THE EFFECT OF PULSE SHAPING QPSK ON BANDWIDTH EFFICIENCY

Josua Bisuk Mubyarto Purba, S.T.
Sheila Horan

THE EFFECT OF PULSE SHAPING QPSK ON BANDWIDTH EFFICIENCY

OVER A NON-LINEAR CHANNEL.

BY

JOSUA BISUK MUBYARTO PURBA, S.T.

A technical report in partial fulfillment

of the requirements for the Degree

Master of Science in Electrical Engineering

New Mexico State University

Las Cruces, New Mexico

June 1997

ABSTRACT

THE EFFECT OF PULSE SHAPING QPSK ON BANDWIDTH EFFICIENCY

OVER A NON-LINEAR CHANNEL.

BY

JOSUA BISUK MUBYARTO PURBA, S.T.

Master of Science in Electrical Engineering

New Mexico State University

Las Cruces, New Mexico, 1997

Dr. Sheila B. Horan, Chair

This research investigates the effect of pulse shaping QPSK on bandwidth efficiency over a non-linear channel. This investigation will include software simulations and the hardware implementation. Three kinds of filters: the 5th order Butterworth filter, the 3rd order Bessel filter and the Square Root Raised Cosine filter with a roll off factor (α) of 0.25, 0.5 and 1, have been investigated as pulse shaping filters. Two different high power amplifiers, one a Traveling Wave Tube Amplifier (TWTA) and the other a Solid State Power Amplifier (SSPA) have been investigated

in the hardware implementation. A significant improvement in the bandwidth utilization (ρ) for the filtered data compared to unfiltered data through the non-linear channel is shown in the results. This method promises strong performance gains in a bandlimited channel when compared to unfiltered systems. This work was conducted at NMSU in the Center for Space Telemetering and Telecommunications Systems in the Klipsch School of Electrical and Computer Engineering Department and is supported by a grant from the National Aeronautics and Space Administration (NASA) # NAG 5-1491.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

α	Rolloff Factor for SRRC filters
ρ	Bandwidth Utilization Ratio
dB	Decibels
dBm	Decibels (1 milliwatt reference)
BPSK	Binary Phase Shift Keying
BW	Bandwidth
CCSDS	Consultative Committee for Space Data Systems
ESA	European Space Agency
GMSK	Gaussian Minimum Shift Keying
GHz	Giga Hertz
HP	Hewlett Packard
IF	Intermediate Frequency
ISI	InterSymbol Interference
JPL	Jet Propulsion Laboratory
MSK	Minimum Shift Keying
NASA	National Aeronautics and Space Administration
NMSU	New Mexico State University
NRZ-L	Non-Return-to-Zero Logic
OQPSK	Offset Quaternary Phase Shift Keying
PSK	Phase Shift Keying

QPSK	Quartenary Phase Shift Keying
Rb	Bit Rate
Rs	Symbol Rate
SFCG	Space Frequency Coordination Group
SPW	Signal Processing Worksystem
SSPA	Solid State Power Amplifier
SRRC	Square Root Raised Cosine
TWTA	Traveling Wave Tube Amplifier
TDRSS	Tracking and Data Relay Satellite System

Chapter 1

INTRODUCTION AND BACKGROUND

In recent years, the demand for communications systems that transmit more data through a bandwidth limited channel is increasing rapidly. The need for bandwidth efficient modulation schemes has driven a great deal of research in this area. One such method for bandwidth efficiency is Pulse Shaping or Spectrum Shaping. Spectrum shaping is a technique that concentrates the signal energy near the carrier and reduces the power contained in the side lobes. This pulse shaping can be done at baseband or at bandpass. In this research, both of them will be investigated.

At the 12th annual meeting of the Space Frequency Coordination Group (SFCG-12), held during November 1992 in Australia, the SFCG requested the Consultative Committee for Space Data Systems (CCSDS) Radio Frequency (RF) and Modulation Subpanel to study and compare various modulation schemes with respect to the bandwidth efficiency, power efficiency, spurious emissions and interference susceptibility. As a result of this meeting, some research regarding spectrum shaping combined with modulation techniques such as Binary Phase Shift Keying (BPSK), Offset Quaternary Phase Shift Keying (OQPSK) and Gaussian Minimum Shift Keying (GMSK) were conducted for the CCSDS-SFCG [1]-[4] by the Jet Propulsion Lab (JPL) and by European Space Agency (ESA) [14]. The simulations of pulse shaping on 8-PSK signaling over non linear satellite channels were performed on the Signal

Processing Worksystem (SPW) [1] simulation software at New Mexico State University (NMSU) in the Center for Space Telemetring and Telecommunications Systems where the power containment, spurious emissions, symbol error rates and non-constant envelope effect on the bandwidth were measured for different types of spectrum shaping filters [11].

The purpose of this research is to investigate the effect of pulse shaped QPSK on bandwidth efficiency over a non-linear channel with software simulations and hardware implementation. Two different high power amplifiers, a Traveling Wave Tube Amplifier (TWTA) and a Solid State Power Amplifier (SSPA), have been utilized and analyzed in the hardware implementation. This work was conducted at NMSU in the Center for Space Telemetering and Telecommunications Systems in the Klipsch School of Electrical and Computer Engineering Department and is supported by a grant from the National Aeronautics and Space Administration (NASA) # NAG 5-1491.

The first chapter of this report has given a brief introduction and background of the work. Chapter 2 will describe the software simulations including the results and Chapter 3 will explain the hardware implementation with the results. Finally, conclusions and suggestions for further work are given at the end of this report in Chapter 4.

---

[1] SPW is a registered trademark of COMDISCO systems, a Business Unit of Cadence Design Systems, Inc. 919 East Hillsdale Blvd., Foster City, CA 94404.

Chapter 2

SOFTWARE SIMULATIONS

This section will describe the software simulations on the effect of pulse shaping QPSK on bandwidth efficiency over a non-linear satellite channel including the results. The software simulations were conducted on Signal Processing Worksystem (SPW) software installed on a SUN Sparc Station 10 and a Hewlett Packard (HP) Model 715/100 Unix Station. The block diagram of the system is given in the Figure 2.1 below:

```
┌──────────┐      ┌──────────┐      ┌──────────┐
│ QPSK     │ ───▶ │ Spectrum │ ───▶ │ Power    │ ───▶
│ Modulator│      │ Shaping  │      │ Amplifier│
└──────────┘      └──────────┘      └──────────┘
```
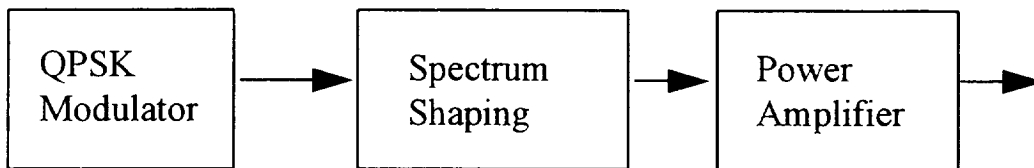
Figure 2.1 - The Block Diagram of The System

Quaternary Phase Shift Keying (QPSK) modulates the Non-Return to Zero Level (NRZ-L) ideal data formats that have symmetric data and the probabilities of 0 and 1 are equal to 0.5. The QPSK signal is at baseband. All simulations were produced at baseband using the complex envelope signal representation. The advantage of using baseband representation is that the computer takes longer to simulate at bandpass since the sampling frequency must be at least twice the highest frequency. The pulse shaping filter or in this case the baseband spectrum shaping filter is used at the output of the modulator. The

3

filters that are used for this research are the 5th order Butterworth filter, the 3rd order Bessel filter and the Square Root Raised Cosine (SRRC) filter with roll off factor 0.25, 0.5 and 1. All of these filters are chosen to be consistent with JPL's work and the CCSDS request. The simulations use the Solid State Power Amplifier (SSPA) at its saturation level to maximize the power. Since the main concern of this research is the bandwidth utilization of the signal bandwidth over the non-linear channels, the bandwidth of the signal with and without the pulse shaping filters are measured at the output of the SSPA. The bandwidth is defined as a point where the power spectra has -50 dB down from the maximum value on the main lobe. Another parameter that is used to measure the bandwidth is BT, which is defined as the multiplication of the bandwidth of the filter and the symbol rate (Rs).

The following specifications were implemented in SPW for the system:

1. The format of the data is NRZ-L.

2. The data is ideal (data is symmetric and the probabilities of 0 and 1 are equal to 0.5).

3. The symbol rate of the QPSK signal is 1 symbol per second (sps).

4. The sample rate is 256 samples/second.

5. The carrier frequency = 0 Hz (baseband simulations).

6. The baseband pulse shaping filters (do not include resistive and reactive losses):

   - Butterworth 5th order (BT=1,2,3)

   - Bessel 3rd order (BT=1,2,3)

   - SRRC with rolloff factor (α) = 0.25, 0.5 and 1

7. The Solid State Power Amplifier (SSPA) model is based on the European Space Agency (ESA) requirements and is 10 watts.

Note: this SSPA was recommended for deep space missions.

2.1 QPSK Source

QPSK is one type of MPSK signal that has constant envelope and modulates 2 bits of data within its 4 phases. Figure 2.2 shows the QPSK signal constellation. It can be seen that each signal point (x) corresponds to one of four phases given by:

$$\theta_1 = 45° \text{ for symbol 00 (decision region: 0° to 90°)}$$

$$\theta_2 = 135° \text{ for symbol 01 (decision region: 90° to 180°)}$$

$$\theta_3 = 225° \text{ for symbol 11 (decision region: 180° to 270°)}$$

$$\theta_4 = 315° \text{ for symbol 10 (decision region: 270° to 360°)}$$
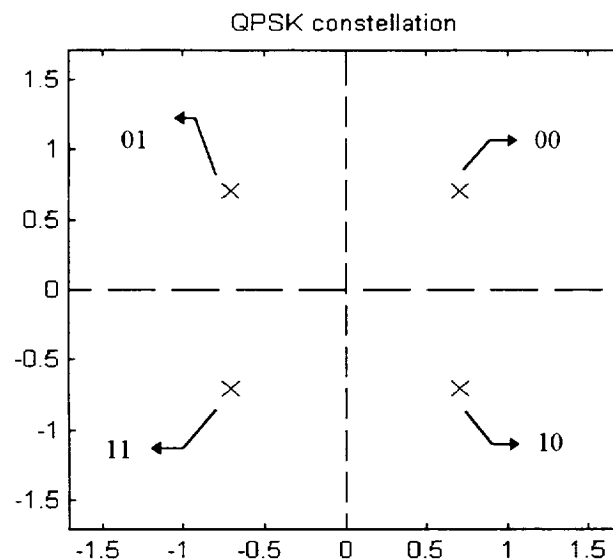
Figure 2.2 QPSK Signal Constellation

One way to describe the QPSK signal is by using two orthogonal carriers modulated by

x and y components of the complex envelope thus

$$g(t) = A_c e^{j\theta(t)} = x_i(t) + j\,y_i(t)$$

where $x_i(t) = A_C \cos\theta_i(t)$ and $y_i(t) = A_C \sin\theta_i(t)$ where $i = 1$ to 4 for QPSK as shown

in Figure 2.2.[11]

For the simulations, a QPSK modulator can be made from the MPSK modulator used

for the 8PSK simulations [11] as shown in Figure 2.3 below where the values of C_i vary

depending on the desired modulator as given in Table 2.1.
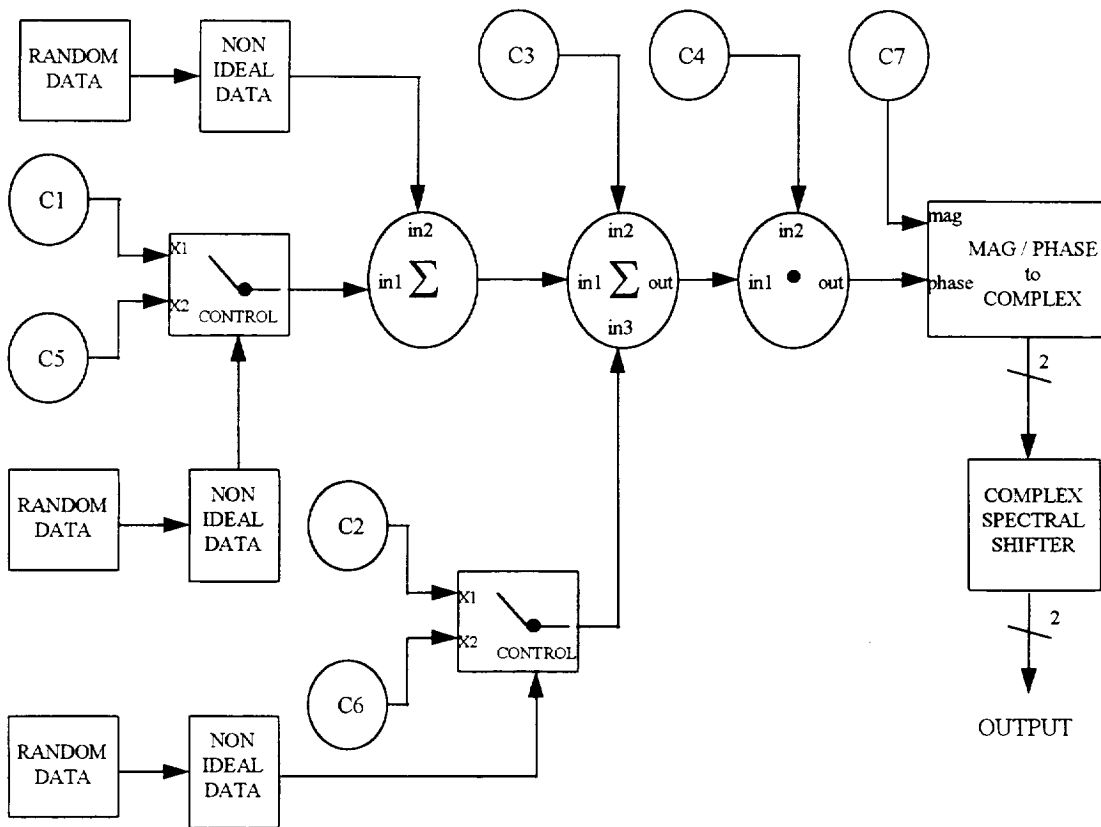
Figure 2.3 - Block Diagram For The BPSK, QPSK and 8PSK Modulator on SPW

6

Table 2.1 Values of Ci for the BPSK, QPSK and 8PSK Simulation Model

Modulation Type	C1	C2	C3	C4	C5	C6	C7
BPSK	0.0	0.0	0.0	$2\pi/2$	0.0	0.0	$(2)^{1/2}$
QPSK	2.0	0.0	0.5	$2\pi/4$	0.0	0.0	$(2)^{1/2}$
8PSK	2.0	4.0	0.5	$2\pi/8$	0.0	0.0	$(2)^{1/2}$

For QPSK, C1=2.0, C2=0.0, C3=0.5, C4=$2\pi/4$, C5=C6=0.0 and C7=$(2)^{1/2}$ are chosen.

2.2 Spectrum Shaping

As mentioned before, the filters that are used for this research are the 5th order Butterworth filter, the 3rd order Bessel filter and the Square Root Raised Cosine (SRRC) filter with roll off factor of 0.25, 0.5 and 1.

2.2.1 Butterworth Filter

The Butterworth family of filters is known to have a "maximally" flat response in the passband region [9]. This is why Butterworth Filters are commonly used. For an example, Figure 2.4 and Figure 2.5 (programmed with Matlab) show the amplitude response and phase response for the 5th order Butterworth filter with cut off frequency 1 Hz. In Figure 2.4 it appears that the amplitude is almost flat as the frequency approaches the cutoff frequency. It can be seen from Figure 2.5 that the phase response changes from a negative number to a positive number when the frequency is close to the cut off frequency in the passband region.
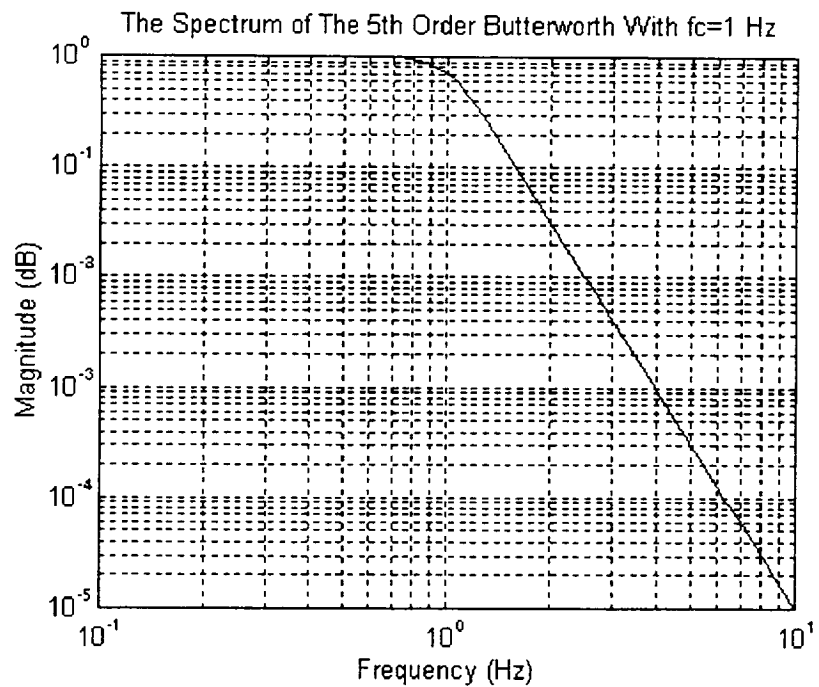
Figure 2.4 - Simulated Amplitude Response of 5th Order Butterworth Filter
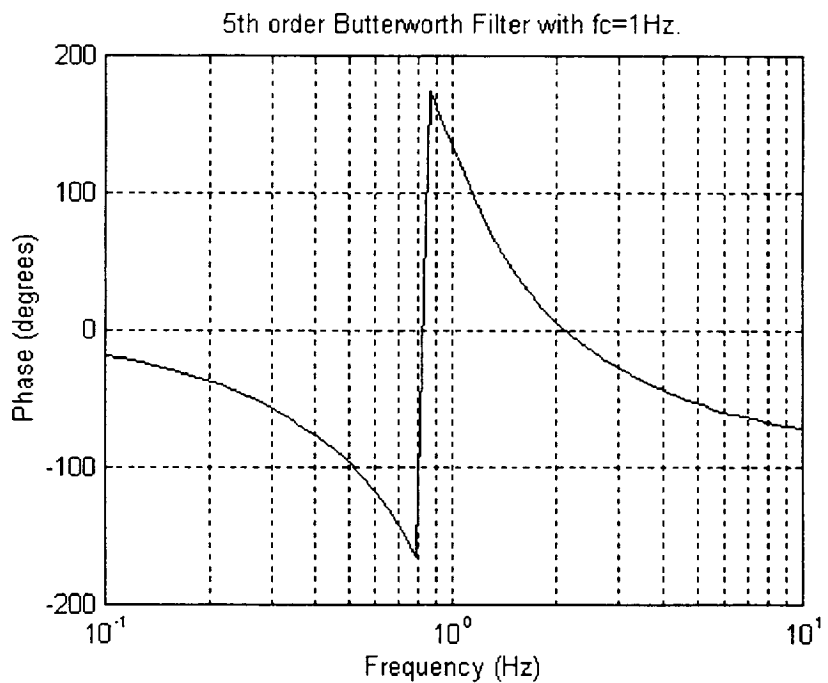
Figure 2.5 - Simulated Phase Response of 5th Order Butterworth Filter

2.2.2 Bessel Filter

The main characteristic of the Bessel family of filters is that they have a relative linear phase in the passband region. This linear phase will have a tendency to prevent dispersion of the signal and therefore would be good for digital pulses. For an example, Figure 2.6 and Figure 2.7 (were programmed with Matlab) show the amplitude response and phase response of the 3rd order Bessel Filter with cut off frequency 1 Hz. The amplitude response for the Bessel filter is not as flat in the passband region as for the 5th order Butterworth filter and the transition from the passband to the stopband region is not as rapid as for the 5th order Butterworth filter. It can be seen in Figure 2.7 that the phase changes from a negative value to a positive value at a frequency after the cut off frequency (1 Hz). This change will have little effect the signal since it is outside of the pass band.
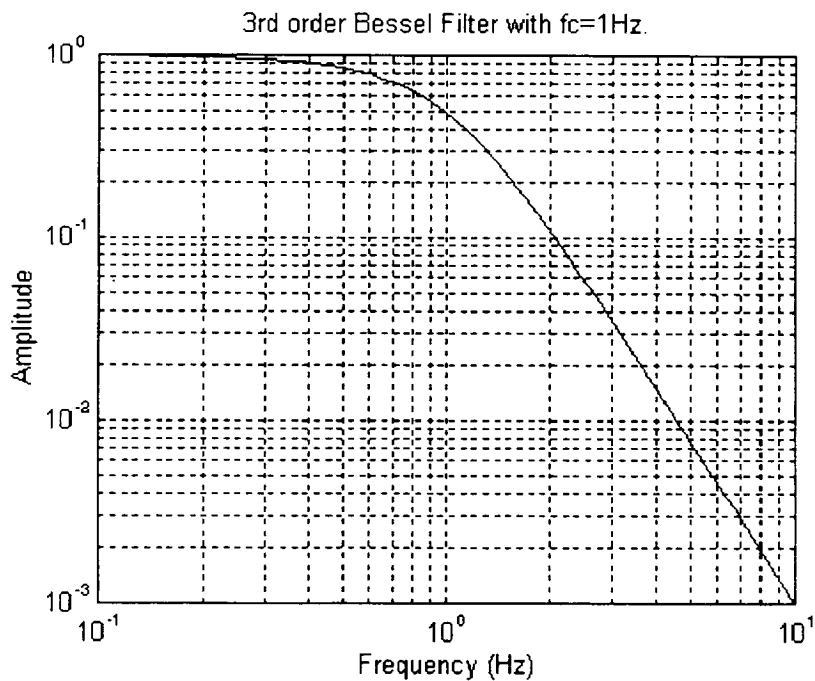
Figure 2.6 - Simulated Amplitude Response of 3rd Order Bessel Filter

9
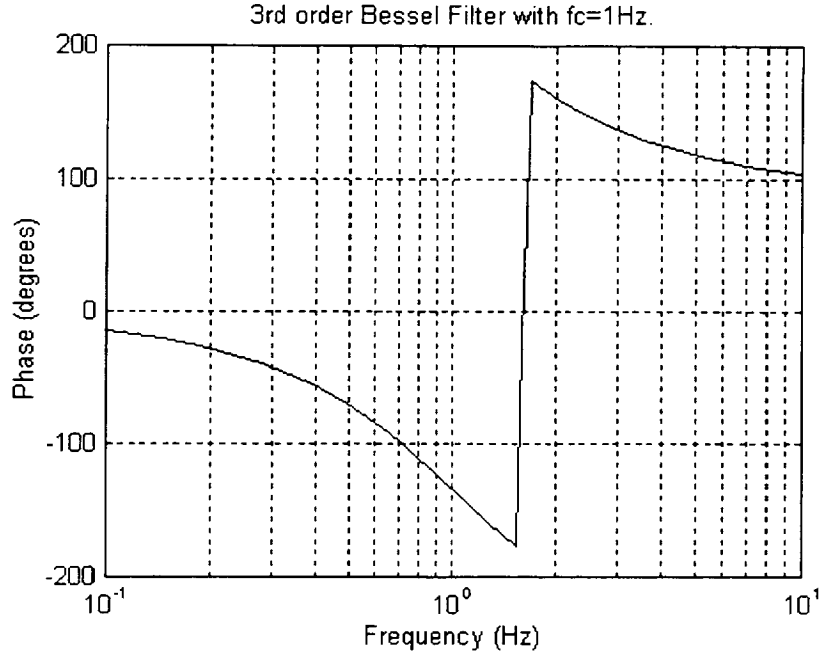
Figure 2.7 - Simulated Phase Response of 3rd Order Bessel Filter

2.2.3 Raised Cosine Filters

The Raised Cosine filters are used to eliminate the ISI in a linear channel. The idea behind the Raised Cosine Filter is that the time signal goes through zero at adjacent sampling points therefore eliminating the interference of other symbols.

The transfer function of the Raised Cosine Filter is [5]

$$Xrc(f) = \begin{cases} T, & 0 \leq |f| < \frac{(1-\alpha)}{2T} \\ \frac{T}{2}\left(1+\cos\left[\frac{\pi T}{\alpha}(|f|-\frac{1-\alpha}{2T})\right]\right), & \frac{(1-\alpha)}{2T} \leq |f| \leq \frac{(1+\alpha)}{2T} \\ 0, & |f| > \frac{(1+\alpha)}{2T} \end{cases}$$

where the zeros will occur at t=nT (T is the sampling interval) and α is the rolloff factor of the excess bandwidth which can be varied from 0 to 1. For an example, Figure 2.8 and

10

Figure 2.9 (were programmed with Matlab) show the frequency response and the time

domain response of the Raised Cosine filter with different rolloff factors ($\alpha = 0$, 0.25,

0.5 and 1) and T = 1 second. The Raised Cosine filters satisfy the Nyquist pulse shaping

criterion or Nyquist condition for zero ISI as mentioned in [8][5].
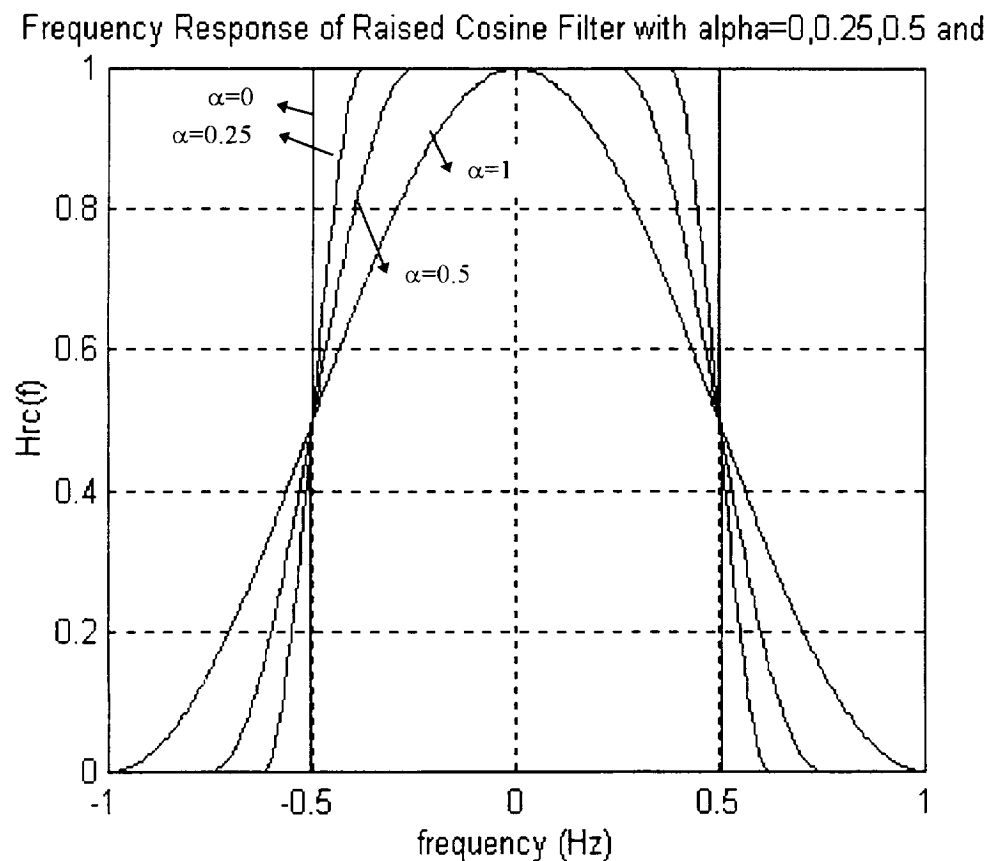
Figure 2.8 - Frequency Response: Raised Cosine Filters with α=0,0.25,0.5 and 1
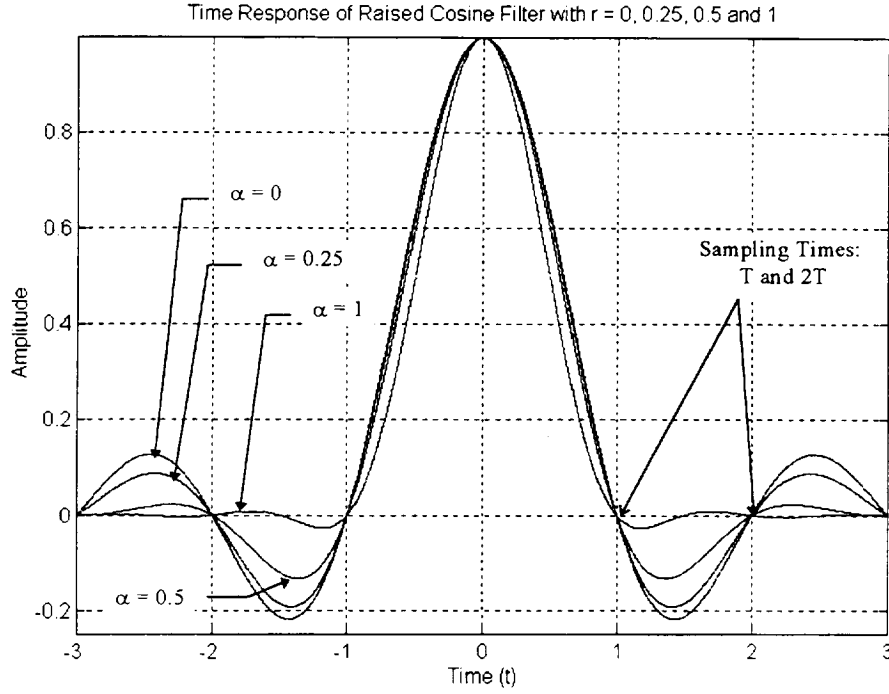
Figure 2.9 - Time Response of Raised Cosine Filters for α=0,0.25,0.5 and 1.

To produce a zero ISI channel the frequency response shown before has to be created. If the frequency response of the transmitter filter and receiver filter are X_T and X_R respectively and the frequency response of the channel is C, then to get the zero ISI the total frequency response of X_T, X_R and C must be equal to X_{rc} as given above or :

$$X_{rc} (f) = X_T (f) . C (f) . X_R (f)$$

If the channel has a large bandwidth compared to the bandwidth of the transmitter and the receiver frequency response or C(f) = 1 for $|f| \leq W$ where W is the bandwidth of the X_T and X_R then

$$X_{rc} (f) = X_T (f) . X_R (f)$$

To get the optimum result, the transmitter filter has to be matched to the receiver filter so

we need to make $X_T(f) = X_R(f)$. Thus

$$X_{rc}(f) = |X_T(f)|^2$$

and

$$X_T(f) = X_R(f) = (X_{rc})^{1/2} = \text{Square Root Raise Cosine Filter} = \text{SRRC}$$

Figure 2.10 shows the eye diagram if the SRRC filter with $\alpha=0.5$ is applied to both the

transmitter filter and receiver filter. Again, if we sample the signal at the right sampling

frequency, i.e. at a sampling frequency equal 1,or 2, we will get no ISI; otherwise the ISI

will occur.
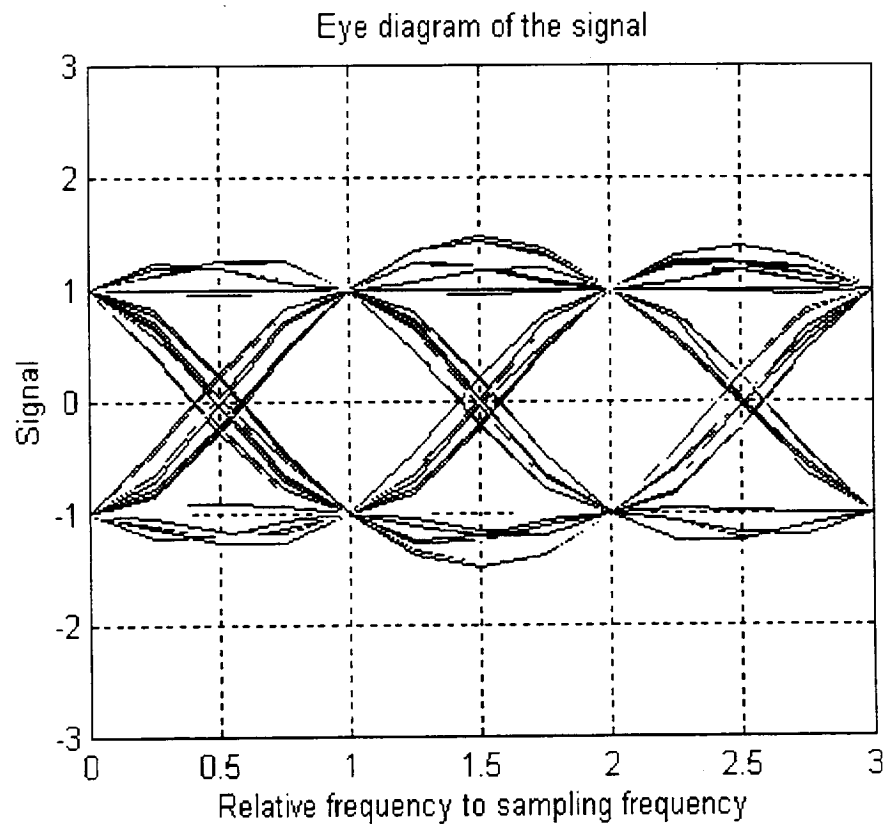
Figure 2.10 The eye diagram if the SRRC with $\alpha = 0.5$ is applied

2.3 Solid State Power Amplifier (SSPA)

Power amplifiers can be utilized in one of two regions, either in a linear region or in a non-linear region. High frequency power amplifiers such as Traveling-Wave Tubes (TWT) and Solid State Power Amplifiers (SSPA) can be linear amplifiers when operated well below the saturation level. If the amplifiers work in their saturation level, the efficiency, e.g., RF output/Direct Current (DC) input is improved, but the amplifier then becomes a non-linear device. Figure 2.11 and Figure 2.12 show the magnitude and phase characteristics' curve for the European Space Agency (ESA) 10 Watts SSPA.
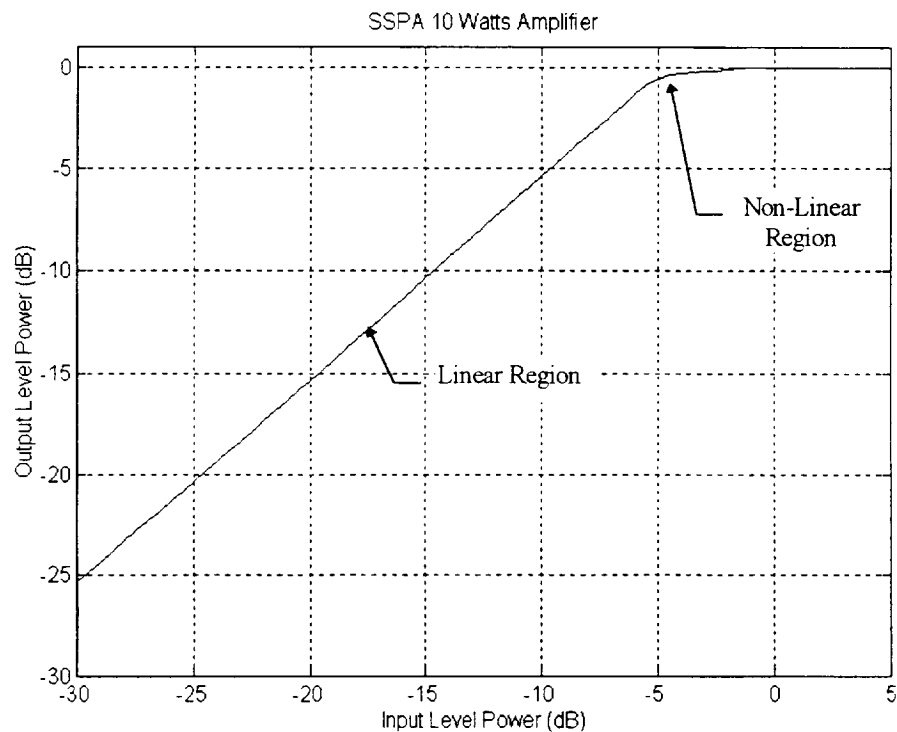
Figure 2.11 - SSPA, ESA 10 Watts, Magnitude Characteristic Curve
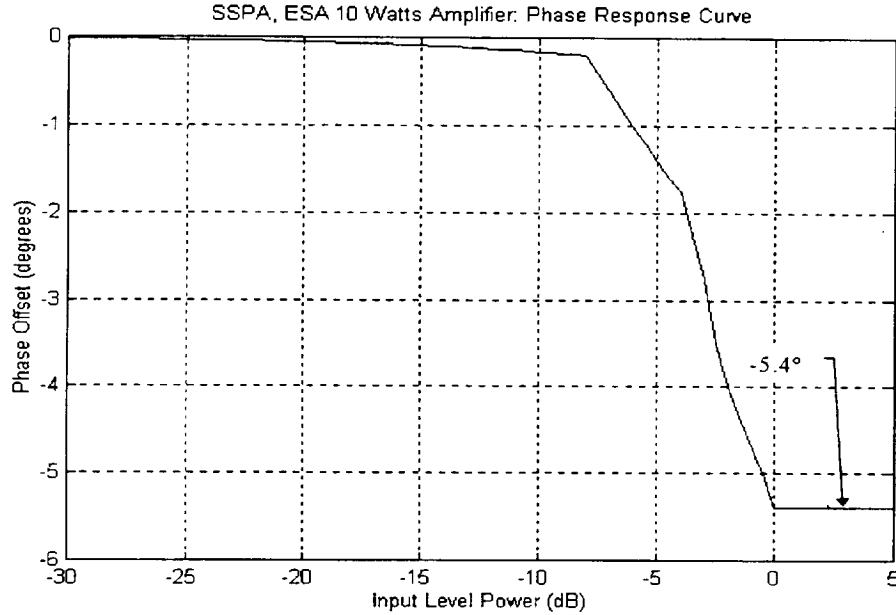
Figure 2.12 - SSPA, ESA 10 watts, Phase (degrees) Characteristics Curve

The non-linearities that occur in the nonlinear region of this amplifier will cause non-linear distortion and Amplitude Modulation-to-Phase Modulation (AM-to-PM) and AM-to-AM conversion effects (linear channels are channels without AM-AM and AM-PM conversions). The AM-to-PM conversion is the change in the output RF voltage that is produced by the variations in input signal level, usually expressed in dB/dB or dBm/dBm. The AM-to-AM conversion is the change in the phase angle of the output RF voltage produced by variations in the input signal level, usually expressed in degrees/dB or degrees/dBm. As mentioned in [8], the analyses of these non-linearities are very complicated.

15

To reduce the effect of these non-linearities, a signal with constant envelope is needed. Therefore constant envelope signals such as BPSK,QPSK, etc. are preferred. However, the pulse shaping used in this work creates a non-constant envelope signal.

2.4 Software Simulation Results

The main focus of this research is the bandwidth efficiency or the bandwidth utilization of the system. The bandwidth in this paper is defined as a -50 dB down from the maximum value. For example, Figure 2.13 shows the unfiltered spectrum and phase at the output of the SSPA. It can be seen that up to ± 25 Rs (Rs = symbol rate), the spectrum does not reach -50 dB point. The spectrum reaches -50 dB at ± 45 Rs (this can be seen from Figure 2.13). The magnitude and the phase of the signal are shown in Figure 2.14. It can be seen that the signals have constant envelopes.
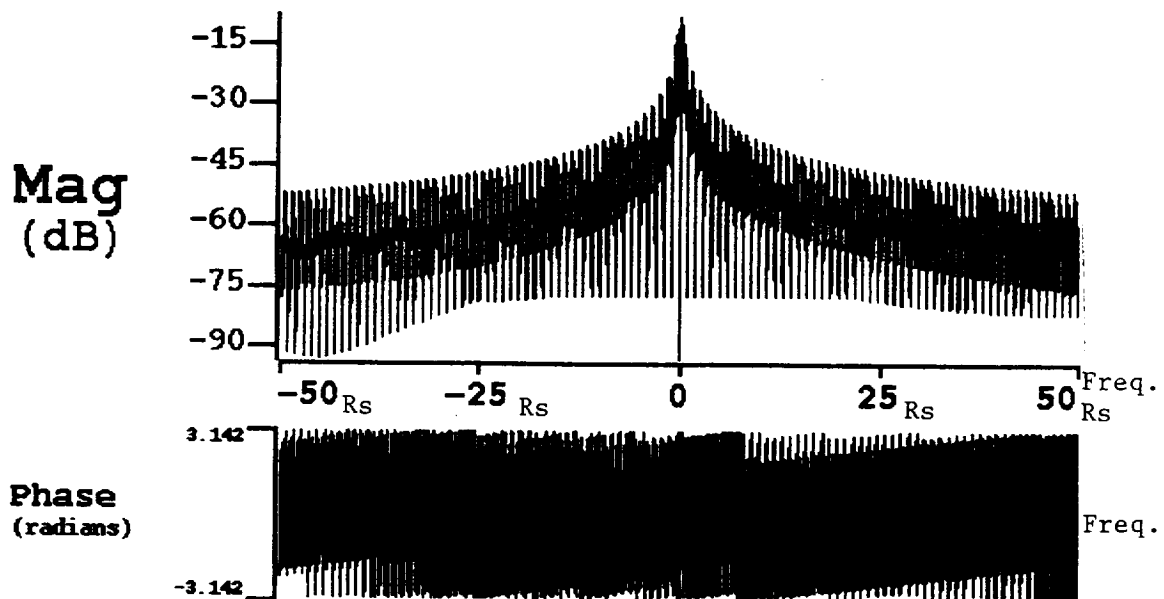
Figure 2.13 The Spectrum and the phase of Unfiltered Signal at The Output of SSPA
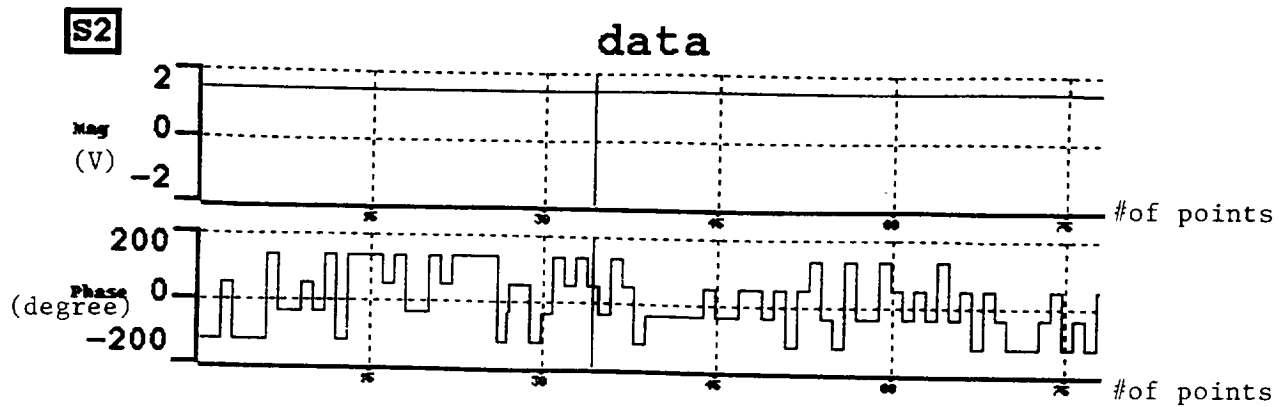
Figure 2.14 The magnitude and the phase of the signals

2.4.1 The 5th Order Butterworth Filter

Figure 2.15 shows the magnitude and the phase of the QPSK signal at the output of the SSPA when the 5th order Butterworth filter with BT=1 is utilized. Comparing this to the original signal (Figure 2.14), Figure 2.15 does not have constant envelope. This is the effect of this spectrum shaping on the signal, it creates a signal with non-constant envelope. The frequency response and the phase response of the system at this time can be seen in Figure 2.16. From the frequency response we get that the -50 dB bandwidth is 5.28 Rs. Section 2.5 on bandwidth utilization gives the complete results of this filter.
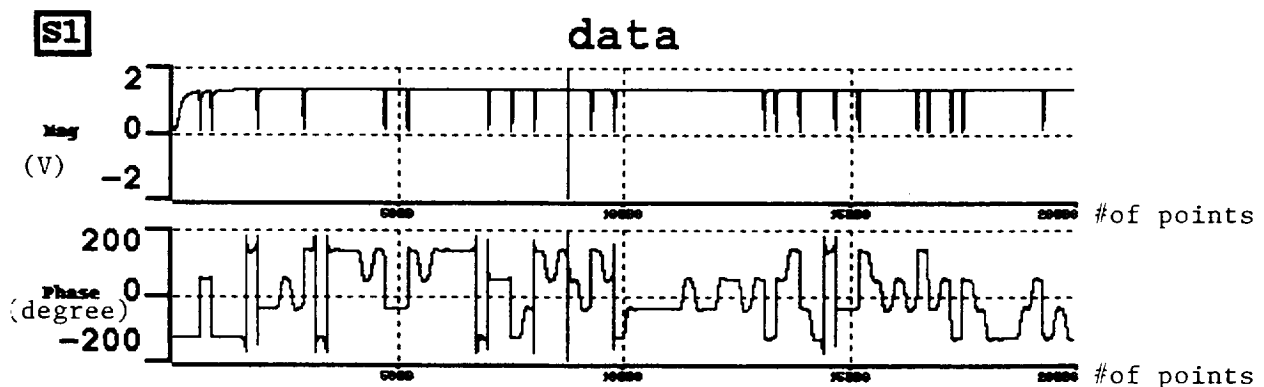
Figure 2.15 Magnitude and Phase at the output of SSPA with 5th order Butterworth

17
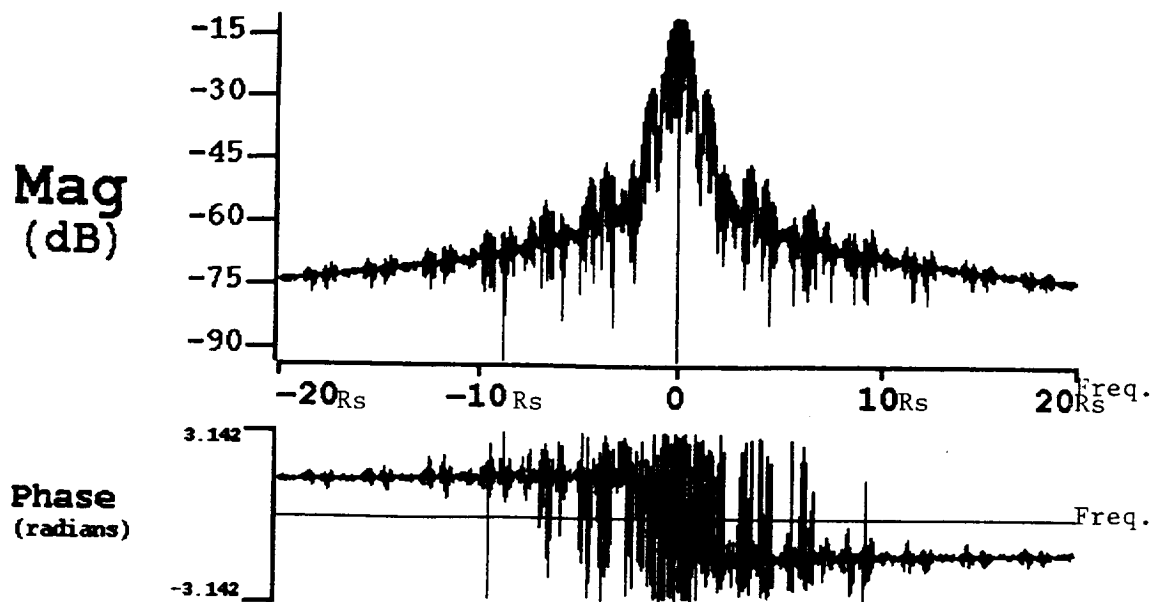
Figure 2.16 Spectrum and Phase at the output of SSPA with 5th order Butterworth

2.4.2 The 3rd Order Bessel filter

The 3rd order Bessel filter with BT= 1 is chosen for this example. Figure 2.17 shows

the magnitude and the phase of the QPSK signal at the output of the SSPA. It can be

seen that the envelope of the signal is not constant anymore. The frequency response and

the phase response of the system is given in Figure 2.18. The frequency response gives the

-50 dB bandwidth as 5.65 Rs. This result is larger than the result for the 5th order

Butterworth filter, therefore the utilization ratio for this filter is less than for the 5th order

Butterworth filter. The complete results will be given in the section on bandwidth

utilization, Section 2.5.
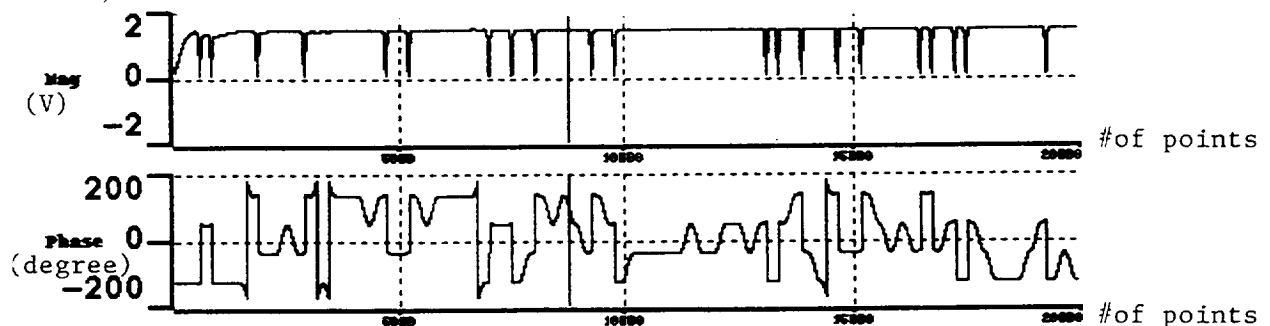
Figure 2.17 Magnitude and Phase at the output of SSPA with 3rd order Bessel
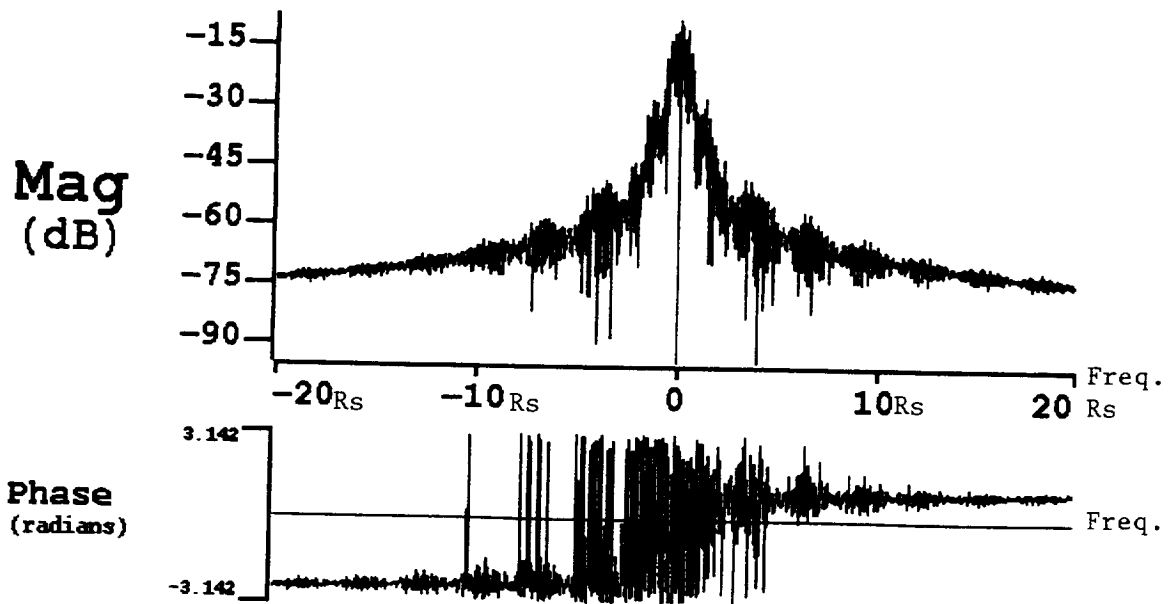
Figure 2.18 Spectrum and Phase at the output of SSPA with 3rd order Bessel

2.4.3 The Square Root Raised Cosine (SRRC) Filter

From the SRRC family, SRRC with $\alpha=0.5$ is chosen as an example. Figure 2.19 shows the magnitude and the phase of the QPSK signal at the output of the SSPA. Again, the signal envelope is not as constant as the source was. The frequency response and the phase response of the system can be seen in Figure 2.20. From the frequency response we get the -50 dB bandwidth is 4.60 Rs. The complete results are given in the following section.
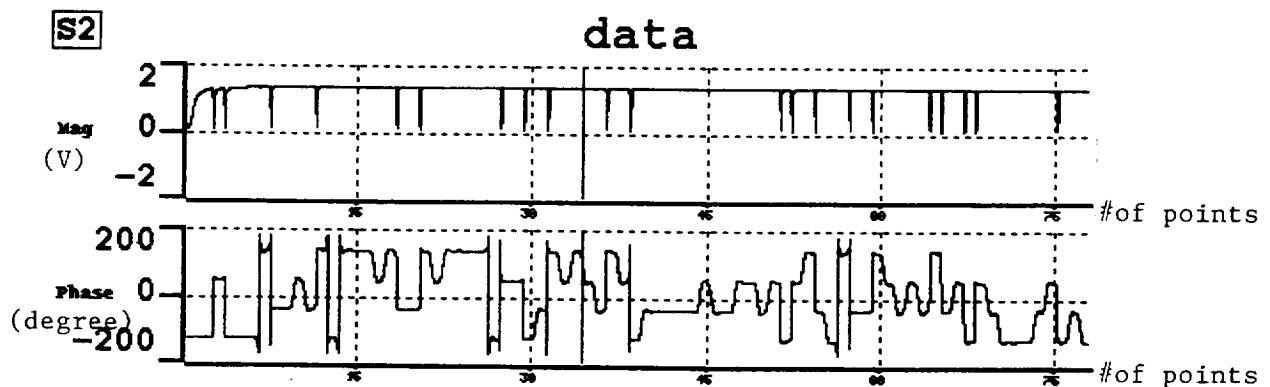
Figure 2.19 Magnitude and Phase at the output of SSPA with SRRC $\alpha=0.5$
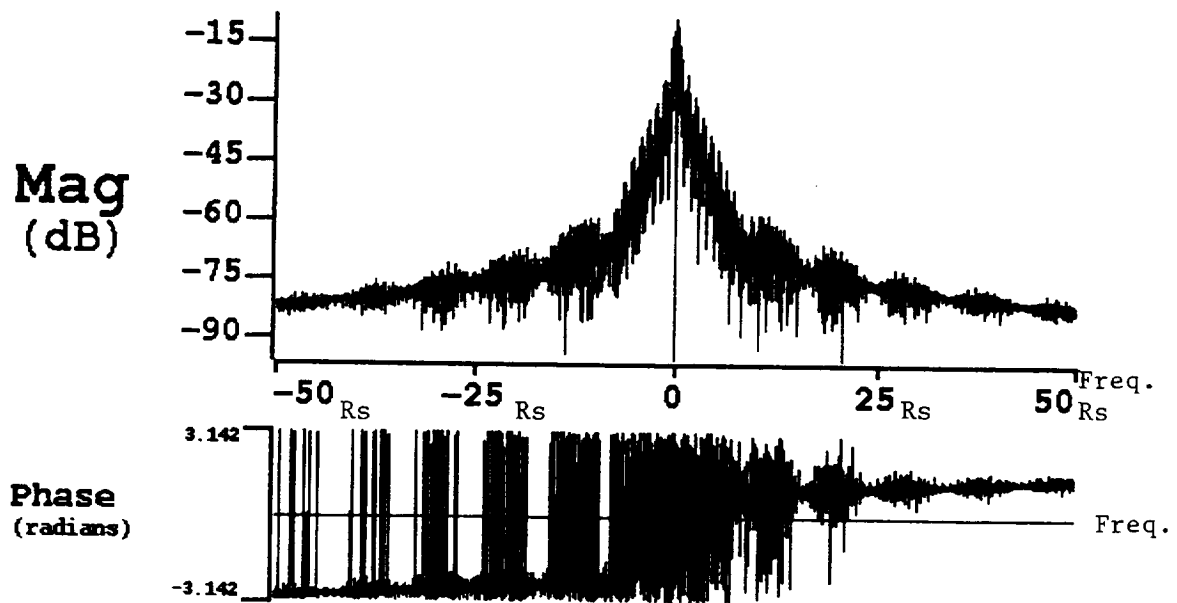
Figure 2.20 Spectrum and Phase at The Output of SSPA with SRRC α=0.5

2.5 Bandwidth Utilization

To see the overall effect of spectrum shaping on the bandwidth efficiency, a frequency

band Utilization Ratio (ρ) was defined as [3]:

ρ = The Bandwidth of the signal without Filtering
        The bandwidth of the signal with Filtering

This ratio is an estimate of how many more signals with shaped spectra can be included in

the bandwidth of the original signal with no filtering. This ratio was derived by using the

following assumption. The spectra from adjacent channels will be permitted to overlap one

another at the point where the signals are at least 50 dB below the main lobe. For an

example, Table 2.2 shows the utilization ratio of the the 5th order Butterworth filter and

the 3rd order Bessel filter for various BT. The -50 dB bandwidth is defined in terms of

symbol rate (Rs). The -50 dB point for the unfiltered data is at 90 Rs and for the 5th order

Butterworth filter is at 5.28 Rs. The utilization ratio is then $\rho = (90/5.28) = 17.05$ and

therefore if this pulse shaping filter is used, 17 signals can be sent in the same bandwidth

as one unfiltered signal was.

Table 2.2 - Utilization Ratio with various BT by using QPSK

Filter Type	BW -50 dB point (BT=1)	Util. Ratio	BW -50 dB point (BT=2)	Util. Ratio	BW -50 dB point (BT=3)	Util. Ratio
None, Unfiltered Data	90 Rs	1	90 Rs	1	90 Rs	1
Butterworth 5th order	5.28 Rs	17.05	8.74 Rs	10.29 Rs	11.15 Rs	8.07
Bessel, 3rd order	5.65 Rs	15.93	10. 26Rs	8.77 Rs	13.93 Rs	6.46

Table 2.2 shows the utilization ratio for various BT for the 5th order Butterworth filter

and the 3rd order Bessel filter. The 5th order Butterworth filter gives higher utilization

ratios than the 3rd order Bessel filter.

Table 2.3 shows the results of all three kinds of pulse shaping filters for QPSK, with

BT=1 for the 5th order Butterworth and the 3rd order Bessel filters. For the SRRC filter,

it can be seen from Table 2.3 that the smaller $\propto$ is the higher the utilization ratio. The

SRRC filter with $\propto = 0.25$ has the largest utilization ratio, then followed by the SRRC

filter with $\propto = 0.5$ and $\propto = 1$. The SRRC with $\propto = 0.25$ and 0.5 have higher utilization

ratios than the 5th order Butterworth filter and the 3rd order Bessel filter. The SRRC with

$\propto = 1$ has similar performance to the 5th order Butterworth filter.

Table 2.3 - Utilization Ratio for QPSK

Filter Type	-50dB BW (Rs)	Utilization Ratio
None, Unfiltered Data	90	1
Butterworth 5th order (BT=1)	5.28	17.05
Bessel, 3rd order (BT=1)	5.65	15.93
SRRC ($\propto$ = 0.25)	4.28	21.03
SRRC ($\propto$ = 0.5)	4.60	19.56
SRRC ($\propto$ = 1)	5.30	16.98

Table 2.4 shows the utilization ratios for 8PSK and QPSK. In this case, the bandwidth is defined in terms of bit rate (Rb). It can be seen that the utilization ratio of 8PSK is higher than QPSK and from these results it would appear that 8PSK should be used rather than QPSK. However, one needs to compare the advantages and the disadvantages of both before making a decision whether 8PSK or QPSK should be used. The other advantages and disadvantages are:

1. QPSK has better signal to noise ratio (Eb/No) than 8PSK [5][8].

2. An 8PSK is a more complex and difficult system to implement than QPSK. Thus, it is cheaper to implement QPSK in hardware than 8PSK.

3. QPSK has been used more often than 8PSK so we do not need to change the system that already exists.

4. 8PSK is more bandwidth efficient.

Figure 2.21 was made from Table 2.4 to visualize the differences between the utilization ratios of QPSK and 8PSK. It can be seen that the difference is almost 50% or the utilization ratios for 8PSK are twice of the utilization ratio of QPSK.

Table 2.4 - Utilization Ratio QPSK Vs. 8PSK[11]

Filter Type	Utilization Ratio (QPSK)	Utilization Ratio (8PSK)
None, Unfiltered Data	1	1
Butterworth 5th order (BT=1)	8.52	17.39
Bessel, 3rd order (BT=1)	7.96	16
SRRC ($\propto$ = 0.25)	10.51	23.5
SRRC ($\propto$ = 0.5)	9.78	23.5
SRRC ($\propto$ = 1)	8.49	18.18
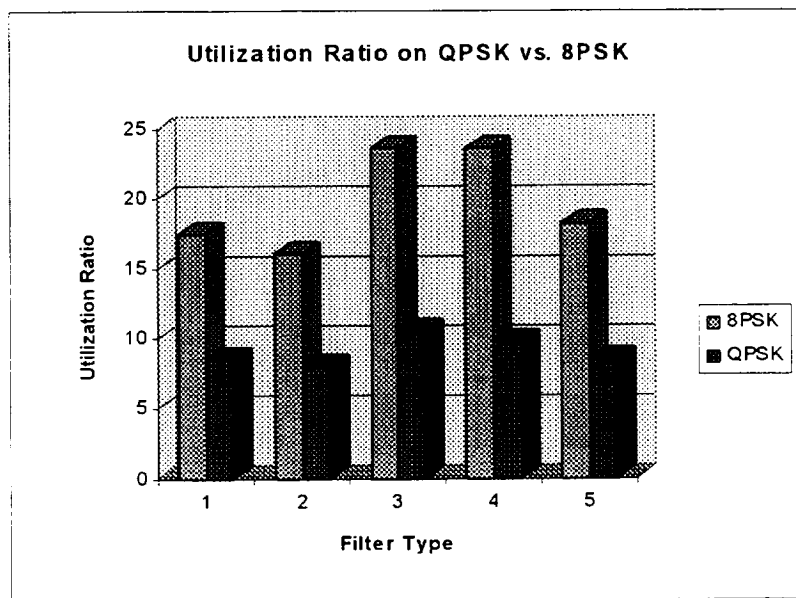
Figure 2.21 The Utilization Ratio of QPSK and 8PSK

Note: 1 is the 5th order Butterworth filter
2 is the 3rd order Bessel filter
3 is the SRRC with $\propto$ = 0.25
4 is the SRRC with $\propto$ = 0.5
5 is the SRRC with $\propto$ = 1

23

Chapter 3

HARDWARE IMPLEMENTATION

This section will describe the hardware implementation of the system including the

results. The block diagram of the system is given in the Figure 3.1 below:
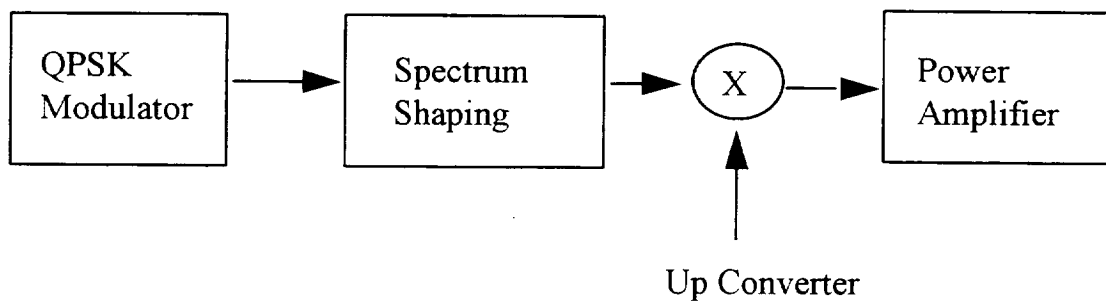
Figure 3.1 - The Block Diagram of The Hardware

The Quadrature Phase Shift Keying (QPSK) signal is produced by a QPSK

modulator at an Intermediate Frequency (IF) of 90 MHz. The pulse shaping filters or

spectrum shaping filters are used at the output of the modulator. The filters that are

used for this research are the 5th order Butterworth filter, the 3rd order Bessel filter

and the Square Root Raised Cosine (SRRC) filter with roll off factor of 0.25, 0.5 and

1. The selection of the filters was determined by the previous work done at JPL

[3],[4]. The up converter is needed to shift the signals to 2 GHz which is in the S-band

frequency range (1.55 GHz - 5.20 GHz). These shifted signals will enter the Power

Amplifier that is operated in its non-linear region to get the maximum power. Two

types of power amplifier are implemented: the Traveling Wave Tube Amplifier (TWTA) and Solid State Power Amplifier (SSPA.) All of them work in the S-band frequency range. The bandwidth utilization will be measured at the output of the power amplifiers. This configuration follows the recommendation from the CCSDS for spectrum shaping at the Intermediate Frequency (IF) [14].

The specifications that are designed and implemented on the system are:

1. The format of ideal data is NRZ-L.

2. Symbol rate : 5 Mbps (the maximum symbol rate that can be produced by HP 8782B).

3. The modulation is QPSK with a carrier frequency = 90 MHz (at Intermediate Frequency - IF).

4. The bandpass pulse shaping filters (do not include resistive and reactive losses) with center frequency 90 MHz and bandwidth 5 MHz (BT=1), 10 MHz (BT=2) and 15 MHz (BT=3):

   - Butterworth 5th Order

   - Bessel 3rd Order

   - SRRC (roll of factor α =0.25, 0.5 and 1)

5. Power Amplifier works at S-band (1.55 GHz - 5.20 GHz) frequency range :

   - For TWTA, the output power is 10 watts

   - For SSPA, the output power is 0.6 watts

   Note: 1. These two HPA's were selected because ESA currently uses the SSPA type amplifier and the Tracking and Data Relay Satellite System (TDRSS)

25

uses the TWTA type amplifier. The actual satellite would use more power, but based on the information from [15] the characteristics of the higher power amplifiers have the same general shape. This being the case, lower power was desired for safety purposes.

2. The complete procedure of the experiments are given in the appendix A.

3. All of the measurements of the power spectra are in dBm.

3.1 The QPSK Modulator

The HP 8782B is utilized to produce the 90 MHz QPSK signal as shown in Figure 3.2 below which was captured with the Digital Storage Oscilloscope (DSO) Lecroy 9384L. We can see that the signal has a constant envelope. The symbol rate of this signal is 5 Mbps, thus the first nulls of its spectrum as shown in Figure 3.3 are 95 MHz and 85 MHz respectively.
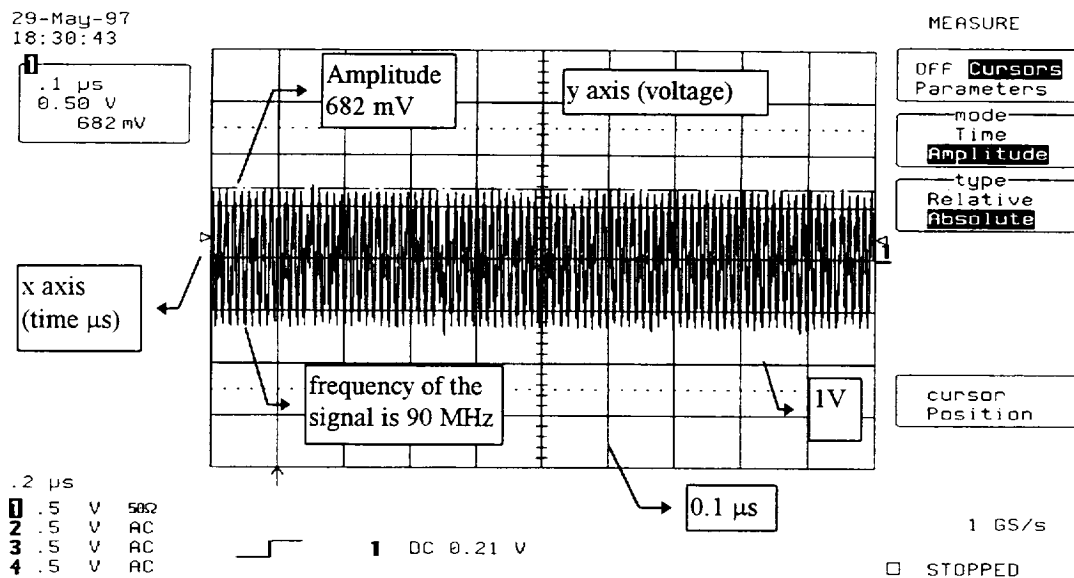
Figure 3.2 - The QPSK Signal that Produced By HP 8782B.

26

29-May-97
18:22:41

frequency: 90 MHz

5 dBm

y axis
power (dBm)

-2dBm

x axis
freq(MHz)

95MHz

-15dBm

100 MHz

REDEFINE A
A=PS(FFT(1))

REDEFINE B
B=PS(AVGP(A))

REDEFINE C
C=1

REDEFINE D
D=2

┌Multi-Zoom┐
 OFF   On

┌for Math use┐
 max points
    10000

B:PS(AVGP(A))
10 MHz
5.0 dBm
        541 mdBm
        55 swps

.1 µs
1 .5 V 50Ω
2 2 mV AC
3 2 mV AC
4 2 mV AC

Freq   90.00 MHz

1 DC 0.20 V

1 GS/s

☐ STOPPED
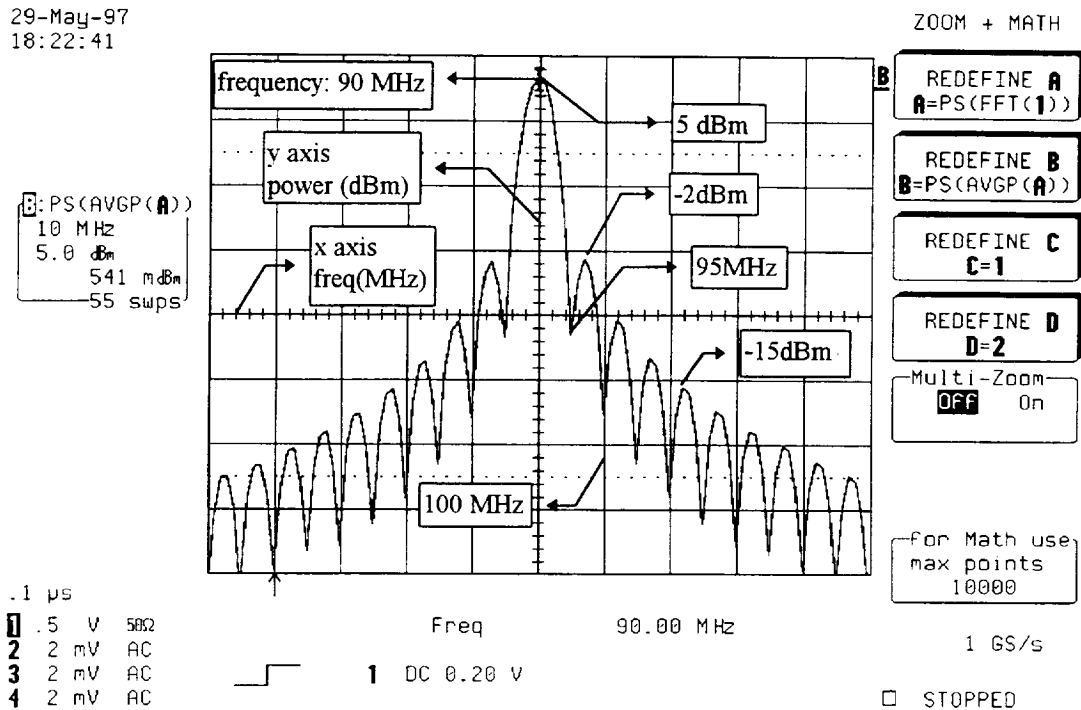
Figure 3.3 The Spectrum of the QPSK Signal at IF 90 MHz.

To count the bandwidth utilization or the bandwidth efficiency of the system, we need to compare the bandwidth of the signal without the filters and with the filters at the output of the high power amplifier. The hardware set up for the unfiltered signal is shown in Figure 3.4. The QPSK signal is shifted up to S-band by using HP8657 B Signal Generator. The spectrum analyzer Tektronix 492 is used to measure the spectrum of the signal at S-band. For an example, Figure 3.5 shows the spectrum of the unfiltered signal at the output of the SSPA. The figure was taken with the camera since the spectrum analyzer Tektronix 492 does not have a printer feature.
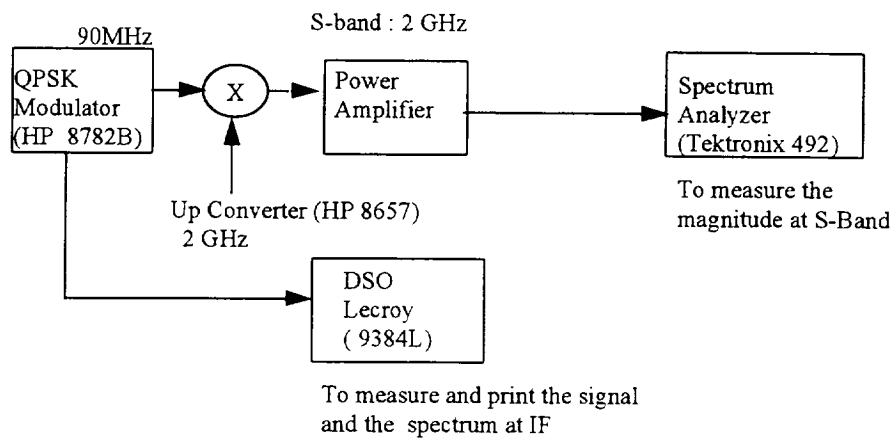
Figure 3.4 - The Hardware Set Up of Unfiltered Signal.
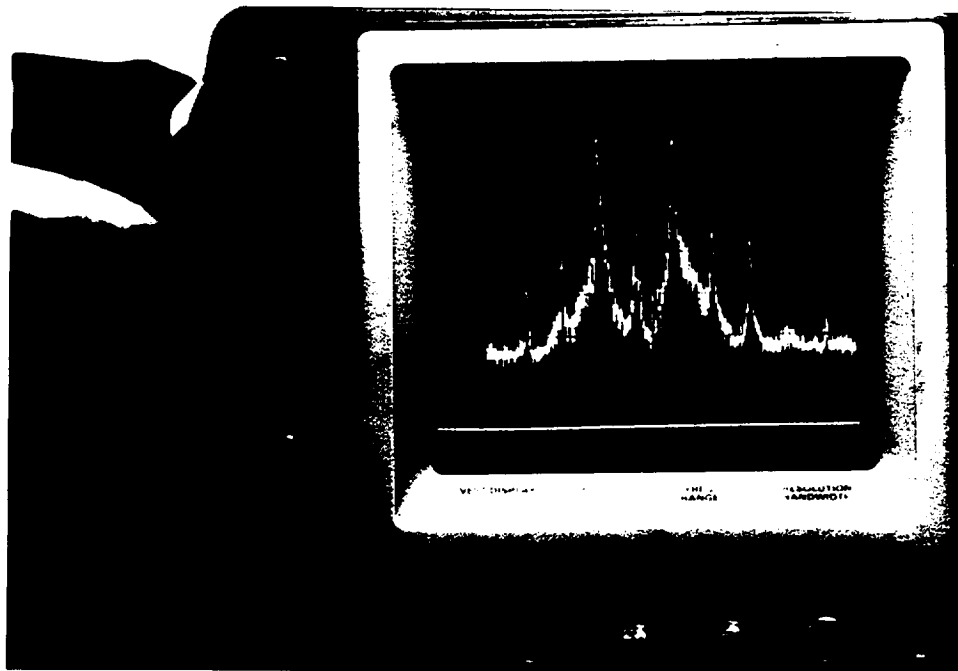
Figure 3.5 The Spectrum of The Unfiltered Signal at The Output of SSPA.

It can be seen in Figure 3.5 that the carrier frequency (2 GHz) is in the middle and it has two side bands. Each side band represents the modulated signal in the IF. For an example, the main lobe of the upper side band which is on the right side of the carrier frequency has a center frequency at 2.091 GHz. The lower side band has a 1.909 GHz center frequency. For analysis purposes, the upper side band is chosen. To measure the bandwidth, the point -50 dB down from the peak of main lobe needs to be identified. The bandwidth of the signal is measured from both sides of the center of the QPSK spectrum that reach -50 dB from the main lobe. Both side bands are necessary due to the lack of symmetry in the spectrum of the signal. All the bandwidths are measured with respect to the symbol rate (Rs). By using the SSPA, the highest magnitude for the upper side band which is at the right side of the 2GHz carrier is -2dBm. The -50 dB point down is at 2.262 GHz on the right side of the main lobe and at 1.9195 GHz on the left side of the main lobe. The difference between these frequencies is 342.5 MHz. These results show that the unfiltered bandwidth at the output of the SSPA is 68.5 Rs (68.5*5 Mbps = 342.5). The same procedure is used on the TWTA and the result is 67.9 Rs. All other output spectra of the HPA are performed using the same procedure. The results are given later in this chapter. Note that the bandwidth that was found in the software simulation (which has bandwidth 90 Rs), is larger than these results since in hardware there is power dissipation. On the other hand, there is no power dissipation in the software simulation and the system is close to the ideal system.

3.2 The Filters

A programmable Transversal Filter (PTF) is utilized as a pulse shaping filter by downloading the coefficients of its 127 taps from a Personal Computer (PC). These coefficients are created with MATLAB [2]. The program listing is given in Appendix B. The following steps are followed to create the program:

1. Matlab provides the functions to create the Butterworth and the Bessel filters. For the SRRC, the Matlab function has to be programmed by using the equations that are given in Chapter 2.

2. 128 coefficients are taken from the frequency response of the filters and they will be used as the raw data for the 128 points of the taps of the PTF. The first coefficient has to be deleted since the PTF has only 127 taps.

3. The odd coefficient has to be multiplied by -1.

4. Each coefficient has to be quantized to to have an integer value between -31 (minimum value) and 31 (maximum value). Then, the coefficients are ready to be loaded to the filter by using the program : "loaddata.exe"

Figure 3.6 shows the hardware set up for the filtered signal. As mentioned in Chapter 2, there are three types of filters that are used: the 5th order Butterworth filter, the 3rd order Bessel filter and the SRRC with $\alpha = 0.25$, 0.5 and 1. The symbol rate for the QPSK signaling is 5 Mbps. The results from each filter will be explained in the next section.

---

[2] Matlab is a registered trademark of The MatWorks Inc., Cochituate Place, 24 Prime Park Way, Natick, Mass. 01760.

```
              ┌──────────┐
              │ Computer │
              └──────────┘
                   │
   90 MHz          │  90MHz        S-band : 2 GHz
┌──────────┐  ┌──────────┐      ┌──────────┐      ┌──────────────────┐
│ QPSK     │  │ Pulse    │      │ Power    │      │ Spectrum Analyzer │
│ Modulator│─▶│ Shaping  │─▶(X)─▶│ Amplifier│─────▶│ (Tektronix 492)  │
│ (HP8782B)│  │ Filter   │   ▲  │ (SSPA &  │      └──────────────────┘
└──────────┘  │ (PTF)    │   │  │  TWTA)   │
              └──────────┘   │  └──────────┘
                   │    Up Converter 2GHz
              ┌──────────┐
              │ DSO      │
              │ Lecroy   │
              │ 9384L    │
              └──────────┘
```
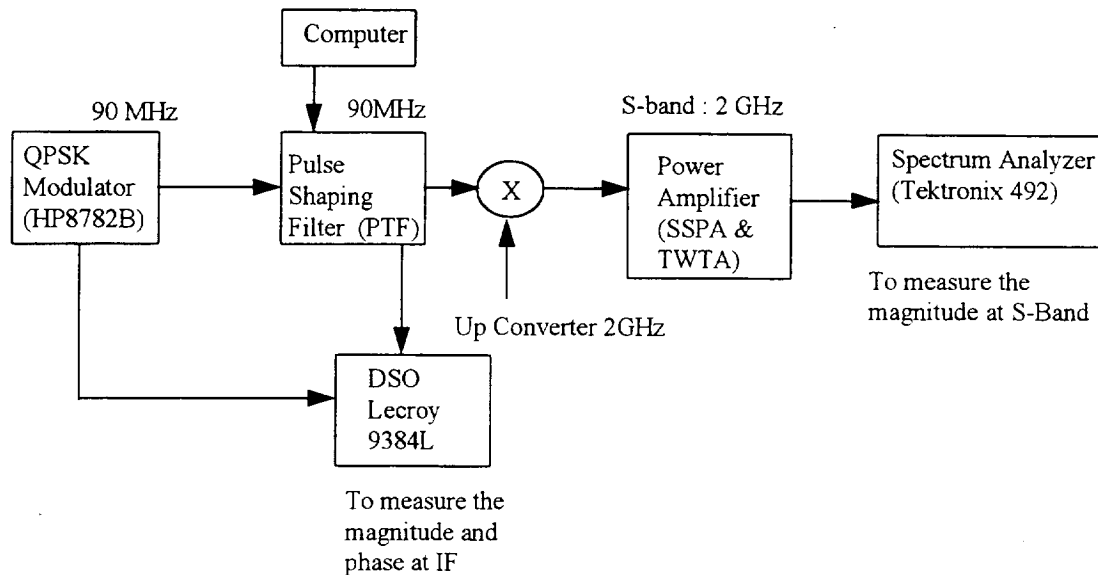
Figure 3.6 - The Set Up for Filtered Signal

As mentioned before that to input the coefficients of the PTF's 127 taps, a computer (PC) is needed. Two signals enter the Lecroy DSO, one from the QPSK modulator and one from the PTF. These two signals are used to measure the phase characteristic of the filter. The characteristic of the magnitude of the filters also will be given later in the next section. The signals are shifted to the S-band frequency by using the signal generator HP 8657B. Two high power amplifiers have been used, the first is a Traveling Wave Tube Amplifier (TWTA) that was made by the Hughes Aircraft Company with serial number 8010H. The second one is the Solid State Power Amplifier (SSPA) that was made by Mini Circuits with serial number ZHL-42. Both of them were applied in the S-band frequency range.

31

3.2.1 The 5th Order Butterworth Filter

A 5th order Butterworth filter with BT of 1,2 and 3 (BT = the bandwidth of the filter times the symbol rate (Rs) of the signal) was implemented. The signal at the output of the filter for BT =2 is shown in Figure 3.7. It can be seen that it has a non-constant envelope. The frequency response at the output of the filter is shown in Figure 3.8 and the measured phase is given in Figure 3.9.
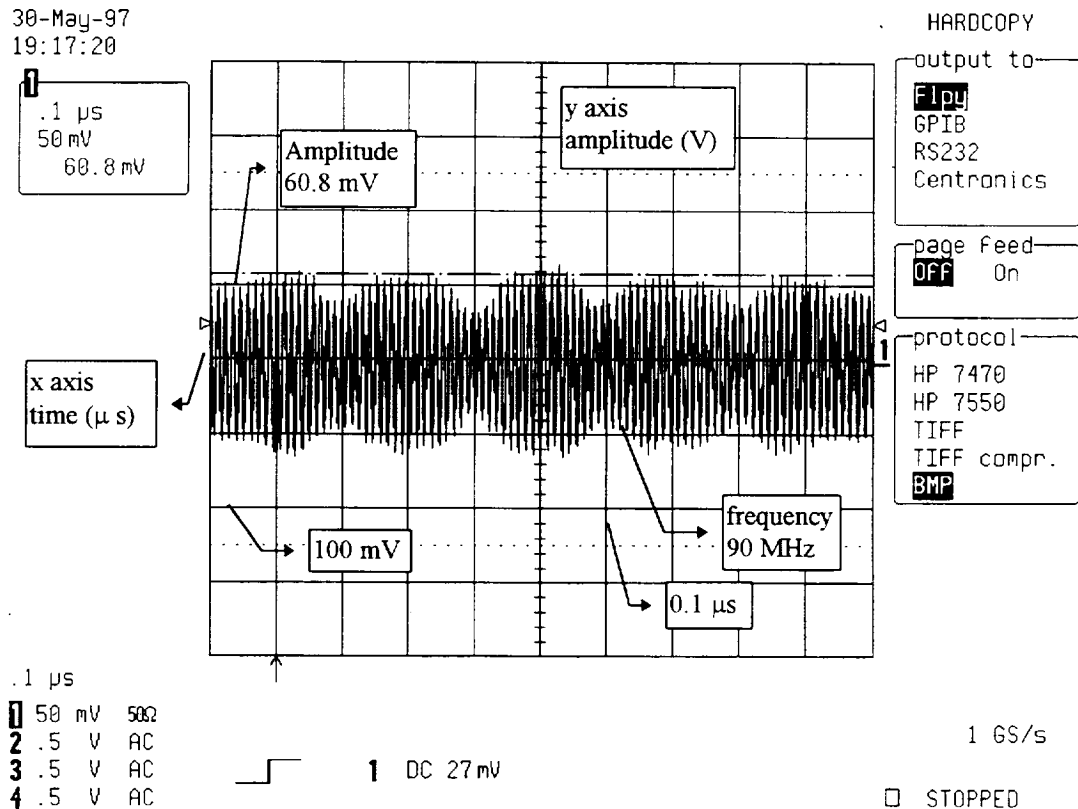
Figure 3.7 The Signal at The Output of The 5th order Butterworth Filter
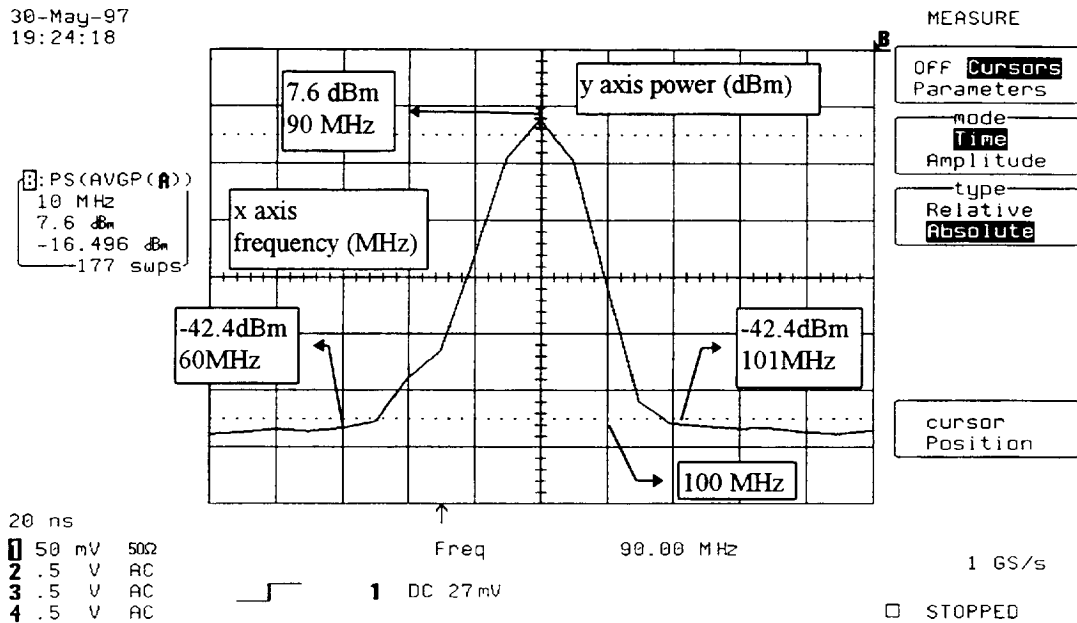
Figure 3.8 The Spectrum at The Output of The 5th Order Butterworth Filter
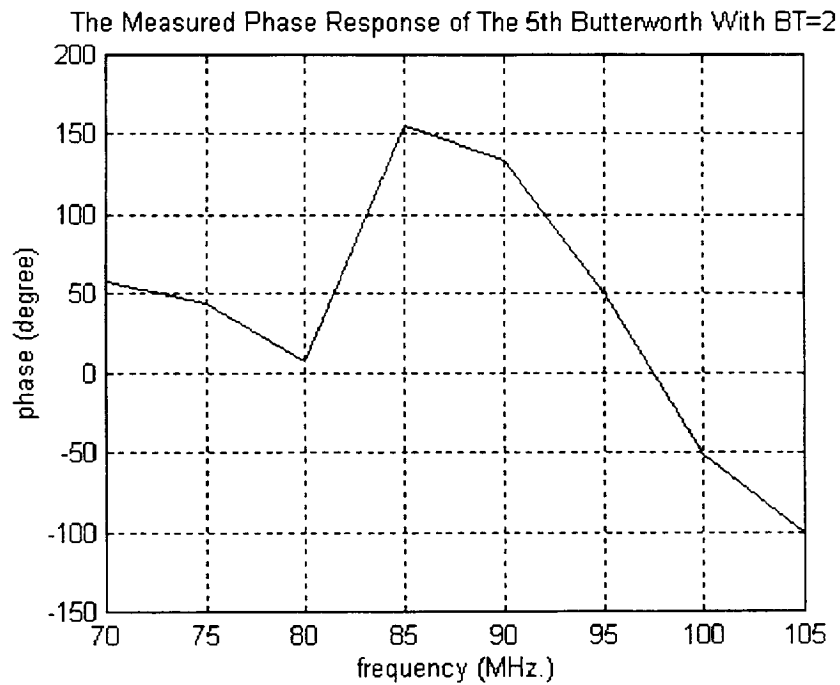
Figure 3.9 The Measured Phase Characteristic of the 5th Order Butterworth filter

33

As a comparison, Figures 3.10 and 3.11 show the frequency response and phase response that were created in Matlab with BT=2 (the same BT used for the hardware implementation). Theoretically, with BT=2, the bandwidth is 10 MHz and the cut off frequency (-3dB down) are at 85 MHz and 95 MHz. However, we are not concerned with the -3dB bandwidth, we are concerned with the -50 dB andwidth. From the hardware implementation results, we get that the -50dB point are at 60 MHz and 101 MHz, thus, the bandwidth is 41 MHz. It can be seen that they have similar forms. For an example, the phase response on the simulation has a similar pattern with the measured one. The phase has transitions on the cut off frequency that will affect the signal in the passband region.
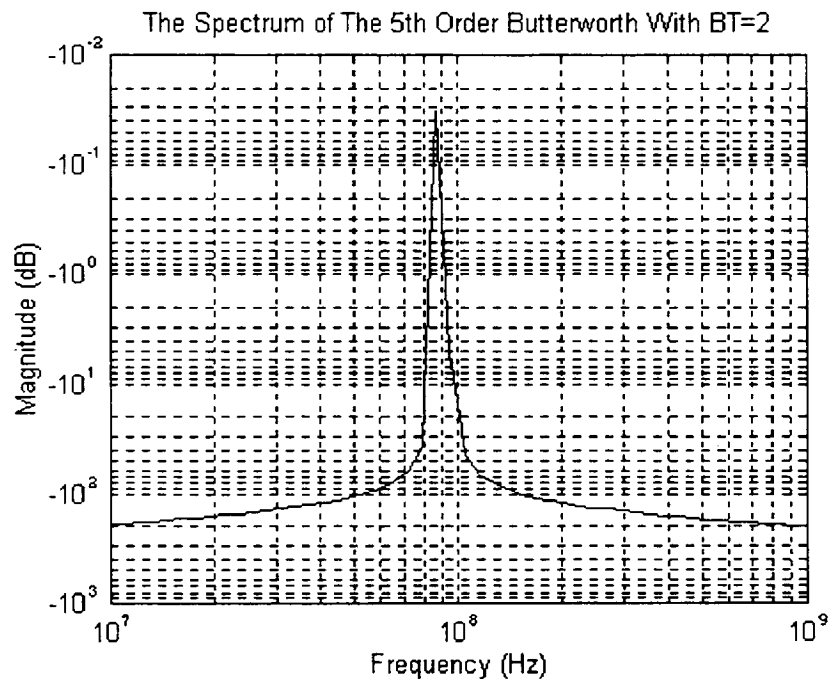
Figure 3.10 The 5th Order Butterworth Simulated Frequency Response

The Phase of The 5rd Order Butterworth with BT=2
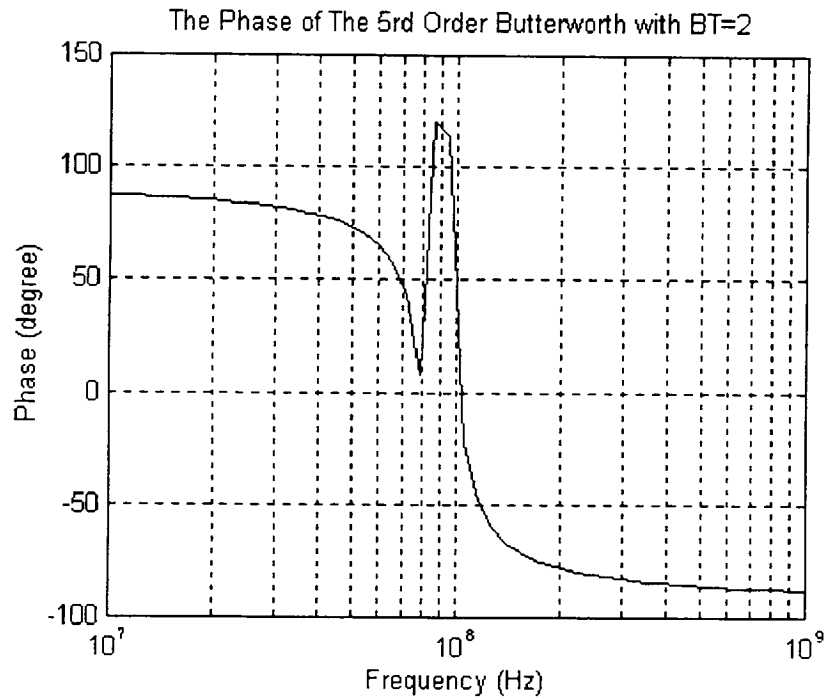
Figure 3.11 The 5th Order Butterworth Simulated Phase Response

The frequency response of the signal at the output of the high power amplifier, for the SSPA, is given in Figure 3.12. The maximum point of the upper side band spectrum is -26 dBm. By using the same procedure as was given previously, the -50 dB points for the SSPA (operated at its saturation region) are at 2.128 GHz and 2.0535 GHz. Thus the bandwidth is equal to 14.9 Rs or 74.5 MHz. The difference between this bandwidth and the bandwidth at IF is 74.5 MHz - 41 MHz = 33.5 MHz. This is due to the fact that the SSPA is in its saturated region. The complete results are given in section 3.4 (section on bandwidth utilization).

35

Figure 3.12 The Spectrum at The Output of SSPA of The 5th order Butterworth

3.2.2 The 3rd Order Bessel filter

The second filter that has been used is the 3rd order Bessel filter with BT 1,2 and 3. The filter output for BT=2 is shown in Figure 3.13. It can be seen that it also has a non-constant envelope. Comparing this to the signal at the output of the 5th order Butterworth filter shows that this signal has a larger deviation in its amplitude. The frequency response at the output of the filter which was taken with the Lecroy DSO 9384L is shown in Figure 3.14 and the measured phase is given in Figure 3.15.

MEASURE

OFF **Cursors**
Parameters

┌mode──────┐
Time
Amplitude

┌type──────┐
Relative
Absolute

.2 µs
50 mV
    95.2 mV

95.2 mV

50mV

y axis
amplitude (mV)

x axis
time (µ s)

Amplitude
100 mV

0.2µs

frequency
90MHz.

cursor
Position

.2 µs

0 50 mV 50Ω
2 .5 V AC
3 .5 V AC
4 .5 V AC

1 DC 27mV

1 GS/s

☐ STOPPED
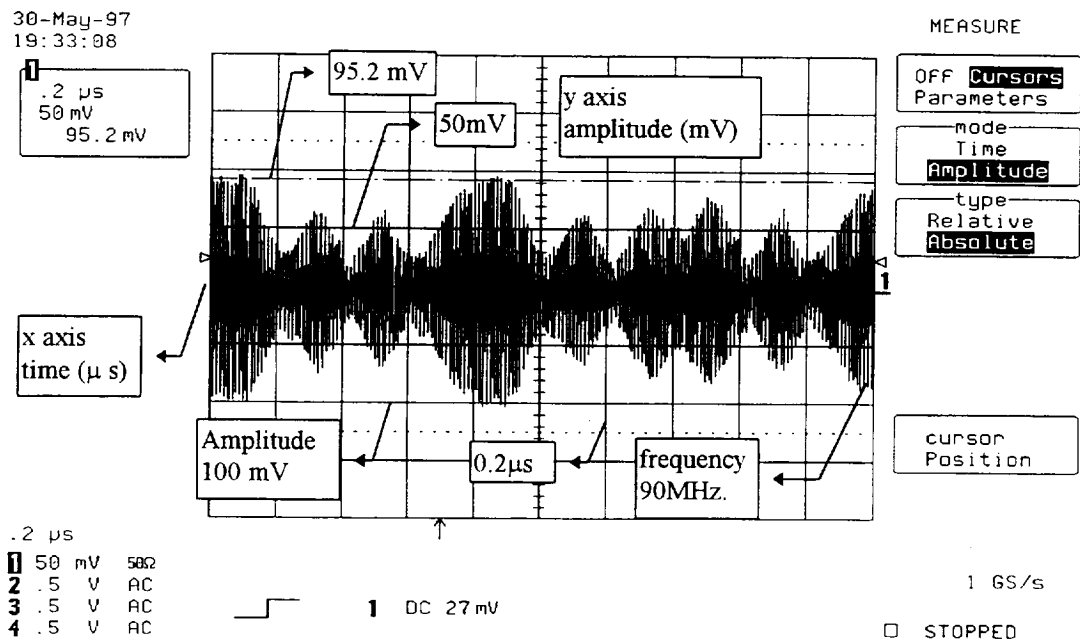
Figure 3.13 The Signal at The Output of The 3rd Order Bessel Filter

MEASURE

OFF **Cursors**
Parameters

┌mode──────┐
Time
Amplitude

┌type──────┐
Relative
Absolute

7.5 dBm
90MHz

y axis Power (dBm)

B:PS(AVGP(**A**))
10 MHz
7.6 dBm
-12.526 dBm
────154 swps

x axis
frequency (MHz)

-42.5dBm
65MHz

-42.5dBm
110MHz

cursor
Position

100MHz

20 ns

0 50 mV 50Ω
2 .5 V AC
3 .5 V AC
4 .5 V AC

1 DC 27mV

Freq   90.00 MHz

1 GS/s

☐ STOPPED
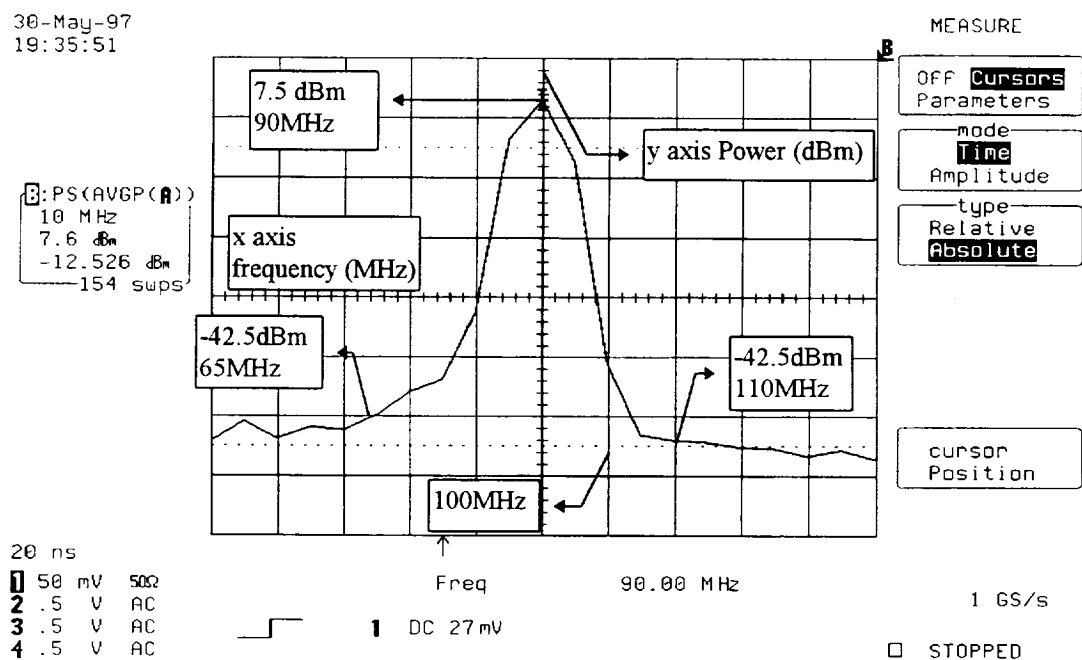
Figure 3.14 The Spectrum at The Output of The 3rd Order Bessel Filter
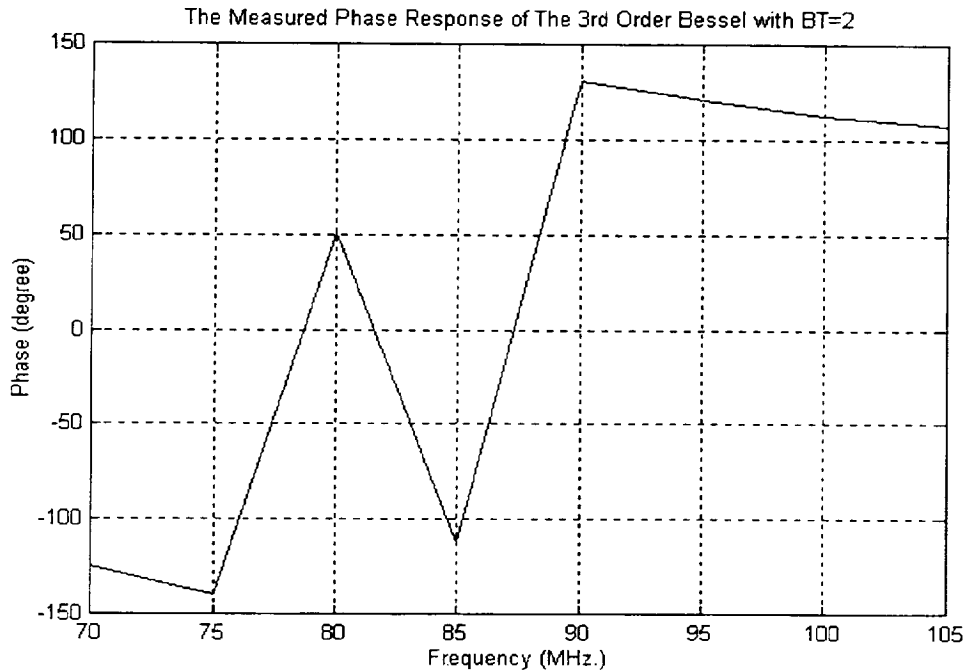
Figure 3.15 The Measured Phase of the 3rd Order Bessel Filter.

Again, as a comparison, Figure 3.16 and 3.17 show the frequency response and

phase response that were created with Matlab with BT=2 (the same BT used for the

hardware implementation). It can be seen that the frequency response for the hardware

implementation has a wider bandwidth than the software simulation. The software

simulation has cutoff frequencies at 85 MHz and 95 MHz. The -50 dB points are at

65 MHz and 110 MHz. Thus the bandwidth is 45 MHz.

The frequency response of the signal at the output of the high power amplifier, in

this particular case the SSPA is chosen again, is given in Figure 3.18. The maximum

value of the upper side band spectrum is -20 dBm. By using the same procedure as

that mentioned previously, the -50 dB points for the SSPA are at 2.1335 GHz and

2.049 GHz. Thus the bandwidth is equal to 16.9 Rs or 84.5 MHz. The difference

between the bandwidth at IF and the bandwidth at S-band is 84.5 MHz - 45 MHz =

39.5 MHz. The phase response on the simulation also has a pattern similar to the

measured one. The complete results are given in the section on bandwidth utilization,

Section 3.4.
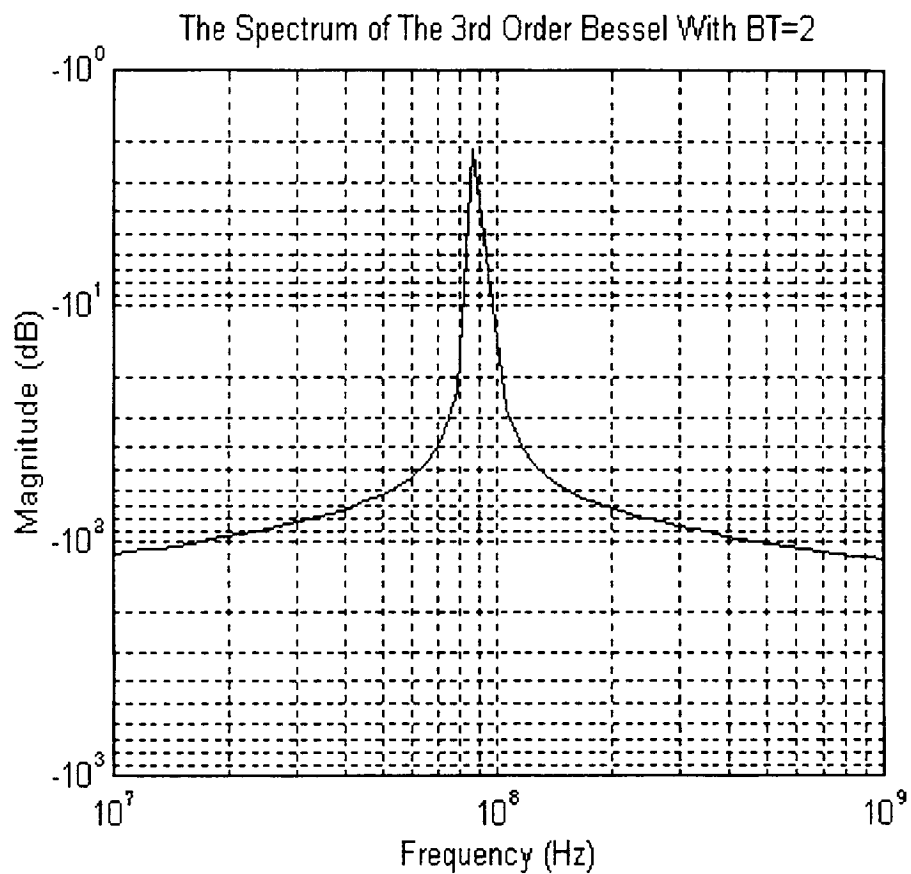
Figure 3.16 The 3rd Order Bessel Filter Simulated Frequency Response.

The Phase of The 3rd Order Bessel with BT=2
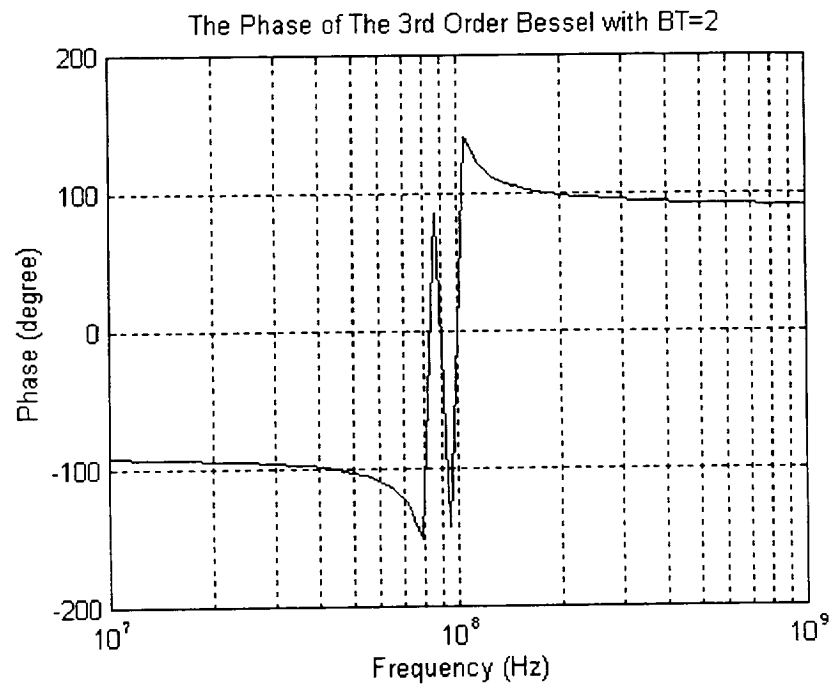
Figure 3.17 The 3rd Order Bessel Filter Simulated Phase Response.

Figure 3.18 The Spectrum at The Output of SSPA of The 3rd Order Bessel Filter

3.2.3 The Square Root Raised Cosine (SRRC) Filter

The last filter that has been used is the SRRC with the roll off factor α=0.25, 0.5 and 1. For an example, the SRRC with α=0.5 is chosen. The signal at the filter output is shown in Figure 3.19 below. It can be seen that it also has a non-constant envelope. It's envelope is close to a constant envelope for a particular time range and then has a zero crossing. The frequency response at the output of the filter which was taken with Lecroy DSO 9384L is shown in Figure 3.20 and the measured phase is given in Figure 3.21. The -50 dB points at IF are 88 MHz and 102 MHz, the bandwidth is 34 MHz or 6.8 Rs.
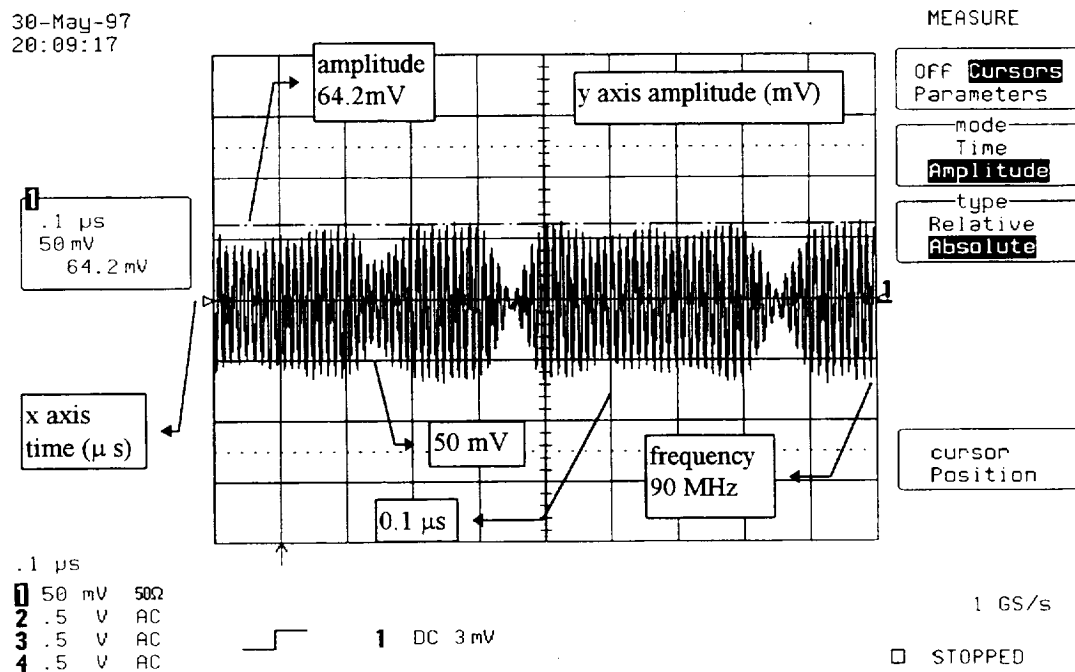
Figure 3.19 The Signal at The Output of The SRRC Filter with α = 0.5

B:PS(AVGP(A))
10 MHz
7.3 dBm
-16.232 dBm
820 swps

MEASURE

OFF **Cursors**
Parameters

mode
Time
Amplitude

type
Relative
Absolute

7.5 dBm
90MHz

y axis power (dBm)

x axis
frequency (MHz)

-42.5dBm
102MHz

-42.5dBm
68 MHz

cursor
Position

100MHz

20 ns

0 50 mV 50Ω
2 .5 V AC
3 .5 V AC
4 .5 V AC

Freq   90.00 MHz

1 DC 1 mV

1 GS/s

□ STOPPED

Figure 3.20 The Spectrum at The Output of The SRRC Filter with $\alpha = 0.5$
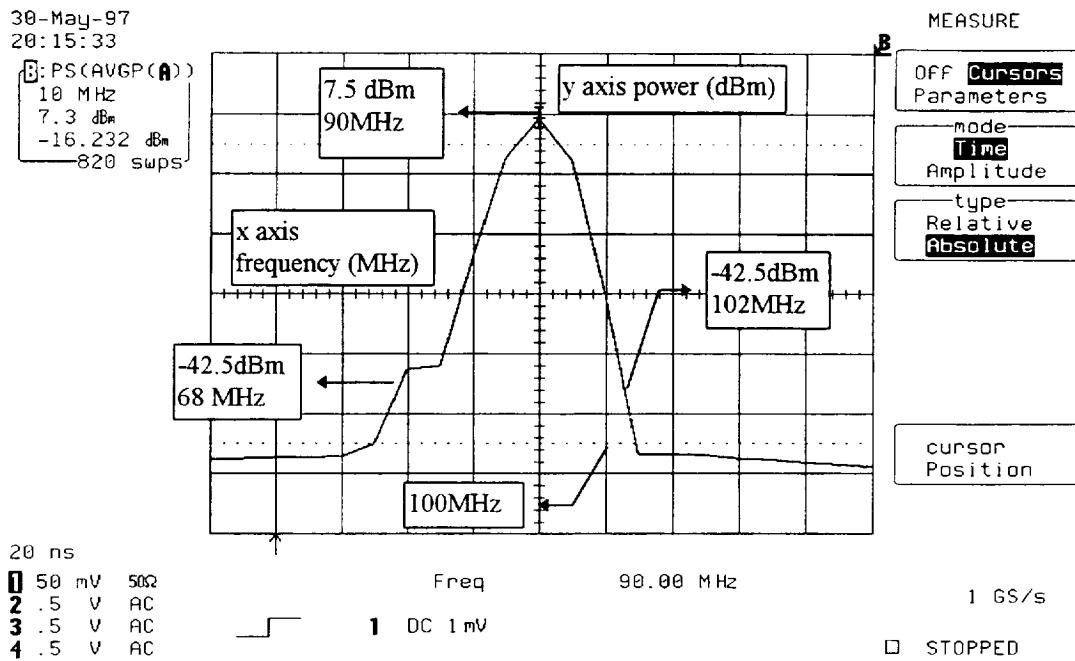
The phase measured of SRRC with alpha=0.5
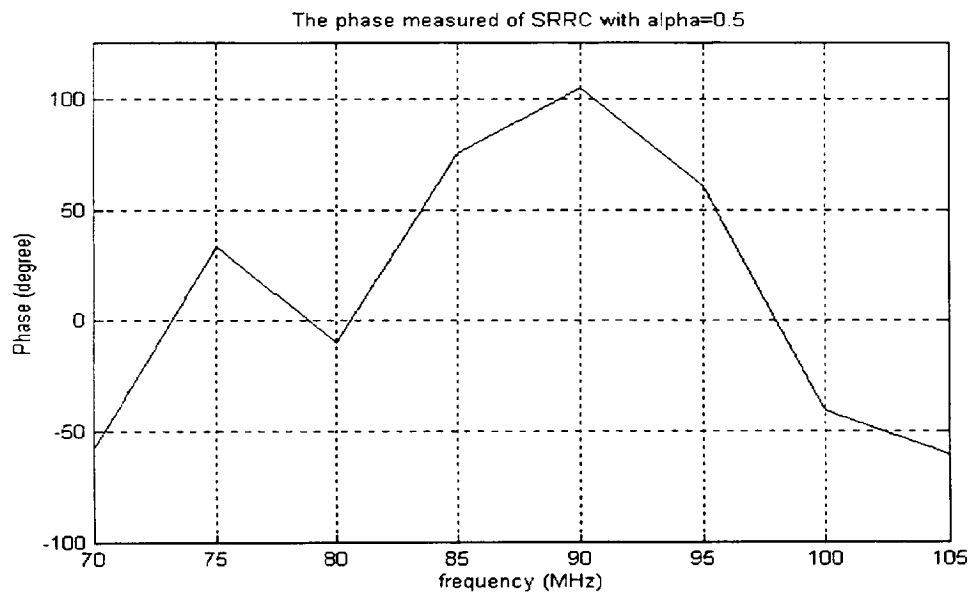
Figure 3.21 The Phase Measured at The Output of The SRRC Filter with $\alpha = 0.5$

For the SRRC filters, the measured phase response cannot be compared with the software because the phase with the software was made with respect to the number of Fast Fourier Transform Coefficients (FFT) not with respect to the frequency (see Figure 3.22 Below). It can be seen that Figure 3.21 and Figure 3.22 are totally different.

The Phase Response of SRRC with alpha=0.5

Figure 3.22 The SRRC filter ($\alpha = 0.5$) Simulated Phase Response

The frequency response of the signal at the output of the high power amplifier, in this particular case the SSPA is chosen again, is given in Figure 3.23. The -50 dB points for this SRRC filter are at 2.109 GHz and 2.073 GHz. Thus the bandwidth is equal to 36 MHz or 7.2 Rs. The complete results are given in Section 4.3.
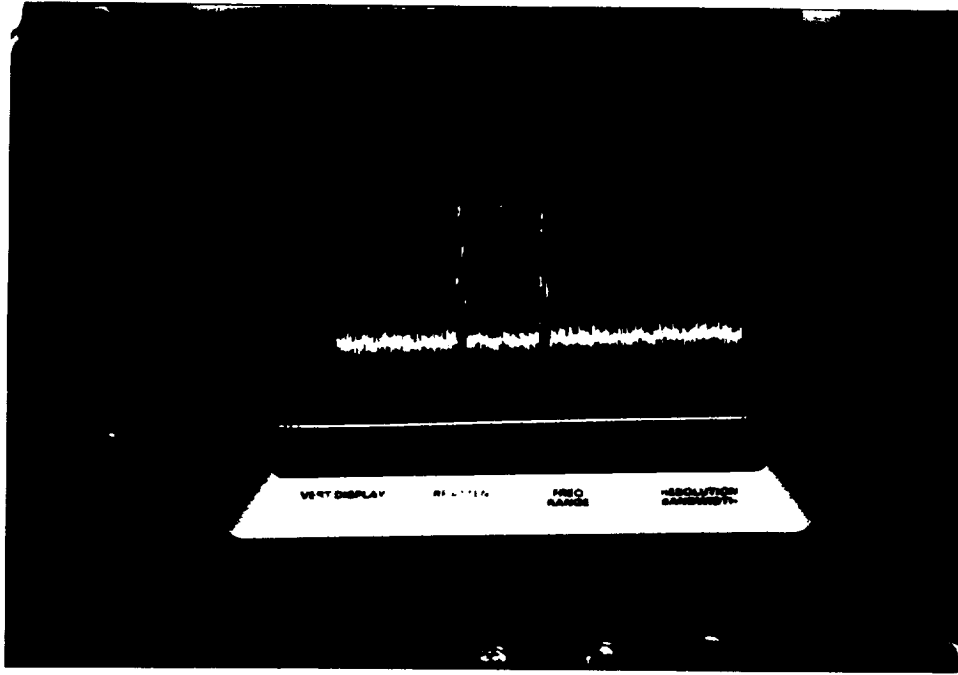
Figure 3.23 The Spectrum at The Output of SSPA with The SRRC Filter $\alpha = 0.5$

3.3 The Power Amplifier
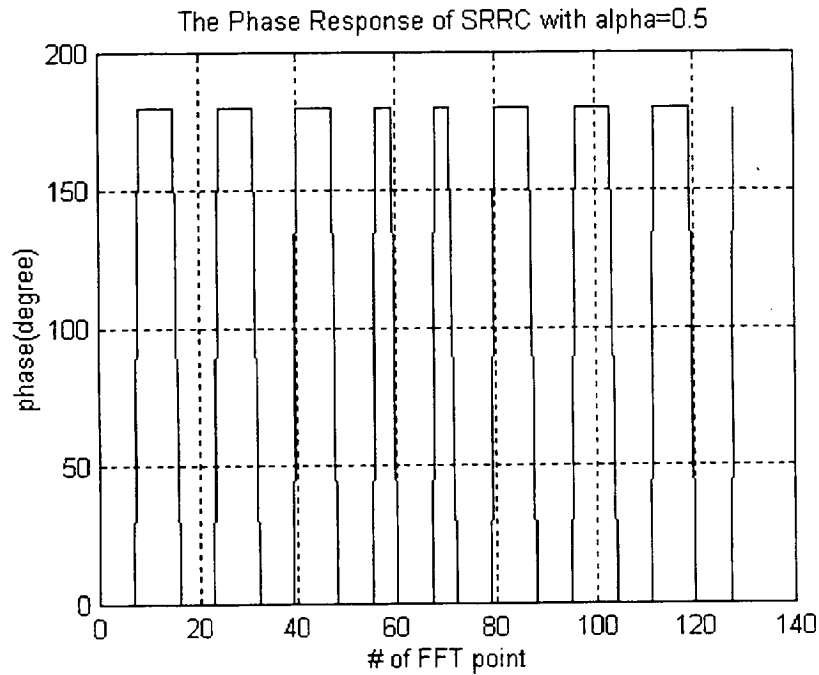
As mentioned in Chapter 2, the power amplifiers can be utilized in one of two regions, either in a linear region or in a non-linear region. High frequency power amplifiers such as Traveling-Wave Tubes (TWT) and Solid State Power Amplifier (SSPA) can be linear amplifiers when operated well below the saturation level. In this work, both of them have been utilized in their non-linear (saturation) region to maximize the signal power.

Figure 3.24 shows the set up configuration to measure the characteristics of the TWTA and the SSPA. In this case, we define the characteristic of the high power

amplifier as a magnitude characteristic (the output power as a function of the input power) and as a phase characteristic (the output phase as a function of the power input). To measure the output magnitude of the power amplifier, a 2 GHz sinusoid signal generated by the HP 8657B was used. Tektronix 492 spectrum analyzer was used to measure the magnitude of the signal spectrum. To measure the phase shift, the down converter is needed to shift the frequency of the signal down from S-band to the IF. The DSO Lecroy 9384L was used to see and measure the phase difference between the signal before and after the power amplifiers.
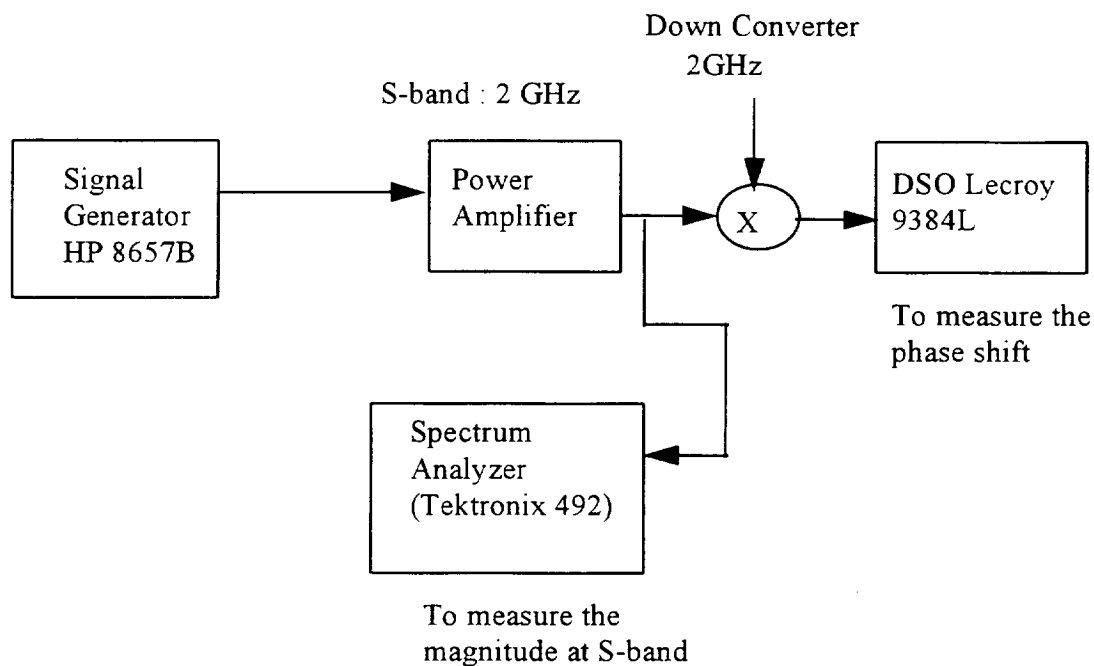
Figure 3.24 - The Measurement of The Characteristic of Power Amplifier

The plot of the characteristics of the TWTA are given in Figure 3.25 for the

magnitude and Figure 3.26 for the phase. The SSPA characteristics are given in

Figure 3.27 and in Figure 3.28. As mentioned in Chapter 2, the SSPA has less power

and a lower dynamic range, which is verified from these results. For the magnitude, the

characteristic of the TWTA has a wider non linear region than the SSPA. The TWTA

has a larger phase shift than the SSPA. Comparing these results to the SSPA European

Space Agency (ESA) 10 Watts Magnitude and Phase characteristics' (Figure 2.11 and

Figure 2.12), we can see that both of the magnitude characteristics are similar,

however the phase characteristics are different.

Figure 3.25 - The Characteristic of Magnitude of TWTA

Figure 3.26 - The Characteristic of Phase of TWTA

Figure 3.27 - The Characteristic of Magnitude of SSPA

Figure 3.28 - The Characteristic of Phase of SSPA

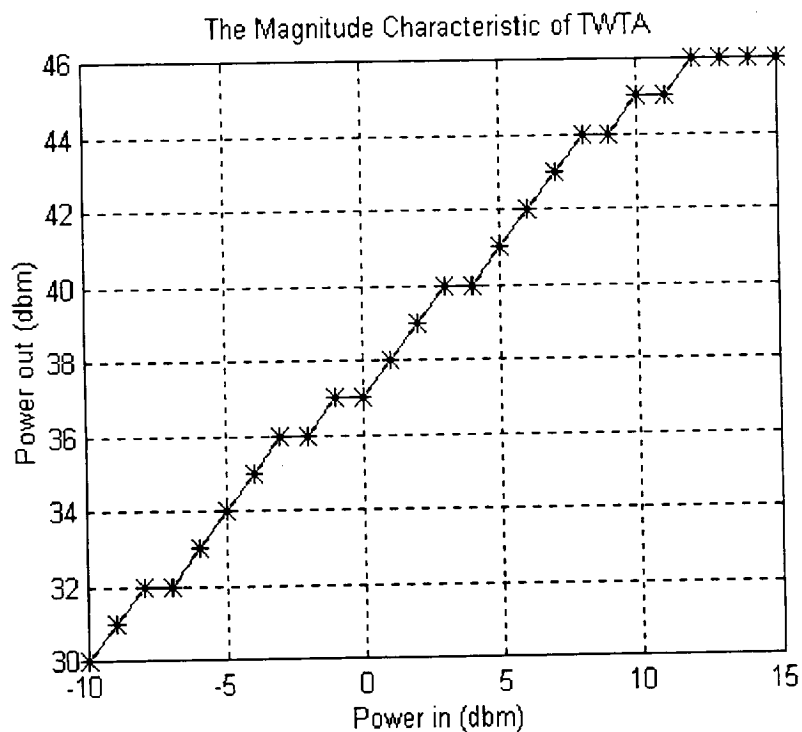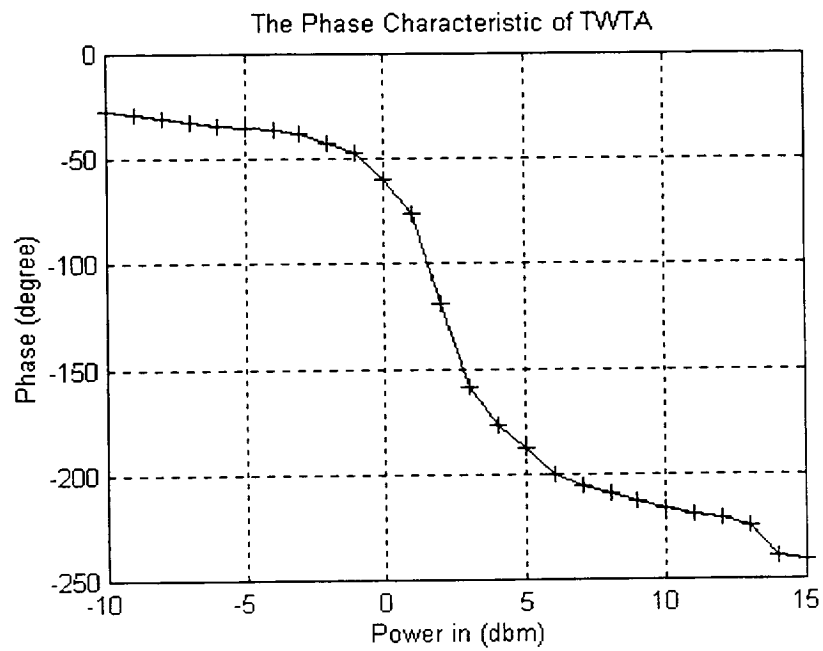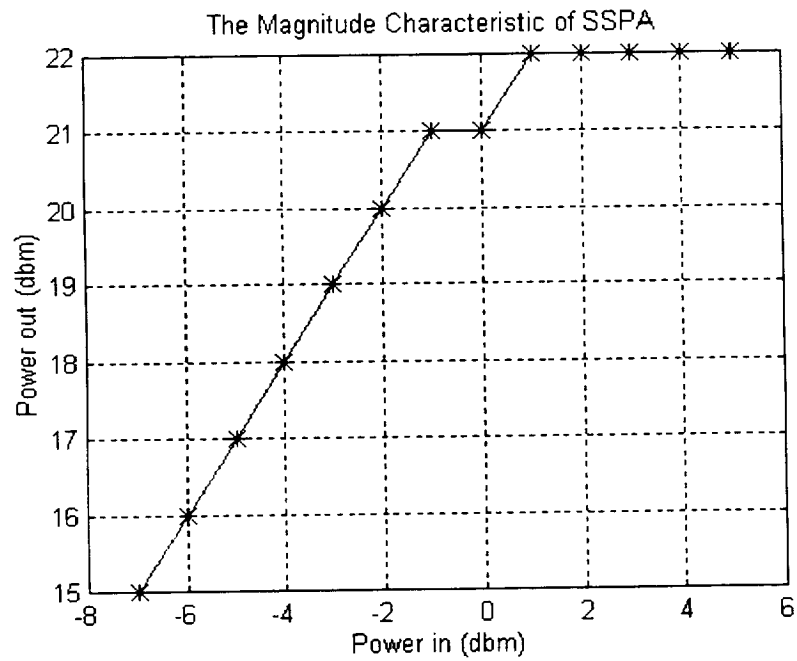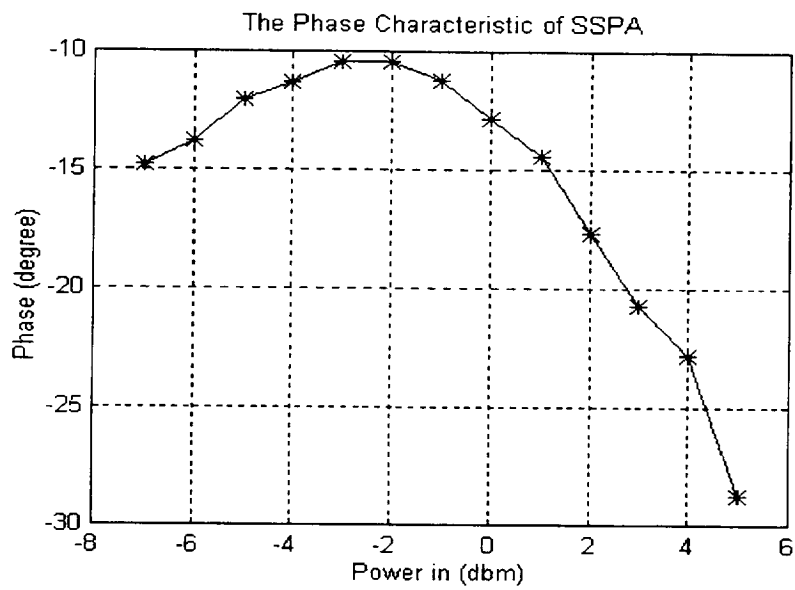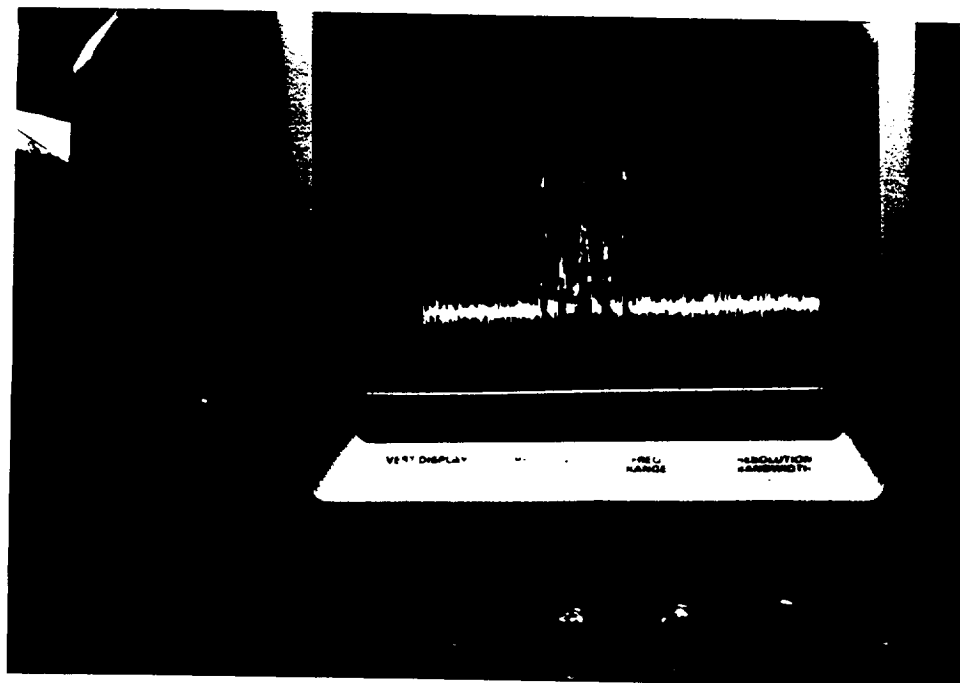3.29 The example of the output of TWTA with 3rd order Bessel filter

Figure 3.29 and Figure 3.18 (shown in page 40) show the effects on the spectrum of the signal with the same filter (3rd order Bessel filter) but with different high power amplifiers. It can be seen that with the TWTA (Figure 3.29), there is a spurious emission in the spectrum between the carrier frequency (2 GHz) and the filtered spectrum. Figure 3.29 shows that the upper side band has the maximum magnitude -19 dBm and the spurious emission has the maximum magnitude -38 dBm. It means that the spurious emission is still within the -50 dB range of the filtered spectrum. On the other hand, with the SSPA (Figure 3.18) there is no spurious emission. This spurious emission will reduce the utilization ratio of the TWTA as shown in the next section.

3.4 Bandwidth Utilization

The purpose of this section is to investigate the bandwidth efficiency or the bandwidth utilization by using pulse shaping on QPSK over a non-linear channel. As mentioned in Chapter 2 that to see the overall effect of spectrum shaping, a frequency band Utilization Ratio (ρ) was defined as [3]:

$$\rho = \frac{\text{The Bandwidth of the signal without Filtering}}{\text{The bandwidth of the signal with Filtering}}$$

Table 3.1 shows the utilization ratio for filters used with the TWTA. Without spurious emissions, the pulse shaping gives significant improvement on bandwidth efficiency. It can be seen that if the spurious emissions from the TWTA are counted,

the utilization ratio becomes smaller. The SSPA utilization ratios are shown in Table 3.2. The SSPA has no spurious emissions and the pulse shaping here also gives significant improvement on the bandwidth efficiency compared to the unfiltered signal. If the SSPA and the TWTA without spurious emissions are being compared, the results are about the same. The only disadvantage for the TWTA is that the spurious emission exists and it takes up more of the bandwidth. This will reduce the utilization ratio.

For the SRRC filter, it can be seen from Table 3.1 and Table 3.2 that the smaller α is the higher the utilization ratio becomes. This pattern follows the pattern from software simulation results. The SRRC with $\alpha = 0.25$ has similar performance to the 5th order the Butterworth filter and the SRRC with $\alpha = 0.5$ has similar performance to the 3rd order Bessel filter and the SRRC with $\alpha = 1$ has the worst utilization ratio.

Table 3.1 - Utilization Ratio with TWTA

Filter Type	only filter -50 dB point w/o spu.emis	Utilization Ratio of TWTA	with spu.emis. spec -50 dB point	Utilization Ratio of TWTA
None, Unfiltered Data (reference)	67.9 Rs	1	67.9 Rs	1
Butterworth 5th order	7.4 Rs	9.17	26.8 Rs	2.53
Bessel, 3rd order	8.5 Rs	7.98	27.2 Rs	2.49
SRRC ($\alpha = 0.25$)	6.6 Rs	10.28	24.9 Rs	2.73
SRRC ($\alpha = 0.5$)	7.3 Rs	9.30	26.1 Rs	2.60
SRRC ($\alpha = 1$)	9.0 Rs	7.54	28.1 Rs	2.41

Table 3.2 - Utilization Ratio with SSPA

Filter Type	SSPA -50 dB point	Utilization Ratio of hardware
None, Unfiltered Data (reference)	68.5 Rs	1
Butterworth 5th order (BT=1)	7.5 Rs	9.13
Bessel, 3rd order (BT=1)	8.3 Rs	8.25
SRRC ($\propto$ = 0.25)	6.1 Rs	11.23
SRRC ($\propto$ = 0.5)	7.2 Rs	9.51
SRRC ($\propto$ = 1)	9.1 Rs	7.53

Table 3.3 shows the comparison between the software simulations and the hardware implementations. The utilization ratios from the hardware implementations are smaller than the results for the software simulation. Even with the differences, the hardware implementation still gives a significant improvement over the non-filtered system. The pulse shaping technique does give significant improvement in bandwidth efficiency for QPSK signaling over a non-linear channel.

Table 3.3 - Utilization Ratio on QPSK software and hardware with SSPA

Filter Type	-50 dB BW (SW)	Util. Ratio (SW)	-50 dB BW (HW)	Util. Ratio (HW)
None, Unfiltered Data	90 Rs	1	68.5 Rs	1
Butterworth 5th order (BT=1)	5.28 Rs	17.05	7.5 Rs	9.13
Bessel, 3rd order (BT=1)	5.65 Rs	15.93	8.3 Rs	8.25
SRRC ($\propto$ = 0.25)	4.28 Rs	21.03	6.1 Rs	11.23
SRRC ($\propto$ = 0.5)	4.60 Rs	19.56	7.2 Rs	9.51
SRRC ($\propto$ = 1)	5.30 Rs	16.98	9.1 Rs	7.53

* Note : SW = software simulation and   HW= hardware implementation

Table 3.4 and Figure 3.30 show the comparison of utilization ratios for the software and the hardware results for the 3rd order Bessel and the 5th order Butterworth filters with BT=1,2 and 3 using the SSPA. As the BT increases, the utilization ratio decreases rapidly from BT=1 to BT=2, and decreases slowly from BT=2 to BT=3. The utilization ratios for the hardware implementation for the 5th order Butterworth are smaller than the software implementation. The utilization ratio of the hardware implementation for the 3rd order Bessel are also less than the software implementation. It can be seen from Table 3.4 that the 5th order Butterworth is recommended over the 3rd order Bessel filter. These results also show that the hardware implementation is not perfect but does follow the software simulation results.

Table 3.4 - Utilization Ratio with various BT by using SSPA

Filter Type	BW -50 dB point (BT=1)	Util. Ratio	BW -50 dB point (BT=2)	Util. Ratio	BW -50 dB point (BT=3)	Util. ratio
None, (sw) Unfiltered	90 Rs	1	90 Rs	1	90 Rs	1
Butterworth 5th (sw)	5.28 Rs	17.05	8.74 Rs	10.29	11.15 Rs	8.07
Bessel, 3rd order (sw)	5.65 Rs	15.93	10. 26Rs	8.77	13.93 Rs	6.46
None, (hw) Unfiltered	68.5 Rs	1	68.5 Rs	1	68.5 Rs	1
Butterworth 5th (hw)	7.5 Rs	9.13	14.9 Rs	4.59	22.16 Rs	3.09
Bessel, 3rd order (hw)	8.3 Rs	8.25	16.9 Rs	4.05	25.47 Rs	2.69

* Note : sw = software simulation
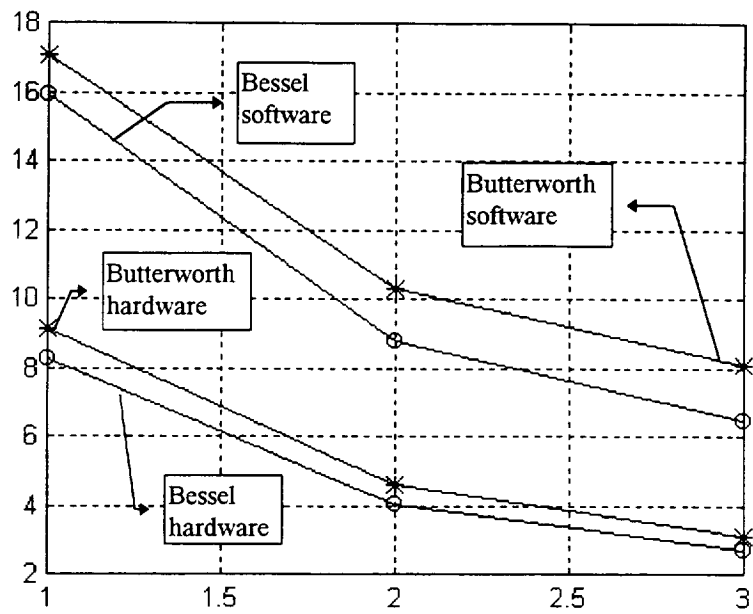 hw= hardware implementation

Figure 3.30 The Comparison between software and hardware on the Bessel and the Butterworth filters

Chapter 4

CONCLUSION AND RECOMMENDATIONS

This section will explain the conclusions and suggestions for further study from the research of the effect of pulse shaping QPSK on bandwidth efficiency over non-linear channels that consists of the software simulations and the hardware implementations.

4.1 Conclusion

For the simple but practical systems studied, pulse shaping on QPSK signaling does provide the bandwidth efficiency that was indicated through software simulations.

Regarding QPSK and 8PSK schemes, with the same filters and with respect to bit rate (Rb), the results show that 8PSK has higher utilization ratios than QPSK. In general, 8PSK contains more information than QPSK, however QPSK has better performance against noise (Eb/No)[5][8]. From the hardware point of view, QPSK is used more often than 8PSK and QPSK has a simpler and less expensive hardware implementation than 8PSK. So, there are trade offs that should be considered in making decisions whether QPSK or 8PSK is utilized.

Regarding the software simulations, the SRRC filters with α=0.25,0.5 have the highest utilization ratio. Then, they are followed by the 5th order Butterworth filter, SRRC α=1 and the 3rd order Bessel. For the SRRC family, we can see that the higher the roll off factor the lower the utilization ratio.

Concerning the hardware implementations, the SRRC filter with α=0.25 has the highest utilization ratio. Then, followed by the 5th order Butterworth filter, the SRRC filters with α=0.5 and the 3rd order Bessel filter. The SRRC filter with α=1 has the lowest utilization ratio. The 5th order Butterworth filter is recommended over the 3rd order Bessel filter. For the SRRC, it can be seen that the smaller the roll off factor the narrower the bandwidth and the higher utilization ratio. This result follows the software simulation results. It is shown that the hardware implementation results are not as good as the software simulation results. This follows from the fact that the hardware implementations include non ideal components while the software simulations reflect ideal conditions.

The SSPA provides a more linear magnitude characteristic and less phase shift compared to the TWTA. Eventhough the TWTA has higher power and a wider dynamic range, the SSPA still gives better frequency response since it has no spurious emissions in its spectrum when it is utilized in its non-linear region (saturation region). These spurious emissions reduce the utilization ratio of the bandwidth.

4.2 Recommendations

For future investigation, there are some suggestions for further study:

1. Build a receiver and perform the Bit Error Rate (BER) data runs.

2. Implement 8PSK signaling scheme in hardware.

3. To place the pulse shaping filter before the modulator and hold everything else

fixed. This would need three PTF filters.This will also give a constant envelope signal.

4. To use the 3rd order Butterworth filter and the 5th order Bessel filter on the pulse shaping filters and compare the results.

REFERENCES

[1] Warren L. Martin and Tien M. Nguyen, "CCSDC - SFCG Efficient Modulation Methods Study, A Comparison of Modulation Schemes, Phase 1: Bandwidth Utilization (Response to SFCG Action Item 12/32)," SFCG-13, Ottawa Canada, 13-21 October 1993, report dated 24 September 1993.

[2] Dr. Manfred Otter, "CCSDC - SFCG Efficient Modulation Methods Study, A Comparison of Modulation schemes, Phase 1b: A Comparison of QPSK, OQPSK, BPSK, and GMSK Modulation Systems (Response to SFCG Action Item 12/32)," European Space Agency/ESOC, Member CCSDS Subpanel 1E, (RF and Modulation), June 1994.

[3] Warren L. Martin and Tien M. Nguyen, "CCSDC - SFCG Efficient Modulation Methods Study, A Comparison of Modulation Schemes, Phase 2: Spectrum Shaping (Response to SFCG Action Item 12/32)," SFCG Meeting, Rothenberg, Germany 14-23 September 1994, report dated August 1994.

[4] Warren L. Martin, Tien M. Nguyen, Aseel Anabtawi, Sami M. Hinedi, Loc V. Lam and Mazen M. Shihabi, "CCSDC - SFCG Efficient Modulation Methods Study Phase 3: End-to-End System Performance," Jet Propulsion Laboratory, April 1997.

[5] John G. Proakis, "Digital Communications," McGraw-Hill, 1995, Third Edition.

[6] "Acoustic Charge transport Technology: Principles and Applications," Comlinear Corporation, 1992.

[7] Andreas Antoniou, " Digital Filters: Analysis and Design," McGraw-Hill,1979.

[8] Leon W. Couch II, "Digital and Analog Communication Systems," Macmillan Publishing Company, 1993 , Fourth Edition.

[9] Stephen Horan, "Introduction to PCM Telemetering Systems," CRC Press Inc. 1993.

[10] Lonnie C. Ludeman, "Fundamentals of Digital Signal Processing," John Wiley & Sons, 1986.

[11] Ruben Caballero, B.Eng, "8-PSK Signaling Over Non-Linear Satellite Channels," Master Thesis , New Mexico State University, May 1996.

[12] "Noise Generator NC 6108 Operating Manual," Noise Com. Inc, 1990.

[13] "RF/IF Designer's Handbook," Mini Circuits, 1993.

[14] G. Block, "Efficient Modulation Study," Consultative Committee For Space Data System, Interim Report, April 1997.

[15] "TWT/TWTA Handbook", Hughes Aircraft Company, Electron Dynamics Division, 1992.

Appendix A

THE TEST PROCEDURE FOR

HARDWARE IMPLEMENTATION

This section will explain the test procedure for the hardware implementation. The block diagram of the system is given in Figure A.1.
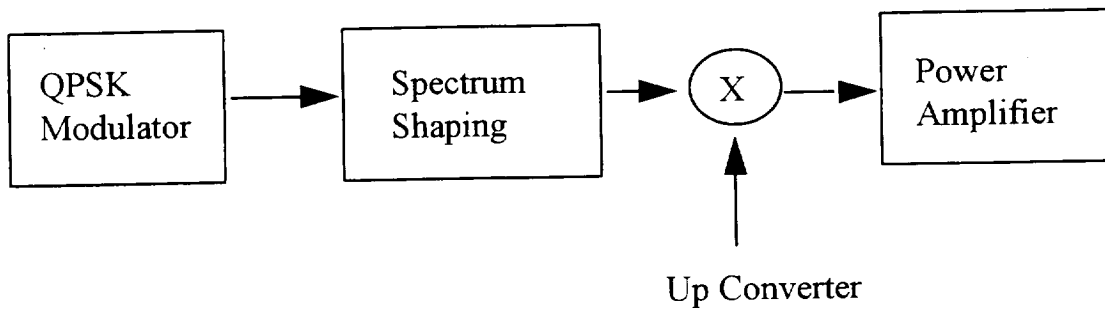

Figure A.1 - The Block Diagram of The System

The HP 8782B Vector Signal Analyzer is utilized to produce the 90 MHz QPSK signal. The QPSK signal goes to the spectrum shaping filter. The filters that are used for this research are the 5th order Butterworth filter, the 3rd order Bessel filter and the Square Root Raised Cosine (SRRC) filter with roll of factor 0.25, 0.5 and 1. The up converter is needed to shift the signals to S-band frequency (1.55 GHz - 5.20 GHz). These shifted signals will enter the Power Amplifier that is operated in its non-linear region to get the maximum power. There are two kinds of power amplifier that have

been used: the Traveling Wave Tube Amplifier (TWTA) and Solid State Power

Amplifier (SSPA.) All of them work in the S-band frequency range.

There are three different hardware configurations that have been used:

1. To measure the unfiltered signal.

2. To measure the filtered signal.

3. To measure the characteristic of the high power amplifier.

A.1. The Set Up For The Unfiltered Signal

The hardware set up for the unfiltered signal is given in Figure A.1 below.
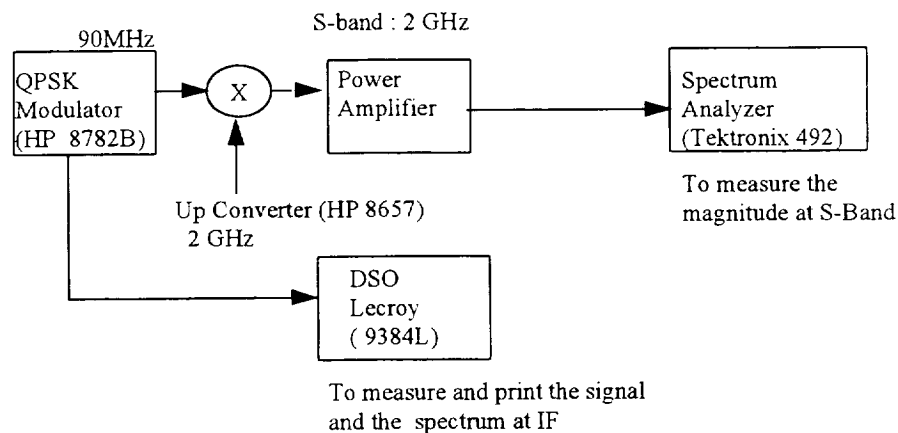

Figure 3.4 - The Hardware Set Up of Unfilter Signal

The following steps are utilized:

1. The QPSK modulator (HP 8782B) should have the following condition:

1.1 The modulation on.

1.2 The Rf output on.

1.3 Prbs on.

1.4 Set frequency to 90 MHz.

1.5 Set the modulation to QPSK.

1.6 Set level as desired, usually from the lower value, for example -10 dBm to the higher value.

1.7 Connect the Rf output to channel 1 of DSO Lecroy 9384L by using the RG 58A/u coaxial cable. Use the same cable to the mixer.

2. The signal generator for up converter (HP 8657) should have the following set up:

2.1 Set the Rf output on.

2.2 Set the frequency 2000 MHz.

2.3 Set the amplitude as desired.

2.4 The RG 8A/u 50 ohms cable (the thick one) is used to connect the output to the mixer.

3. The mixer is ZFM 4212 of Mini Circuits.

4. There are two high power amplifiers that have been used. The first one is a Traveling Wave Tube Amplifier (TWTA) that was made by the Hughes Aircraft Company with a serial number 8010H. The second one is the Solid State Power Amplifier (SSPA) that was made by Mini Circuits with a serial number ZHL-42. Both of them were implemented in the S-band frequency range.

4.1 For the 8010 H TWTA, the following steps should be followed:

4.1.1 Before operating the TWTA, be sure that the output is connected to a

coaxial directional coupler and the load. In this case, the coaxial

directional coupler of Narda Corp., model : 3003 - 10 with a serial

number 21540 has been used. The directional coupler has two outputs,

one goes to the load and the other one which has -10 dB attenuation

is connected to the spectrum analyzer the Tektronix 492 with The

RG 8 A / u 50 ohms cable (the thick one). The load is the N 9525

ARRA load with serial number 858.

**DO NOT OPERATE THE TWT WITHOUT THE COAXIAL
DIRECTIONAL COUPLER AND THE LOAD. YOU WILL
DESTROY THE TWTA.**

4.1.2 Turn on the power, but don't turn on the operate switch. It is

necessary to wait for 15 minutes to let the tube warm up.

4.1.3 Turn on the operate switch. During the operation, pay attention to

the helix current light, faults light and operate light. If the faults light

comes on and gives an error message, turn off the operating switch

immediately. If it is necessary, turn off the power switch also.

4.1.4 For safety reasons, turn off the operating switch after it has been used for

more than 15 minutes. The power does not need to be turned off. Wait

for about 10 minutes then turn on and start operating again.

5. The following steps are used to measure the spectrum of the signal by using DSO

Lecroy 9384L:

5.1 Use channel 1 as a terminal to the DSO.

5.2 Press auto set up.

5.3 Press math setup, followed by redefined A and answer yes to confirm.

5.4 Select FFT and power spectra from the menu.

5.5 Don't forget to select of channel 1, since the signal can use channel 1 as a terminal input.

5.6 Average FFT is desired. In order to do that, press math set up again and redefined B.

5.7 Select FFTAVG and power spectra from the menu.

5.8 Select of A, to get FFT average of the FFT of the signal.

6. The following steps are used to save the signal to the floppy disk and insert it into the word processor i.e. Microsoft word:

6.1 Press utilities.

6.2 Select hardcopy setup.

6.3 Select flpy for floppy disk and insert the floppy disk into the drive.

6.4 Select protocol : BMP, the format of the file that will be saved.

6.5 Press screen dump and the file will be saved.

A.2. The Set Up For The Filtered Signal

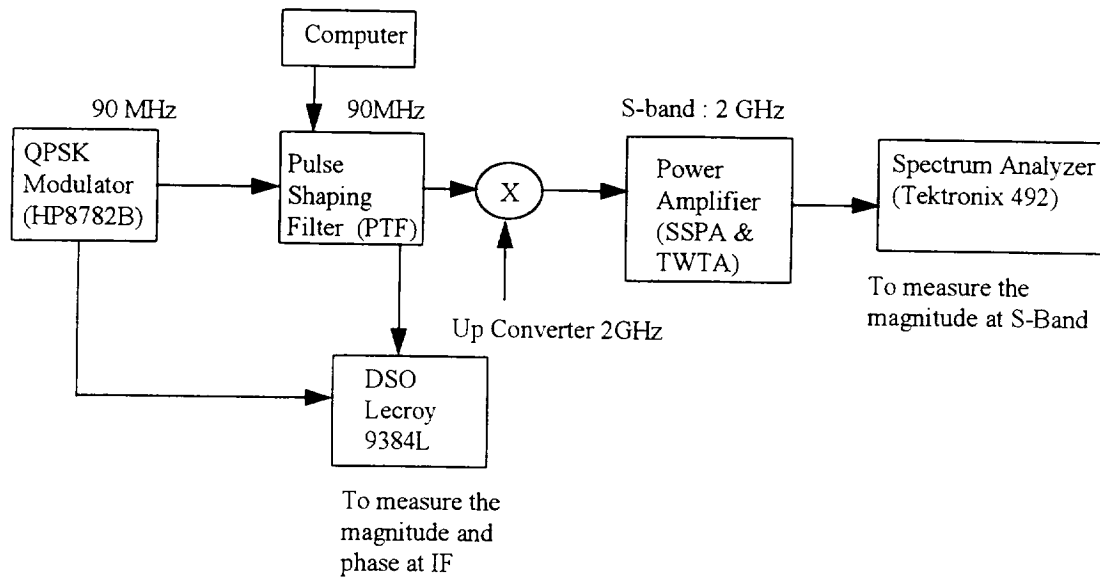The hardware set up for the filtered signal is given in Figure A.2.

Figure A.2 - The Hardware Set Up of Filter Signal

Most of the system and the set up steps are same as before, but add the following steps:

1. A programmable Transversal Filter (PTF) of Comlinear Corp is utilized as a pulse shaping filter by downloading the coefficients of its 127 taps through the Personal Computer (PC). These coefficients are created with MATLAB. The program listing is given in appendix B.

2. Connect the parallel port of the computer to the parallel port of the PTF.

3. Don't forget to connect the PTF to the power supply with polarity +12 and -5.

4. REMEMBER THAT THE MAXIMUM POWER INPUT IS 10 dBm. IF WE

EXCEED THIS VALUE, WE MAY DESTROY THE PTF.

5. Everytime we want use the PTF, we need to load the coefficients that have been

made with MATLAB to the PTF by using the file "Loaddata.exe".

A.3. The Set Up For The Measurement Of The Power Amplifier

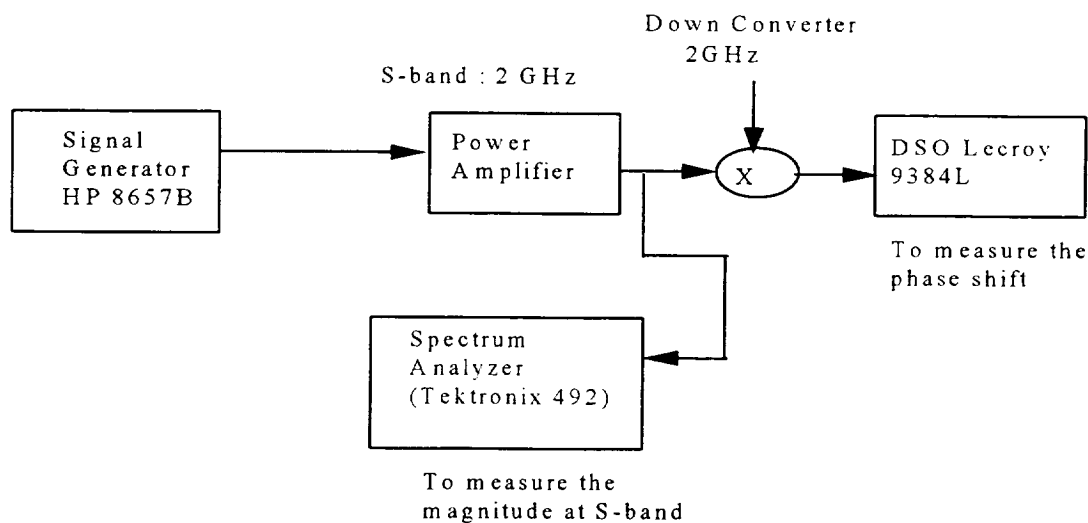The hardware set up for the filtered signal is given in Figure A.3.

Figure A.3 - The Measurement of The Characteristic of Power Amplifier

Follow the same steps as before, but add:

1. The signal generator 8657B is used as a source to the power amplifier and as a

signal multiplier to the output of the signal output of power amplifier.

2. All of the connections on the S-band frequency range have to use the RG 8a/u 50

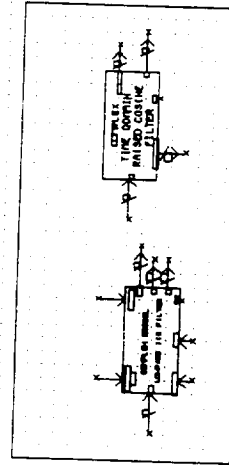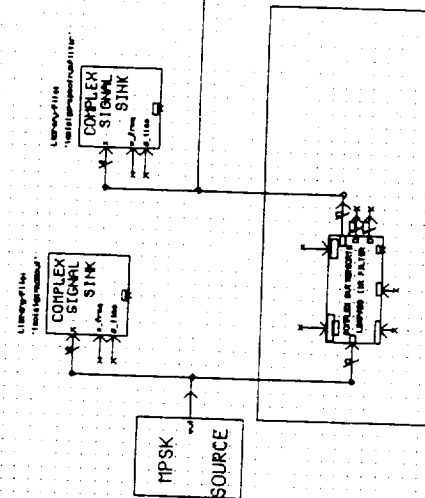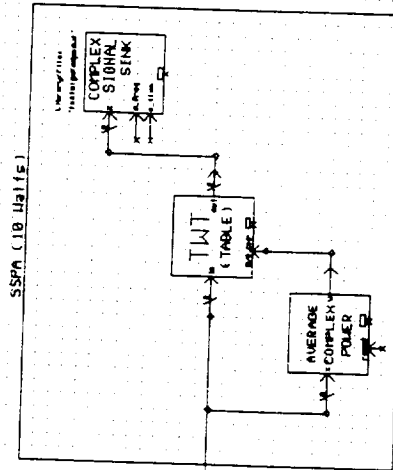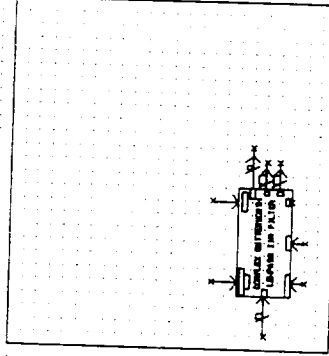ohm (the thick one).

Appendix B

THE SPW DETAIL PROGRAM

Appendix C

THE LISTING PROGRAM

```
%%%%%%%%%%%%%%%%%%%%
% For Butterworth and Bessel filter
% filename: filterph.m
%%%%%%%%%%%%%%%%%%%%
clear all;

% for butterworth filter;
w1=[85000000 95000000]; % the cutoff freq in this case for BT=2.
[b,a]=butter(5,w1,'s');  % 5th order Bessel filter
% for bessel 3rd order
% [b,a]=besself(3,w1);

h=freqs(b,a,128); % take 128 point of freq response and

%quantize the coefficients to become from -31 to 31
hq=h*(31/max(abs(h)));
hq=round(hq);

for k=1:127    % odd coeff multiply with -1
  hq1(k)=hq(k)*(-1)^k;
end;

fid=fopen('butter5.dat','wt'); % save to the text file. for bessel filter give name
fprintf(fid,'%6i\n',hq1);       % with bessel3.dat
fclose(fid)


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% for different BT, need to change the cut off frequency of the filter
% then the coefficients will be put into the PTF by using computer and file "loaddata.exe"
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%
% for SRRC
%%%%%%%%%%%%%%%%%%%%%%%%%
clear all;

nfft=128;
beta=.5; (will change for different beta, 0.25 and 1)


step=1;
```

```
t=((-nfft/2+1):nfft/2)/step+1e-9;

rcos=(sin(pi*t)./(pi*t)).*(cos(beta*pi*t)./(1-(4*beta^2*t.^2)));
RCOS=fft(rcos,nfft);
SRRC=sqrt(abs(RCOS));
srrc=real(ifft(SRRC,nfft));
h=[srrc(nfft/2+1:nfft) srrc(1:nfft/2) srrc(nfft/2+1)];

%quantize the coefficients to become from -31 to 31
hq=h*(31/max(abs(h)));
hq=round(hq);

for k=1:127       % odd coeff multiply with -1
 hq1(k)=hq(k)*(-1)^k;
end;

fid=fopen('SRRC5.dat','wt'); % save to the text file.
fprintf(fid,'%6i\n',hq1);
fclose(fid)


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% for different alpha, need to change the alpha frequency of the filter
% then the coefficients will be put into the PTF by using computer and file "loaddata.exe"
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```