M.4 for the cases with and without the Balun.

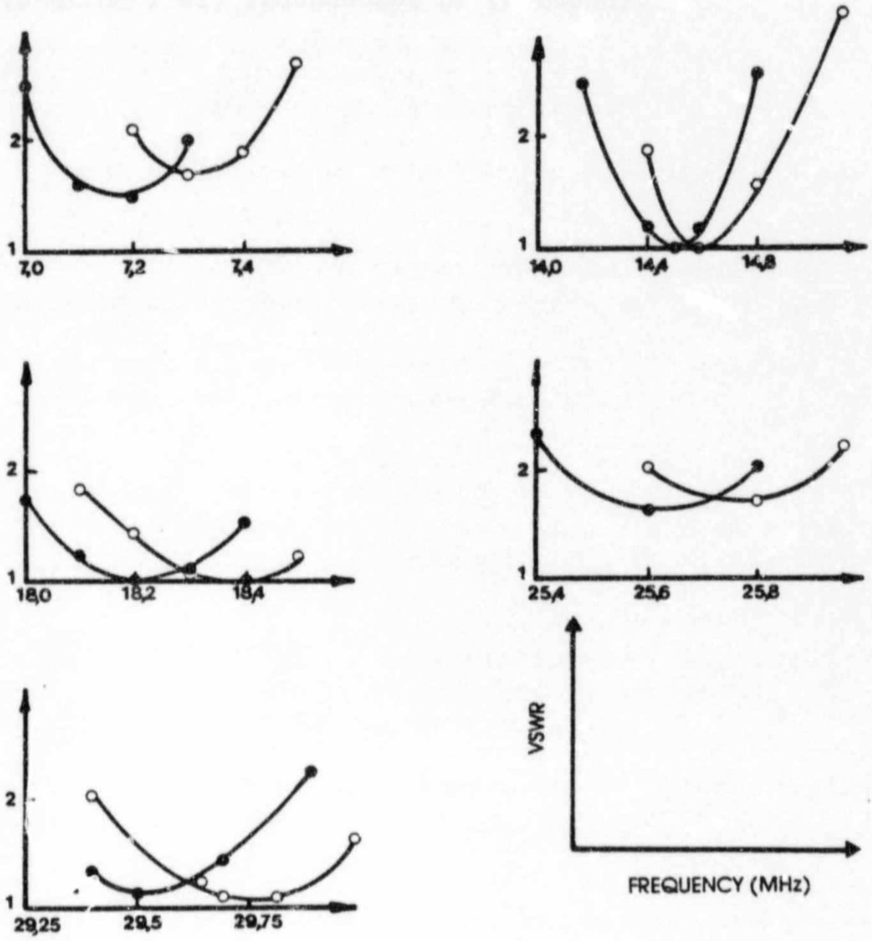

Figure M.4 : the comparative performance of the antenna system with and without a Balun.

● With Balun
o Without Balun

It will be noted from Fig. M.4 that the effect of the Balun is to lower the optimum frequency of the antenna system by about 1 per cent on each band. It is postulated that the decrease in frequency is probably due to the inductive loading provided by the Balun itself. In view of this a more acceptable technique may be to use a so-called Choke Balun (Maxwell, op cit, p. 40) which consists merely of a number of high permeability ferrite beads slipped on to the coaxial transmission line, Z_4, near its junction with L_2. This effectively increases the surface impedance of the braid thereby reducing the braid-outer current. This method, unlike other forms of choke devices (eg. the bazooka or sleeve balun) is effectively independent of frequency.

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