CSIRO DIVISION OF RADOPHYSICS

THE AUSTRALIA TELESCOPE

AT/22.1.1/029
Receivers
Technical Notes and Reports

SPURIOUS SIGNALS, COMB LINES AND LOCAL OSCILLATORS

1.0 INTRODUCTION

With the selected system design, it is inevitable that there will be some leakage of a comb of signals onto the local oscillator signals used for the C/X, L/S and UHF conversion stages. This note looks at the maximum desirable levels for these spurious signals, for the following conditions.

(i) Only spurious signals produced by the direct connection of the Local Oscillator system to the Conversion electronics will be considered. Leakage of signals, by radiation, into the horn and front end assembly will not be examined at all.

(ii) The report considers the worse case conditions, for which there is no phase rotation and the RF signals have no bi-phase modulation.

(iii) The tolerable level of spurious signals is lower for spectral line observations than for continumum observations. Therefore, the maximum level of spurious signals is determined for the case where the usual maximum number of spectral line channels is spread across the minimum bandwidth. A twelve hour integration time is assumed.

Note that for brevity in this report, L-band, S-band, C-band and X-band are the nomenclature for the AT designated RF bands, 1.25-1.78, 2.2-2.5, 4.4-6.1 and 8.0-9.2 GHz respectively.

The C/X local oscillator is phase locked with a 10 MHz offset to a selected comb signal produced from a 320 MHz signal. The L/S local oscillator is similar, but the comb is spaced at 20 MHz intervals. The UHF local oscillator contains only tones at 160, 480, 640 and 800 MHz that are significant.

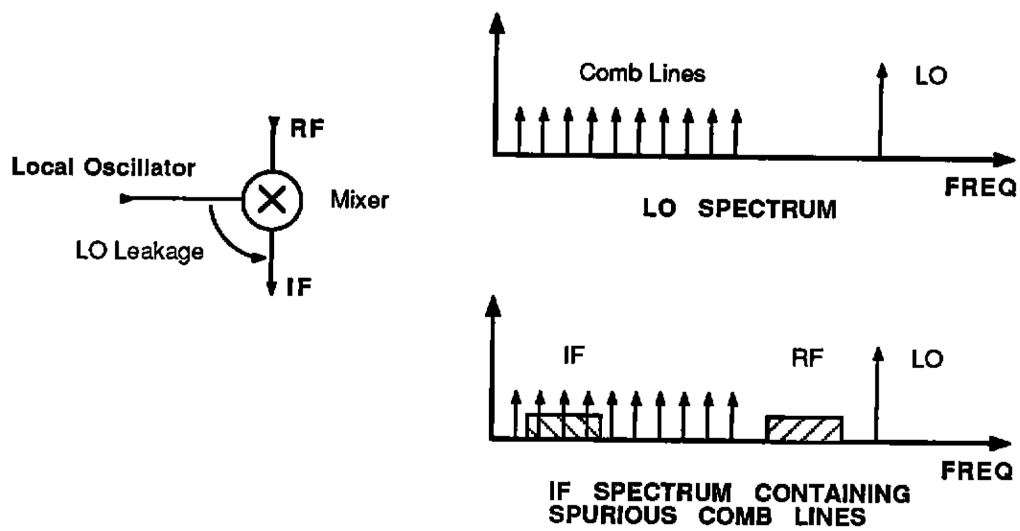
2.0 COMB LINES AND SPURIOUS SIGNAL GENERATION

As the reference signal for the comb generation is phase stabilised at each antenna, interefence produced by comb components would be phase coherent, for observations of the south pole region. For observations of most parts of the sky, the level of the spurious signals, after correlation, would be reduced due to fringe rotation.

There are several methods by which these comb lines may produce spurious signals and a false final spectrum from the telescope.

2.1 Comb lines in the IF bands

If there are spurious comb lines on the local oscillator's signals at frequencies within the IF (Intermediate Frequency) band of the conversion, they will leak across the mixer due to the finite LO-IF isolation, and appear with the correct signals in the IF band. They may not be obvious with a spectrum analyser, but a synthesis radiotelescope using cross-correlation techniques with long integration times is capable of detecting very small signals deeply embedded in the noise.



This problem of comb lines at IF frequencies will be looked at in more detail later.

2.2 Comb lines within the RF bands

These may leak across to the RF port of the mixer, due to the finite LO-RF isolation, be reflected off any mismatch of the components on the RF port of the mixer, and then appear in the RF input of the mixer. They would then be converted to the IF band.

Also, there would be a conversion product produced within the mixer. For a double-balanced mixer, the levels are difficult to estimate, as it is unusual to have the signal being converted on the LO port, simultaneously with the LO signal. An experimental procedure was used to measure this component. It will be described later.

2.3 Intermodulation products

Intermodulation products, caused by multiples of the LO signal and multiples of various comb components can lead to spurious signals being generated within the IF passband. As the comb levels on the LO signal are very low, intermodulation products caused by mixing of multiples of these is not a problem for the conversion system. (It may lead to problems within the LO generation system however).

In order to estimatewhat intermodulation products exist and their possible levels, a program written by Russell Gough may be used. It is based on a paper by Bert C. Henderson, "Reliably Predict Mixer IM Suppression." (Ref. 1)

For example, the program was run for an LO frequency of 7.05 GHz at +10 dBm. The RF signal, at -60 dBm, was any CW signal that was a multiple of 320 MHz in the region from 320 MHz to 25 GHz. Harmonic components up to the 3rd of any of the RF input signals, and up to the 7th of the LO signal were allowed. The program selected those spurious signals in the region 2.0 - 2.5 GHz. An edited listing of the output is following.

	START GHz	STOP GHz	STEP GHz	POWER dBm	MAX HARMONIC
RF	0.320	25.000	0.320	-60.0	3
LO	7.050	7.050	0.000	10.0	7

	RF GHz	N	LO GHz	M	IF GHz	LEVEL dBm	COMMENTS
	1.600	3	7.050	-1	2.250	-228	
**	4.800	1	7.050	-1	2.250	- 60	primary conv'n
	5.440	3	7.050	-2	2.220	-244	
	8.640	3	7.050	-4	2.280	small	
**	9.280	1	7.050	-1	2.230	- 60	primary conv'n
*	11.840	1	7.050	-2	2.260	- 95	2nd harmonic con'n
	12.480	3	7.050	-5	2.190	-214	
	15.680	3	7.050	-7	2.310	-211	
*	16.320	1	7.050	-2	2.220	- 95	2nd harmonic con'n
	17.280	3	7.050	-7	2.490	-211	
*	18.880	1	7.050	-3	2.270	- 70	3rd harmonic con'n
	22.400	2	7.050	-6	2.500	-169	
*	23.360	1	7.050	-3	2.210	- 70	3rd harmonic con'n

A summary of the results is as follows:

(i) Firstly a note about the expected spurious levels. This program produces reasonably good estimates when the mixer is used normally, i.e. with the RF signal on the RF port. However in our case, the "RF signal" (i.e. the undesired comb components) is actually present on the LO port, simultaneously with the LO signal. The frequencies of spurious components generated will be correct, but the levels could be out by tens of decibels. An experimental procedure was used to measure these levels.

(ii) The primary conversion products are the worst. A comb at 4.8 GHz or 9.28 GHz gets converted down to the IF band.

(iii) Second harmonic and third harmonic conversion products cause problems also. Components at 11.84, 16.32 (for second harmonic conversion), 18.88 and 23.36 GHz (for third harmonic conversion) cause spurious IF signals.

(iv) Intermodulation products produced by mixing of the LO, or multiples of the LO, with harmonics of the comb components do give spurious signals, but these levels, as indicated, are extremely low.

(v) The leakage of the comb from the LO to IF port of the mixer does not appear in the list of components of IM products. (It is not a mixer type output).

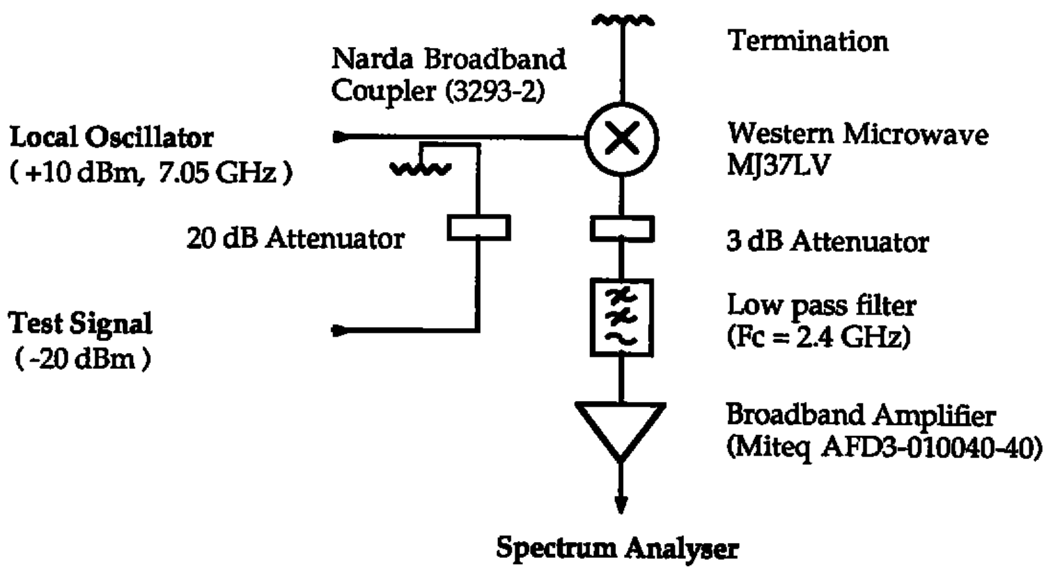
3.0 MEASUREMENT OF COMB LEAKAGE AND INTERMODULATION PRODUCTS

In this test set-up, a single tone is added to the local oscillator signal. The local oscillator signals used for the conversion system actually contain many low level tones. These are all multiples of a fundamental frequency (320 MHz for the C/X LO) and hence are related in phase. In the time domain, the low level comb is likely to resemble a delta function. The levels of the intermodulation signals produced by this comb may be different to the levels of the intermodulation signals produced by discrete spurious signals. However, provided that there are not a large number of components of the comb of significant amplitude, the results are likely to be similar.

3.1 C-X Conversion

(i) test procedure

An experimental procedure was used to determine approximate levels for the intermodulation products and comb leakage to the IF port of the C-X mixer. The test set-up was as follows:

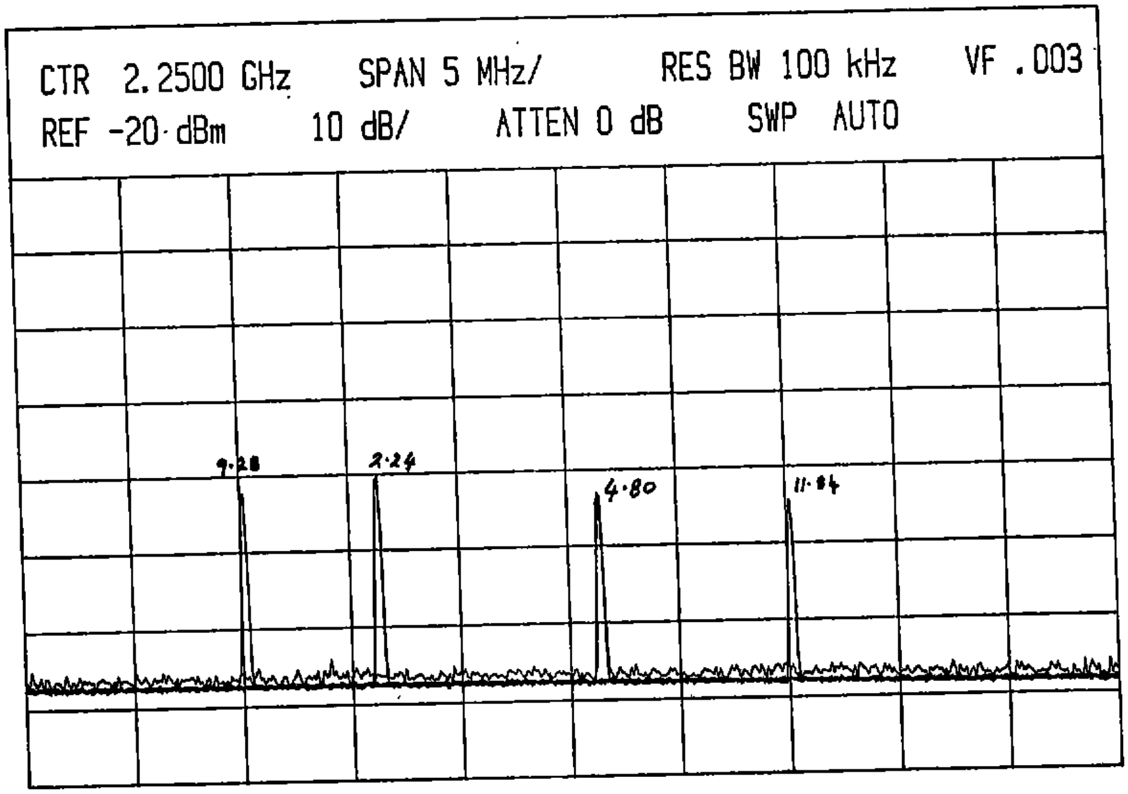


The broadband coupler was used to add a test signal to the LO signal. The 3 dB attenuator provides a reasonable bandwidth match to the IF port at the LO frequency. A good match is particularly important on the IF port to obtain low intermodulation products within the mixer. The low pass filter attenuates the LO leakage from the mixer which would tend to saturate, or cause IM products in the following broadband amplifier. This amplifier is required as the noise floor of the spectrum analyser is rather high.

Note that the level used for the signal injection into the LO port is -50 dBm. This is 10 dB higher than that used in the computer test. It made the levels a little easier to see on the spectrum analyser.

(ii) Results of the C-X Mixer test

Following is a copy of the results. The numbers near the spurious signals are the frequencies that generated that IF output. The signals are not exactly on 2.25, 2.24 GHz etc. as the sweepers used for the test signal injection, and possibly the spectrum analyser, may have been slightly incorrect in frequency. Only test signals up to 12 GHz were used. Note when reading the level of the spurious signals that there is a net gain of approximately 27dB after the mixer.



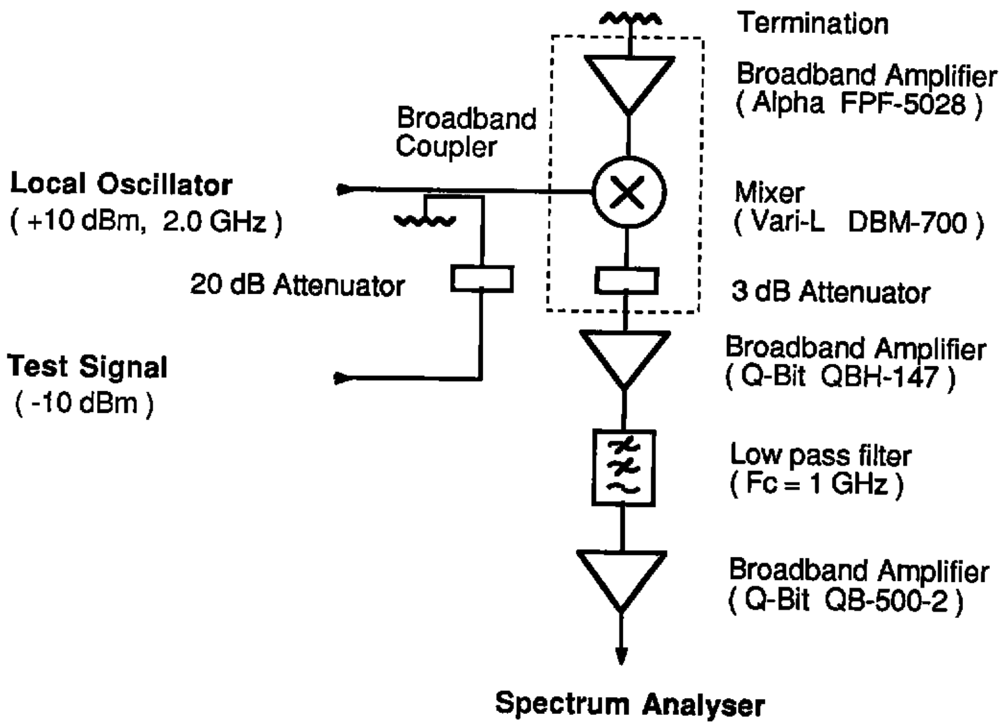
The levels of the comb leakage, at 2.24 GHz, and the first conversion products (produced by 4.80 and 9.28 GHz) and of the 2nd harmonic conversion products (produced by 11.84 GHz) are, rather surprisingly, all about the same level, and about 40 dB below the level of the tone injected into the LO port. The spurious IF signals are directly proportional to the level of the injected signals. Reduce the signals by 10 dB and the spurious IF signals also reduce by 10 dB.

After obtaining the preceeding results, the test set-up was altered so the effects of a mismatch on the RF port could be examined. A prototype C/X mixer subassembly was used that has an inbuilt power divider on the RF port. For a test input signal at 4.8 GHz, changing the impedance on the RF input port of the subassembly from a 50 ohm termination to a short-circuit or open-circuit gave only a couple of dB change for the spurious IF product.

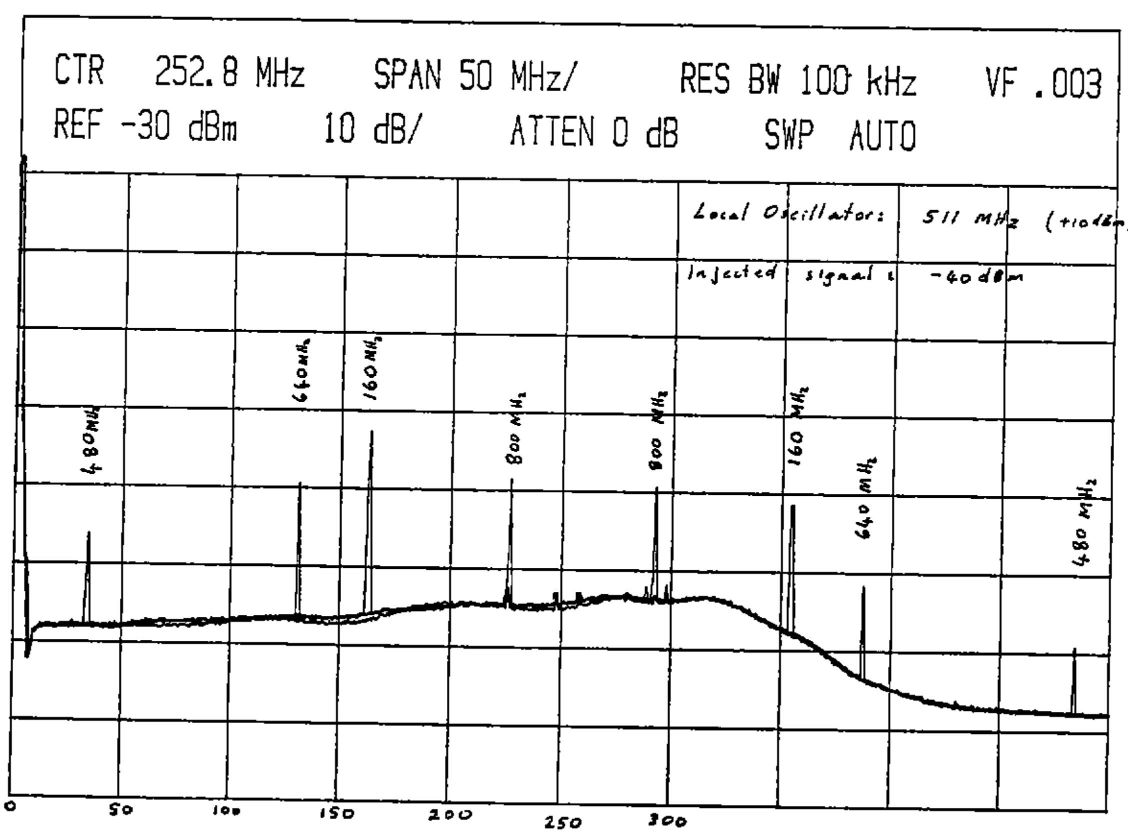
In conclusion, the isolation of spurious products into the IF output generated by the two main mechanisms, ie direct comb leakage and intermodulation products, is of the order of 40 dB.

3.2 L/S Conversion

A block diagram of the test system used is as follows:



The following is a plot of the spurious leakage, first, second and third conversion products for the mixer. The level of test signals injected into the LO port was set at -50 dBm. In the test set-up, there was net gain of 32 dB after the mixer.

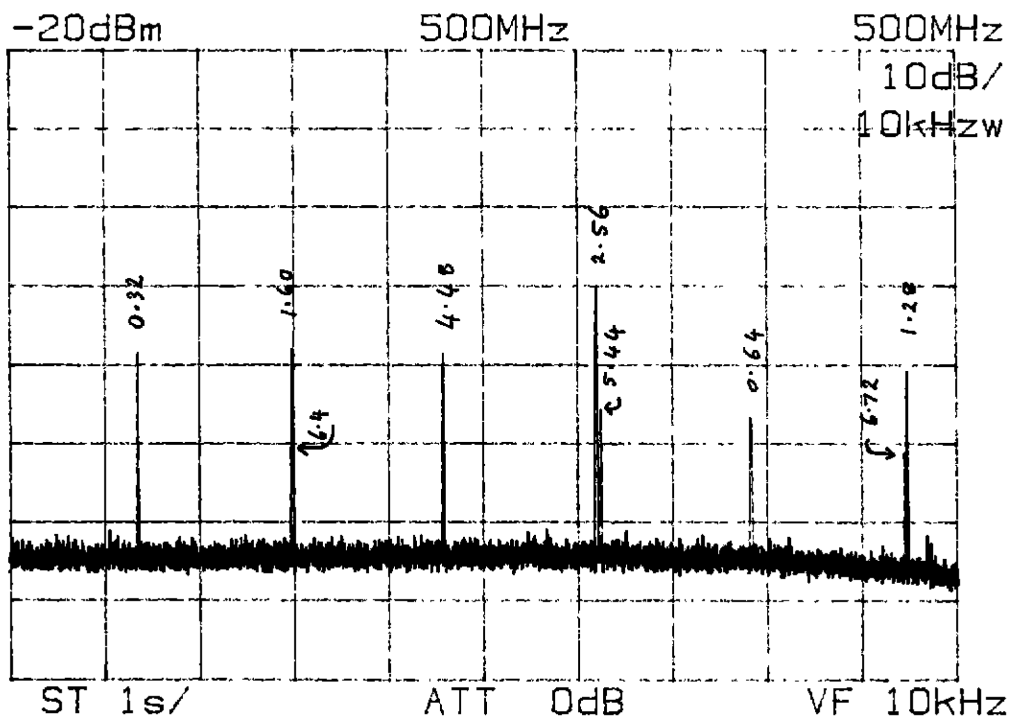


The leakage of signals at the IF frequency (from about 300-800 MHz) was about -40 dB, but the first conversion produce was only about 32 dB below the level of the signal on the LO. The Intermodulation Products involving the second and third harmonics of the local oscillator were lower. They were about 40 dB below the level of the signal on the LO input.

3.3 UHF Conversion

A similar test set-up to the L/S conversion was used. The mixer (Vari-L DBM143) was followed by a net gain of 20 dB. A lowpass filter with cutoff at 320 MHz was included in the circuit. A Mini-Circuit ZDC-10-1 coupler was used for injecting the 160 MHz and 480 MHz test signls into the RF port. A ZDC-10-2 coupler was used for the 640 and 800 MHz test signals.

The following is a plot of the spurious leakage and conversion products for the mixer. As the spurious signals had such a low amplitude, the level of test signals injected into the LO port was set at -40 dBm.



The leakage of the 160 MHz test signal from the RF port to the IF port was approximately -43 dB. All intermodulation products on the IF were at least 50 dB below the level of the test signal injected into LO port. This is a very good result. These mixers have excellect rejection of spurious signals on the LO port.

4.0 MINIMUM DETECTABLE SIGNAL LEVELS

"The sensitivity is a measure of the weakest source which, in the absence of confusing sources, can be detected with confidence." (Ref 2) From "Radiotelescopes" by W.N. Christiansen and J.A. Hogböm (Ref. 2), the sensitivity may be derived from:-

$$(\Delta T)_{min} = \frac{Q.\,M.\,T_{sys}}{\sqrt{\Delta v.\,t}}$$

where the symbols are as follows:-

$(\Delta T)_{min}$	the noise temperature of minimum detectable source
T_{sys}	the total system noise
Δv	bandwidth
t	the measurement time
M	a factor that depends on the type of receiver (it is 1.41 for a correlation telescope using direct multiplication)
Q	a factor by which we multiply the r.m.s. deflection due to noise in order to obtain the minimum detectable signal. It is usually in the range $2<Q<5$.

For the Australia Telescope, the following values could be used:-

$T_{sys} = 30$
Δv = 488 Hz (1024 channels in 0.5 MHz)
t = 4.3×10^4 seconds (12 hours)
M = 1.41
Q = 3

Using the above information, the sensitivity $(\Delta T)_{min}$ would be 0.03K, for the narrowest bandwidth spectral line channel.

Notes

(i) The values used are not critical. An estimate of the maximum spurious level is required. We would try to ensure that the levels were somewhat below the calculated maximum values.

(ii) The system temperature depends on the RF band being received, and may be a little higher for the higher frequency bands.

(iii) The bandwidth is the minimum that would normally be used, with full recirculation of the correlator across the narrowest bandwidth (i.e. 1024 channels across 0.5 MHz).

From the following equation, the minimum detectable signal at the outputs of the mixers may be determined.

$$P = kTBG$$

where P is Power (in watts)
k is Boltzmann's constant
T is noise temperature
B is bandwidth
G is gain,

For the C/X conversion, there is approximately 51 dB of gain from the input of the Low Noise Amplifier (LNA) to the output of the mixer. Therefore, the minimum detectable signal at the output of the mixer is approximately -137 dBm.

For the L/S conversion, there is approximately 57 dB of net gain from the input of the Low Noise Amplifier (LNA) to the output of the mixer, giving the minimum detectable signal at the output of the mixer of -131 dBm.

The UHF conversion has about 68 dB of net gain before the mixer. Therefore the minimum dectable signal for this conversion is about -120 dBm.

5.0 MAXIMUM SPURIOUS SIGNAL LEVEL

Following is the calculation for the maximum spurious signal level for the case when there is no 180 degree phase-switching of the RF signal, and no fringe rotation. Both of these reduce, but do not eliminate, the level of spurious components after correlation.

For the conversion system operating at the designed power levels, the following maximum spurious levels are desirable.

As the C/X mixer provides about 40 dB of attenuation between signals on the LO input and spurious signals on the IF output, the maximum level for signals on the LO input should be about -97 dBm, or about -107 dBc (-107 dB below the carrier).

The L/S mixer provides a little less attenuation to the generation of the spurious signal caused be the primary conversion mechanism. It is only a about 32 dB. Therefore, the maximum level for signals on the L/S LO should be about -98 dBm, or -108 dBc.

The UHF mixer provides a minimum attenuation for the four possible comb lines on the UHF LO of 43 dB, giving a maximum level for these signals on the LO of -77 dBm, or -87 dBc.

However, as the conversion system will operate satisfactorly with 6dB and 8dB less attenuation in the course attenuatot and phase-constant attenuator respectively, a 14dB lower level of spurious signals would be desirable. While it would be unusual for the conversion system to be configured in this low attenuation state, it would be desirable that spurious signals did not begin to appear as the level of attenuation is reduced.

6.0 CONCLUSION

For a correlation telescope, the effects of fringe rotation and bi-phase modulation of the RF signal allow a somewhat higher level of spurious tones on the local oscillator signals to be acceptable. However, I think that it would be desirable to build a system that does not depend on the fringe rotation and modulation for a spurious free spectrum.

In order to eliminate the problem of comb products on the LO signal producing spurious IF signals on the output of the C/X, L/S and UHF conversions, the comb lines should have a maximum level of about. -125 dBc, -125 dBc and -105 dBc respectively. Of course, levels a few dB lower would be nice as they would allow for some variation in mixer parameters.

At present the levels of comb lines on the C-X and L-S prototype local oscillators have been reduced from about -70 to -90 dBc to about -120 dBc by additions of filters and a reduction of the comb power. The comb lines on the UHF LO are about -90 dBc at present, but will be reduced in level by a reduction in the comb power.

The very low levels of comb components on the prototype local oscillator system should give a system that is free of false spectral components due to direct spurious signal generation within the Conversion system.

7.0 REFERENCES

(1) "Reliably Predict Mixer IM Suppression", Bert C. Henderson. Microwaves & RF, November 1983, p.63.

(2) "Radiotelescopes", W.N. Christiansen & J.A. Högbom, Cambridge University Press, 1985 (2nd edition).

George Graves
7 April 1988

GG:PW