A PROJECT REPORT
ON

STUDY OF BAND PASS SAMPLING

BY

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RIKMANTRA BASU

ABSTRACT

In present GMRT system for the antennas, the array will operate in six frequency bands centered around 153, 233, 325, 610 and 1420 MHz with sub-bands of 1060, 1170, 1280, 1390 MHz in the L-band. All these feeds provide dual polarization outputs. Here, the RF signals in two polarizations are passed through two channels each of maximum band width 32 MHz. Then each of these signals are down converted to 70 MHz first and then up converted to 130MHz and 175 MHz respectively in the IF & LO system. The signals are then combined and sent to Central Electronic Building (CEB) through analog optical fiber link. Then the signals are processed in the Base-Band system, where each polarization signal is converted into two sidebands each of 16 MHz bandwidth. Thus a total of 4 baseband channels are available from each antenna, which are sampled and digitized with the analog-to-digital converter with the sampling frequency 32 MSPS.

Now, the future GMRT receiver system is looking for modifying the system such that direct down conversion and digitization of the signals can be done simultaneously, possibly either at the antenna base (ABR) or at the CEB with the concept of bandpass sampling. A project on study of bandpass sampling and its effect on both CW and noise signals is done so as to help in developing a new digitisation scheme for the upgraded GMRT Receiver.

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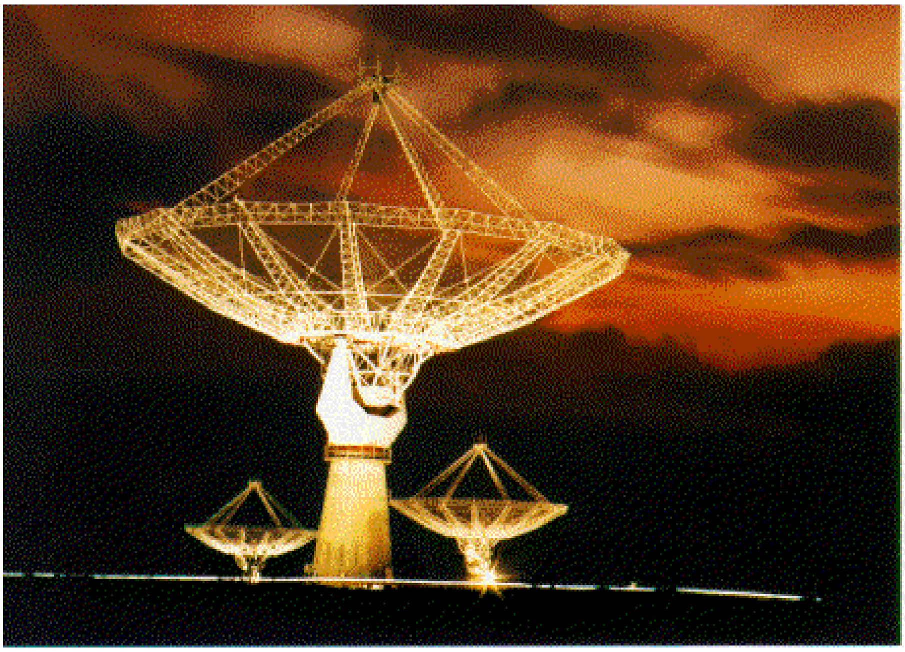
Introduction to GMRT



NCRA has set up a unique facility for radio astronomical research using the meter wavelengths range of the radio spectrum, known as the Giant Meter wave Radio Telescope (GMRT), it is located at a site about 80 km north of Pune. GMRT consists of 30 fully steerable gigantic parabolic dishes of 45m diameter each spread over distances of up to 25 km. GMRT is one of the most challenging experimental programs in basic sciences undertaken by Indian scientists and engineers.

There are total 30 dish antennas. Out of these fourteen dishes are located more or less randomly in a compact central array in a region of about 1 sq. km. The remaining sixteen dishes are spread out along the 3 arms of an approximately Y-shaped configuration over a much larger region, with the longest interferometric baseline of about 25 km.

The multiplication or correlation of radio signals from all the 435 possible pairs of antennas or interferometers over several hours will thus enable radio images of celestial objects to be synthesized with a resolution equivalent to that obtainable with a single gigantic dish 25 km in diameter! The array will operate in six frequency bands centered around 153, 233, 325, 610 and 1420 MHz.

GMRT Receiver System

In present GMRT system for the antennas, the array will operate in six frequency bands centered around 153, 233, 325, 610 and 1420 MHz with sub-bands of 1060, 1170, 1280, 1390 MHz in the L-band. All these feeds provide dual polarization outputs. Here, the RF signals in two polarizations are passed through two channels each of maximum band width 32 MHz. Then each of these signals are down converted to 70 MHz first and then up converted to 130MHz and 175 MHz respectively in the IF & LO system. The signals are then combined and sent to Central Electronic Building (CEB) through analog optical fibre link. Then the signals are processed in the Base-Band system, where each polarization signal is converted into two sidebands each of 16 MHz bandwidth. Thus a total of 4 baseband channels are available from each antenna, which are sampled and digitized with the analog-to-digital converter with the sampling frequency 32 MSPS.

Now an upgraded GMRT receiver system is planned with improved sensitivity, instantaneous bandwidth and more facilities for the Astronomer. In the new scheme being planned a wider bandwidth signal will be digitized with less electronics at the remote antenna sites. The current idea is to transport the entire RF spectrum received at the feeds to the CEB and all further processing to be done there. The possibility of direct down conversion and digitization of the signals is being investigated, with the concept of bandpass sampling. A project on study of bandpass sampling and its effect on both CW and noise signals is done so as to help in developing a new digitization scheme for the upgraded GMRT Receiver.

Chapter 2

ADCs Survey & Card Details

Parameter specifications :-

Mfg.	Device	Pins	Res.	Max. sample rate	Min. supply voltage	Max. supply voltage	Analog i/p BW	Tjitter in(pS) rms
National	ADC082000	24	8 bits	200 MSPS	3 V	3V	500 MHz	2
Analog	AD9410	80	10 bits	210 MSPS	Multi (+3.3, +5) V	Multi (+3.3, +5)	500 MHz	0.65
inear	LTC22201	64	12 bits	185 MSPS	3.3 V		750 MHz	0.15

ADC Card Details

Here AD9288-100 ADC is used for GMRT Receiver system as a part of AL81004C PCI DIGITZER.

Specifications :-

Analog section :-

- 4 channels analog input
- Band width: DC to 80 MHz -3dB, limited by the first input stage of VGA & without VGA ADC bandwidth is 450MHz.

A/D Converter :-

- 8 bit resolution.
- 100 MSPS sampling rate on four channels, 200 MSPS on two channels or 400 MSPS on one channel.
- Sampling rates are: 100 MHz, 50 MHz, 33.33 MHz, 25 Mhz,....to (100/256).

Clock :-

- Both internal and external clocks can be fitted.
- External clock can be a frequency reference (5.00 or 10.00 MHz) or a high speed clock at four times the desired sampling rate.

Memory :-

- Dual-ported on board acquisition memory: 32 M Sample 4 channels at 100 MSPS, 64 M Samples*2 channels at 200 MSPS or 128 M Samples *1 channel at 400 MSPS.

Trigger Sources :-

- Soft ware trigger
- Internal trigger connector, TTL programmable polarity (3 pin header)
- external trigger input (BNC trigger connector), programmable threshold -5.0 V ...+ 5V and polarity, 50 Ohm/1 k Ohm input impedance-software selectable

Chapter 3

Concept of Bandpass Sampling

Band Pass Sampling :-

It is the process of digitizing a continuous band pass signal and at the same time translating the signal at the base band in the frequency domain.

Aliasing :-

Aliasing is an effect that causes higher frequency components takes lower frequency components side. In aliasing different continuous signals to become indistinguishable (or *aliases* to one another) after sampling.

Features :-

1. It is more efficient to sample a band limited signal which starts from other than zero Hz, compared to Nyquist sampling.
2. In bandpass sampling the higher frequency component is shifted or folded back to the lower frequency portion. Here the advantage of aliasing is utilized.
3. Here, more important parameter of the signal is it's band width, than it's highest frequency.
4. It reduces the speed requirement of ADC and also reduces the amount of digital memory necessary. For Nyquist sampling, sampling frequency is at least twice the maximum frequency of the signal which requires more memory. But in case of band pass sampling since band width is the most important criteria under consideration and hence the sampling rate becomes twice of the band width, which causes a reduction in the memory requirement.
5. In band pass sampling, as the center frequency of the signal increases, more replicas will generate and with that more noise will appear at the base band which causes in the degradation of signal-to-noise ratio.

Advantages of Aliasing in Bandpass sampling :-

It causes the direct down conversion of the band pass signal into the lower frequency region along with digitization.

Requirements of Bandpass Sampling :-

Let's assume we have a continuous input bandpass signal of bandwidth B. Its *carrier frequency* is f_c Hz, i.e., the bandpass signal is centered at f_c Hz. That continuous signal is sampled at a rate, say $f_{s'}$ Hz, so the spectral replications of the positive and negative bands, just butt up against each other exactly at zero Hz. With an arbitrary number of replications, say m, in the range of $2f_c - B$, it can be concluded that

$$mf_{s'} = 2f_c - B \quad \text{or} \quad f_{s'} = \frac{2f_c - B}{m} \; . \qquad (1)$$

Of course m can be any positive integer so long as $f_{s'}$ is never less than $2B$. If the sample rate $f_{s'}$ is increased, the original spectra do not shift, but all the replications will shift. These replications will overlap and aliasing occurs. Thus, for an arbitrary m, there is a frequency that the sample rate must not exceed,

$$f_{s'} \le \frac{2f_c - B}{m} \quad \text{or} \quad \frac{2f_c - B}{m} \ge f_{s'} \; . \qquad (2)$$

If the sample rate is reduced below the $f_{s'}$ the spacing between replications will decrease. Again, the original spectra do not shift when the sample rate is changed. At some new sample rate $f_{s''}$, where $f_{s''} < f_{s'}$, the replication will just butt up against the positive original spectrum centered at f_c. In this condition,

$$(m+1)f_{s''} = 2f_c + B \quad \text{or} \quad f_{s''} = \frac{2f_c + B}{m+1} \; . \qquad (3)$$

Now, f_s may be chosen anywhere in the range between $f_{s''}$ and $f_{s'}$ to avoid aliasing, or

$$\frac{2f_c - B}{m} \ge f_s \ge \frac{2f_c + B}{m+1} \; , \qquad (4)$$

where m is an arbitrary, positive integer ensuring that $f_s \geq 2B$. (For this type of periodic sampling of real signals, known as real or first-order sampling, the Nyquist criterion $f_s \geq 2B$ must still be satisfied.).

If we normalize the minimum sample rate by dividing it by the bandwidth B, we get a curve whose axes are normalized to the bandwidth. Regardless of the value of R, the minimum sampling rate need never exceed $4B$ and approaches $2B$ as the carrier frequency increases. Surprisingly, the minimum acceptable sampling frequency actually decreases as the bandpass signal's carrier frequency increases. We can interpret by reconsidering bandpass signal example, where $R = 22.5/5 = 4.5$. This R value is indicated by the dashed line showing that $m = 3$ and f_s/B is 2.25. With $B = 5$ MHz, then, the minimum $f_s = 11.25$ MHz in agreement with Table. The leftmost line shows the low-pass sampling case, where the sample rate f_s must be twice the signal's highest frequency component. So the normalized sample rate f_s/B is twice the highest frequency component over B or $2R$.

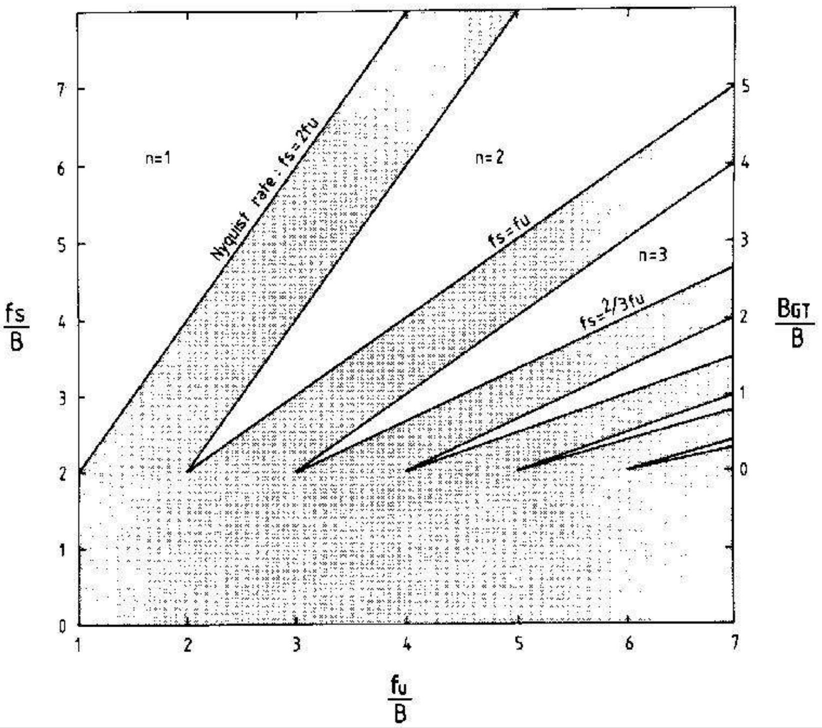


Fig. a Allowed &disallowed(shaded) uniform sampling rates v/s band position.

Chapter 4

Theoretical Study of Bandpass Sampling

Band pass signal specification :-

Band width	**32 MHz**
Center frequency	130 MHz

Interpretation from the sampled signal :-

(1)Here, lower cut-off frequency of the signal = 114 MHz.
Upper cut-off frequency of the signal = 146 MHz.

(2)If sampling frequency is 66.66 MSPS, then Nyquist criteria satisfies, but aliasing occurs in the range of frequency (2*66.66 -114 =) 19.32 MHz.

(3)If sampling frequency is above 292 MHz i. e. in the higher frequency range, then Nyquist criteria satisfies and sampling occurs without aliasing. But in that situation higher frequency region of the spectrum will be wasted and correspondingly the processing overheads for software correlator will increase.

Conclusion :-

(1)Sampling frequency should have to be higher than the Nyquist frequency (292 MHz in this case) to avoid aliasing.

(2)It cannot be taken much higher than the minimum sampling frequency (in this case 64 MHz), then wastage of spectrum occurs.

Solution:

To avoid aliasing with the sampling frequency, the only possible solution is to shift the center frequency by 19.32 MHz i.e. to shift the center frequency at 149.32 MHz.

Band pass signal specification :-

Band width	**32 MHz**
Center frequency	175 MHz

Interpretation from the sampled signal:-

(1)Here, lower cut-off frequency of the signal = 159 MHz.
Upper cut-off frequency of the signal = 191 MHz.

(2)If sampling frequency is above 2*191 = 382 MHz i. e. in the higher frequency range, then Nyquist criteria satisfies and sampling occurs without of aliasing. But in that situation higher frequency region of the spectrum will be wasted and correspondingly the processing time for software correlator will increase.

Conclusion:-

(1)Sampling frequency should have to be higher than the Nyquist frequency to avoid aliasing.

(2)It cannot be taken much higher than the minimum sampling frequency then wastage of spectrum occurs.

Solution:-

To avoid aliasing with the sampling frequency, the only possible solution is to shift the center frequency by 8.98 MHz.

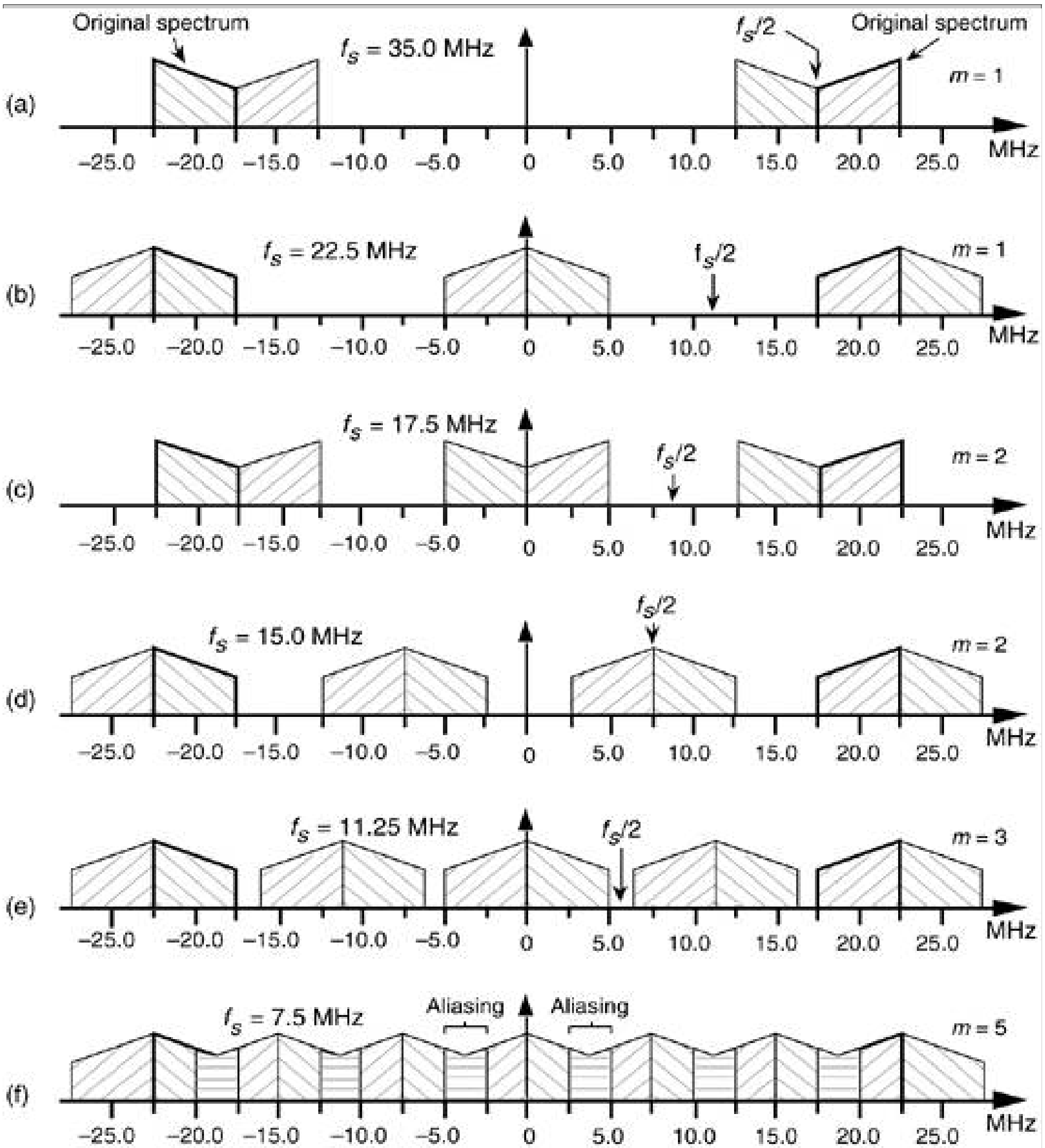


Fig. b Band Pass Sampling Spectrum Conversion with the help of Aliasing

Chapter 5

Experimental Setup & Verifications

Experimental Setup :-

In the frequency conversion panel, the experimental arrangement is such that the noise generating from the noise generator first enters into the amplifier. Then it goes to the 2 way divider, from which one channel enters into the monitoring port and other channel enters into the mixer in which frequencies from local oscillator also gets mixed up. Output of the mixer then enters into low pass filter. The main output of the experimental setup is the output of the mixer. This output can be either band pass signal or base band signal depending on the local oscillator frequency.

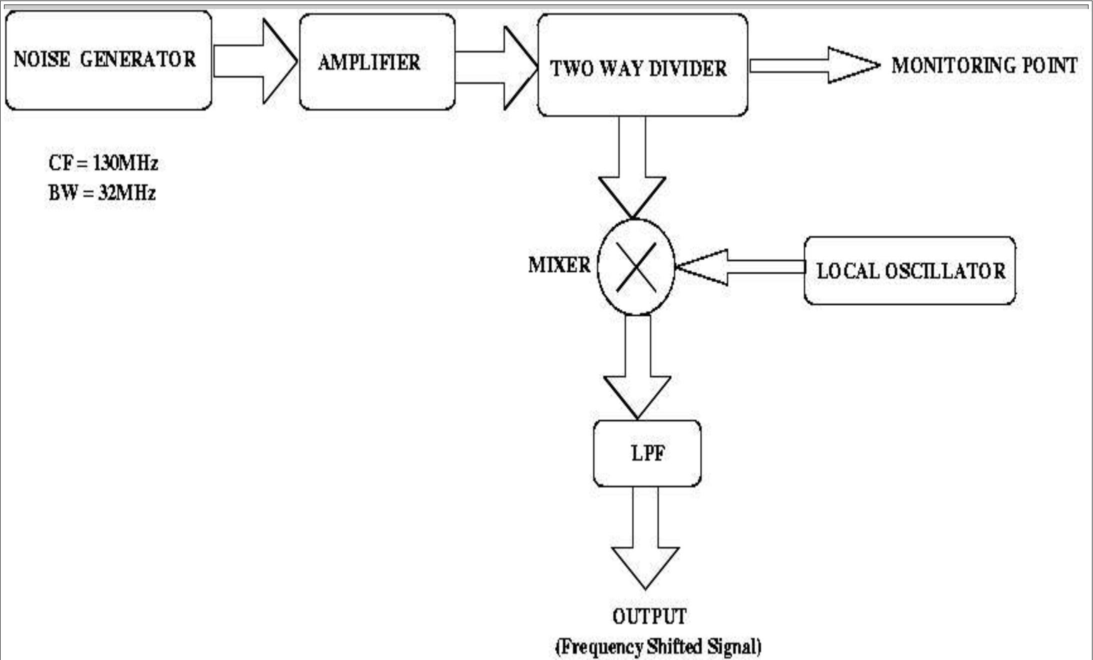


Fig. cFrequency Conversion Panel

Experimental Verification of Base Band Sampling :-

Input Signal Specifications :-

Total power	**-25.5 dBm**
Band width	32 MHz

Sampling Frequency(*fs* = 66.66 MSPS)

Interpretation :-

There is some aliasing on the higher frequency side, almost 20% of the channel includes aliasing. Up to FFT 3400 the sampled signal remains as it is of the input signal, after that aliasing occurs. Hence 66 MSPS is inadequate for 32 MHz base band sampling.

AFTER SAMPLING (sampling frequency = 100 MSPS)

There is almost no difference between the original base band signal spectrum and sampled spectrum because, here sampling rate is much higher than that of the maximum frequency of the base band signal i. e. almost no aliasing occurs.

Conclusion :-

Hence 66MSPS is inadequate for sampling of baseband signal that means in another way 32MHz baseband signal is having pretty higher bandwidth than what is being considered.

Filter Specifications :-

Bandwidth	**32 MHz**
Center Frequency	130 MHz

PARAMETERS	**VALUES**
Positive transition Band width	6 MHz
Negative transition Band width	6 MHz

PARAMETERS	VALUES
1 dB Band width	32 MHz
3 dB Band width	36 MHz
10 dB Band width	38.5 MHz
40 dB Band width	41 MHz

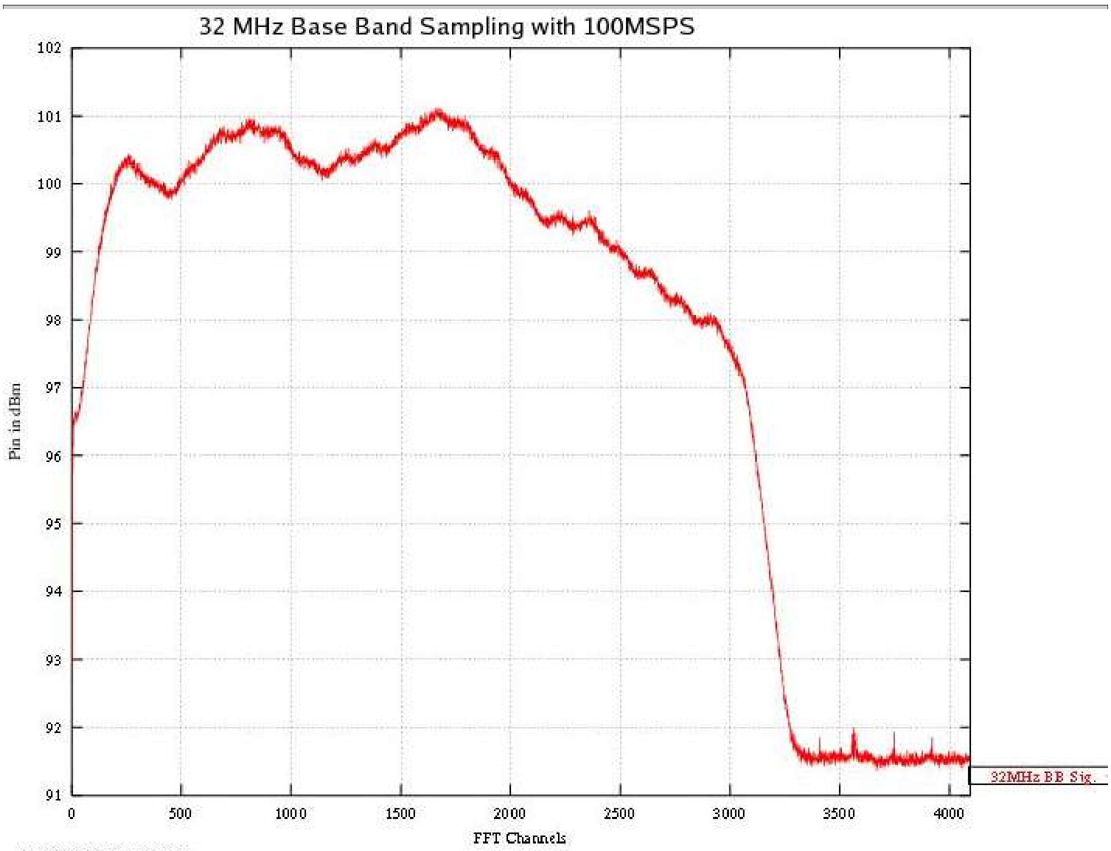


Fig. d 32MHz BB sampling with 100MSPS

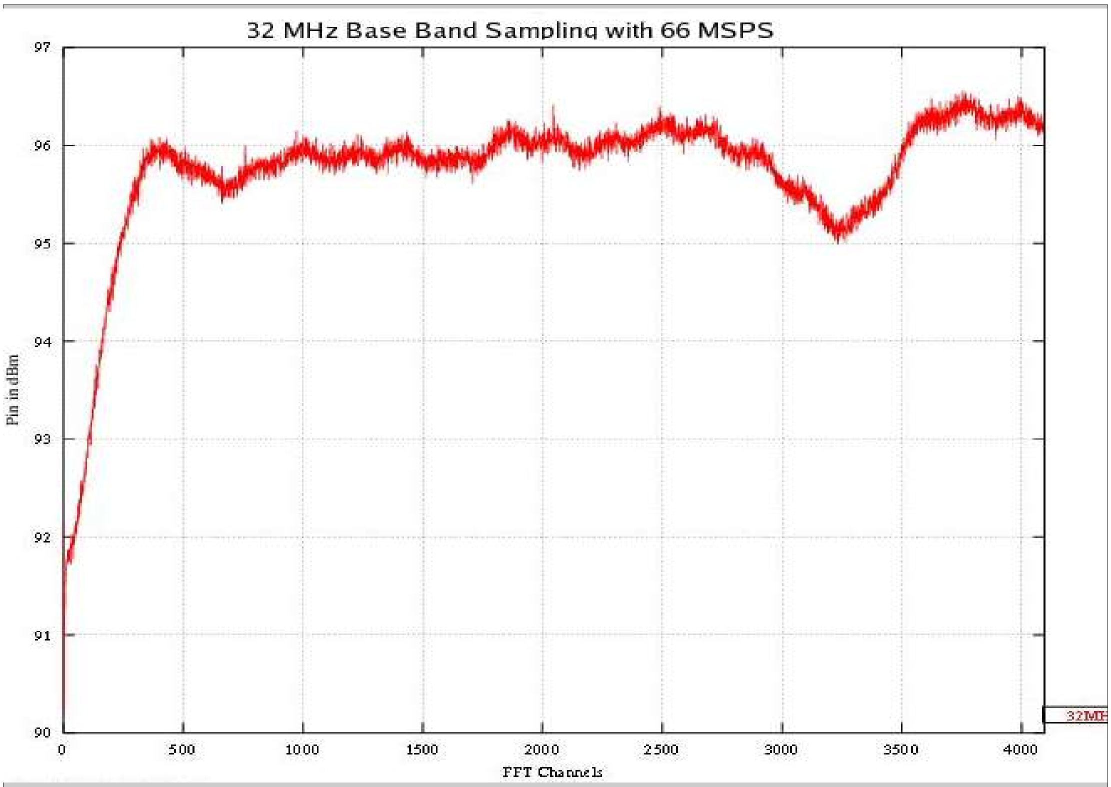


Fig. e 32MHz BB sampling with 66MSPS

<u>Experimental Verification of Bandpass Sampling</u> :-

Input Band Pass signal specification :-

Band width	**36 MHz**
Center frequency	80 MHz
Local Oscillator Frequency	110 MHz
Lower cut-off frequency	62 MHz
Upper cut-off frequency	98 MHz

AFTER SAMPLING (<u>*fs*</u> = 100 MSPS) WITH VGA

Interpretation :-

(1)After sampling the input band pass signal with 100 MSPS, there is almost no difference between the input signal spectrum and the simulated sampled spectrum of the signal.

(2)Since, 100 MHz is out of band of the input band pass signal, hence no aliasing occurs here.

(3)Here, with VGA the sampler card used for the analog-to-digital converter is restricted upto 80 MHz by operation. Due to that restriction a sharp fall off of the spectrum can be shown at the edge and a fine gain control can be observed here.

AFTER SAMPLING (sampling frequency = 100 MSPS) WITHOUT VGA

Interpretation :-

1. After sampling the input band pass signal with 100 MSPS, there is almost no difference between the input signal spectrum and the simulated sampled spectrum of the signal.
2. Since, 100 MHz is is out of band of the input band pass signal thats why no aliasing occurs here.
3. Here, without VGA means the sampler card used for the A to D conversion is not restricted by the limitations of VGA bandwidth up to 80 MHz by operation. Hence no sharp fall can be seen over the edge and a course gain control can be observed.

Input Band Pass signal specification :-

Band width(1 dB)	**32 MHz**
Center frequency	80 MHz
Local Oscillator Frequency	110 MHz
Lower cut-off frequency	62 MHz
Upper cut-off frequency	99.50 MHz

AFTER SAMPLING (sampling frequency = 66.66 MSPS) WITHOUT VGA

Interpretation :-

Since, here sampling frequency falls inside the band of the input band pass signal, Hence a frequency range of (66.66 – 62) MHz or 4.66 MHz gets aliased at the base band.

Comparison between Base Band & Band Pass Sampling :-

By sampling with same sampling frequency, for both base band sampling and band pass sampling same amount of frequency range (4 MHz) has to be aliased theoretically. But the practical scenario is some what different. In band pass sampling along with the signal a reasonable amount of noise also gets folded back. Though same amount of aliasing occurs in both the cases but more noise will appear at the base band due to band pass sampling than base band sampling.

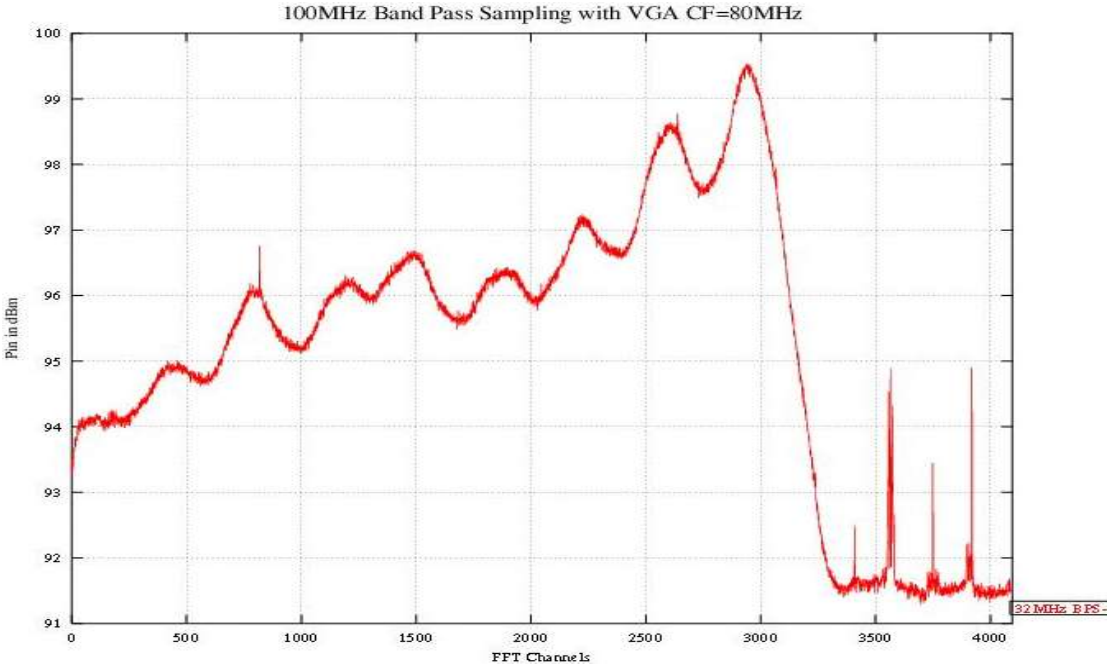


Fig. f100MSPS Bandpass sampling with VGA CF = 80MHz

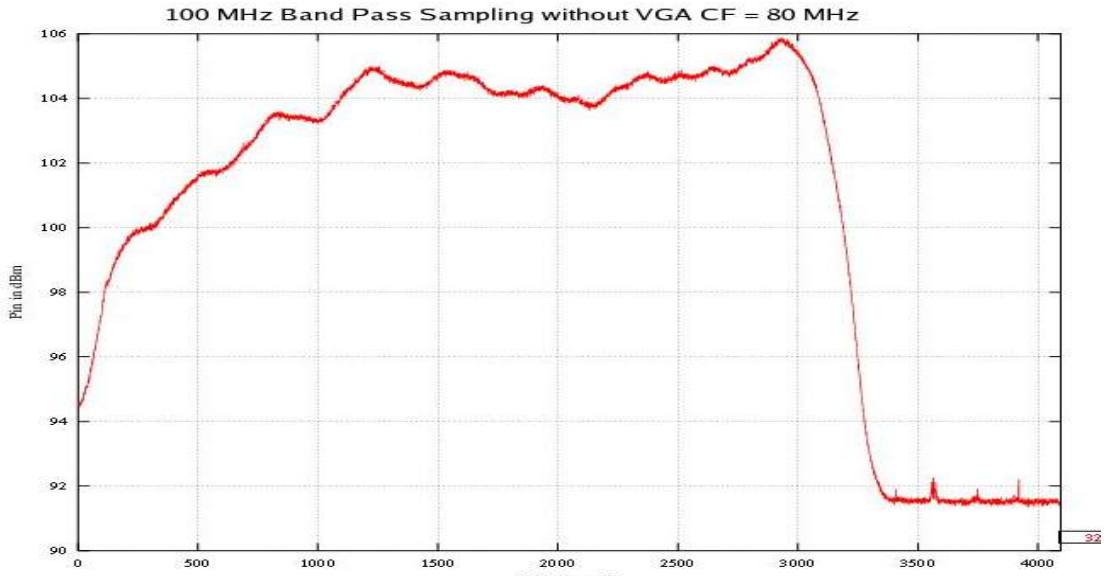


Fig. g 100MSPS Bandpass sampling w/o VGA CF = 80MHz

Chapter 6

Aliasing

Definition :-

Aliasing is an effect that causes higher frequency components takes lower frequency components side. In aliasing different continuous signals to become indistinguishable (or *aliases* to one another) after sampling.

Aliasing also refers to the distortion or artifact that is caused by a signal being sampled and reconstructed as an alias of the original signal.

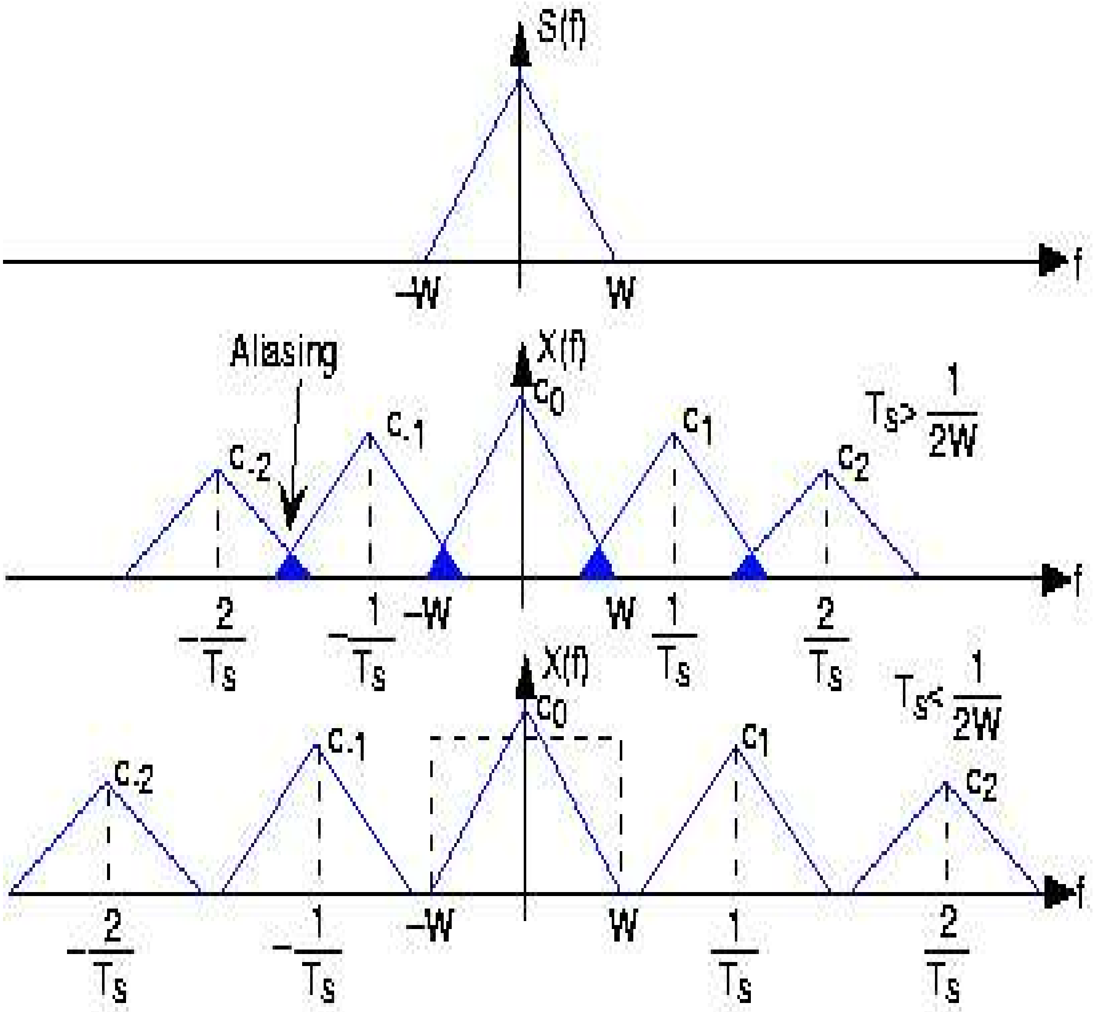
Concept of Aliasing :-

To prevent this aliasing problem, fs must be sufficiently large and the signals must be appropriately before sampling. Specifically, if a sinusoid of frequency f (in cycles per second for a time-varying signal) is sampled f_s samples per second, the resulting samples will also be compatible with a sinusoid of frequency. $Nf_s - f$ and one of frequency $Nf_s + f$, for any integer N. If $f_s > 2f$, the lowest of these image frequencies will be the original signal frequency, but otherwise it will not. In the case that $f_s < 2f < 2f_s$, the lowest image frequencies will be at $f_s - f$, the lowest image frequency in a sense *masquarades* as the sinusoid that was sampled and is called an **alias** of the sinusoid that was actually sampled.

The Nyquist criterion :-

One way to avoid such aliasing is to make sure that there is no periodic components in the signal with a frequency equal to or greater than $f_s/2$. Nyquist criteria -this condition is and is equivalent to saying that the sampling frequency f_s must be high enough; either greater than twice the highest frequency or some other more complicated criterion.

The criterion states is that the minimum sampling rate is $2f_2/m$, where m is the largest integer not exceeding f_2/B. It point out, however, that this lower



bound is not a sufficient condition, since higher sampling frequencies will lead to aliasing in some cases.dhadh

Relation Between Filter Roll-Off, Order and Aliasing :-

As the order of the practical filter increases, more steeper the filter characteristics i. e. more sharper the roll off the filter characteristics. For first order Butter worth filter the steepness of the characteristics is 20 dB/decade, for second order this becomes 30dB/decade and so on. As the order of the filter increases, more steeper is the band shape and amount of aliasing also becomes more less.

Study Aliasing Effect by Varying Center Frequency :-

- **Sampling frequency = 100 MSPS**

(1)Input Noise Signal Specifications :-

Center frequency	**76 MHz**
Local oscillator frequency	206.00 MHz
Lower cut-off frequency	54.00 MHz
Upper cut-off frequency	98.00 MHz
Band width	44.00 MHz

(2)Input Noise Signal Specifications :-

Center frequency	**78 MHz**
Local oscillator frequency	208.00 MHz
Lower cut-off frequency	56.00 MHz
Upper cut-off frequency	100.00 MHz
Band width	44.00 MHz

(3)Input Noise Signal Specifications :-

Center frequency	**80 MHz**
Local oscillator frequency	210.00 MHz
Lower cut-off frequency	58.00 MHz
Upper cut-off frequency	102.00 MHz
Band width	44.00 MHz

Interpretation :-

Since, 100 MHz is outside the band of the band pass signal, so after sampling with 100 MSPS no aliasing effect can be observed, only a little amount of noise due to the application of practical analog-to-digital converter appears at the higher frequency region.

(4)Input Noise Signal Specifications :-

Center frequency	**81 MHz**
Local oscillator frequency	211 MHz
Lower cut-off frequency	59.25 MHz
Upper cut-off frequency	104.50 MHz
Band width	45.25 MHz

Interpretation :-

Since, 100 MHz is inside of the band of the band pass signal, so after sampling with 100 MSPS, a range of frequency (104.50- 100) MHz or 4.50 MHz will be aliased at the base band. Hence a peak can be observed around the lower frequency region of the sampled spectrum in comparison with the actual input signal spectrum.

(5)Input Noise Signal Specifications :-

Center frequency	**82 MHz**
Local oscillator frequency	212 MHz
Lower cut-off frequency	60.38 MHz
Upper cut-off frequency	105.00 MHz
Band width	44.62 MHz

Interpretation :-

Since, 100 MHz is inside the band of the band pass signal, so after sampling with 100 MSPS, a range of frequency (105.00-100) MHz or 5.000 MHz will be aliased at the base band. Hence a peak can be observed around the lower frequency region of the sampled spectrum in comparison with the actual input signal spectrum.

(6)Input Noise Signal Specifications :-

Center frequency	**84 MHz**
Local oscillator frequency	214 MHz
Lower cut-off frequency	62.50 MHz
Upper cut-off frequency	107.25 MHz
Band width	44.75 MHz

Interpretation :-

Since, 100 MHz is inside of the band of the band pass signal, so after sampling with 100 MSPS, a range of frequency (107.25-100) MHz or 7.25 MHz will be aliased at the base band. Hence a peak can be observed around the lower frequency region of the sampled spectrum in comparison with the actual input signal spectrum.

Conclusion :-

As the center frequency of the CW signal increases from the lower frequency region to the higher frequency region, the effect of aliasing will increase after sampling with a particular sampling rate in every situation and correspondingly a portion of frequency gradually increases at the base band of the sampled spectrum in comparison of the input signal spectrum.

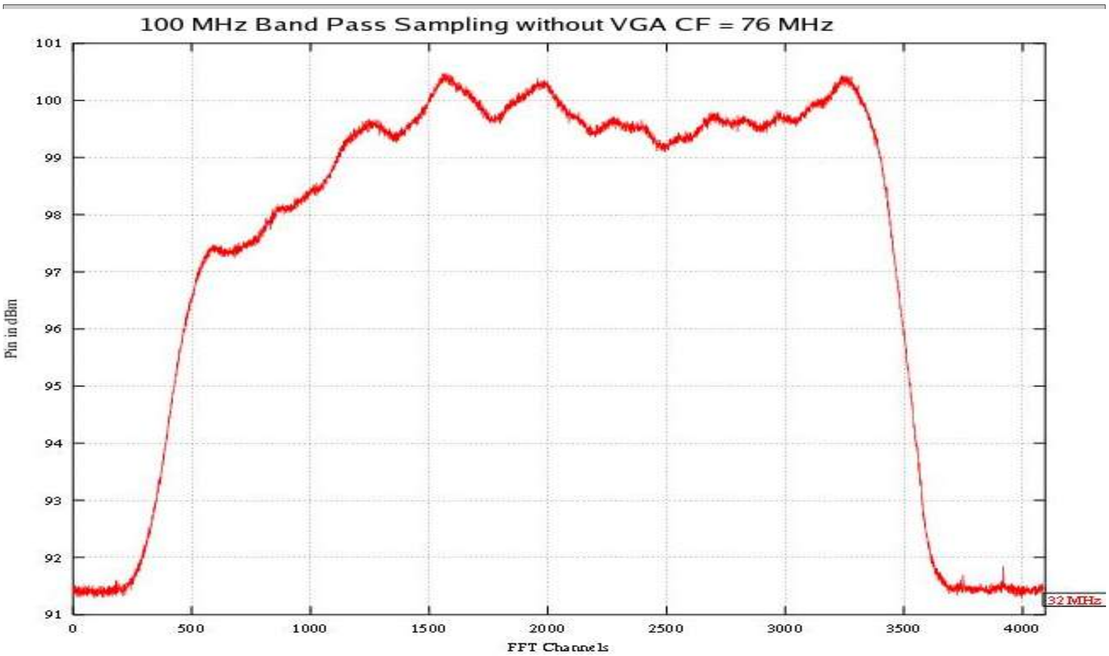


Fig. h CF = 76MHz with 100MSPS Bandpass sampling without VGA.

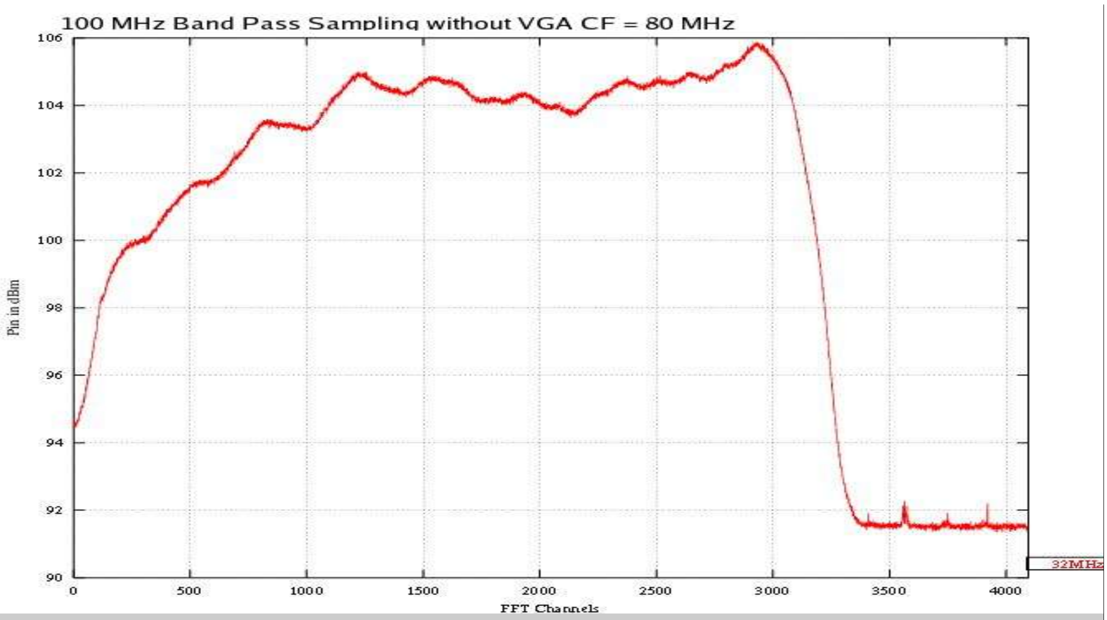


Fig. i CF = 80MHz with 100MSPS Bandpass sampling without VGA.

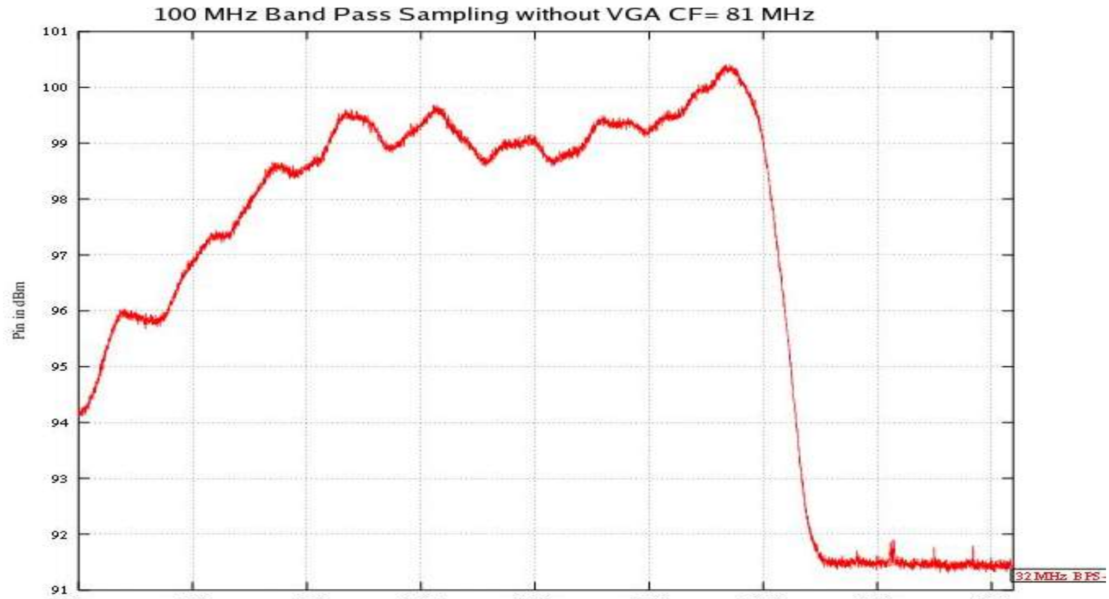


Fig. j CF = 81MHz with 100MSPS Bandpass sampling without VGA.

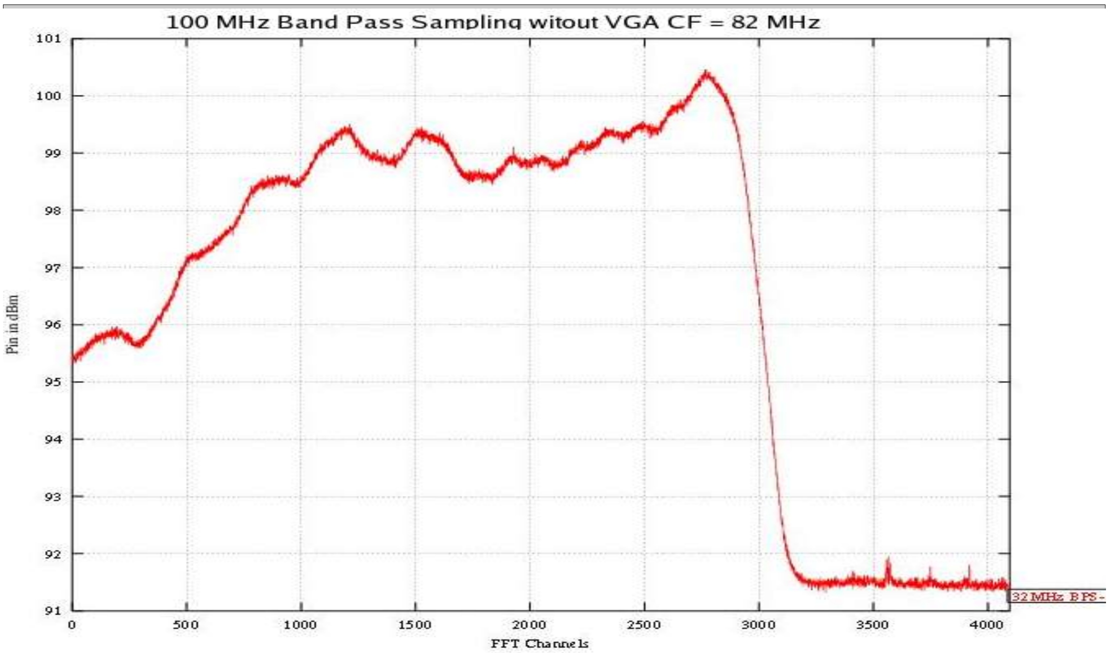


Fig. k CF = 82MHz with 100MSPS Bandpass sampling without VGA.

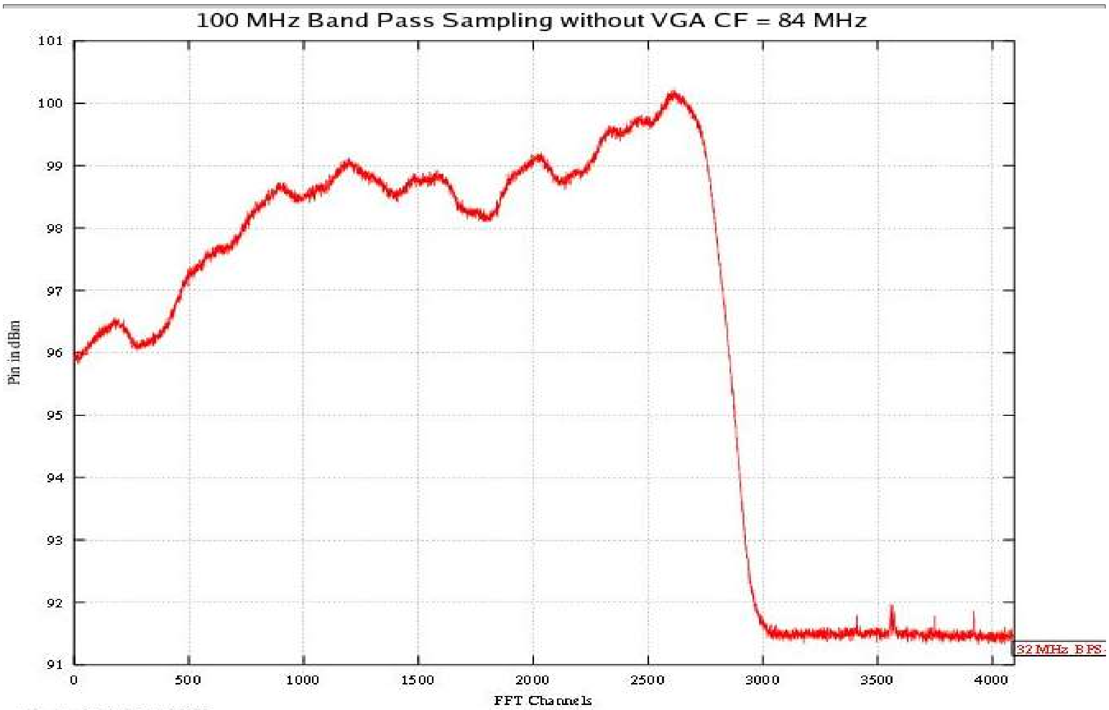


Fig. lCF = 84MHz with 100MSPS Bandpass sampling without VGA.

Chapter 7

Noise In Bandpass Sampled Signals

Noise considerations are not only important only when signal-to-noise is important, but also in the measurement of noise itself. In a sampling system, the periodicity of the spectrum includes a wide out of band noise, are all combined into each of the *fs/2* bands. In applying bandpass sampling to relocate a bandpass signal to a low-pass position, the resulting signal-to-noise ratio will be poorer than that from that of baseband sampled version, in which the signal-to-noise ratio will be preserved. For a system with a bandpass signal of spectral power density S, in-band noise power density of Np, and out-of-band noise power density No. The signal-to-ratio is then S/Np.

For Uniform Noise Spectrum :-

The signal-to-noise ratio for the sampled signal becomes degraded by at least the noise aliased from the bands between dc and the passband, and is thus,

$$SNR = S/Np + (n-1)No \qquad (1)$$

Where, n= no. of bands in the spectrum.

Now, under this situation two cases may arise,

Case-I : (Np>>No)

Signal-to-noise ratio is established before sampling.

Case-I : (Np=No)

Assuming n>>1, signal-to-noise ratio is established after sampling and the degradation in signal-to-noise ratio is

$$D = 10*\log n \qquad (2)$$

For Uniform Noise Spectrum :-

Here, a conservative estimate of the noise power density in each of the bands in the sampled spectrum can be obtained by equating the noise power before and after sampling .

Let, Nea = equivalent noise spectral density of the original signal

Bea = equivalent noise bandwidth of the analog signal

Nes = equivalent noise spectral density of the sampled signal with 2B sampling rate (according to Nyquist criterion), then

$$Nea*Bea = Nes*B \qquad (3)$$

The degradation in signal-to-noise ratio becomes Nes / Nea which, in decibels, is then at least

$$D = 10*\log*(Bea/B) \qquad (4)$$

In general, the potential for signal-to-noise ratio degradation in bandpass sampling systems is considerable, even when the analog spectrum contains only thermal noise.

Noise Effect in Base Band sampling & Band Pass Sampling :-

In band pass sampling noise between DC to bandpass signal gets folded back and appears at the base band. As the center frequency gets higher more amount of noise will be aliased at the base band and the signal's carrier-to-noise ratio will degrade.

Where, in case of base band of sampling there is no question of aliasing of noise and it's signal-to-noise ratio becomes preserved.

Conclusion :-

- For doing bandpass sampling the bandwidth of the band limited signal should be taken as stop band bandwidth instead of 3dB bandwidth.
- For practical bandpass sampling, there is a need to sample at above the theoretical minimum rate. In order to increase the sampling rate care should be taken for the bands for which aliasing will occur. Operating at a non minimum sampling rate is equivalent to the introduction to the guard bands or a corresponding tolerance, the guard-band size, and the various allowed non minimum sampling rates.
- The band has to be integer positioned and to be sampled with uniform sampling.
- In the sampling process, the signal becomes degraded owing to aliasing of the noise, between DC and at least the original band pass spectral position. This degradation is unavoidable and simple estimate for the degradation can be estimated in terms of band position.

Chapter 8

Sampler Card Analog Bandwidth Test

Experimental Aim :-

Initially a 3 MHz CW signal was sampled with 33.33MSPS. Here, sampler card with VGA has been used which is theoretically restricted up to 450 MHz. Now the frequency of CW signal was increased up to 500 MHz in a fashion of fs+/-3, 2fs+/-3 and so on, and every time the carrier power of the signal and the corresponding FFT channel had been observed, after sampling with the same sampling rate. At last for some of the frequencies carrier-to-noise ratio were calculated.

● **Sampling rate, fs = 33 M Samples/sec**

CENTER FREQUENCY (in MHz)	CARRIER POWER (dBm)	CHANNEL
3	7.26E+013	739
33.33	1.15E+014	739
36.33	5.13E+013	737
63.66	1.91E+014	740
69.66	1.67E+014	737
130.32	1.56E+014	741
136.32	1.19E+015	735
196.98	1.04E+013	742
202.98	3.72E+012	735
263.64	1.20E+013	744
269.64	1.23E+013	732
330.3	3.27E+012	746

CENTER FREQUENCY (in MHz)	**CARRIER POWER (dBm)**	**CHANNEL**
336.3	1.96E+012	730
396.96	1.44E+012	747
402.96	5.50E+011	728
430.29	1.06E+010	1494
436.29	1.02E+010	728
463.62	1.03E+006	749
469.62	9.82E+004	740
496.95	6.71E+013	3

Calculation for Carrier To Noise Ratio (CNR) :-

FREQUENCY (MHz)	**CNR**
3	1.05E+005
36.33	7.90E+004
69.66	7.10E+004
136.32	5.80E+004
202.98	4.10E+004
269.64	1.42E+004
336.3	6.40E+002

Interpretation :-

- By sampling the CW signal of increasing frequencies with constant sampling rate (33 MSPS), it was observed that the carrier or signal power decreases constantly with the increasing frequency. Initially it was highest and at about 469.62 MHz no effective carrier power can be detected. When the sampling rate was increased above of 469.95 MHz, at around 500 MHz only noise power was in picture at the two extreme channels.
- As the frequency of the CW signal increases, then after sampling the signal for every frequency with same sampling rate, carrier-to-noise ratio decreases constantly.

Conclusion :-

Since, here the ADC card has a theoretical limitation up to 450 MHz, which can be practically explained from this decreasing carrier power interpretation. Practically can be said that the analog band width of the sampler card is around 470 MHz. This can be interpreted from the corresponding carrier power plot.

As the CW signal shifts to the higher frequency region more noise will appear due to band pass sampling of the signal and hence the carrier-to-noise ratio decreases.

Chapter 9

Summary And Future Work

Summary :-

1. Theoretical study of band pass sampling and aliasing.
2. Experimental verification for base band sampling.
3. Experimental verification for band pass sampling.
4. Experimental verification on the effect of aliasing in band pass sampling by varying the center frequency of the noise signal.
5. Theoretical study of the effect of noise in band pass sampling.
6. Experimental verification of the effect of noise in band pass sampling and the degradation of carrier-to-noise ratio.
7. Determination of the analog band width of the sampler card.

Future Work :-

- The RF signal has to be digitized and down converted at the antenna base directly and the sampled signal has to be directly received to the front-end. For that purpose AD converter with much higher conversion rate and analog input bandwidth will be required.
- The current limitation of the sampler card used in the present GMRT receiver system is that it has coarse gain control over a wide analog input bandwidth or fine gain controle over very narrow analog bandwidth and has to be overcome with fine gain control over much wide input bandwidth.

REFERENCES

1. Vaughan, R., Scott, N. and White, D.
   "The Theory of Bandpass Sampling"
   IEEE Trans. on Signal Processing, Vol 39, No. 9, September 1991, pp. 1973-1984.

2. Acquisition Logic AL 81004C PCI Digitizer, manual.

3. Richard G. Lyons
   inform IT-understanding of DSP.

4. Proakis and Manolakis
   "Digital Signal Processing"
   Third edition.

5. Feldman, C.B., and Bennet, W.R.
   "Band width and Transmission Performance"
   Bell system Tech. journalvol. 28.

6. Hill,G.
   "The Benefits of Under sampling"
   Electronic Design, July 11, 1994.

7. Lyons, R.G.
   "How Fast Must You Sample"
   Test and Measurement World, November 1988.