AT/23.4.1/012

Control information for the LO and correlator version 1.1

M.Kesteven & R.P.Norris 15 October 1986
revised, 23 November 1986

revisions:
1.1 fix the sign of most expressions: $+ f_L$, not $- f_L$

The purpose of this note is to collect in one place the algorithms to be used by the observing task (OBS) in order to implement the Ephemeris calculations, and correctly control an observation.

It will be noticed that the LO/sampler chains are convoluted in the extreme - the probability is high that several revisions of this document will be required.

Just prior to an integration the ephemeris routine will calculate delay and the first two delay derivatives for each antenna. (The delay is for a wavefront arriving from the field centre - the point being tracked). These values need to be converted to:

a set of frequencies for the various local oscillators in the mixer chain;
a starting phase, phase rate and phase rate curvature for the fringe rotator;
a starting phase and phase rate for the sampler;
a delay, expressed in samples, for the delay line (the FIFO).

definitions:

f is a frequency observed by the antennas.

f_{obs} is the frequency (at the centre of the band) requested by the observer.

f_{mid} is the frequency to which f_{obs} has been translated, at the sampler input. f_{mid} is defined by the sampling (1/2/4-bit), and by the requested bandwidth. Appendix 1 tabulates the values, with their derivation.

τ is the geometrical delay, computed by the ephemeris routines (cf. AT/25.1.1/025)
τ is a function of time; we will approximate it over an integration, by :

$$\tau = \tau_0 + \tau_1 t + \tau_2 t^2$$

ϕ_f is a phase contribution, antenna based, slowly variable in time, and including the frequency dependance due to the extra instrumental delays.

f_{Li} is the frequency of the i^{th} local oscillator in the chain.

ϕ_{Li} is its phase; for all but the last oscillator, this should be a constant. Fringe tracking will be done at the last LO, varying ϕ_{Li}

IS_i is an index (+ or -1) related to the sideband chosen. IS = -1 if the spectrum is inverted.

I_{U1} is an index (+ or -1) defined by the nature of the LO conversion: $I_U = +1$ for an upconversion.

....

The Local Oscillators

At the start of the mixer chain the signal can be written as:

$$g(t) = a(f) \cos [\, 2\pi f (t - \tau) + \phi_f]$$

At the input to the sampler the argument of the cosine is translated to:

$$\begin{aligned} arg = \{\, & 2\pi t \left(f + f_{L1} I_{U1} + \frac{f_{L2} I_{U2}}{IS_1} + \frac{f_{L3}\, I_{U3}}{IS_1 IS_2} + \ldots \right) \\ & - 2\pi f\tau + \phi_f \\ & + \phi_{L1}\, I_{U1} + \frac{\phi_{L2}\, I_{U2}}{IS_1} + \frac{\phi_{L3}\, I_{U3}}{IS_1 IS_2} + \ldots \} \, IS_1 IS_2 IS_3 \,. \end{aligned}$$

To simplify the notation:

$$I_j = \prod_{i=1}^{j} IS_i$$

$$f_L = f_{L1}\, I_{U1} + \frac{f_{L2}\, I_{U2}}{I_1} + \frac{f_{L3} I_{U3}}{I_2} + \ldots$$

$$\phi_L = \phi_{L1}\, I_{U1} + \frac{\phi_{L2}\, I_{U2}}{I_1} + \frac{\phi_{L3} I_{U3}}{I_2} + \ldots$$

And,

$$arg = \{2\pi(f + f_L)\,(t - \tau) + \phi_f + (f_L \tau + \phi_L)\} I_n$$

where n is the total number of LOs in the chain.

Fringe rotator:

We will adjust the phase of the last LO in such a manner that :

$$2\pi f_L \tau + \phi_L = 0$$

The algorithm for calculating $\{f_{Li}\}$ is given in appendix 2.

$(f + f_L) I_n$ falls in the band required at the sampler - (64 to 128 MHz for 4-bit sampling, for example), with $(f_{obs} + f_L) I_n = f_{mid}$ being the basic requirement.

The signal presented to the sampler has an argument given by :

$$arg = \{2\pi(f + f_L)(t - \tau) + \phi_f\} I_n$$

Sampler and delay line (FIFO)

We want a sample stream which tracks the incoming wavefront - it should have the same time dependance as the argument above : $(t - \tau)$. Consider the function:

$$S(t) = \sin\left[2\pi \frac{f_s}{2}(t - \tau)\right]$$

where f_s is the nominal sampling frequency. (128 MHz for 4-bit sampling).

A sample is taken whenever $S(t) = 0$ -- ie. when the argument is an integer multiple of π:

$$2\pi \frac{f_s}{2}(t - \tau)_\sigma = \sigma\pi \qquad \text{defines the } \sigma^{th} \text{ sample,}$$

$$(t - \tau)_\sigma = \frac{\sigma}{f_s}$$

The data leaving the FIFO thus has the form :

$$\{\cos[(2\pi(f + f_L)\frac{\sigma}{f_s} + \phi_f) I_n]\}$$

We implement the sampler operations in 2 steps:

a). we offset the phase of the sampler oscillator in order to accomodate the variable component of τ, as well as the fractional sample part of the fixed delay; the expression above for S(t) performs this function.

b). we delay the data stream by N_s samples.

The initial number of samples to discard will therefore be:

$$N_s = \mathrm{INT}\ [\tau_0 f_s]$$

For the benefit of the FIFO we express N_S in bits, not samples .

$$N_S(\text{bits}) = N_S \times 1, 2 \text{ or } 4$$

The operation of the FIFO is discussed in appendix 3.

The sampler *qua* mixer.

Most of the AT samplers operate with the signal frequency $(f + f_L)$ in a band above $(f_S/2)$. This means that the sampler will operate as a mixer, translating the video band down to baseband - and in general a further spectrum inversion will result. However, unlike a mixer, a phase shift in the sampler oscillator produces a delay, rather than a frequency-independent phase shift. The phase shift at the correlator will be the delay multiplied by the video frequency.

This matter is discussed in appendix 4.

Hardware Initialization

A number of switches and attenuators need to be set when a new frequency is band is chosen. The steps required are listed in appendix 5.

Appendix 1.

f_{mid} for the different sampling rates and bandwidths.

revisions:
1.1 f_{mid} for 0.5 MHz band should be 98.25 MHz

This tabulation also includes the spectrum inversion index (IS), covering the first sampler (at the antenna), the additional narrow band oscillators, and the second sampler.

			IS
1-bit sampling:			
	384 MHz	for the 256 to 512 MHz filter	-1
	640 MHz	512 to 768 MHz filter	+1
2-bit sampling:			
	192 MHz	128 to 256 MHz	-1
4-bit sampling :			
	96 MHz	for 64 MHz Bandwidth	-1
	112	32	-1
	104	16	-1
	100	8	+1
	102	4	-1
	99	2	-1
	98.5	1	+1
	98.25	0.5	+1

NOTE : there is an optional band inverter available at the output of the D/A - there is therefore an additional (optional) table of settings:

80 MHz	for 32 MHz Bandwidth	+1
88	16	+1
92	8	-1
90	4	+1
93	2	+1
93.5	1	-1
93.75	0.5	-1

Details of the narrow band filters:

32 MHz BW : from the 0 - 32 MHz region of the reconstituted 4-bit (64 MHz) signal.
ie. 96 - 128 MHz before the first sampler.
No additional LO inversions.
One sampler inversion. (The first sampler).

f_{mid} = **112 MHz**

16 MHz must lie in the range 48 - 64 MHz after mixing with 80 MHz
ie. 16 - 32 MHz region of the reconstituted signal (A/D signal).
ie. 96 - 112 MHz before the first sampler.
one LO inversion
16 MHz BW, starting at 48 MHz at the second sampler.
two sampler inversions.

f_{mid} = **104 MHz.**

8 MHz 8-16 MHz after mixing with 64 MHz.
ie. 48 - 56 MHz after mixing with 80 MHz
ie. 24 - 32 MHz from the A/D
ie. 96 - 104 MHz before the first sampler.
two LO inversions
8 MHz BW, starting at 8 MHz at the second sampler.
two sampler inversions

f_{mid} = **100 MHz**

4 MHz 8 - 12 MHz after mixing with 64 MHz.
ie. 52 - 56 MHz after mixing with 80 MHz
ie. 24 - 28 MHz from the A/D
ie. 100 - 104 MHz at the first sampler.
two LO inversions
4 MHz BW, starting at 8 MHz at the second sampler.
one sampler inversion.

f_{mid} = **102 MHz.**

2 MHz 2 - 4 MHz. after mixing with 16 MHz
ie. 12 - 14 MHz after mixing with 64 MHz
ie. 50 - 52 MHz after mixing with 80 MHz
ie. 28 - 30 MHz from the A/D
ie. 98 - 100 MHz at the first sampler.
three LO inversions
2 MHz BW starting at 2 MHz at the second sampler
2 sampler inversions.

f_{mid} = **99 MHz.**

1 MHz 2 - 3 MHz after mixing with 16 MHz
ie. 13 - 14 MHz after mixing with 64 MHz
ie. 50 - 51 MHz after mixing with 80 MHz
ie. 29 - 30 MHz from the A/D
ie. 98 - 99 MHz at the first sampler.
three LO inversions
1 MHz BW starting at 2 MHz at the second sampler.
one sampler inversion.

f_{mid} = **98.5 MHz**

0.5 MHz 2 - 2.5 MHz after mixing with 16 MHz
ie. 13.5 - 14 MHz after mixing with 64 MHz
ie. 50 - 50.5 MHz after mixing with 80 MHz
ie. 29.5 - 30 MHz from the A/D
ie. 98 - 98.5 MHz at the first sampler.
three LO inversions
0.5 MHz BW starting at 2 MHz at the second sampler
one sampler inversion.

f_{mid} = **98.25 MHz**

Appendix 2.

The LO algorithm: how do we choose the Local oscillator frequencies?

revisions:

1.1 (23/11/86) fix the algebra (sign of f_L); change some values (GN's version); substantially modify the implementation algorithm section.

Contents:

A .. hardware list
B .. frequency limitations imposed by the hardware
C .. additional constraints
D .. the algorithm used to define the LO frequencies suitable for a given observing frequency.

A .<u>Hardware: what oscillators are there?</u>

1. UHF band : L4 : 511 to 520 MHz ..
   L2 : 600 to 609 MHz ..
   U4 : 760 to 769 MHz .. in 1 MHz steps
   U2 : 831 to 840 MHz ..

In addition to the gross tuning (1 MHz steps), these oscillators provide the fringe tracking with rates in the range -2 KHz to +2 KHz, in steps of 0.2 mHz.

2. L/S band : 1.775 to 2.215 GHz in 10 MHz steps

3. C/X band: 6.71 to 8.32 GHz in 320 MHz steps

4. K/Q band: 16 to 20 GHz. 4 GHz steps ?

5. F band

6. W band

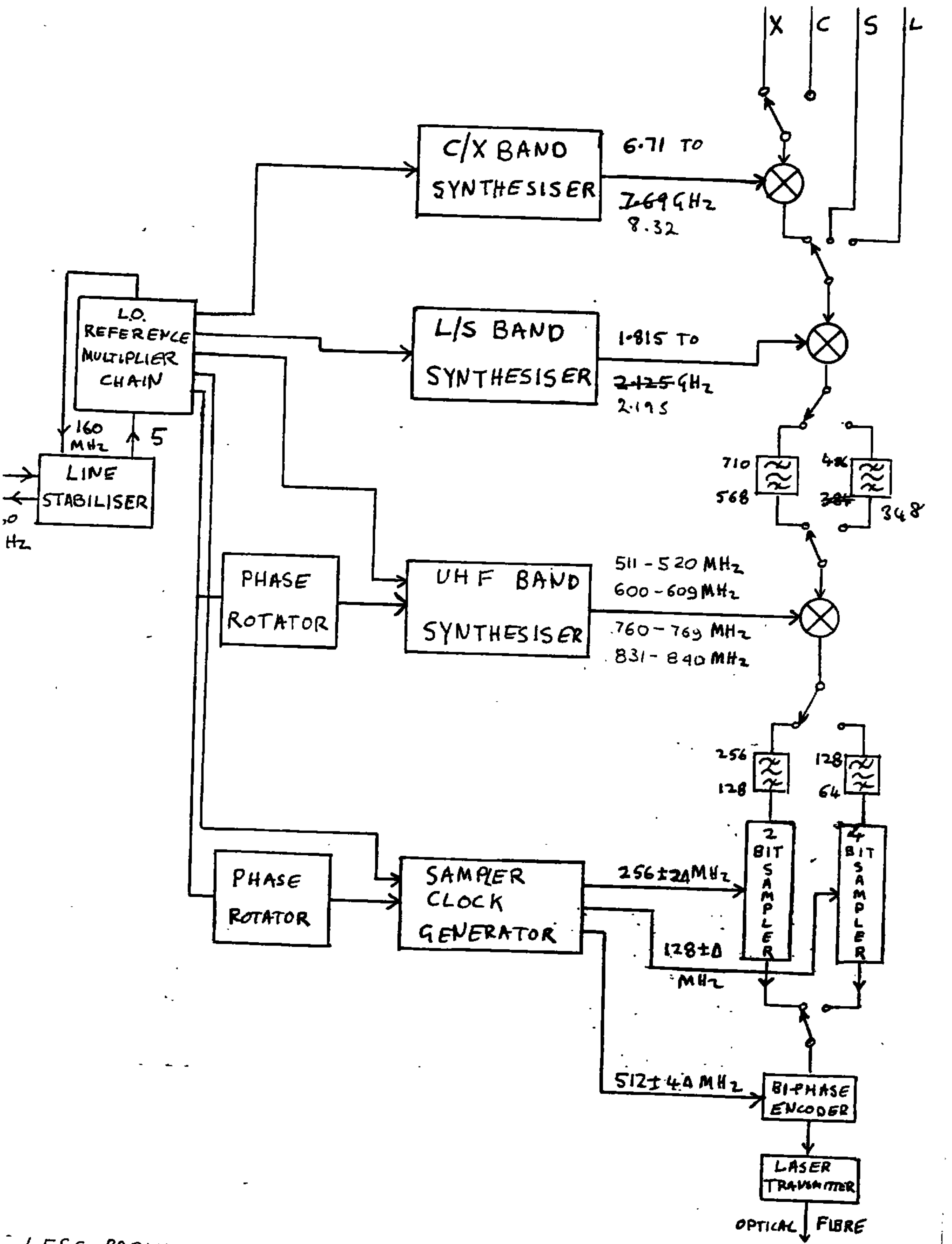
7. UHF upconverter : 1.92 GHz

8. Narrow band oscillators - 80 MHz +/- 0.5 MHz in 4 kHz steps
   (for 16 MHz BW and below)

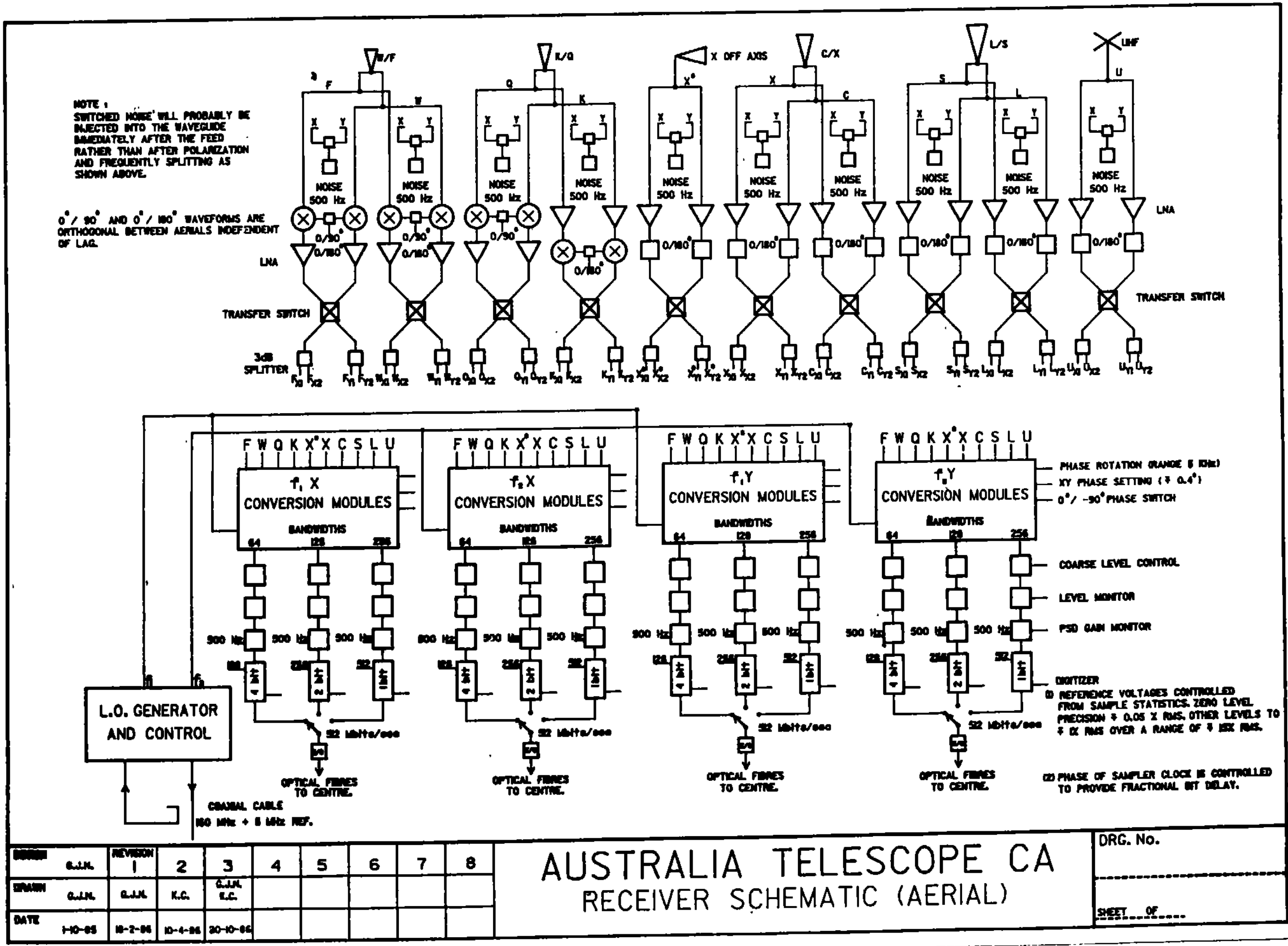
   64 MHz (for 8 MHz BW and below)
   16 MHz (for 2 MHz BW and below)

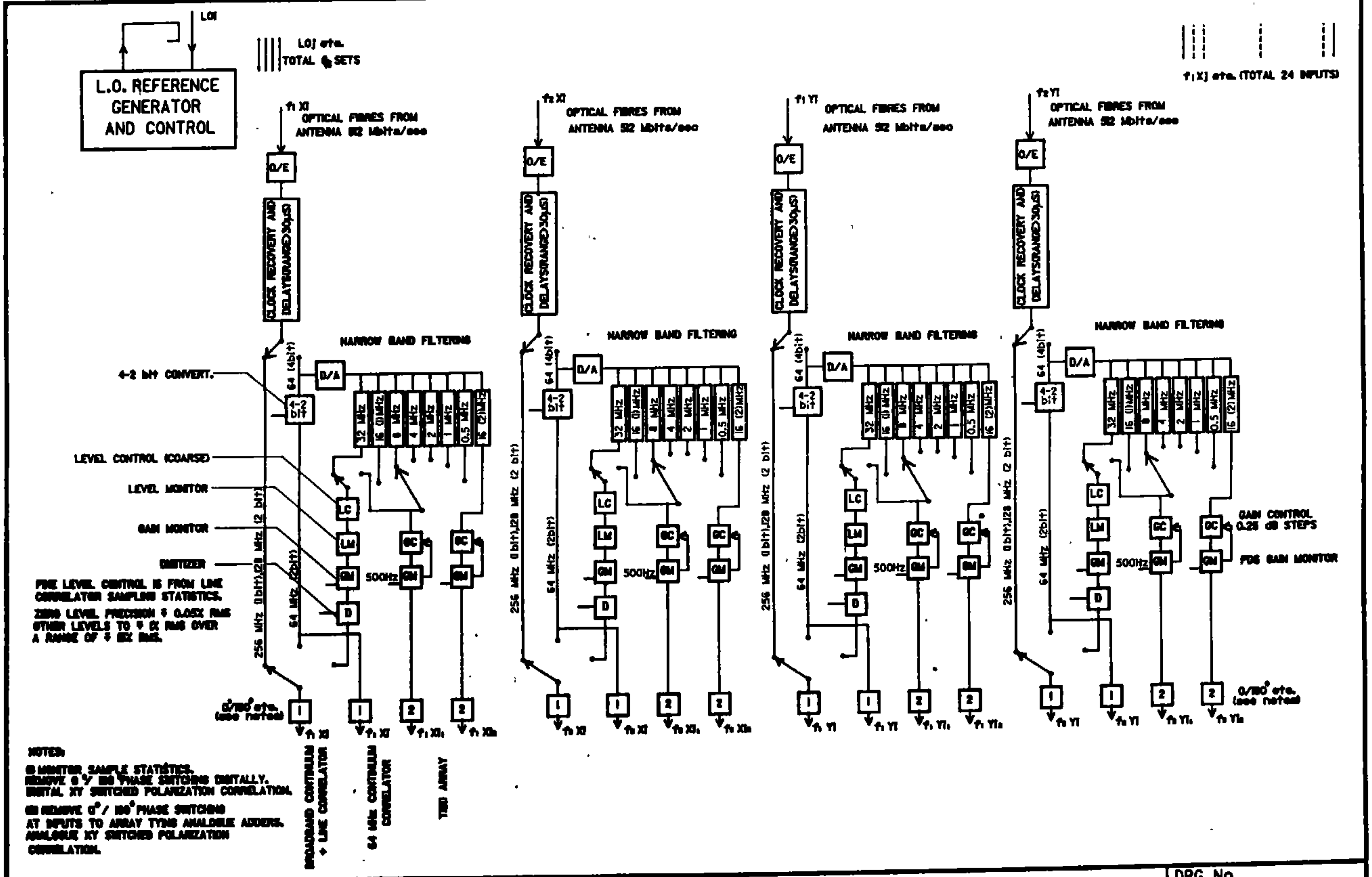
9. Samplers - These operate at 512MHz (1-bit sampling),
   256 MHz (2-bit)
   128 MHz (4-bit)
   The phase of these units is adjusted (offset and rate) so as to provide fractional bit delay correction.

Figure 1 shows the hardware relevant to the L/S/C/X band operation.



LESS PROVISIONAL


NOTE :
SWITCHED NOISE WILL PROBABLY BE INJECTED INTO THE WAVEGUIDE IMMEDIATELY AFTER THE FEED RATHER THAN AFTER POLARIZATION AND FREQUENTLY SPLITTING AS SHOWN ABOVE.
0°/ 90° AND 0°/ 180° WAVEFORMS ARE ORTHOGONAL BETWEEN AERIALS INDEPENDENT OF LAG.
W/F
K/Q
X OFF AXIS
C/X
L/S
UHF
NOISE 500 Hz
0/90°
0/180°
LNA
TRANSFER SWITCH
3dB SPLITTER
F W Q K X° X C S L U
f1 X CONVERSION MODULES
f2 X CONVERSION MODULES
f1 Y CONVERSION MODULES
f2 Y CONVERSION MODULES
BANDWIDTHS
64
128
256
500 Hz
512 Mbits/sec
OPTICAL FIBRES TO CENTRE.
PHASE ROTATION (RANGE 5 KHz)
XY PHASE SETTING (∓ 0.4°)
0°/ -90° PHASE SWITCH
COARSE LEVEL CONTROL
LEVEL MONITOR
PSD GAIN MONITOR
DIGITIZER
(1) REFERENCE VOLTAGES CONTROLLED FROM SAMPLE STATISTICS. ZERO LEVEL PRECISION ∓ 0.05 % RMS. OTHER LEVELS TO ∓ 1% RMS OVER A RANGE OF ∓ 10% RMS.
(2) PHASE OF SAMPLER CLOCK IS CONTROLLED TO PROVIDE FRACTIONAL BIT DELAY.
L.O. GENERATOR AND CONTROL
COAXIAL CABLE 160 MHz + 5 MHz REF.
DESIGN G.J.N.
DRAWN G.J.N.
DATE 1-10-85
REVISION 1 G.J.N. 18-2-86
2 K.C. 10-4-86
3 G.J.N. K.C. 30-10-86
4 5 6 7 8
AUSTRALIA TELESCOPE CA
RECEIVER SCHEMATIC (AERIAL)
DRG. No.
SHEET OF



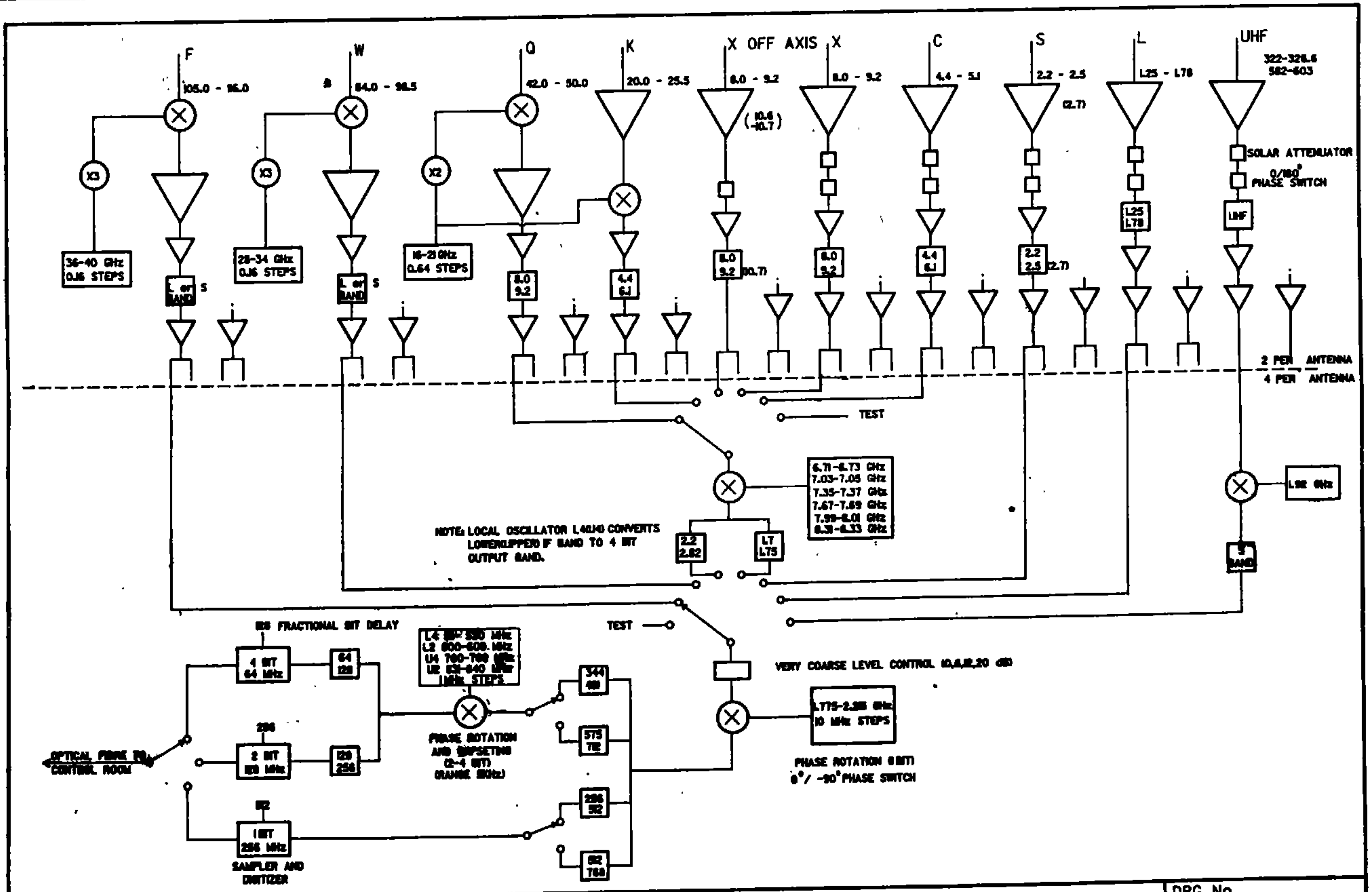
DESIGN G.J.N.	REVISION 1	2	3	4	5	6	7	8
DRAWN G.J.N.	G.J.N.	K.C.						
DATE 1-10-85	10-2-86	16.4.86						

AUSTRALIA TELESCOPE CA

RECEIVER SCHEMATIC (CENTRAL BUILDING)

DRG. No.

SHEET __ OF ______

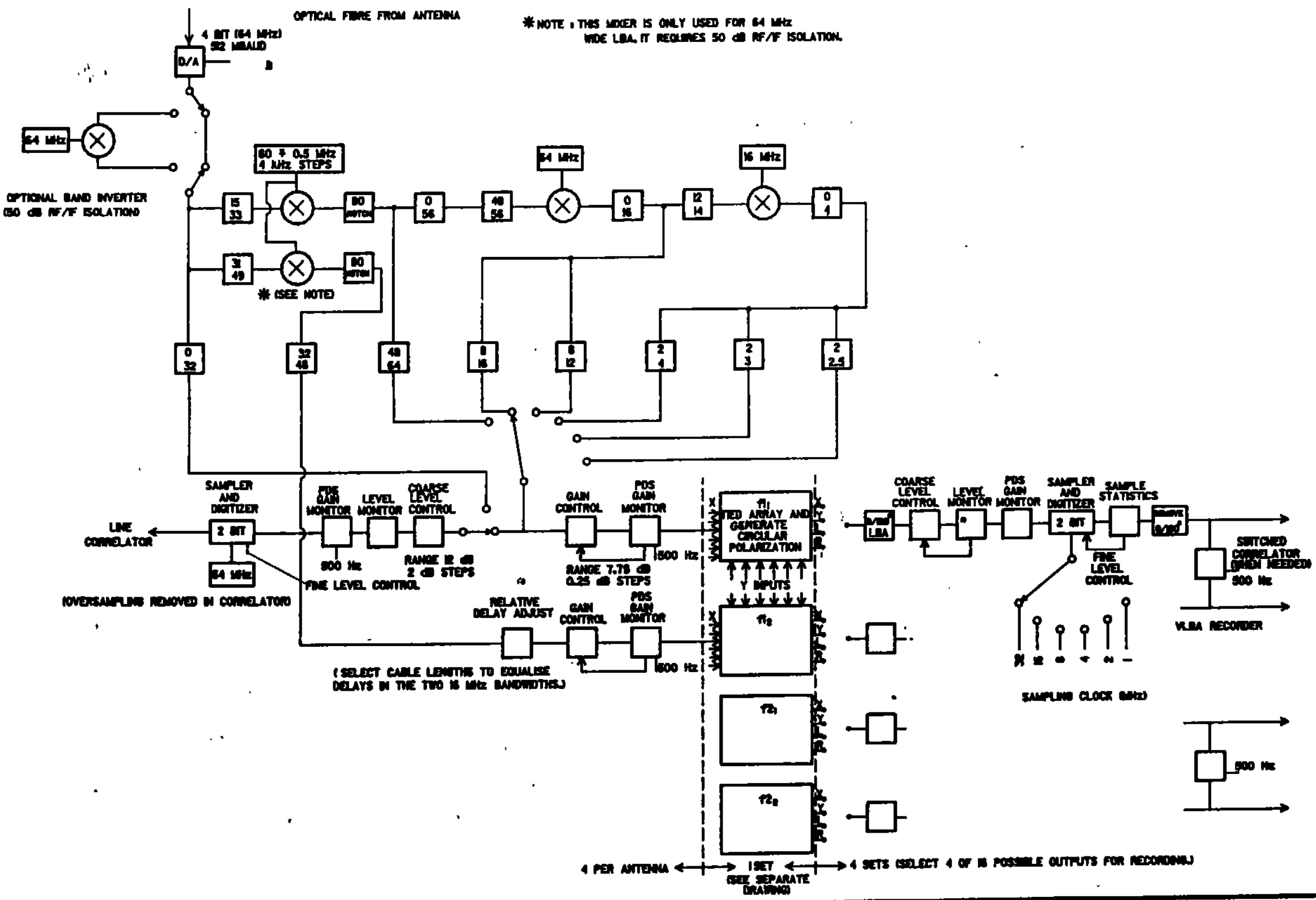


DESIGN	REVISION 1	2	3	4	5	6	7	8
G.J.N.								
DRAWN G.J.N.	G.J.N.	K.C.	G.J.N. K.C.					
DATE 1-10-86	18-2-86	10-4-86	20-10-86					

AUSTRALIA TELESCOPE CA
FRONT END CONVERSION SCHEME

DRG. No.

SHEET ____ OF ______



DESIGN G.J.N.	REVISION 1	2	3	4	5	6	7	8
DRAWN G.J.N.	G.J.N.	K.C.						
DATE 1-10-85	10-2-86	10-4-86						

AUSTRALIA TELESCOPE CA

CONVERSION SCHEME NARROW BAND TUNING

DRG. No.

SHEET ___ OF ______

4

B. The frequency choices imposed by the hardware.

B.1 The samplers. These require data in the bands :

either 256 - 512
or 512 - 768 MHz for 1-bit sampling;

128 - 256 MHz .. 2-bit.

64 - 128 MHz .. 4-bit

B.2 The UHF synthesizer has four possibilities :

L4 : 511 to 520 MHz
L2 : 600 to 609

U4 : 760 to 769
U2 : 831 to 840

All four oscillators are tunable in 1 MHz steps.

These oscillators will operate on data from the filters :

L : 344 to 481 MHz
U : 575 to 712 MHz

Therefore : **for 4-bit sampling,** use one of:

L4 , with L filter : (511-128 = 383) to (520 - 64 = 456) MHz
L4, U filter : (511+64 = 575) to (520+128 = 648) MHz

U4, U filter : (760 -128 = 632) to (769 - 64 = 705) MHz

for 2-bit sampling, use one of:

L2 : (600-256 = 344) to (609-128 = 481) MHz

U2 : (831-256 = 575) to (840-128 = 712) MHz

in summary:

L4 accepts	383 to 456 MHz	from the L filter
	or 575 to 648	from the U filter
U4	632 to 705	U
L2	344 to 481	L
U2	575 to 712	U

B.3 The other oscillators.

In the following sections we indicate the options available: the frequency ranges accessible with each local oscillator range. The limits adopted need to be treated with care: the receiver bandpasses are not rectangular, so some additional frequencies could be extracted. The calculations are based on 4- or 2-bit sampling. Observations at bandwidths less than 64 MHz will also utilize (at the antenna) the full 64 MHz bandwidth - final narrow band filtering will take place at the central site; this means that narrow band observations near the edge of the receiver band may have the bulk of the 64 MHz band outside the limits adopted here.

L band

The receiver is good for a range of 1.25 GHz to 1.75 GHz.
(But the L band filter, used by some higher frequencies, covers the band 1.17 to to 1.78 GHz).

The L band oscillator operates in the range 1.775 to 2.215 GHz in 10 MHz steps.

for 4-bit sampling, the limits are:

L4 : (1.775-0.456 = 1.319) to (2.215-0.383 = 1.832) GHz .. L filter
L4 : (1.775-0.648 = 1.127) to (2.215-0.575 = 1.640) GHz .. U filter
U4 : (1.775-0.632 = 1.143) to (2.215-0.705 = 1.510) GHz .. U filter

That is :

obs. freq :	1.17 to 1.510 GHz	1.319 to 1.75	1.17 to 1.640
L/S osc :	1.802 to 2.215	1.775 to 2.133	1.818 to 2.215
UHF syn :	U4	L4	L4
filter :	U	L	U
LO inversions	2	2	1

This table is shown schematically in figure 2.

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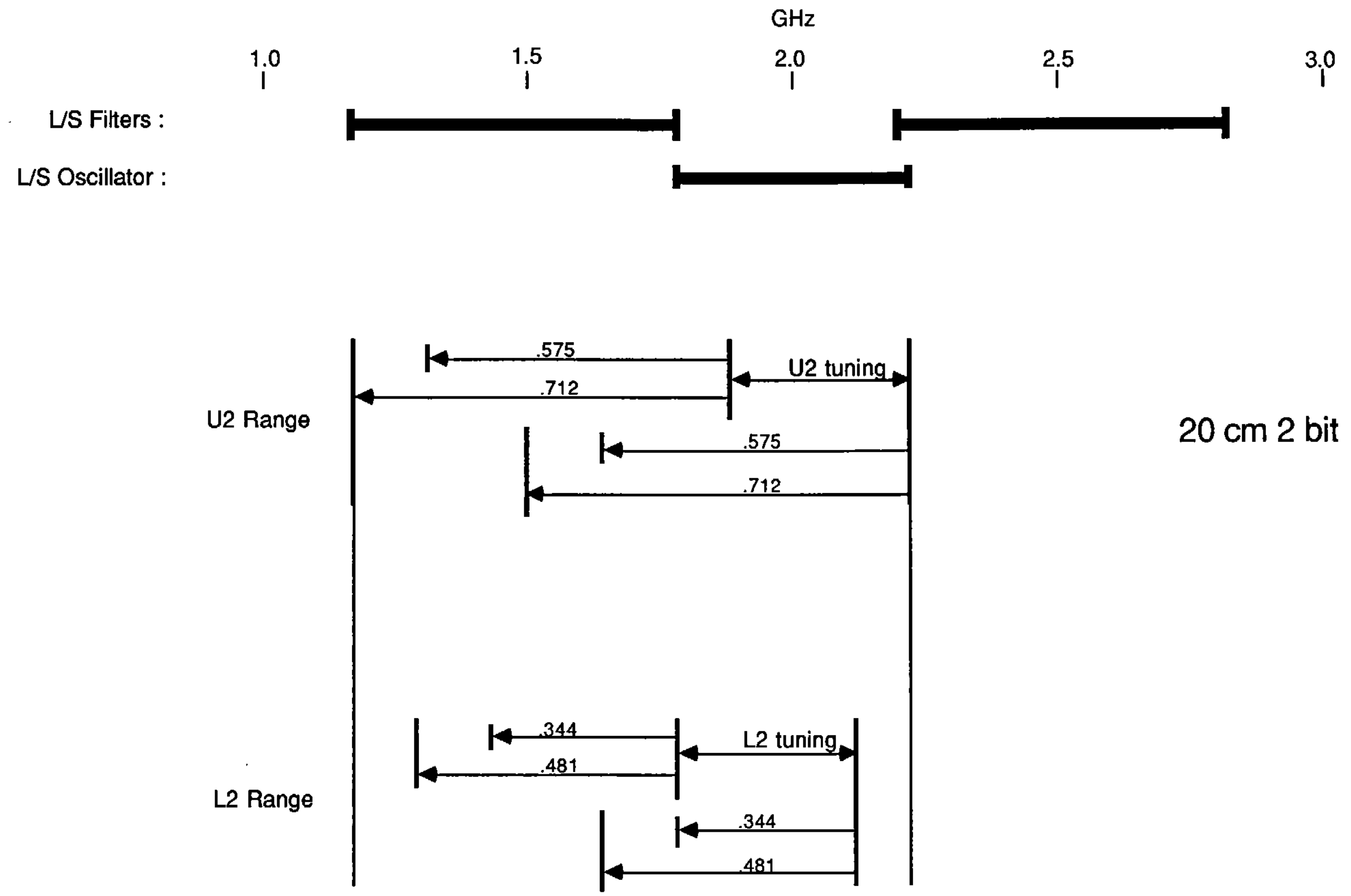
for 2-bit sampling :

L2 : (1.775-0.481 = 1.294) to (2.215-0.344 = 1.871) GHz
U2 : (1.775-0.712 = 1.063) to (2.215-0.575 = 1.640) GHz

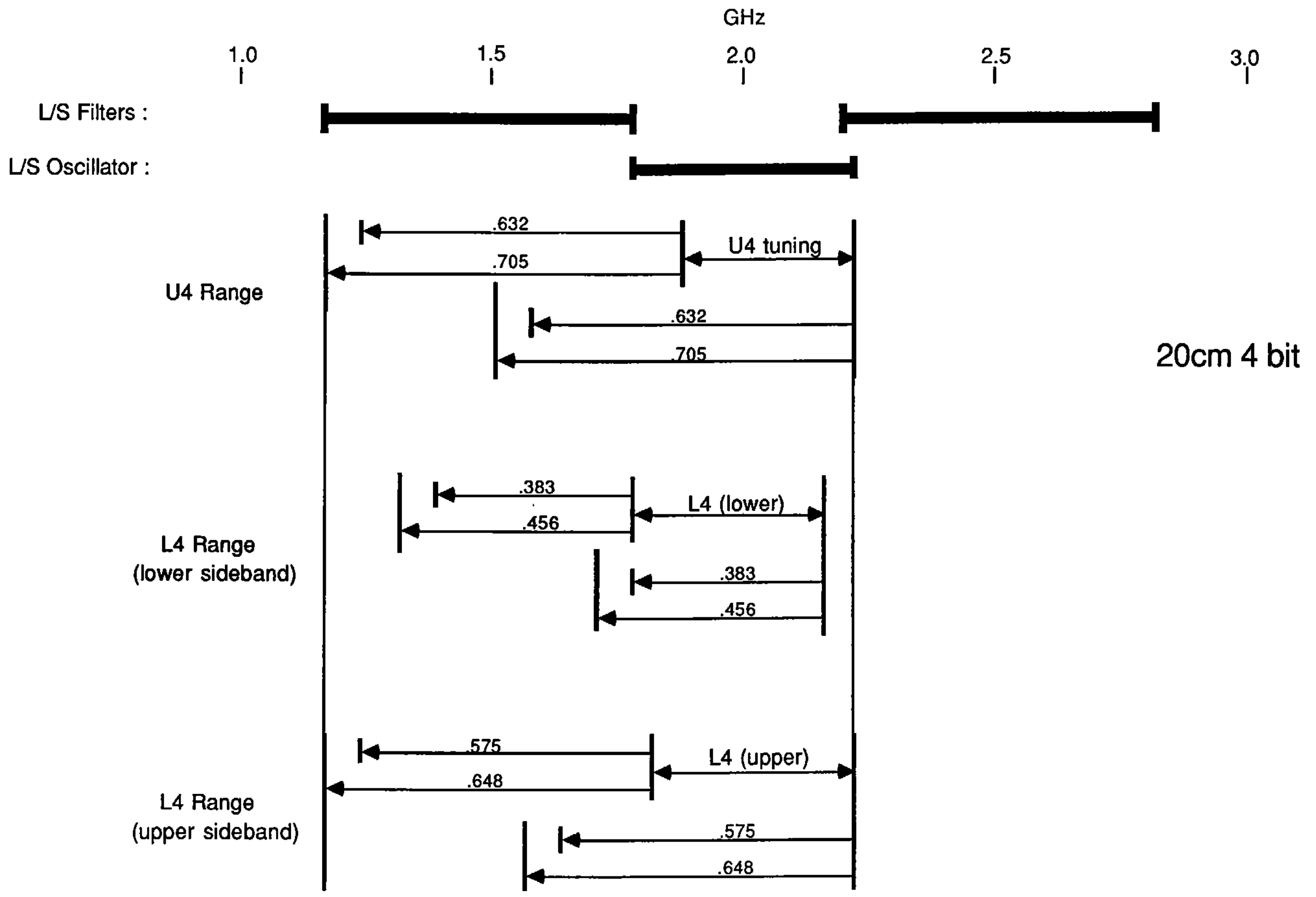
That is :

obs. freq :	1.17 to 1.640 GHz	1.294 to 1.75
L/S osc :	1.882 to 2.215	1.775 to 2.094
UHF syn :	U2	L2
filter	U	L
LO inversions	2	2

see figure 3.



GHz
1.0
1.5
2.0
2.5
3.0
L/S Filters :
L/S Oscillator :
.575
U2 tuning
.712
U2 Range
.575
.712
20 cm 2 bit
.344
L2 tuning
.481
L2 Range
.344
.481


GHz
1.0
1.5
2.0
2.5
3.0
L/S Filters :
L/S Oscillator :
U4 Range
.632
.705
U4 tuning
.632
.705
20cm 4 bit
L4 Range
(lower sideband)
.383
.456
L4 (lower)
.383
.456
L4 Range
(upper sideband)
.575
.648
L4 (upper)
.575
.648

S band

The receiver is designed for the range : 2.2 to 2.5 GHz
(But the S band filter operates over the range 2.2 to 2.82 GHz

The oscillator : 1.775 to 2.215 GHz in 10 MHz steps.

the limits :

L4 : (1.775+0.383 = 2.158) to (2.215+0.456 = 2.671) GHz
L4 : (1.775+0.575 = 2.350) to (2.215+0.648 = 2.863) GHz
U4 : (1.775+0.632 = 2.407) to (2.215+0.705 = 2.920) GHz
L2 : (1.775+0.344 = 2.119) to (2.215+0.481 = 2.696) GHz
U2 : (1.775+0.575 = 2.350) to (2.215+0.712 = 2.927) GHz

4-bit sampling:

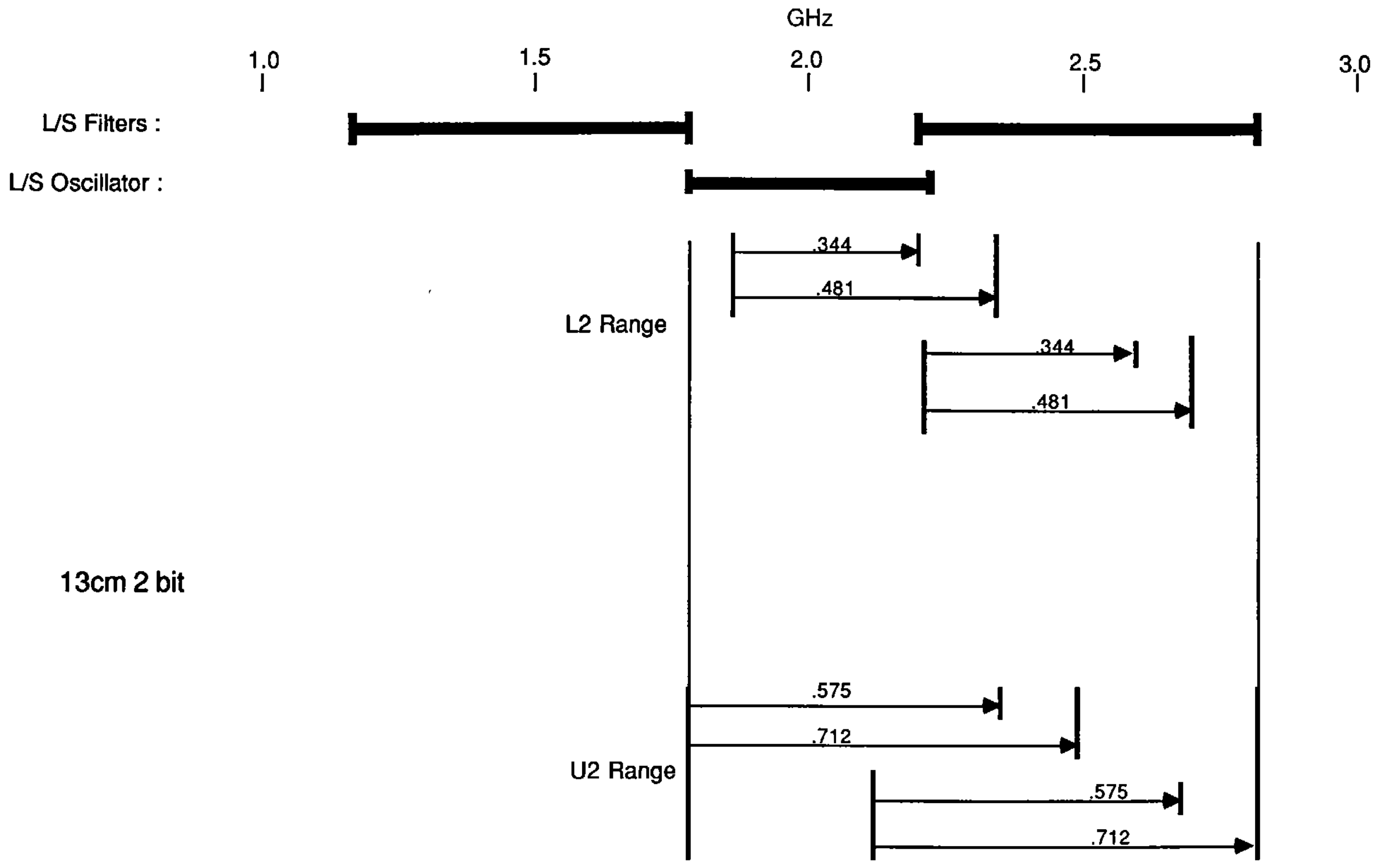
obs freq :	2.2 to 2.671 GHz	2.35 to 2.8 GHz	2.407 to 2.8 GHz
L/S osc :	1.817 to 2.215	1.775 to 2.154	1.775 to 2.095
UHF syn :	L4	L4	U4
filter	L	U	U
LO inversions	1	0	1

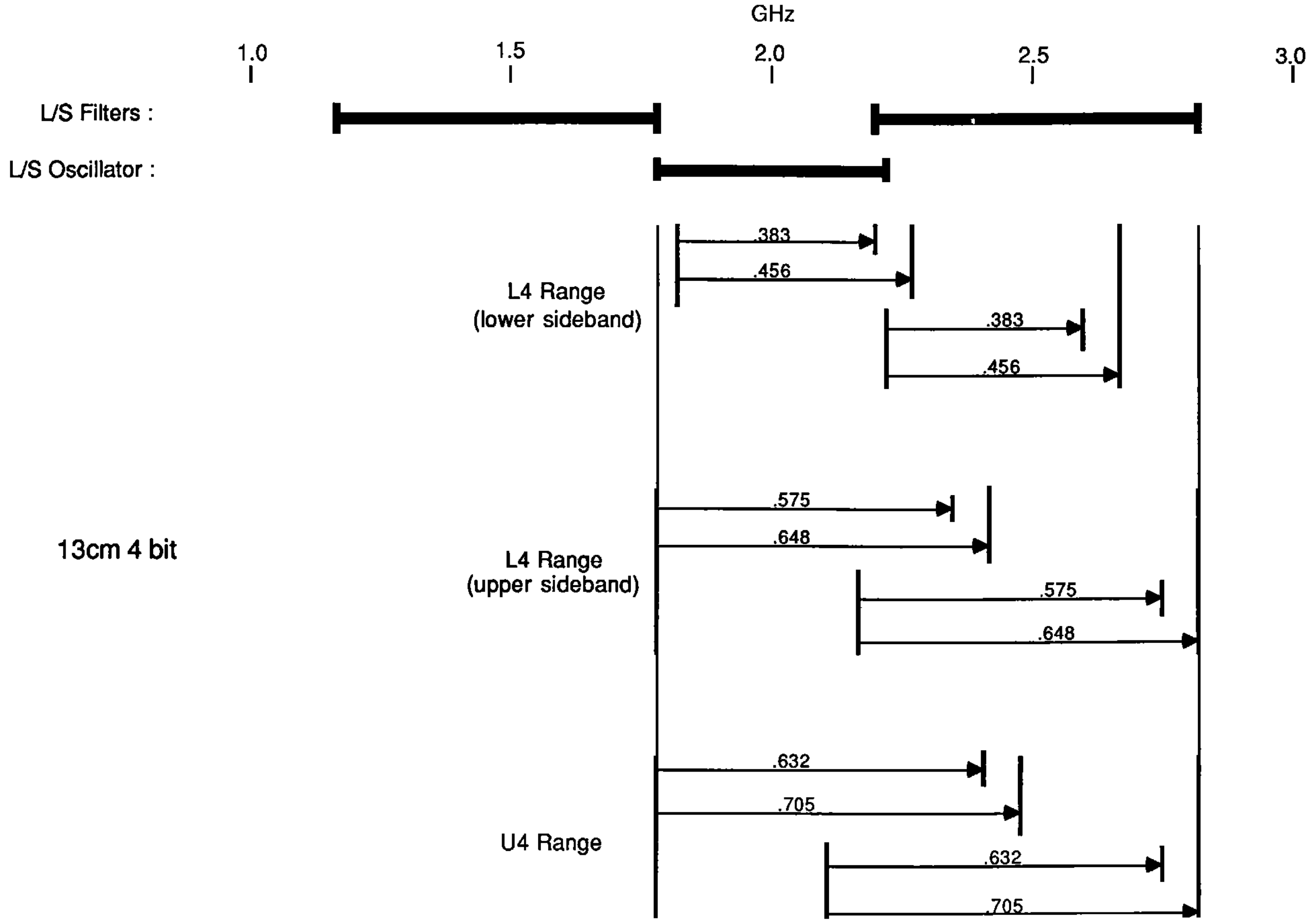
see figure 4.

2-bit sampling

obs freq :	2.2 to 2.696 GHz	2.350 to 2.8 GHz
L/S osc :	1.856 to 2.215	1.775 to 2.088
UHF syn:	L2	U2
filter	L	U
LO inversions	1	1

see figure 5.


GHz
1.0
1.5
2.0
2.5
3.0
L/S Filters :
L/S Oscillator :
.344
.481
L2 Range
.344
.481
13cm 2 bit
.575
.712
U2 Range
.575
.712


GHz
1.0
1.5
2.0
2.5
3.0
L/S Filters :
L/S Oscillator :
13cm 4 bit
L4 Range
(lower sideband)
.383
.456
.383
.456
L4 Range
(upper sideband)
.575
.648
.575
.648
U4 Range
.632
.705
.632
.705

C band

Observing frequency range : 4.4 to 6.1 GHz

C/X oscillator : 6.71 to 8.32 in steps of 320 MHz

making use of the previous ranges, we get the following table relating possible observing frequencies and oscillator settings. We still await a definitive table of preferred settings.

Note that we make use of the fact that the filters between the C/X and the next stage are broader than the L/S observing range : 1.17 to 1.75 GHz and 2.2 to 2.82 GHz.

The table shows the IF frequency (presented to the next mixer), as dictated by the observing frequency requested and the limited range of first LO frequencies.

Observing frequency (band centre)

LO	4.4	4.51	4.96	5.46	6.1
6.71	2.31 ..	2.2	1.75	1.17	
7.03		2.82 .. 2.2		1.75	1.17
7.35			2.82 .. 2.2	1.75	.... 1.17
7.67			2.82 ...	2.2	1.7 1.57
7.99				2.82 ..	2.2

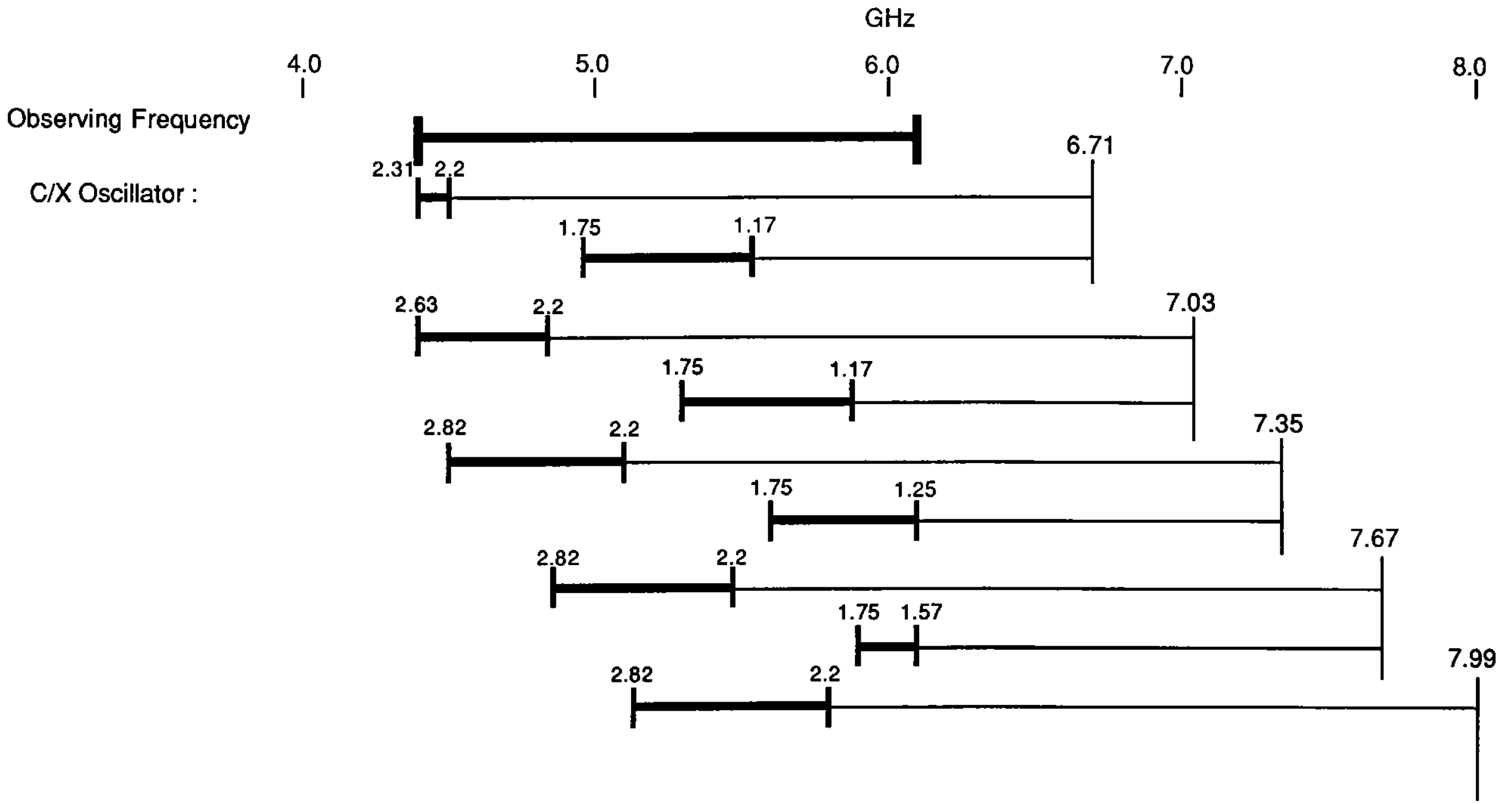
(see figure 6.)

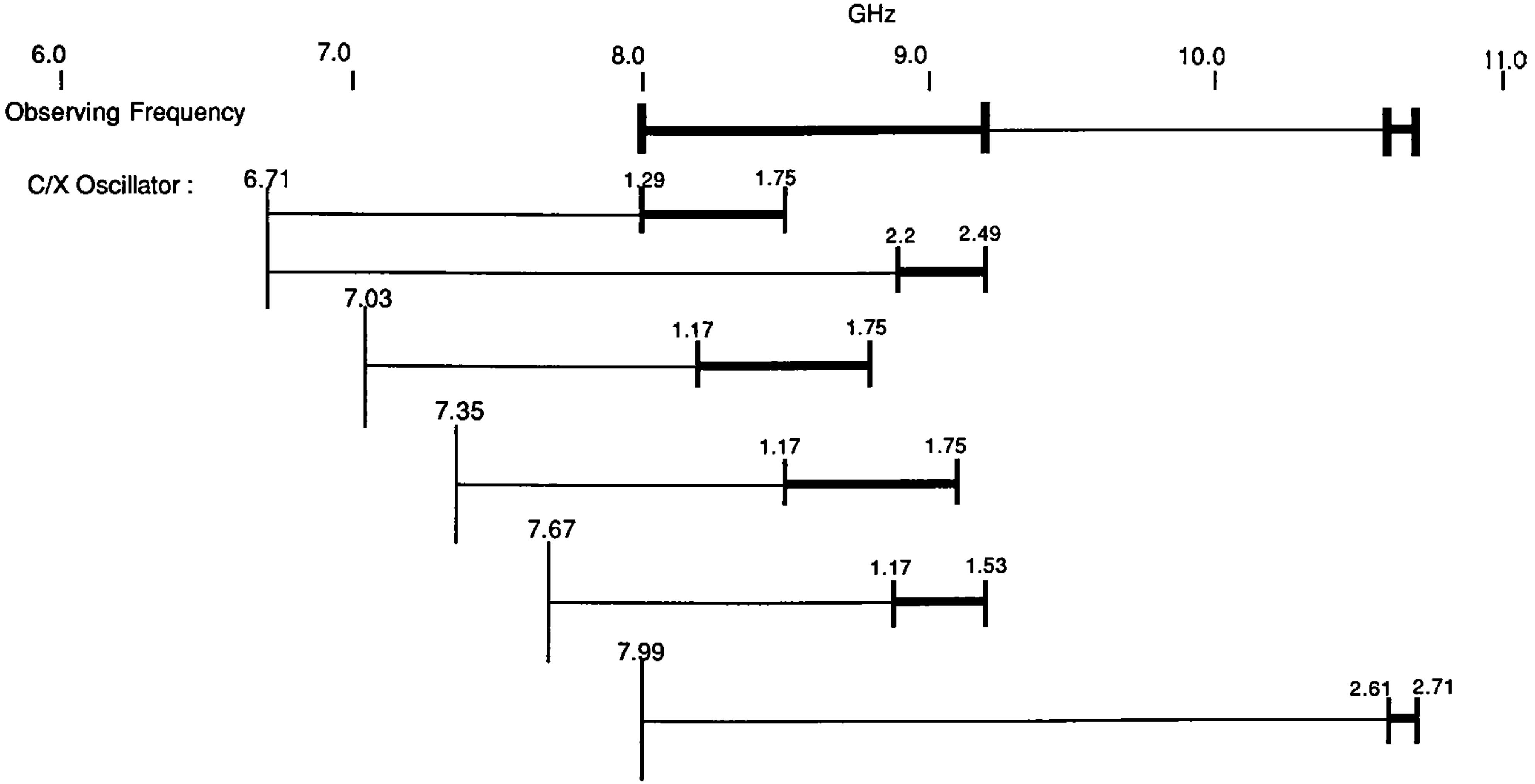
X band

Observing frequency range : 8.0 to 9.2 GHz.
Same oscillator range as for C band, leading to a similar table:
(shown in figure 3).

	8.0		8.9	9.2
6.71	1.29 .... 1.75		2.2 ...	2.49
7.03		1.17 .... 1.75		
7.35		1.17	1.75	
7.67			1.17	1.53

(see figure 7).


GHz
4.0
5.0
6.0
7.0
8.0
Observing Frequency
C/X Oscillator :
2.31
2.2
6.71
1.75
1.17
2.63
2.2
7.03
1.75
1.17
2.82
2.2
7.35
1.75
1.25
2.82
2.2
7.67
1.75
1.57
2.82
2.2
7.99



GHz
6.0
7.0
8.0
9.0
10.0
11.0
Observing Frequency
C/X Oscillator :
6.71
1.29
1.75
2.2
2.49
7.03
1.17
1.75
7.35
1.17
1.75
7.67
1.17
1.53
7.99
2.61
2.71

3 cm

K band

Observing frequency range : 20.0 to 25.5 GHz
K/Q oscillator : 16.0 to 20.0

Thus we should be able to find a combination to translate the observing frequency range down to a usable window.

C. Constraints

In general there will be several options for a given frequency: several different LO combinations which will correctly translate the observing band down to baseband. Some further selection criteria are required. One general consideration is to keep the LO outside of an observing band :

C.1 L band, 4-bit sampling.

(i). All 4 IFs are in the L band. This could happen with two independent windows observing the L band; it could also happen with the C/X combination, with both C and X having their first IF falling in the L band. Choose the UHF synthesizer frequencies furthest from the L band.

use U4/U	for the range	1.17 to 1.51 GHz.
use L4/L		1.5 to 1.78 GHz

(ii). Both L and S bands in use.

U4/U	for	1.17 to 1.32 GHz
L4/L		1.32 to 1.78 GHz

C.2 L band, 2-bit sampling

(i). Only L band in use.

U2/U	1.17 to 1.64 GHz
L2/L	1.64 to 1.78 GHz

(ii). Both S and L in use

U2/U	1.17 to 1.29
L2/L	1.29 to 1.78

C.3 S band, 4-bit.

(i) Only S band in use.

L4/L	2.2 to 2.4 GHz
U4/U	2.4 to 2.8 GHz

(ii) Both bands in use.

L4/L	2.2 to 2.67 GHz
U4/U	2.67 to 2.8 GHz

C.4 S band, 2-bit

(i) Only S band in use.

L2/L	2.2 to 2.35 GHz
U2/U	2.35 to 2.8 GHz

(ii) Both S and L in use

L2/L	2.2 to 2.7 GHz
U2/U	2.7 to 2.8 GHz

C.5 C band

(i) Only C band in use.

S-band filter, and highest C/X LO	4.4 to 5.4 GHz
L-band filter, and highest C/X LO	5.4 to 6.1 GHz

(ii) Both C and X in use

S-band filter, and lowest C/X LO	4.4 to 5.1 GHz
L-band filter, and lowest C/X LO	5.1 to 6.1 GHz

C.6 X band

(i) Only X-band in use

L-band filter, lowest C/X LO	8.0 to 8.98 GHz
S-band filter, lowest C/X LO	8.98 to 9.2 GHz

(ii) Both C and X in use

Always use L band filter; highest C/X LO.

C.7 10.6 to 10.7 X-band extension

use S-band filter, and 7.99 GHz.

D. **Implementation**

The operation proceeds in stages, one for each LO. For each LO we specify an input (data) frequency (middle of the observing band, for the first LO); from the database we can identify a suitable LO together with the parameters defining the frequency translation. We use this information to obtain an output frequency which we then use as input to the next LO.

D.1 Calculate the LO frequencies.

Having identified the LO (see D.2), find the actual frequency of the LO:

information from the database:

IS = sign of the LO .. -1 for lower sideband, +1 for upper
I_U = up- or down-conversion index; +1 for up; -1 for down.
f_{target} = target output frequency (this is the middle of the band acceptable to the next stage)
Δ is the LO step size.

The bandwidth requested by the observer provides a further parameter, a frequency offset. This is needed at bandwidths below 64 MHz in order to ensure that the band of interest is centred on the narrow band filters at the central site.

We form $f_{out} = f_{target} + \text{offset}$

we require :

$f_{out} = [\, f + I_U(f_1 + z\Delta) \,]\ IS$

m = INTEGER(z+0.5) (m integer).

for example :

request: f = 1.4 GHz; 64 MHz bandwidth,
database: $f_L = 1805$ $\Delta = 10$ IS = -1 $I_U = -1$ $f_{target} =$ 668 MHz.
Offset = 0 MHz

$668 = [\, 1400 - (1805+10z\,) \,]\,(-1)$

$= 405 + 10z$

z = 26.3
m = 26

....
Notes:

1. The algorithm outlined above is quantized, in 1 MHz steps for the UHF synthesizers If greater precision is required - for the narrow bandwidth observations, the 80 MHz

oscillator will need to be tuned - in 4 kHz steps. Collaboration with the fringe tracking oscillator (the UHF synthesizer) will be needed.

2. Doppler tracking

There are two problems here:

a). We need to adjust the phase of the fringe rotators to ensure that a source at the field centre is observed with zero phase on all baselines - -This can require a fringe rate of up to 150 Hz (on the 6 km. baseline, and 100 GHz observing frequency).

b). We need to ensure that a spectral feature remains in the same channel of the cross-spectrum during the course of a day's observing -- This can require a frequency offset of up to 150 KHz (common to all antennas).

The first requirement is easily satisfied with the proposed fringe rotator. The second cannot be met with this hardware. For narrow bandwidths (< 32 MHz) we can use a common 80 MHz (+/- 0.5 MHz), tunable in 4 KHz steps, in conjunction with the fringe rotator. That is, with m steps of 4 KHz, together with an offset ∂f applied to all the fringe rotators. Bandwidths of 32 MHz and greater will require the software solution outlined by RPN (AT/23.4/011)

3. Warning

The phase of an LO at one frequency setting canot be deduced from the phase at a different setting - each setting will require a separate calibration.

Further fine tuning:

On the algorithm described above there will likely remain an error: we asked for f_r but only achieved f_a, leaving an error : $\Delta = f_r - f_a$.

If the bandwidth is ≤ 32 MHz we can make some further corrections at the central site:

$$1^{st}\ LO = 80.10^6 + 4000m\ \text{Hz}$$

where $m = \text{INT}\ \{0.5 + (\Delta f + f_{doppler})/4000\}$

leaving a residual of $\delta f = (\Delta f + f_{doppler}) - 4000m, \qquad -2000 \leq \delta f \leq 2000$

A final refinement would be to offset the UHF fringe rotator by δf. This could be difficult, since there are 6 antennas, each with a different fringe rotator setting. However, the range of fringe rates is modest ($\leq$145 Hz. at 100 GHz), so this scheme should be possible.

D.2 How to choose an LO

The data base contains 5 tables to be used:

D1 : Bandwidth/offset/number sampling bits
D2 : The LO characteristics.
D3 : The observing band-frequency identification.
D4 : The LO constraints.
D5 : The LO

The operation sequence:

1). Given the requested bandwidth, consult table D1 to get the OFFSET and number of sampling bits (NBITS)

2). Given the frequencies of the two independent channels, consult table D3 to get the band identifications. For the first LO, the two frequencies will be the requested observing frequencies.

3). Consult table D4 to obtain a list of possible frequency ranges. (Ie. obtain a list of f_{low} and f_{high}). Determine from this list the suitable range, and thus determine the appropriate entry in table D5.

4). Consult table D5 to obtain the algorithm parameters for the LO chosen. Table D2 is also needed.

5). Compute the actual LO frequency, and thus define the output frequency.

6). If the output frequency is not suitable for a sampler, (ie. if not bands 1 to 7) return to 2).

Table D1: **Bandwidth - Offset relation**

Bandwidth (MHz)	OFFSET (MHz)	NBITS
256	0	1
128	0	2
64	0	4
32	16	4
16	8	4
8	4	4
4	6	4
2	3	4
1	2.5	4
0.5	2.25	4

Table D2: **Characteristics of each LO.**

LO name	Lowest freq. MHz	step size MHz	maximum number of steps
L4	511	1	9
L2	600	1	9
U4	760	1	9
U2	831	1	9
L/S	1775	10	45
C/X	6710	320	4

Table D3: **Frequency band identification**

frequency range (GHz) f_1	f_2	band number	
.383	.456	1 ..	
.575	.648	2 ..	
.632	.705	3 ..	4-bit sampling
.344	.481	4 ..	
.575	.712	5 ..	2-bit sampling
1-bit LO		6	
1-bit LO		7	
UHF ?		8	
1.17	1.75	9	
2.2	2.8	10	
4.4	6.1	11	
8.	10.7	12	
20.	25.5	13	
100.	110.	14	

Table D4: **LO option table**

band	same_band(*) ?	NBITS	version	f_{low} (GHz)	f_{high}	INDEX in LO table
1	N/R	4	0	.383	.456	1
2	N/R	4	0	.575	.648	2
3	N/R	4	0	.632	.705	3
4	N/R	2	0	.344	.481	4
5	N/R	2	0	.575	.712	5
9	yes	4	0	1.17	1.51	6
9	yes	4	0	1.51	1.78	7
9	no	4	0	1.17	1.32	6
9	no	4	0	1.32	1.78	7
9	yes	2	0	1.17	1.64	8
9	yes	2	0	1.64	1.78	9
9	no	2	0	1.17	1.29	8
9	no	2	0	1.29	1.78	9
10	yes	4	0	2.2	2.4	10
10	yes	4	0	2.4	2.8	11
10	no	4	0	2.2	2.67	10
10	no	4	0	2.67	2.8	11
10	yes	2	0	2.2	2.35	12
10	yes	2	0	2.35	2.8	13
10	no	2	0	2.2	2.7	12
10	no	2	0	2.7	2.8	13
11	yes	4	0	4.4	5.4	14
11	yes	4	0	5.4	6.1	15
11	no	4	0	4.4	5.1	14
11	no	4	0	5.1	6.1	15
11	yes	2	0	4.4	5.4	14
11	yes	2	0	5.4	6.1	15
11	no	2	0	4.4	5.1	14
11	no	2	0	5.1	6.1	15
12	yes	4	0	8.0	8.98	16
12	yes	4	0	8.98	9.2	17
12	no	4	0	8.0	9.2	16
12	yes	2	0	8.0	8.98	16
12	yes	2	0	8.98	9.2	17
12	no	2	0	8.0	9.2	16

(*) : same_band .. are the two independent frequencies in the same band ? [Y/N]
N/R : not relevant

Table D5: **The LO PARAMETERS**

Index	LO name	IS	IU	f_{target} (MHz)	filter
1	L4	-1	-1	96	L
2	L4	+1	-1	96	U
3	U4	-1	-1	96	U
4	L2	-1	-1	96	L
5	U2	-1	-1	96	U
6	L/S	-1	-1	668.5	N/R
7	L/S	-1	-1	419.5	N/R
8	L/S	-1	-1	643.5	N/R
9	L/S	-1	-1	412.5	N/R
10	L/S	+1	-1	419.5	N/R
11	L/S	+1	-1	668.5	N/R
12	L/S	+1	-1	412.5	N/R
13	L/S	+1	-1	643.5	N/R
14	C/X	-1	-1	2500	S_band
15	C/X	-1	-1	1475	L_band
16	C/X	+1	-1	1475	L_band
17	C/X	+1	-1	2500	S_band

D2.1 The LO algorithm in detail:

This version of the algorithm has been implemented by J.Argyros, allowing the OBS process to translate the observer's requested frequencies into a set of LO requests, with the specific parameters (Tables D1 to D5) residing in the database. The final step, converting the LO frequencies to control bytes that will be sent by the ACC to the hardware via a dataset is described in section D2.2

Input : two observing frequencies, f_{obs} (1) and f_{obs} (2), as well as the associated bandwidths, B(1) and B(2).

Initialize: 1). get OFF(i) , and NBITS(i) (based on B(i)).

(These are offset and number of sampling bits respectively).

2). set up : IS(i) = +1 ...... LO inversion index
$f(i) = f_{obs}(i) - OFF(i)$

LOOP over LOs (ie. step down in frequency, from observing frequency down to the passband acceptable to the samplers):

identify the bands : f(i) --> band(i)

set the logical same_band : true if band(1) = band(2)

LOOP over (i) :

use band(i), same_band and NBITS(i) to find the set of possible frequency ranges :

$\{f_{low}\}$, $\{f_{high}\}$ and the associated index {index}

take the first acceptable range : require $f_{low} < f(i) < f_{high}$

use the index to provide : LOname
f_0 (lowest frequency to which this LO can tune)
LOstep (frequency increment for this LO)
IS (which sideband to use)
IU (UP/DOWN conversion index)
f_{target} (approximate output frequency)
Switch (may need to set a filter switch)

solve for z : $f_{target} = (f(i) + IU*(f_0 + z*LOstep))*IS$

$m = INT(z+0.5)$

$f_{LO}(i) = f_0 + m*LOstep$

update: $f(i) = (f(i) + IU*f_{LO}(i))*IS$

$IS(i) = IS(i)*IS$

control : convert $f_{LO}(i)$ to a dataset 2-byte sequence, and set the LO

Set the filter switch, if necessary

end loop (i)

Finished ? Have we reached one of the UHF synthesizers.?
This is equivalent to the question : band(i) < 8 ?

If so, STOP processing this IF (i). (With Offset-X we can have LO chains of different length - - in all other cases the chains are of equal length).

End loop (LO)

D2.2 FORTRAN code to compute the LO control bytes.

```
        subroutine cx (frequency, control, error)

c  This subroutine produces the control bytes for the C/X local
c  oscillator.
c  It takes frequency (in Hz) as input, and generates the two-byte
c  control word for the control.

c  Based on A.Young's algorithm of 24 October 1986

c  frequency must lie in range 6.71e+9 to 7.67e+9, in steps
c  of 320 MHz.

c  mjk, 24 November 1986

        implicit none

        integer*2 control, l_and /'FFF'x/, l_or/'4000'x/
        real      frequency, freq
        integer*4 error, check

c-----------------------------------------------

c.. convert to MHz. and check

        freq = frequency * 1.e-6
        check = int(freq)
        if ((check.lt.6710) .or. (check.gt.7670)) then

c  sound alarm ?
          error = -1
          goto 1000

        elseif (mod((check-6710),320).ne.0) then

c  yet another cause for alarm
          error = -1

        else
          control = int(freq*0.4096)
          control = iand (l_and, control)
          control = ior  (l_or,  control)
          error = 0

        end if

        end
*******************************************************************
```

```
      subroutine LS (frequency, control, error)

c  This subroutine produces the control bytes for the L/S local
c  oscillator.
c  It takes frequency (in Hz) as input, and generates the two-byte
c  control word for the control.

c  Based on A.Young's algorithm of 24 October 1986

c  frequency must lie in range 1775 to 2215 MHz in steps of 10 MHz

c  mjk, 24 November 1986

      implicit none

      integer*2 control, l_and /'FFF'x/, l_up/'D000'x/,
     :             l_down /'5000'x/
      integer   check, error
      real      frequency, freq

c-------------------------------------------------------

c.. convert frequency to MHz, and check validity

      freq = frequency * 1.e-6
      check = int(freq)

      if ((check.lt.1775) .or. (check.gt.2215)) then
        error = -1

      elseif ((mod(check,20).ne.5)
     :    .and. (mod(check,20).ne.15)) then
        error = -1

     -else
        control = int(freq * 1.6384)
        control = iand (control, l_and)

        if (mod(check,20).eq.5) then
          control = ior (control, l_up)
        else
          control = ior (control, l_down)
        end if

        error = 0

      end if

      end
************************************************************************
```

```
      subroutine uhf (frequency, band, control, error)

c  This subroutine produces the control bytes for the UHF local
c  oscillator. (The phase, rate and second derivative are set
c  separately in FRINGE)
c  It takes frequency (in Hz) as input, and generates the one-byte
c  control word for the control.

c  Based on A.Young's algorithm of 24 October 1986

c  Four bands are used : L4 (511 to 520 MHz) . . band = 0
c                        L2 (600 to 609 MHz) . . band = 2
c                        U4 (760 to 769 MHz) . . band = 3
c                        U2 (831 to 840 MHz) . . band = 1
c  all in 1 MHz steps.

c  mjk, 24 November 1986

      implicit none

      integer*2 control, blank/'F'x/
      real      frequency, freq
      integer*4 error, check, band

c-------------------------------------------------------------

      freq = frequency * 1.e-6
      check = int(freq)

      if (band.eq.0) then
       if ((check.lt.511) .or. (check.gt.520)) then
        error = -1
       else
        check = 518 - check
        check = iand (check, blank)
        control = check*16 + band*4
        error = 0
       end if

      elseif (band.eq.1) then
       if ((check.lt.831) .or. (check.gt.840)) then
        error = -1
       else
        check = 838 - check
        check = iand (check, blank)
        control = check*16 + band*4
        error = 0
       end if

      elseif (band.eq.2) then
       if ((check.lt.600) .or. (check.gt.609)) then
        error = -1
       else
```

```
    check = check - 602
    check = iand (check, blank)
    control = check*16 + band*4
    error = 0
  end if

elseif (band.eq.3) then
  if ((check.lt.760) .or. (check.gt.769)) then
    error = -1
  else
    check = check - 838
    check = iand (check, blank)
    control = check*16 + band*4
    error = 0
  end if

else
  error = -1

end if

end
```

A.C.Young

24 October 1986

ANTENNA L.O. SYSTEM SPECIFICATIONS (Draft)

"7 GHz" (C/X) SYNTHESISER

This subsystem contains two independent oscillators each split into two outputs.

POWER OUTPUT (Each output)

10 milliwatts (+10 dBM) ± 2 dB

FREQUENCY RANGE

6710 to 7690 MHz
(operates over 6 to 9 GHz but some specs. may not be tested.)

OUTPUT FREQUENCY

Can only take - discrete values given by

N * 320 ± 10 MHz (where N is integer).

This is essentially 320 MHz steps.

PHASE NOISE

Better than 2 degrees rms.

PHASE STABILITY

Better than 3 degrees rms over 30 minutes
(with respect to central site "clock")'

HARMONICS

Below -40 dB below carrier

SPURIOUS OUTPUTS

Below -70 dB below carrier

CONTROL INPUT

The frequency of the C/X L.O. is set by a 16 bit digital word. The numbers which have to be sent to the appropriate data set and thence to the YIG DSI are shown below. The first 12 bits set the free running frequency of the YIG oscillator where 4096 corresponds to 10.0 GHz.

The last four bits are used to control the other functions of the lock loops. The first bit controls the sign of the gain of the loop amplifier, a 1 corresponds to an upper sideband lock and a 0 to a lower sideband lock. The second bit is used to disable the phase lock loop, a 1 allows the loop to acquire lock and a 0 disables the loop giving the free running YIG oscillator frequency. The last two bits are not used.

Replacing the last digit in the HEX command (C OR 4) by a 0 disables the phase lock loop but still sets the required free running frequency of the YIG oscillator.

"2 GHz" (L/S) SYNTHESISER

This subsystem contains two independent oscillators each split into outputs.

POWER OUTPUT (EACH OUTPUT)

10 milliwatts (+ 10 dBM) $\pm$ 1 dB

FREQUENCY RANGE

1815 to 2215 MHz
(operates over 1500 to 2220 MHz but some specs may not be tested.)

OUTPUT FREQUENCY

Can only take discrete values given by

$$N * 20 \pm 5 \text{ MHz (where N is integer.)}$$

That is 10 MHz steps.

PHASE NOISE

Better than 2 degrees rms.

PHASE STABILITY

Better than 1 degree rms over 30 minutes (with respect to central site "clock")

HARMONICS

Below -40 dB below carrier.

SPURIOUS OUTPUTS

Below -70 dB below carrier

CONTROL INPUTS

The frequency of the L/S L.O. is set by a 16 bit digital word. The numbers which have to be sent to the appropriate data set and thence to the YIG DSI are shown below. The first 12 bits set the free running frequency of the YIG oscillator where 4096 corresponds to 2.5 GHz.

The last four bits are used to control the other functions of the lock loops. The first bit controls the sign of the gain of the loop amplifier, a 1 corresponds to an upper sideband lock and a 0 to a lower sideband lock. The second bit is used to disable the phase lock loop, a 1 allows the loop to acquire lock and a 0 disables the loop giving the free running YIG oscillator frequency. The third bit is unassigned. The last bit is used to disable the step recovery diode stabilisation loop , a 1 allows the stabilisation to take place and a 0 disables the bias control by discharging the integrator.

Replacing the last digit in the HEX command (D or 5) by a 0 disables the phase lock loop and step recovery diode stabiliser but still sets the required free running frequency of the YIG oscillator.

UHF SYNTHESISER

This subsystem contains four independent oscillators. Each output can be independently set in frequency, phase, rate, etc.

POWER OUTPUT

10 milliwatts (+ 10 dBM)±1.5 dBM.

FREQUENCY RANGE

Four separate bands are provided with 1 MHz steps within each band.

Band L4 = 511 to 520 MHz
Band L2 = 600 to 609 MHz
Band U4 = 760 to 769 MHz
Band U2 = 831 to 840 MHz

PHASE NOISE

Better than 2 degrees rms

PHASE STABILITY

Better than 1 degree rms over 30 minutes

HARMONICS

Below -30 dB below carrier

SPURIOUS OUTPUTS

Below -70 dB below carrier

PHASE

Can be set over the range 0 to 360 degrees in 0.18 degree steps. This phase is the phase at the start of the next 5 second cycle.

RATE

Can be set over the range -2 KHz ($4\pi*10^3$ rads/sec) to +2 KHz in steps <0.2 millihertz (0.07 deg/sec)

SECOND DERIVATIVE (phase curvature)

Can be set over the range +3 Hz per sec. to -3 Hz per sec in steps of approximately 10^{-5} Hz per sec.

CONTROL INPUTS

An 8 bit number is required to set the rest frequency.

Two bits set the required band as follows.

00 for L4	10 for L2
11 for U4	01 for U2

The four most significant bits set the 1 MHz steps.

L4 (--00)	L2 (--10)	U4 (--11)	U2 (--01)	
520	600	760	840	1110--
519	601	761	819	1111--
518	602	762	838	0000--
517	603	763	837	0001--
516	604	764	836	0010--
515	605	765	835	0011--
514	606	766	834	0100--
513	607	767	833	0101--
512	608	768	832	0110--
511	609	769	831	0111--

These six bits are followed by a bit that disables the phase lock loop to test the free running frequency: 1 allows the loop to lock for normal operation and 0 disables lock. The final bit is unused.

For example 766 MHz requires 01001110

PHASE Requires an 11 bit number where the MSB is 0 for < 180deg and1 for ≥ 180deg and the following 10 bits specify the phase value.

N = Phase (degrees) /0.18 = Phase (rads) *1000/2π
where $0 \leq N < 2^{10}$ (excluding the MSB (sign))
e.g. for 236° Set MSB to 1 (since ≥180°)
followed by N = 56/0.18 = 311 and the required binary number is 10100110111.

RATE requires a 25 bit signed number M (24 bits + sign)

$$M = 2^{26} * f/(10^4 + f) \text{ and } f = 10^4 * M/(2^{26} - M)$$

where $2^{-24} < M < 2^{24}$ and f is the signed rate in Hz.

e.g. for +100 Hz fringe rate $M = 2^{26}/101$ and the required binary number is 0000101----

SECOND DERIVATIVE requires a signed 19 bit number K (18 bits plus sign)

$$K = C * 2^{43}/(10^4(10^4 + f))$$

where C is the required 2nd deriv. (Hz per sec)
f is the signed rate (Hz)

e.g. for 0.01 Hz per sec. (at 100 Hz rate)

K = 870.9003 (=0000000000000001101100111).

Note on signs of Rate and Second Derivative

A positive value for K always gives an increase in the absolute value of rate f. It MUST therefore change sign at TRANSIT. This can give problems where either rate or second derivative is zero (e.g. at transit) unless C is set to zero for that cycle.

A positive value for phase will advance the phase of the UHF local oscillator in Bands L2 and U4. Similarly, a positive value of rate f will increase the UHF LO frequency in these bands.

However the reverse is true in bands L4 and U2 due to a change in the conversion sign within this LO synthesiser.

Appendix 3.

FIFO operation and requirements

Prior to each integration period the observing task (OBS) will compute, for each data stream, the arrival time of the first valid data point.

The FIFO will place this first data point at the head of the queue, with the subsequent samples behind it.

The correlator will wait until all the FIFOs have received their first data point before extracting data from the FIFO.

This is accomplished with a mix of hardware and software:

1. We will maintain a highly accurate clock at each antenna (called the "LO synchronising cycle"). All antennas will start an integration at the same instant (ie., at the same CAT); this instant is defined by the LO sync. cycle.

The sampler is switched on at the start of each integration period. At the head of the data stream, signalling the start, is a special sequence, the "synchronising pulse". This sync. pulse is the time reference point for the delay calculations.

2. The observing task will compute, for each antenna, the time interval between the sync. pulse and the arrival of the first wavefront common to all antennas. The delay (expressed as a number of bits) is sent to the FIFO.

3. Just prior to the start of an integration each FIFO is "armed" - it is set scanning the data stream looking for the sync. pulse.

4. On receipt of the sync. pulse the FIFO counts the samples, discarding the data until the delay count is reached. The data is then entered into the FIFO.

5. The correlator will wait until all the FIFOs have reached their delay count and have started storing data before it starts extracting data. (It should wait an additional 10 samples or so to ensure that no problems occur in the last FIFO to reach its delay count - under unfavourable conditions it could run out of data towards the end of the integration period if the correlator started promptly).

6. The transmission time from the antenna to the correlator is of importance only in that it dictates the length of the FIFO - data must not overflow while we wait for data from the most distant antenna.

7. A clock error (at the antenna) affects the delay count, reducing it if the clock is late.

Figure 1 shows in schematic form the relationship of the various time intervals.

<u>In summary</u>

The observing task will send to the correlator 3 items : the START time of an integration, the STOP time and the delay, expressed as the number of bits to skip. All delays will be positive - we can add a common offset to all delays to ensure this.

Appendix 4

The functioning of a sampler.

revision
1.1 the sign of the LO frequency was incorrectly stated.

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1. Basics

Consider the signal : $g(t) = \cos(2\pi f t)$, sampled at a frequency f_s. From Nyquist's theorem we know that the frequencies f should all lie within a bandwidth $(f_s/2)$. The n^{th} sample occurs at time $t_n = (n / f_s)$. The sample phases are thus :

$$\phi_n = 2\pi f \frac{n}{f_s}$$

A number of frequency bands are indistinguishable by this sampling :

a). 0 to $f_s/2$; f_s to $3 f_s/2$; .. ie, (pf_s to $pf_s + f_s/2$), p integer.

these correspond to $f = f_a + pf_s$, where $0 < f_a < f_s/2$

b). {($pf_s + f_s/2$) to $(p + 1) f_s$ } corresponding to $f = (p+1)f_s - f_a$

In case a). the frequencies are simply translated in frequency, in multiples of f_s; in case b). there is a frequency translation, and an inversion. The bulk of the AT sampler operations correspond to case b).

2. Delay tracking and correlating.

At the input to the sampler the signal has the form :

$$g(t) = a(f) \cos \{[2\pi (f + f_L) (t - \tau) + \phi_f] I_n\}$$

$(f + f_L)$ is an IF frequency, I_n is an index (+ or -1) related to the sideband chosen.

This continuous signal is quantized, delayed and correlated with a similar stream from another antenna. We follow the sequence of operations, particularly with reference to the mixing properties of the sampler.

The sampling pulses are derived from an oscillator :

$$S(t) = \sin [2\pi \frac{f_s}{2} (t - \tau)]$$

The sampling instants are defined by the zero-crossings of S(t) :

$$\pi f_s(t - \tau)_\sigma = \sigma\pi$$

ie.

$$(t - \tau)_\sigma = \frac{\sigma}{f_s}$$

The trick is to ensure that the σ^{th} sample from antenna A and the σ^{th} sample from antenna B both correspond to the same wavefront.

Sampling starts at the same instant (CAT) at all antennas. If we define the sample at $t = \tau_0$ to be the zeroth sample ($\sigma = 0$), then the first sample to leave the antenna will be numbered

$$N_s = INT[-\tau_0 f_s]$$

This the number of samples to be discarded after receiving the synchronising pulse.

(There is a minor inconsistency here (but one of no consequence for the AT) : in both the LO and sampler computations we apply corrections at time t for a wavefront which is presently time τ away. Since τ itself is a function of time there is a small error (about one part in 10^9 as a worst case for the CA). Thus N_s should more properly be $\tau_0 f_s (1 - \tau_1)$. This is the same (in samples), as $\tau_0 f_s$. The LBA may require some special treatment - perhaps correcting in software, a la PTI).

A clock error will affect the sampling :

$$(t + CE - \tau)_\sigma = \frac{\sigma}{f_s}$$

$$(t - \tau)_\sigma = \frac{\sigma}{f_s} - CE$$

So that the sampled data presented to the correlator is then :

$$\cos \{[2\pi(f + f_L)[\frac{\sigma}{f_s} - CE] + \phi_f] I_n\}$$

In most cases the signal presented to the sampler ($f - f_L$) is at a frequency above ($f_s/2$) - see appendix 1; we will find that the sampler/correlator will translate the signal down to baseband - with a spectrum inversion. However, the phase contribution resulting from a clock error (CE) will be based on the original frequency.

The cross-correlation is given by :

$$C(m) = \frac{1}{N} \sum \cos(\text{stream A}) \; \cos(\text{stream B, offset by m samples})$$

$$= \cos\{[\, 2\pi\, (f+f_L)(\frac{m}{f_s} - CE) + \phi_f]\, I_n\}$$

We fourier transform to obtain the cross-spectrum:

$$F(s) = \frac{1}{M} \sum_{m=-\frac{M}{2}}^{\frac{M}{2}-1} \exp\,(-j2\pi \frac{m}{f_s} s)\; C(m)$$

$$F(s) = \frac{1}{M} \frac{\sin\,\{2\pi M \frac{(f+f_L)I_n - s}{f_s}\}\; \exp\,\{-j[2\pi(f+f_L)CE+\phi_f]\, I_n\}}{\exp\,\{j2\pi \frac{(f+f_L)I_n - s}{f_s}\} - 1}$$

$$+ \frac{1}{M} \frac{\sin\,\{2\pi M \frac{(f+f_L)\, I_n + s}{f_s}\}\; \exp\,\{j[2\pi(f+f_L)\, CE+\phi_f]\, I_n\}}{1 - \exp\,\{-j2\pi \frac{(f+f_L)\, I_n - s}{f_s}\}}$$

(The first term applies to the even bands, the second to the inverted bands).

In general - with M large - F(s) will be small, except where the denominator tends to zero. This happens (for the even bands) if :

$$\frac{(f+f_L)\, I_n - s}{f_s} = p, \quad p \text{ integer.}$$

In the vicinity of such a frequency (s) we have:

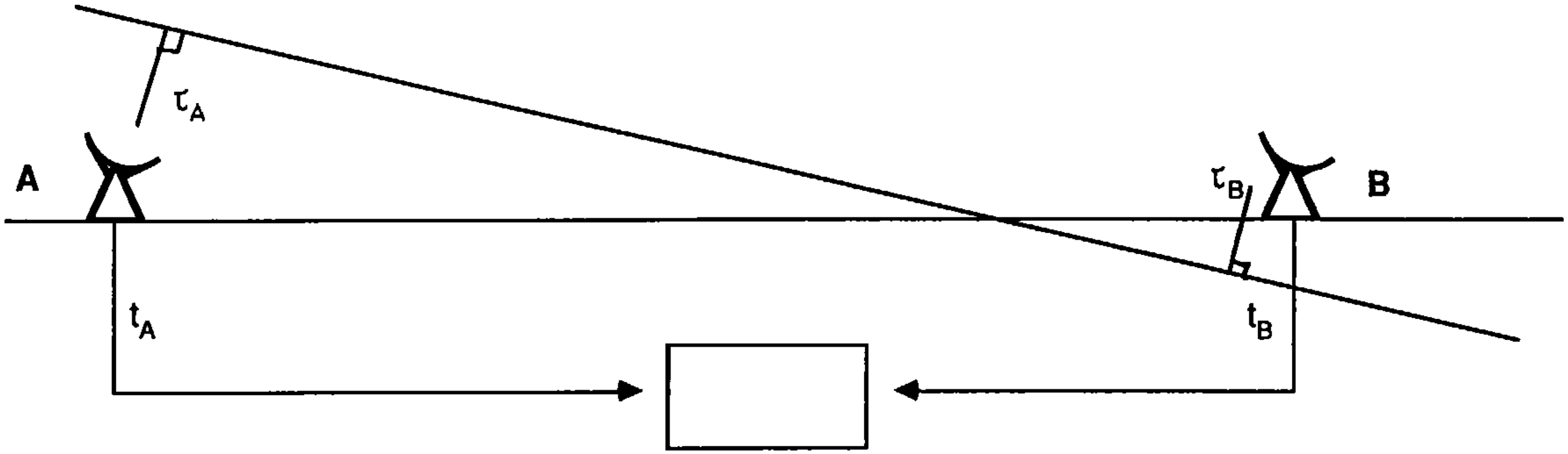
$$F(s) = \text{sinc}\,\{2\pi M \frac{(f+f_L)I_n - s}{f_s}\}\; \exp\,\{\, -j[2\pi(f+f_L)CE+\phi_f]I_n\}$$

Thus F(s) will show a peak at $s = (f + f_L)\, I_n - p\, f_s$, in the baseband. This is the spectral response to our initial signal f. The clock error, however, behaves as if applied at a frequency $(f + f_L)\, I_n$, which is above baseband.

The other solution, applicable to the inverted bands, occurs when:

$$\frac{(f+f_L)\, I_n + s}{f_s} = p, \quad p \text{ integer}$$

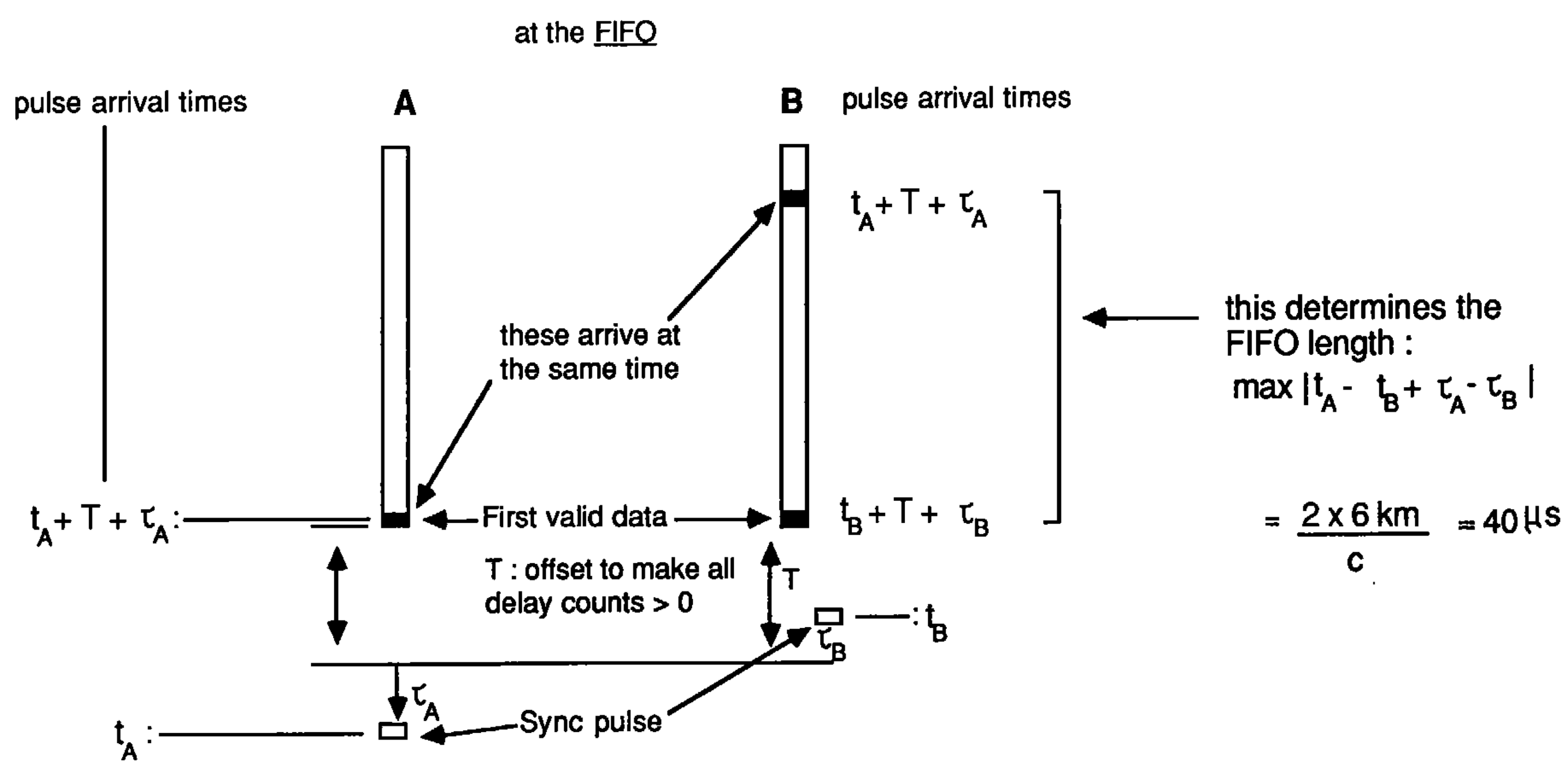
..



Geometric delay : τ_A (>0), τ_B (<0) } on this diagram

Transmission time (antenna to correlator) : t_A, t_B

Assume the sync. pulse emitted at t=0



Appendix 5

Hardware Initialization

1. Is the turret in position for this frequency ?

2. Switch on the LNA (?)

3. Transfer switch at the antenna (X -> X; Y -> Y or
X -> Y; Y -> X)

4. first receiver select : Q, K, X (off-axis), X, C

5. second receiver select : F, W, 1st. rec. select (2.2-2.8 GHz),
1st. rec. (1.17-1.75 GHz), S, L, UHF

6. IF filter : 348-484 MHz or 565-716 .. 2 or 4 bit sampling

256-512 MHz or 512-768 .. 1 bit sampling

7. Samplers : 1, 2 or 4 bit.

8. Solar attenuator . . separate controls for each band?

9. Very coarse level control : 0, 6, 12, 20 dB.

10. Narrow band select switch (32/16/8/4/2/1/0.5 MHz BW)

Revised tables D2 to D4
of AT/23.4.1/012

Table D2: **Characteristics of each LO.**

LO name	Lowest freq. MHz	step size MHz	maximum number of steps
L4	511	1	9
L2	600	1	9
U4	760	1	9
U2	831	1	9
LS	1775	10	45
CX	6710	320	4

Table D3: **Frequency band identification**

frequency range (GHz) f_1	f_2	band number	
.383	.456	1 ..	
.575	.648	2 ..	
.632	.705	3 ..	4-bit sampling
.344	.481	4 ..	
.575	.712	5 ..	2-bit sampling
1-bit LO		6	
1-bit LO		7	
UHF ?		8	
1.17	1.75	9	
2.2	2.8	10	
4.4	6.1	11	
8.	10.7	12	
20.	25.5	13	
100.	110.	14	

Table D4: **LO option table**

band	same_band(*) (yes/no)	NBITS	version	f_{low} (GHz)	f_{high}	INDEX in LO table
1	N/R	4	0	.383	.456	1
2	N/R	4	0	.575	.648	2
3	N/R	4	0	.632	.705	3
4	N/R	2	0	.344	.481	4
5	N/R	2	0	.575	.712	5
9	yes	4	0	1.17	1.51	6
9	yes	4	0	1.446	1.78	7
9	no	4	0	1.17	1.385	6
9	no	4	0	1.32	1.78	7
9	yes	2	0	1.17	1.64	8
9	yes	2	0	1.511	1.78	9
9	no	2	0	1.17	1.419	8
9	no	2	0	1.29	1.78	9
10	yes	4	0	2.2	2.475	10
10	yes	4	0	2.410	2.8	11
10	no	4	0	2.2	2.67	10
10	no	4	0	2.605	2.8	11
10	yes	2	0	2.2	2.479	12
10	yes	2	0	2.35	2.8	13
10	no	2	0	2.2	2.690	12
10	no	2	0	2.561	2.8	13
11	yes	4	0	4.4	5.465	14
11	yes	4	0	5.4	6.1	15
11	no	4	0	4.4	5.1	14
11	no	4	0	5.035	6.1	15
11	yes	2	0	4.4	5.529	14
11	yes	2	0	5.4	6.1	15
11	no	2	0	4.4	5.1	14
11	no	2	0	4.971	6.1	15
12	yes	4	0	8.0	8.98	16
12	yes	4	0	8.815	9.2	17
12	no	4	0	8.0	9.2	16
12	yes	2	0	8.0	8.98	16
12	yes	2	0	8.851	9.2	17
12	no	2	0	8.0	9.2	16

(*) : same_band .. are the two independent frequencies in the same band ? [Y/N]
N/R : not relevant

Table D5: **The LO PARAMETERS**

Index	LO name	IS	IU	f_{target} (MHz)	filter
1	L4	-1	-1	96	L
2	L4	+1	-1	96	U
3	U4	-1	-1	96	U
4	L2	-1	-1	192	L
5	U2	-1	-1	192	U
6	LS	-1	-1	668.5	N/R
7	LS	-1	-1	419.5	N/R
8	LS	-1	-1	643.5	N/R
9	LS	-1	-1	412.5	N/R
10	LS	+1	-1	419.5	N/R
11	LS	+1	-1	668.5	N/R
12	LS	+1	-1	412.5	N/R
13	LS	+1	-1	643.5	N/R
14	CX	-1	-1	2500	S_band
15	CX	-1	-1	1475	L_band
16	CX	+1	-1	1475	L_band
17	CX	+1	-1	2500	S_band