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COURSE ON BASIC TELECOMMUNICATIONS SCIENCE

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Understanding Grafex Frequency Predictions

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These notes are intended for internal distribution only.

HELPFUL HINTS ON RADIO WAVE PROPAGATION

- Use of a frequency during the hours when the GRAFEX symbol is "F" should ensure that good communication is achieved on most days of the month.
- Using a frequency when the symbol is "%" should be satisfactory on more than half of the days in the month. In this case, a secondary frequency should be considered for those periods when the selected frequency is not supported because of the day-to-day variability of the ionosphere.
- A situation requiring the use of a frequency in the "%" region can arise around local night-time when the OWF falls rapidly, or, especially just after dawn when the OWF rises rapidly.
- It should be possible to maintain good communication during times when two modes are possible ("M" and "B") provided that the signals received on the two modes are not comparable in strength.
- Generally, signals propagated by the first E mode and the second F mode are several dBs weaker than the signal propagated by the first F mode.
- If the antenna favours the first F mode (by its gain pattern) this will further reduce the possibility of interference.
- There is the possibility of multi-mode interference when operating with frequencies from the "M" and "X" regions.
- It is undesirable to operate close to the ALF (the symbol "A" indicates that the frequency is much too close to the ALF) as signal strength may be reduced by absorption.

1. INTRODUCTION

IPS GRAFEX frequency predictions contain a wealth of radiopropagation information for HF communicators. For any month, the predictions provide information concerning transmission conditions and possible propagation modes for a given circuit. Information is presented for frequencies in the range 1-40 MHz using tables and pictorial format of symbols and letters.

2. BACKGROUND INFORMATION

a. The ionosphere and its reflection properties.

The ionosphere is that part of the upper atmosphere which is partially ionised by the sun's radiation and consists of three regions which are denoted by the letters D, E and F. The level of ionization is strongly influenced by the activity cycle of the sun and also by the combined effects of the earth's magnetic field and upper atmospheric winds.

HF communications rely on radio waves being reflected back to earth from the ionosphere. As radio waves pass through the lower ionosphere (the D region) the signal is attenuated; lower frequencies being attenuated more than higher frequencies. Radio waves that are not completely absorbed in the D region will be reflected in either the E region or F region of the ionosphere; normally the higher the frequency, the deeper into the ionosphere the radio wave penetrates before reflection. If the frequency becomes too high, then the radio wave will pass completely through the ionosphere.

b. Propagation Modes.

HF radio waves will propagate from a transmitter to a receiver via the ionosphere by whatever path (or mode) is available. If any path is available, no matter how unexpected, the radio wave will use it. However, rather than model all paths, computations are performed for those paths most likely to be useful to radio communicators. For the majority of cases, the most likely path is also the simplest path.

GRAFEX predictions are a compact description combining information of up to four likely paths for a given circuit. Two of these paths are propagated via the E region and two by the F region.

Each path can be ranked in order of likelihood. The most likely path is usually the one that has the least attenuation (or pathloss). This normally corresponds to the path with the least number of reflections, or hops, in the ionosphere.

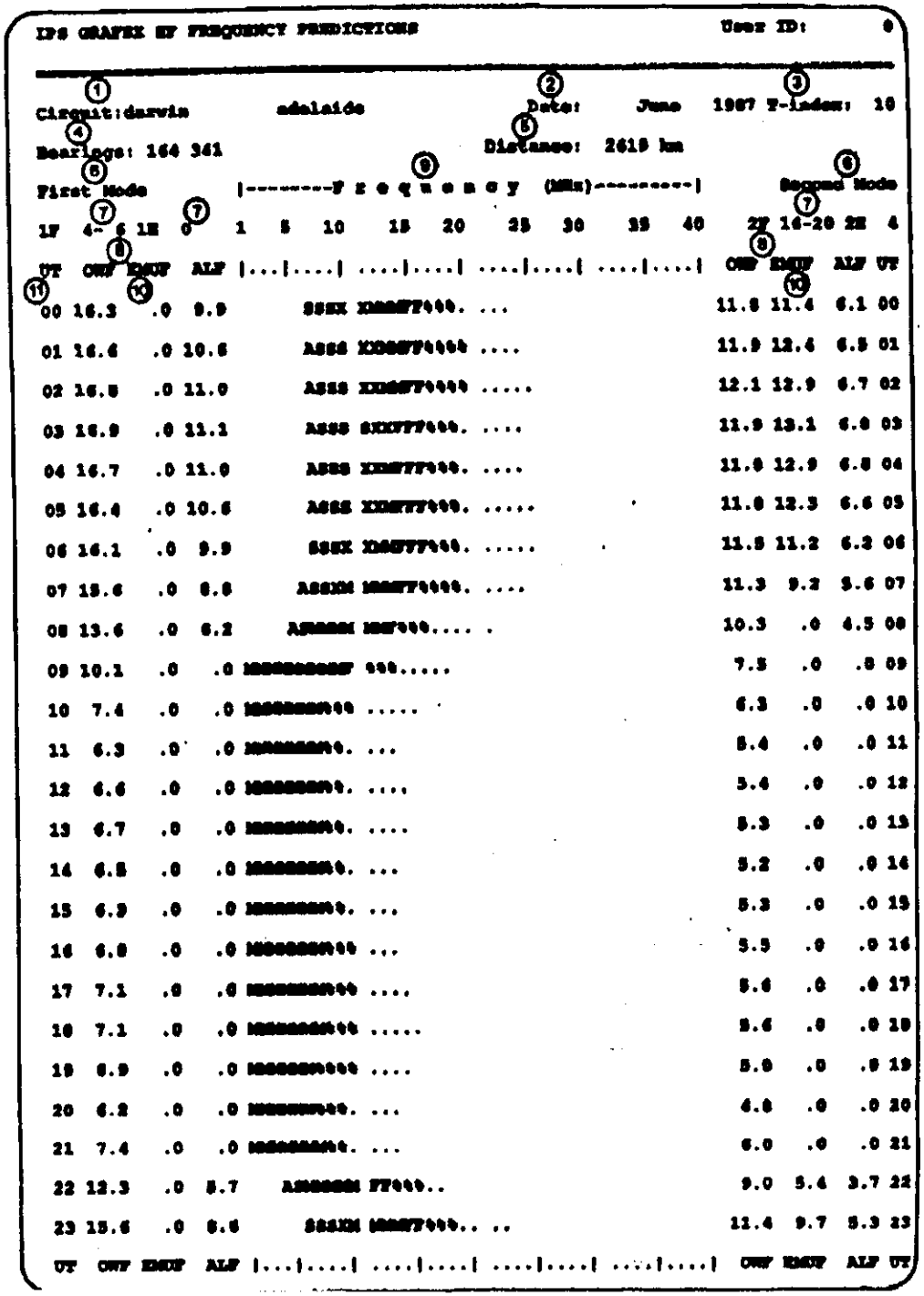
The communication path or mode that requires the **least number of hops** between transmitter and receiver, is called the **first mode.** The path that requires **one extra hop** is called the **second mode.** For more detailed information, see Appendix A.

3. MAIN FEATURES OF GRAFEX PREDICTIONS

The following list identifies various features of the frequency prediction chart.

(1)	Identification	Predictions are identified by the names of the terminals of the circuit (normally western terminal first).
(2)	Time Period	The month for which predictions are valid.
(3)	T Index	The level of activity for which the prediction applies is specified by the value of the T index.
(4)	Bearings	The true (not magnetic) bearings in degrees from each of the two terminals (western terminal first).
(5)	Circuit Length	Great circle distance between terminals. ("District" predictions apply for all distances between 0 and 300 km from the transmitter).
(6)	Mode	Predictions are made for two modes, each mode usually consisting of E and F layer hops.
(7)	Elevation angles	Range of radio wave take-off angles (in degrees) for each mode for each layer.
(8)	Two Layers	Predictions are made for both the E and F layers (height variation).
(9)	Horizontal Axis	Frequency in MHz.
(10)	OWF, EMUF, ALF	Tables of optimum working frequency (OWF), E-layer maximum usable frequency (EMUF) and absorption limiting frequency (ALF). See Appendix A for definitions.
(11)	Vertical Axis	Universal time (diurnal variation).

See Appendix B for a full description of GRAFEX symbols.



4. HOW TO USE A GRAFEX PREDICTION

The following examples are to be read in conjunction with the GRAFEX prediction shown on each opposing page.

Example 1:

A radio operator in Sydney wishes to contact a fellow operator in Wellington at 10:00 UT. What will be the propagation conditions for the frequencies available? The Sydney operator has an antenna which radiates energy at 5° - 50° above the horizontal.

Solution:-

i. Determine the possible propagation modes. The fourth line of GRAFEX shows the possible modes and corresponding radio wave elevation angles: first mode 1F (6° - 8°), 1E (0°);- second mode 2F (20° - 23°), 2E (6°).

Since the antenna angular range is 5° - 50° above the horizontal, it will transmit via the 1F, 2F and 2E modes. No radio wave will be transmitted via the 1E mode because the circuit length exceeds 1800km.

ii. Locate the time 10 UT in the first column of numbers on the left side of the chart. Values for the first mode OWF, EMUF and ALF are read from successive columns and have values: 6.4, 0.0, 0.0 MHz respectively. Corresponding values for the second mode are read from the columns on the right side of the chart: 5.1, 0.0, 0.0 MHz.

iii. Determine the propagation conditions from the letters and symbols read from left to right at 10 UT.

Analysis:

- The first mode EMUF is 0.0 MHz for all hours because of the circuit length. The first mode ALF and second mode EMUF and ALF have a value of 0.0 MHz between 6 to 20 UT because it is night-time during these hours.
- For frequencies 1 to 6 MHz the symbol "M" applies. This indicates propagation is possible via both the 1F and 2F modes. For frequencies above the second mode OWF (5.1 MHz) and the top "M" symbol (6MHz), the 1F mode will be present on nearly all days of the month with the 2F mode present on 15-27 days. Both modes will be present on all days of the month for frequencies below 5.1 MHz.
- Frequencies in the ranges 7 to 8 MHz and 9 to 11 MHz have the symbols "%" and ".", respectively. These symbols refer to propagation conditions for the 1F mode only. The Sydney operator could transmit solely via this mode at these higher frequencies. However, there is a smaller percentage of days for which successful communication is possible, i.e., 7 to 8 MHz (15-27 days), 9 to 11 MHz (3-15 days).

Conclusions:

- Frequencies below 5.1 MHz will propagate via both 1F and 2F modes on nearly all days of the month. A fading signal will result from multimode propagation unless the antenna provides more than 3 dB gain to either the 1F or 2F mode.
- Frequencies in the range 5.1 to 6 MHz will succeed on more than 27 days of the month. Propagation will be via the 1F mode and possibly the 2F mode (50%-90% chance). A steady signal will result from propagation via the 1F mode alone. Again, a fading signal could result from multimode propagation, as described above.
- Frequencies in the range 7 to 8 MHz will succeed on 15 to 27 days of the month while frequencies in the range 9 to 11 MHz will succeed on less than 15 days of the month. On those days when the signal does propagate, it will do so via the 1F mode only. Therefore a steady signal should result.

IPS GRAFEX HF FREQUENCY PREDICTIONS — User ID: 0

Circuit: Sydney — Wellington — Date: June 1987 T-index: 10

Bearings: 119 284 — Distance: 2228 km

First Mode				Frequency (MHz)									Second Mode			
1F 6- 8	1E 0			1	5	10	15	20	25	30	35	40	2F 20-23		2E 6	
UT	OWF	EMUF	ALF										OWF	EMUF	ALF	UT
00	13.8	.0	8.8			SSSXX	MFF%%%	..					9.5	10.9	5.2	00
01	14.1	.0	9.0			SSSXX	MFF%%%	..					9.6	11.0	5.4	01
02	13.9	.0	8.9			SSSXX	MFF%%%	...					9.8	10.7	5.4	02
03	14.3	.0	8.6			SSSXX	MFF%%%	..					10.0	10.0	5.3	03
04	14.7	.0	7.9			ASSXXX	MFF%%%	...					10.0	8.8	5.0	04
05	14.1	.0	6.7			SSXXXX	FFF%%	...					9.2	6.0	4.4	05
06	11.9	.0	.0	MMMMMMMF	F	%%%	..						7.6	.0	3.2	06
07	8.5	.0	.0	MMMMMMF	%%	...							5.8	.0	.0	07
08	6.8	.0	.0	MMMMMM	%%	..	..						5.3	.0	.0	08
09	6.5	.0	.0	MMMMMM	%%	..	.						5.2	.0	.0	09
10	6.4	.0	.0	MMMMMM	%%	..	.						5.1	.0	.0	10
11	6.7	.0	.0	MMMMMM	%%	..	.						5.3	.0	.0	11
12	6.7	.0	.0	MMMMMM	%%	..	.						5.2	.0	.0	12
13	6.5	.0	.0	MMMMF	%%	..							4.9	.0	.0	13
14	6.9	.0	.0	MMMMMM	%%	..	.						5.2	.0	.0	14
15	7.0	.0	.0	MMMMMM	%%	..	.						5.3	.0	.0	15
16	6.9	.0	.0	MMMMMM	%%	..							5.2	.0	.0	16
17	6.9	.0	.0	MMMMMM	%%	..							5.0	.0	.0	17
18	6.7	.0	.0	MMMMF	%%	..							4.8	.0	.0	18
19	6.5	.0	.0	MMMMF	%%	.							4.9	.0	.0	19
20	7.0	.0	.0	MMMMM	%%	.							5.6	.0	.0	20
21	10.8	.0	5.9		AS	MMMF	%%%	.					7.3	5.3	3.9	21
22	12.9	.0	7.6			ASSXXX	FF	%%%	..				9.3	8.7	4.6	22
23	13.9	.0	8.4			ASSSXX	MFF	%%%	..				9.5	10.1	5.0	23
UT	OWF	EMUF	ALF										OWF	EMUF	ALF	UT

Example 2

What are the best times for a Brisbane radio operator to contact Noumea on 7 MHz in June 1987? The operator's antenna has maximum gain at an elevation angle of less than 20° above the horizontal.

Solution

i. Determine the possible propagation modes. Since the antenna has maximum gain at less than 20° above the horizontal, the possible propagation modes will be only:- First mode - 1F (14° -18°), Second mode - 2E (12°). The 1E (3°) and 2F (30° - 36°) modes are not supported as the radio wave vertical elevation angles are beyond the antenna's transmitting limits (the lower limit of the most commonly used antenna is 4°).

ii. Determine the propagation conditions from the letters and symbols for 7 MHz. Symbols are read from the top (00 UT) to the bottom (23 UT) of the chart.

Analysis

- For 00 UT to 03 UT the symbol "S" applies. This indicates that propagation is possible via the 2F mode only. Since the antenna does not transmit energy at high enough elevation angles for this mode, these hours are not suitable. The 1F mode is not propagated because 7.0 MHz is below the first mode ALF (7.1 to 7.3 MHz).
- At 04 UT the symbol "X" applies and indicates that propagation is possible via the 2E mode as well as mixed E and F modes on nearly all days of the month. Although the 1F mode is available, because 7.0 MHz is below the first mode OWF (11.5 MHz at 04 UT), it may be a weak signal because it is close to the first mode ALF (6.7 MHz). However, since both the E and F modes are available, there is a possibility that interference fading of the signal may occur.
- From 05 to 07 UT the symbol "M" applies. This symbol usually indicates that propagation via the 1F, 1E and 2F modes is possible but since the antenna can only support the 1F mode, the symbol will refer to this mode only. Since 7.0 MHz is below the first mode OWF (11.5 to 8.9 MHz) for 05 to 07 UT and above the first mode ALF (6.0 to 0.0 MHz), the 1F mode at 7 MHz will be available on nearly all days of the month.
- The "%" symbol applies from 08 to 19 UT and "F" symbol at 20 UT. Each symbol indicates that propagation is possible via the 1F mode only. The symbol "%" indicates that propagation is possible on 15-27 days of the month while "F" indicates that propagation is possible on nearly all days of the month.
- For 21 UT the symbol "M" applies, while for 22 to 23 UT the symbol "X" applies. These conditions have already been discussed.

Conclusion

- The hours 00 to 03 UT are not suitable for communications on 7 MHz since no propagation is available.
- Propagation is possible at 04 UT and 22 to 23 UT via the 1F and 2E modes. However there is the chance of fading.
- From 05 to 07 UT and at 21 UT, propagation is possible on nearly all days of the month via the 1F mode only. Therefore a steady signal should result.
- Between 08 to 19 UT communications will succeed on 15 to 27 days of the month via the 1F mode only, and so a steady signal should result.
- At 20 UT communications on 7 MHz will succeed on nearly all days of the month with a steady signal propagated via the 1F mode only.

IPS GRAFEX HF FREQUENCY PREDICTIONS — User ID: 0

Circuit: Brisbane — Noumea — Date: June 1987 — T-index: 10

Bearings: 70 244 — Distance: 1671 km

First Mode — Frequency (MHz) — Second Mode

1F 14-18 1E 3 — 1 5 10 15 20 25 30 35 40 — 2F 30-36 2E 12

UT	OWF	MUF	ALF		OWF	MUF	ALF	UT
00	11.5	13.0	7.1				7.6	8.5	4.1	00
01	11.2	14.1	7.3				7.8	8.7	4.1	01
02	11.0	14.1	7.2				7.4	8.8	4.1	02
03	11.1	13.6	7.1				7.4	8.5	4.0	03
04	11.5	12.8	6.7				7.8	7.9	3.8	04
05	11.5	11.3	6.0				7.5	6.8	3.4	05
06	11.0	8.4	4.7				7.2	4.7	2.8	06
07	8.9	.0	.0				5.9	.0	.0	07
08	6.5	.0	.0				4.5	.0	.0	08
09	5.9	.0	.0				4.1	.0	.0	09
10	5.5	.0	.0				3.8	.0	.0	10
11	5.5	.0	.0				3.7	.0	.0	11
12	5.6	.0	.0				3.7	.0	.0	12
13	5.5	.0	.0				3.7	.0	.0	13
14	5.4	.0	.0				3.6	.0	.0	14
15	5.6	.0	.0				3.8	.0	.0	15
16	5.7	.0	.0				3.9	.0	.0	16
17	5.7	.0	.0				3.8	.0	.0	17
18	5.5	.0	.0				3.7	.0	.0	18
19	5.6	.0	.0				4.0	.0	.0	19
20	7.8	.0	.0				4.8	.0	1.9	20
21	10.4	9.6	5.3				6.7	5.4	3.1	21
22	11.4	11.8	6.3				7.4	7.1	3.6	22
23	11.7	13.1	6.8				7.6	8.0	3.9	23
UT	OWF	MUF	ALF		OWF	MUF	ALF	UT

APPENDIX A

OPERATING FREQUENCIES AND PROPAGATION MODES

a) Operating Frequencies

For any circuit there is a maximum usable frequency (MUF), which is the highest frequency supported by a particular region of the ionosphere. The MUF for the E region is denoted by EMUF and for the F region, FMUF or MUF.

The MUF varies from day-to-day due to prevailing conditions in the ionosphere. Consequently, it is not possible to predict exact values. However, it is possible to predict frequencies with a 10%, 50% or 90% chance of successful propagation. These frequencies are called the upper decile, median and lower decile MUF's. The lower decile MUF is also known as the Optimum Working Frequency (OWF).

Frequencies greater than the upper decile will be propagated on less than 3 (10%) days of the month, while frequencies less than the lower decile will be propagated on at least 27 (90%) days of the month. The median MUF represents the frequency value for which that frequency will be propagated up to 15 (50%) days of the month.

The symbols which make up a GRAFEX represent propagation information on a range of frequencies which lie between the upper decile MUF and the absorption limiting frequency (ALF) for the first and second modes. The ALF indicates the lower limit of the usable frequency band and takes into account signal attenuation due to absorption and the effects of E-layer screening.

b) Propagation Modes

GRAFEX predictions provide radiopropagation information for only the E and F layers. This information does not include sporadic-E (Es) propagation. Sporadic-E is a thin layer of unusually high ionization (thus a good reflector of HF signals) located in the E region. Es is particularly prevalent during the summer. The presence of sporadic-E can lead to signal fading and screening. However, if conditions are appropriate, Es can also help to provide strong signal reflection. This is why sporadic-E is often blamed when predictions are unsuccessful.

The upper panel of Figure A1 shows examples of **one-hop modes** (propagation via one layer only). Thus 1E, 1Es, 1F means one-hop propagation via the E, Es and F layers repectively. **Simple multihop modes** are shown in the middle panel which illustrates 2 hops via the E and Es layers (2E, 2Es) and 3 hops via the F layer (3F). Examples of **complex modes** are shown in the lower panel where propagation can be via the E, Es and F layers. IPS predictions do not contain any modes which include an Es reflection.

For circuit lengths of less than 4000 km, the first mode is usually 1F or 1E so that the second mode is specified by 2F or 2E. For lengths greater than 4000 km, the first mode can be either 2F or 3F (propagation via the E layer is not considered for distances greater than 6000 km) so that the second mode is specified by 3F or 4F.

If the antenna beamwidth is too wide, no discrimination between modes can be achieved and multipath or interference fading may result. Some conditions where multipath fading can occur are shown in Figure A2. These occur when two or more modes of comparable signal strength are received simultaneously. This condition is described by the symbols "M" and "X" in a GRAFEX prediction.

FIGURE A1 PROPAGATION MODES

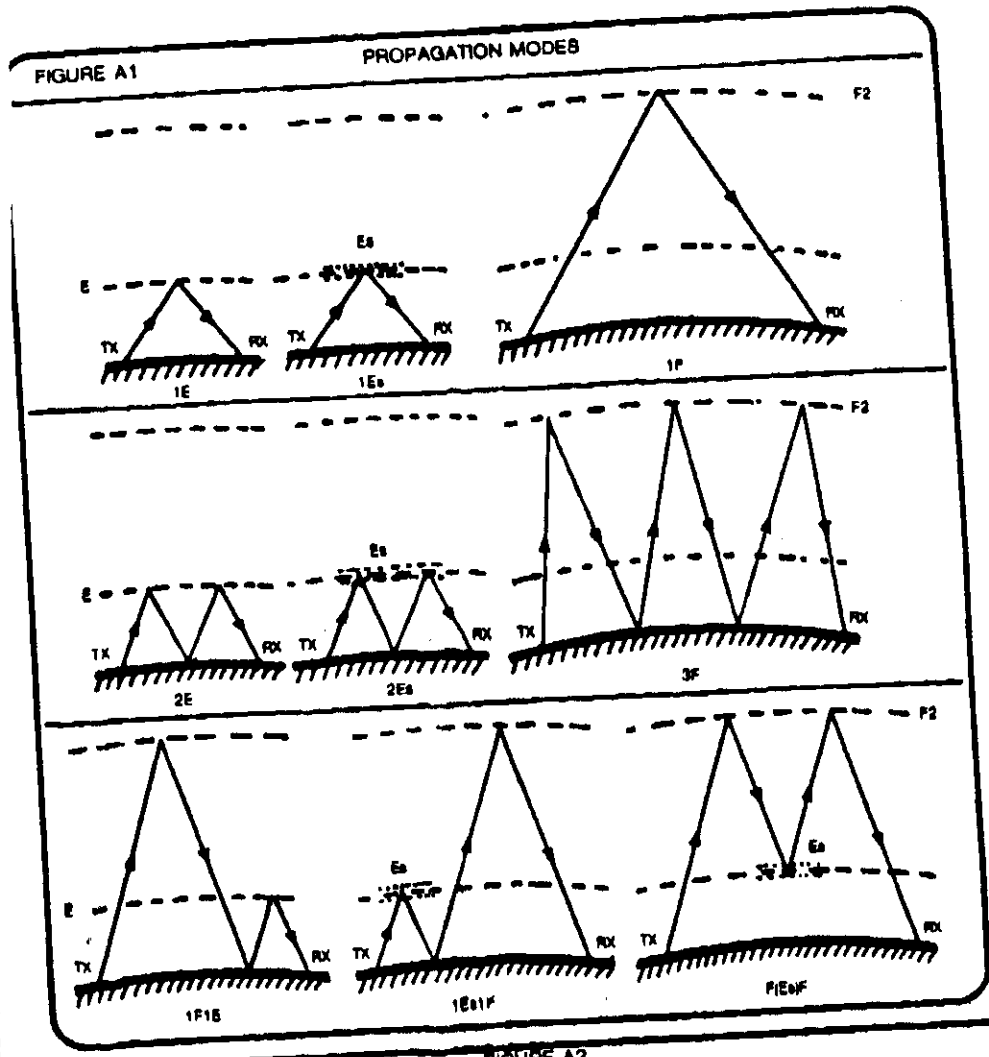
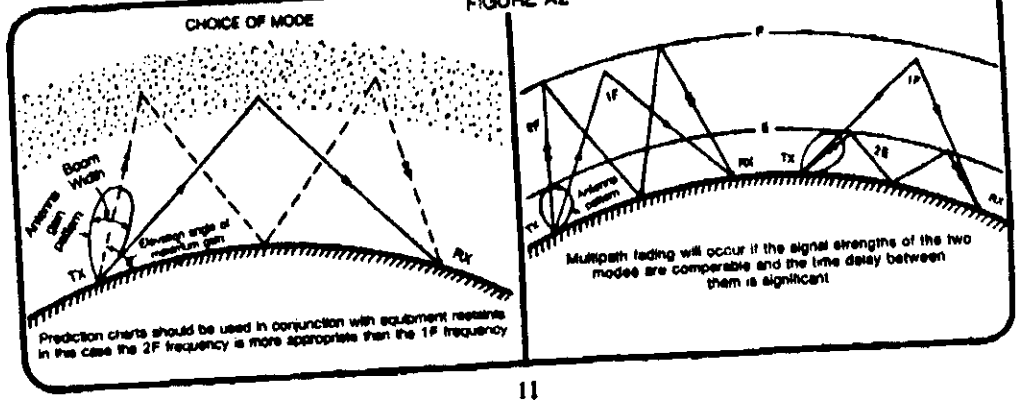


FIGURE A2



APPENDIX B

DEFINITION OF GRAFEX SYMBOLS

A description of GRAFEX symbols is given below. A symbol will indicate that propagation is possible:

'blank'	on less than 3 days of the month. This symbol is also used when the frequency is below the ALF and no propagation is possible.
'.'	on 3 to 15 days of the month via the first F-layer mode.
'%'	from 15 to 27 days of the month via the first F-layer mode.
'F'	via the first F-layer mode on almost all days (ie. more than 27 days of the month).
'E'	via the first E-layer mode and may be possible via the first F-layer mode for 3 to 15 days of the month.
'P'	on all days of the month via the first E-layer mode and may also be possible via the first F-layer mode on 15 to 27 days of the month.
'B'	via the first E-layer and F-layer modes on over 27 days of the month.
'M'	via the first F-layer mode on 27 days of the month, the second F-layer mode on 15 to 27 days of the month, and possibly the first E-layer mode. Note that the signal is likely to propagate strongly on each of these modes and this could result in interference fading.
'S'	via the second F-layer mode on 15 to 27 days of the month. As this frequency is below the first F mode ALF, propagation is possible only by the second mode.
'X'	via the second E-layer and other modes, such as mixed E, F and higher order F modes. Interference fading will probably occur.
'A'	Low signal strengths should be expected, due to high absorption of the radio wave, because the frequency is very close to the ALF.

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