IF CONVERSION and NARROW-BAND ANALOG FILTERING

1.0 INTRODUCTION

This report describes one possible solution to the problem of reductions in the I.F. bandwidth for the Australian Telescope.

Sections of this report were discussed at the A.T. Symposium "Digital Vs. Analogue Filters and the Implications on the L.O. Design", held on 24th May, 1984.

As several different approaches were raised at this symposium, the final system will, almost certainly, be different to that proposed here. This report was prepared to outline a system that uses only analog filtering, and to estimate its complexity, stability and approximate cost.

As stated in the AT Systems Definition (Ref 1), one of the choices for the IF data stream is a time multiplexed signal consisting of:

1. 40 MHz bandwidth (continuum), 2 bit sampled
2. 10 MHz bandwidth (tied array and narrowband line), 4 bit sampled
3. 20 MHz bandwidth (wideband line), 2 bit sampled.

By providing both a broadband (40 MHz) and narrowband simultaneously, phase corrections derived by the continuum may be applied to the spectral line channels.

For narrowband spectral line observations, the band needs to be narrowed down, in factors of 2, to 0.625 MHz (Ref 1). The options available for the IF data stream are then:-

1. 160 MHz, 1 bit sampled
2. 80 MHz, 2 bit sampled
3. a time multiplexed signal consisting of:
   (a) 40 MHz (continuum), 2 bit sampled
   (b) 10 MHz (tied array and narrow band line), 4 bit sampled

(c) One of the following:-
- 20 MHz (wideband line), 2 bit sampled
- 10 MHz (narrowband line), 4 bit sampled
- 5 MHz (narrowband line), 4 bit sampled
- 2.5 MHz (narrowband line), 4 bit sampled
- 1.25 MHz (narrowband line), 4 bit sampled
- 0.625 MHz (narrowband line), 4 bit sampled

At present, it has not been decided by which means this reduction in bandwidth is to be accomplished. One of the original proposals was to use digital filters at the inputs of the correlator (Ref 2). J.O'Sullivan described some aspects of digital filters in the report "Digital Filtering for the AT" (Ref 3) and looked very briefly at the requirements for a filter to reduce the bandwidth of the 160 MHz bandwidth signals, in factors of 2, to 0.625 MHz. The digital filtering section of Correlator System Workshop Report (Ref 2) considers digital filtering of a 10 MHz bandwidth signal.

There are different options for filtering of the 160 MHz bandwidth signal.

1. Digital filtering of 160 MHz bandwidth
2. Analog filtering down to 10 MHz as given in the report by T.Percival, "New Proposal For IF Converter For AT" (Ref 4) followed by digital filtering
3. All analog filtering, down to the minimum bandwidth of 0.625 MHz

This report contains a proposal for a receiver system having only <u>analog</u> filters.

Before describing the system, it would be good to have a brief look at some of the properties of analog and digital filters, particularly when used in a correlation telescope.

2.0 ANALOG AND DIGITAL FILTERS

Some of these points are discussed in Ref 2 and Ref 3.

2.1 Digital Filters

1. Extremely good (or perfect) amplitude and phase stability over the band
2. May be very large if bandwidths are large and high "decimation" factors are used
3. Power supply requirements may be high and reliability may decrease if the filter system becomes too complex
4. Digital filters need to be <u>bandpass</u> and not lowpass. This requirement is discussed in Ref 5
5. Fairly large ripple (1 dB) in order to have a reasonable length shift register in the digital filter (Ref 2)
6. May be awkward to measure the system temperature over the narrow bandwidths, if digital filters are used. An estimate of the system temperature may be made for the 10 MHz bandwidth. However, if a strong spectral line occupies, say, the 0.625 MHz bandwidth, its system temperature may be considerably higher. Provision may be needed to measure system temperatures after the digital filtering.
7. The digital filtering may be at the antennae or at a central location. If it is located at the antennae, RF shielding must be extremely good to stop any interference from the digital waveforms. (Put the filters in the Pedestal Room!)

2.2 Analog Filters

1. The phase stability of the filters may not be good, particularly for a narrowband bandpass filter of high order. The phase may change with a change in temperature, and this phase change may not be uniform across the band. The phase stability of the receiver system is of primary importance to a correlation telescope. This is the main reason for considering the use of digital filtering. Stability problems will be considered later.
2. Using analog filters makes the IF Conversion System more complex. However, as the filters are passive devices, the reliability of the IF system should still be very good. Commercially available filters, which may prove to be suitable, should be small enough to fit in an IF Converter

Module.

3. If all the narrowband filters are placed in a central location, two problems may be present:-
   (a) The digital IF signal needs to be converted back to frequencies are fairly high, the D to A converter outputs may contain glitches. The filtering may adequately remove these.
   (b) The System Temperature Calibration system becomes a little more complex in that it is spread over two locations. However, this is a fairly trivial matter.

3.0 SYSTEM DESIGN CONSIDERATIONS

As much of the system to be described is similar to that proposed by T. Percival (Ref 4), many of the constraints are the same.

Briefly, the design considerations are:-

1. The 40 MHz (continuum), 10 MHz (tied array and narrowband line), and spectral line ($\leq$20 MHz) bandwidths do not need to be coincident. This simplifies the Local Oscillator system and reduces the possibility of self-generated interference.

2. It is most important that interference caused by Local Oscillator and Sampling signals be kept to an absolute minimum.

3. The images of the bands need to be attenuated by at least 40 dB for the maps to have a high dynamic range. This aspect is discussed more fully in References 5 and 6.

4. <u>Bandpass</u> filters (not lowpass) are to be used. (Refer to Ref 5.)

5. If possible, the LO signals are to be sub-multiples of 640 MHz as it simplifies the LO section and reduces the possibility of self generated interference. However, this design does contain a 15 MHz LO. By using this particular signal, it is easier to obtain filters that have the required phase stability.

6. For good phase stability, narrowband bandpass filters of high order are to be avoided. Therefore the 0.625 MHz bandwidth filter needs to have a fairly low centre frequency. It would be difficult to achieve the required 40 dB rejection of an image band with an image rejection mixer. Therefore, conversion to base-band is difficult.

A centre frequency of a few MHz would be optimal.

7. The IF Converter System designed by T. Pervival contains an image-reject mixer. The system to be described is slightly different and does not contain one of these mixers. (They are available commercially and are easily made at these low frequencies and bandwidths. The system is simpler if one is not needed.) Other than the filters that define the final IF bandwidths, the system contains only low order and fairly wide filters.

8. The samplers require a fixed signal level. Continuously-variable attenuators change their phase with attenuation. To restrict the dynamic range of these attenuators, switchable fixed attenuators are also used.

9. To reduce the interference problems, it may be possible to "switch off" the 80 MHz, 40 MHz, and 20 MHz sampling signals when the 160 MHz or 80 MHz bandwidths are being observed.

10. A switch, instead of a power divider, is used at the input section of the module to provide higher isolation between the sections.

11. If analog filters are used to reduce the bandwidth for the narrowband spectral line observations, another conversion stage must be added to the IF Converter module. The existence of another local oscillator signal increases the possibility of internally generated interference. Care must be taken that the extra LO does not cause problems.

12. For the narrower bandwidths, it would be possible to use lower frequency sampling signals. At present (Ref 4), the lowest sampling frequency is 20 MHz. As these sampling signals have a high harmonic content, it would not be desirable to have any more of them, particularly a lower frequency one. It would be much better to over-sample the signal with the 20 MHz sampling frequency and latch only the data required. The narrow bandwidths (0.625 to 5 MHz) must be in the correct part of the spectrum for this to work.

4.0 <u>SYSTEM DESCRIPTION</u>

Diagram 4.0.1 "Signal Flow Diagram" gives an outline of the signals within the I.F. Converter. For clarity, all amplifiers, attenuators, power splitters and most of the switches have been deleted, leaving essentially only the filters and mixers. The full block diagram is given in Diagram 7.0.1.

The input to the IF Converter Module contains broadband noise (continuum, with perhaps spectral lines) in the range 160 MHz to 320 MHz. After amplification, the signal is switched to one of three sections. The 160 MHz and 80 MHz bandwidth signals do not require any further mixing. After variable attenuators, amplifiers, filters and level detectors, the signals are sampled.

For bandwidths of 40 MHz and less, the signal is split into two parts. The output of mixer "A" is filtered to give the 40 MHz and 20 MHz bandwidths. The filter "E" before this mixer attenuates the image by 40 dB. Section 5 gives image bands and filter requirements for the mixers.

The output of mixer "B" is split into two parts. One part is filtered to give the 10 MHz bandwidth signal. The other part is mixed down by mixer "C". The output of this mixer is switched to the appropriate filter and sampled at 20 MHz. Bandwidths of 5, 2.5, 1.25 and 0.625 MHz are thus obtained. These signals are over-sampled. Due to the 15 MHz LO signal and the specifications of the filters "K" to "N", the signals are derived from frequency bands near 20 MHz. Over-sampling of the signals may be avoided by only latching the appropriate outputs of the samplers.

The Diagram 4.0.2, "Oversampling of the Narrow Bandwidths", shows this relationship between the filters and the samplers. Consider the 2.5 MHz bandwidth band. The 5-7.5 MHz band of the filter is derived from the 20-22.5 MHz band. As the samplers are at 20 MHz, this band is equivalent to a 0 to 2.5 MHz band. Therefore, the band is oversampled. For Nyquist sampling, only the appropriate outputs of the samplers need be latched.

The system could have been designed with a L.O. of 16 MHz instead of 15 MHz. The fractional bandwidths of the narrow-band filters would be slightly larger and the signal would probably be a little easier to generate. However, as the mixer produces harmonics of the L.O. signal, a 32 MHz signal would be produced. This will be attenuated by both the image reject filter "J" and the I.F. filter "I". If the attenuation is not sufficient, it will be aliased into the 20-30 MHz band and may appear as a spectral line.

5.0 MIXERS AND THEIR IMAGES

MIXER	RF INPUT	LO	IMAGE BAND	OUTPUT
A	240-280	160	40- 80	80-120
A	200-220	160	100-120	40- 60
B	180-190	160	130-140	20- 30
C	10-15	15	5-10	5-10

C	10-12.5	15	7.5-10	5-7.5
C	10-11.25	15	8.75-10	5-6.25
C	10-10.625	15	9.375-10	5-5.625

6.0 FILTER SPECIFICATIONS

Following is a table showing the filters shown in the proposed system, the nominal "rectangular" passband and the specifications for Tchebyscheff bandpass filters.

The last two columns show the percentage bandwidth. "Band #1" is the 0.1 or 0.2 dB bandwidth, "Band #2" is the 3 dB bandwidth. The phase slope would be steeper past the 0.1 or 0.2 dB points.

FILTER	NOMINAL PASSBAND (MHz)	IMAGE BAND (MHz)	ORDER	PASSBAND (MHz)	RIPPLE (dB)	% of BAND #1	% of BAND #2
A	640-800	160-320	3	620-820	0.1	125	
B	160-320		3	140-340	0.1	125	
C	160-320	≤160, ≥320	6	175.5-289.2	0.1	71	77
C	160-320	≤160, ≥320	8	169.5-301.0	0.1	82	86
C	160-320	≤160, ≥320	6	174.1-291.8	0.2	73	78
C	160-320	≤160, ≥320	8	168.7-302.6	0.2	84	86
D	160-240	≤160, ≥240	6	169.2-226.2	0.1	71	77
D	160-240	≤160, ≥240	8	165.7-231.4	0.1	82	86
D	160-240	≤160, ≥240	6	168.5-227.2	0.2	73	78
D	160-240	≤160, ≥240	8	165.2-232.2	0.2	84	86
E	200-280	40-80,100-120	4	190-290	0.1	125	
F	80-120	≤80, ≥120	6	84.6-113.1	0.1	71	77
F	80-120	≤80, ≥120	8	82.9-115.7	0.1	82	86
F	80-120	≤80, ≥120	6	84.3-113.6	0.2	73	78
F	80-120	≤80, ≥120	8	82.6-116.6	0.2	84	86
G	40- 60	≤40, ≥60	6	42.3- 56.5	0.1	71	77
G	40- 60	≤40, ≥60	8	41.4- 57.8	0.1	82	86
G	40- 60	≤40, ≥60	6	42.1- 56.8	0.2	73	78
G	40- 60	≤40, ≥60	8	41.3- 58.0	0.2	84	86
H	180-190	130-140	3	176-194	0.1	180	
I	20- 30	≤20, ≥30	6	21.2- 28.3	0.1	71	77
I	20- 30	≤20, ≥30	8	20.7- 28.9	0.1	82	86

I	20- 30	$\leq$20, $\geq$30	6	21.1- 28.4	0.2	73	78
I	20- 30	$\leq$20, $\geq$30	8	20.7- 29.0	0.2	84	86
J	20- 25	5- 10	3	18- 27	0.1	180	
K	5- 10	$\leq$5, $\geq$10	6	5.48- 9.04	0.1	71	77
K	5- 10	$\leq$5, $\geq$10	8	5.30- 9.41	0.1	82	86
K	5- 10	$\leq$5, $\geq$10	6	5.44- 9.12	0.2	73	78
K	5- 10	$\leq$5, $\geq$10	8	5.27- 9.45	0.2	84	86
L	5-7.5	$\leq$5, $\geq$7.5	6	5.29- 7.07	0.1	71	77
L	5-7.5	$\leq$5, $\geq$7.5	8	5.18- 7.23	0.1	82	86
L	5-7.5	$\leq$5, $\geq$7.5	6	5.27- 7.10	0.2	73	78
L	5-7.5	$\leq$5, $\geq$7.5	8	5.16- 7.26	0.2	84	86
M	5-6.25	$\leq$5, $\geq$6.25	6	5.16- 6.05	0.1	71	77
M	5-6.25	$\leq$5, $\geq$6.25	8	5.10- 6.13	0.1	82	86
M	5-6.25	$\leq$5, $\geq$6.25	6	5.15- 6.06	0.2	73	78
M	5-6.25	$\leq$5, $\geq$6.25	8	5.09- 6.14	0.2	84	86
N	5-5.625	$\leq$5, $\geq$5.625	6	5.08- 5.53	0.1	71	77
N	5-5.625	$\leq$5, $\geq$5.625	8	5.05- 5.56	0.1	82	86
N	5-5.625	$\leq$5, $\geq$5.625	6	5.08- 5.54	0.2	73	78
N	5-5.625	$\leq$5, $\geq$5.625	8	5.05- 5.57	0.2	84	86

Note that for the filters that define the IF bandwidths, there is a choice of the specifications. More spectral line information is available if the higher order filters are used. However, their phase stability is probably worse. Cauer (elliptic) filters, of order about 5, may be suitable. These are also being investigated.

7.0 NOTES ON THE I.F. CONVERTER SYSTEM

1. The filters are isolated from the variable attenuators by an amplifier. Bandpass filter characteristics alter if the terminating impedance changes. The variable attenuators are likely to change their match with changing attenuation setting.

2. Broadband matching on all ports of the mixers would be desirable, particularly on the IF port.

3. To keep the IF power constant for various bandwidths, appropriate attenuators are placed in series with the filters that determine the IF bandwidth.

4. Detectors:-
For the 160 MHz bandwidth, the IF power detector must be of an analog design. However, for bandwidths less than this, there is a choice. For a multi-level sampler and broadband noise, it is possible to determine the power level from the sampler outputs (Ref 7). The block diagram just shows the detectors as diodes. The level control and calibration system is discussed more fully in Ref 4.

5. The overall gain for the module has not yet been determined accurately. The gain of the amplifiers has not been shown on the block diagram, but would be typically about 18dB.

8.0 STABILITY

The stability of the receiver is of primary importance.

1. AMPLITUDE STABILITY:
The noise injection system should be able to allow for small, slow changes in gain and system temperature. The accuracy of this calibration scheme depends on the stability of the noise sources and the I.F. level detection scheme.

2. PHASE STABILITY:
The L.O. system will be phase stabilised. However, there will be no phase calibration scheme within the receiver itself. It must be designed to be as phase stable as possible for changes in temperature, power supply and L.O. variations.

The main components that may give changes in phase are:
(a) Amplifiers
(b) Mixers
(c) Switches
(d) Filters

AMPLIFIERS:

Use broad-band amplifiers if possible. Usually these have much less phase slope than narrower bandwidth devices and are more phase stable. (Don't use amplifiers at frequencies where their gain is changing rapidly!) For the RF amplifiers, initial tests on the Avantek AFT series indicate that the amplifiers should not be a major source of phase variations.

MIXERS:

The I.F. phase may change with LO level. An initial investigation has been done (Ref 8).

SWITCHES:

No tests have been done on switches yet. With suitable drive circuitry, the variation in phase of the Pin-switches should be able to be minimised. (Could use coaxial switches instead.)

FILTERS:

These may be the dominant cause of phase instability within the receiver system. Preliminary tests are being done for I.F. and RF filters, for both commercially available and "in-house" units.

9.0 APPROXIMATE COST

An accurate, detailed analysis of the cost of a module has not been done. Following is an approximate cost.

ITEM		NO.	COST EACH	TOTAL ($)
AMPLIFIERS		20	25	500
		6	50	300
FILTERS		9	400	3600
		4	200	800
ATTENUATORS:	fixed	10	15	150
	preset	6	100	600
	ALC	6	200	1200
MIXERS		2	40	80
		1	20	20
SWITCHES:	3PST	3	300	900
	4PST	2	400	800
	2PST	2	40	80
POWER SPLITTERS		3	40	80
DECTECTORS, Synch. Demod		6	40	240
CONNECTORS: (backplane)	RF input	1	30	30
	LO input	2	30	60
	Samplers	5	30	150

Total (per module) $9630

10.0 REFERENCES

1. AT/01.13/004 AT SYSTEMS DEFINITION

2. AT/10.4/003 REPORT OF THE WORKSHOP ON THE AUSTRALIAN TELESCOPE CORRELATION SYSTEM.

3. AT/24.1/002 DIGITAL FILTERING FOR THE AT

4. AT/22.1.1/001 NEW PROPOSAL FOR IF CONVERTER FOR AT

5. AT/22.1.1/004 I.F. ANALOG FILTERS: Their Bandshape

6. AT/22.3/004 AT/23./2.3/004 IMAGE REJECTION REQUIREMENTS FOR THE A.T.

7. C. AGAU PhD Thesis, University of Sydney, 1982.

8. AT/22.1.1/002 MIXERS AND PHASE STABILITY: A Preliminary Investigation

George Graves
30 May 1984

SIGNAL FLOW DIAGRAM

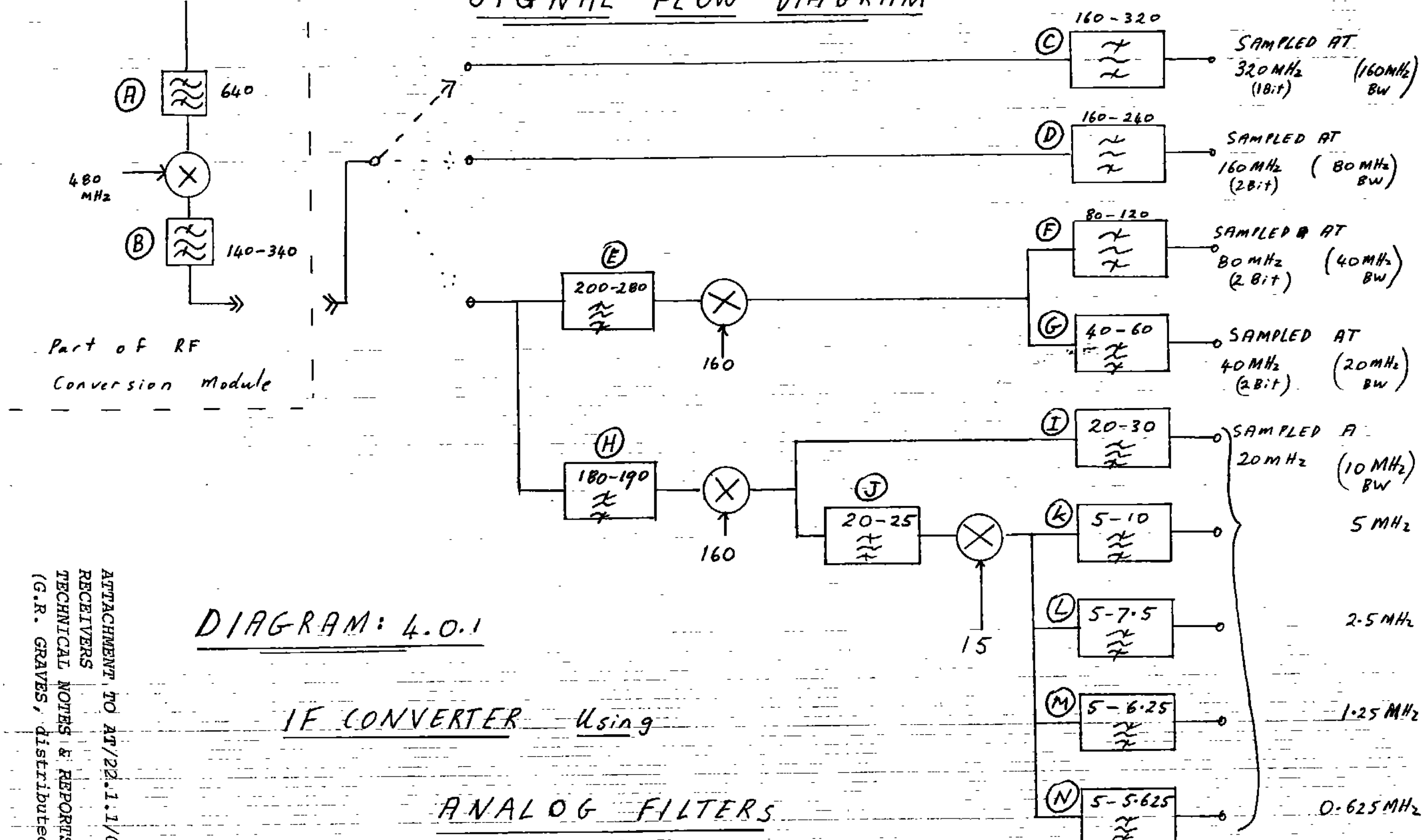


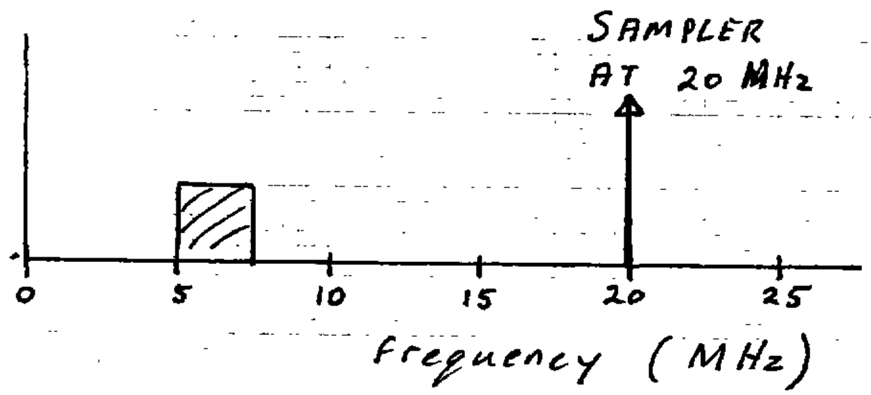
DIAGRAM: 4.0.1

IF CONVERTER Using

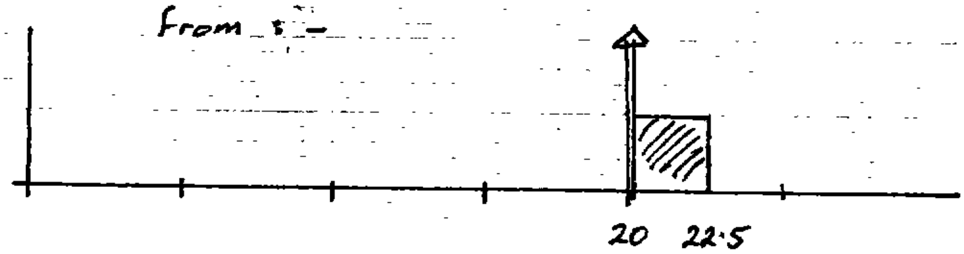
ANALOG FILTERS

(George Graves 24 May 84)

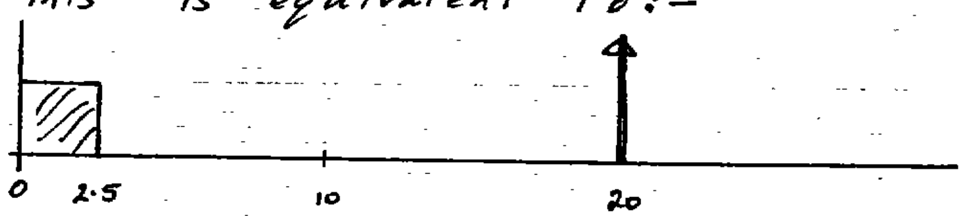
ATTACHMENT TO AT/22.1.1/003
RECEIVERS
TECHNICAL NOTES & REPORTS
(G.R. GRAVES, distributed 12.6.84)



This 5 - 7.5 MHz band was derived from :-



As the sampling is at 20 MHz, this is equivalent to:-



Therefore, the signal is oversampled.

Diagram 4.0.2: " OVERSAMPLING of the NARROW BANDWIDTHS "

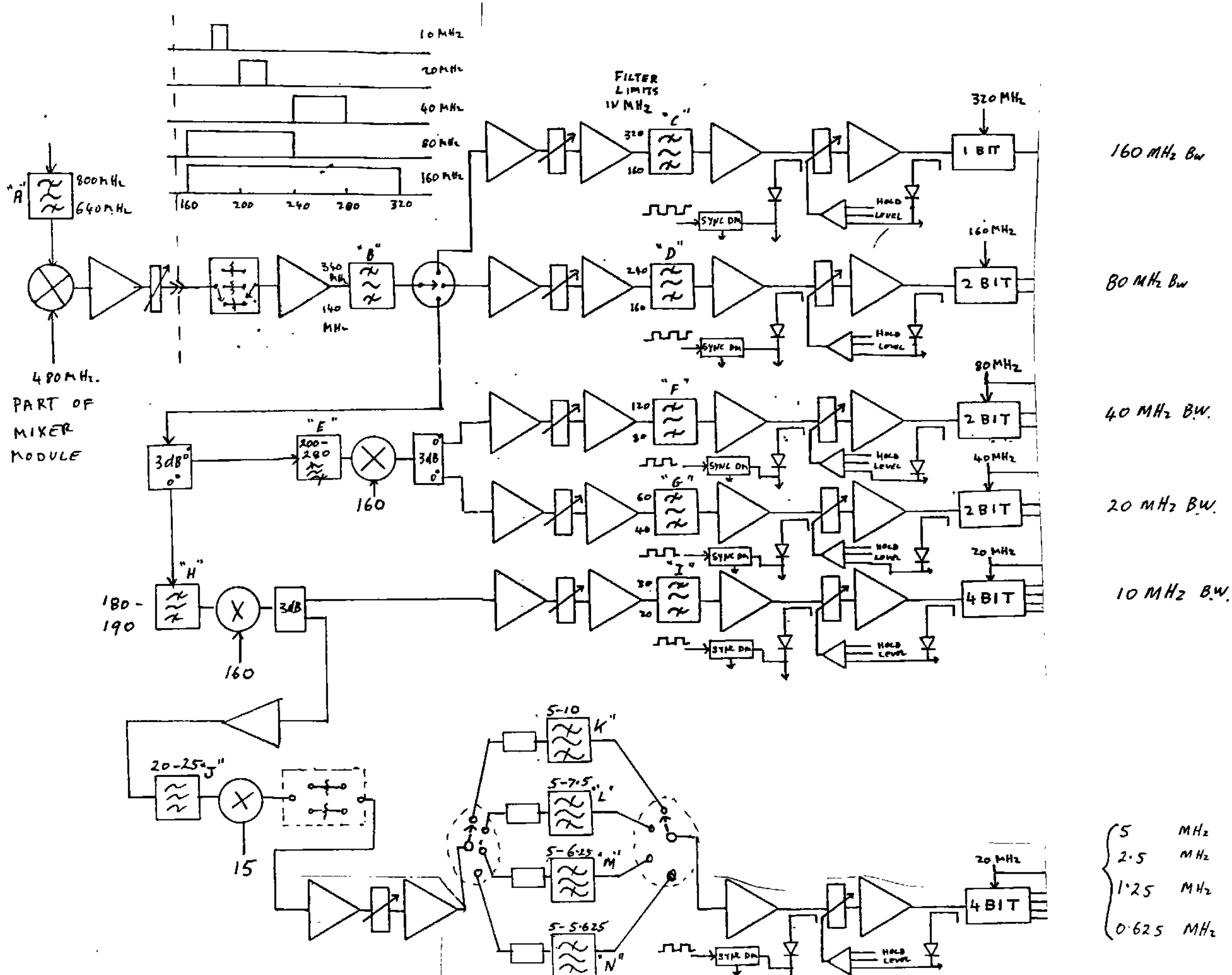


DIAGRAM 7.0.1 "I.F. CONVERTER Using ANALOG FILTERS