RF & Communication Trainer

GRF-1300A
TEACHER'S BOOK

USER MANUAL and TEXT BOOK

GW INSTEK PART NO. 82RF-13002M01

ISO-9001 CERTIFIED MANUFACTURER

GW INSTEK

Good Will Instrument Co., Ltd.
No. 7-1, Jhongsing Rd., Tucheng Dist., New Taipei City 236, Taiwan.

Table of Contents

SAFETY INSTRUCTIONS

This chapter contains important safety instructions that should be followed when operating and storing the GRF-1300A. Read the following before any operation to ensure your safety and to keep the GRF-1300A in the best condition.

Safety Symbols

These safety symbols may appear in this manual or on the instrument.

⚠ WARNING	Warning: Identifies conditions or practices that could result in injury or loss of life.
⚠ CAUTION	Caution: Identifies conditions or practices that could result in damage to the GRF-1300A or to other objects or property.
⚡	DANGER High Voltage
⚠	Attention: Refer to the Manual
⏚	Protective Conductor Terminal
⏚	Earth (Ground) Terminal
🗑	Do not dispose electronic equipment as unsorted municipal waste. Please use a separate collection facility or contact the supplier from which this instrument was purchased.

Safety Guidelines

General Guideline

⚠ CAUTION

- Do not place heavy objects on the device.
- Do not place flammable objects on the device.
- Avoid severe impact or rough handling that may damage the device.
- Avoid discharges of static electricity on or near the device.
- Use only mating connectors, not bare wires, for the terminals.
- The device should only be disassembled by a qualified technician.

(Measurement categories) EN 61010-1:2010 specifies the measurement categories and their requirements as follows. The device falls under category I.

- Measurement category IV is for measurement performed at the source of a low-voltage installation.
- Measurement category III is for measurement performed in a building installation.
- Measurement category II is for measurement performed on circuits directly connected to a low voltage installation.
- Measurement category I is for measurements performed on circuits not directly connected to Mains.

Power Supply

⚠ WARNING

- AC Input voltage: 100 ~ 240V AC, 50 ~ 60Hz.
- Connect the protective grounding conductor of the AC power cord to an earth ground to prevent electric shock.

Fuse

⚠ WARNING

- Fuse type: 1A/250V.
- Only qualified technicians should replace the fuse.
- To ensure fire protection, replace the fuse only with the specified type and rating.
- Disconnect the power cord and all test leads before replacing the fuse.
- Make sure the cause of the fuse blowout is fixed before replacing the fuse.

Cleaning the GRF-1300A

- Disconnect the power cord before cleaning the device.
- Use a soft cloth dampened in a solution of mild detergent and water. Do not spray any liquid into the device.
- Do not use chemicals containing harsh products such as benzene, toluene, xylene, and acetone.

Operation environment

- Location: Indoor, no direct sunlight, dust free, almost non-conductive pollution (Note below) and avoid strong magnetic fields.
- Relative Humidity: < 80%
- Altitude: < 2000m
- Temperature: 0°C to 40°C

(Pollution Degree) EN 61010-1:2010 specifies pollution degrees and their requirements as follows. The device falls under degree 2.

Pollution refers to "addition of foreign matter, solid, liquid, or gaseous (ionized gases), that may produce a reduction of dielectric strength or surface resistivity".

- Pollution degree 1: No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
- Pollution degree 2: Normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected.
- Pollution degree 3: Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation which is expected. In such conditions, equipment is normally protected against exposure to direct sunlight, precipitation, and full wind pressure, but neither temperature nor humidity is controlled.

Storage environment	• Location: Indoor • Relative Humidity: < 70% • Temperature: -10°C to 70°C
Disposal	Do not dispose this device as unsorted municipal waste. Please use a separate collection facility or contact the supplier from which this instrument was purchased. Please make sure discarded electrical waste is properly recycled to reduce environmental impact.

Power cord for the United Kingdom

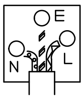
When using the device in the United Kingdom, make sure the power cord meets the following safety instructions.

NOTE: This lead/appliance must only be wired by competent persons

⚠ WARNING: THIS APPLIANCE MUST BE EARTHED

IMPORTANT: The wires in this lead are coloured in accordance with the following code:

Green/ Yellow:	Earth
Blue:	Neutral
Brown:	Live (Phase)



As the colours of the wires in main leads may not correspond with the coloured marking identified in your plug/appliance, proceed as follows:

The wire which is coloured Green & Yellow must be connected to the Earth terminal marked with either the letter E, the earth symbol ⏚ or coloured Green/Green & Yellow.

The wire which is coloured Blue must be connected to the terminal which is marked with the letter N or coloured Blue or Black.

The wire which is coloured Brown must be connected to the terminal marked with the letter L or P or coloured Brown or Red.

If in doubt, consult the instructions provided with the equipment or contact the supplier.

This cable/appliance should be protected by a suitably rated and approved HBC mains fuse: refer to the rating information on the equipment and/or user instructions for details. As a guide, a cable of 0.75mm^2 should be protected by a 3A or 5A fuse. Larger conductors would normally require 13A types, depending on the connection method used.

Any exposed wiring from a cable, plug or connection that is engaged in a live socket is extremely hazardous. If a cable or plug is deemed hazardous, turn off the mains power and remove the cable, any fuses and fuse assemblies. All hazardous wiring must be immediately destroyed and replaced in accordance to the above standard.

ABOUT THIS BOOK

This textbook was developed in conjunction with the GRF-1300A RF & Communication Trainer and the GSP-730 3GHz spectrum analyzer as an RF communications education system. It not only offers detailed examples, but also the practical knowledge necessary for RF measurements, such as spectrum analyzer principals, as well as AM and FM communication systems.

For you to easily understand the contents of this textbook, we have included as many pictures and diagrams as possible to strengthen your comprehension.

This book is divided into a teacher version and student version. All experiment results are included in the teacher edition. In addition, chapters with an asterisk (*) indicate additional text for advanced reading not present in the student addition. Students will not be effected by the omission of the additional text. To further help students, the student edition will contain a "Notes" section in these missing areas.

INTRODUCTION to the GRF-1300A

The GRF-1300A is a well designed training kit capable of producing a 3MHz baseband signal and a carrier signal up to 900MHz. The GRF-1300A is also able to perform AM and FM RF circuit experiments as well. The practical exercises in the training kit meet the needs of most general RF courses. The GRF-1300A consists of three modules, namely: a baseband module, an RF Synthesizer/FM module and an AM module. The baseband module can simulate a baseband signal and includes sine, square or triangle waveforms. Its output frequency and amplitude are adjustable. During experiments the three kinds of waveforms can be arbitrarily switched back and forth to meet the signaling requirements of each of the different experiments.

The RF Synthesizer/FM module is used to generate an adjustable carrier frequency as well as perform frequency modulation. This module covers some of the focus points in the RF circuit theory. This will be highlighted in practical experiments in later chapters. FM waveforms can also be produced by using this module together with the baseband module. The GSP-730 spectrum analyzer can be used to observe the various characteristics of an FM waveform.

The AM module and baseband module can be used together to perform amplitude modulation experiments. The GSP-730 Spectrum Analyzer can be used to observe the various characteristics of an AM waveform.

The mixer can convert the RF signal into an intermediate frequency signal or it can do the opposite and convert the intermediate frequency signal into an RF frequency signal in order to transmit or process the carried message, respectively

This experiment system can be connected to a computer via the USB interface. The interface can be used to turn individual circuits on or off so that students can perform diagnostic experiments.

Students can learn the fundamental aspects of RF theory through a variety of experiments. Understanding RF theory has been made easier by breaking the RF circuits into fundamental functions. This allows students to see in detail how the theory relates to the practical aspects of the RF circuitry.

This system is a collection of different functions: signal generation, frequency modulation, amplitude modulation, communication and other functions. Connecting different modules together can create a number of different RF circuit experiments. Specific experiments will be highlighted in later chapters. The GRF-1300A RF & Communication Trainer is designed to modulate an audio signal with a carrier waveform. The system takes into account the difficulties arising from RF circuit theory and knowledge. It focuses on these theories and sets up experiments to understand the theoretical aspects of RF circuitry – This also has the added benefit of increasing a student's interest to learn RF circuits.

igure A-1. The GRF-1300A control panel

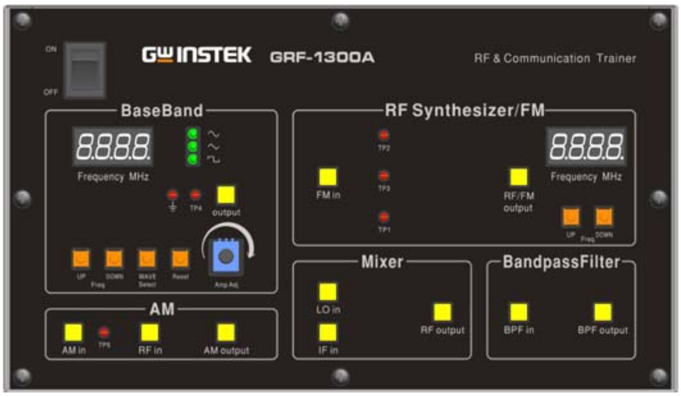


Figure A-2. Reference platform: GSP-730 Spectrum Analyzer

Package Contents

This package contains the GRF-1300A unit, RF cable – 3 * 10cm, 1*20cm,RF cable 2* 80cm, a user manual CD, a student book, an antenna, a power cord and so on.

Title	Photo	No	Note
GRF-1300A		1	
RF wire		3	100mm
RF wire		1	200mm
RF wire		2	800mm
Antenna		2	800-1000MHz
AC power cord		1	100-240V～50-60Hz
CD		1	User manual and software
Adapter		1	N-SMA Adapter
Student Textbook		1	RF & Communication Trainer

Product Specifications and Function

Function	Item	Spec.
Base Band	Waveforms	Sine, Square, Triangle
	Frequency Range	0.1~3MHz (Triangle-0.1~1MHz) Step: 10kHz
	Amplitude	≥1.5Vpp ≥0.75Vpp into 50Ω
	Harmonics Distortion	≤-30dBc
RF/FM Analysis	Frequency Accuracy	±0.15MHz
	Adjustable Range	≥45MHz (870M~920M) Step: 1MHz
	Power Range	≥-15dBm
FM	Max Frequency Deviation	>3MHz
AM	Peak Difference	≥-18dBm
Mixer	LO+IF	⩾-35dBm

	LO-IF	≥-35dBm
Mixer+modulation	≥-60dBm	
Bandpass Filter	Frequency Centre: 2.4GHz	Bandwidth:±20MHz
Communication	Turn circuits on or off by remote command for the diagnostic experiments.	

Usage Instructions

Procedure

1. For safety purposes, please connect the unit to the correct AC power source: 100V~240V, 50-60Hz.

   Make sure the ground terminal is properly earthed to prevent electric shock.

2. The power socket and USB port are on the rear panel. The power switch is on the upper left-hand side of the device.

USB port

AC socket

Power switch

3. When using several modules together at the same time, connect each module with the appropriate RF cable.

Figure A-3. Connection diagram between different modules

4. The UP and DOWN buttons on the Baseband module can be used to adjust the frequency of the baseband signal. The baseband module is adjustable in 10kHz steps.

   - *WAVE Select* is used to select three different baseband waveforms. When the waveform is selected, the corresponding LED light will be lit up.

   - The *Reset* button is used to reset the GRF-1300A. When reset, the GRF-1300A will output a 0.10MHz sine wave baseband signal and a carrier signal with a frequency 880MHz.

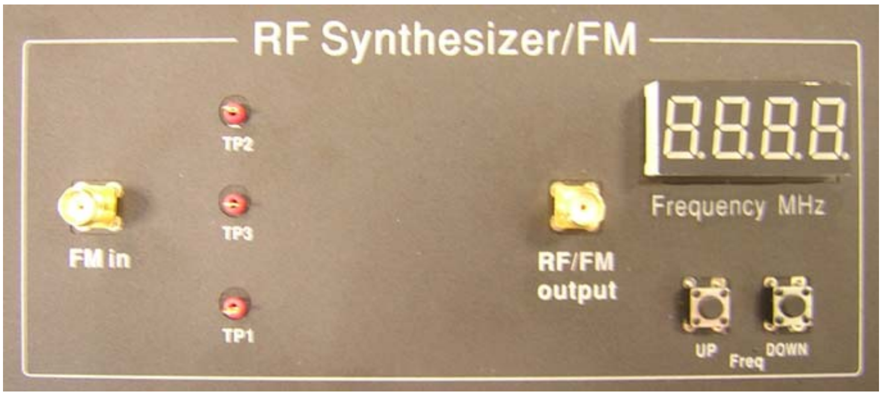
- The *output* port is used to output the set baseband signal.
- The four-digit display is used to display the frequency of the output baseband signal.
- TP4 (test point 4) is used to monitor the output signal from the output port.
- The potentiometer knob is used to adjust the voltage of the output baseband signal. Turn clockwise to increase the amplitude and turn anticlockwise to decrease its amplitude.

Figure A-4.
Baseband module

5. The UP and DOWN buttons on the RF Synthesizer / FM module can be used to adjust the frequency of the carrier. The carrier can be adjusted in 1MHz steps.

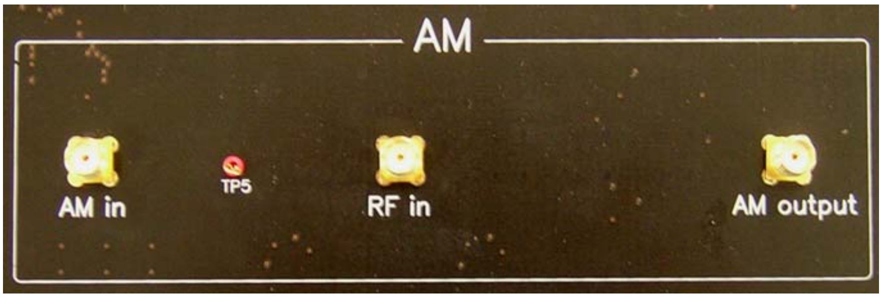
    - The Four-digit display is used to display the frequency of the carrier signal.
    - *FM in* port and *RF / FM Output* port are used to receive the FM signal and output the carrier signal respectively.
    - TP2, TP3 and TP1 are used to monitor for breaks in the circuit. For the position of each test point, please see Figure A-7.

Figure A-5. RF Synthesizer/FM module



6. The AM module is used for amplitude modulation. The *AM in* port and *RF in* port are used to input the modulating signal and the carrier signal respectively. The *AM output* port outputs the amplitude modulated waveform.

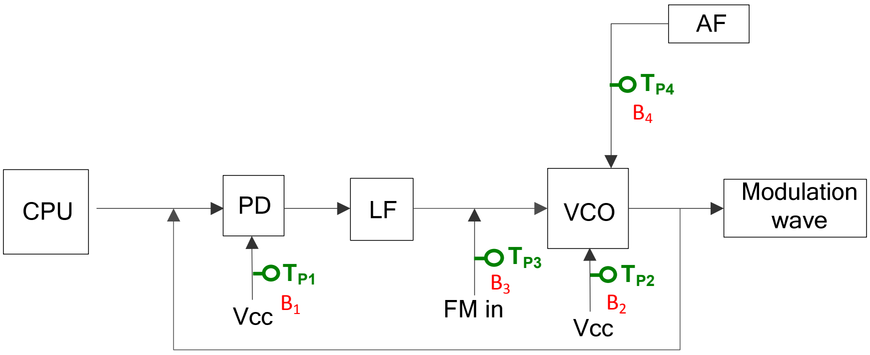
Figure A-6. AM module



The mixer can convert the RF signal into an intermediate frequency signal or it can do the opposite and convert the intermediate frequency signal into an RF frequency signal in order to transmit or process the carried message, respectively

7. There are five test points (Tp1, Tp2, Tp3, Tp4, Tp5) on the panel. These five test points are set at different points in the circuit path of the connected modules. Their specific locations are as shown in the Figure below. They are turned on or off by their corresponding relays (B1, B2, B3, B4, B5). An oscilloscope can be used to detect/determine the status of the circuitry at these test points.

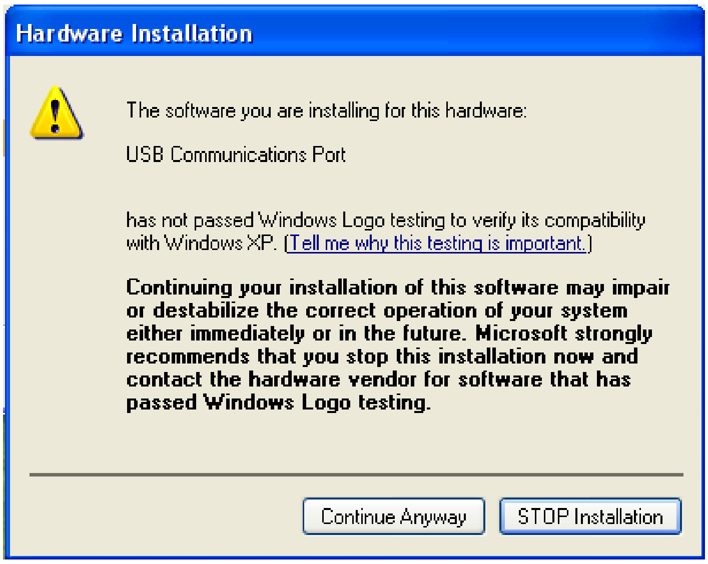
Figure A-7. Circuit location of each test point



8. Install the GRF-1300A driver onto the PC.

- Connect the GRF-1300A to the PC. Below are the steps for installing the software. Add the install software to the install directory. Click next and a window as shown below appears.

Figure A-8. Software installation



Hardware Installation

The software you are installing for this hardware:

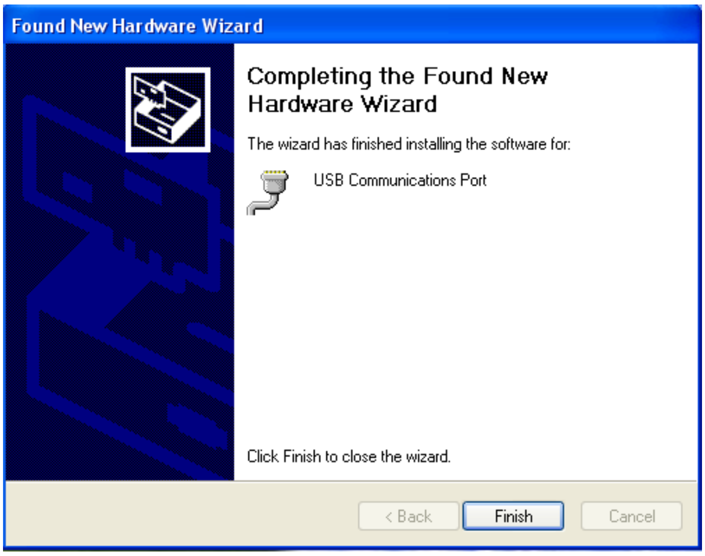
USB Communications Port

has not passed Windows Logo testing to verify its compatibility with Windows XP. (Tell me why this testing is important.)

Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the hardware vendor for software that has passed Windows Logo testing.

- Next, click on the “Continue Anyway” button to continue the installation until the installation procedure is complete.

Figure A-9. Installation procedure is complete



Completing the Found New Hardware Wizard

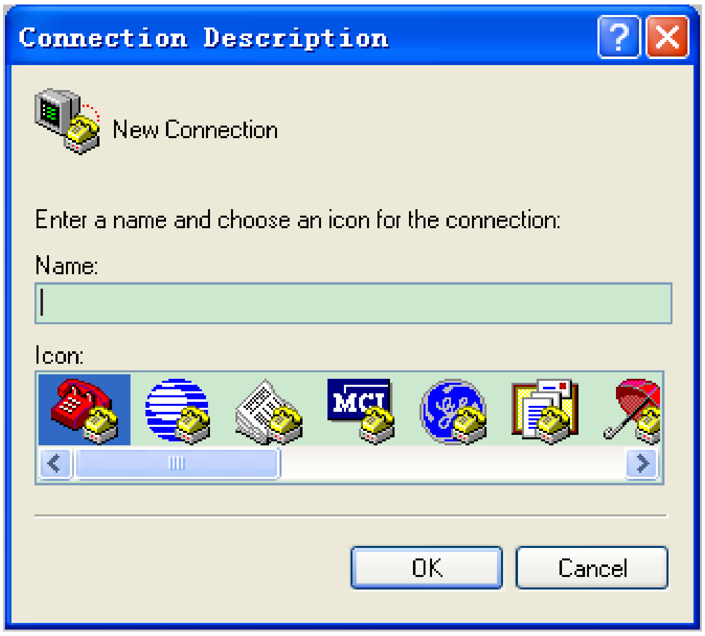
The wizard has finished installing the software for:

USB Communications Port

Click Finish to close the wizard.

- After the software installation is complete, users can perform a system error check by sending commands to the GRF-1300A using Hyper Terminal.

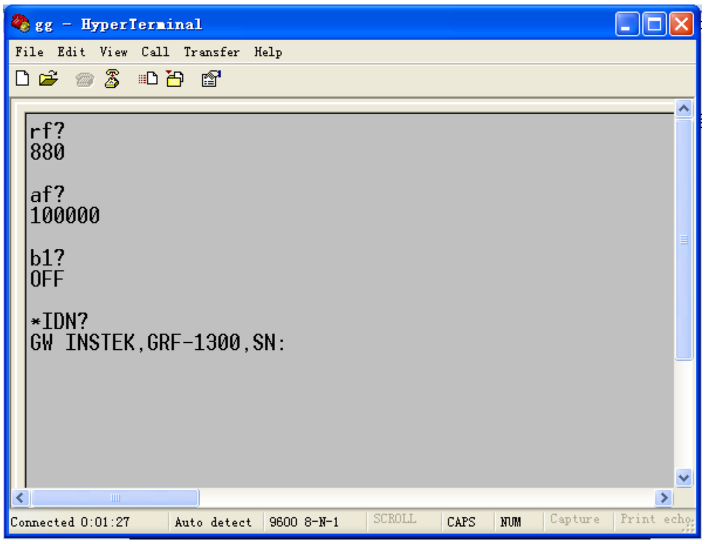
Figure A-10. Operation interface for HyperTerminal



Enter a name and choose an icon for the connection:

Name:

Icon:



```
rf?
880

af?
100000

b1?
OFF

*IDN?
GW INSTEK,GRF-1300,SN:
```

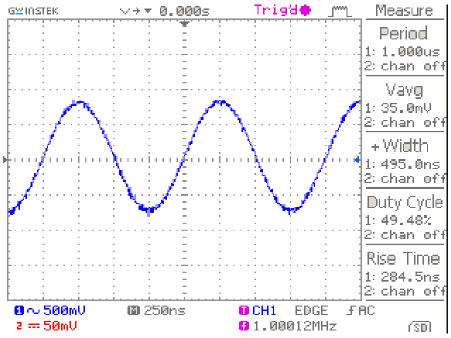
9. Below is a table listing each instruction and a description of each function.

Instruction	Function
*IDN?	Returns the manufacturer, model name and serial number.
RF?	Returns the value on the digital display of the FM/RF module.
AF?	Returns the value on the digital display on baseband module.
WAVE?	Returns the waveform type on the baseband module.
Bn? (n is the relay number for the corresponding test point)	Returns the state (open or closed) of the currently selected relay.
WAVE:0	The waveform to sine.
WAVE:1	Set the waveform to triangle.
WAVE:2	Set the waveform to square.
Bn:0 ('n' is the relay number. I.e., B1:0)	Set the relay of corresponding no. to OFF.
Bn:1 ('n' is the relay number. I.e., B3:1)	Set the relay of corresponding no. to ON.
AF:N(N is setting frequency)	Set the AF frequency to N.
RF:N(N is setting frequency)	Set the RF frequency to N.

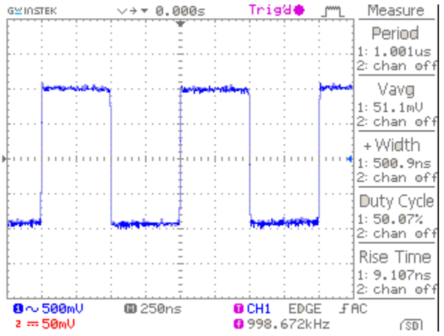
OVERVIEW of the TIME and FREQUENCY DOMAIN

Observation from a different perspective

When a signal is said to be in the time domain, it means that the signal is expressed as a function of time. For example, if we describe a sine wave signal that repeats once each microsecond (µsec, 10^{-6}), it means that the period of the signal is 1 microsecond. Usually we use an oscilloscope to measure these signal characteristics in the time domain. In addition, when we talk about the rise and fall time of a square waveform, we also can observe that in the time domain. Phase delay is also measured in the time domain. Oscilloscopes are well-known electrical signal measurement instruments that perform measurements in the time domain.



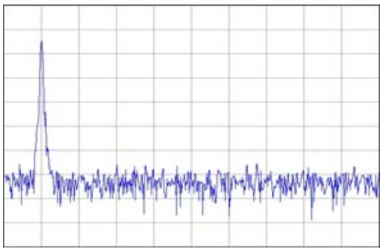
1µsec sine wave

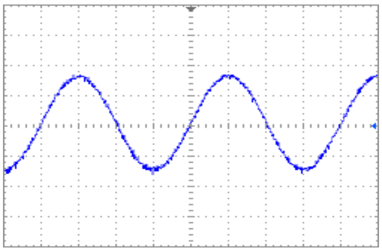


Square wave with the same period

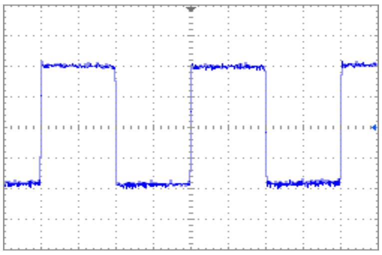
However, when we observe a sine wave and a square wave with the same amplitude and period, is there a way to describe the difference between them? Frequency domain measurements just provide a different view point.

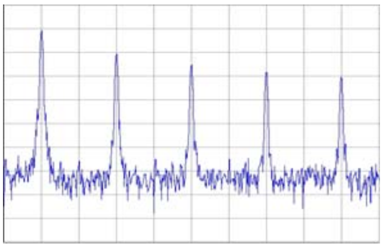
First we will explain what frequency domain means. Frequency domain means to observe the frequency composition of a signal. If we add a sine wave signal that has a 1 microsecond period to a spectrum analyzer, we will see an obvious signal on the scale at 1 megahertz (MHz). We know that frequency is the inverse of period. Therefore, a sine wave with a period of microsecond has a frequency of 1MHz. You can measure voltage from an oscilloscope and power (dBm) from a spectrum analyzer. Voltage and power can be converted from one to the other, so both of them can be used to display the strength of a signal. Here we introduce a basic concept first. Each frequency point in the spectrum represents a sinusoidal wave (could be a sine or cosine) of a single frequency.





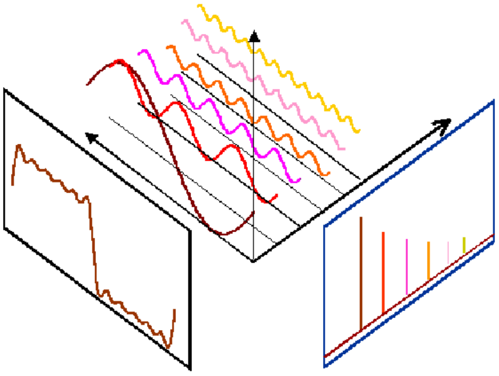
What about a square wave? We will now explain how a square waveform and sine waveform are different to each other in the frequency domain. If we input a square wave with a period of 1 microsecond into a spectrum analyzer, its waveform performance (we usually to say its *spectrum* or *frequency distribution*) is as follows.





If we compare it with a sine wave spectrum, we can observe that in addition to the point at the1MHz scale, other signal points also appear at higher frequencies and with decreased amplitudes. Therefore it shows that a square wave also includes a combination of signals that are multiples of the frequency baseband in addition to the 1MHz base frequency (fundamental frequency).

We can see a classic relationship between the time domain and frequency domain in the illustration below. A square wave signal in the time domain can be decomposed into multiple basic harmonic waves. The distribution of these harmonic components can be clearly seen in the frequency domain. Frequency domain analysis describes the characteristics of a signal from another viewpoint.


Time domain
Frequency domain

Fourier Series*

Introduction

Most people may have heard of the Fourier series or Fourier transform. It doesn't matter if you haven't, it will not hinder you from reading this text. The Fourier series was originally created by Joseph Fourier to solve the heat equation in metal plate, but became a good tool for analyzing the frequency domain and harmonic waves for the signals and systems fields. After reading this chapter, you may even feel that this French mathematician, that was born in 1768, was pretty cool!

Fourier, Joseph
(1768-1830)

Fourier thought that any periodic function can be decomposed into an infinite sum of sine functions (sin (nx)) and cosine functions (cos (nx)). Here, n is a positive integer (n=1,2,3…). This means that any periodic function can be created by a combination of multiple sinusoidal functions. In general, a period of 2π, (-π, π) can be expressed as a periodic function f(x). This can be expressed in the following form:

$$f(x) = \frac{a_0}{2} + a_1\cos(x) + a_2\cos(2x) + a_3\cos(3x) + \ldots + a_n\cos(nx)$$
$$+ b_1\sin(x) + b_2\sin(2x) + b_3\sin(3x) + \ldots + b_n\sin(nx)$$

where

$$a_0 = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x)d_x \qquad a_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x)\cos(nx)d_x$$

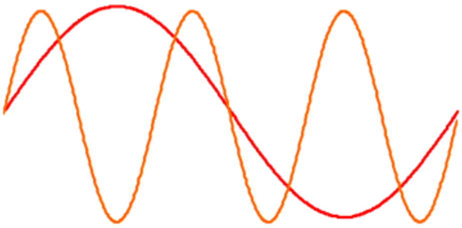
$$b_n = \frac{1}{\pi}\int_{-\pi}^{+\pi} f(x)\sin(nx)d_x$$

The mathematical function above shows that any periodic function f(x) with a period of 2п can be decomposed, classified and organized into a combination of the three types of functions, the constant a_0, the cosine functional group ancos(nχ) and the sine functional group bnsin(nχ). The so-called constant a_0 is the DC component of a signal. This function integrates f(x) from п to

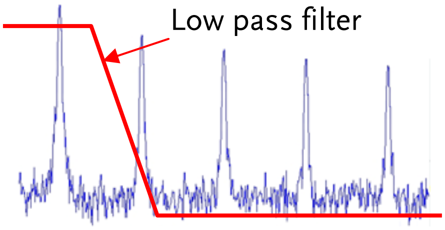
–π, and then divides by π. That is, it calculates the average over π, i.e., the DC component. In terms of a pure AC signal, the DC component or constant value is 0.

Looking at the sine function, sin(x) we know that if we draw sin(3x) and sin(x), we can see the frequency of sin(3x) is three times that of sin(x), and that sin(nx) is naturally n times the frequency of sin(x). This observation is also true for cosine functions. The Fourier series tells us that any periodic function can be regarded as the sum of the DC component, the multiple sine terms and the multiple cosine terms. The Fourier series coefficients that were calculated from the above integrals are in fact the magnitude of each of harmonic(n). Therefore multiplying the Fourier coefficients with their corresponding harmonic, and then adding the resulting terms together would result in the original f(x) equation.

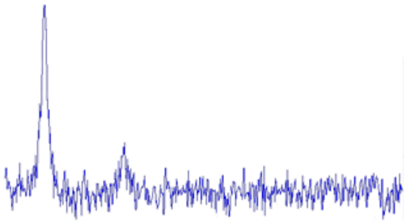
Sin(x) and sin(3x) waveforms



What is the purpose of converting a signal from the time domain to the frequency domain?
In fact, the frequency domain concept is also very important in system signal analysis. Take this simple case for example, before we can design a noise filter, we must first know the frequency of the signal and the frequency of the noise signal. Another example, to design a 2.4GHz antenna, it is more intuitive to measure the frequency response in the frequency domain than in the time domain. Furthermore, analysis and computation of a linear system is simpler in the frequency domain compared to in time domain. In the time domain, most signals and systems must use the process of convolution to solve linear equations whereas in the frequency domain only the operators need to be multiplied together. It is much easier. The majority of our communication systems and signals are linear systems. Thanks to Mr. Fourier, he made our engineering math class difficult, but he also enabled us to use our phones to conveniently keep in touch with our friends after class.



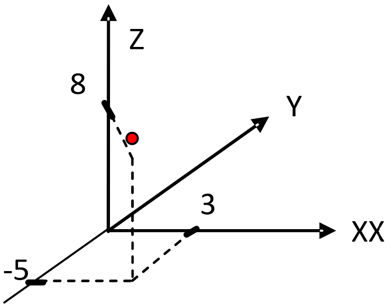
Signal with harmonic noise



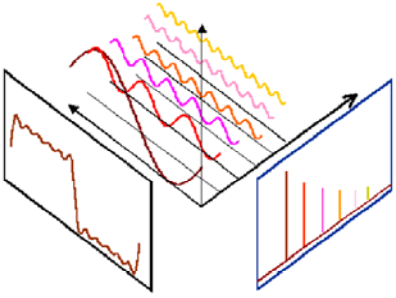
Signal after passing through the low pass filter

Before ending the introduction to the Fourier series, we'll explain a few things. First is the formula for calculating the Fourier series coefficients. It is based on the theory that cos(x), sin(x), cos(2x), sin(2x)... cos(nx), sin(nx) are regarded as a set of 2n +1 axes (including DC, n = 0) in a coordinate system. For example, there are 3 axes, x, y and z in a three dimensional space. There are 2n +1 coordinate axes in the periodic function world. The integral formulas from the Fourier coefficients are methods to calculate each component of the function f(x) on the (2n+1) axes. This is just like the point (3, -5, 8) in a three dimensional space where its components in the x, y and z axes are 3, -5, 8, respectively. In vector analysis, we calculate these components by inner product. While in the Fourier series, it uses the integral formulas above (another form of the inner product algorithm formula) to calculate each of the components. Further calculations of this sort needs further study in the area of linear algebra.

The point (3, -5, 8) in Cartesian coordinates has the components 3, -5, 8 in the x, y, and z axis respectively.

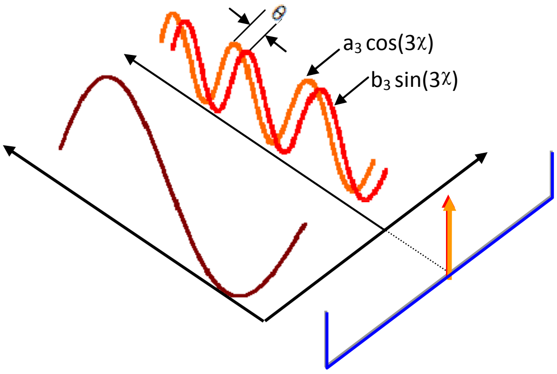


The different Fourier coefficients represent each frequency component on the axis.

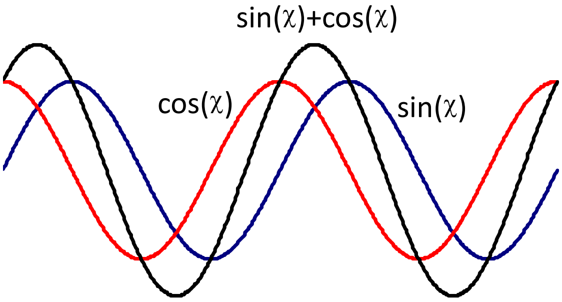


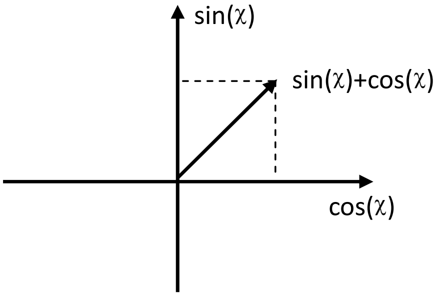
Also keep in mind that the calculated value of the Fourier coefficients in each n represent the components of its multiplier (ie, harmonic). For example whether it is cos(3x) or sin(3x), they are all components of the third harmonic. If we use a spectrum analyzer to measure the third harmonic of the signals, $a_3\cos(3\chi)$ & $b_3\sin(3\chi)$, the actual measurement would be the product of $a_3\cos(3\chi)$ & $b_3\sin(3\chi)$. However these two signals have a phase difference, θ. Can this phase difference be measured on a spectrum analyzer? The following diagram illustrates quite simply why it can be measured in the time domain.

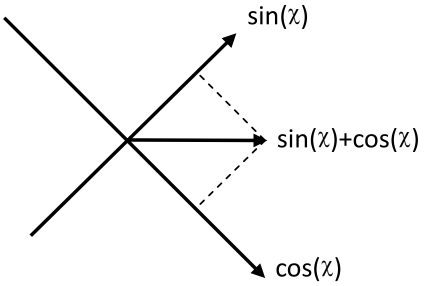
The phase difference, θ, of sin(3x) and cos(3x) can't be directly measured from the frequency domain.



The figure above shows that the phase difference between the two signals can't be seen in the frequency domain. However, if the sine signal and cosine signal are added together, a waveform with a higher amplitude that either lags the sine wave by π/4 or leads the cosine wave by π/4s would be created. This waveform can then be used a reference waveform. A reference signal is needed so that when it is rotated to 0° (by 45°or π/4) it allows linear vectors to be used to determine the phase of the sine and cosine signals, and thus the phase difference. This is illustrated below.







Performing measurement of the phase difference in the frequency domain is the same as performing vector signal analysis. This requires the a_3 and b_3 components to be measured individually, and then the cotangent function, tan^{-1} (a3/b3), can be used to find the phase. A vector signal analyzer is needed for further measurement and analysis.

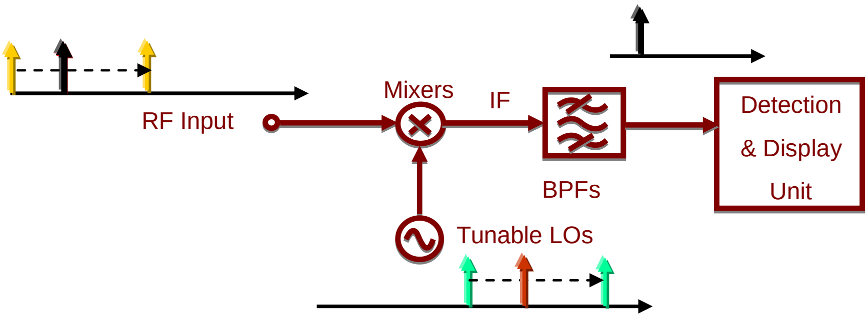
AN INTRODUCTION to SPECTRUM ANALYZERS

Spectrum analyzers are one of the most important instruments for RF microwave measurements. Being familiar with spectrum analyzers in general is very important for operating high frequency microwave equipment or for performing communication measurements. In addition, being familiar with the basic operating principals will allow you to quickly understand other related test equipment. In this chapter, we will briefly introduce the basic working principles of the spectrum analyzer. After understanding the basic working principles, you will find that a spectrum analyzer can be a handy tool to use.

Broadband Receiver

The principal function of a spectrum analyzer is to convert the input signal frequency down to a frequency (band) that detection circuitry can handle. For example, a 2.4GHz signal needs to be down-converted to several MHz before the Detection & Display unit can process the signal. Therefore a spectrum analyzer must be able to reduce the frequency band down to several MHz. The first half of a spectrum analyzer is called the radio frequency module and its task is to reduce the input signal frequency. A mixer and a bandpass filter are used to decrease the frequency (they can raise the frequency as well). The mixer is a component with three ports: two inputs and one output. Assume that the two input frequencies on input port are f_{RF} and f_{LO} respectively, and then the output frequency will be $f_{IF.}$ f_{IF} is made of two signals of different frequencies (f_{LO}- f_{RF} and f_{LO}+ f_{RF}) that appear on the output port at the same time. One signal is the sum of the input signals and the other is the difference. Determining which of the IF signals that will be used depends on the system and subsequent bandpass filter design. As for why the three ports are named after RF, LO, IF, they are just the conventional terms that are used.

Figure B-1. The basic structure of a broadband receiver

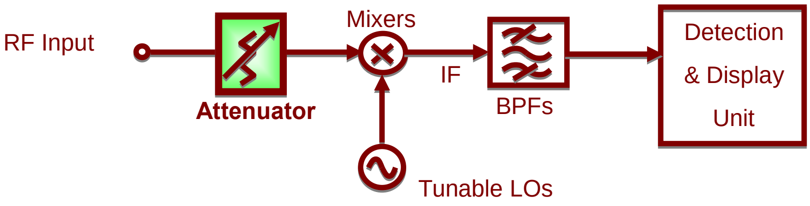


Next, we are going to introduce the other basic functional blocks that a spectrum analyzer is composed of. These blocks are often mentioned when instructed on how to use a spectrum analyzer.

Attenuator

An attenuator on the RF input path can increase the dynamic range of the input signal level or provide more input protection to the spectrum analyzer. Referring to Figure B-2, the attenuator limits the signal level coming to the mixer (RF end) to a certain level. If the input signal is above a reference level, it can cause measurement errors, or cause spurious noise.

Figure B-2. Attenuator



Resolution Bandwidth Filter

When the input signal frequency is converted to an IF, a RBW (resolution bandwidth) filter is used to distinguish the signals that are close to each other in frequency. Figure B-3 shows this concept.

Figure B-3. Basic structure of a resolution bandwidth filter

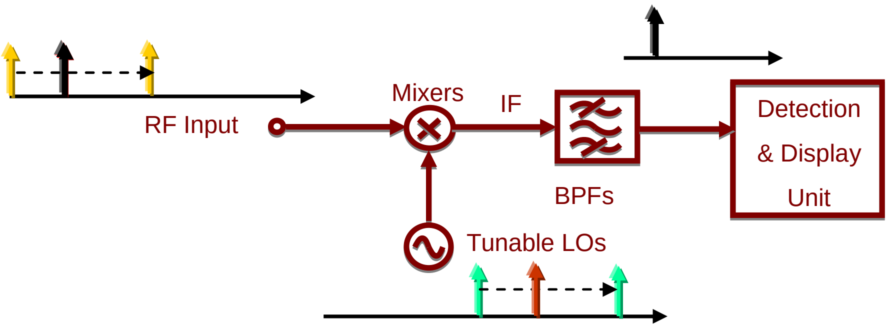
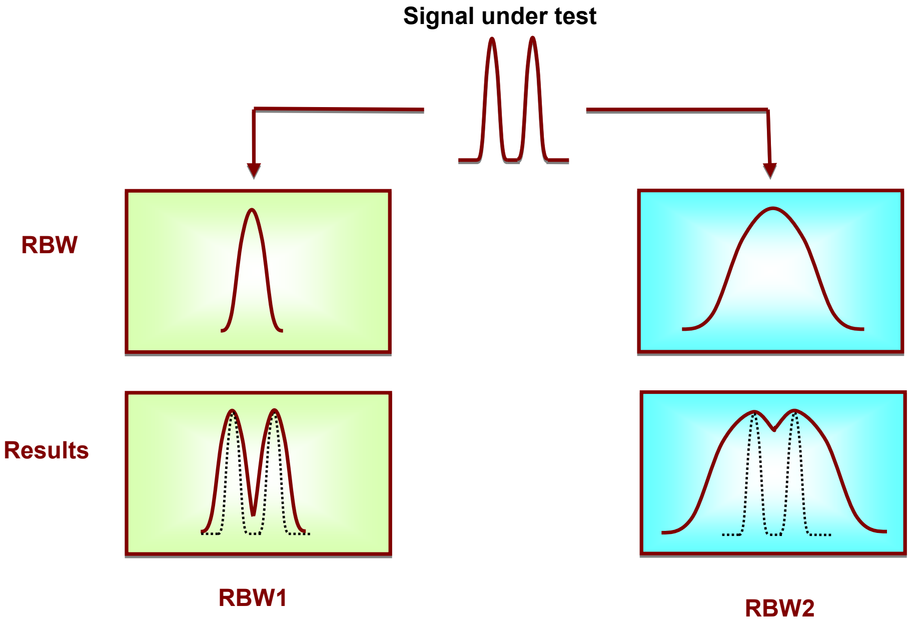


Figure B-4 shows how two different RBW filters distinguish between two signals that are close to each other in frequency. The bandwidth of RBW2 is wider that of RBW1.

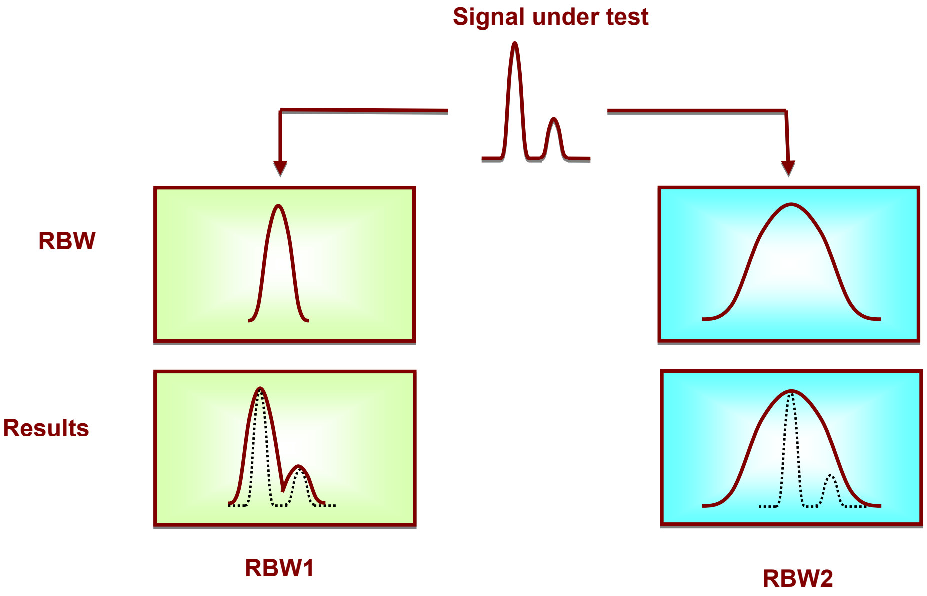
Figure B-4. The effect of different RBWs (1)



After passing the narrower RBW1 filter, the components of the two tone signal are clearly distinguished from each other as a result. But in the wider RBW2 filter, the result is not as clear as RBW1. We can predict that if the resolution bandwidth of RBW2 is wider, we could even misinterpret the result as only one signal. This will also happen if these two signals are even closer together in frequency.

Another case is when the amplitude of one signal is much higher than the other; the smaller signal can still be detected using RBW1, but it is obscured if RBW2 is used. Figure B-5 illustrates this difference. This is why these filters are known as resolution bandwidth filters.

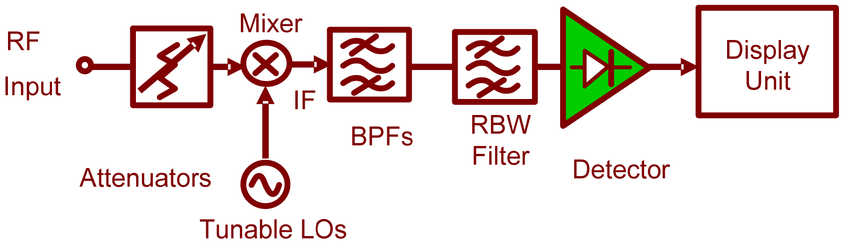
Figure B-5. The effect of different RBWs (2)



Detector

Following the RBW filter, the detector detects the power and coverts it to DC voltage via an ADC so that it can be displayed.

Figure B-6. Detector



Video Bandwidth Filter

However, a filter is employed after the detector to filter out the noise generated by the detector. This is the function of the VBW (video bandwidth) filter as shown in Figure B-7.

Figure B-7. VBW filter

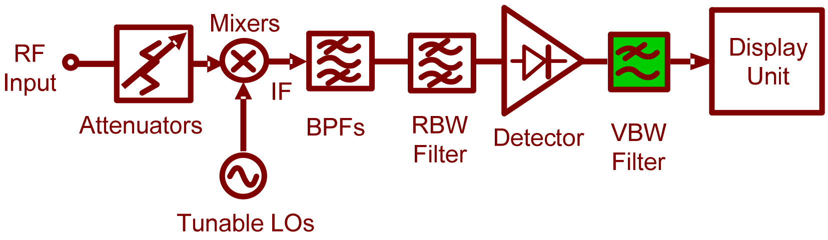
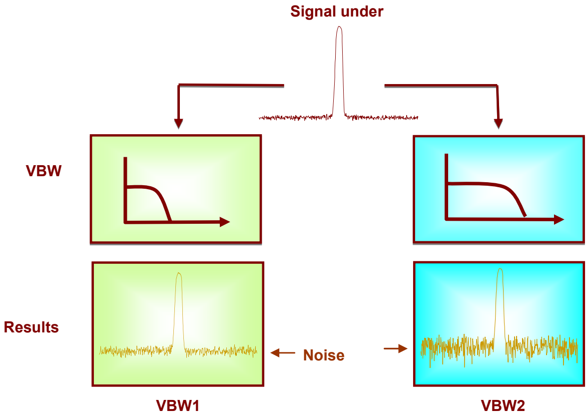


Figure B-8 shows how the VBW affects the displayed output. If the signal under test passes through two different VBW filters, in which VBW1 is less than VBW2, we can see that the magnitude of the noise floor of VBW2 is greater than that in VBW1. But notice that the average level of the noise floor remains the same. The VBW filter only averages the noise level; It doesn't affect the overall amplitude of the signal noise floor.

Figure B-8. Different VBWs



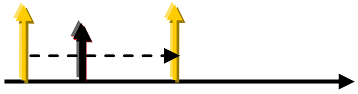
Superheterodyne Spectrum Analyzer*

For example, if the system needs to reduce the frequency of an input test signal from 2.4GHz (2400MHz, fRF) down to 20MHz, we need a local oscillator with a frequency of 2420MHz to be fed into the mixer, and then we will get two signals with a frequency of 4,820 MHz and 20MHz, respectively, from the output port. Because what we want is the 20MHz signal, the signals must past through a band pass (or low pass) filter to extract the 20MHz signal and exclude any other unwanted signals (including the 4820MHz signal). However, even though the frequency of the 4820MHz signal is high enough that it can't be processed, we still filter it out to avoid unnecessary noise. In addition, we can use a 2380MHz LO signal as well to generate a 20MHz IF signal. Because this will produce a 20MHz and a 4780MHz signal – we can also use the same method to filter out the unwanted 4780MHz signal.

Spectrum analyzers have a very wide input frequency range. For example, with a range of 500kHz to 3GHz, a tunable local oscillator needs to generate a signal that is suitable to shift the signal to a lower frequency. Using the same examples above, in terms of 2400MHz, we can let the local oscillator signal source be 2420MHz and produce a 20MHz IF signal. However this will make us run into a problem because the local oscillator signal of 2420MHz and the IF signal of 20MHz falls into the input frequency range (inside 500kHZ ~ 3GHz) of the spectrum analyzer. If the local oscillator signal or the IF signal falls into the input frequency range, more noise will be produced. This is as not all of the input signals are completely isolated at the mixer. The higher-order harmonic components from the mixer input and outputs would appear at the intermediate frequency IF output. Therefore the local oscillator frequency and the IF signal frequency must be greater than the input frequency. This type of receiver system is known as a superheterodyne receiver system.

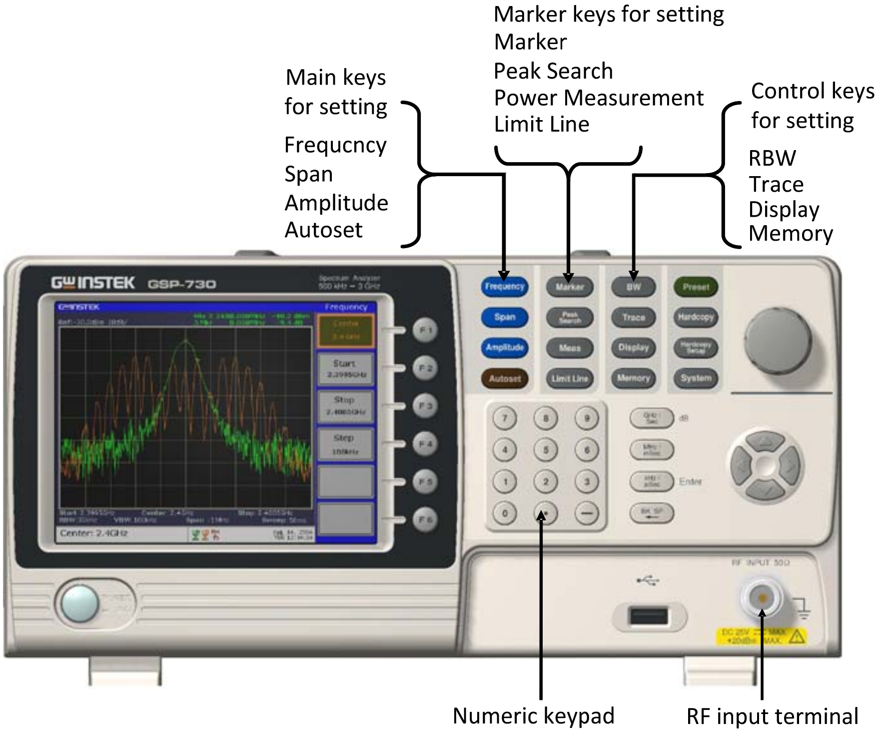
For example, if we design the IF signal to be equal to 3200MHz, when the input is 2400MHz, the local oscillator signal is equal to 5600MHz. An LO input of 5600MHz will produce a 3200MHz IF that we want as well as the inter-modulation frequency of 8000MHz (5600 +2400). In other words, regardless of whether the IF signal is 3200MHz (or 8000MHz), or the LO signal is 5600MHz, both will not become a source of noise in the input frequency range.

Those of you with sharp eyes may have noticed that in the example above that we still haven't shifted the input signal to a lower frequency! We shifted the input signal (2400MHz) to a higher IF (3200MHz), but why didn't we shift it to a lower frequency? As a spectrum analyzer is a broadband receiver, we must first shift the IF to a higher frequency and then shift the signal to a lower frequency in later stages. Therefore swept spectrum analyzers usually need several LO stages to convert the initial IF to the final IF.



RF COMMUNICATION and SIGNALS EXPERIMENTS

In this chapter we will explain the basic operating principals of a spectrum analyzer and introduce the measurement experiments. Prior to this, we will briefly explain how to operate the GW Instek GSP-730 spectrum analyzer. For more detail about its operation, please refer to the GSP-730 user manual.



Experiment 1: Basic Operation of a Spectrum Analyzer

Relevant information

In addition to the sky, oceans and forests, there is an invisible, intangible, inaudible and complex electromagnetic network in our living environment. This network is intertwined with wireless signals of various frequency bands. Although these signals are invisible and intangible, we can use a spectrum analyzer to understand and analyze these wireless signals.

In this experiment, the GSP-730 spectrum analyzer is used to capture some wireless signals in the environment. This experiment will help students to become familiar with using spectrum analyzers as well as to arouse their curiosity in the field of RF signals.

Experiment equipment

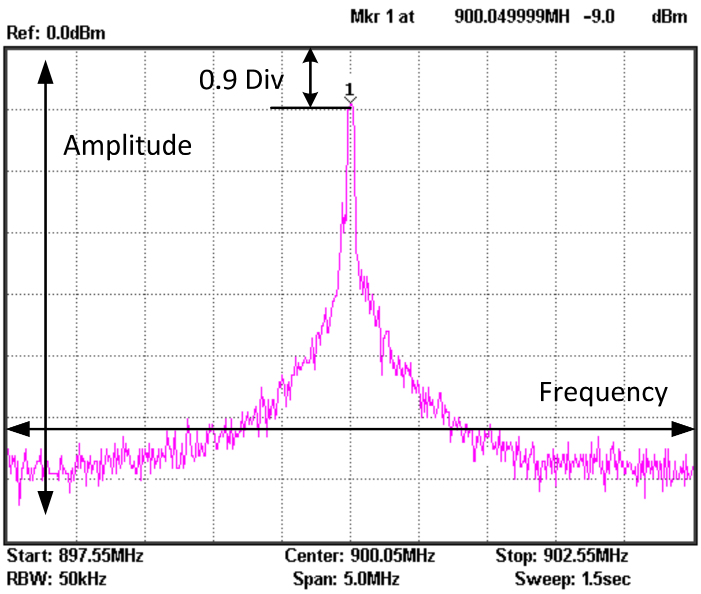
Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	Adapter	1	N-SMA
3	Antenna	1	800-1000MHz

Experiment goals

To become familiar with how to use the GSP-730 and how to use parameter settings such as frequency, amplitude and markers.

Experiment principles

Spectrum analyzers are mainly used to measure physical quantities such as the frequency and amplitude of a signal. For basic operation, the frequency range must be set first, then the reference level amplitude.



The figure above is a screen shot from a typical spectrum analyzer display. The horizontal setting is frequency and the vertical axis is amplitude. Therefore a spectrum analyzer is basically used to perform frequency and amplitude-related measurements. We can operate a spectrum analyzer by using the Frequency, Amplitude and other function keys in conjunction with the keypad to control the frequency, amplitude and other related settings.

The Frequency, Amplitude and Span keys as well as the keypad and unit keys.

There are two ways to set the frequency. If the frequency of the signal that you want to measure is known, then we can set the frequency using the center frequency and span functions. If we need to measure a frequency *range*, then we can set the start and stop frequency range.

Experiment contents

Connect the antenna to the GSP-730 spectrum analyzer to test the radio waves in the environment.

Experiment steps

1. Connect the antenna to the GSP-730 spectrum analyzer.

   Measure the strength of a mobile phone's transmitter signal. Because the frequency band of a mobile phone is between 800MHz - 1900MHz, we will set the frequency range between 800 - 1900MHz.

2. Set the GSP-730 as follows:

   - Start frequency: 800MHz,
     Stop frequency: 1900MHz
   - Reference level：-30dBm
   - RBW（RBW）：Auto

   Step1 Frequency F2 8 0 0 MHz/mSec Start 800.0MHz

   Step2 Frequency F3 1 · 9 GHz/Sec Stop 1.9GHz

   Step3 Amplitude F1 — 3 0 GHz/Sec Ref. Level -30.0dBm

Step4 BW F1 RBW Auto Man

3. Now we should see some signals on the spectrum analyzer screen. Identify the three highest peaks and write down their frequency values. The reference level can be used to adjust the strength of the signal.

4. As mobile phones use frequency hopping, we can use the Peak Hold function to hold the reading of the signal on the display screen. Record the frequency and amplitude of the signal.

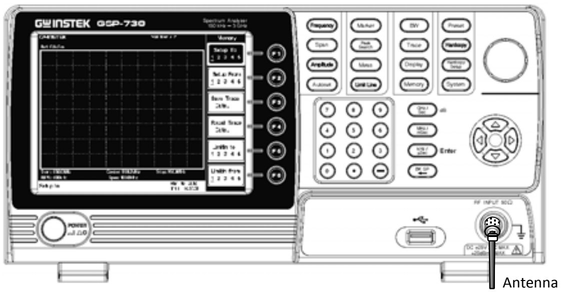
Step5 Trace F3 Peak Hold

5. Change the span to 5MHz. Set the center frequency to each of the above three frequency points in sequence so that you can observe each one more accurately. Record these three frequency points in Table 1-1.

Step6 Frequency F2
Set the center frequencies to each of the three frequency points

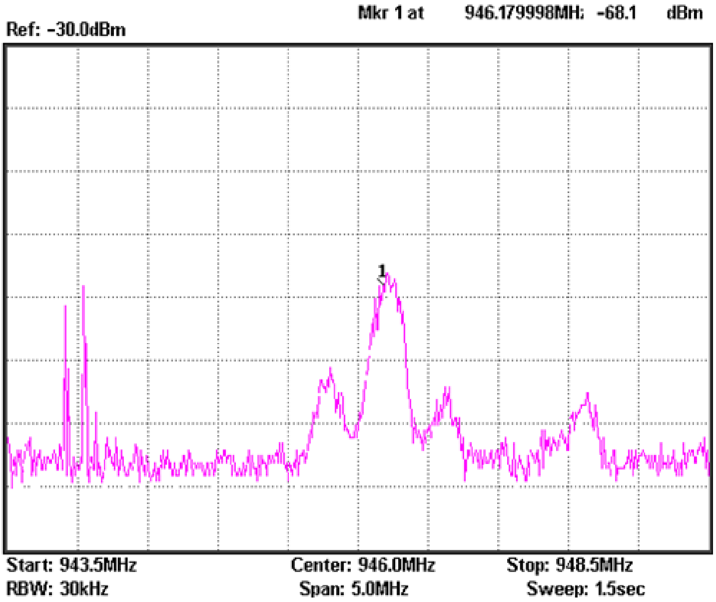
Step7 Span 5 MHz/ mSec Span 5.0MHz

6. Testing the wireless signals in the environment is shown in the picture below.

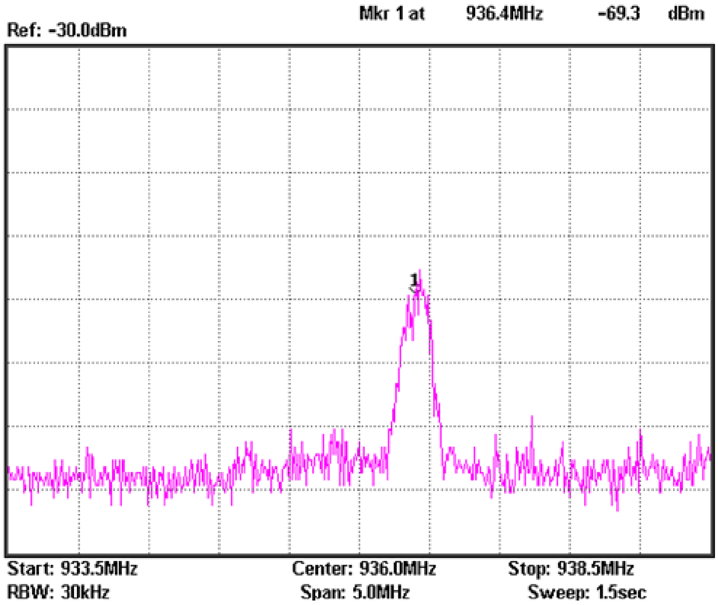


Experiment results

Table 1-1. Frequency and amplitude of mobile phone's transmitter signal.



Frequency: 946.17MHz
Amplitude: -68.1dBm



Frequency: 936.4MHz
Amplitude: -69.3dBm

Question In addition to the mobile phone signal, what other wireless signals can be measured in the environment?

Ans: There are various other wireless signals with different frequencies in the environment. For example, 80 ~ 108MHz FM broadcast signals.

Experiment 2: Measuring a Baseband Waveform

Relevant information

Relative to oscilloscopes, spectrum analyzers have many outstanding advantages. They are also the primary measurement tool for measuring frequency domain data. Learning how to use a spectrum analyzer is an essential skill that every student must master to gain RF knowledge.

By measuring a baseband signal, this experiment allows students to comprehensively understand how to operate a spectrum analyzer and lays the foundation for subsequent experiments.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	1	800mm
4	Adapter	1	N-SMA

Experiment goals

1. Measurement and analysis on a basic signal.
2. To understand how to use the GRF-1300A system to output a baseband signal.

Experiment principles

Set the GRF-1300A to output a 1MHz sine waveform and use the GSP-730 to measure its spectrum.

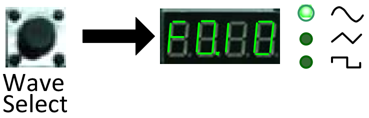
Experiment contents

Set and then measure the spectrum of a 1MHz sine wave. Measure the harmonic ratio at each of the harmonic frequencies.

Experiment steps

1. Turn on the GRF-1300A and the GSP-730.
2. Set the GRF-1300A baseband as follows:
   - Waveform: Sine wave
   - Frequency: 1MHz.
   - Turn the amplitude knob clockwise to its end.

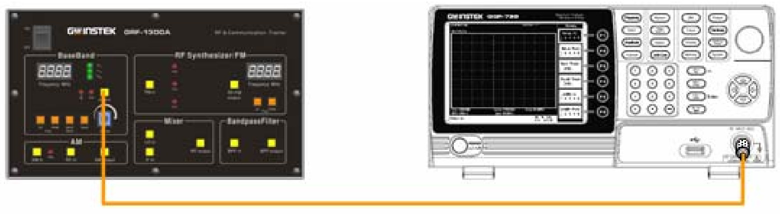
Step1



Step2

Step3 

3. Connect the baseband signal from the output port of the GRF-1300A to the input terminal of the GSP-730 using the RF wire.



4. Set the GSP-730 as follows:

   - Center frequency: 2.5MHz
   - Start frequency: 0kHz,
     Stop frequency: 5MHz
   - Reference level: 10dBm
   - RBW: Auto

Step1 **Frequency** F1 2 · 5 MHz/mSec **Center 2.5MHz**

When the first step is done, steps 2 and 3 (below) will have already been automatically set. Students may do steps 2 and 3 here is for reference only.

Step2 **Frequency** F2 0 MHz/mSec **Start 0.0kHz**

Step3 **Frequency** F3 5 MHz/mSec **Stop 5.0MHz**

Step4 **Amplitude** F1 1 0 GHz/Sec **Ref. Level 10.0dBm**

Step5 **BW** F1 **RBW Auto Man**

5. Utilize the Marker function on the spectrum analyzer to determine the harmonic ratio and draw the spectrum in Table 2-1.

Step6 **Peak Search**

After step 6 is done, make sure the "Delta" marker is used for the next steps and not the "Normal" marker. Set the Delta Marker to the peak point of each harmonic and make a record by drawing a simple sketch of the spectrum in table 2-1.

Step7 Marker F3 Mode Normal Delta 1 MHz/mSec

Step8 Marker F3 Mode Normal Delta 2 MHz/mSec

6. A function signal generator can also be used as a signal source in the above measurement, but be aware that the amplitude of the output signal can't be too high.

dBm is a power unit that is referenced to 1mW. The formula for X dBm = 10*log(Px/1mW)

Putting 10 mW into the above formula, we get 10 * log (10/1) = 10 * 1 = 10dBm. Similarly if we input 100 mW into the above formula, X = 10 * log (100mW/1mW) = 10 * 2 = 20dBm.

Because the output voltage of a signal generator is often used expressed as a voltage into a 50 ohm load, you must convert voltage to power. A few common values are listed below:

Converting Voltage to dBm: (into 50 ohm load)

Vpp (V)	Vm (V)	Vrms (V)	P (mW)	dBm
10.00	5.00	3.54	250.00	23.98
5.00	2.50	1.77	62.50	17.96
2.00	1.00	0.71	10.00	10.00
1.00	0.50	0.35	2.50	3.98

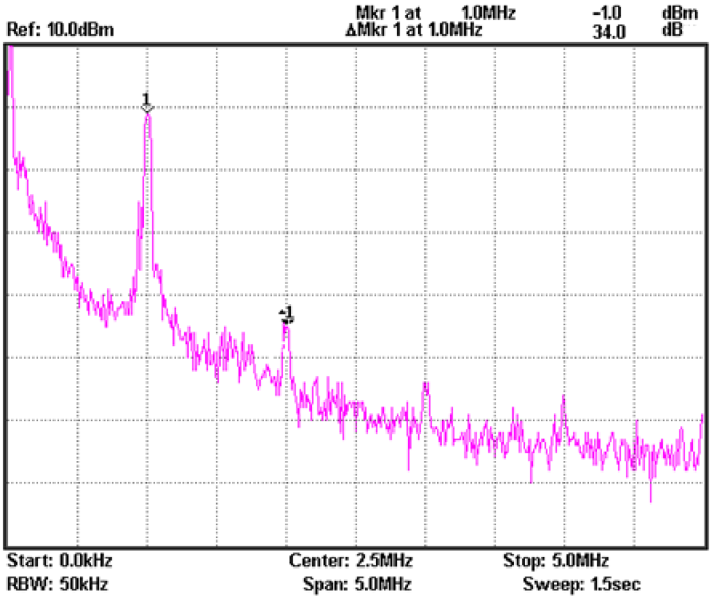
Converting dBm to Voltage: (into 50 ohm load)

dBm	P (mW)	Vrms (V)	Vm (V)	Vpp (V)
20.00	100.00	2.24	3.16	6.32
10.00	10.00	0.71	1.00	2.00
0.00	1.00	0.22	0.32	0.63
-10.00	0.10	0.07	0.10	0.20

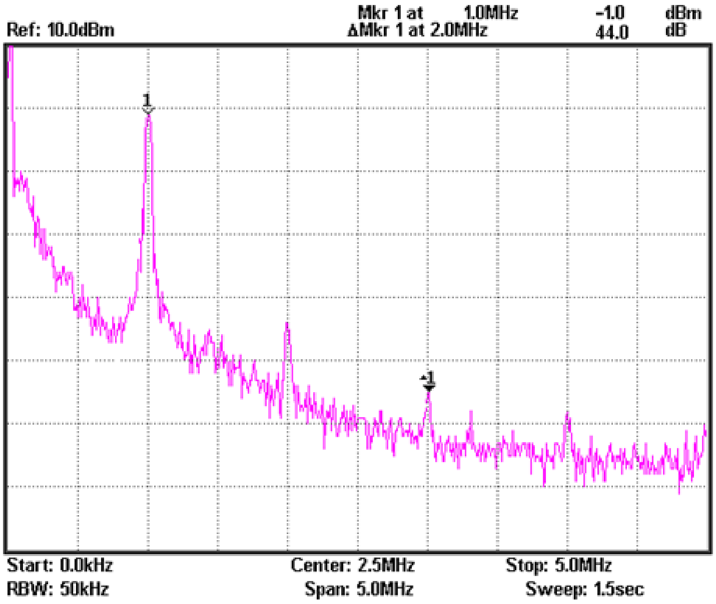
If voltage is measured without a load on an oscilloscope, the Vpp and Vm values should be multiplied by 2. For instance, when we get a measured value of 4Vpp into no load, it is the equivalent of 2Vpp into 50 ohms, or 10dBm after conversion.

Experiment results

Table 2-1. 1MHz sine wave spectrum test results



The 2nd harmonic ratio is: 34.0dB



The 3rd harmonic ratio is:44dB

Question

1. What is the spectrum of a theoretical sine wave and why is it different with the actual measured one?

   Ans: Theoretically the spectrum of a sine wave should only have one frequency. However, because the circuit that generates the sine wave has harmonic distortion, harmonics creep into the sine wave. For the reason above, its spectrum will have more than one frequency component when it is observed.

2. What is the frequency domain features of the analyzed signal?

   Ans: For complex signals, Fourier analysis can be used to decompose a signal into a number of sinusoidal components. Each sinusoidal component is characterized by its amplitude and phase. The amplitude and phase of each sinusoidal component is arranged in order of frequency to form a spectrum. Theoretically the sinusoidal components in the complex signal spectrum can be expanded to infinity. However, because the energy of the original signal is generally concentrated in the lower frequency range, components higher than a certain frequency are generally ignored in engineering applications.

Caution

1. The output power should not exceed the rated input of the spectrum analyzer, otherwise the spectrum analyzer will be damaged.

2. When using the RF cable to make a connection, be sure to tighten the connector.

Experiment 3: Different Baseband Waveforms and their Harmonic Measurement

Relevant information

You should already be familiar with electrical signals in general. We have already said that an oscilloscope is used to observe the amplitude of a waveform. In other words, it is used to observe how an electrical signal, X(t), varies over time. However, depending on what we are trying to study, the reason for measuring a signal can also be different. For example, when we analyze amplifiers, filters and mixers, we are no longer interested in measuring a function related to time, but a response function which can be characterized by frequency.

In this experiment, you will find that analyzing a signal in the frequency domain often has a lot of advantages compared to analyzing a signal in the time domain. You will also find that there is a relationship that exists between the time domain and the frequency domain, and will thus gain a better understanding of the theory behind the Fourier series.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	Oscilloscope	1	GDS-2204
4	RF wire	1	800mm
5	Adapter	1	N-SMA

Experiment goals

1. Measure the harmonic content that is output from the baseband signal.

2. Use the measurement results to verify the Fourier series theorem.

3. Understand the internal relationship between the time domain and the frequency domain in a signal.

4. Use this experiment to become familiar with how to measure the spectral characteristics of a typical signal, such as the amplitude and frequency.

Experiment principles

Set the waveform on the GRF-1300A and measure the harmonic spectrum. Switch to a different waveform and measure the harmonic spectrum. Compare the differences. The relationship between the time domain and the frequency domain has already been introduced in chapter 3. We won't repeat it again here.

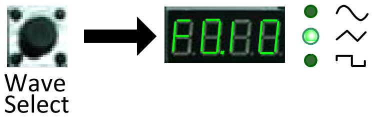
Experiment contents

We will become familiar with using a spectrum analyzer and how to use the GRF-1300A by analyzing the spectrum of a simple triangle and square wave signal.

Experiment steps

1. Turn on the GRF-1300A and the GSP-730.
2. Set the GRF-1300A baseband as follows:
   - Waveform: triangle
   - Frequency: 1MHz.
   - Turn the input amplitude knob clockwise to the end.

Step1



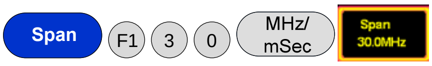
Step2

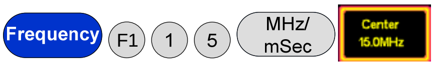
Step3

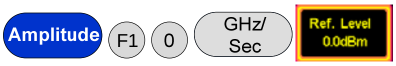
3. Connect the baseband signal from the output port on the GRF-1300A to the input terminal on GSP-730 with the RF cable.

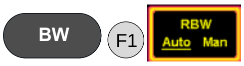
4. Set the GSP-730 as follows:
   - Center frequency: 15MHz
   - Start frequency: 0kHz,
     Stop frequency: 30MHz, Span: 30MHz
   - Reference level: 0dBm

- RBW: Auto

Step1 

Step2 

Step3 

Step4 

5. Observe the spectrum that appears. Use the Marker function on the spectrum analyzer to determine the harmonic ratio and draw the spectrum in Table 3-1.

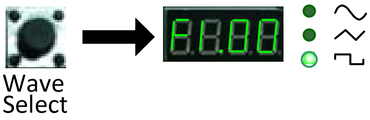
Step5 

After step 4 is done, make sure the "Delta" marker is used for the next steps and not the "Normal" marker. Set the Delta Marker to the peak point of each harmonic and make a record by drawing a simple sketch of the spectrum in table 3-1.

Step6 

Step7 

6. Select the square wave on the GRF-1300A Baseband module. Do the same spectrum measurements that were performed in the previous steps.

Step8 

7. Observe the square wave spectrum that appears on the spectrum analyzer. Use the marker function to record the harmonic ratio and draw the spectrum in table 3-3. Draw the spectrum of the square wave spectrum as you did previously for the triangle wave. Remember to remove the

delta marker (Δ-Marker) that was originally used with the

triangle wave.

Step9 

After the spectrogram on table 3-3 is drawn, measure the harmonic ratio of each harmonic using the following steps:

Step10 Marker F3 Mode Normal Delta 1 MHz/mSec

Step11 Marker F3 Mode Normal Delta 2 MHz/mSec

In accordance to the method that is used above to measure the harmonic ratio, students can try to measure the harmonic ratio of the higher order harmonics.

8. After measuring the spectrum, connect the output port to the input port of the oscilloscope and measure the time domain waveform of the triangle wave and square wave, and record the results in Table 3-2 and Table 3-4.

Experiment results

1. The measurement results of the time domain waveforms and the frequency domain spectrum for both the triangle and square waves.

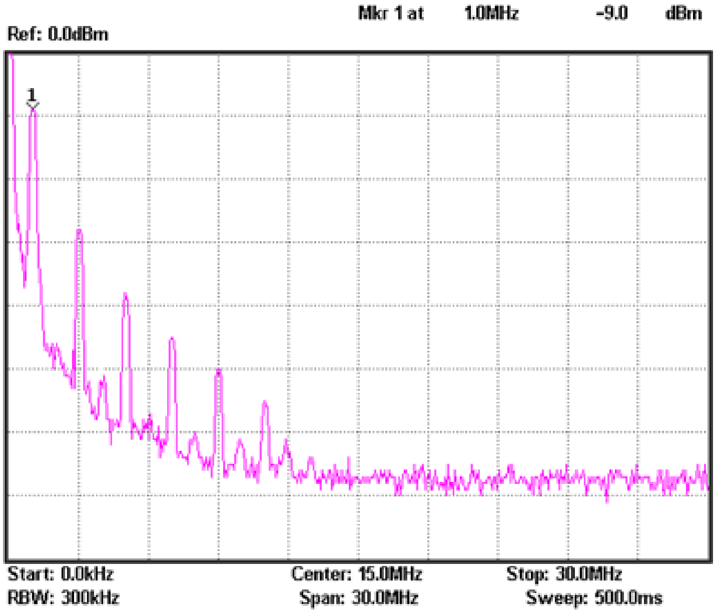


Table 3-1. 1MHz triangle wave spectrum test results.

Table 3-2. Time domain waveform of the 1MHz triangle wave.

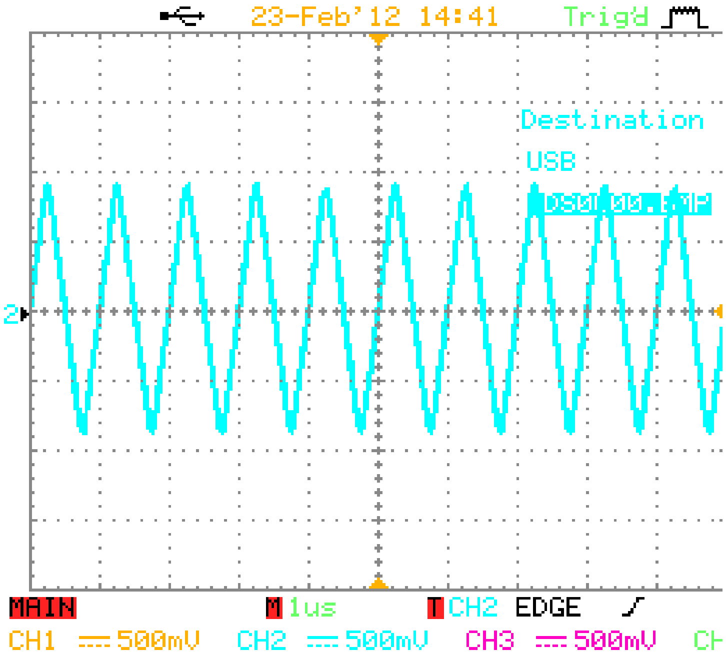
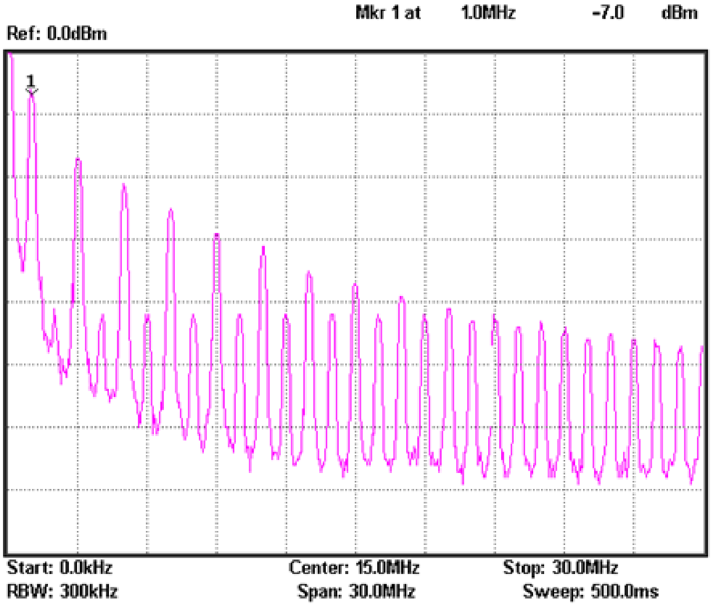


Table 3-3. 1MHz square wave spectrum test results.



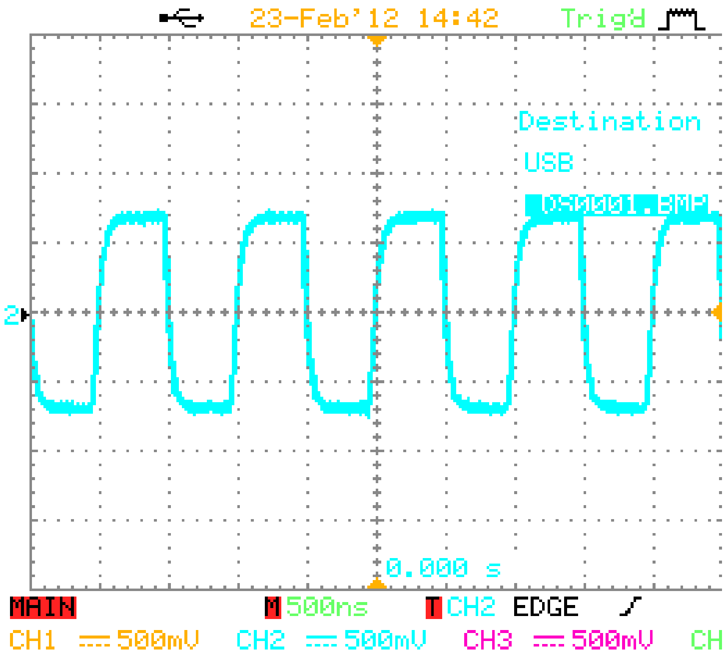
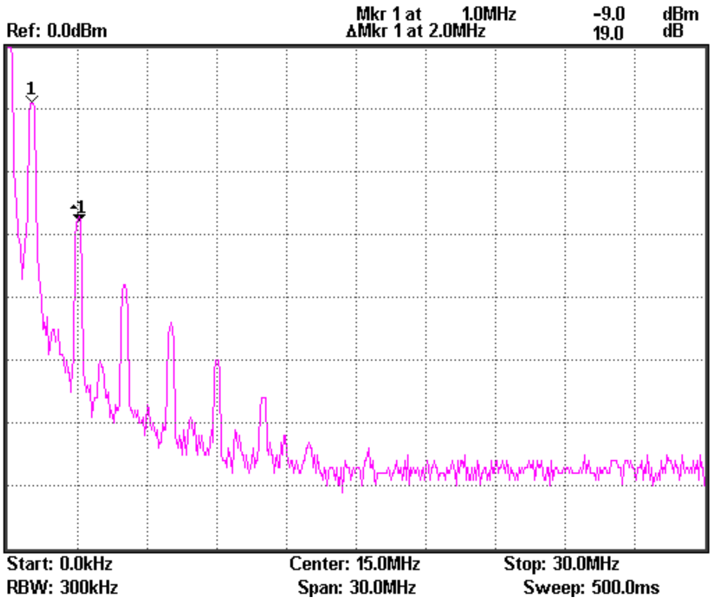


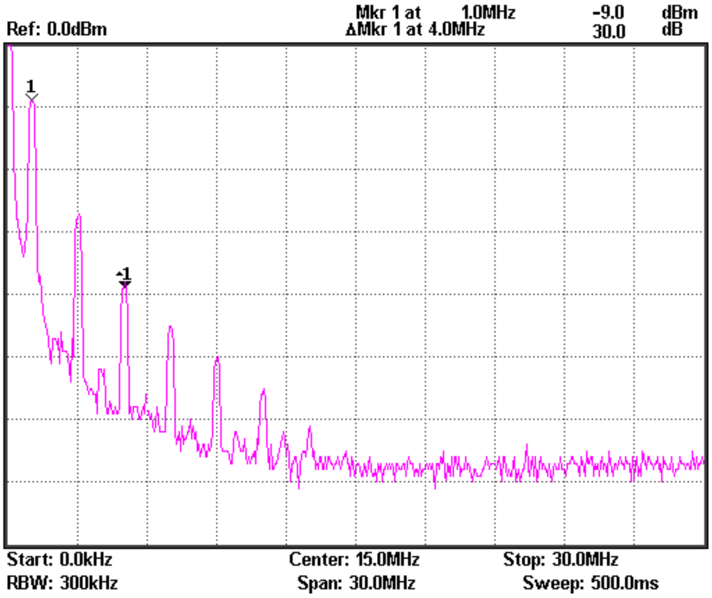
Table 3-4. Time domain waveform of the 1MHz square wave.

2. For the triangle waveform, measure the harmonic ratio of the 3rd and 5th harmonic. For the square waveform, measure the harmonic ratio of the 2nd and 3rd harmonic.

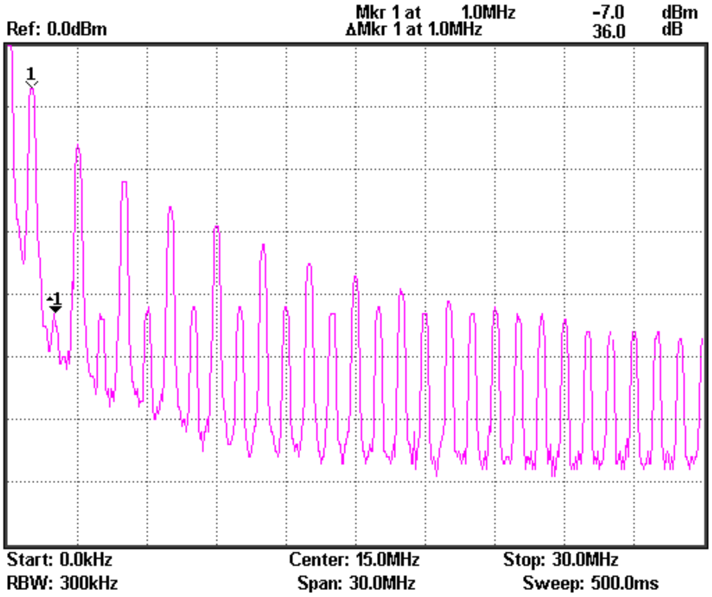
Harmonic ratio of the 3rd harmonic for triangle wave (19bB)



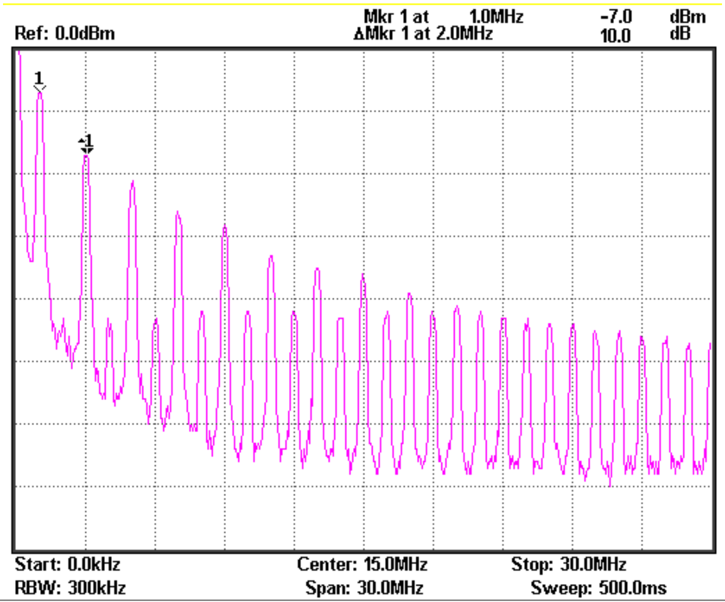
Harmonic ratio of the 5th harmonic for triangle wave (30bB)



Harmonic ratio of the 2nd harmonic for square wave (36.0dB)



Harmonic ratio of the 3rd harmonic for square wave (10dB)



Question

1. Compare the measurement results from the frequency domain and the time domain, and consider the relationship to the Fourier series theory.

   Ans: According to the Fourier theory, any periodic signal can be decomposed into a number of sine waves that are composed of a number of different frequencies.

   $$x(t) = \sum_{i=0}^{N} x_i \sin(\omega_i t + \phi_i)$$

   In the formula, $\omega_0 = 2\pi f_0$. ω_0 is known as the fundamental frequency (base frequency) and ω_i is an integer multiple of ω_0 (harmonics).

2. Analyze the difference between the triangle and square wave spectrum. Write their Fourier series in the form of a trigonometric function. What relationship do you find between each harmonic and each term in the series?

   Ans: Assume that a formula for a triangular wave function is: Because the trigonometric formula is an even function $\therefore b_n = 0$, then

   $$a_0 = \frac{1}{T}\int_{-T/2}^{T/2} x(t)\,\mathrm{d}t = \frac{1}{T}\cdot\frac{TA}{2} = \frac{A}{2}$$

   $$a_n = \frac{2}{T}\int_{-T/2}^{T/2} x(t)\cos n\omega_0 t\,\mathrm{d}t$$

   $$= \frac{4}{T}\int_{0}^{T/2} (A - \frac{2A}{T}t)\cos n\omega_0 t\,\mathrm{d}t$$

$$= \frac{4}{T}\int_0^{T/2}(-\frac{2A}{T}t)\cos n\omega_0 t\,\mathrm{d}t = -\frac{8A}{T^2}\int_0^{T/2} t\cos n\omega_0 t\,\mathrm{d}t$$

$$= -\frac{8A}{T^2}(\frac{t}{n\omega_0}\sin n\omega_0 t + \frac{1}{n^2\omega_0^2}\cos n\omega_0 t)\Big|_0^{T/2}$$

$$= \begin{cases} \dfrac{4A}{\pi^2 n^2} & n = 1,3,5... \\ 0 & n = 2,4,6... \end{cases}$$

Thus we obtain the Fourier series of the triangular wave.

$$x(t) = \frac{A}{2} + \frac{4A}{\pi^2}\sum_{n=1,3,\cdots}^{\infty}\frac{1}{n^2}\cos n\omega_0 t$$

If we take

$$x(t) = a_0 + \sum_{n=1}^{\infty} A_n \sin(n\omega_0 t + \phi_n)$$

,

then the amplitude of the N-th harmonic is

$$A_n = \sqrt{a_n^2 + b_n^2} = \frac{4A}{n^2\pi^2}$$

And the phase of the N-th harmonic is

$$\phi_n = \arctan\frac{a_n}{b_n} = \frac{\pi}{2}$$

Caution There are different ways to set the center frequency on a spectrum analyzer. Set it according to your needs.

Experiment 4: Measurement of the RF Carrier

Relevant information

In communication systems, RF signals generally use carrier signals. As a low frequency signal cannot be easily transmitted very far over air, the low frequency message (such as voice) must be placed into a higher frequency signal so it can be being transmitted over a distance using an antenna. This high-frequency signal carries the message, and is thus called the carrier. In this experiment we will perform basic measurements on RF signals and measure important parameters such as phase noise and harmonic distortion.

The carrier of this experimental system is generated by a PLL. Phase locked loops are widely used as phase-locked receivers, or for phase-locked frequency modulation and demodulation. They are also often used as a local oscillator for transmitters and receivers. We must learn in detail the working principles of PLL circuits when we study RF circuits. This experiment allows students to comprehend high frequency signals by measuring the carrier frequency spectrum. It also makes students recognize the basic structure of a PLL circuit. In the following experiments, we will further study the locked and unlocked conditions of a phase-locked loop.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	1	800mm
4	Adapter	1	N-SMA

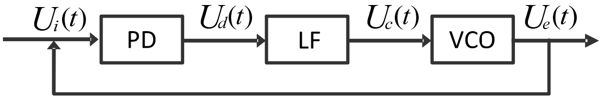
Experiment goals

Measure an RF signal from the GRF-1300A RF & Communication Trainer. Also perform measurements on more important parameters such as phase noise and harmonic distortion.

Experiment principles

A Phase locked loop (PLL) is a phase error control system. It compares the phase between a reference signal and an output signal to generate a phase error voltage for adjusting the frequency output of the voltage-controlled oscillator – for the purpose of synchronizing the output frequency with the reference signal. Its basic circuit structure is shown in Figure 4-1.

Figure 4-1. PLL circuit structure



Above: PD is the phase-locked loop phase detector, LF is the loop filter and VCO stands for voltage-controlled oscillator.

The purity of the output signal from the VCO is directly related to the phase noise. The lower the distortion of the output signal, the lower the harmonic components and noise contained in the output signal.

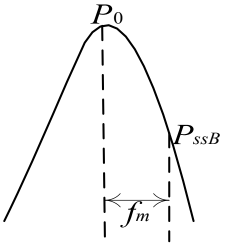
Phase noise is usually specified in dBc/Hz at a given frequency offset value, where dBc is dB in relation to the center frequency. The phase noise of an oscillator is normalized to the noise generated in a bandwidth of 1Hz. The phase noise is usually calculated using the formula below, where f_m is the frequency of a single sideband from the carrier and P_{ssB} is the measured sideband power:

$$L(f_m) = (P_{ssB} - P_0) - \log B + 2.5$$

where,

$B = 1.2RBW$ (RBW is the resolution bandwidth)

Figure 4-2. Phase noise definition



As the oscillator is a non-linear component, it will produce higher-harmonic content. Harmonic distortion is also an important factor for RF signals. In general we use a filter to filter this out.

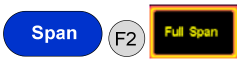
Experiment contents

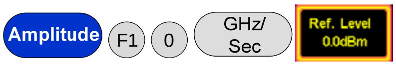
1. Measure the RF signal spectrum.
2. Measure the harmonic distortion of the RF signal.
3. Measure the phase noise of the RF signal.

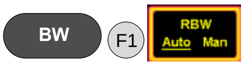
Experiment steps

Measure the RF signal spectrum and harmonic distortion.

1. Turn on the GRF-1300A and GSP-730. Leave the GRF-1300A in its power-on state.
2. Connect the RF/FM output port on the GRF-1300A to the input terminal on GSP-730 with the RF cable.
3. Set the GSP-730 as follows:
   - Span: Full Span
   - Reference level: 0dBm
   - RBW: Auto: Auto

Step1


Step2


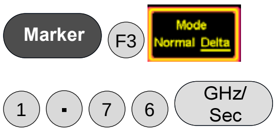
Step3


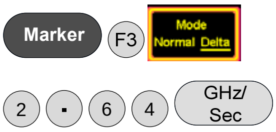
4. On the observed spectrum, use the marker function to measure the amplitude of each frequency point. The Next peak function can be used to find each consecutive peak. Plot the results in table 4-1.

Step4


Step5


5. Draw the results in table 4-1. The harmonic ratio of each the harmonic can be measured according to the following steps.

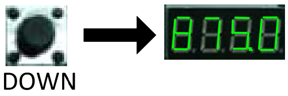
Step6


Step7


For the last two steps, the span is quite large, and may produce some errors. To find the second and third harmonic, you may need to fine-tune the frequency. Record the results in table 4-2.

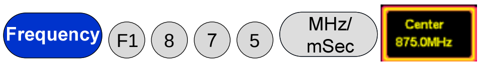
Measure the RF phase noise.

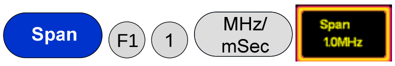
1. Turn on the GRF-1300A and the GSP-730.
2. Set the GRF-1300A RF Synthesizer/FM as follows:
   - Carrier frequency: 875MHz

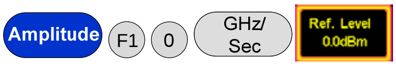
Step1 

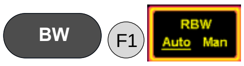
3. Connect the RF/FM output port on the GRF-1300A to the input terminal on GSP-730 with the RF cable.

4. Set the GSP-730 as follows:
   - Center frequency: 875MHz
   - Span: 1MHz
   - Reference level: 0dBm
   - RBW: Auto

Step1 

Step2 

Step3 

Step4 

Step5 

5. Record the carrier power. Set the deviation of the carrier frequency f_m to a deviation (∆) of 100kHz. Use the Delta marker function on the spectrum analyzer to measure the ∆ value.

Step6 Marker F3 Mode Normal Delta 1 0 0 kHz/uSec

Record the value, then calculate the phase noise according to the formula, and record the spectrum and measurement results in Table 4-3.

6. Adjust the PLL output frequency to 900MHz, and again measure the power and phase noise corresponding to the frequency.

Step7


Step8 Frequency F1 9 0 0 MHz/mSec Center 900.0MHz

Step9 Peak Search

Record the carrier power. Set the deviation carrier frequency

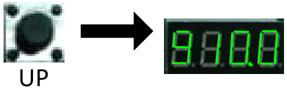
f_m to a deviation (∆) of 100kHz. Use the Delta Marker function

on the spectrum analyzer to measure the ∆ value.

Step10 Marker F3 Mode Normal Delta 1 0 0 kHz/uSec

Record the value, then calculate the phase noise according to the formula, and record the spectrum and measurement results in Table 4-3.

7. Adjust the PLL output frequency to 910MHz, and again measure the power and phase noise corresponding to the frequency.

Step11


Step12 Frequency F1 9 1 0 MHz/mSec Center 910.0MHz

Step13 Peak Search

Record the carrier power. Set the deviation carrier frequency

f_m to a deviation (△) of 100kHz. Use the Delta Marker function

on the spectrum analyzer to measure the △ value.

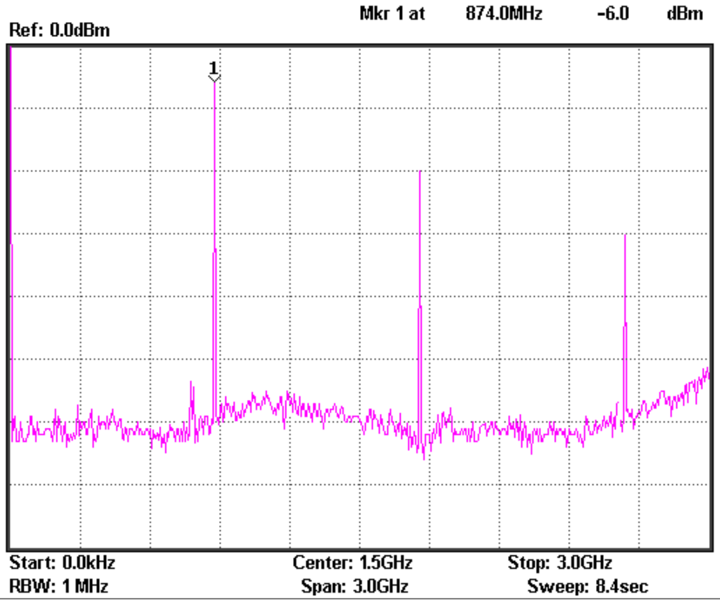
Step14 Marker F3 Mode Normal Delta 1 0 0 kHz/ uSec

Record the value, then calculate the phase noise according to the formula, and record the spectrum and measurement results in Table 4-3.

Experiment results

1. Measurement of the RF signal spectrum.

Table 4-1. RF Signal Spectrum



2. RF Signal Harmonic measurements

Table 4-2 2nd Harmonic measurement(14 dB)

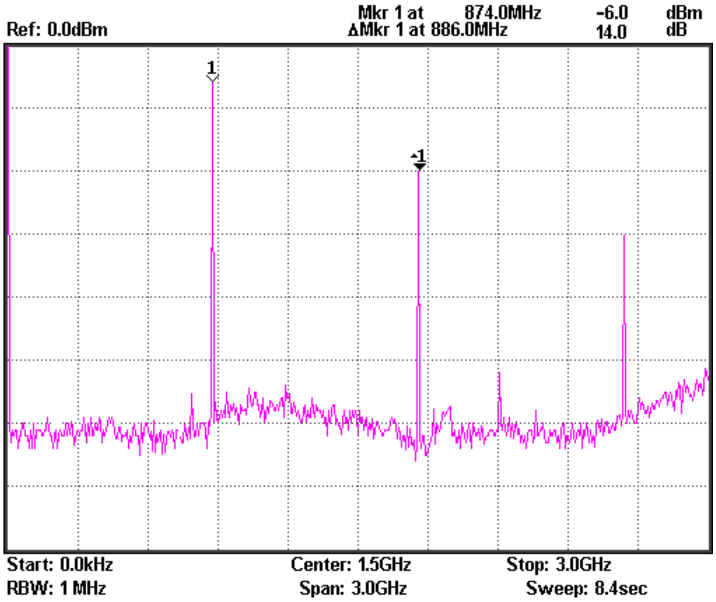
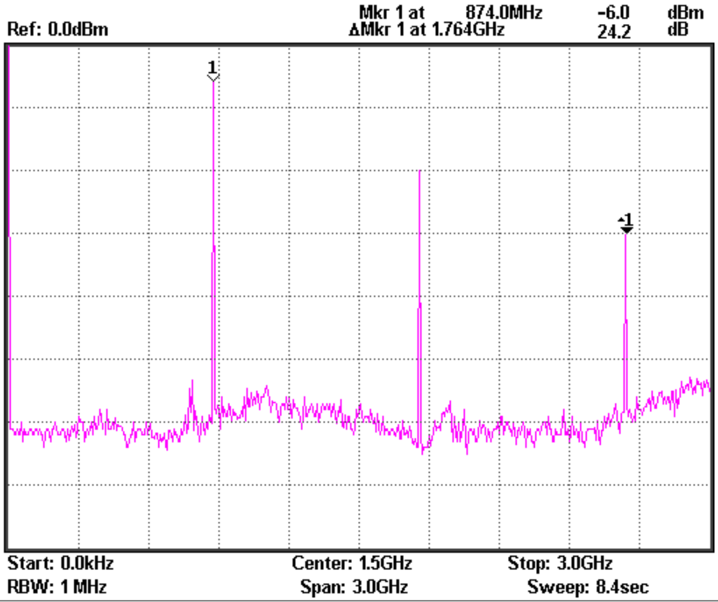
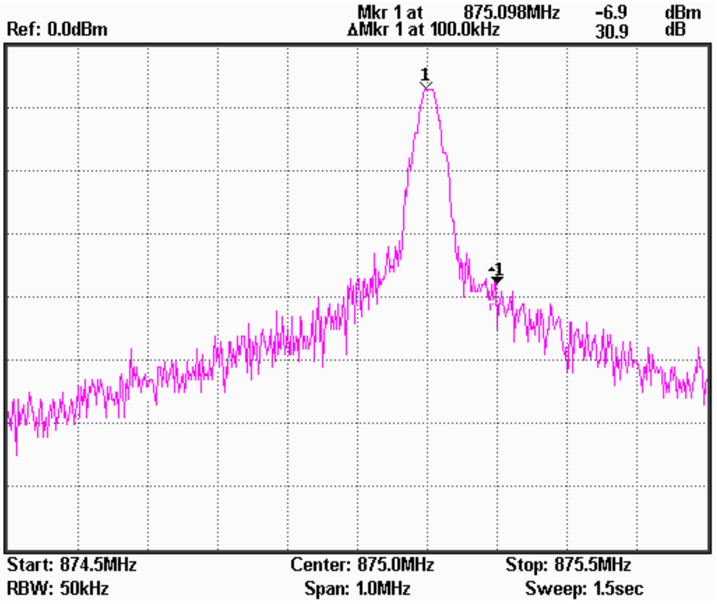


Table 4-2 3rd Harmonic measurement(24.2dB)

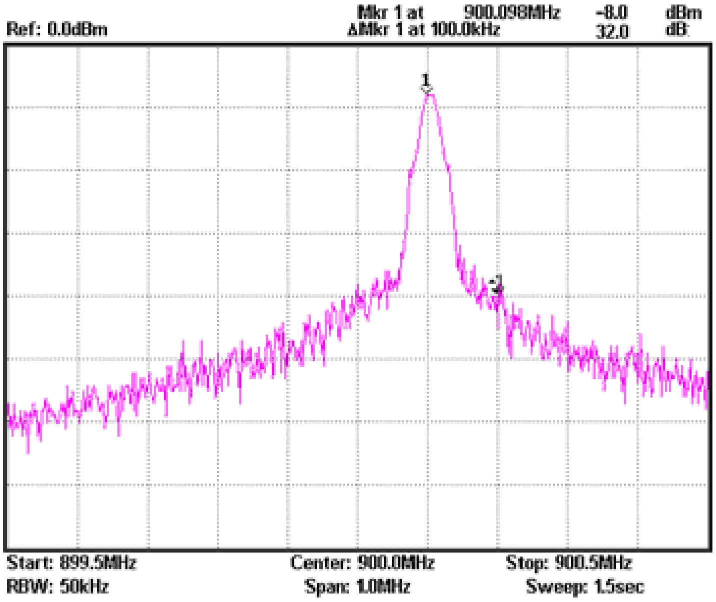


3. Phase noise measurement results

Table 4-3. Phase Noise measurement results

Carrier Frequency	Experiment results
875MHz	 Carrier frequency:875.09MHz Output power: -6.9dBm Phase noise: -30.9-10lg（1.2*50000）+2.5=-76.18dBc/Hz（100KHz）

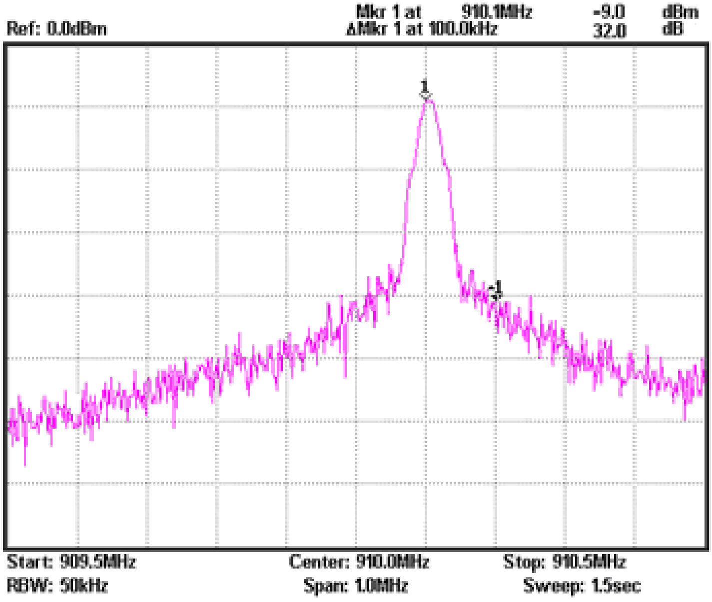
900MHz



Carrier frequency:900.09MHz Output power: -8.0dBm

Phase noise: -32-10lg(1.2*50000)+2.5=-77.28 dBc/Hz(100KHz)

910MHz



Carrier frequency:910.1MHz Output power: -9.0dBm

Phase noise: -32-10lg(1.2*50000)+2.5=-77.28 dBc/Hz(100KHz)

Questions

1. A PLL circuit is formed by which parts? Explain the function of each part.

   Ans: A Phase-locked loop is mainly composed of the phase detector, loop filter and voltage controlled oscillator (VCO). The phase detector is primarily responsible for detecting a phase error between the input reference signal and the output signal from the VCO. The output signal from the phase detector, after passing through the loop filter to filter out the high-frequency signals and noise, is sent to the VCO to adjust the oscillator output frequency. When the frequency and phase of the output signal from VCO is different to that of the reference signal, the process above will keep going until the frequency and phase of the VCO output signal are the same as that of the reference signal.

2. What are the advantages of a PLL?

   Ans: There will be no difference in frequency when the loop is locked. PLLs feature good narrowband tracking; A PLL can filter out the noise at the same time as locking the carrier signal to achieve the role of a narrowband filter. A PLL is essentially a nonlinear system. It also has a threshold effect when influenced by strong noise. However, when it is used as an FM demodulator, the threshold performance can be better than circuits that use a limiter and a discriminator. Therefore, a PLL can phase track the VCO phase input, while also having a good filtering effect on noise.

3. Explain the causes of phase noise? How can we improve phase noise?

   Ans: In the output signal of the oscillator, noise is generated mainly from the transistors and passive circuits. Since the oscillator is a non-linear element, the voltage and current levels of the noise is changing with the oscillator all the time. To improve the phase noise, firstly select active elements with a low-noise index, and secondly select resonance circuits with a high Q factor.

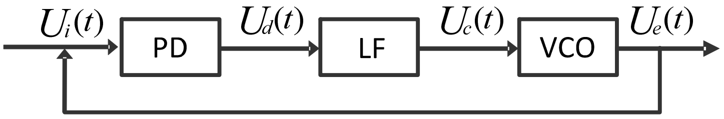
Caution Be sure to tighten the connectors when connecting the RF cable.

Phase Locked Loop *

Experiment principles

A Phase locked loop (PLL) is a phase error control system. It compares the phase between a reference signal and an output signal to generate a phase error voltage for adjusting the frequency of the VCO – for the purpose of synchronizing the VCO with the reference signal. Its basic circuit structure is shown in Figure 1.

Figure 1. PLL circuit structure



Above: PD is the phase-locked loop phase detector, LF is the loop filter and VCO stands for voltage-controlled oscillator.

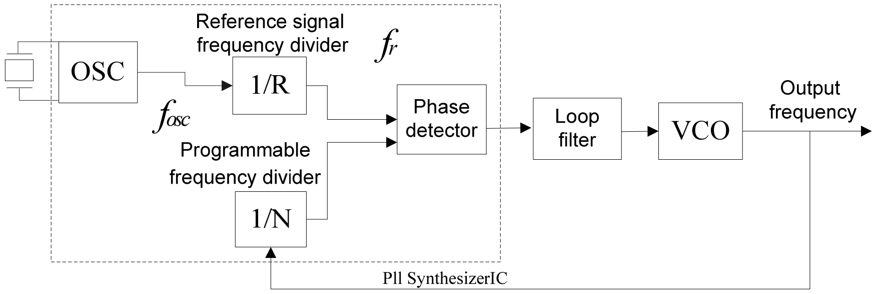
The phase detector is responsible for receiving the reference signal Ui (t) and the VCO output signal Ue (t), and outputs a phase error signal Ud (t). The phase error signal then goes through a loop filter to filter out the high-frequency signal components and noise. The filtered voltage is a DC voltage, Uc (t), that is then fed to the VCO to control the oscillator output signal frequency. When the frequency and phase of the VCO output signal and the reference signal are not the same, this process will continue until the VCO output signal frequency and phase is the same as the reference signal. The reference signal and VCO output signal divide their frequency to a lower frequency via their respective frequency dividers. These frequencies are then compared by the phase detector. As low frequencies are used for the comparison, digital circuitry can be used for the phase detector.

Phase detectors and frequency dividers can be made as integrated circuits, reducing the volume of a PLL circuit. This experimental system uses the phase locked loop from an integrated circuit.

1. Phase detector

To understand a phase detector, we will first look at the structure of a phase detector in a PLL using a practical application.

Figure 2. Practical application of a PLL



The frequency that is output from the reference signal frequency divider and the programmable divider are input into the phase detector. The phase detector contains two D flip-flops, two transistor switches, a charging circuit, an inverter and an AND gate. Each D flip-flop has a CK clock signal and a CLR clear signal. The reference signal U1 is input into the CK input of the top D flip-flop, and the U2 input is input into the CK input of the bottom D flip-flop. The output from both of the two D flip-flop outputs, for the UP and DN output respectively, make up the phase detector output Ud. The UP, DN, and output states of the D flip-flops are as shown in Table 1. When the UP and DN signals are both a logical "1", both the D flip-flops will be turned off due to the AND gate. This will also prevent both of the transistors from turning on at the same time and thus prevent the power (VCC) from shorting directly to ground.

Figure 3. Phase detector schematic

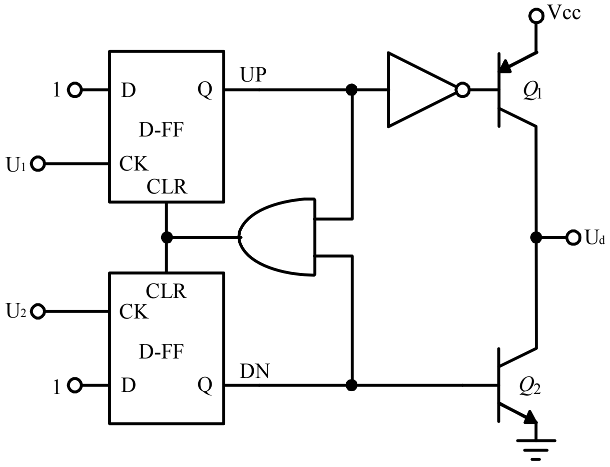
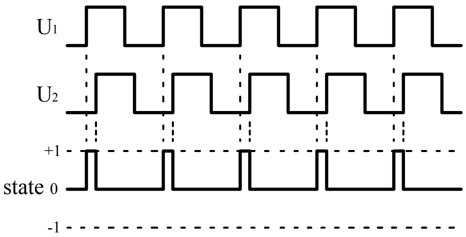


Table 1. The UP, DN and output state relationship

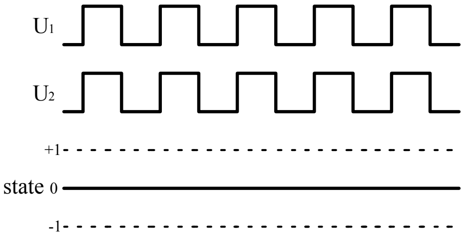
UP	DN	Q_1	Q_2	U_d	State
0	0	OFF	OFF	High impedance	0
0	1	OFF	ON	GND	-1
1	0	ON	OFF	Vcc	1
1		1		Reset Up and DN zero	

Based on the table above, we can see what the output state is of U_d when U_1 and U_2 have different phases. Figure 3-4 illustrates the output state of U_d.

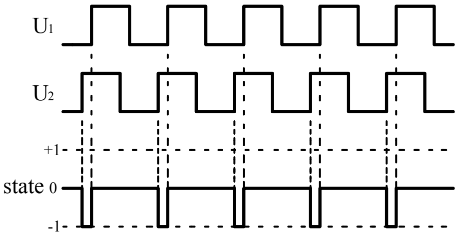
Figure 4. Ud output state with different input phases.



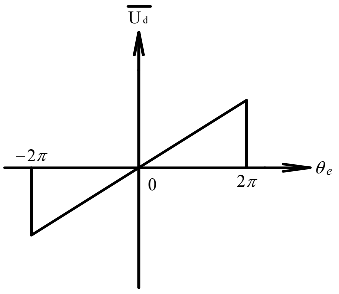
U1 phase leads U2 phase



U1 has the same phase as U2



The U1 phase lags U2 the phase



Graph of how Ud changes with phase

2. The voltage-controlled oscillator (VCO)

The voltage-controlled oscillator (VCO) is an oscillator in which its output signal frequency varies with a change of the input voltage. It can also be used as a voltage frequency converter, a frequency sweep signal generator or even as a frequency modulator. Frequency modulation in this experiment uses the VCO, making it an important part of the PLL. The VCO can achieve voltage-control in two ways:

(1) By directly changing the values of the oscillation circuit components (R, L, C), which will determine the oscillation frequency.

(2) Control the charge or discharge of the current or the voltage of the timing components in a multivibrator.

This experiment uses voltage-controlled components. A voltage-controlled diode is used to change the capacitance value of the oscillation circuit which changes the oscillation frequency.

In the oscillator output signal, noise is generated from the transistors and passive circuit elements. As the oscillator is a non-linear element, the voltage and current noise that is generated will vary with changes in the oscillation frequency. Phase noise affects the spectral purity of the oscillator. Phase noise and jitter are two related quantities associated with the same event. Ideally, the fixed frequency of a perfect pulse signal (1 MHz for example) should be exactly 1 microsecond with a transition every 500ns. Unfortunately however, the perfect signal does not exist. As the period between each pulse varies, the arrival time of each successive pulse is uncertain. This uncertainty is the phase noise, which could also be considered as jitter.

3. Loop Filter

The loop filter (LF) is used to filter out the high frequency components and noise in the output signal from the phase detector so as to leave only a DC signal and use this DC signal to control the output frequency of the VCO. Therefore, the loop filter is actually a low pass filter.

Take into consideration why a loop filter is actually needed. A loop filter is mainly used to provide a DC voltage for the VCO to control its output frequency. If you temporarily ignore the effect of the loop filter in the phase-locked loop system, you would need to reduce the bandwidth as much as possible in the PLL design so that its output voltage is as close to DC as possible. But if the bandwidth is too small, it will cause the locking time to be prolonged so much that the system can’t even go into the locked state. In actual circuit applications, we could consider adding a group of ripple filters to the low pass filter, which would give even greater high frequency signal attenuation and bring the output signal closer to a DC voltage level.

Experiment 5: AM Signal Measurement

Relevant information

Message signals are usually of a low frequency. In general, these low frequency signals are not appropriate for transmission. Therefore, modulation is required to transmit messages for communication and test systems. Modulation is a signal adjustment method used in signal transmission. It is used to modulate a low frequency signal which carries information with a signal of an appropriate frequency. This is used to solve problems associated with the amplification and transmission of weak signals. The role of modulation in RF communication systems is essential. Not only is modulation used to modulate the original low-frequency signal and its transmission, but it is also used for frequency division multiplexing (FDM). If signals with the same frequency range are transmitted on the same channel at the same time, they can easily interfere with each other, and hence why they are first modulated onto different carriers so that multiple signals can be transmitted simultaneously. These experiments start with amplitude modulation. The spectrum analyzer is used to measure the characteristics of AM signals, which has a great significance for students to master FM as well as AM principles and characteristics.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	2	100mm
4	RF wire	1	800mm
5	Adapter	1	N-SMA

Experiment goals

1. Learn the working principals of amplitude modulation.
2. Use the spectrum analyzer to measure the AM characteristics of an RF signal.

Experiment principles

Modulation is the process of moving a low-frequency signal to a high-frequency and then transmitting the high-frequency signal. Generally the low frequency signal carrying the original information is called the modulating signal or baseband signal. The high-frequency signal is known as the carrier signal. After the carrier signal is modulated by the modulating signal, the resultant signal is called the modulated wave. There are three kinds of modulation methods that are used: AM, FM and phase modulation.

This experiment begins with AM to learn some modulation theory. AM uses the modulating signal to control the amplitude of the high-frequency carrier signal. The modulating signal is used to alter the amplitude of the carrier in proportion to the amplitude of the modulating signal. A high frequency carrier signal that is amplitude modulated is called an AM wave. AM waves are divided into ordinary AM waves, double-sideband AM waves with suppressed carrier transmission and single-sideband AM waves with suppressed carrier transmission.

1. The formula to express the modulated waveform is as follows:

   Assuming that the modulating signal is a sine wave of a single frequency ($\Omega=2\pi f_\Omega$)

   And
   $u_\Omega(t) = U_{\Omega m} \cos\Omega t = U_{\Omega m}\cos 2\pi f_\Omega t$ (5.1)
   then the carrier signal is
   $u_c(t) = U_{cm} \cos\omega_c t = U_{cm}\cos 2\pi f_c t$ (5.2)

   Because the carrier frequency remains unchanged after amplitude modulation and the amplitude of an AM wave is proportional to the modulating signal, therefore, the modulated wave can be expressed as below:

   $u_{AM}(t) = U_{AM}(t)\cos\omega_c t = U_{cm}(1+m_a\cos\Omega t)\cos\omega_c t$ (5.3)

   To simplify the analysis, we set the initial phase angle of both waveforms to zero. In formula (5.3), m_a is known as the degree of AM modulation or the AM modulation index.

   Namely, $m_a = \dfrac{k_a U_{\Omega m}}{U_{cm}}$

   This equation indicates to what degree the carrier amplitude is controlled by the modulating signal. The constant k_a is a proportional constant determined by the modulation circuit. The AM modulation index should be less than or equal to 1. When the AM modulation index is greater than 1, it is called over modulation and will distort the modulated signal.

   We can see from this that the AM wave also oscillates at a high frequency. Its amplitude varies regularly (envelope changes) and is proportional to the modulating signal.

Therefore, the information in a modulating signal is carried in the amplitude of an amplitude modulated wave. The following figure shows how a signal changes from a carrier signal (unmodulated state) to an AM wave (modulated state).

Figure 5-1. A diagram showing how an unmodulated carrier signal undergoes the process of modulation.

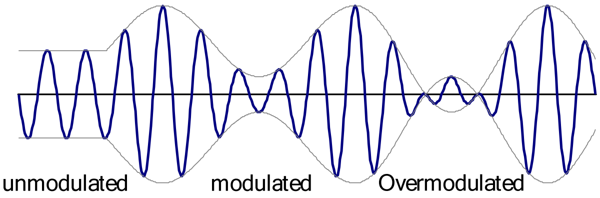
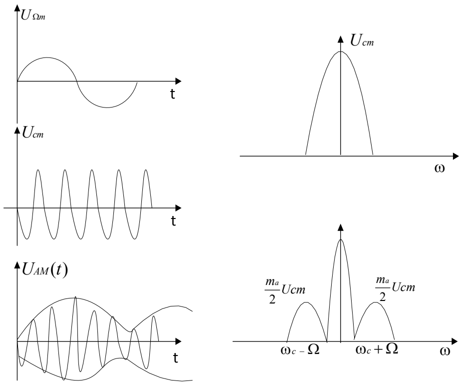


Figure 5-2. AM waveform in the time domain and the frequency domain



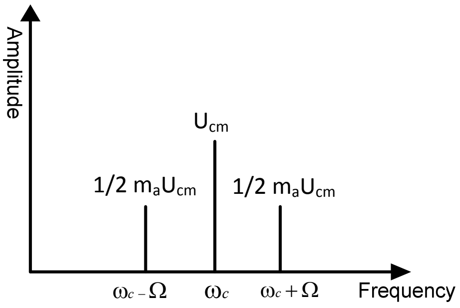
2. AM Wave Spectrum

Expand formula (4.3) to get the following formula:

$$u_{AM}(t)=U_{cm}\cos\omega_c t+\frac{1}{2}m_aU_{cm}\cos(\omega_c+\Omega)t+\frac{1}{2}m_aU_{cm}\cos(\omega_c-\Omega)t$$

As can be seen here, a single modulated audio signal consists of three high frequency components. In addition to the carrier, two new frequency components (ω_c+Ω) and (ω_c - Ω) are included. One is higher than ω_c, known as the upper sideband, and the other is lower than ω_c, known as the lower sideband. Its spectrum is shown in Figure 5-3.

Figure 5-3. Spectrum of an AM wave



From the above analysis, we can understand that amplitude modulation is a process of shifting a low frequency modulating signal into the sideband of a high frequency carrier. Obviously, in AM waves, the carrier does not contain any useful information. Information is only included in the sidebands.

Experiment contents

1. Measure the waveform and spectrum of an AM wave.
2. Measure the spectrum of the AM wave with different carrier frequencies and with modulating signals with different amplitudes.

Experiment steps

1. Turn on the power to the GRF-1300A and GSP-730.
2. Set the GRF-1300A as follows:
   - Set the GRF-1300A to the default power-on state.
   - Connect the output port on the Baseband module to the AM in port on the AM module with an RF cable.
   - Connect the RF/FM output port on the RF Synthesizer/FM to the RF in port on the AM module with an RF cable.
   - Turn the potentiometer clockwise to the end.
3. Connect the AM output port to the input port of the spectrum analyzer with the 800mm RF cable.

4. Set up the GSP-730 as follows:
   - Center frequency:880MHz
   - Span: 5MHz
   - Reference level: 0dBm
   - RBW: Auto

Step1 Frequency F1 8 8 0 MHz/mSec Center 880.0MHz

Step2 Span 5 MHz/mSec MHz/mSec Span 5.0MHz

Step3 Amplitude F1 0 GHz/Sec Ref. Level 0.0dBm

Step4 BW F1 RBW Auto Man

5. Use the Marker function to measure the carrier component of the AM wave on the spectrum analyzer and the power of the upper and lower sidebands. Use the oscilloscope to measure the voltage at TP4 in relation to the position of the potentiometer (i.e., the modulating amplitude). Draw the spectrum diagram in Table 5-4.

Step5 Peak Search

Step6 Marker F3 Mode Normal Delta 1 0 0 kHz/uSec

6. Turn the potentiometer counterclockwise to the half-way mark. Measure the voltage with the oscilloscope. By changing the output amplitude of the modulating signal, can you observe any change in the spectrum? Record the experiment in Table 5-4.

7. Turn the potentiometer counterclockwise to decrease the output voltage. Measure the voltage with the oscilloscope. Observe any changes in the spectrum of the AM wave and record it in Table 5-4.

8. Turn the potentiometer clockwise to the maximum. Adjust the UP button on the Baseband module to adjust the frequency of modulating signal. Do you see any change in the AM wave spectrum? Compare the experiment results with that of the original baseband frequency of 100kHz and record it to Table 5-5.

Step7


Step8 Marker F3 Mode Normal Delta 3 0 0 kHz/uSec

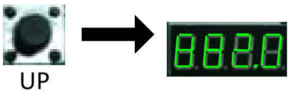
9. Use the UP button on the Baseband module to adjust the frequency of the modulating signal. Do you see any change in the AM wave spectrum? Record the result in Table 5-5.

Step9


Step10 Marker F3 Mode Normal Delta 6 0 0 kHz/uSec

10. After completing the experiment steps above, press the Reset button, and then use the UP button on the RF Synthesizer/ FM module to change the frequency of the carrier signal. Is there is any change in the AM wave spectrum? Compare the experiment result with that of the original carrier frequency of 880MHz and record it to Table 5-6.

Step11 
Reset

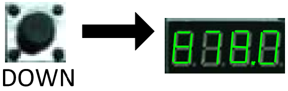
Step12 

UP

Step13 Peak Search

Step14 Marker F3 Mode Normal Delta 1 0 0 kHz/ uSec

11. Use the DOWN button on the RF Synthesizer/FM module to change the frequency of the carrier signal. See if there is any change to the AM wave spectrum and record it Table 5-6.

Step15 

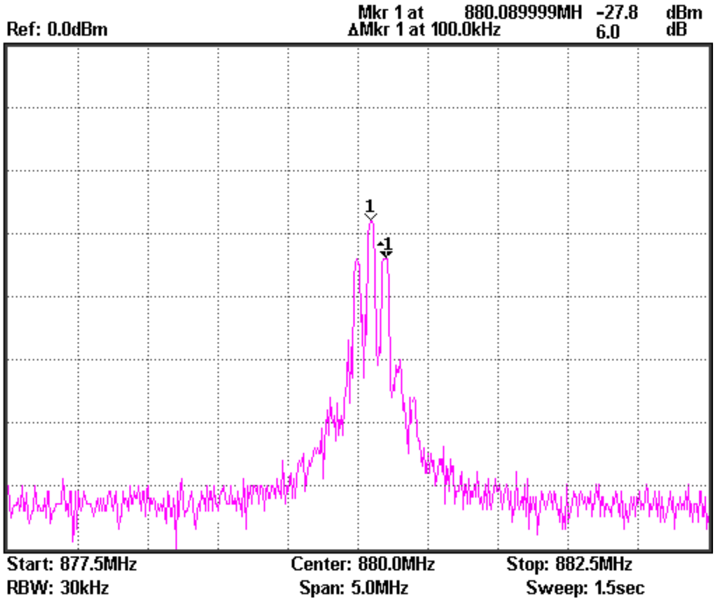
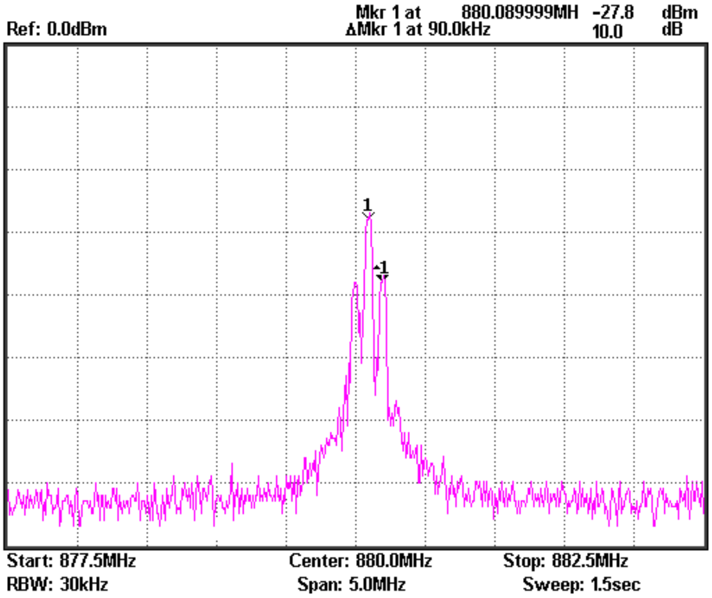
DOWN

Step16 Peak Search

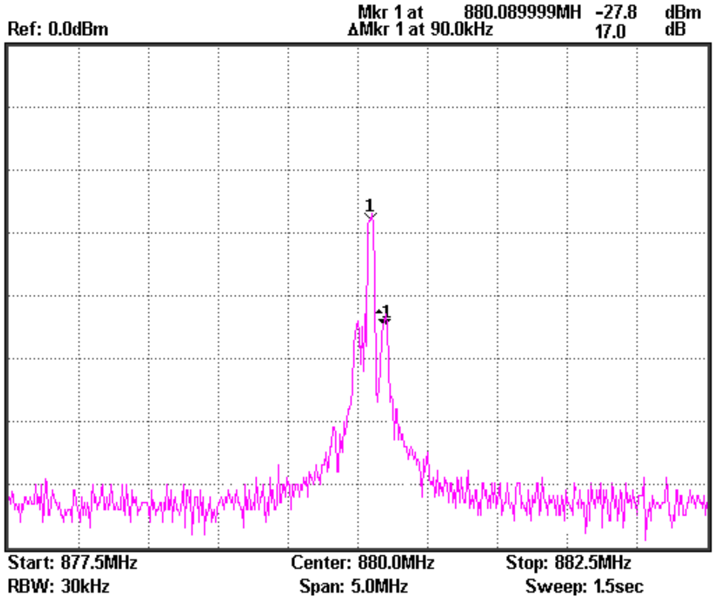
Experiment results

1. Changing modulating voltage

Table 5-4. Experiment results: Changing the modulating voltage

Modulating voltage	Experiment results
Vpp:2.4Vpp	 Carrier power: -27.8dBm Modulation index: : -27.8-6.0=-33.8dBm Lower sideband power: : 1
Vpp: 1.8Vpp	 Carrier power: -27.8dBm Modulation index: : -27.8-10.0=-37.8dBm Lower sideband power: : 0.63

Vpp:
0.6Vpp



Carrier power: -27.8dBm

Modulation index: : -27.8-17.0=-44.8dBm

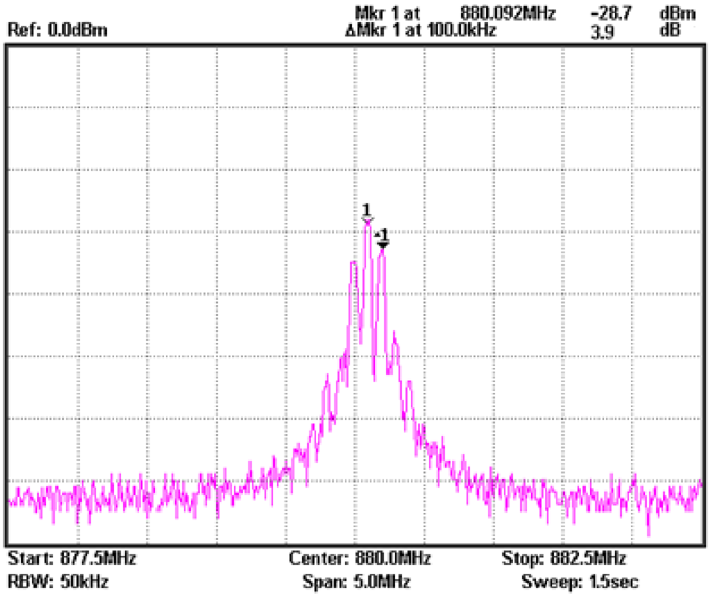
Lower sideband power: : 0.28

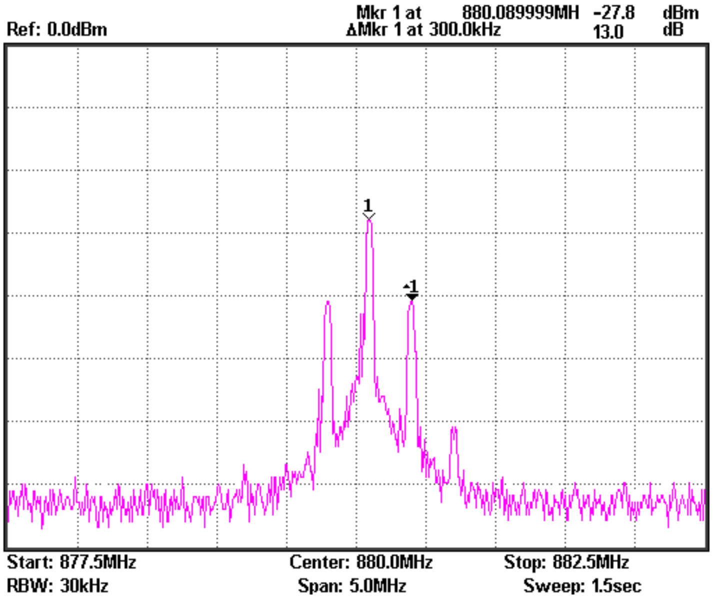
Conclusion: From the experimental data it can be seen that by changing the amplitude of the modulating voltage, a proportional change will occur in the amplitude of the upper sideband and lower sideband frequencies in the modulated waveform. This doesn't affect the amplitude of the carrier power. From the calculated results, it can be seen that changing the amplitude of the modulating signal can also change the modulation index.

Note When the base band output is not connected to the AM input port, it's amplitude is 2.4Vpp. When it is connected to the AM input port, the voltage of TP4 will be reduced to 1.2Vpp due to the 50Ω load of the AM input port.

2. Changing the modulating signal frequency.

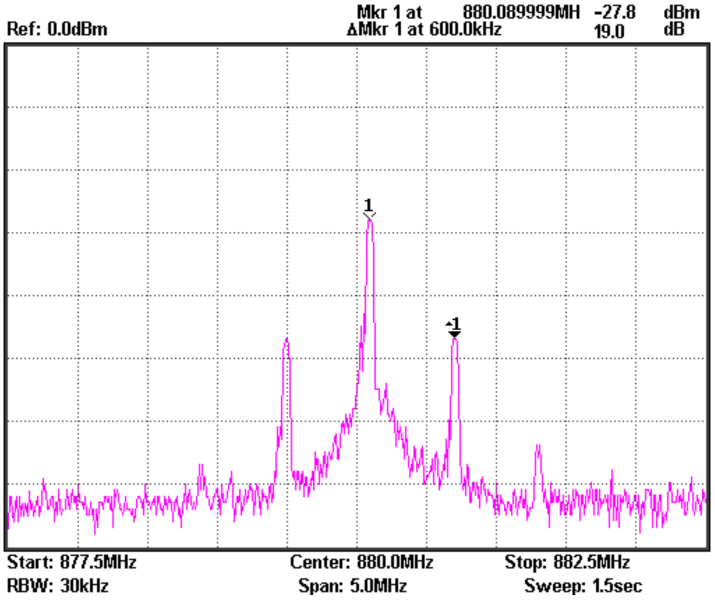
Table 5-5. Experiment results: Changing the modulating signal frequency.

<table>
<tr><th>Modulating frequency</th><th>Experiment results</th></tr>
<tr><td>100kHz</td><td>

Carrier power: : -27.8dBm
Lower sideband power: : -27.8-3.9=-31.7dBm</td></tr>
<tr><td>300Khz</td><td>

Carrier power: : -27.8dBm
Lower sideband power: : -27.8-13=-40.8dBm</td></tr>
</table>

600kHz



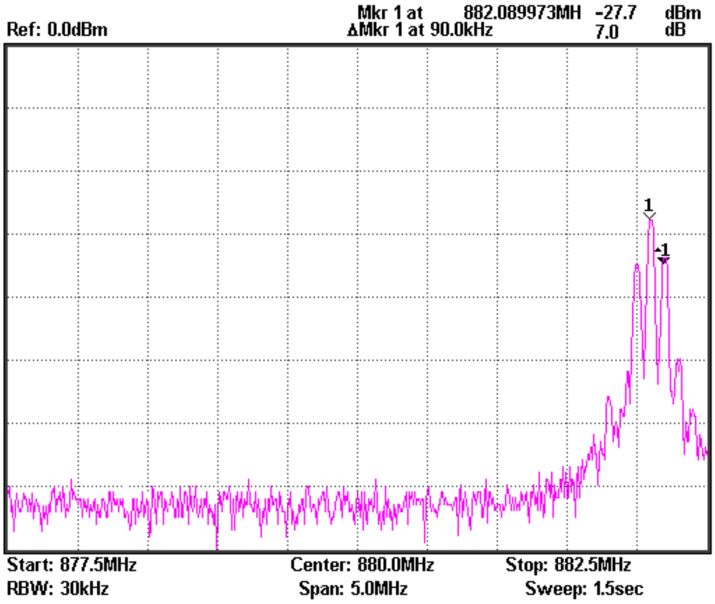
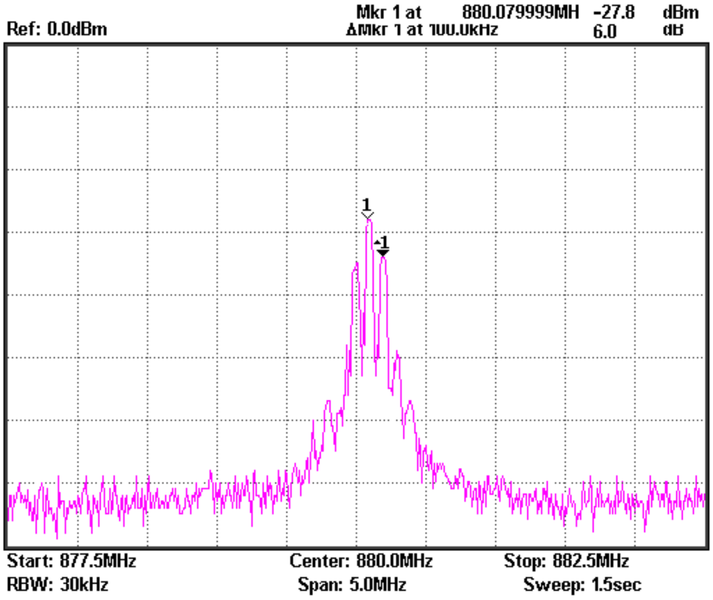
Carrier power: : -27.8dBm

Lower sideband power: : -27.8-19=-46.8dBm

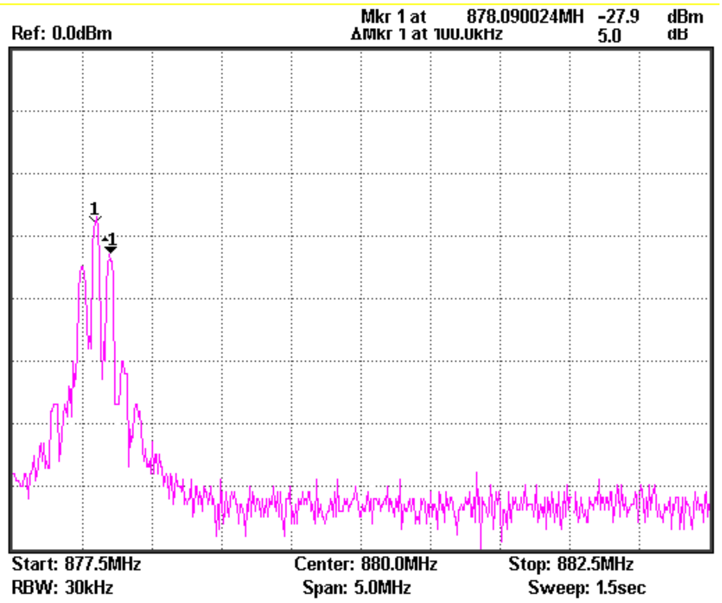
Conclusion: The distance from upper sideband and lower sideband to carrier in the AM wave changes in respect to the changes to the frequency of the modulating signal, and it is equal to the frequency in the modulated signal. The amplitude of the lower sideband and upper sideband decrease slightly with the increase of the frequency in the modulating signal.

3. Changing the carrier frequency.

Table 5-6. Experiment results: Changing the carrier frequency.

Carrier Frequency	Experiment results
882MHz	
880MHz	

878MHz



Conclusion: Changing the carrier frequency does not affect the amplitude of the modulated signal. The frequency of the modulated signal sidebands on both sides of the carrier follow the change in frequency of the carrier. The distance to the carrier remains constant when the carrier moves.

Questions

1. If we change the frequency of the modulating wave but keep the amplitude the same, will the AM wave be affected?

   Ans: From the experiment results we can see that when changing the frequency of the modulating wave, but keeping the amplitude the same, the difference in frequency between the upper sideband and lower sideband increases with an increase in the frequency of the modulating signal. The entire bandwidth of the modulated wave is two times modulating signal spectrum.

2. If the input cables on the AM modules were switched (Connect the baseband signal to the "RF in" terminal and connect the carrier signal to the "AM in" terminal.) what will happen and why?

   Ans: From the experiment result, we can see that the AM wave eventually can be modulated which shows that the modulation circuit used in this experiment likely uses a balanced modulator with symmetrical diodes.

Experiment 6: FM signal measurement

Relevant information

Since frequency modulation is a common type of modulation, it is important to learn the principles and characteristics of FM waves. Compared to AM waves, the amplitude of an FM wave doesn't carry the modulating signal information. This allows an amplitude limiter to be used to eliminate the magnitude interference before demodulation. The noise power spectral density in an FM wave band is evenly distributed at the input terminal. But due to frequency modulation, it is affected by frequency at the output terminal. Because the bandwidth of a modulated signal is far less than the FM wave bandwidth, it can pass through a low-pass filter to attenuate noise and increase the output signal to noise ratio during demodulation. FM waveforms are advantageous as they utilize power efficiently and have a high degree of fidelity as they rely on the phase of the modulated signal and not the amplitude to carry the baseband signal. The FM circuit in this experiment uses a phase-locked loop. The phase-locked loop circuit principles described earlier can be used to study the application of a phase-locked loop circuit for this section.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	2	100mm
4	RF wire	1	800mm
5	Adapter	1	N-SMA

Experiment goals

1. Understand the working principals of frequency modulation.
2. Use a spectrum analyzer to measure the FM characteristics of an FM wave.
3. Master phase-locked loop principals that are used in FM.

Experiment principles

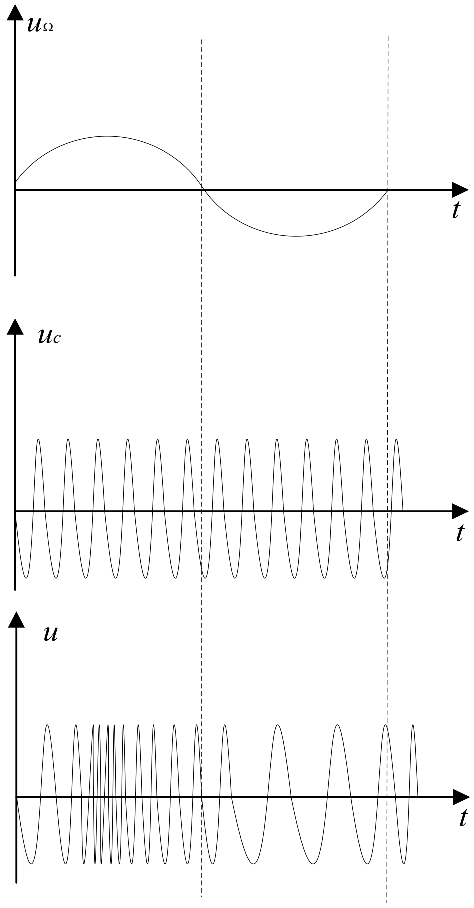
1. Time domain analysis. Frequency modulation is a type of modulation in which the instantaneous frequency deviation of the modulated signal with respect to the frequency of the carrier signal is directly proportional to the instantaneous amplitude of the modulating signal.

Assume that the modulating signal is
$u_{\Omega}(t) = U_{\Omega m}\cos\Omega t$

And the carrier signal is
$u_c(t) = U_{cm}\cos\omega_c t = U_{cm}\cos 2\pi f_c t$

An FM signal varying to changes in the modulating signal is shown in Figure 6-1.

Figure 6-1. An FM signal varying to the change of a modulating signal



In the positive half-period of the modulating signal, the frequency of the modulated signal is higher than the frequency of the carrier signal. At the peak of the positive half-period, the angular frequency of the modulated signal is at its peak.

In the negative half-period of the modulating signal, the frequency of the modulated signal is lower than the frequency of the carrier signal, and its angular frequency is at its lowest. The angular frequency ω of an FM wave changes in response to changes in the modulation signal.

Then $\omega=\omega_c+\Delta\omega\cos\Omega t$

In this formula, ω_c is the angular frequency of the carrier wave, $\Delta\omega$ is the offset of the angular frequency determined by the modulating signal U_Ω

The general expression for the FM signal:

$$u(t)=U_{cm}\cos[\omega_c t+k_f\int_0^t u_\Omega(t)dt+\varphi_0]$$

$$=U_{cm}\cos[\omega_c t+k_f\int_0^t U_{\Omega m}\cos\Omega t dt+\varphi_0]$$

$$=U_{cm}\cos[\omega_c t+\frac{k_f U_{\Omega m}}{\Omega}\sin(\Omega t)+\varphi_0]$$

Assume that, $M_f=\frac{k_f U_{\Omega m}}{\Omega}=\frac{\Delta\omega_m}{\Omega}$

In this formula, M_f is called the FM index, $\Delta\omega_m$ is called the maximum angular frequency deviation, its value is proportional to the amplitude of the modulating signal.

---

2. Frequency domain analysis
   Expressed by the time domain FM wave

$$u(t)=U_{cm}\cos[\omega_c t+\frac{k_f U_{\Omega m}}{\Omega}\sin(\Omega t)+\varphi 0]$$

$$=U_{cm}\cos[\omega_c t+m_f\sin(\Omega t)+\varphi_0]$$

Let the initial phase angle be 0 and expand as follows:

$$u(t)=U_{cm}[\cos\omega_c t\cos(m_f\sin\Omega t)+\sin\omega_c t\sin(m_f\sin\Omega t)]$$

When $m_f<<1$, $\cos(m_f\sin\Omega t)\approx 1$

$\sin(m_f\sin\Omega t)\approx(m_f\sin\Omega t)$

Then we get, $u(t) = U_{cm}\cos\omega_c t + m_f U_{cm}\sin\omega_c t\sin\Omega t$

$$= U_{cm}\cos\omega_c t + \frac{m_f U_{cm}}{2}\cos(\omega_c + \Omega)t + \frac{m_f U_{cm}}{2}\cos(\omega_c - \Omega)t$$

We can see when m_f <<1, the FM wave spectrum is composed of the carrier, (ω_c+Ω) frequency component and (ω_c - Ω) frequency component.

When m_f >>1

$$\cos(m_f\sin\Omega t) = J_0(m_f) + 2J_2(m_f)\cos 2\Omega t + 2J_4(m_f)\cos 4\Omega t + \ldots\ldots$$

$$\sin(m_f\sin\Omega t) = 2J_1(m_f)\sin\Omega t + 2J_3(m_f)\cos 3\Omega t + 2J_5(m_f)\sin 5\Omega t + \ldots\ldots$$

In this formula, $J_n(m_f)$ is called an n-order Bessel function of the first kind.

There are an infinite number of frequency components in FM waves, and they are distributed symmetrically around the center of carrier frequency. The amplitude of each component depends on the Bessel functions.

Theoretically, FM bandwidth is infinite, but the energy of an FM signal is mainly concentrated near the carrier frequency. The sidebands of the FM signal only contain a small amplitude component and are generally ignored in practice by engineers. Provided that the amplitude at the sidebands is negligible, less than 10%, we can get the FM wave band as follows:

$B=2(m_f+1)F$

From above analysis

Because $m_f = \frac{\Delta\omega_m}{\Omega} = \frac{\Delta F}{F}$

Therefore $B=2(\Delta F + F)$

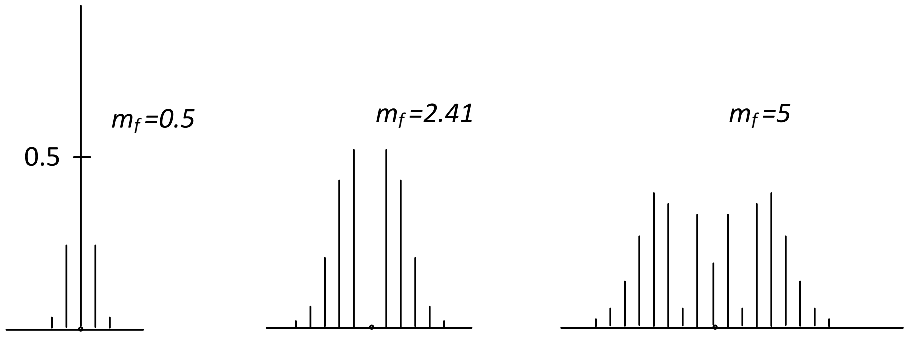
When $\Delta F >> F$, it is wide band modulation,

$m_f >> 1,\ B \approx 2\Delta F$

When $\Delta F << F$, it is narrow band modulation,

$m_f << 1,\ B \approx 2F$

The amplitude of the sideband components in an FM signal is related to the frequency modulation index. This can be seen in the comparison table in the appendix. Below we have a few examples of the absolute magnitudes of the sidebands for signals with a modulation index of 0.5, 2.41 and 5.

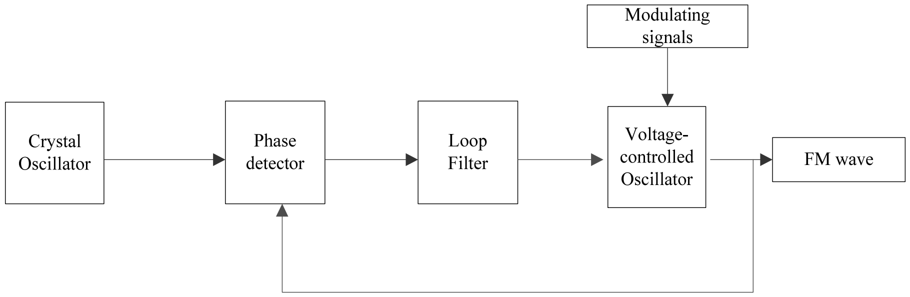


The FM circuit in the GRF-1300A uses a phase-locked loop. Using a PLL circuit for FM modulation not only solves the center frequency stability problems in direct FM modulation but also the narrow FM range limitations when using a crystal oscillator.

The spectrum of the modulating signal must be outside the of low-pass filter passband to achieve a phase-locked FM wave.

When the center frequency of the VCO is locked on to a stable high frequency, it allows the VCO to shift in frequency when the modulating signal is varied.

Figure 6-2. GRF-1300A FM principle



Experiment contents

1. Measure the FM wave spectrum.
2. Observe how the amplitude of the modulating signal affects the FM wave frequency deviation.
3. Observe how the frequency of the modulating signal affects the FM wave frequency deviation.

Experiment steps

1. Turn on the GRF-1300A and GSP-730.
2. Set the GRF-1300A as follows:

- Under the default state (the state from power-up), turn the potentiometer to the minimum position.
- Connect the output port on the Baseband module to the FM in port on the RF Synthesizer/FM module with an RF cable.
- Connect the RF/FM output port to the RF input port on the spectrum analyzer with an RF cable.

3. Set the GSP-730 as follows:
    - Center frequency:880MHz
    - Span: 50MHz
    - Reference level: 0dBm
    - RBW: Auto (default state is 100kHz)

Step1 Frequency F1 8 8 0 MHz/ mSec Center 880.0MHz

Step2 Span F1 5 0 MHz/ mSec Span 50.0MHz

Step3 Amplitude F1 0 GHz/ Sec Ref. Level 0.0dBm

Step4 BW F1 RBW Auto Man F4 RBW 100 kHz

4. Use the Marker function on the spectrum analyzer and measure the carrier position at this time.

Step5 Peak Search

5. Turn the potentiometer clockwise to an arbitrary position. Measure the voltage with an oscilloscope. Does the FM wave spectrum change after the output amplitude of the modulating signal has changed? Follow the steps below to measure the frequency deviation and record it in Table 6-2.

Step6 Marker F3 Mode Normal Delta ●

6. Turn the potentiometer clockwise again to a different position. Measure the voltage with an oscilloscope. Does the spectrum

of the FM wave change when the output amplitude of modulating signal changes? Follow the steps below to measure the frequency deviation and record it in Table 6-2.

Step7 

7. Adjust the potentiometer to the maximum position. Repeat the above steps and record the results in Table 6-2.

Step8 

8. After the completing the experiment steps above, see if there is any change to the spectrum of the FM wave when the UP button on the baseband module is used to change the frequency of the modulating signal. Compare this to the original 100kHz baseband signal and record it to Table 6-3.

Step9 

9. Change the modulating signal frequency to 600KHz. Observe the change in the spectrum of the FM wave and record the results in Table 6-3.

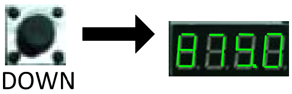
Step10 

10. Change the modulating signal frequency to 1MHz. Observe the change in the spectrum of the FM wave and record the results in Table 6-3.

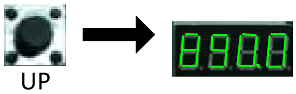
Step11 

11. After the completing the experiment steps above, press the Reset button, and minimize the amplitude of the modulating signal in order to view the FM spectrum within a span of 50MHz. Then use the DOWN button on the RF Synthesizer/FM module to change the frequency of the carrier signal. See if there is any change in FM wave spectrum. Compare this result to the original carrier frequency of 880MHz and record it in Table 6-4.

Step12 

Step13 

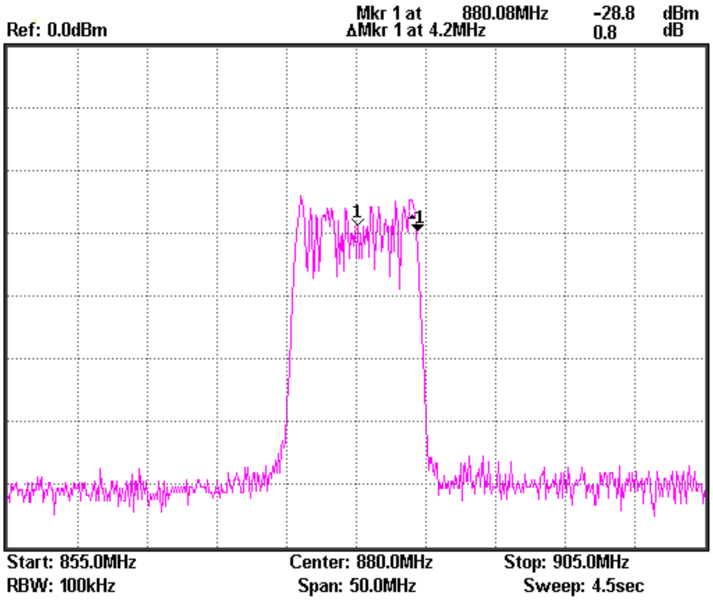
12. Adjust the carrier frequency again. See if there is any change on FM wave spectrum and record it to Table 6-4.

Step14 

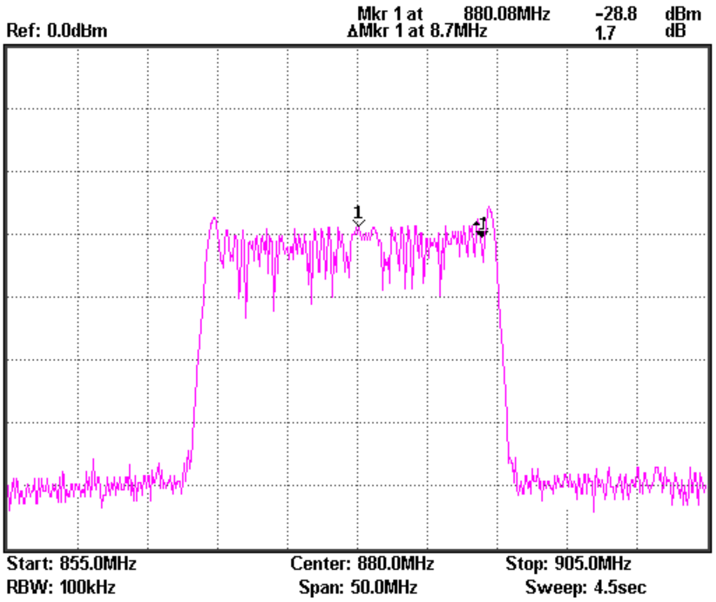
Experiment results

1. Changing the amplitude of the modulating signal.

Table 6-2. Experimental Results: Changing the amplitude of the modulating signal

Modulating voltage	Experiment result
Vpp:0.8Vpp	 Frequency deviation: 4.2MHz FM index: 42

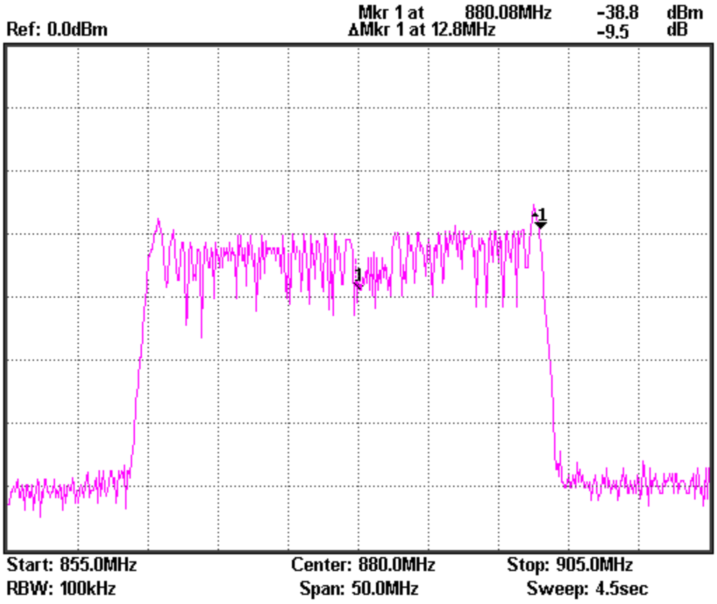
Vpp: 1.8Vpp



Frequency deviation: 8.7MHz

FM index: 87

Vpp:2.4Vpp



Frequency deviation: 12.8MHz

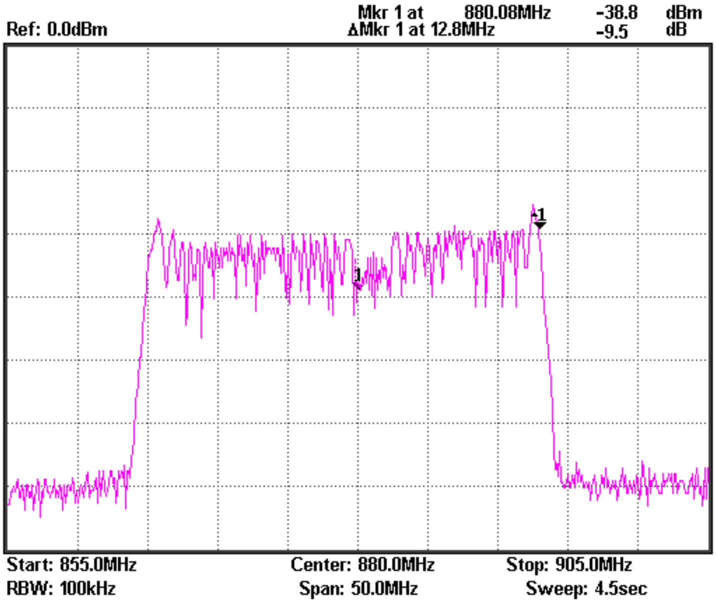
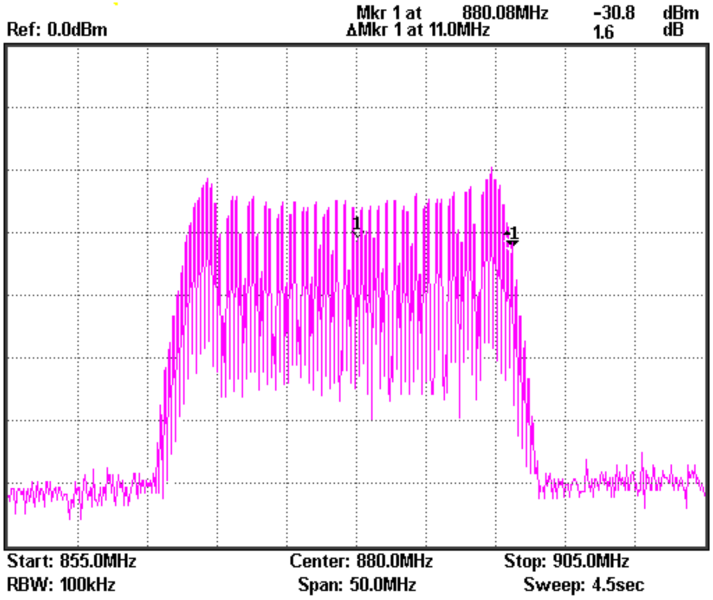
FM index: 128

Conclusion

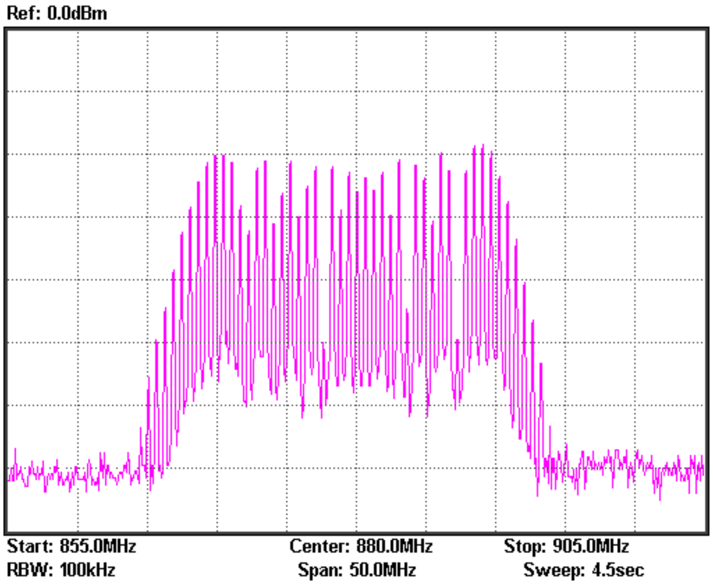
By keeping the modulating frequency unchanged, the frequency deviation of the modulated signal increases with the increase in amplitude of the modulating signal. The amplitude of the modulated signal remains constant.

2. Changing the frequency of an FM signal.

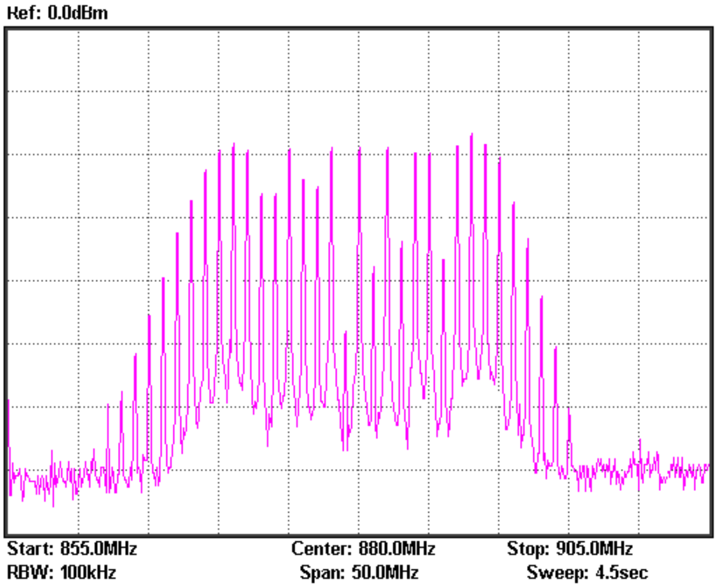
Table 6-3. Experimental results: Changing the frequency of the FM signal

Modulating frequency	Experimental result
100kHz	
300Khz	

600kHz



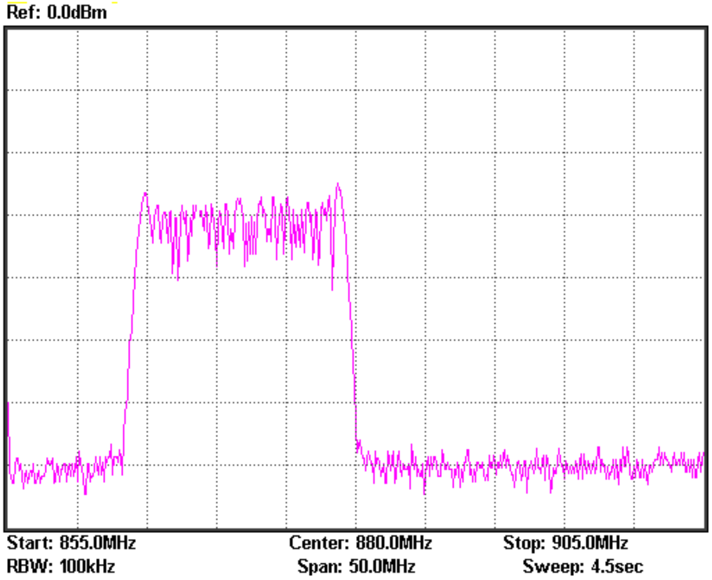
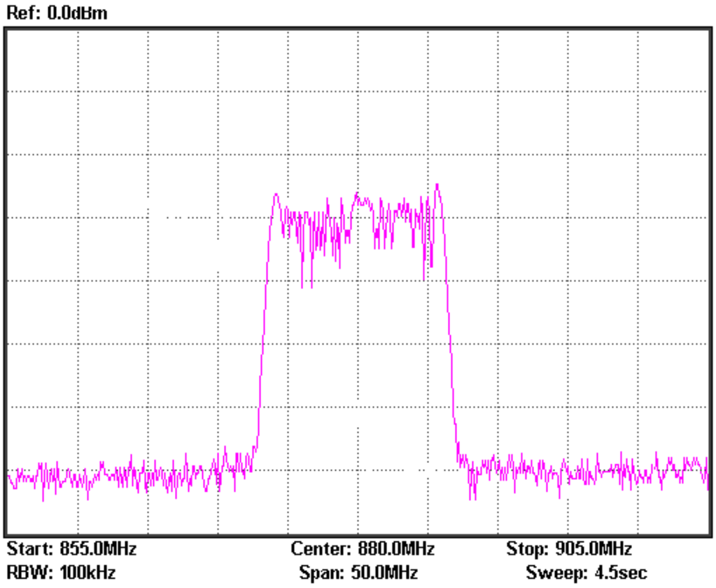
1MHz



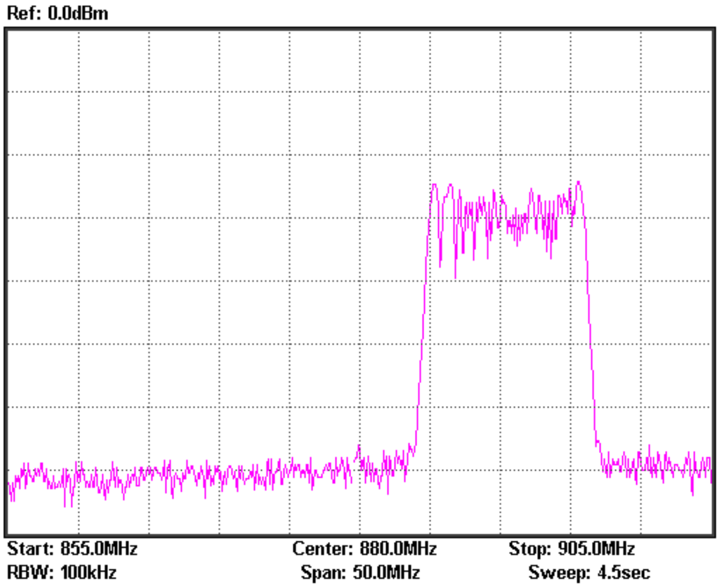
Conclusion	The frequency of the modulating signal affects the rate at which the side-frequency changes. Increasing the frequency of the modulation signal on the condition of keeping the amplitude of modulating signal unchanged will decrease the modulation index (Mf). Meanwhile, the side-frequency component is reduced, but the bandwidth remains unchanged.

3. Changing the carrier frequency

Table 6-4. Experimental results: Changing the carrier frequency

Carrier frequency	Experimental result
875MHz	
880MHz	

890MHz



Conclusion After the modulating signal is modulated onto the carrier signal, any changes to the carrier frequency have no effect on other modulation parameters.

4. Draw a table to record the time domain waveform of the AM wave that is measured by the oscilloscope.

Question

1. For FM waves, if we keep the modulating signal amplitude constant and double the frequency, how will the frequency deviation and bandwidth change in the modulated signal?

Ans: From the analysis of the experiment results, we can see that the frequency deviation remains constant, but the bandwidth is halved.

2. Calculate the FM index of the modulation circuit from the measured data obtained from the spectrum analyzer.

Ans: Please check out the experiment results

Experiment 7: Using a Spectrum Analyzer in Communication Systems

Relevant information

ACPR and OCBW are important parameters in the measurement of RF modulated signals. It is very important to master using a spectrum analyzer to measure ACPR and OCBW. We must know how to utilize a spectrum analyzer to measure the RF parameters that are frequently used and to lay the foundation for future use. ACPR is the ratio of the amount of power leaked to an adjacent channel from the main channel. OCBW is the occupied bandwidth that contains a specific percentage of the total integrated power of the channel. At present, third generation mobile communication systems (3G) are becoming ubiquitous, while some countries and companies are looking to develop fourth generation mobile communication systems (4G). This experiment, therefore, has a high practical value for the measurement of CDMA RF power and related fields.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	2	100mm
4	RF wire	1	800mm
5	Adapter	1	N-SMA

Experiment goals

1. To understand ACPR measurement principles and to perform actual ACPR measurements.

2. Understand OCBW measurement principles and to perform actual OCBW measurements.

Experiment principles

1. ACPR Measurement

ACPR (Adjacent Channel Power Ratio) is the ratio of the amount of power leaked to an adjacent channel from the main channel. It represents how much power from the transmitter leaks into the transmission band of other channels. The adjacent channel usually refers to the closest adjacent channels near the transmission channel, other channels can also be selected, depending on the measurement requirements.

When two signals with similar frequencies are input into an RF power amplifier, there are not only two output signals, but also the inter-modulation signals (input signal 1 ± input signal 2). A typical input and output frequency spectrum is shown in Figure 7-1.

Figure 7-1. RF power amplifier input and output

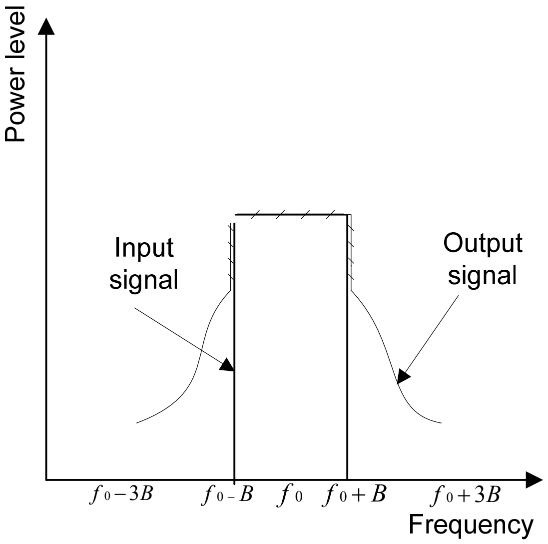
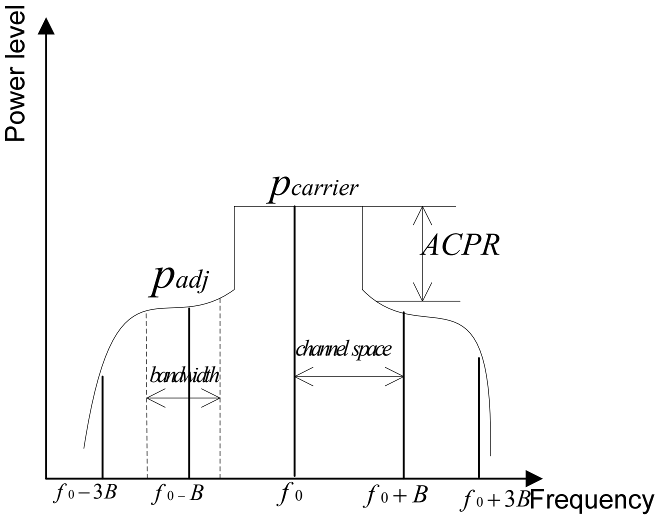


Figure 7-2. Definition of ACPR



In accordance with the definition of ACPR (Figure 7-2), we know that $ACPR = 10 \log (P_{adj} / P_{carrier})$.

When using a spectrum analyzer to measure ACPR, first you need to select the appropriate settings for the span and the resolution bandwidth (RBW). The span needs to be greater than the measurement bandwidth. The RBW should be equal to approximately 1% of the measurement bandwidth. Because the sweep time of the spectrum analyzer is inversely proportional to the square of the RBW, the RBW settings should be considered.

The RBW should not more than 4% of the measured channel bandwidth. Otherwise, the RBW will too wide and will obscure the original spectrum of channel. The RBW settings on the GSP-730 have a number of set ranges, therefore it fine to set the RBW to Auto mode.

2. OCBW-measurement

OCBW measurement is for measuring the bandwidth that the channel occupies for a specified amount of power. This is used to measure the occupied bandwidth as a percentage of the channel power for a specified amount of power. Commonly used parameters for the measurements are: channel bandwidth, channel spacing and OCBW %.

Experiment contents

1. Measure the ACPR from the FM signal produced by the GRF-1300A.
2. Measure the OCBW from the FM signal produced by the GRF-1300A.

Experiment steps

1. Turn on the GRF-1300A and GSP-730.
2. Set up the GRF-1300A as follows:
   - Set the GRF to the power-on default state.
   - Use the RF wire to connect the baseband output to the FM in port on the RF synthesizer/FM module.
   - Connect the output terminal on the RF/FM module to the input terminal on the spectrum analyzer with the RF cable.

3. Set up the GSP-730 as follows:
   - Center frequency:880MHz
   - Span: 10MHz
   - Reference level: -10dBm
   - RBW: Auto

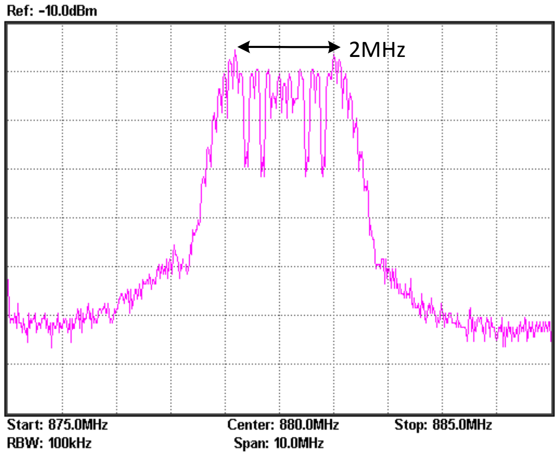
Step1 Frequency F1 8 8 0 MHz/mSec Center 880.0MHz

Step2 Span F1 1 0 MHz/mSec Span 10.0MHz

Step3 Amplitude F1 — 1 0 GHz/Sec Ref. Level -10.0dBm

Step4 BW F1 RBW Auto Man

4. Adjust the FM frequency deviation to 1MHz (2MHz in total) with the amplitude knob.



5. Measure the ACPR and OCBW after these settings are performed.

ACPR measurement

Step1 Meas F2 ACPR ON OFF

Step2 F1 Main CH BW

Set the bandwidth of the main channel to 2MHz.

Step3 F2 Main CH Space
Set the main channel space to 5MHz.

Step4 F3 ACPR Setup.. F1 Adj CH BW 1
Set the bandwidth of the 1st adjacent channel 0.8MHz.

Step5 F2 Adj CH Offs 1
Set the offset of the 1st adjacent channel to 2MHz.

Step6 F3 Adj CH BW 2
Set the bandwidth of the 2nd adjacent channel to 0.5MHz.

Step7 F4 Adj CH Offs 2
Set the offset of the 2nd adjacent channel to 4MHz.

Increase the frequency deviation to 2MHz (4MHz in total) using the amplitude knob. Measure the ACPR again and record the results to table 7-1.

OCBW measurement

Step1 Meas F3 ACPR ON OFF

Step2 F1 Main CH BW
Set the bandwidth of the channel that you will measure to 2MHz.

Step3 F2 Main CH Space
Set the span of the main channel space to 10MHz.

Step4 The OCBW% is default at 90%.

Record the measurement data in Table 7-2

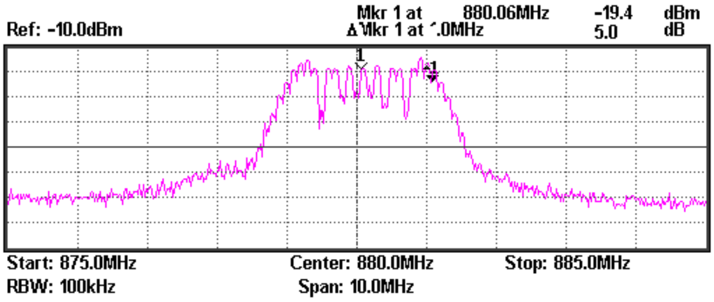
Step5 Adjust the frequency deviation of FM wave by adjusting the potentiometer of GRF-1300A. Measure the OCBW% again and record the results to table 7-2.

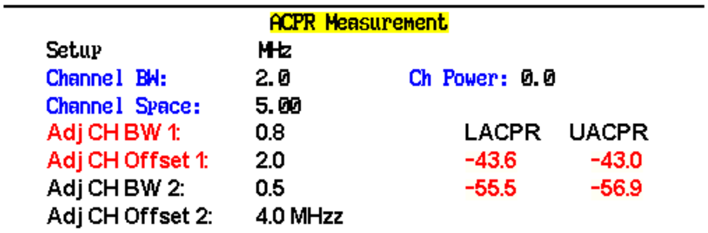
Record the measurement data in Table 7-2

Experiment results

1. ACPR measurement results

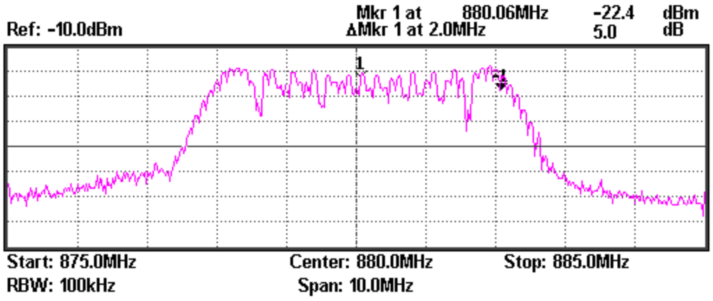
1MHz frequency deviation results

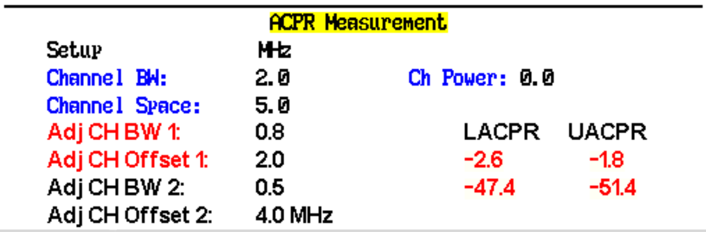

Ref: -10.0dBm
Mkr 1 at 880.06MHz -19.4 dBm
ΔMkr 1 at ´.0MHz 5.0 dB
Start: 875.0MHz Center: 880.0MHz Stop: 885.0MHz
RBW: 100kHz Span: 10.0MHz


ACPR Measurement

Setup	MHz		
Channel BW:	2.0	Ch Power: 0.0	
Channel Space:	5.00		
Adj CH BW 1:	0.8	LACPR	UACPR
Adj CH Offset 1:	2.0	-43.6	-43.0
Adj CH BW 2:	0.5	-55.5	-56.9
Adj CH Offset 2:	4.0 MHzz		

2MHz frequency deviation results


Ref: -10.0dBm
Mkr 1 at 880.06MHz -22.4 dBm
ΔMkr 1 at 2.0MHz 5.0 dB
Start: 875.0MHz Center: 880.0MHz Stop: 885.0MHz
RBW: 100kHz Span: 10.0MHz


ACPR Measurement

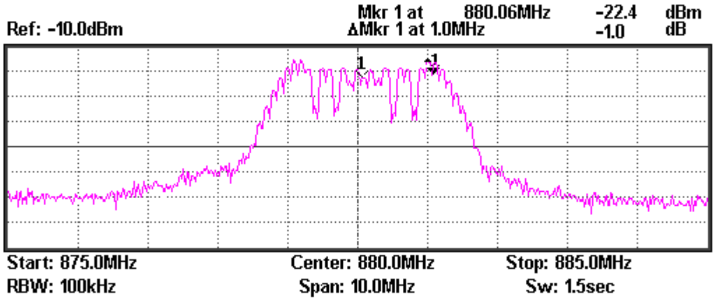
Setup	MHz		
Channel BW:	2.0	Ch Power: 0.0	
Channel Space:	5.0		
Adj CH BW 1:	0.8	LACPR	UACPR
Adj CH Offset 1:	2.0	-2.6	-1.8
Adj CH BW 2:	0.5	-47.4	-51.4
Adj CH Offset 2:	4.0 MHz		

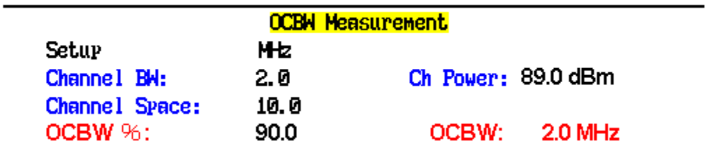
Table 7-1. ACPR measurement results

	Item			
Test No.	Lower ACPR1	Upper ACPR1	Lower ACPR2	Upper ACPR2
1	-42.3	-43.0	-55.6	-55.9
2	-42.2	-42.9	-55.4	-57.0
3	-43.0	-43.4	-55.6	-57.2
4	-42.5	-43.5	-55.3	-57.3
Average	-42.5	-43.2	-55.5	-56.85

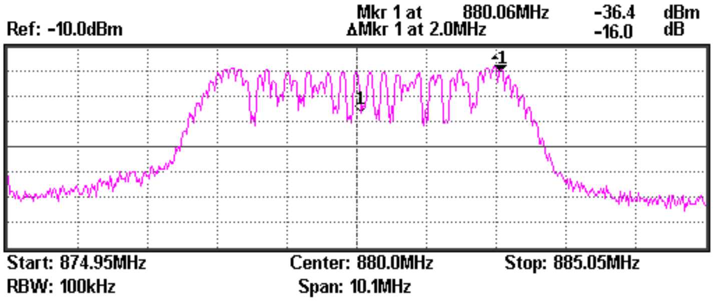
2. OCBW measurement results

1MHz frequency deviation results


Ref: -10.0dBm
Mkr 1 at 880.06MHz -22.4 dBm
ΔMkr 1 at 1.0MHz -1.0 dB
Start: 875.0MHz
RBW: 100kHz
Center: 880.0MHz
Span: 10.0MHz
Stop: 885.0MHz
Sw: 1.5sec


OCBW Measurement
Setup MHz
Channel BW: 2.0 Ch Power: 89.0 dBm
Channel Space: 10.0
OCBW %: 90.0 OCBW: 2.0 MHz

2MHz frequency deviation results


Ref: -10.0dBm
Mkr 1 at 880.06MHz -36.4 dBm
ΔMkr 1 at 2.0MHz -16.0 dB
Start: 874.95MHz
RBW: 100kHz
Center: 880.0MHz
Span: 10.1MHz
Stop: 885.05MHz

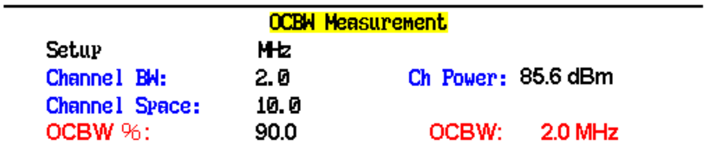

OCBW Measurement
Setup MHz
Channel BW: 2.0 Ch Power: 85.6 dBm
Channel Space: 10.0
OCBW %: 90.0 OCBW: 2.0 MHz

Table 7-2. OCBW measurement results

OCBW%：90%

Test No.	CH Power	OCBW
1	89.2	2
2	89.1	2
3	89	2
4	89.2	2
5	89.2	2

Questions Describe the definition for ACPR?

Ans: ACPR stands for adjacent channel power ratio. It is the average power ratio of the adjacent frequency to that of the transmission channel power. It represents how much energy from the transmitter falls within the transmission band of other channels. Generally the channels directly adjacent to transmission channels are considered, but in special cases other channels can also be considered.

Caution Taking multiple measurements and the getting average value is required for ACPR and OCBW measurements. Using the Average function cannot be used as it uses a logarithmic method to calculate the average.

Experiment 8: Measurement of communication products

Relevant information

The computer mouse has experienced nearly four decades of evolution and development since its inception in 1968. With the popularity of consumer oriented computers over the past decade, the mouse has seen tremendous progress. From the early mechanical wheel mouse to the current mainstream optical mouse or the high-end laser mouse, each evolution of the mouse has been more enjoyable to use each time. In addition, the demand for better work environments has made the wireless mouse very popular. Wireless technology, depending on the frequency band and its purpose, is divided into different categories such as Bluetooth, Wi-Fi (IEEE 802.11), Infrared (IrDA), ZigBee (IEEE 802.15.4) and so on. But for the current mainstream wireless mouse, there are three different categories: 27Mhz, 2.4G and Bluetooth.

This experiment actually performs measurements on actual communication products (a wireless mouse in this case). After performing this experiment you should have a good understanding of the spectrum analyzer and the measurement methods used. This experiment will help to consolidate your RF knowledge and to strengthen your practical spectrum analyzer skills.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	2.4G wireless mouse	1	
3	Antenna	1	800-1000MHz
4	Adapter	1	N-SMA

Experiment goals

1. Use the spectrum analyzer to measure some parameters from common every-day electronic communication products.

2. Learn how a wireless mouse works.

Experiment principles

In this experiment we will use a 2.4G wireless mouse. It uses the so-called 2.4G frequency band. The advantage of the 2.4G band over the 27MHz band is that the 27MHz band has a shorter transmission distance and is prone to interference from other devices. We call it 2.4G because it operates in the 2.4GHz frequency band. In most countries, this frequency band is license-free.

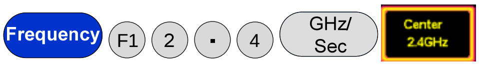
The principle of the wireless mouse is actually very simple. It mainly uses digital radio technology to provide adequate bandwidth for communications equipment over a short distance. It is ideal for peripheral equipment such as mice and keyboards. The working principles behind a wireless mouse and that of a traditional mouse are the same. The only difference is that the X & Y position, as well each button press is transmitted wirelessly via a transmitter. The wireless receiver then passes this information to the host after decoding the signal. The driver then tells the operating system to convert the signal to mouse actions.

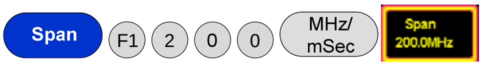
Experiment contents

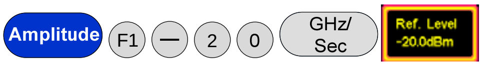
Measure the frequency and power of the signal that is transmitted from a wireless mouse.

Experiment steps

1. Connect the antenna to the input port of the spectrum analyzer.
2. Set up the GSP-730 as follows:
    - Center frequency: 2.4GHz
    - Span: 200MHz
    - Reference level: -20dBm
    - RBW: Auto

Step1 

Step2 

Step3 

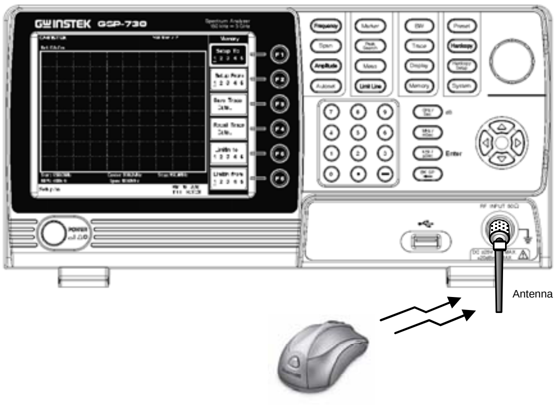
Step4 

3. Turn the wireless mouse on.

Step5 

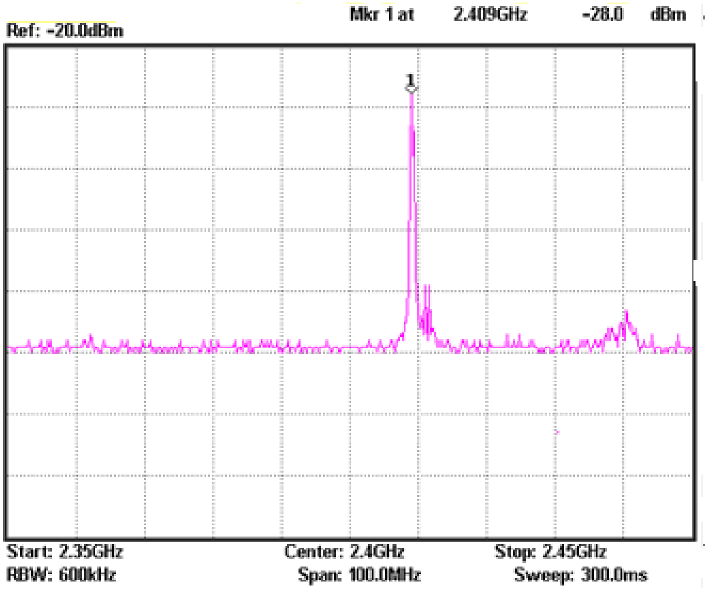
Step6 

4. A connection diagram is shown below.



5. A blue tooth device or wireless network card can also be used in the same way to create a signal to measure.

Experiment results



Transmitting frequency: 2.409GHz

Transmitted signal power: -28.0 dBm

Question What are the advantages for a wireless mouse to operate in the 2.4 G bandwidth?

Ans: As wireless mice use the 2.4-2.485GHz ISM wireless band, it can be used license-free and free of charge in most countries around the world. This clears the biggest obstacle for a product to become popular. This also means that the mice do not interfere with other wireless devices.

Tip	Use the Peak Hold function on the spectrum analyzer to capture the signal emitted from the wireless mouse. It is not easy to dynamically measure the signal.

Experiment 9: Production Line Applications

Relevant information

A spectrum analyzer can be used in Pass/Fail testing of RF communication products. Testing can be done either manually with a stand-alone instrument or via remote control using a PC. When using remote control, the spectrum analyzer parameter settings and test results can be returned remotely. This saves a lot of time and can improve the efficiency of a production line. In this experiment, we will imagine that the GRF-1300A is in a production line environment. We will use the limit line function to perform a simple test to see if a product has passed the test and return the test results using remote commands.

Experiment equipment

Item	Equipment	Quantity	Note
1	Spectrum analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	RF wire	1	800mm
4	Adapter	1	N-SMA

Experiment goals

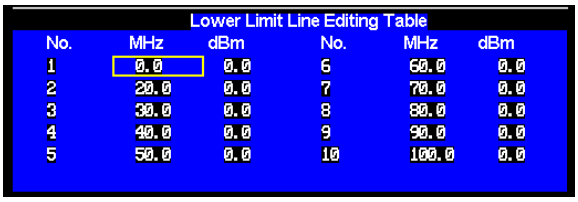
1. Learn how to edit the pass/fail limit lines and understand how to perform pass/fail testing.

2. Use remote commands to read back test data from the spectrum analyzer.

Experiment principles

1. Limit line editing and Pass/Fail testing.
   The upper and lower limit lines apply throughout the entire frequency span. The limit lines can be used to detect if the signal amplitude is above or below a set amplitude level. The judgment of the pass/fail test is shown on the bottom of the screen.

   To create a limit line, edit the ten points in the lower Limit Line Editing Table, shown below.



Lower Limit Line Editing Table

No.	MHz	dBm	No.	MHz	dBm
1	0.0	0.0	6	60.0	0.0
2	20.0	0.0	7	70.0	0.0
3	30.0	0.0	8	80.0	0.0
4	40.0	0.0	9	90.0	0.0
5	50.0	0.0	10	100.0	0.0

Set the amplitude and frequency of each point. Use the arrow keys to move the cursor to each of the different points. Use the same method is used to edit both the upper and lower limit lines. Pass/Fail testing can be started after setting the limit lines.

2. Use the remote commands to read back test results. Manually setting the spectrum analyzer for testing can be time-consuming. Here we will use remote commands to set various parameters on the spectrum analyzer remotely. We will briefly explain some of these commands below.

Frequency Commands	meas:freq:cen?	Return the center frequency in kHz.
	meas:freq:cen	Sets the center frequency, for example: meas:freq:cen_100_mhz
	meas:freq:st?	Returns the start frequency in kHz.
	meas:freq:st	Sets the start frequency, for example: meas:freq:st_100_mhz
	meas:freq:stp?	Returns the stop frequency in kHz.
	meas:freq:stp	Sets the stop frequency, for example: meas:freq:stp_100_mhz
Span Commands	meas:span?	Returns the frequency span settings.
	meas:span	Sets the frequency span settings, for example: meas:span:10_mhz
	meas:span:full	Sets the span to Full Span mode.
Amplitude Commands	meas:refl:unit?	Returns the reference level unit.
	meas:refl:unit	Sets the reference level unit. Parameters: 1(dBm), 2(dBmV), 3(dBuV)

	meas:refl?	Returns the reference level in dBm.
	meas:refl	Sets the reference level in dBm. For example: meas:refl:-30
Limit line Commands	meas:lmtline:on	Turns the limit lines on. Parameters: 0(low limit line), 1(high limit line)
	meas:lmtline:off	Turns the limit lines off. Parameters: 0(low limit line), 1(high limit line)
	meas:lmtline: passfail_on	Turns pass/fail testing on.

Experiment contents

1. Set the upper and lower limit lines to perform a pass/fail test on the signal from the GRF-1300A.
2. Use remote commands to remotely setup the spectrum analyzer.

Experiment steps

1. Turn on the GRF-1300A and GSP-730.
2. Set the GRF-1300A to the power-on default state.
3. Connect the RF wire from the output port on the baseband module to the FM in port on the RF Synthesizer/FM module.

4. Set up the GSP-730 as follows:
   - Center frequency: 880MHz
   - Span: 50MHz
   - Reference level: 0dBm
   - RBW: Auto

Step1 Frequency F1 8 8 0 MHz/mSec Center 880.0MHz

Step2 Span F1 5 0 MHz/mSec Span 50.0MHz

Step3 Amplitude F1 0 GHz/Sec Ref. Level 0.0dBm

Step4 BW F1 RBW Auto Man

5. Limit line Pass/Fail test.

Step5 Limit Line F3 Edit..

Step6 F1 Limit High Low F2 Edit Table ON OFF

Below the display, you can set the magnitude and frequency of each point. Move the cursor to select a point and edit it with the number pad and unit keys. Press F6 to return to the previous menu.

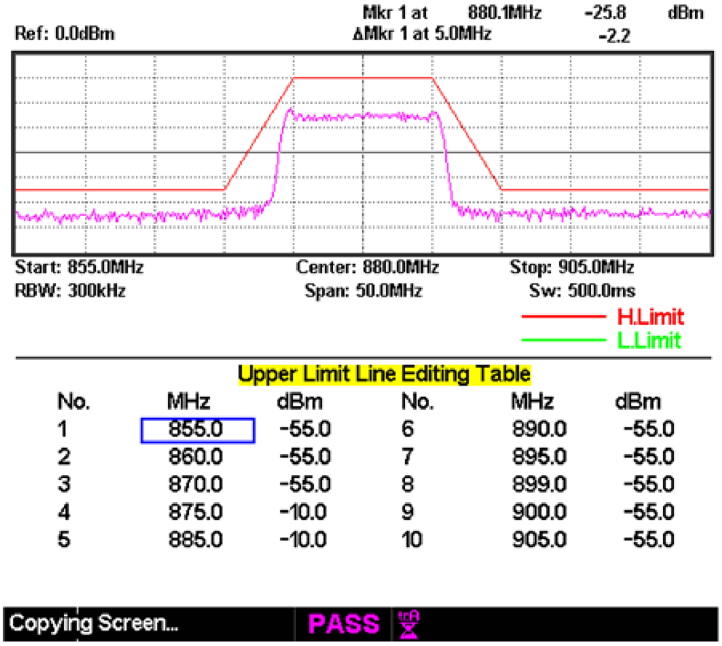
Step7 F1 Pass/Fail ON OFF

6. According to the procedures above, students can set the limit lines.
7. Adjust the amplitude knob on the GRF-1300A. Observe the Pass/Fail test results and record the results to table 9-1.
8. The same functionality can be achieved by sending remote commands from a PC using HyperTerminal.

Experiment results

Table 9-1. Results for adjusting the position of the amplitude knob.

5MHz frequency deviation test results.



Ref: 0.0dBm

Mkr 1 at 880.1MHz -25.8 dBm

ΔMkr 1 at 5.0MHz -2.2

Start: 855.0MHz Center: 880.0MHz Stop: 905.0MHz

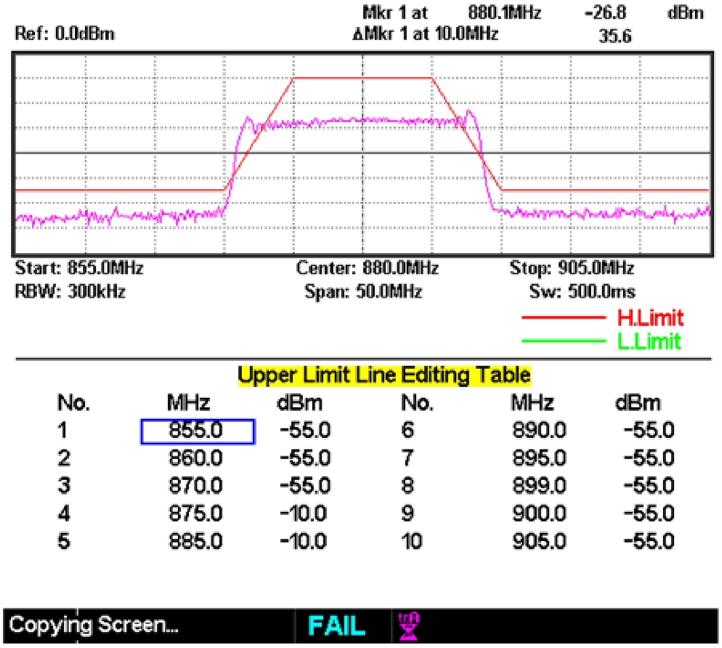
RBW: 300kHz Span: 50.0MHz Sw: 500.0ms

Upper Limit Line Editing Table

No.	MHz	dBm	No.	MHz	dBm
1	855.0	-55.0	6	890.0	-55.0
2	860.0	-55.0	7	895.0	-55.0
3	870.0	-55.0	8	899.0	-55.0
4	875.0	-10.0	9	900.0	-55.0
5	885.0	-10.0	10	905.0	-55.0

Copying Screen... PASS

10MHz frequency deviation test results.



Ref: 0.0dBm

Mkr 1 at 880.1MHz -26.8 dBm

ΔMkr 1 at 10.0MHz 35.6

Start: 855.0MHz Center: 880.0MHz Stop: 905.0MHz

RBW: 300kHz Span: 50.0MHz Sw: 500.0ms

Upper Limit Line Editing Table

No.	MHz	dBm	No.	MHz	dBm
1	855.0	-55.0	6	890.0	-55.0
2	860.0	-55.0	7	895.0	-55.0
3	870.0	-55.0	8	899.0	-55.0
4	875.0	-10.0	9	900.0	-55.0
5	885.0	-10.0	10	905.0	-55.0

Copying Screen... FAIL

Experiment 10: Mixer

Relevant information

In experiment 5 and 6 we introduced how the signal is modulated onto a carrier. However, what are the other processes that need to be performed on the modulated signal before it can be transmitted?

One thing called a frequency mixer is very import in this process. The main function of a frequency mixer is to perform frequency conversion; The mixer can convert the RF signal into an intermediate frequency signal or it can do the opposite and convert the intermediate frequency signal into an RF frequency signal in order to transmit or process the carried message, respectively. The goal of this experiment is to observe how a mixer will shift the frequency spectrum of a signal from a spectrum point of view and to understand the principles of the mixer.

Experiment Equipment

Item	Equipment	Quantity	Note
1	Spectrum Analyzer	1	GSP-730
2	RF & Communication Trainer	1	GRF-1300A
3	USB Signal Generator	1	USG-LF44
4	RF cable	2	100mm
5	RF cable	1	200mm
6	RF cable	1	800mm
7	Adapter	1	N-SMA

Experiment goals

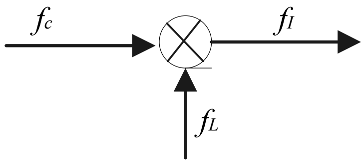
1. To understand the working principles of the mixer.
2. To observe frequency shift by analyzing the frequency spectrum with a spectrum analyzer.
3. To measure mixer parameters such as conversion gain and port isolation.

Experiment principals

1. Introduction to the concept of mixing
   The mixer is used for frequency conversion. Mixing is also known as conversion. Mixing is used to convert a modulated signal with a carrier frequency f_c to a modulated signal with the carrier the frequency f_L for processing at the next circuit. This process is called frequency shifting (shifting of the frequency spectrum). Frequency conversion by the mixer needs to maintain the modulation from the modulated carrier unchanged~ so it still carries information and has no distortion.

   The basic function of a mixer is to maintain the modulation of the modulated signal constant, only to increase (up-conversion) or decrease (down conversion) the carrier frequency. From the spectrum point of view, the essence of mixing is to linearly move the spectrum of the modulated signal along the frequency axis. Therefore, a mixer circuit must be composed of a non-linear device with a multiplicative function as well as band-pass filters, as shown in 10-1.

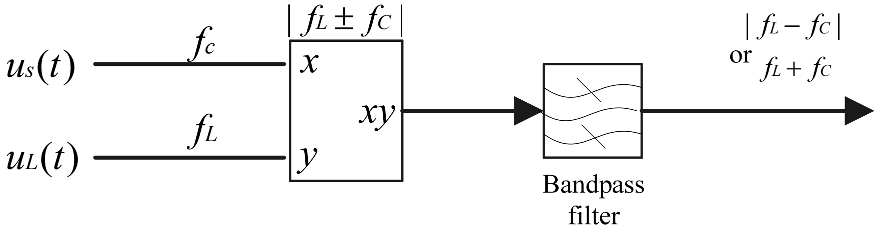
Figure 10-1
The mixer circuit



The mixer multiplies the modulated signal $u_s(t)$ with carrier frequency f_c and the local oscillator signal $u_L(t)$ with the oscillation frequency f_L, as shown in figure 10-2. According to the multiplication of trigonometric functions, the multiplication of the inputs results in the addition and difference of f_c and f_L .I.e., $f_I = f_L + f_C$ and $f_I = | f_L - f_C |$, where f_I is called the intermediate frequency. The mixing frequency signal with the carrier frequency f_I is called the intermediate frequency signal $u_i(t)$.

Figure 10-2

Mixer signal diagram

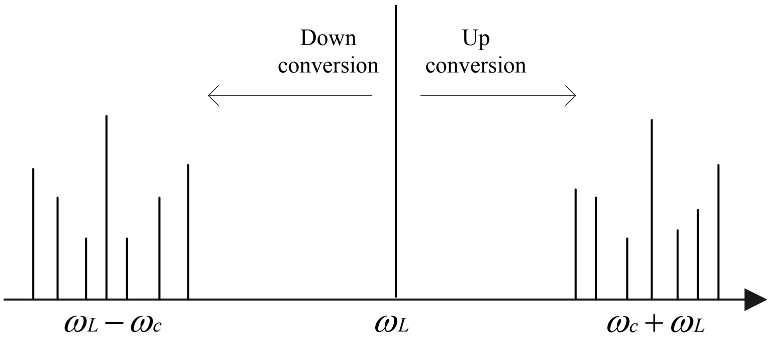


Say the modulated input signal $u_s(t)$ is $u_s(t) = V_s \cos(\omega_c t)$, the local oscillation signal $u_L(t)$ is $u_L(t) = V_L \cos(\omega_L t)$, then the product becomes

$$u_I(t) = V_S V_L \cos(\omega_c t)\cos(\omega_L t) = \frac{V_S V_L}{2}[\cos(\omega_c + \omega_L)t + \cos(\omega_L - \omega_c)t]$$

Passing through a band-pass filter and removing one of the frequency components ($\omega_c + \omega_L$ or $\omega_L - \omega_c$) completes the frequency conversion. Generally the new carrier frequency is called the IF signal.

The spectrum of the calculated result above is shown in the diagram below.



We can see from the spectrum shift in the chart above that the mixing frequency signal is the addition and subtraction of the input signal and the LO signal. As the frequency mixing device is generally a non-linear device, it is obvious that a non-linear combination of frequency distortion and interference will inevitably occur in the mixing process. The harmonic components of the LO signal and the input signal will also be input into the frequency mixer as well, therefore, the output will have the positive and negative components for each harmonic.

In a wireless transceiver circuit, the front-end small-signal low noise amplifier (LNA) and the IF amplifier (IFA) has far less non-linear frequency distortion than that produced by the frequency mixer. Therefore the combined non-linear distortion and frequency interference in the wireless receiver circuit is mainly generated by the frequency mixer circuit. The non-linear characteristics of the frequency mixer for engineering is commonly expressed by the following expansion formula:

$$i = a_0 + a_1 u + a_2 u^2 + a_3 u^3 + \ldots$$

In the formula u is the total signal that is added to the input end of the frequency mixer. Say the composition of u is

$$u = u_1 \cos \omega_1 t + u_2 \cos \omega_2 t + u_3 \cos \omega_3 t$$

Substituting U

$$
\begin{aligned}
i &= A_0 + A_1(u_1 \cos \omega_1 t + u_2 \cos \omega_2 t + u_3 \cos \omega_3 t) \\
&+ A_2(u_1^2 \cos 2\omega_1 + u_2^2 \cos 2\omega_2 + u_3^2 \cos 2\omega_3) \\
&+ A_3(u_1^3 \cos 3\omega_1 + u_2^3 \cos 3\omega_2 + u_3^3 \cos 3\omega_3) \\
&+ \ldots. + A_P \cos(\pm\omega_3 + \omega_1)t + A_q \cos(\pm\omega_3 \pm \omega_2)t \\
&+ A_m \cos(\pm\omega_3 + 2\omega_1 \pm \omega_2)t \\
&+ A_n \cos(\pm\omega_3 + \omega_1 \pm 2\omega_2)t \\
&+ A_x \cos(k\omega_3 + r\omega_1 + s\omega_2)t \\
&+ \ldots
\end{aligned}
$$

Where, the A0 term is the DC component items, the A1 term is the fundamental term, while the A2 term and the A3 term are the 2nd and 3rd order harmonics, respectively. Higher harmonic components have been ignored. These frequency components are produced after the mixer and are filtered out with a bandpass filter. They do not affect any subsequence stages. The Ap and Aq terms are useful IF terms and should be received by the receiver normally. The Am and An components are the third-order intermodulation frequency components and they also contribute to channel interference. It is difficult to use filters to filter out the third-order intermodulation interference. The most effective means of reducing third order interference is by designing and producing a mixing device with good linearity. Integrated mixing devices usually express the level of third-order intermodulation interference using the IP3 point (third order intermodulation intercept point). A large IP3 value indicates a mixer with good linearity. Circuit design that minimizes the amplitude of the RF signal input so that the mixer operates more linearly can also reduce third order intermodulation products.

2. The main parameters of the frequency mixer
   The main technical indicators in the frequency mixer include conversion gain, 1dB compression point, port isolation and so on.

   (1) Conversion gain
   The ratio of RF input power level to the output signal power level is called conversion gain, Gc. I.e.,

$$G_c = 10\lg\frac{P_I}{P_R}$$

In the formula, both the RF input power P_R and IF output power P_I use dBm as the unit.

There exists conversion loss when the conversion gain is <1, therefore, for passive diodes, which is expressed by Lc. While for active frequency mixers such as transistors, FETs or integrated analog multipliers, the conversion gain is frequency gain> 1.
In measuring the conversion gain Gc, the LO drive power must be a fixed power level. For example, for a diode ring mixer with a 50Ω input/output impedance, the LO standard power level is 7dBm. For the integrated analog multiplier MC1596, the LO standard power level is 20dBm.

When measuring and applying the frequency mixer, it should be noted that impedance matching should be used with the three ports of the frequency mixer. When the RF port of the frequency mixer passes through image rejection filter and is connected to LNA, the input impedance in the RF port of frequency mixer must match the output impedance of its filter to ensure the performance of the filter. Generally the output impedance of the filter is 50Ω. Similarly, the output impedance of the IF port of the frequency mixer should match the input impedance of the IF filter. Generally the impedance of an IF filter with a frequency lower than 100MHz is greater than 50Ω.

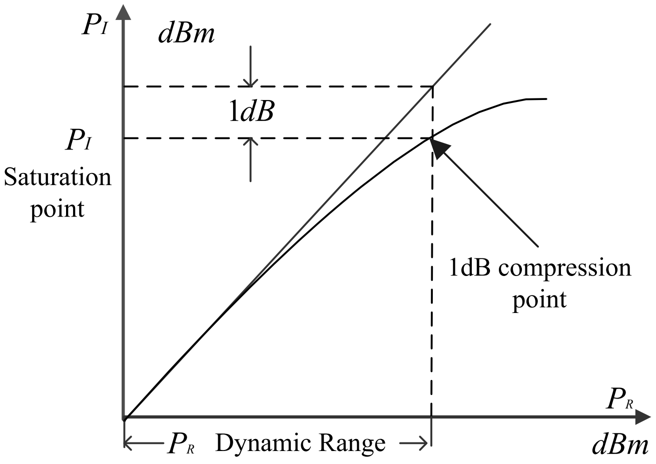
(2) 1dB compression point

The Compression point is used to denote the non-linear distortion of a frequency mixer. For a signal with small RF, the frequency mixer is a linear network. When the RF input level is much smaller than the LO level, the frequency mixer operates linearly. In other words, the RF output increases linearly with an increase in the RF input level. However, when the RF input increases to a certain extent, such as when the difference between the RF input level and the LO level is more than 10dB, the rate of the IF output slows, and the relationship between the RF input and RF output is no longer linear. At this point, the frequency mixer begins to enter saturation and exhibits non-linear distortion as shown in Figure 10-3

The figure shows that the conversion compression point is the point in which the IF output power level deviates from the linear ideal by 1dB. Obviously, the conversion compression point indirectly expresses the extent of the nonlinear distortion of the frequency mixer. For a LNA this 1dB compression point can also be used to represent the linear amplification range for a LNA.

10-3

1dB compression point



(3) Port isolation

The port isolation of the mixer characterizes the balance of the internal circuitry, which determines the amount of feedthrough leakage between the mixer and each port. Theoretically the ports on a mixer should be strictly isolated, but because practical internal mixer circuitry is somewhat unbalanced, it will generate signal feedthrough between each port.

If the isolation between each port of the frequency mixer is low, it will directly affect the following aspects: The leakage of the LO signal port to the RF port will affect the LNA and even radiate through the antenna. With a diode ring frequency mixer in particular, when an LO signal passes through the LO port and leaks into the RF input port, it will transmit out the LO signal through the antenna to create interference in the adjacent channels. The leaking power from the RF port to the LO port makes the LO vulnerable to frequency pulling. When the LO port leaks to the mixer output port, a big LO signal can affect the amplification of the IF signal.

Experiment contents

1. Observe frequency shift.
2. Measure port isolation and conversion gain.
3. Use the GRF-1300A to emit a 2.4GHz modulated signal.

Experiment steps

1. Turn on the GRF-1300A and GSP-730.
2. Set up the GRF-1300A.

- Connect an RF cable from the RF/FM port in the synthesizer/FM module to the IF In port in the Mixer module.
- Connect an RF cable from the USG (USB signal generator) output port to the LO In port in the mixer module.
- Connect an RF cable from the RF output in the mixer module to the RF port of the spectrum analyzer.
- Use PC software to set the USG frequency to 1520MHz.

3. Set the spectrum analyzer as follows:

- Center frequency: 2.4 GHz
- Span:FULL
- Reference level:0dBm
- Resolution bandwidth: Auto

Step1 Frequency F1 2 . 4 GHz/Sec Center 2.4GHz

Step2 Span F2 Full Span

Step3 Amplitude F1 0 GHz/Sec Ref. Level 0.0dBm

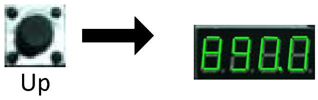
Step4 BW F1 RBW Auto Man

4. Observe the spectrum distribution with the spectrum analyzer. Get the spectrum distribution at the time of frequency mixing. Measure the magnitude of each spectral line and draw it into

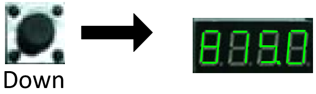
table 10-1.

Step5 Peak Search

5. Adjust the frequency of the RF output in the RF Synthesizer/FM module. Observe the changes on the spectrum analyzer and record it in table 10-1.

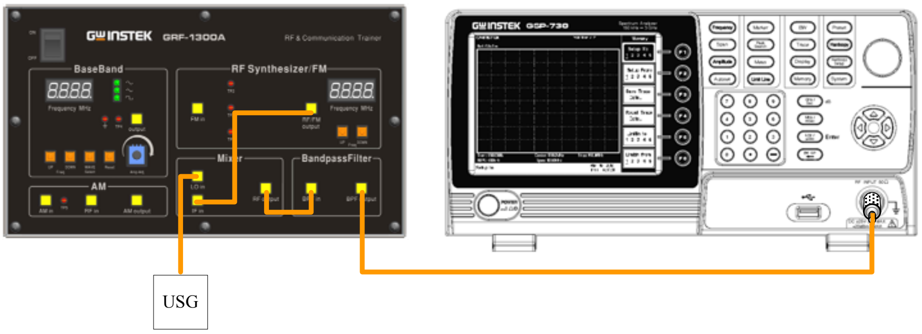
Step6 

6. Adjust the frequency of the RF output in the RF Synthesizer/FM module. Observe the changes on the spectrum analyzer and record it in table 10-1.

Step7 

7. Obtain the spectrum and amplitude of each spectral line according to the previous step, calculate the conversion gain of the down-converted product and calculate the isolation degree in the IF In port. Record the experimental results in the table 10-2.

8. After completion of the above experimental steps, adjust the RF frequency in the RF Synthesizer / FM module to 880MHz. Then, connect the RF output port in the Mixer module to the BPF in port in the Band Pass Filter module with the RF cable. Connect the RF cable that was originally connected to the RF output port in the Mixer module to BPF output port and keep the other connected to the input port of the spectrum analyzer.



9. Spectrum analyzer settings remain unchanged.

10. Observe what changes on the spectrum analyzer and record in table 10-3.

11. Maintain the same connections as used in step 10. Connect the output port in the Base Band module to the FM port in the RF synthesizer/FM module with an RF cable. Adjust the potentiometer in the bassband so that the audio signal is at a certain level.

12. Now set the GSP-730 as follows:

- Center frequency: 2.4GHz
- Span: 50MHz
- Reference level: 0dBm
- Resolution bandwidth(RBW): Auto

Step8 Frequency F1 2 · 4 GHz/Sec Center 2.4GHz

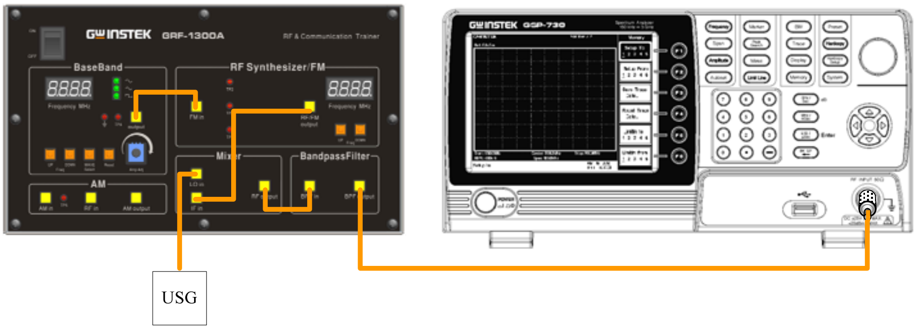
Step9 Span F1 5 0 MHz/mSec Span 50.0MHz

Step10 Amplitude F1 0 GHz/Sec Ref. Level 0.0dBm

Step11 BW F1 RBW Auto Man

13. Observe what changes on the spectrum analyzer and record it in table 10-3.

14. Covert the AM modulated signal to 2.4 GHz according to the method used to generate an AM modulated signal in experiment 5. Record the result in table 10-3.



Experiment results

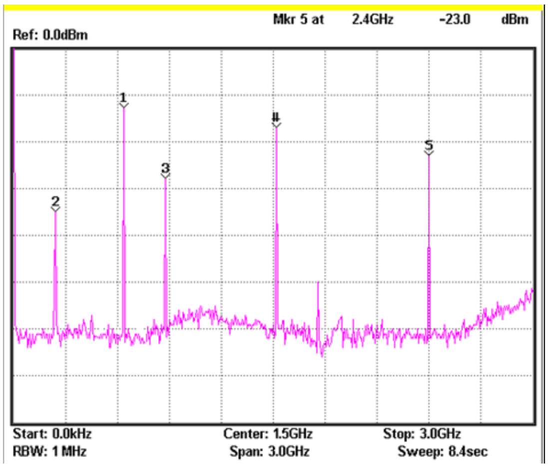
1. Frequency shifting with the mixer

Table 10-1

RF Frequency	Test Results

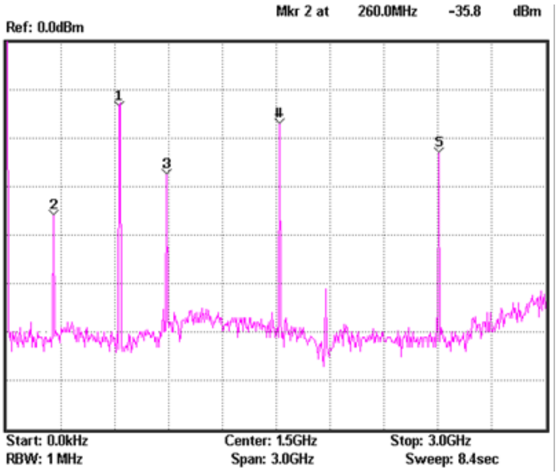
Frequency shifting result

880MHz



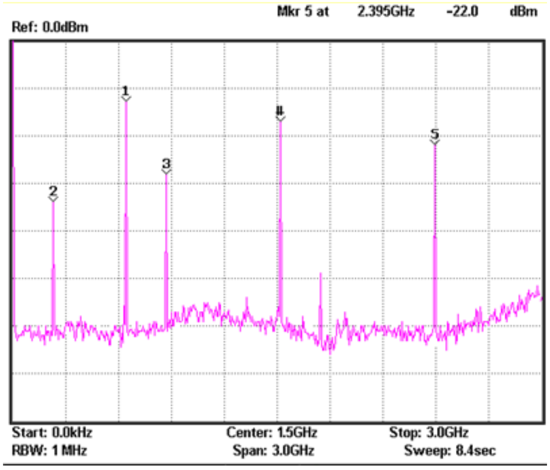
Amplitude of each frequency point:
Point 1:640MHz @-12.2dBm point 2:240MHz@-35Dbm
Point 3:880MHZ@-24.6dBm Point 4:1520MHz@-17.3dBm
Point 5:2.4GHz @-23.0dBm

890MHz



Amplitude of each frequency point:
Point 1:630MHz @-11.6dBm point 2:260MHz@-35.8dBm
Point 3:890MHZ@-26.6dBm Point 4:1520MHz@-17.6dBm
Point 5:2.41GHz @-21.6dBm

875MHz

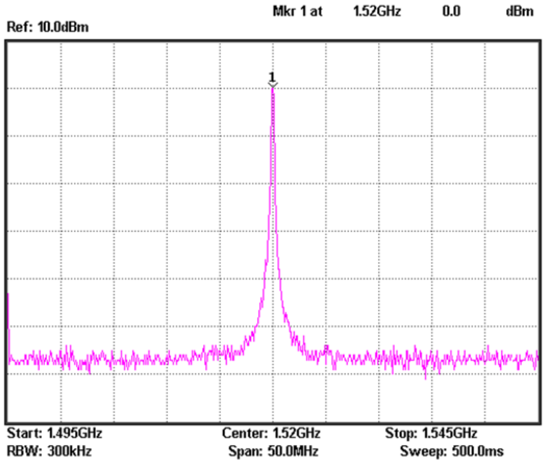


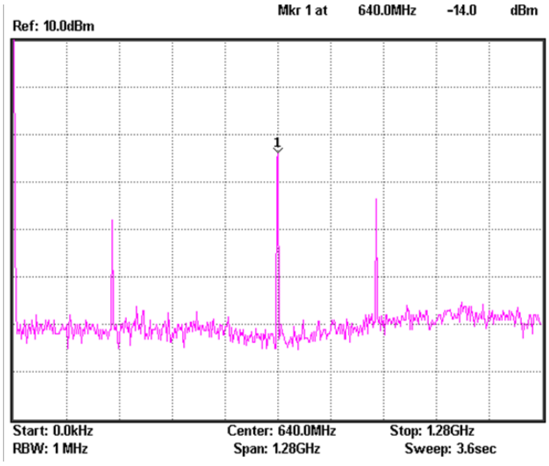
Amplitude of each frequency point:
Point 1:645MHz @-11.3dBm point 2:230MHz@-32.0dBm
Point 3:875MHZ@-27.6dBm Point 4:1520MHz@-16.6dBm
Point 5:2.395GHz @-22.0dBm

2. Conversion gain for the down-converted product and the isolation degree of the IF In port.

Table 10-2 Conversion gain

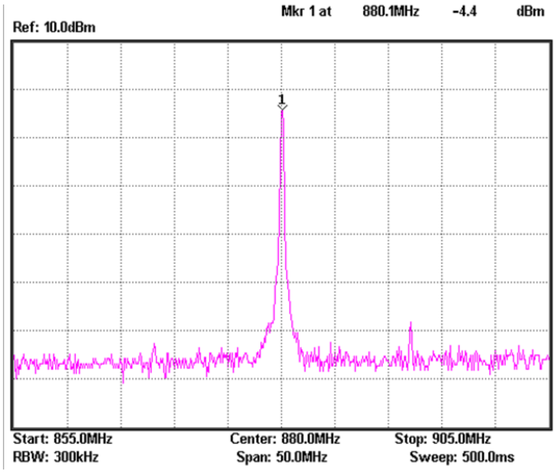
Calculation of gain and isolation

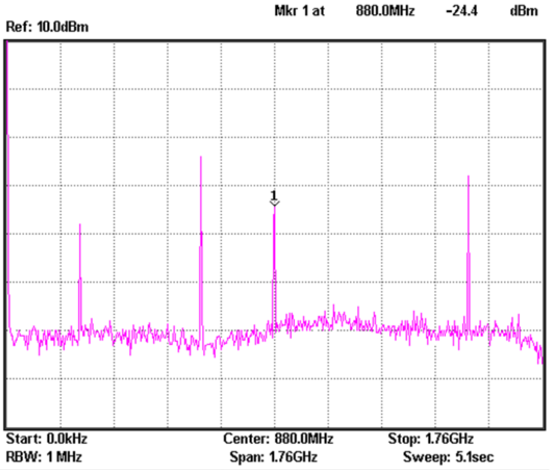




Gain:0.04

IF In port isolation





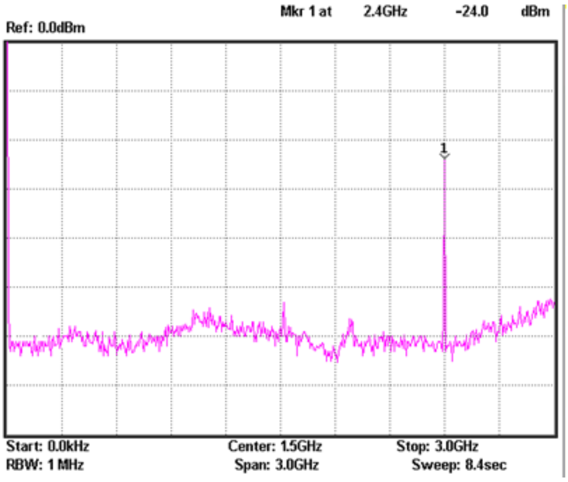
Isolation:0.18

3. 2.4GHz modulated signal

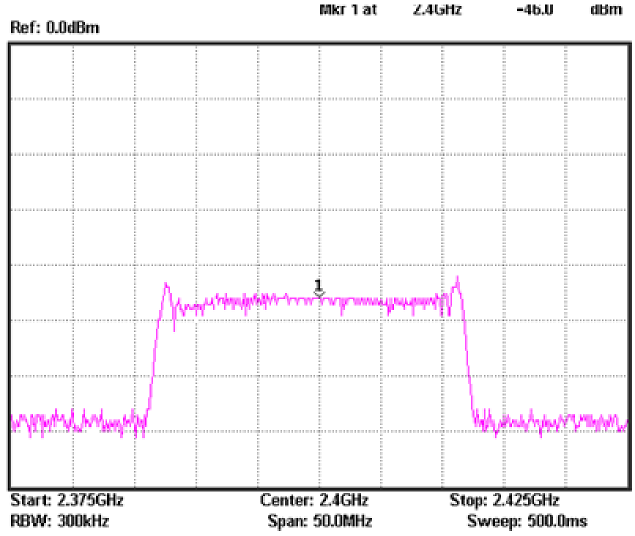
Table 10-3

2.4GHz modulated signal

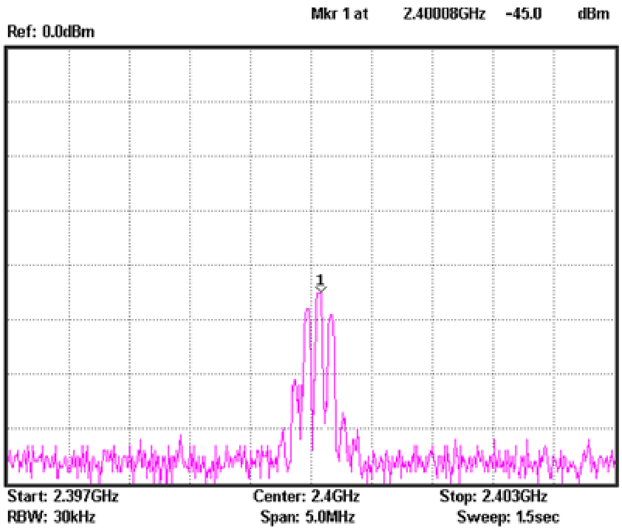
Unmodulated signal



FM modulated signal



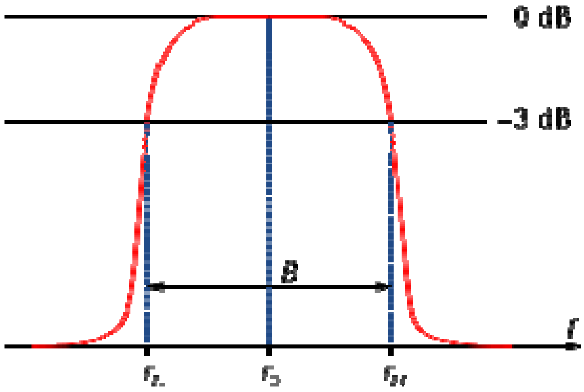
AM modulated signal



Questions

1. What are the characteristics of a bandpass filter?

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range.



2. Why are there 5 frequency points in the output spectrum of the frequency mixer?

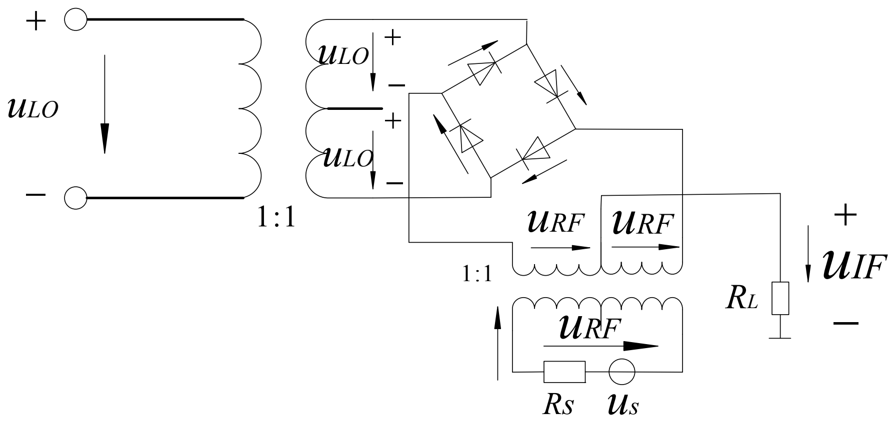
The Am and An components are the third-order intermodulation frequency components and they also contribute to channel interference. It is difficult to use filters to filter out the third-order intermodulation interference. The most effective means of reducing third order interference is by designing and producing a mixing device with good linearity.

Mixer Circuit Introduction*

Relevant information Mixer circuits can be divided into 2 types of circuits: passive and active circuits. Active mixer circuits are commonly formed from single transconductance types, such as single balanced mixers and the Double Balanced Gilbert Mixers. Common passive mixer circuits include diode mixer circuits and passive FET mixer circuits.

1. Diode Double Balanced Mixer Circuit.

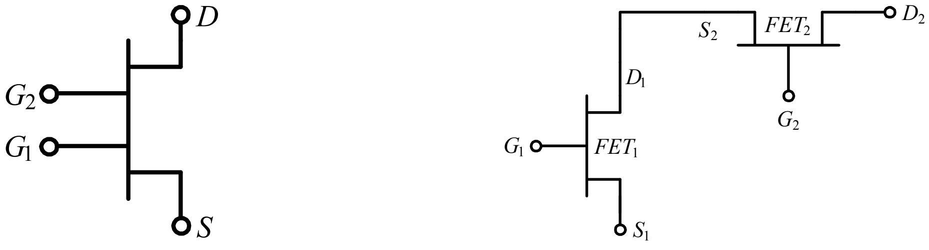
The most common double balanced diode mixer is also known as a ring mixer. It consists of 4 diodes in a loop configuration. It has 3 ports: the LO port, the RF port and the IF ports. If the local oscillator voltage is $u_{LO}(t) = u_{LO}\cos\omega_{LO}t$ and the RF voltage is $u_{RF}(t) = u_{RF}\cos\omega_{RF}t$ respectively, then the LO port and the RF input port both go through transformers into a single-ended input with a balanced input impedance. If the intermediate frequency (IF) port is unbalanced then the LO signal amplitude is greater than the RF signal. In this condition the diodes and the local oscillator control the switching. The intermediate frequency output voltage is determined from the IF output load resistance RL.



The double balanced diode mixer uses four diodes to perform frequency mixing. These four transistors are working in a linear fashion. The isolation characteristics of the 3 ports of the double balanced diode mixer are related to how well matched the diodes are to each other and the symmetry of the transformers.

2. FET Mixer Circuit

Figure 10.1 shows a dual gate field effect transistor. The figure shows that a dual gate field-effect transistor configuration is similar to a single gate configuration, but there is also a second field-effect transistor or a Schottky contact at the gate to form a dual gate field-effect transistor. Usually when simulating or analyzing a circuit design, a pair of single stage transistors are connected in a cascode configuration as it may be difficult to find a suitable dual gate field-effect transistor.



(a) Dual gate field-effect transistor

(b) The equivalent iterative model

Figure 10.1 dual gate field effect transistor and its equivalent iterative model

The main advantages of dual gate field-effect mixers are:
The dual gate field-effect transistor itself; the capacitance between the each gate is very small so therefore the isolation characteristics are very good for the LO and RF signals which are input into the transistor gates.

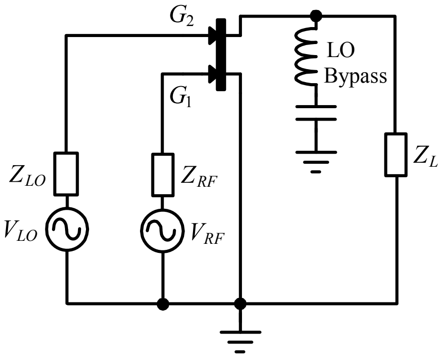


Figure 10.2 A typical dual gate field-effect transistor mixer circuit.

Figure 10.2 shows that dual gate field-effect transistors, unlike single gate transistor mixers, do not need to balance the LO or RF inputs when they are added to the base. Additionally it can also provide conversion gain so that the mixer has an amplifying function. Usually the RF signal is connected to the 1st gate, the LO signal is connected to the 2nd gate and the IF signal is output from the source output. The advantage of such a connection is that the mixer can achieve a lower noise index level. To achieve a better mixing performance, FET1 must be operating in a linear region and FET2 should be biased for saturation. When the LO input is input into the second base terminal, since the LO signal's amplitude is high enough to change the bias voltage of the FET1 source, this results in the transistor operating in the linear region and the saturated regions to modulate FET1 transconductance values, resulting in a mixed signal. Figure 10.3 shows the small circuit equivalent model of a dual gate field-effect transistor mixer.

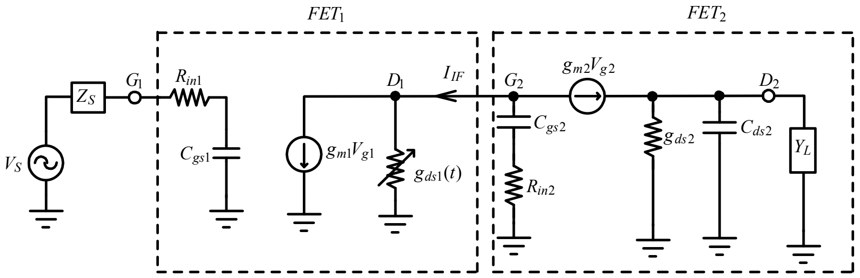


Figure 10.3. Small circuit equivalent model of a dual gate field-effect transistor mixer.

Since the role of mixing is in FET1, we can set FET1 with the mutual conductance value gm1(t) and the drain-to-source admittance gds1(t). Expressed as a Fourier expansion we get:

$$g_{m1}(t) = G_{m0} + G_{m1}\cos(\omega_{LO} + \Phi_{m1}) + G_{m2}\cos(2\omega_{LO} + \Phi_{m2}) + ... \quad (10\text{-}1)$$

$$g_{ds1}(t) = G_{d0} + G_{d1}\cos(\omega_{LO} + \Phi_{d1}) + G_{d2}\cos(2\omega_{LO} + \Phi_{d2}) + ... \quad (10\text{-}2)$$

The drain current for FET1 can be expressed as:

$$I_{IF}(t) = g_{m1}(t)v_{g1}(t) + g_{ds1}(t)v_{d1}(t) \quad (10\text{-}3)$$

$$\begin{aligned} I_{IF}(t) = {} & G_{m0}v_{g1}(t) + G_{m1}\cos(\omega_{LO} + \Phi_{m1})v_{g1}(t) + \\ & G_{m2}\cos(2\omega_{LO} + \Phi_{m2})v_{g1}(t) + ... + \\ & G_{d0}v_{d1}(t) + G_{d1}\cos(\omega_{LO} + \Phi_{d1})v_{d1}(t) + \\ & G_{d2}\cos(2\omega_{LO} + \Phi_{d2})v_{d1}(t) + ... \end{aligned} \quad (10\text{-}4)$$

Put $v_{g1}(t) = v_{g1}\cos(\omega_{RF}) + ...$ into the equation from 10-3. The trigonometric product results in the sum and difference operations. By removing the frequency output items, we obtain:

$$I_{IF}(\omega_{IF}) = 1/2(G_{m1}v_{g1}(\omega_{RF}) + G_{d1}v_{d1}(\omega_{RF}) + G_{d0}v_{d1}(\omega_{IF})) \quad (10\text{-}5)$$

Using this formula we can understand the working principals of the mixer. In addition, when a drain is connected to the LO Bypass, high frequency signals (RF and LO) can be filtered out to improve conversion gain.

For mixer production and analysis we would normally pass the required parameters and equivalent circuit model into computer-aided design software to accurately simulate and predict the mixer conversion gain, port isolation and IP3 etc. However as we do not have such a program but still need to have accurate nonlinear transistor models we will use the 3SK241 transistor. The documentation for this transistor unit has all the data needed to calculate the required information.

Mixer conversion gain is defined as the output of the intermediate frequency signal (IF) and the input signal (RF) power ratio. To achieve a good mixer conversion gain, it is important that we select the bias value that is written on the data sheet as the reference point. Use a spectrum analyzer to determine the maximum conversion gain by adjusting the DC bias from the reference DC bias point. Lastly, we set the circuit bias at VDS = 3V, IDS = 10mA (approximately).

The actual circuit which is based on the 3SK241 dual gate field-effect transistor is shown in figure 10.4. The DC bias is formed from the R1 and R2 resistors, the bypass capacitors from the C3 and C4 capacitors, the RF current choke inductor is made from L3, the low pass filter is made from the C5 and C6 capacitors as well as the L4 inductor.

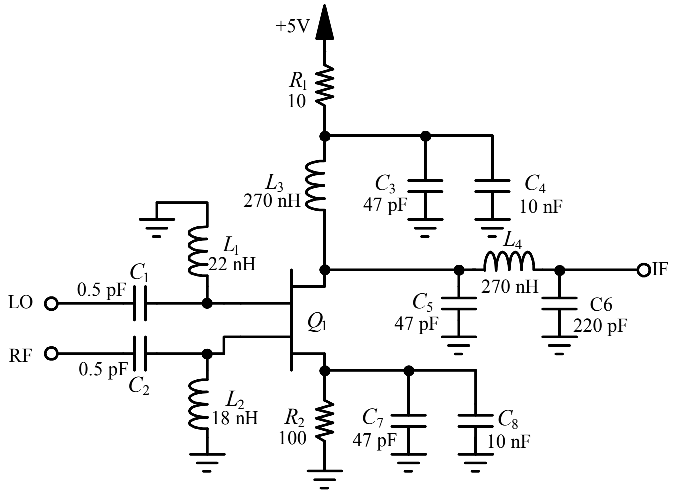


Figure 10.4. 900MHz dual gate field-effect transistor mixer circuit.

TEST for LEARNING OUTCOMES

In the previous experiments, we introduced the concepts behind phase locked loops, amplitude modulation and frequency modulation, and we now have a good understanding of them. But that is not enough to fully grasp RF circuits. This experiment combines these three parts to form one system. Each module in the circuit can be turned on or off via remote commands so that the experiments can be used to diagnose (simulated) malfunctions. When students analyze the causes of these malfunctions, they will have an overall understanding about the relationship and principles behind each one. This helps students build their knowledge of PLLs, AM and FM.

Experiment Aim:

1. Understand how and why a phase locked loop enters the lock state or loses the lock state.
2. Have an understanding of the overall communication system.

Experiment Contents The instructor will send remote commands to the GRF-1300A and create a malfunction. Students can use an oscilloscope, spectrum analyzer and/or other measurement instruments to try to deduce/verify the cause of the malfunction/fault.

1: RF signal Fault Simulation

The Instructor is to set the faults as follows on the GRF-1300A and let the students design a test project to analyze the cause of the malfunction(s).

1. Set the GRF-1300A to the default power-on state.
2. Connect the RF/FM output port to the RF input port on the spectrum analyzer.
3. Establish a connection with PC through a USB cable. (See the section about the GRF-1300A installation).
4. Set the analyzer in accordance with the method in the previous experiment.

Fault 1 Execute the instruction B1:1

Fault description: The Four-digit display on the RF Synthesizer/FM module on the GRF-1300A panel displays 880MHz, but the frequency measured by the spectrum analyzer deviates from 880MHz. The RF frequency can’t be adjusted up or down on the GRF-1300A.

Hypothesis: Although there is a frequency output from the oscillator, it is not locked on to a frequency. In another words, the phase-locked loop does not lock properly. However the oscillator is working properly. Conclusion: It may be due to the phase detector on the phase-locked loop not working properly.

Verification Check to see if the phase-locked loop circuit is working properly. Use a multimeter to measure the voltage at Tp1 and Tp2. From the measurement results, the voltage at Tp1 should be abnormal and normal at Tp2, therefore the PLL isn't working properly.

Fault 2 Execute the instructions B1:0 and B2:1

Fault description The frequency on the RF module cannot be adjusted up or down and there is no signal displayed on the spectrum analyzer.

Hypothesis: A possible reason for there being no RF signal output is that the VCO is not working properly, or a fault occurred in the PLL. This would stop the locked frequency from being adjusted.

Verification: Measure the voltage at Tp1 and Tp2 respectively and check if they are normal to verify the above hypothesis. Using a multimeter, if the voltage is normal at Tp1, but abnormal at Tp2, it could be infered that there is something wrong with the oscillator.

2: FM Fault Simulation

1. Set the GRF-1300A to the default power-on state.
2. Connect the *output* port on the Baseband module to the *FM in* port on the RF Synthesizer/FM module with an RF cable.
3 Turn the potentiometer until the output voltage causes the modulated signal to be seen on the spectrum analyzer.

Fault 1: Execute the instructions B1:1

Fault description: The frequency on the RF module can't be adjusted up or down. The FM wave spectrum can be observed on the spectrum analyzer but the carrier frequency deviates from the displayed value on the GRF-1300A. Turn the potentiometer right and left to see if FM wave deviation changes.

Hypothesis: FM modulation can be performed which means that both the modulating signal and the carrier signal can be output normally. The possibility of the failure of these parts can be excluded. As the carrier frequency can't be adjusted, the PLL is working in the unlocked state.

Verification: Use a multimeter to measure the voltage at Tp1. We should observe that the voltage here is abnormal, so the hypothesis is correct. Go to find where fault lies.

Fault 2 Execute the instructions B1:0 and B2:1

Fault description The frequency on the RF module can be adjusted up or down, but the FM wave spectrum doesn't appear on the spectrum analyzer.

Hypothesis: If no frequency modulation waveform appears, it may indicate that something wrong with the modulating signal or the carrier. As the carrier frequency can't be adjusted, it may mean that the PLL is working in the unlocked state.

Verification: Use an oscilloscope to measure the waveform at Tp3. As a Sine wave output can be found here, it means that the modulating signal output is normal, and that the failure of that part can be excluded. Use a multimeter to measure the voltage at Tp2, and Tp1. We should find that the voltage at Tp2 is abnormal which means the oscillator is not working properly.

Fault 3 Execute the instructions B2:0 and B3:1

Fault description: The frequency on the RF module can be adjusted up or down. No modulated wave appears on the spectrum analyzer, but the carrier spectrum appears on the spectrum analyzer and with the same frequency as that displayed on the RF module.

Hypothesis: As the frequency of the carrier output can be adjusted, that means that the all the circuits on the phase locked loop work properly. But as no modulation can be seen means that the modulating signal output or transmission of the modulating signal has something wrong.

Verification: Use an oscilloscope to measure the signal at Tp3 and Tp4. Here we will find that there is a signal output at Tp4, but none at Tp3. That means that the modulating signal has problems in the transmission process.

Fault 4 Execute the instructions B3:0 and B4:1

Fault description The frequency on the RF module can be adjusted up or down and the FM wave spectrum doesn't appear on the spectrum analyzer. However, the carrier frequency is different with that displayed on the RF module.

Hypothesis: As the carrier output has adjustable frequency means that the all circuits on the phase locked loop work properly. But as modulating signal cannot be seen means that the modulating signal output or the transmission of the modulating signal has something wrong

Verification: Use an oscilloscope to measure the waveform at Tp3 and Tp4. We should find that there is no signal at both Tp3 and Tp4 which means that there is no modulating signal output at all.

3: AM Fault Simulation

1. Set the GRF-1300A to the default power-on state.
2. Disconnect the original connection. Connect the *output* port to the *AM in* port with an RF cable. Connect the *RF/FM output* port to the *RF in* port with an RF cable.
3. Turn the potentiometer until the output voltage causes the modulated waveform to seen on the spectrum analyzer.
4. Set the spectrum analyzer according to the settings used in the previous AM experiment.

Fault 1 Execute the instruction B1:1

Fault description: The frequency on the RF module can't be adjusted up or down, the AM wave spectrum appears on the spectrum analyzer, but the carrier frequency is different with that displayed on the RF module.

Hypothesis: Amplitude modulation can be performed which means that the modulating signal and the carrier signal can be output normally. We can exclude the possibility of the failure of the oscillator and the modulating signal. As the carrier frequency can't be adjusted means that the PLL is working in the unlocked state.

Verification: Use a multimeter to measure the voltage at Tp1. The voltage value at this point appears to be abnormal, so the hypothesis is true. Find where fault lies.

Fault 2 Execute the instructions B1:0 and B2:1

Fault description Modulation does not occur and the frequency on the RF module can't be adjusted up or down.

Hypothesis: Amplitude modulation does not occur which means that the modulating signal or carrier probably has something wrong. Meanwhile, the carrier frequency can't be adjusted which means that the PLL does not work in the locked state.

Verification: Use an oscilloscope to measure the waveform at Tp5. We will find that the sine wave output appears there which means that the modulating signal output is normal, thus we can exclude the possibility of it having failed. Use a multimeter to measure the voltage at Tp2, and Tp1. We will find that the voltage at Tp2 is abnormal, so we can conclude that the oscillator is not working properly.

Fault 3 Execute the instructions B2:0 and B5:1

Fault description The frequency on the RF module can be adjusted up or down, and a spectrum with the same frequency as that displayed on the RF module appears on the spectrum analyzer. But no amplitude modulation appears.

Hypothesis: Amplitude modulation does not occur, but the carrier is output. The carrier frequency can be adjusted, which means that its output is normal. The problem may be caused by the modulating signal not being output or modulating signal not being transmitted.

Verification: Measure the waveform at Tp4 and Tp5 with an oscilloscope. We will find that the waveform output appears at Tp4 but not at Tp5 which means that the modulating signal has a problem in the transmission process.

Fault 4 Execute the instructions B5:0 and B4:1

Fault description: Amplitude modulation doesn't occur. The carrier spectrum appears on the spectrum analyzer and the frequency on the RF module is adjustable.

Hypothesis: No AM appears, but the carrier output appears and its frequency is adjustable. This means that the carrier output is normal. The fault may be with the modulating signal output or in the transmission process.

Verification: Use an oscilloscope to measure the waveform at Tp4 and Tp5. We will find no waveform output which means that the modulating signal has something wrong at the (baseband) output terminal.

The instruction settings listed above are only for the analysis of some possible fault conditions. The instructor can increase the difficulty and set several fault conditions at the same time for students to analyze.

Additional Knowledge*

Principles

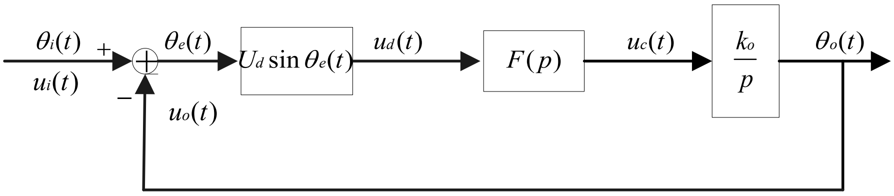
A phase looked loop is made from a phase detector (PD) and a low pass filter (LF). The PLL is a negative phase feedback system. The PD is used to detect the phase error between ui(t)and uo(t) to then get the error voltage ud(t). The LF is used to filter out high frequency components that are output from a multiplier (including the carrier frequency and other high frequency noise) to form the control voltage uc(t). Under the interaction of uc(t), the phase of uo(t) is close to that of ui(t).

Assume that $u_i(t) = U_i \sin[\omega_i(t) + \theta_i(t)]$;
$uo(t) = U_o \cos[\omega_i(t) + \theta_o(t)]$;

Then, $u_d(t) = U_d \sin\theta_e(t)$, $\theta_e(t) = \theta_i(t) - \theta_o(t)$

Therefore, the PD in a PLL is a sine PD. Assume that uc (t)= ud (t)F (p) and F(p) is the transmission operator. ko is the voltage-controlled sensitivity of VCO. The mathematical model of the loop is shown in Figure 1.

Figure 1 Mathematical model of PLL

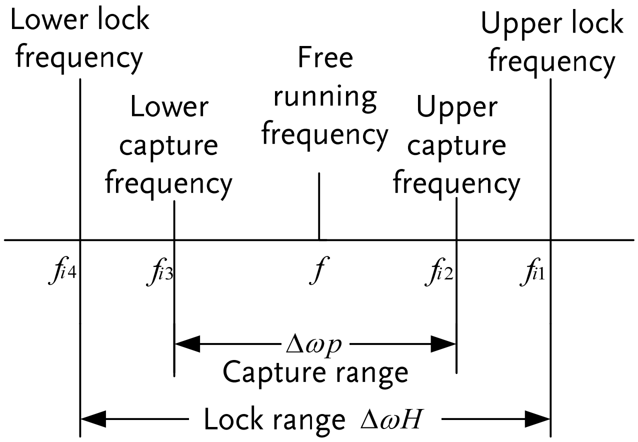


When ui(t) is a sine signal with a fixed frequency (θi(t) is a constant), under the interaction of the loop, the VCO output signal frequency can vary from the free-running frequency ωo(the frequency of the VCO when there is no input signal) to the input signal frequency ωi. At this time θo (t) is a constant too. ud (t) , uc (t) are all DC. We call this the locked state of the loop.

At this time the two frequencies at the two phase detector inputs are exactly the same, but they have a certain phase difference. At this point Δωo =ωi - ωo is defined as the inherent loop frequency difference. If the PLL is originally at the free-running frequency f, and the input signal frequency, fi, can deviate from f to the upper limit value fimax or to the lower limit value fimin, the loop still can enter the locked state through adjustment. The range, fimax - fimin =Δωp is known as the capture range.

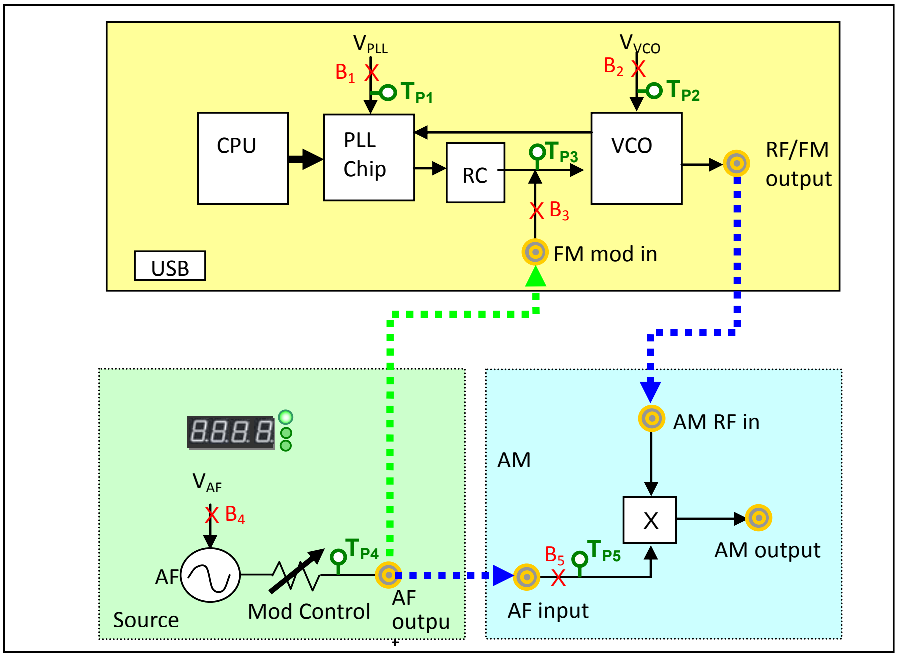
If the loop is already in a state of lock and the VCO output frequency or frequency of the input signal changes (such as a change in temperature or supply voltage), then the phase of the VCO will continuously track the phase of the input signal. This process is known as tracking, the maximum frequency that can be tracked is called the lock range, denoted by ΔωH.

Figure 2 Illustration of the Capture range versus the Lock range.



Generally, $\Delta\omega p < \Delta\omega H$ is a requirement in a PLL. When $|\Delta\omega o| < \Delta\omega p$, the loop can enter the locked state. When $|\Delta\omega o| > \Delta\omega p$ the loop cannot enter the locked state. After the loop has been locked, if $\Delta\omega o$ changes and $|\Delta\omega o| > \Delta\omega H$, the loop can't be kept in the locked state. In both of the last two cases, the loop is in the unlocked state. When $\omega i > \omega o$, the loop is in the unlocked state. Here, $ud(t)$ is an asymmetric beat voltage with a wider positive period. On the contrary when $\omega i < \omega o$, $ud(t)$ is an asymmetric beat voltage with a wider negative period.

Relays are set in each major part of the phase-locked loop on the GRF-1300A. The opening and closing of these relays are controlled by commands. By turning parts of the circuit on or off, we can observe the corresponding events to analyze how parts of the circuit interact. Meanwhile, the five test points are also set on the panel to monitor the presence or absence of the test point signals to determine whether the phase-locked loop is in the locked or unlocked state. The communication system structure is shown below.



APPENDIX

We have included some commonly-used conversion tables for use with the questions.

dBm Conversion Table

dBm, dBuV and dBmV are all absolute units. i.e., they represent a physical quantity. The corresponding conversion tables are below:

dBm	mW	uV	dBuV	dBmV
-30	0.001	7071.07	76.9897	16.9897
-25	0.003	12574.33	81.9897	21.9897
-20	0.010	22360.68	86.9897	26.9897
-15	0.032	39763.54	91.9897	31.9897
-10	0.100	70710.68	96.9897	36.9897
-5	0.316	125743.34	101.9897	41.9897
0	1.000	223606.80	106.9897	46.9897
5	3.162	397635.36	111.9897	51.9897
10	10.000	707106.78	116.9897	56.9897
15	31.623	1257433.43	121.9897	61.9897
20	100.000	2236067.98	126.9897	66.9897
25	316.228	3976353.64	131.9897	71.9897
30	1000.000	7071067.81	136.9897	76.9897

The relationship between dB and dBc

The figures in the table above are based on a 50Ω load. As an example, as -30dBm is equal to 0.001mW or 10^{-6}W, therefore with a 50Ω load it is 7071.07 uV or 0.007071mV. The formulas and derivations from the above table are:

$$P_{inmW} = 10^{\frac{dBm}{10}} \Rightarrow V = \sqrt{P \times R}$$

$$\Rightarrow dBuV = 20 \times \log(\frac{V}{uV})$$

further $dBm = 10 \times \log(\frac{P}{mW})$ $\quad dBmV = 20 \times \log(\frac{V}{mV})$

As for dB and dBc, they are relative units. In terms of power, a difference of 20dB is equal to a difference of 100 times.

Question What is the difference between 0dBm and-50dBm? Is it 50dB or 50dBm?

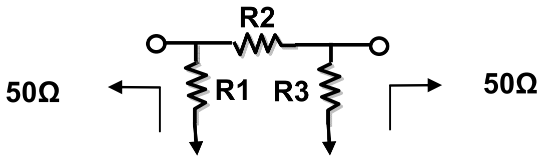
Answer 50dB

Explanation 0dBm = 1mW, -50dBm = 10^{-5}mW, therefore the difference of both is 10^5 times which equal to 50dB or a difference of 0.99999mW

And 0.99999mW is equal to -0.0000434dBm ≈ 0dBm.

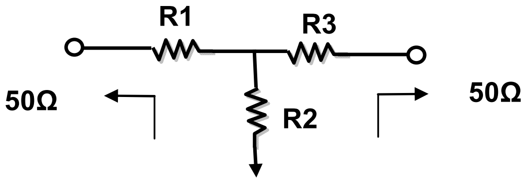
50dBm = 10^5mW = 100W. Obviously 50dBm is the wrong answer.

Resistor Values in π -type Resistance Attenuators



dB	R1	R2	R3
1	869.55	5.77	869.55
2	436.21	11.61	436.21
3	292.40	17.61	292.40
4	220.97	23.85	220.97
5	178.49	30.40	178.49
6	150.48	37.35	150.48
7	130.73	44.80	130.73
8	116.14	52.84	116.14
9	104.99	61.59	104.99
10	96.25	71.15	96.25
11	89.24	81.66	89.24
12	83.54	93.25	83.54
13	78.84	106.07	78.84
14	74.93	120.31	74.93
15	71.63	136.14	71.63
16	68.83	153.78	68.83
17	66.45	173.46	66.45
18	64.40	195.43	64.40
19	62.64	220.01	62.64
20	61.11	247.50	61.11
25	55.96	443.16	55.96
30	53.27	789.78	53.27
35	51.81	1405.41	51.81
40	51.01	2499.75	51.01

Resistor Values in T-type Resistance Attenuators



dB	R1	R2	R3
1	2.88	433.34	2.88
2	5.73	215.24	5.73
3	8.55	141.93	8.55
4	11.31	104.83	11.31
5	14.01	82.24	14.01
6	16.61	66.93	16.61
7	19.12	55.80	19.12
8	21.53	47.31	21.53
9	23.81	40.59	23.81
10	25.97	35.14	25.97
11	28.01	30.62	28.01
12	29.92	26.81	29.92
13	31.71	23.57	31.71
14	33.37	20.78	33.37
15	34.90	18.36	34.90
16	36.32	16.26	36.32
17	37.62	14.41	37.62
18	38.82	12.79	38.82
19	39.91	11.36	39.91
20	40.91	10.10	40.91
25	44.68	5.64	44.68
30	46.93	3.17	46.93
35	48.25	1.78	48.25
40	49.01	1.00	49.01

Modulation Index and Sideband Amplitude Comparison Table

Modulation index	Sideband																
	Carrier	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0.00	1.00																
0.25	0.98	0.12															
0.5	0.94	0.24	0.03														
1.0	0.77	0.44	0.11	0.02													
1.5	0.51	0.56	0.23	0.06	0.01												
2.0	0.22	0.58	0.35	0.13	0.03												
2.41	0	0.52	0.43	0.20	0.06	0.02											
2.5	−0.05	0.50	0.45	0.22	0.07	0.02	0.01										
3.0	−0.26	0.34	0.49	0.31	0.13	0.04	0.01										
4.0	−0.40	−0.07	0.36	0.43	0.28	0.13	0.05	0.02									
5.0	−0.18	−0.33	0.05	0.36	0.39	0.26	0.13	0.05	0.02								
5.53	0	−0.34	−0.13	0.25	0.40	0.32	0.19	0.09	0.03	0.01							
6.0	0.15	−0.28	−0.24	0.11	0.36	0.36	0.25	0.13	0.06	0.02							
7.0	0.30	0.00	−0.30	−0.17	0.16	0.35	0.34	0.23	0.13	0.06	0.02						
8.0	0.17	0.23	−0.11	−0.29	−0.10	0.19	0.34	0.32	0.22	0.13	0.06	0.03					
8.65	0	0.27	0.06	−0.24	−0.23	0.03	0.26	0.34	0.28	0.18	0.10	0.05	0.02				
9.0	−0.09	0.25	0.14	−0.18	−0.27	−0.06	0.20	0.33	0.31	0.21	0.12	0.06	0.03	0.01			
10.0	−0.25	0.04	0.25	0.06	−0.22	−0.23	−0.01	0.22	0.32	0.29	0.21	0.12	0.06	0.03	0.01		
12.0	0.05	−0.22	−0.08	0.20	0.18	−0.07	−0.24	−0.17	0.05	0.23	0.30	0.27	0.20	0.12	0.07	0.03	0.01

Declaration of Conformity

We
GOOD WILL INSTRUMENT CO., LTD.
No. 7-1, Jhongsing Rd, Tucheng Dist., New Taipei City 236. Taiwan.

GOOD WILL INSTRUMENT (SUZHOU) CO., LTD.
No. 69 Lushan Road, Suzhou City(Xin Qu), Jiangsu Sheng, China. declare that the below mentioned product
Type of Product: **RF & Communication Trainer**
Model Number: **GRF-1300A**
are herewith confirmed to comply with the requirements set out in the Council Directive on the Approximation of the Law of Member States relating to Electromagnetic Compatibility (2004/108/EEC) and Low Voltage Directive (2006/95/EEC).

For the evaluation regarding the Electromagnetic Compatibility and Low Voltage Directive, the following standards were applied:

◎ **EMC**	
EN 61326-1:	Electrical equipment for measurement, control and laboratory use -- EMC requirements (2006)
Conducted & Radiated Emission ClassB EN 55011: 2009+A1: 2010	Electrostatic Discharge IEC 61000-4-2: 2008
Current Harmonics EN 61000-3-2: 2006+A2: 2009	Radiated Immunity IEC 61000-4-3: 2006+A2: 2010
Voltage Fluctuations EN 61000-3-3: 2008	Electrical Fast Transients IEC 61000-4-4: 2004+A1: 2010
-------------------------	Surge Immunity IEC 61000-4-5: 2005
-------------------------	Conducted Susceptibility IEC 61000-4-6: 2008
-------------------------	Power Frequency Magnetic Field IEC 61000-4-8: 2009
-------------------------	Voltage Dip/ Interruption IEC 61000-4-11: 2004

Low Voltage Equipment Directive 2006/95/IEC	
Safety Requirements	IEC 61010-1: 2010 (Third Edition)