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THESIS

DATA SET SIMULATION AND RF PATH MODELING OF A QPSK RADIO COMMUNICATION SYSTEM

by

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September 2005

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DATA SET SIMULATION AND RF PATH MODELING QPSK RADIO COMMUNICATION IDENTIFICATION

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ABSTRACT

This project simulates QPSK modulation signals and uses a laboratory environment to create deteriorating effects of real-world high frequency (HF) transmissions that may modify the ideal QPSK waveform. These modifications may be identifiable in order to “fingerprint” the source of the modifications. To simulate the transmission path in the real world a signal generator is used to create the QPSK I/Q signal at the HF operating frequencies and a digital sampling oscilloscope acts as a receiver and records the data for analysis. A computer with MATLAB Instrument-control Toolbox is used to generate a random-input data stream as an input to the signal generator, which modulates the RF signal. The RF signal was chosen to be at HF (5-15 MHz) and the QPSK modulation was at 9600 baud. The deterioration effects of a real world transmitter site were chosen to be associated with the output amplifier linearity and with the transmission line condition between the transmitter and antenna.

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I. INTRODUCTION

QPSK digital modulation is used for data transmission in cable and radio frequency transmitting systems. Although QPSK is fairly resistant to noise, the deteriorating effects of real-world transmissions can modify the ideal QPSK waveform; these modifications may be detectable in order to "fingerprint" the source of the modification. The data rates and frequencies of this study are 9600 baud and 5 to 15 MHz and using a signal generator and digital sampling oscilloscope act as a transmitter and receiver to simulate the real-world transmission. The RF path from the generator to the sampling oscilloscope is modified in a manner that simulates a real-world system.

This study provides the Navy with a sample RF signal of QPSK modulation which simulates a real-world transmission system and its RF cables. By knowing the signal modifications that are created by these experiments, the Navy can begin to "fingerprint" signals received from real-world transmitters that have similar RF path anomalies.

To simulate the transmission path in the real-world, a signal generator is used to create the QPSK I/Q signal at the HF operating frequencies and RF system effects on the transmitted signal in the real-world, certain cables and RF circuit components are used to simulate the transmitting system, including "matched" 50-*ohm* cables and "mismatched" 75-*ohm* cables, combinations of different cables, parallel loads, series loads, and linear and saturated amplifier modes.

The digital sampling oscilloscope acts as a receiver and records the data for analysis. In order to simulate a long data stream, a computer with MATLAB Instrument-control Toolbox is used to generate a random-input data stream as an input to the signal generator, which modulates the RF signal.

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II. DEFINING THE SCOPE OF THE EXPERIMENT

A. BACKGROUND

The military employs a number of different types of radio communication transmitter sites: man-mobile stations, ship or aircraft platforms, and fixed stations. Man-mobile and ship or aircraft platforms are mobile stations. Fixed stations are facilities built in desired locations. Different stations can produce different kinds of effects on signal transmission and reception. Fixed stations are easy to simulate initially and to develop for further study and are widely used in real-world communications, thus a fixed station is simulated in this experiment. When signals travel from a transmitter to a receiver, they pass through amplifiers, transmission lines, antennas, and filters, etc. Each RF component can modify the signal depending on the component's characteristics. Modulation is a key factor in signal transmission. Received signals rely on the modulation type used to carry the message. The transmission path from the transmitter to the antenna terminals and the modulation for a QPSK radio communication system are simulated in this thesis.

B. STATIONS

A communication station is a facility containing a transmitter or a receiver. The man-mobile or ship platforms are considered as a mobile stations. Stated locations for the transmitter and the receiver are labeled a fixed station. Different types of stations may have different effects on the received signals. The following sections discuss the effects caused by different kinds of stations.

1. Mobile Station

In a mobile station, the platform may be moving during transmission and reception. The target is not always fixed at the same position. When the target moves during transmission or reception, it can cause signal fading. In addition, radio propagation is very complex; it can cause multi-path scattering, shadowing, and attenuation effects. Figure 2.1 shows two types of fading that can occur with mobile station transmissions, long term fades and short term fades.

a. ***Long Term Fades***

(1) Attenuation: In free space, power degrades by $\frac{1}{d^2}$.

(2) Shadows: Signal blocked by obstructing structure.

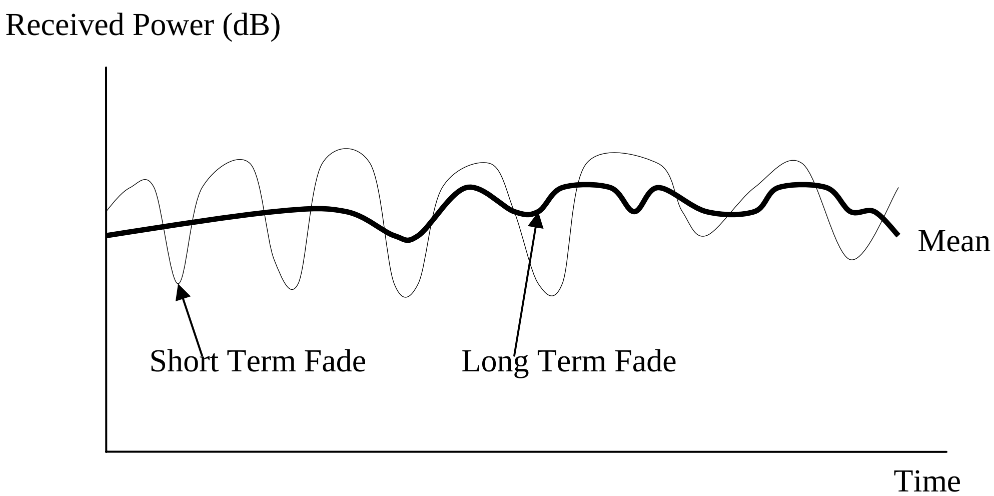

Figure 2.1 Types of Fading

b. ***Short Term Fades***

Short term fades come from multi-path effects during rapid changes in signal strength over a small area or time interval, random frequency modulation due to varying Doppler shift on different multi-path signals, and time dispersion (echoes) caused by multi-path propagation delay. [Ref .1]

2. Fixed Station

In fixed station communication sites, transmitters and receivers are located at fixed positions. During communication, received signal power is more stable than for mobile stations. In addition, fixed stations are easy to simulate in the laboratory and this thesis focuses on fixed stations, where the main topics of concern are transmission path effects and the modulation technique, both of which are described later.

C. TRANSMISSION LINE EFFECTS

When users communicate with each other, a signal passes from the transmitter through the transmission line to the antenna. The antenna propagates the signal into free space, usually in a preferred direction; the signal is received by an antenna at a receiving station. The signal path has three different portions, which are the transmitter to the antenna, the propagation medium, and the antenna to the receiver. The propagation medium and transmission line are two factors that can contribute to distortions and attenuation of the signal. Transmission line effects are covered in this thesis.

A transmission line connects a transmitter to an antenna. Its function is to deliver all the signal power to the antenna. A perfect transmission line does not radiate and has no loss. When an antenna is connected directly to a transmitter, the load on the transmitter is the antenna impedance. When a transmission line connects a transmitter to an antenna, the load on the transmitter is not necessarily the antenna impedance, but rather the transmission line input impedance, which may or may not be the same as the line's characteristic impedance (Z_0). The output impedance of the transmitter must match the input impedance of the transmission line for the antenna to receive maximum power transfer to the antenna. If a transmission line is terminated in a load not equal to its characteristic impedance, then the impedance on that line varies along its length due to the presence of both incident and reflected waves. This condition can exist during this study and is discussed in a later section.

The characteristic impedance of a transmission line is determined by the size and shape and spacing of the conductors and the type of insulating material between them. If the distributed inductance, L, and capacitance, C, per unit length of a line is known, then the characteristic impedance is:

$$Z_0 = \sqrt{\frac{L}{C}} \text{ ohms.} \tag{2.1}$$

These data are found in the markings on the cable. In radio-communications, a cable of $Z_0 = 50\,\Omega$ is in common use for transmission lines. For receive-only systems, $75\,\Omega$ cables are also used. Because $50\,\Omega$ cable is the best compromise between power handling capability and loss, whereas $75\,\Omega$ cable is optimized for having the lowest attenuation without regard to power handling ability, in the laboratory, both $50\,\Omega$ and $75\,\Omega$ cables are used to simulate real-world transmission lines. [Ref. 2]

D. MODULATION TECHNIQUES

Modulation**,** in communications, is the process by which some characteristic of a carrier wave is varied in accordance with an information-bearing signal wave, the modulating wave. Demodulation is the process by which the original signal is recovered from the wave produced by modulation. The original, unmodulated carrier wave may be from any source such as an antenna fed by a transmission line. The carrier wave can be a direct current, an alternating current, or a pulse train. During modulation, it is modified such that its amplitude, frequency, or some other property varies with the information wave.

1. Amplitude Modulation

Amplitude modulation (AM) is the modulation method used in the AM radio and short-wave broadcast bands. In this system the intensity or amplitude of the carrier wave varies in accordance with the modulating signal. When the carrier is modulated, a fraction of the power is converted to sidebands, extending above and below the carrier frequency by an amount equal to the highest modulating frequency. If the modulated carrier is rectified and the carrier frequency is filtered out, the modulating signal can be recovered. Amplitude modulation is not a very efficient method for sending information; the power required is relatively large because the carrier, which contains no information, is sent along with the information. In a variant of amplitude modulation, called single sideband modulation (SSB), the modulated signal contains only one sideband and no carrier. The information can be demodulated only if the carrier is used as a reference. This is normally accomplished by generating a voltage waveform in the receiver at the carrier frequency. Single sideband modulation is used for long-distance telephony (such as in the amateur radio bands) and telegraphy over land and in submarine cables. [Ref. 3]

2. Pulse Modulation

Pulse modulation involves modulating a carrier that is a train of regularly recurrent pulses. The modulation might vary the amplitude (PAM or pulse amplitude modulation), the duration (PDM or pulse duration modulation), the position (PPM or pulse position modulation), or the presence of the pulses (PCM or pulse code modulation). PCM is often used to send digital data, i.e. the audio signals on a compact disc. Pulse code modulation, developed in 1939 by the English inventor Alec H. Reeves, is a very important form of pulse modulation because it can be used to transmit information over long distances with very little interference or distortion. For this reason it has become increasingly important in the transmission of data in the space program and between computers. Although PCM transmits digital instead of analog signals, the modulating wave is continuous. Digital modulation is keyed by a digital modulating signal. The two most common digital modulating techniques are phase-shift keying (PSK) and frequency-shift keying (FSK) modulation. [Ref. 3]

3. Frequency Modulation

In frequency modulation (FM), the frequency of the carrier wave is varied so that the change in frequency at any instant is proportional to the information signal which also varies with time. Its principal application is also in radio, where it offers increased noise immunity and decreased distortion, compared to AM transmissions, at the expense of greatly increased bandwidth. The FM band has become the choice of music listeners because of its low-noise, wide-bandwidth qualities; it is also used for the audio portion of television broadcast.

4. Phase Modulation

Phase modulation, like frequency modulation, is a form of angle modulation because the phase angle of the sinewave carrier is changed by the modulating wave. The two methods are similar in the sense that any attempt to shift either the frequency or phase is accomplished by a change in the other. Quaternary Phase Shift Keying (QPSK), one type of phase modulation, is commonly used in communication. Information in binary is conveyed over a communication channel or circuit by modulating a sinusoidal RF carrier. The baseband information bit stream modulates the carrier by means of discrete changes in the instantaneous carrier phase. The “PSK” in QPSK refers to the use of Phase Shift Keying, a form of phase modulation that is accomplished by the use of a discrete number of phase states. QPSK refers to PSK with four states. A method with half that number of states is Binary Phase Shift Keying (BPSK). The “Quaternary” in QPSK refers to four phase states of the carrier waveform, -135, -45, +135, and +45 degrees. Because QPSK has four possible phases, QPSK can encode two bits per symbol.

In QPSK modulation, information is conveyed via phase variations. In each time period, one phase change can occur. Since there are four possible phases, there are 2 bits of information conveyed within each time period. Figure 2.2a demonstrates the partitioning of a typical pulse stream for QPSK modulation.

Figure 2.2a shows the input data stream $d_k(t) = d_0, d_1, d_2, ...$ consisting of eight bipolar pulses; that is $d_k(t)$ are +1 or -1, representing binary one and zero, respectively. The pulse stream is divided into in-phase parts, d_I, and quadrature parts, d_Q, exemplified in Figure 2.2b.

$$d_I(t) = d_{0,} d_2, d_4, ...(even\, bits) \tag{2.2}$$

$$d_Q = d_1, d_3, d_5, ...(odd\, bits) \tag{2.3}$$

It is important to note that $d_I(t)$ and $d_Q(t)$ make up $d_k(t)$. The digital QPSK modulation signal is created by summing a cosine function modulated with the $d_I(t)$ stream and sine function modulated by the $d_Q(t)$ stream, as follows:

$$s(t) = \frac{1}{\sqrt{2}} d_I(t) \cos[2\pi f_0 t + \frac{\pi}{4}] + \frac{1}{\sqrt{2}} d_Q(t) \sin[2\pi f_0 t + \frac{\pi}{4}] \tag{2.4}$$

Using trigonometry,

$$\sin(x \pm y) = \sin x \cos y \pm \cos x \sin y \text{, and} \tag{2.5}$$

$$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y, \tag{2.6}$$

equation (2.4) can be written as

$$s(t) = \cos[2\pi f_0 t + \frac{\pi}{4}], \tag{2.7}$$

which is the output of a QPSK modulation signal. When this signal is transmitted, the receiver must demodulate the signal and recover the data. The hardware portion of the QPSK technique can be found in textbooks such as "Digital Communication," Second Edition. [Ref. 3]

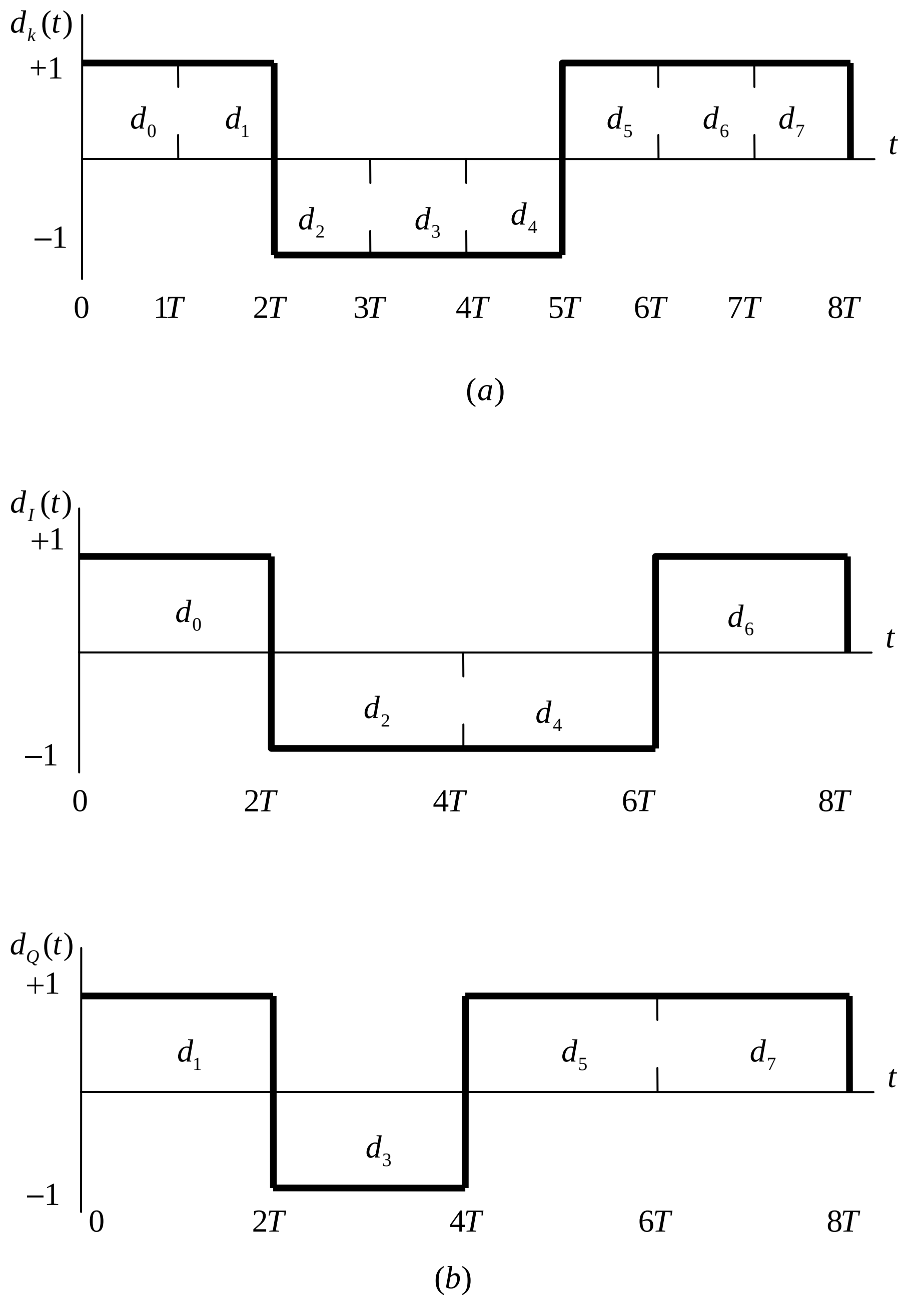

Figure 2.2 QPSK Modulation

Sometimes, it is useful to represent the modulation technique with its signal space representation in the $I-Q$ plane as shown in Figure 2.3. The four points in the plane represent the four possible phase shifts of the QPSK signal. These four points represent an ideal QPSK constellation. The sequence in the constellation depends on the input data train.

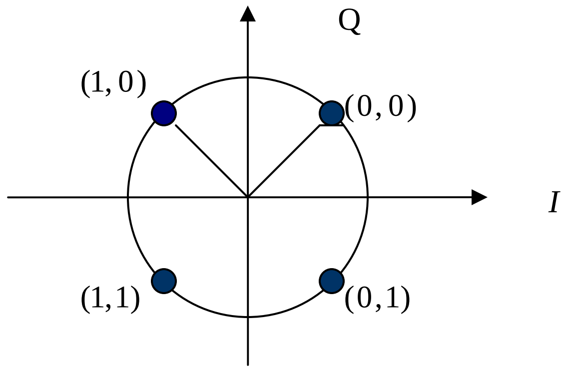

Figure 2.3 QPSK Constellation

In real-world QPSK transmissions, these four points are changed to a “scatter” cluster around the ideal point shown, as shown in Figure 2.4, which is an inevitable consequence of any pulse shaping and relates to increased bit-error rate for the signal. [Ref. 4]

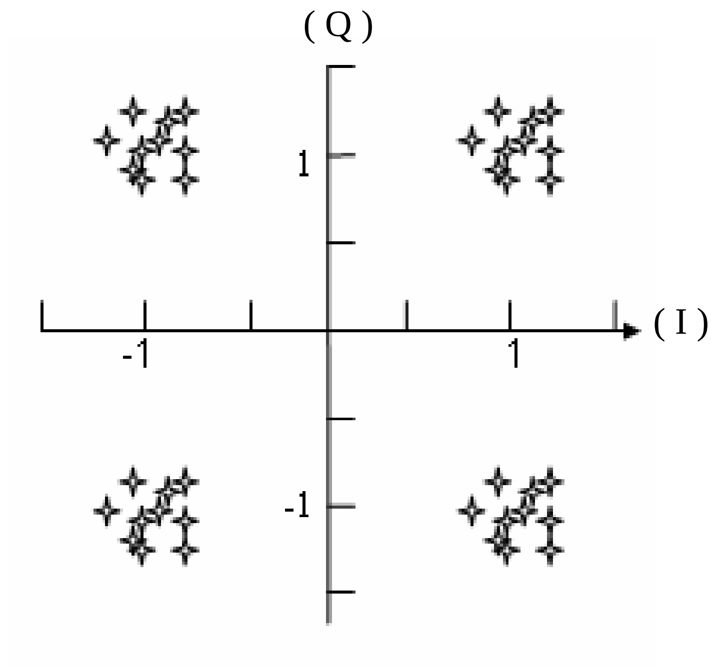

Figure 2.4 QPSK Real-world Constellation

E. SUMMARY

The scope of this research is the replication of portions of fixed station operations in the laboratory to simulate a portion of a real-world QPSK communication scenario. A signal generator and digital sampling oscilloscope were used as a transmitter and receiver. Cables combined with amplifiers and resistors simulated amplifier and transmission line effects. The RF fingerprint of a part of the communication system is thus determined.

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III. USING EQUIPMENT TO SIMULATE QPSK COMMUNICATION

A. EQUIPMENT MAPPING

In the laboratory, a digital sampling oscilloscope can be used to simulate the receiver and a signal generator and amplifier can serve as the transmitter. The transmitter-to-antenna path is simulated with coaxial cables and RF circuit components.

B. FUNCTIONS OF THE EQUIPMENT

The signal generator (SG) and digital sampling oscilloscope (DSO) must be selected and set up correctly to support the experiment.

1. Signal Generator

An Agilent E4436B ESG-DP Series Digital RF Signal Generator, shown in Figure 3.1, is used to simulate the transmitter in a radio station. It generates and modulates a signal which is identical to that of the communication system under study.

Figure 3.1 Agilent E4436B ESG-DP Series Digital RF Signal Generator

The features of the signal generator are:

- 250 kHz to 3 GHz frequency range with enhanced phase noise performance,
- RF modulation bandwidth up to 35 MHz,
- Optional dual arbitrary waveform generator and/or real-time I/Q baseband generator,
- 40 MHz sample rate and 14-bit I/Q resolution,
- 1M sample (4 MB) memory for waveform playback and 1M sample (4 MB) memory for waveform storage,

- Custom digital modulation [>15 variations of FSK, MSK, PSK, and QAM, AM, FM, phase modulation, pulse modulation, and step/list sweep (frequency and power)] and
- GPIB and RS-232 connectivity.

2. Digital Sampling Oscilloscope

The digital sampling oscilloscope used to simulate a receiving system is the Tektronix TDS 5104B, 1 GHz, 4 channel digital sampling oscilloscope; it also performs the task of sampling the signal received from the signal generator, and is shown in Figure 3.2.

The following are the features of the DSO:

- 1 GHz Bandwidth,
- 4 Channel Input,
- 5 GS/s Sample Rate,
- Up to 16 M Record Length,
- 100,000 waveforms/s Maximum Waveform Capture Rate,
- Windows 2000 Operating System,
- Computerized Display and Interface Controls,
- CD-RW Drive, and
- GPIB Controller.

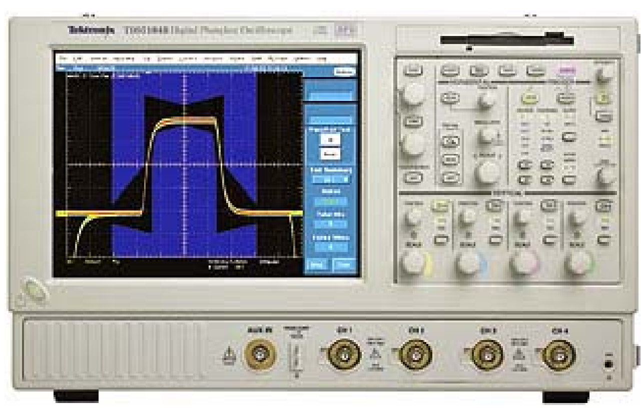

Figure 3.2 Tektronix 5104 Digital Sampling Oscilloscope

In recording the data to the scope, the number of data samples is selected based on storage space and the Nyquist theorem. These steps are described in chapter IV. E.

C. SUMMARY

This chapter focused on using equipment to simulate QPSK communication. The signal generator generates a RF signal, modulated with QPSK, at the desired frequency and amplitude. One method of defining a QPSK signal is to type in randomly-generated I and Q values, but that method has a limit of 256 sets imposed by the signal generator. Another is to input the data from an external source, using a PC to control the signal generator. The external input method is discussed in the next chapter. The DSO is primarily used to sample the signal from the signal generator and store it for further analysis. The sample rate is an important factor for signal recovery. Determining this value is discussed in the next chapter.

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IV. CREATING RF TRANSMISSION SYSTEM DISTURBANCES IN THE LABORATORY

A. DESCRIPTION

When RF signals propagate in the real world, they are affected by many factors, such as the distortion of the amplifiers following the signal generator, portions of the transmitter-modulator and different impedances between the instruments in the transmission line portion of the system, etc. This thesis simulates several different deteriorating effects on the transmissions of QPSK modulation, including transmission line system effects and amplifier distortion.

B. THE TRANSMISSION SYSTEM

1. Transmission Line Effects

In the real world RF signals are generated, passed through transmission lines to an antenna and radiated into space. This project simulates the transmission lines as part of the path of the signal from the transmitter to the receiver, and determines the effect on the received signal. The effects that can be created in a laboratory environment include impedance terminations and mismatches from dissimilar characteristic impedance and from low-quality cable connectors.

a. Similar Characteristic Impedance: Single 50-Ohm Cable

This situation simulates the effect of an ideal transmission line path. The 50-ohm cable represents the standard cable that is normally used in communication systems, and is the same as the output impedance of the signal generator and the input impedance of the DSO.

b. Dissimilar Characteristic Impedance: Single 75-Ohm Cable

This test is to show the different RF cable characteristic impedance mismatch between a transmitter or a receiver and the antenna.

c. Low-Quality Cable Connector: 50, 100, 200 Ohm Resistors in Parallel and in Series

These situations show the different effects on signal propagation through the transmission line when there are lumped impedance mismatches in the cable system.

2. Transmitter Amplifier Distortion Effect

By using an amplifier in the signal path from the signal generator to the transmission line, signal distortion effects from the amplifier can be observed.

a. Linear Operation

All amplifiers exhibit an "output power vs. input power" curve. Amplifiers in normal operation have an input-output curve that is linear.

b. Non-Linear Operation

When the "output power vs. input power" curve increases by a small percentage as the input continues to increase beyond the maximum normal value, "saturation" or non-linear operation occurs.

C. LABORATORY EQUIPMENT DESCRIPTIONS

1. Digital Sampling Oscilloscope

The Tektronix TDS 5140 used in this project has a 100M bit memory and 1 Gs/sec sample rate and can display the signal waveform generated by the signal generator and record it to a CD for later analysis.

2. Signal Generator

The Agilent 4436B signal generator can create an RF waveform from 1 kHz to 3 GHz. With its UN8 real-time I/Q baseband generator, the signal generator can create up to 256 sets of I&Q values of modulation. The DSO and SG setup are depicted in Figure 4.1.

3. RF Amplifier

An HP 8347A amplifier is connected between the SG and the transmission line as in Figure 4.2. It is used to increase the generator output to the level in the linear region and also into the nonlinear region, where saturation occurs.

4. Coaxial Lines

Some cables, with lumped-series impedance as mentioned above, are used to show the effects of transmission line irregularities. The transmission path settings are shown in Figure 4.3.

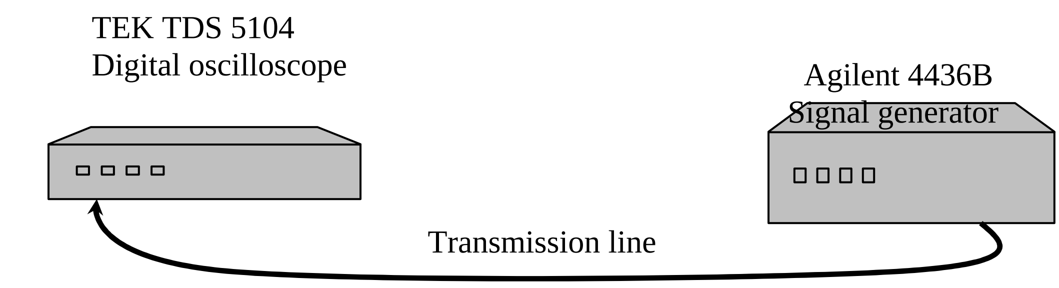

Figure 4.1 DSO and SG Connections

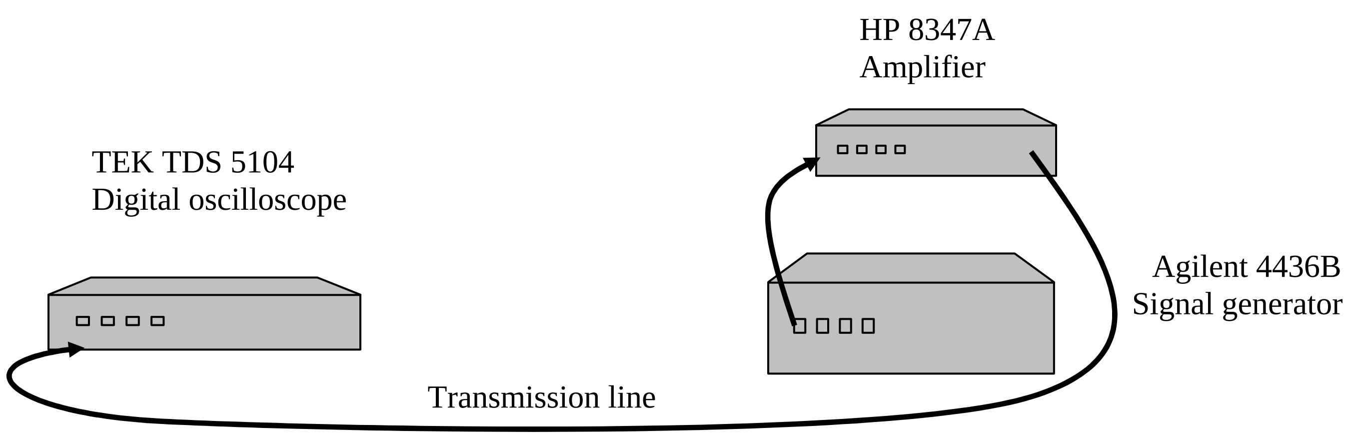

Figure 4.2 DSO, SG and Amplifier Connections

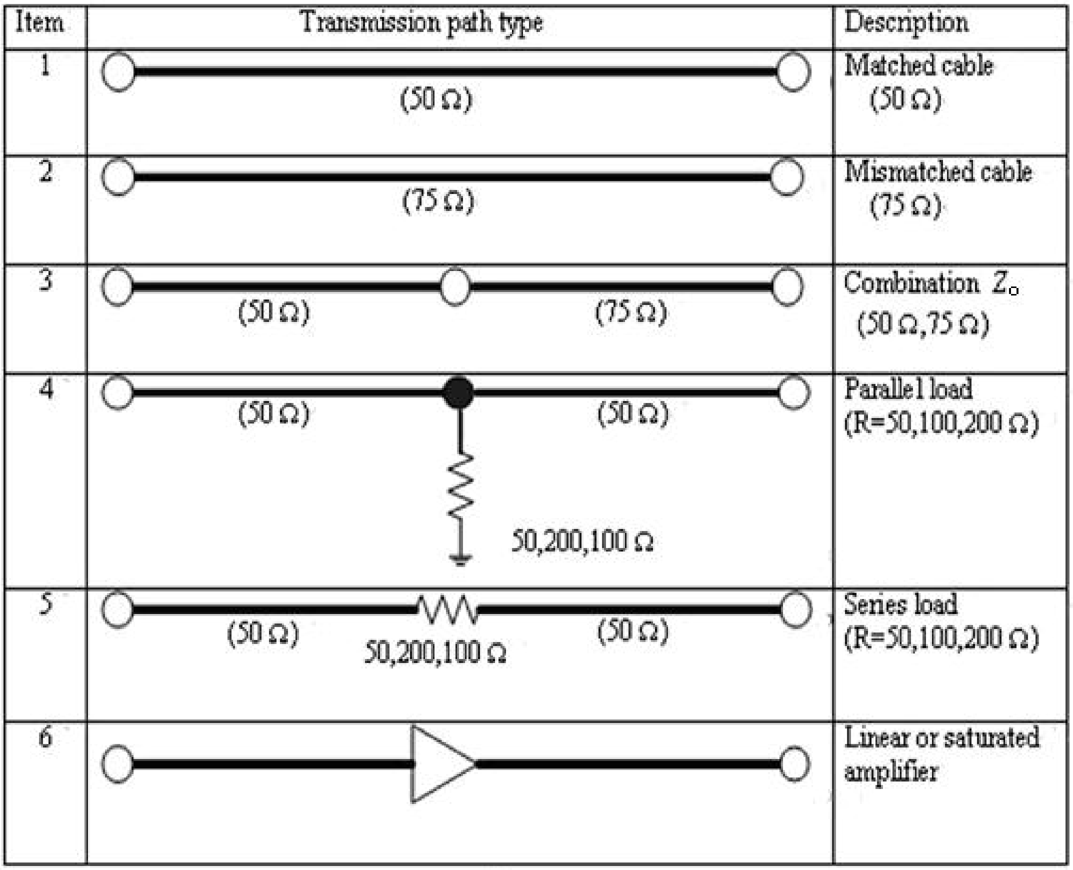

Figure 4.3 Transmission Path Types

D. RANDOM DATA STREAM GENERATION

The simulation of a real world QPSK signal is a substantial problem. In the real-world, the signal is transformed into a binary form, modulated by a QPSK modulation scheme, and then delivered to antenna, transmitted through the air and received by a second antenna, etc. The following describes the generation of a bit stream for analysis, by two methods.

1. Manual Input of I/Q Signals

With the UN8 real-time I/Q baseband generator, the signal generator can accumulate a maximum of 256 sets of I/Q data from manual-input random data sets. In order to simplify the process, a combination of 1 and -1 were used to represent I and Q (see Appendix C). This signal stream is too short for the reader to analyze, and it is so short (25 msec) that it is not feasible to observe the waveform on the DSO. The solution is either to repeat the 256 sets of I/Q data over and over, or try to input data continuously into the signal generator for modulation.

2. Generating I/Q Data from a Program

It is difficult to generate the desired signal using only a PC card. The best solution is to "communicate" with the signal generator in order to generate signals continuously. Then, there must be a common language or data format. It was discovered that by using MATLAB 7.04 (with its Instrument Control Toolbox, see Appendix D), very long sets of binary data could be created and sent to the signal generator. The data is created by MATLAB code in the form of a binary array stream, and then input to the SG for use as I/Q data sets. Theoretically, there would be an "infinite set" of data for modulating the signal generator, but actually, the number is limited by the memory of the signal generator which is 1 Mbyte. The maximum size data set that can be accepted by the SG is 1512 bits of binary data, which is equal to 756 sets of I/Q data. (See Appendix E)

E. SAMPLING AND RECORDING THE MEASUREMENT FROM THE DSO

Two problems arise: how to sample the data and how to record the data. The client of this study asked that the minimum data sample should be 6 samples/RF carrier cycle and that there be at least one phase change in every period of record. This format limit produced the following units.

- Carrier frequency: f_c (Hz)
- Baud rate: R (bits/sec)
- Duration (the same as the time in the "window" of DSO): t_m (sec)
- Number of phase changes in the window = $\frac{f_c}{R} * t_m$ (times)
- Minimum requested sample rate (for DSO)

  = 6 (samples/cycle)* f_c (cycle/sec)

  = 6 f_c (samples/sec)

There is a trade-off between duration and sample rate. The duration and sample rate calibration are combined together in the DSO; that is, the duration cannot be adjusted without changing the sample rate. After some trial and error, Table 4.1 is developed:

Carrier Frequency (f_c)	Baud Rate (R)	Cycles per Phase Change	Average Sample Points per Cycle	Number of Phase Changes per Record	Sample Rate (DSO)
5 MHz	9600	520.8	20	768	10^8 samples/sec
10 MHz	9600	1041	13.33	768	10^8 samples/sec
15 MHz	9600	1562.2	6.66	768	10^8 samples/sec

Table 4.1 Calculated Average Sample Points

The following is the figure from the real data that was recorded, and shows that it can satisfy the client's request.

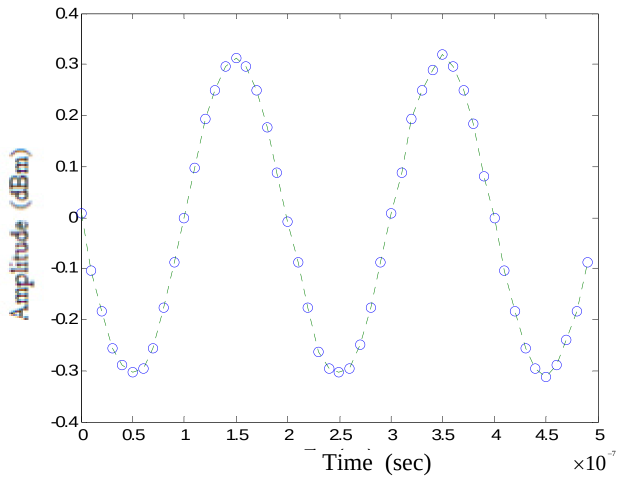

Figure 4.4 Recorded Data (f_c = 5 MHz)

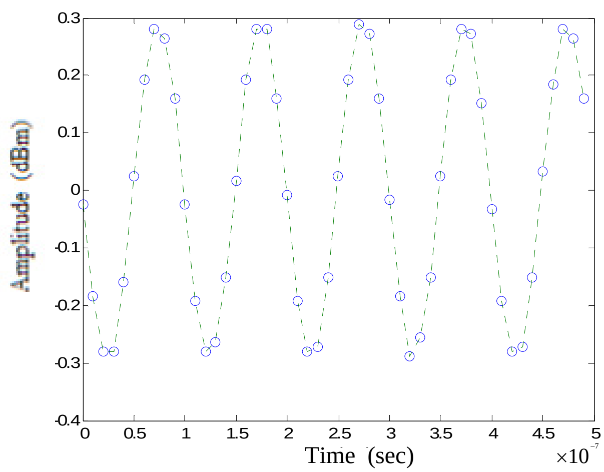

Figure 4.5 Recorded Data (f_c = 10 MHz)

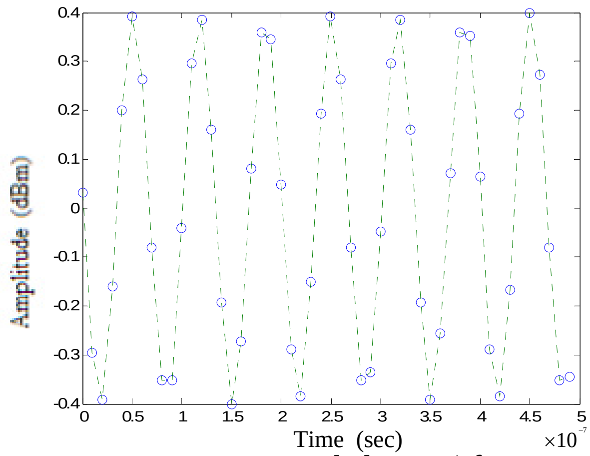

Figure 4.6 Recorded Data ($f_c = 15$ MHz)

F. SUMMARY

There are two effects that were considered in this test. One is transmission line effects, and the other is transmitter amplifier distortion effects. For transmission line effects, different cables with resistor loading combinations are applied. For transmitter amplifier distortion effects, linear operation and non-linear operation are simulated. The laboratory equipment, which includes the digital sampling oscilloscope, signal generator, RF amplifier, and coaxial lines, are described in this chapter. Two random data stream generation methods were used in this project: manual input and generation from a computed program (by using MATLAB). Using the calculated minimum request sample rate, the DSO sample rate must be set at 10^8 samples/sec to satisfy the minimum 6 samples/cycle requirement. Finally, by looking at the output example figures, the algorithm is validated and the output figures can be used for further analysis.

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V. MEASUREMENT ANALYSIS

A. THE “REAL WORLD” QPSK SIGNAL ENVELOPE

1. QPSK Amplitude Envelope

The “textbook” description of the four phase states of the carrier waveform can result in a stream of pure RF carrier cycles with an “occasional instantaneous phase jump of the RF waveform” to one of the four phase states. When the RF and modulation waveforms require any kind of severe transition, bandwidth limitations in any practical RF modulated system will create a waveform that “gradually” switches from maximum positive amplitude to maximum negative amplitude of the required QPSK phase state. However, the above “textbook” transition will never happen in the real world, as shown in this study, since the required instantaneous bandwidth becomes astronomical. QPSK is not technically a constant envelope because of its discontinuous phase change. The QPSK signal does not have a constant amplitude envelope, but Offset QPSK (OQPSK) has a smoother envelope. For this reason, OQPSK is more often used.

2. QPSK Amplitude Envelope Example Analysis

In order to prove that the recorded data is correct, an example is used for analysis. For example:

- Carrier frequency: 5 MHz
- Sample rate: 9600
- Power: 0 dBm
- Cable impedance: 50 ohms
- Record length: 8,000,000 points
- The recorded figure from the DSO is shown in Figure 5.1

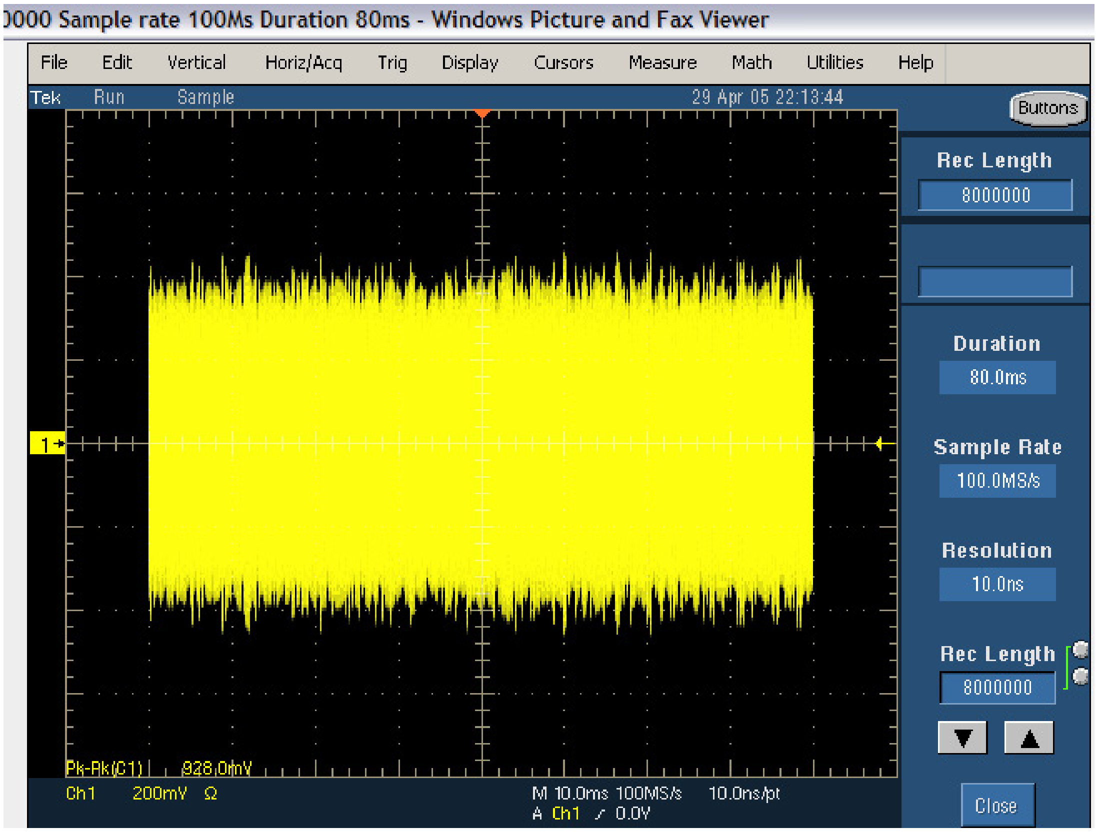

Figure 5.1 Example of a QPSK RF Waveform

It is very difficult to observe the configuration of this signal. However, if some of the 65536 points, which is the limit of EXCEL, the program used for the plots, is extracted, and the recorded data plotted, Figure 5.2 is obtained.

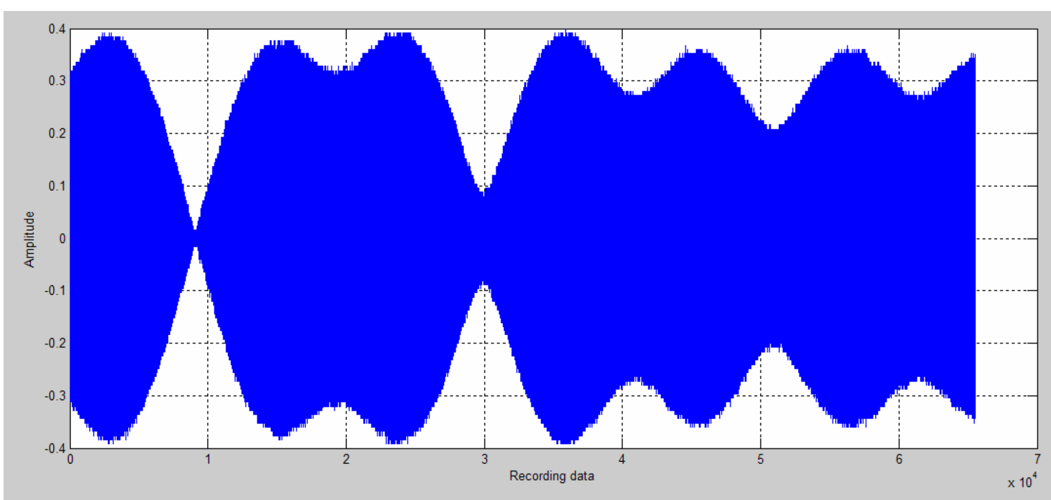

Figure 5.2 Envelope of a QPSK Signal

From Figure 5.2 the envelope of the QPSK signal can be observed. It appears to be an AM signal but is not, as shown from previous discussions. In order to verify that the phase's change produces the "AM", the signal minimum can be expanded. There seems to be a phase change between 8000 and 10000. When the envelope is enlarged, Figure 5.3 clearly shows that there is an abrupt phase change at about point 9130.

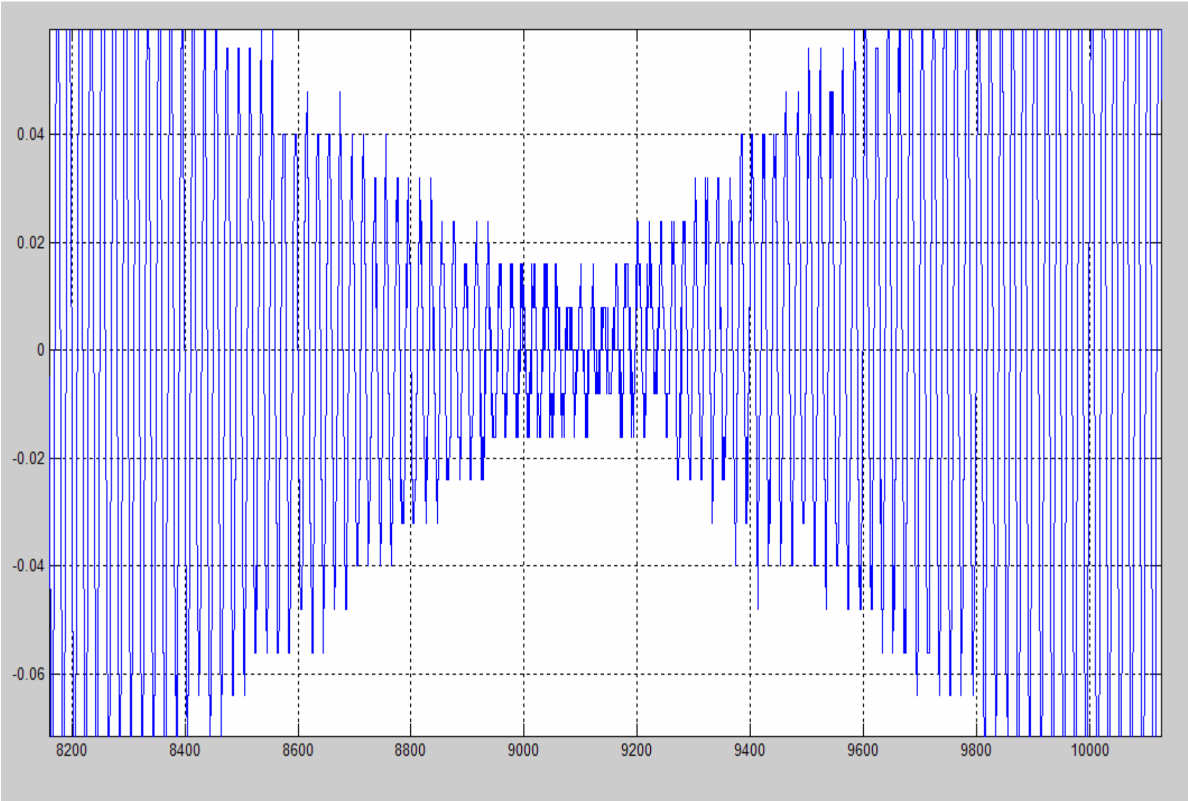

Figure 5.3 Enlarged Image of the Envelope of a QPSK Signal

B. TRANSMISSION LINES

1. Transmission Line Characteristics

a. Transmission Line Length

Three transmission lines are used in this project, with the physical lengths listed in Table 5.1. It is important to know if the transmission line length is a factor for this test.

For example, the RF carrier frequency $f_c = 5$ MHz

from $\lambda = c / f_c$, where $c = 3*10^8 m/\sec$ and the wavelength $\lambda = 60$ m .

The time for the wave to propagate through the line is needed. The ε_r of the lines is not known, but the time of travel could be determined by using a Time Domain Reflectometer (TDR). The result is shown in Table 5.1. The L1 cable provided very little time delay (about 1/8 of a wavelength) at 5 MHz, so it is a short transmission line for this frequency and for all other frequencies used in this project. The importance of line length is not a factor in the study until line length becomes a significant fraction of a message character length. Since the baud rate is 9600 bits/sec, the transmission line length would have to be about 21 km long to become a factor that causes a measurable effect in the transmission of the message characters.

Cable Designation	Resistor (ohms)	Time Domain Reflectometer Measured (10nsec/div)	Physical Length (meters)
L1 (92/94)	50	0.083 μsec	7.64
L2 (82879)	50	0.083 μsec	7.57
L3 (RG-11)	75	0.05 μsec	5.78

Table 5.1 Physical Length and TDR Measurements

b. Match and Mismatch

In this project, the cables were so short at the frequencies of operation that they are considered lossless. For a lossless transmission line system, the reflection coefficient Γ_g from SG and Γ_L the reflection coefficient from the load on the transmission lines is

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad \text{and} \tag{5.1}$$

$$\Gamma_g = \frac{R_g - Z_0}{R_g + Z_0} \quad , \tag{5.2}$$

where Z_0 = impedance of load, and R_g = internal impedance of SG.

The internal impedance of the signal generator and the DSO are both 50 ohms. When these two are connected by cable L1, there is no other reflection effect ($R_g - Z_0 = 0$), that affects the signal envelope [Ref. 5].

c. Impedance

The V to I ratio for an incident-traveling wave or for a reflected-traveling wave on a transmission line is always V/I = Z_0. The RF wave amplitude unit used in this project is power in dBm.

From $$P = I * V \quad , \tag{5.3}$$

for series loads $$I = V / Z_0 \quad \text{and} \tag{5.4}$$

for parallel loads $$V = Z_0 * I \ . \tag{5.5}$$

Thus $$P = I * V = Z_0 * I^2 \tag{5.6}$$

or $$P = I * V = V^2 / Z_0 \ . \tag{5.7}$$

From (5.6) and (5.7), the amplitude of an RF wave is proportional to Z_0 when the load is in series, but is inverse proportional to Z_0 when the load is in parallel.

For mismatched loads in this project, the impedance is found by applying the Ohm's Law, because the lines are lossless. The following table shows the impedance of mismatched cable in this project.

Resistor	50 Ω	100 Ω	200 Ω
Impedance Z (In Series)	100 Ω	150 Ω	250 Ω
Impedance Z_0 (In Parallel)	25 Ω	33.3 Ω	40 Ω

Table 5.2 Impedance of Combination Resistor

2. Transmission Line Analysis

a. Matched Cable (as Figure 4.3, Item 1)

There is no power loss or reflection in the transmission line. The wave form is a perfect QPSK envelope.

b. Mismatched Cable (as Figure 4.3, Item 2)

There is no power loss in this transmission line. There is continuous signal reflection occurring in the transmission line because of mismatch line at the DSO point. This will not change the power level of the signal, but it changes the wave form.

c. Combination Z (as Figure 4.3, Item 3)

There is no power loss in the transmission line system, but there is more reflection in the system. The signal travels from the SG and is partially reflected at the junction of the two cables. The remaining signal keeps traveling along the 75Ω transmission line, and is partially reflected again at the DSO point.

d. Parallel Load (as Figure 4.3, Item 4)

There are power loss and reflection in the left hand side of the path because of the resistor. The current is divided at the resistor, but there is no signal reflection of the right hand part because of the same impedance of the transmission line and the DSO.

e. In Series Load (as Figure 4.3, Item 5)

There is power loss and reflection in the left hand side of the path because of the resistor. The voltage is divided at the resistor, but there is no reflection in the right hand side of the path because of the same impedance of the transmission line and the DSO.

f. Linear or Saturated (as Figure 4.3, Item 6)

When an amplifier is added in the system, the signal is amplified. In the linear operation region, the signal is just amplified and no distortion occurs. When the amplifier is in the non-linear (or saturated) mode, distortion occurs and modifies the waveform.

C. AMPLIFIER CHARACTERISTIC

The purpose of a power amplifier is to receive a low-level signal from a source device and increase the signal for driving an output transducer, such as an antenna. Ideally, the only difference between the input signal and the output signal is the amplitude of the signal. In the real-world, amplifiers alter input signals. No amplifier is exactly ideal. The output of all amplifiers contains additional signal components that are not present in the input signal; these additional (and unwanted) characteristics may be lumped together and are generally known as distortion [Ref.6], as shown in Figure 5.4.

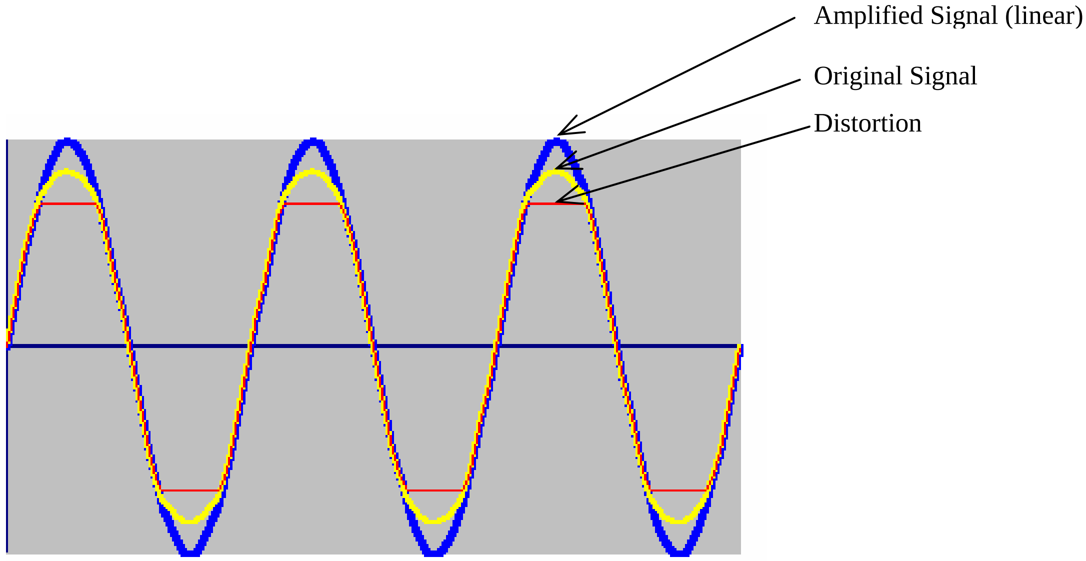

Figure 5.4 Distortion of a Signal Waveform by an Amplifier

The distortion of the RF waveform caused by a non-linear amplifier creates additional RF frequencies that are multiples of the carrier, and each of the “extra” frequencies (sums and differences of the intended carrier and the distortion frequencies) contain modulation components (more bandwidth) that is present at the same time as the intended (desired) modulation components. These “extra” modulation products “contaminate” the demodulation process and can alter the message content, for any line length or propagation path length. It will be difficult to recover the intended phases of the sent message. The following is the setup of the amplifier used in this project.

Step	Instrument	Signal Level (dBm)	Command
1	SG	+10	No Amplifier
	DSO	+10	
2	SG	-22.5	Unleveled (not overdriven)
	Amp	+10	
	DSO	+10	
3	SG	-12.5	Leveled (no visible envelope distortion)
	Amp	+2	
	DSO	+10	
4	SG	+11.5	Amplifier overdriven (distortion)
	Amp	+10	
	DSO	+10	

Table 5.3 Equipment Settings for Amplifier Linearity Tests

D. OUTPUT OBSERVATIONS

In order to compare how differences between the carrier frequency may affect the RF signal, two carrier frequencies, f_c = 5 MHz, and f_c = 15 MHz, were used.

1. Matched Cable (Typical)

A matched transmission line is used as the standard to compare to other conditions of the signal source-to-receiver, and its "modulated RF envelope". Figure 5.5 and Figure 5.6, will be used as the standard envelope in the following analysis. The carrier frequency is the only factor changed in this set of tests. It can be expect that there are more RF amplitude cycles in the higher frequency carrier than for the lower frequency carrier during the same message period, but the difference can not be seen in modulated RF envelope. There is one significant difference between these two figures: the depth of "wrinkles" in Figure 5.6 is deeper than that of Figure 5.5.

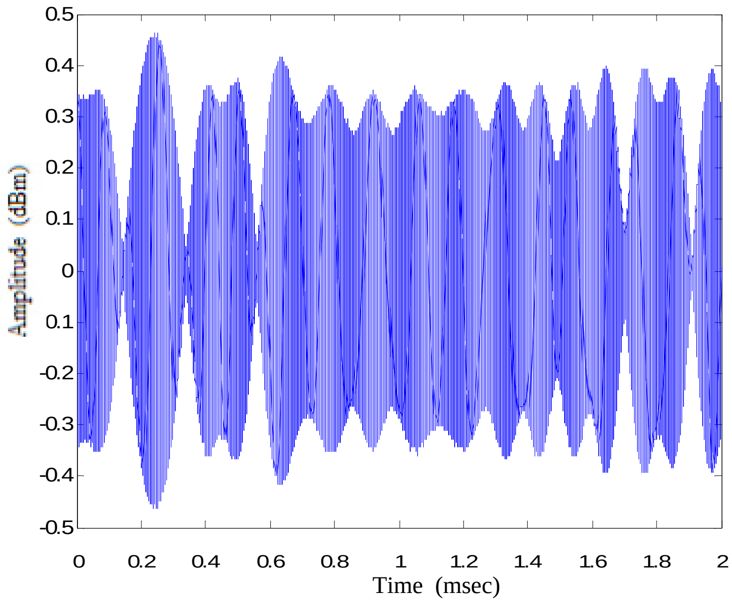

Figure 5.5 Modulated RF Envelope of $f_c = 5$ MHz on 50 Ohm Cable

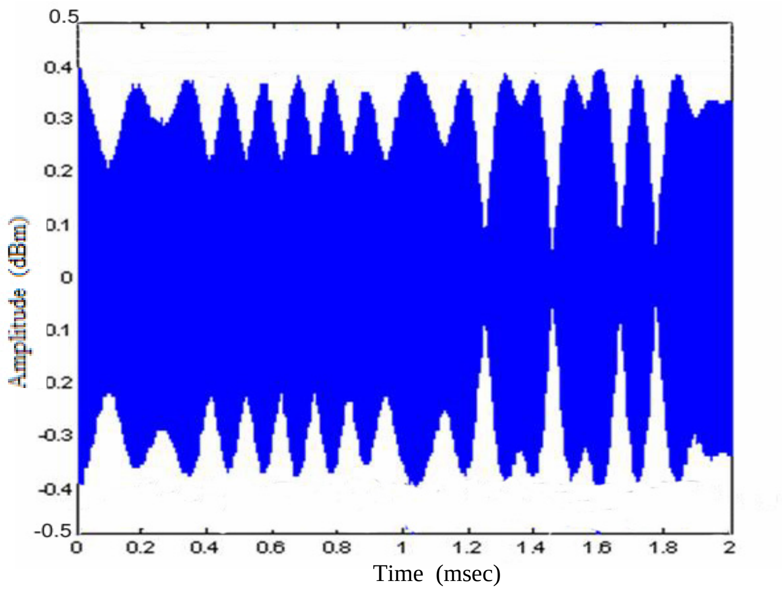

Figure 5.6 Modulated RF Envelope of $f_c = 15$ MHz on 50 Ohm Cable

2. Mismatched Cable

In this mismatched cable (75 ohm), the maximum amplitude is about 0.44, in Figure 5.7, which is slightly less than for the matched cable (50 ohm). This is the result of impedance difference. When the carrier frequency is different, there is one significant difference from the following two figures: the wrinkles in Figure 5.7 are more separated and regular than those of Figure 5.8.

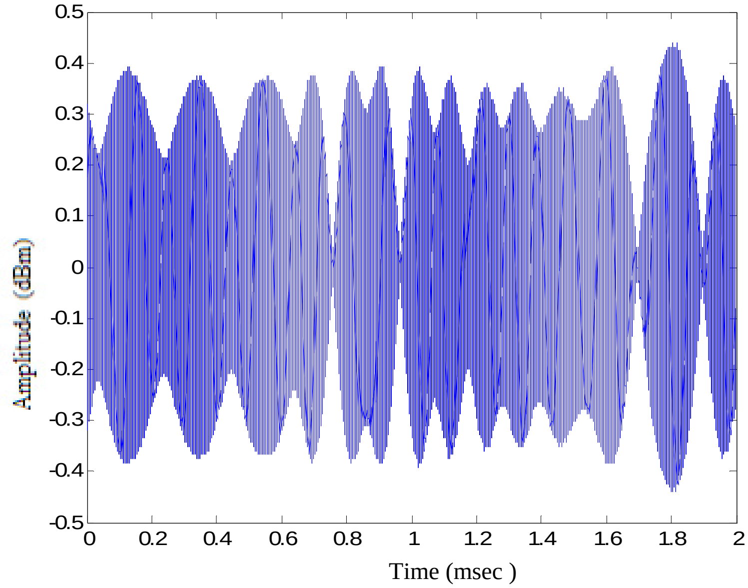

Figure 5.7 Modulated RF Envelope of $f_c = 5$ MHz on 75 Ohm Cable

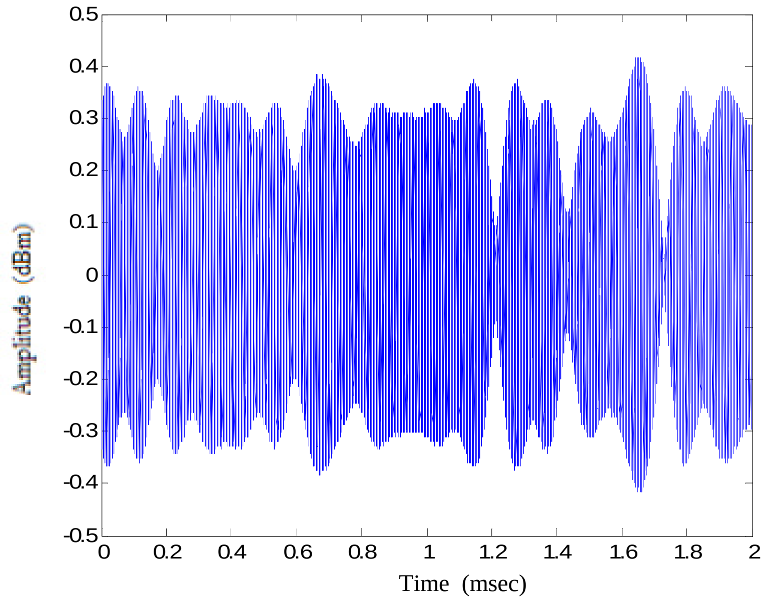

Figure 5.8 Modulated RF Envelope of $f_c = 15$ MHz on 75 Ohm Cable

3. Combination of Two Cables of Different Characteristic Impedances

When two different impedance cables are combined (a 50 ohm cable connected with a 75 ohm cable), the maximum amplitude is 0.42, as in Figure 5.9. It is smaller than the standard envelope because there are reflections at the point of connection, and that causes wave-canceling, and reinforcement. The wrinkles in Figure 5.9 are slightly more crowded than those of Figure 5.10.

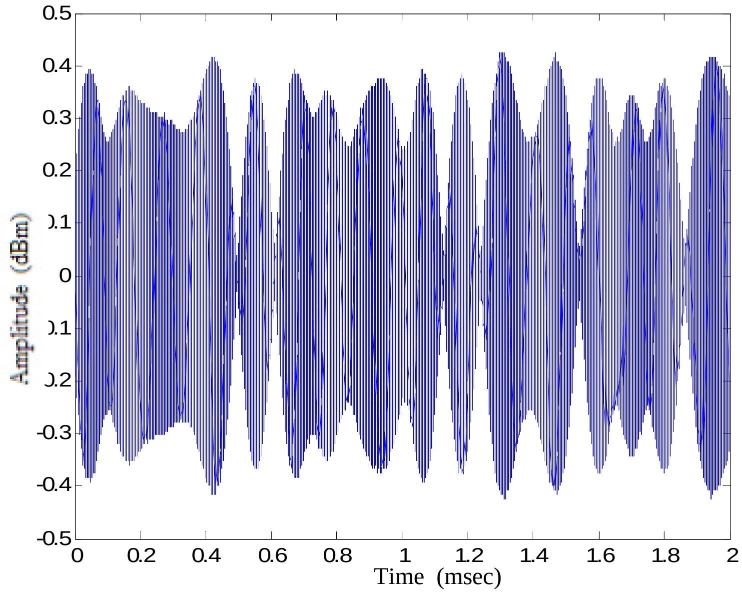

Figure 5.9 Modulated RF Envelope of $f_c = 5$ MHz on 50 Ohm and 75 Ohm Series Connected Cables

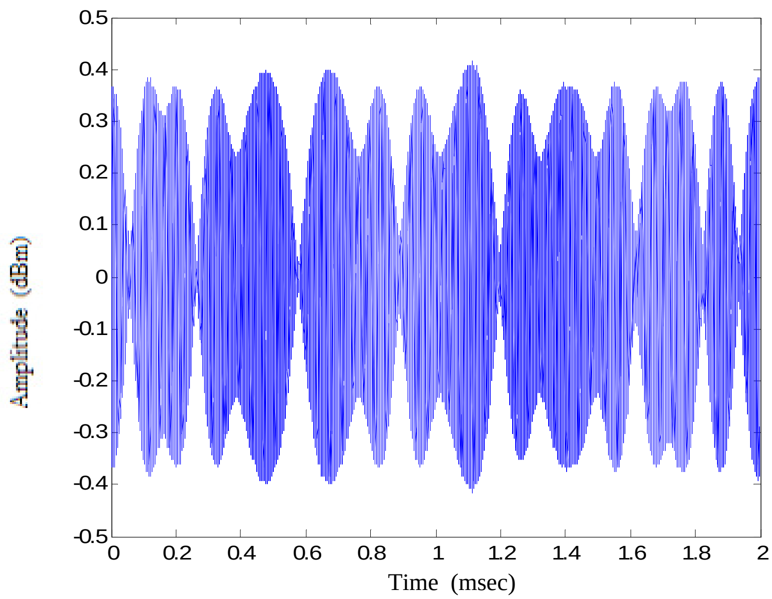

Figure 5.10 Modulated RF Envelope of $f_c = 15$ MHz on 50 Ohm and 75 Ohm Series Connected Cables

4. Parallel Loads

a. R = 50 Ohm

When the transmission line has a parallel 50 ohm load, the maximum RF signal amplitude is 0.3, as in Figure 5.11. It is significantly lower than that of a normal 50 ohm cable connection. The envelope of signal is more uniform when the frequency is lower than when the frequency is higher, as Figure in 5.12.

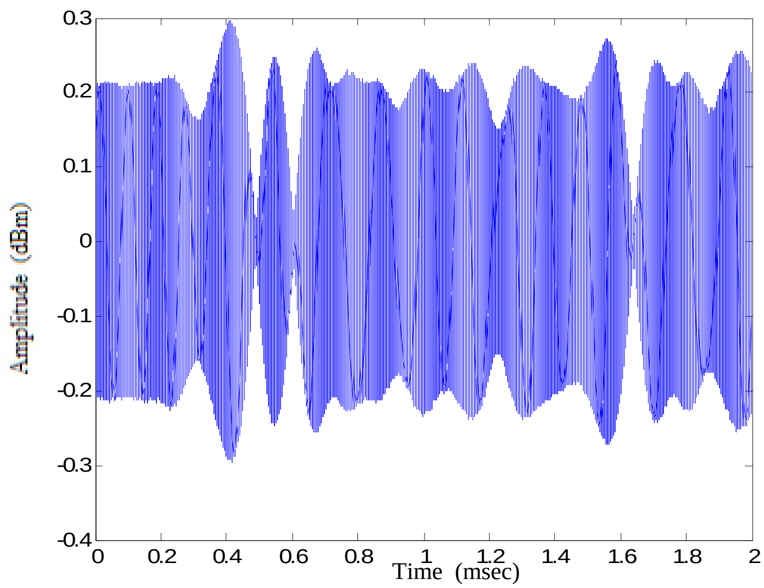

Figure 5.11 Modulated RF Envelope of $f_c = 5$ MHz with a 50 Ohm Parallel Load

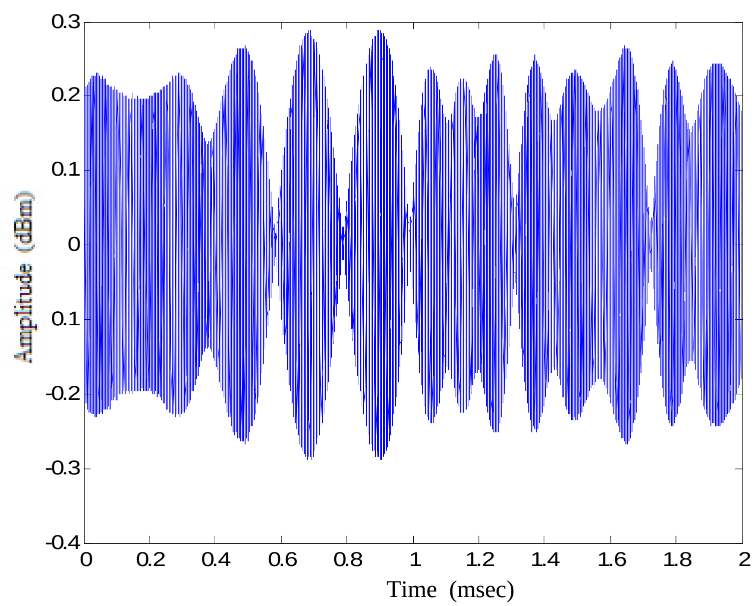

Figure 5.12 Modulated RF Envelope of $f_c = 15$ MHz with a 50 Ohm Parallel Load

b. R = 200 Ohm

When the transmission line has a 200 ohm parallel load connected to it, the maximum RF signal amplitude is 0.39, as in Figure 5.13. The amplitude is significantly lower than that of standard connection, but it is higher than for a parallel 50 ohm load. The envelope of signal is slightly more uniform when the frequency is lower than when the frequency is higher, as in Figure 5.14.

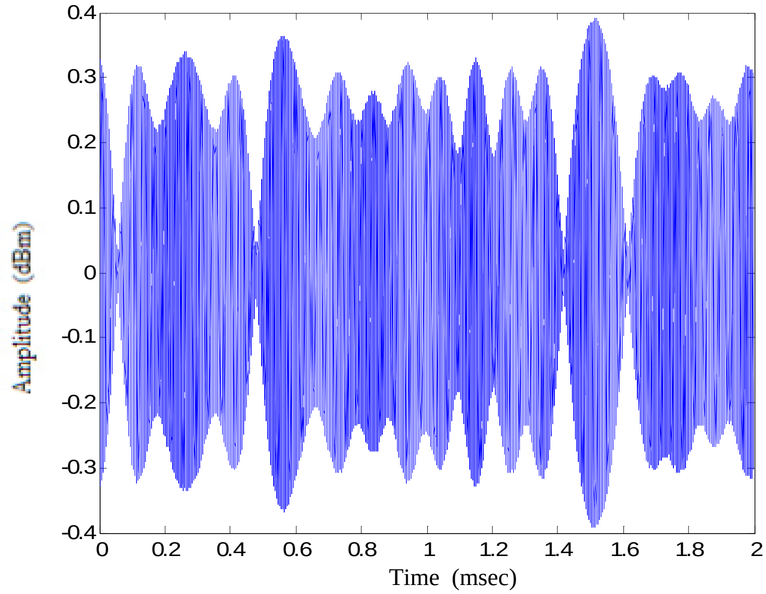

Figure 5.13 Modulated RF Envelope of $f_c = 5$ MHz with a 200 Ohm Parallel Load

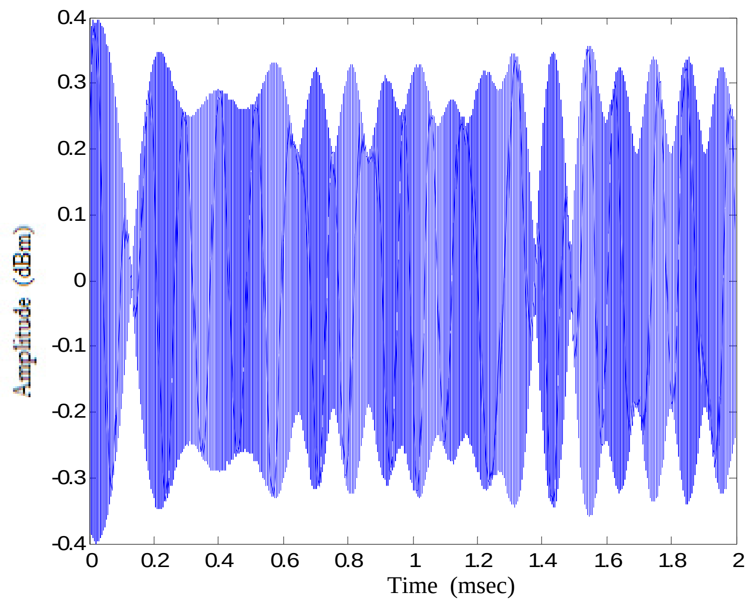

Figure 5.14 Modulated RF Envelope of $f_c = 15$ MHz with a 200 Ohm Parallel Load

5. Series Loads

a. R=50 Ohm

When the transmission line connected in series with a 50 ohm load, the maximum RF signal amplitude is 0.29, as in Figure 5.15. It is significantly lower than that of a standard envelope because load divides the voltage. The envelope of signal is more uniform when the frequency is lower than when the frequency is higher, as in Figure 5.16.

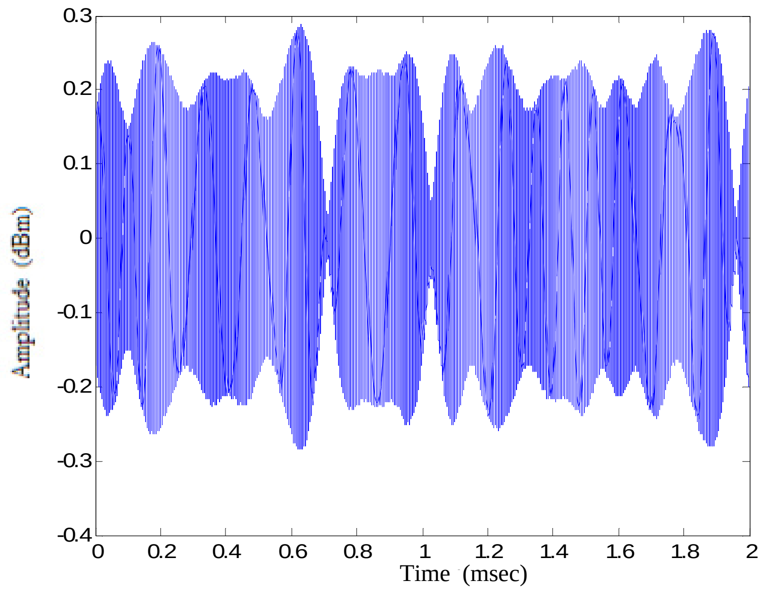

Figure 5.15 Modulated RF Envelope of $f_c = 5$ MHz with a 50 Ohm Series Load

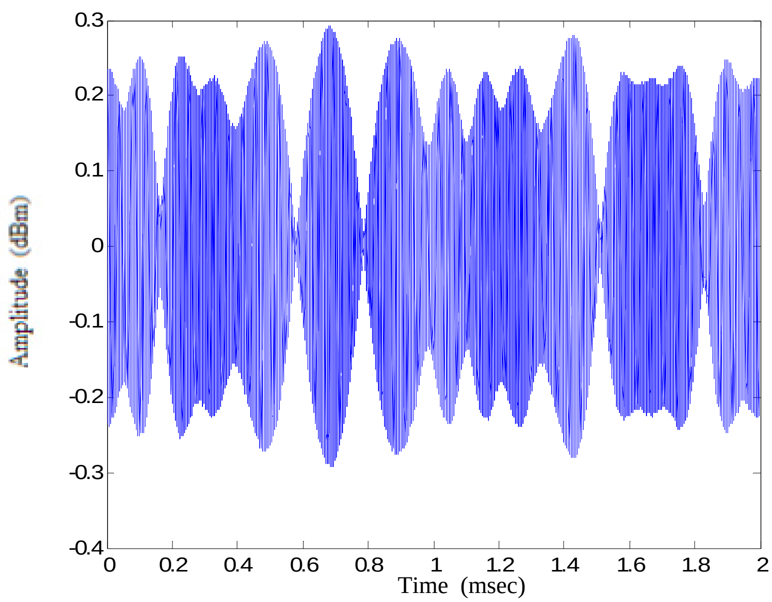

Figure 5.16 Modulated RF Envelope of $f_c = 15$ MHz with a 50 Ohm Series Load

b. R= 200 Ohm

When the transmission line is connected in series with a 200 ohm load, the maximum RF signal amplitude is 0.15, as in Figure 5.17. It is significantly lower than that of the standard envelope. The envelope of signal is more uniform when the frequency is lower than when the frequency is higher, as Figure 5.18

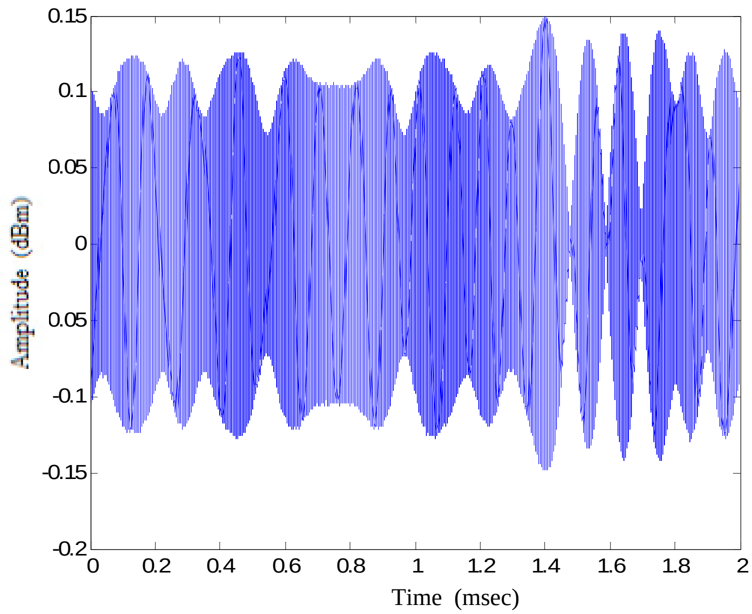

Figure 5.17 Modulated RF Envelope of $f_c = 5$ MHz with a 200 Ohm Series Load

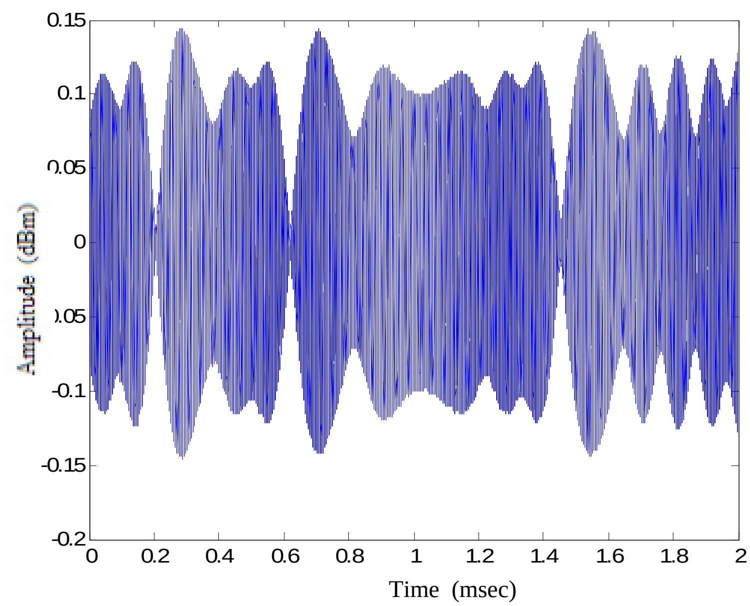

Figure 5.18 Modulated RF Envelope of $f_c = 15$ MHz with a 200 Ohm Series Load

6. Linear or Saturated Amplifier

a. Carrier Frequency (f_c) = 5 MHz

When the SG output is set to 10 dBm, the DSO reading is also 10 dBm. Figure 5.19 (a) shows an amplitude of 1.3 dBm. When the signal level is decreased and amplified by the amplifier operating in the linear region (not overdriven and unleveled), the envelope is as in Figure 5.19 (b). There is no significantly different envelope shape compared with Figure 5.19 (a), except the lower amplitude. The next step is to increase the SG signal output, and adjust the amplifier to "leveled", where the amplifier increases the output to some leveled value. That means the output will not increase when the input increases. This may cause the signal "distortion", as in Figure 5.19 (c), but it is not so obvious. The envelope amplitude difference is significant in this situation. Increasing the SG output until the "overdrive" light is on, is the saturated situation, as in Figure 5.19 (d) shows. The amplitude peaks are limited at 1.2 dBm.

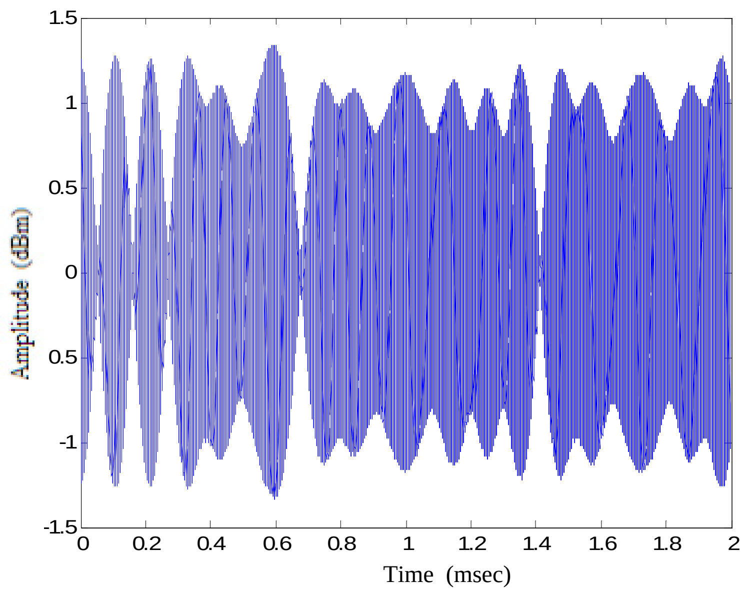

Figure 5.19 (a) Modulated RF Envelope for SG Output at 10 dBm for f_c = 5 MHz (No Amplifier)

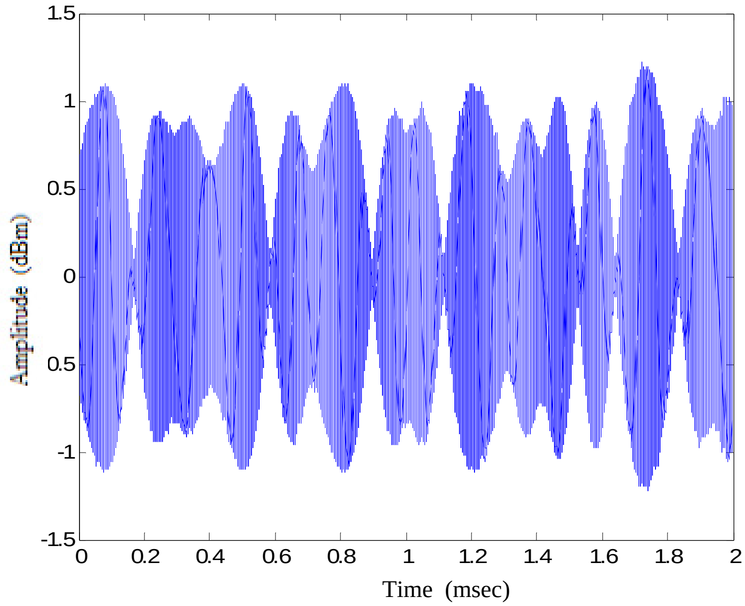

Figure 5.19 (b) Modulated RF Envelope of Linear Amplifier at $f_c = 5$ MHz.

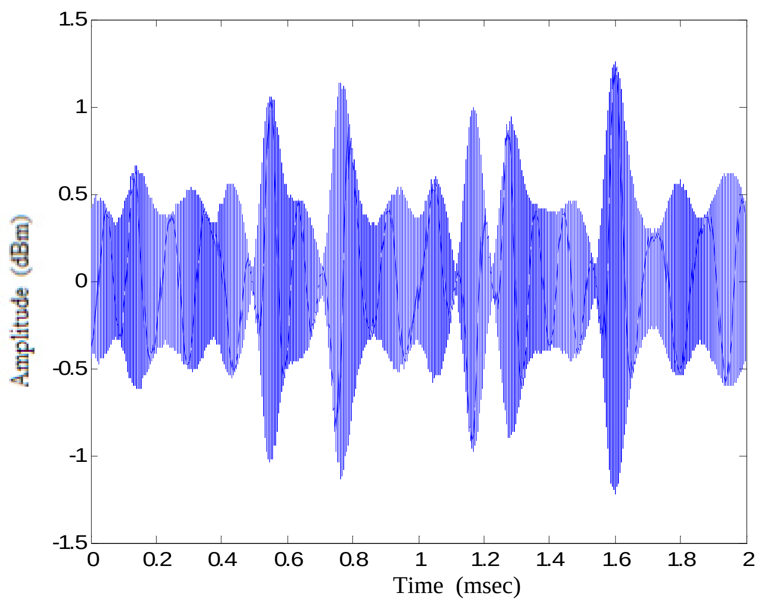

Figure 5.19 (c) Modulated RF Envelope of Leveled Amplifier at $f_c = 5$ MHz

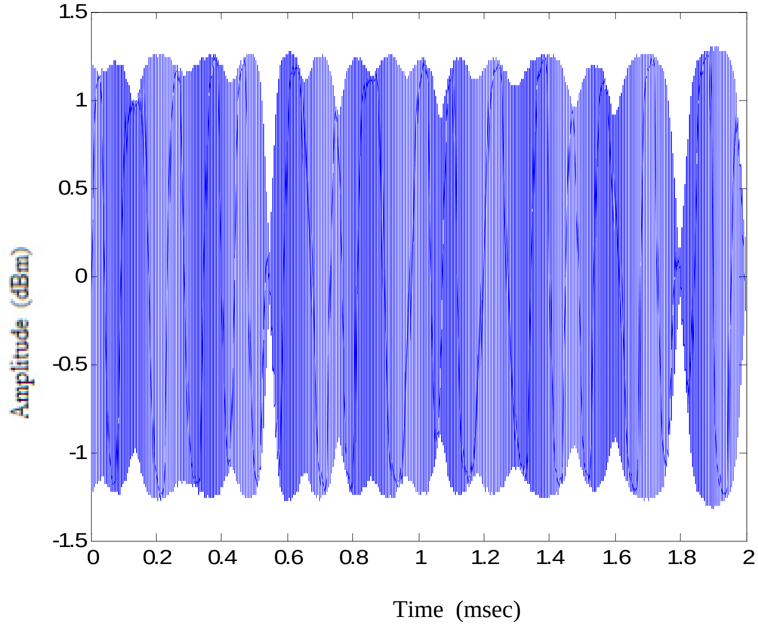

Figure 5.19 (d) Modulated RF Envelope of Amplifier Overdriven at $f_c = 5$ MHz

b. Carrier Frequency (f_c) = 15 MHz

The settings and steps are all the same as previous except the carrier frequency. However, from the following figures [Figure 5.20 (a) to Figure 5.20 (d)], there is no significant difference in signal envelope between this situation and previous situation.

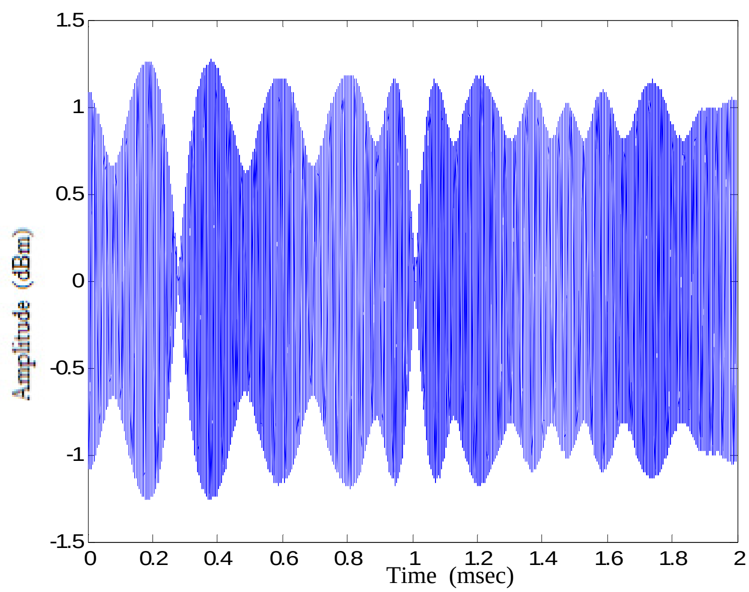

Figure 5.20 (a) Modulated RF Envelope for SG output at 10 dBm for f_c = 15 MHz (No Amplifier)

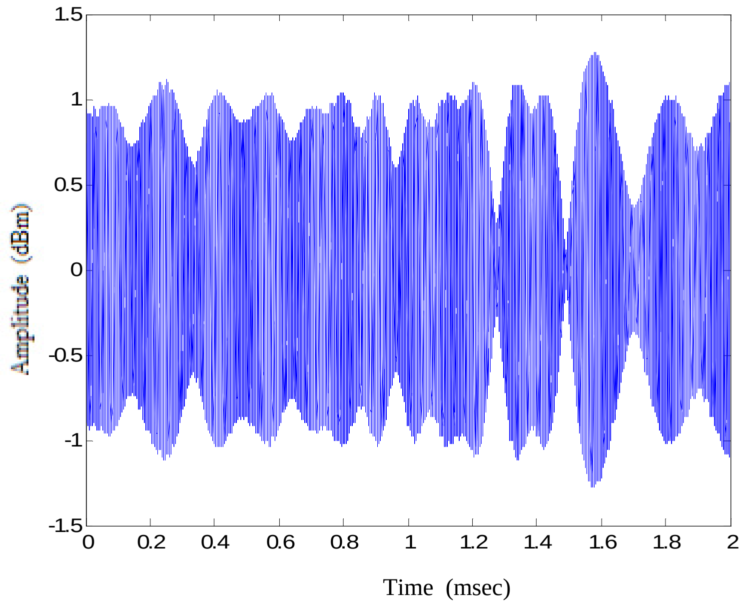

Figure 5.20 (b) Modulated RF Envelope of Linear Amplifier at $f_c = 15$ MHz

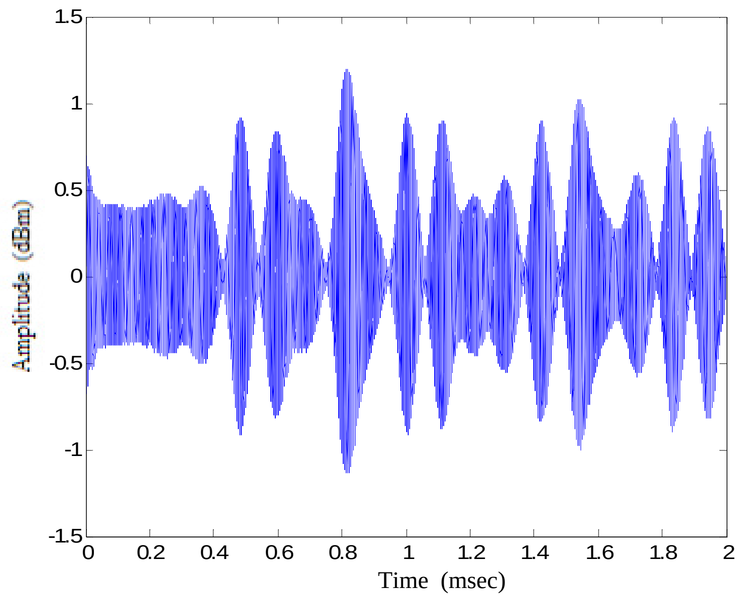

Figure 5.20 (c) Modulated RF Envelope of Leveled Amplifier at $f_c = 15$ MHz

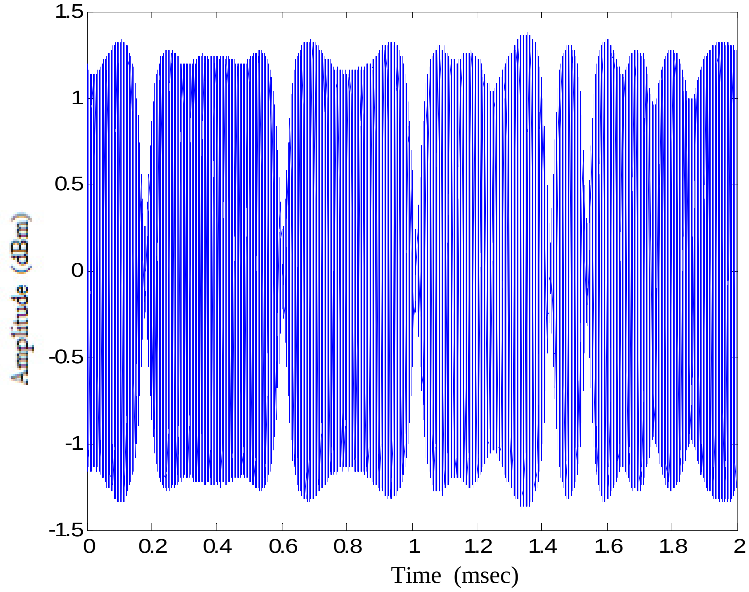

Figure 5.20 (d) Modulated RF Envelope for Amplifier Overdriven at $f_c = 15$ MHz

VI. THE FORMAT OF THE DATA FILES

As mentioned previously, there are 8,000,000 points in each file. The files were divided into two parts: 256 sets of random I/Q values, and 512 sets of I/Q values generated by MATLAB. The files were named by the situation under which the file was generated. For example, for $f_c = 5$ MHz, L1 and L2 lines in parallel with a 50 ohm resistor. There is a “5 MHz” folder, with a subfolder in it labeled: “L1+50 ohm resistor in parallel +L2”. There are two files in this folder: one is an image file, the other is a data file. Every signal file, including image files (.bmp) and data files (.dat), is 107 Mb in size, and the data will be stored on CD-ROM, which will be sent to the University of Texas for further analysis.

The University of Texas group will use the data as unknown signals and analyze the information contained in the signals to determine if the effects that were simulated and investigated in this thesis are detectable.

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VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This project began as an attempt to determine how QPSK modulation might be distorted by mechanisms in the RF path of a QPSK radio communication system. Simulating the QPSK modulation signal and using a laboratory environment to create deteriorating effects on the signal was the object of this project.

A signal generator was used as a signal source to create a set of I/Q values to simulate the information. Transmission lines are used to simulate part of the RF transmission path. A digital oscilloscope was used to simulate a receiver and to record the received data for further analysis.

The RF signals were chosen in the HF band (5-15 MHz) and modulation was at 9600 baud. RF waveforms were analyzed and then stored for further study. A propagation path was set up in the laboratory to simulate part of a real-world situation. The RF path was confined to coaxial cables. Transmission line effects were an important factor. Other factors, including loads, cable mismatch, and amplifier linearity, also were examined.

Different lengths of data sets were created by manual input and from MATLAB code. Due to limitations of the instruments, a limited number of data sets could be created. By comparing the different situations, the authors were able to identify each different situation that might create some kind of signal quality deterioration then recorded the data for further research.

This study provides the Navy with a sample RF signal of QPSK modulation that simulates part of a real-world transmission system and its RF cables. By knowing the signal modifications that are created by these experiments, the Navy may be able to “fingerprint” signals received from real-world transmitters which that have similar RF path anomalies.

There are still two problems remaining to be solved. The first one is that the data that can currently be created is limited, which may be a problem for analysis, because the data set repeats many times in just one second, which is almost impossible in the real world. The other is that the propagation path factors are important factors to be considered but these are difficult to simulate in a laboratory environment. Building a model that simulates the propagation environment is a critical issue for future study.

B. FUTURE WORK

For the purpose of simulating the real-word communication system, this model provides a reasonable platform for future work. Additionally, the benefits of the signal modification that are created by these experiments can be realistically represented. Future work may consist of:

- Creating a model to simulate the propagation path effects,
- Creating a model to simulate the environmental effects,
- Creating a model to simulate the motion platform effects, and
- Simulating the sea-state effects.

The above simulations would eventually result in a clear understanding of the different effects on the communication system. Further simulation with these models may result in the development of the HF QPSK communication system fingerprint.

APPENDIX A. SIGNAL GENERATOR SET UP PROCEDURE

Signal Generator setup:

1. Set the amplitude to the desired value with the amplitude adjustment button.
2. Set the symbol rate to 9600 baud.
3. For QPSK modulation to function, choose “Select user defined I and Q function” and type in a data file contained 256 sets I and Q values which was randomly generated by using MATLAB.
4. When I and Q table is set up, save it to a file for future use.
5. Recall I and Q table from that file. The different I and Q value in that table represents the constellation of the QPSK modulation signal.
6. Select the “Modulation On” button to apply the modulation function to the generator.
7. Connect signal output to the receiving system.

Digital Sampling Oscilloscope set up:

1. Power on the DSO; wait for 10 minutes for warm-up and self tests.
2. Choose the parameters to adjust the DSO screen as needed.
3. Select an adequate sample rate for sampling data. The sample rate corresponds to the recording length and file size.
4. Save the sampling data to a specified file and save the file on a CD.

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APPENDIX B. EXPERIMENTAL SETUP

The model set up in this experiment can be rebuilt for future work. Each component can be installed according to the previous parameters in order to get the same measurement result.

The experiment can be rebuilt by following the below steps:

1. Use the Signal Generator as a transmitter.
2. Set up the Signal Generator by following the steps laid out in Appendix A
3. Use the Digital Sampling Oscilloscope as a receiver and to collect data from the Signal Generator.
4. The Digital Sampling Oscilloscope can be set up by following the steps listed in Appendix A.
5. The data sets used to modulate the QPSK signal can be either internally provided or externally fed in.
    a. The internal real-time modulation can be done by manually typing in the data set, but the maximum is 256 data sets.
    b. The Signal Generator has a GPIB port that can receive external input data. Use a PC as a remote controller; it can download the data sets to the signal generator via a GPIB card. In this experiment, MATLAB was used to control the GPIB card. The MATLAB code used to control the GPIB card is listed in Appendix D.
6. Transmission Path Simulation

A transmission line is used to simulate the transmission path in this test. The distortion and mismatch effects can be achieved by connecting a resistor, amplifier or different impedance cable to the transmission line. The connection diagram is described in Chapter IV.

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APPENDIX C. MANUAL QPSK DATA INPUT

No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q
1	-1	-1	17	1	-1	33	-1	1	49	-1	-1	65	-1	-1	81	-1	1	97	-1	-1	113	-1	1
2	-1	1	18	-1	1	34	1	1	50	-1	-1	66	1	-1	82	1	-1	98	-1	-1	114	1	-1
3	1	1	19	-1	1	35	1	-1	51	1	-1	67	1	1	83	-1	1	99	1	1	115	-1	1
4	1	-1	20	-1	-1	36	-1	1	52	-1	-1	68	-1	-1	84	1	1	100	1	1	116	1	1
5	-1	1	21	1	-1	37	1	-1	53	1	-1	69	-1	-1	85	1	-1	101	-1	1	117	1	-1
6	-1	1	22	1	1	38	-1	1	54	-1	1	70	1	1	86	-1	-1	102	-1	-1	118	1	1
7	1	-1	23	-1	-1	39	1	1	55	-1	-1	71	1	1	87	1	-1	103	1	-1	119	-1	-1
8	-1	-1	24	1	-1	40	1	-1	56	1	-1	72	-1	1	88	-1	1	104	1	1	120	-1	-1
9	1	1	25	-1	1	41	-1	1	57	1	-1	73	-1	-1	89	-1	-1	105	1	-1	121	1	1
10	1	1	26	1	1	42	-1	-1	58	-1	1	74	1	-1	90	1	-1	106	1	1	122	1	1
11	-1	1	27	1	1	43	1	-1	59	1	-1	75	1	1	91	-1	-1	107	-1	-1	123	1	-1
12	1	-1	28	-1	-1	44	1	1	60	-1	1	76	-1	1	92	1	-1	108	1	-1	124	1	1
13	-1	1	29	1	-1	45	-1	-1	61	1	1	77	1	-1	93	1	-1	109	-1	1	125	-1	-1
14	1	-1	30	-1	1	46	1	-1	62	1	-1	78	-1	1	94	-1	1	110	-1	1	126	1	1
15	1	1	31	-1	1	47	-1	-1	63	-1	-1	79	1	1	95	1	1	111	1	-1	127	-1	-1
16	-1	-1	32	1	1	48	1	1	64	1	-1	80	1	-1	96	-1	-1	112	-1	1	128	1	-1
No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q	No	I	Q
129	-1	1	145	-1	-1	161	-1	1	177	-1	1	193	1	1	209	-1	1	225	-1	1	241	-1	-1
130	1	-1	146	1	1	162	1	-1	178	-1	-1	194	-1	1	210	1	-1	226	-1	-1	242	1	-1
131	-1	1	147	1	1	163	-1	1	179	1	-1	195	-1	-1	211	-1	1	227	1	-1	243	1	1
132	1	1	148	-1	1	164	1	1	180	1	1	196	1	-1	212	1	1	228	1	1	244	1	-1
133	-1	-1	149	-1	-1	165	1	-1	181	1	-1	197	1	1	213	1	-1	229	1	-1	245	-1	-1
134	-1	-1	150	1	-1	166	1	1	182	-1	-1	198	1	-1	214	-1	-1	230	-1	-1	246	1	1
135	1	1	151	1	1	167	-1	-1	183	1	-1	199	-1	-1	215	1	-1	231	1	-1	247	-1	-1
136	1	1	152	1	-1	168	-1	-1	184	-1	1	200	-1	1	216	-1	1	232	-1	1	248	1	1
137	-1	1	153	-1	-1	169	-1	1	185	-1	-1	201	-1	-1	217	-1	-1	233	-1	-1	249	1	-1

138	**1**	**1**	154	**1**	**-1**	170	**-1**	**-1**	186	**1**	**-1**	202	**1**	**-1**	218	**1**	**-1**	234	**1**	**-1**	250	**-1**	**-1**
139	**1**	**-1**	155	**-1**	**1**	171	**-1**	**-1**	187	**1**	**1**	203	**1**	**1**	219	**-1**	**-1**	235	**-1**	**1**	251	**1**	**-1**
140	**-1**	**1**	156	**-1**	**-1**	172	**1**	**-1**	188	**-1**	**1**	204	**1**	**-1**	220	**1**	**-1**	236	**1**	**-1**	252	**-1**	**1**
141	**1**	**1**	157	**1**	**-1**	173	**1**	**1**	189	**1**	**-1**	205	**1**	**1**	221	**1**	**-1**	237	**-1**	**1**	253	**1**	**1**
142	**1**	**-1**	158	**1**	**-1**	174	**-1**	**1**	190	**-1**	**1**	206	**-1**	**-1**	222	**-1**	**1**	238	**-1**	**-1**	254	**1**	**-1**
143	**-1**	**-1**	159	**-1**	**-1**	175	**1**	**-1**	191	**-1**	**-1**	207	**1**	**-1**	223	**1**	**1**	239	**1**	**-1**	255	**-1**	**-1**
144	**1**	**-1**	160	**1**	**1**	176	**-1**	**1**	192	**1**	**-1**	208	**-1**	**-1**	224	**-1**	**-1**	240	**-1**	**1**	256	**-1**	**-1**

APPENDIX D. MATLAB CODE

```
%
%***************************************************************************
%
% 1. This code is used to generate random data sets for an Agilent signal generator.
% 2. The signal generator can accept at most 1512 bits of random numbers to generate random
%     756 sets of I/Q.
% 3. This code should be used with the Instrument Control Toolbox.
%
%
%***************************************************************************
%
% decide how many the random number you want to generate from the signal generator.
% the number should de divided by 8
%
numbits=input('How many bits of data ? ');
numbytes=ceil(numbits/8);
% generate a set of 128 random characters (numbers) from 0 to 255
% Note: 2 bits= 1 byte in ASCii

x=round(255*rand(numbytes,1));
% This data set is uniformly distributed within bytes
% but the bits will be more nearly normally distributed

% convert the bytes to ASCii strings
xstr=char(x)

% now ,make it all one really big string
outstr=[];% output this string
binstr=[];
% make the out put matrix
for row=1:numbytes
   outstr=[outstr,xstr(row)];
   binstr=[binstr,dec2bin(x(row),8)];
end

% then ,we build the command string for the signal generator from Tool Box
numdigit=1+floor(log10(numbytes))
cmdstr=[':MEMory:DATA:BIT “bitdata”, ',num2str(numbits),',
#',num2str(numdigit),num2str(numbytes),outstr];

% establish a connection with the siggen
% test if the signal generator work well
% the default value of signal port is 1
io = agt_newconnection('gpib',0,19)

% to check if the port is equal to 1
[status, status_description,query_result] = agt_query(io,'*idn?')
% if the answer is not equal to 1, the connection can not be work well
if (status < 0) return; end

% if the connection have been completed, then set up the parameter

% set up the carrier frequency and power
```

```
disp('freq')
[status, status_description] = agt_sendcommand(io, 'SOURce:FREQuency 3000000')
pause
disp('power')
[status, status_description] = agt_sendcommand(io, 'POWer 0')
pause

% turn off arbitrary generator before downloading
disp('arb')
[status, status_description] = agt_sendcommand(io,':SOURce:RADio:ARB:STATe OFF')
pause
% this downloads the data string to the siggen
disp('cmdstr')
[status, status_description] = agt_sendcommand(io, cmdstr)
pause
% set machine back to local control
disp('local')
[status, status_description] = agt_sendcommand(io, ':LOCal 7')
pause
```

APPENDIX E. MATLAB GENERATED DATA (1512 SYMBOLS)

111100100011101110011011011111001110001111000010011101000000010111010001
011100011001110111001010111010111011110000101101011001111110111111101010
011010011110010000001111010110101100111100000011001000110011010000110011
100110100100010100110011000001001011111001110001111011100111011101101011
110110001000011000110100101010111101011000000101101011100110000111010100
100000001011010101101101010011100011000000110001101011100100110110001010
001001101011001001100000110110111101101010010111011111111110010111010010
101001001101000110101000010101110100101001010111100010001011100101001111
110101101001000101011110101100111000101101110001101100011001111011001011
111101001000010111100000000101100111110100100010101000000110111111011100
001000110000000111110010000110011010011001010100101001001011110000001000 1
111111001001010101101100100000110101010101101110001110101001010011000010
100001111010001100110101011000011100100010101110011101101001000111001011
000011111001101000001101011010100100111011011111000001001100010011111000
111111001100100101110000011111110011011110100100010100101111010110111001
011010011011111001000100011100001110111010101110001101101101011010100000
001000100011010110011011101000010101111010010011011100110000101100000111
010100000000000110110001010101110000110000000100110011100100110110000010 0
000001000011000010010110000011110101111010100001101101111011000100010101
011101000111000101011010001001111010110010110010101110100111101010001101
000111110111001110110111111001000100011001000000111011101001110111100110 1

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