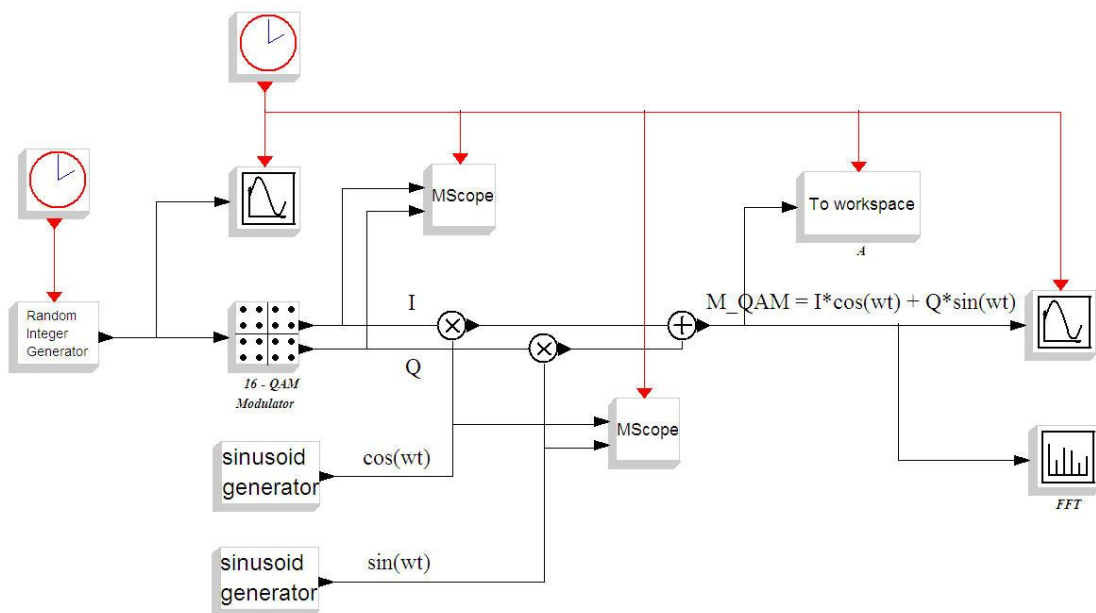




LEARN TELECOMMUNICATIONS BY SIMULATION

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ISBN 978-0-9880490-0-0

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1

Introduction

I have always found that learning something is helped by using more than one of your senses if at all possible. Linking several things together can be a powerful way to anchor something in your mind. One of the benefits of being an amateur radio operator is that when you study to get your license you invariably build or work with equipment. So diagrams and equations are not just abstract things, they relate to real things. Computer simulation adds a further dimension to learning. We are able to actually build a system in software and see the same waveforms that we would see on an oscilloscope or spectrum analyzer without having to build or buy the equipment.

In this text I will overview the most common Telecommunications signal types in use nowadays and build models to simulate their operation on a basic level. Wherever possible, I will compress the spectrum into the audio range so that we can not only see but hear the signal as well. To do this I will use freely available open source tools such as ScicosLab and the Modnum Toolbox. I will also include real world signal captures so that we can compare real hardware signals to our simulations.

When we analyze all the commonly used Telecommunications Signals in use today, we will discover that most of the newer ones use common digital modulation techniques such as PSK Phase Shift Keying, QAM Quadrature Amplitude Modulation and OFDM Orthogonal Frequency Division Multiplexing. A separate section is present for each one of these techniques as well as AM Amplitude Modulation, FM Frequency Modulation and PM Phase Modulation.

During my career as a Telecommunication engineer and Professor of Engineering Technology, I have found that keeping things as simple as possible pays off. I have been able to work on design projects and implement them in the field as well. I worked in many countries and learned valuable lessons. I always like doing measurements different ways on different equipment/systems and getting approximately the same answer. I like equipment that is small, rugged, portable and battery powered (many telecom sites only have DC power). Things never quite go as planned, so being flexible and organized is essential.

Building Telecom models in software also provides a bridge to DSP Digital Signal Processing. DSP is used in all branches of Telecommunications. Once a signal is described mathematically in a discrete fashion, then DSP algorithms can be applied. Young people these days love using computers, so tying math and computers together is a win-win process.

This text has been designed as an e-book. In order to see a diagram, just mouse over the figure and the hyperlink will open up the appropriate drawing. Links have been included to descriptive videos and code files. The video [intro.mp4](#) explains how to use the text. Appendix A and video [scicos.mp4](#) describes the installation and use of ScicosLab and the Modnum Toolbox. Read this section first!

www.clarktelecommunications.com

2

Open Source Tools & Instrumentation. Scilab, ScicosLab.

In order to build the various models and scripts used in this text, I will use ScicosLab or Scicos with the Modnum Toolbox. This powerful software is Open Source and freely available for download:

ScicosLab Latest Version 4.4.1 as of Apr 2012:

www.scicoslab.org

Modnum Toolbox Version 4.2.2 as of Apr 2012:

www.scicos.org/ScicosModNum/modnum_web/web/eng/eng.htm

Appendix A and video [scicos.mp4](#) contain detailed instructions how to download, install and use this software. Most examples in the text are built two ways. The first way is using a script program in ScicosLab and the second way is using the graphical blockset from the Modnum Toolbox within Scicos.

For real world signal captures, I will use either the RFSPACE SDR-IQ (0 - 30MHz) Software Defined Receiver or the Signal Hound SA44B Software Defined Spectrum Analyzer (0 - 4.4GHz).

RFSPACE SDR-IQ: www.rfspace.com/RFSPACE/SDR-IQ.html

Signal Hound: www.signalhound.com/SA44B.htm

3

Overview of Telecommunications Signals

Let us consider some of the most popular Telecommunications signals in use nowadays. **Fig 3.1** Lists the various systems. There are various ways to classify these signals:

- Personal, Commercial, Industrial, or Military
- Broadcast
- Baseband or Modulated
- Wired (Cable, Fiber Optics, Power Line Carrier) or Wireless
- Terrestrial or Satellite

Popular Telecommunications Signals	Description
Cellular Telephony	Personal, Wireless, PSK or CDMA
Internet	Personal, Wired, OFDM
WiFi	Personal, Wireless, OFDM
HDTV	Broadcast, Wireless, ASK
FM Radio	Broadcast, Wireless, FM
Satellite Radio	Broadcast, Wireless, PSK
AM Radio	Broadcast, Wireless, AM
Telephony Landline	Personal, Wired, Baseband Analog

Fig 3.1 Popular Telecommunications Signals

For example consider Cellular Telephony. Cellular Telephony uses Wireless to communicate between the subscriber cell phone and the cellular base station. Various modulation techniques are used. For instance GSM and CDMA are two widely used techniques. GSM uses a type of digital phase modulation or PSK. Another popular signal is analog FM radio. FM radio has been around since the 1950's. It allows for stereo transmission with excellent sound quality and very simple transmission equipment.

When we consider all the various signals, we see that they all contain some combination of the basic building blocks that we will cover in the next chapters:

- Baseband analog and digital
- AM amplitude modulation analog and digital
- FM Frequency modulation analog and digital
- PM Phase modulation analog and digital
- QAM Quadrature Amplitude Modulation, combination of digital AM & PM
- OFDM Orthogonal Frequency Division Multiplexing, many PSK/QAM signals
- CDMA Code Division Multiple Access

Digital Telecommunications systems are often analyzed according to the OSI or TCP/IP models, **Fig 3.2**. In this text, we will be considering the so called Physical 1 Layer. Upper layers are concerned more with software concepts. The Physical 1 Layer is concerned with the actual signal voltage that is placed on the cable or wireless link.

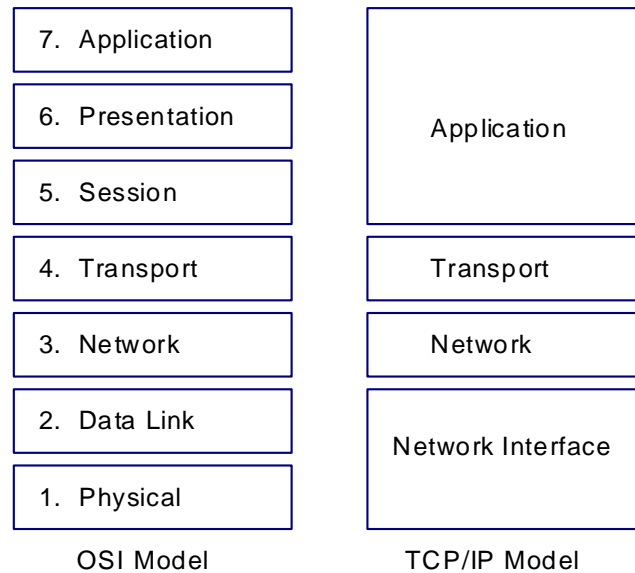


Fig 3.2 OSI & TCP/IP Models

The video [over_sigs.mp4](#) discusses these concepts further.

4

Baseband Analog and Digital Signals

4.1 Baseband Analog - Single Tone

Baseband is a relative term and refers to frequencies that are close to DC and have not been modulated or shifted by a carrier. Human speech as monitored from a microphone contains frequencies from about 20 Hz to 7KHz. Human hearing extends to about 20KHz max. An analog video signal contains frequencies from approx. DC to several MHz. A baseband data signal contains frequencies from approx. DC to the data rate and beyond. The video [bb.mp4](#) introduces these topics.

The simplest of all baseband signals is a single tone. **Fig 4.1** [bb_tone.sce](#) is a ScicosLab program to generate a single tone at 1000Hz and plot the waveform in time and plot its spectrum in the frequency domain. **Fig 4.2** [bb_tone.cos](#) does exactly the same thing but uses the Scicos graphical block structure. Both files are explained in the demo file [bb_analog.mp4](#). **Fig 4.3** shows the time domain and spectral display of the single tone.

Note that a single tone has a single line spectrum at the tone frequency. Conversely, a line in the spectrum of a signal indicates that the signal contains a tone component at that frequency.

```

1 //This file simulates a single baseband tone
2 //Am = tone amplitude in volts peak
3 //Fm = modulation frequency
4 //Fs = sampling frequency 22050Hz
5 //J.Clark April2nd-2012
6 -----
7
8 //Enter the tone parameters
9 Am=1;
10 Fm=1000;
11 -----
12
13 //Calculate the tone waveform
14 nm=2*pi*Fm*Fs;
15 Ts=1/22050;
16 Ts=1/Fs;
17 t=0:Ts:1;
18 h=size(t, '**');
19 h=mat*sin(nm*t);
20 c1f(0);
21 c1f(1);
22 -----
23
24 //Graph The tone waveform
25 //scf(0) open graphic window #0
26 scf(0);
27 plot(t, h);
28 xtitle("Baseband Single Tone", "Time Secs", "Amplitude Volts")
29 -----
30
31 //Calculate the spectrum with fft
32 //scf(1) open graphic window #1
33 scf(1);
34 y=fft(h);
35 sample_rate=1/Ts;
36 f=sample_rate*(0:(h/2))/h;
37 n=size(f, '**');
38 t=max(abs(y(1:n)));
39 plot2d(f, 20*log10(abs(y(1:n))/t));
40 xtitle("Baseband Single Tone", "Frequency Hz", "Relative Amplitude dBc")
41 -----

```

Fig 4.1 Baseband Analog Single Tone
[bb_tone.sce](#)

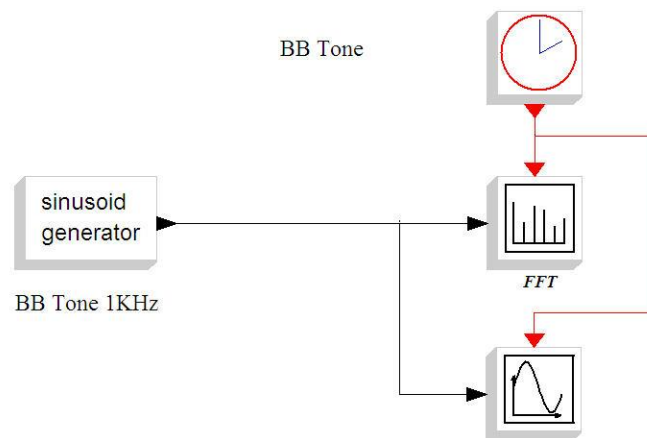


Fig 4.2 Baseband Analog Single Tone
[bb_tone.cos](#)

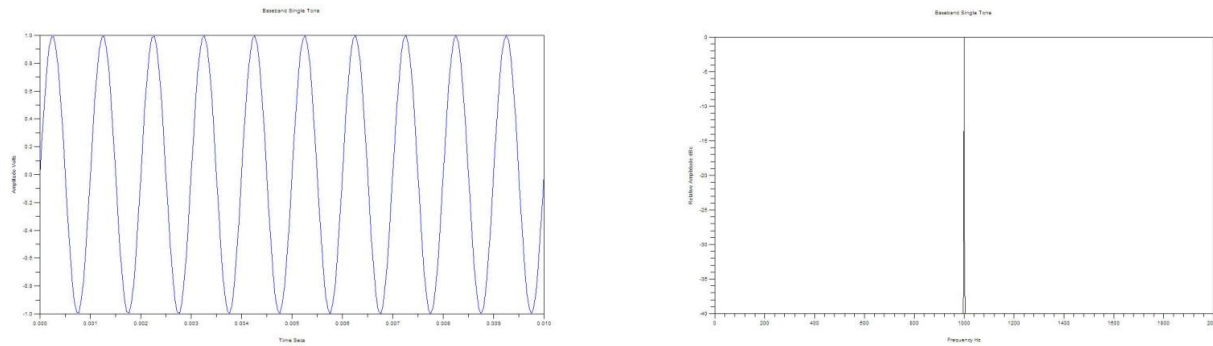


Fig 4.3 Baseband Analog Single Tone [bb_tone.sce](#) Scope & Spectral Display

4.2 Analog Baseband - Multiple Tones

In most cases the baseband will consist of a more complicated signal consisting of many tones. Speech for instance consists of a multiple tones and music consists of hundreds of tones. To get a feeling for this, **Fig 4.4** [bb_tones.sce](#) & **Fig 4.5** [bb_tones.cos](#) show the time and frequency domain displays of a baseband signal consisting of 3 tones with different frequencies and amplitudes:

- Tone 1 = 1KHz @ 3 Volt
- Tone 2 = 2KHz @ 2 Volt
- Tone 3 = 3KHz @ 1 Volt

```

1 //This file simulates a 3 tone baseband
2 //Am = tone amplitude in volts peak
3 //Fm = modulation frequency
4 //Fs = sampling frequency 22050Hz
5 //J.Clark April2nd-2012
6 //-----
7
8 //Enter the tone parameters
9 Am1=3;
10 Fm1=1000;
11 Am2=2;
12 Fm2=2000;
13 Am3=1;
14 Fm3=3000;
15 //-----
16
17 //Calculate the tone waveform
18 vm1=Am1*cos(2*pi*Fm1*t);
19 vm2=Am2*cos(2*pi*Fm2*t);
20 vm3=Am3*cos(2*pi*Fm3*t);
21
22 Ts=1/22050;
23 Te=1/Fs;
24 N=1/Te;
25 h=ones(1,N);
26 Vm=Am1*cos(2*pi*Fm1*t)+Am2*cos(2*pi*Fm2*t)+Am3*cos(2*pi*Fm3*t);
27 c1F(0);
28 c1F(1);
29 //-----
30
31 //Graph The tone waveform
32 //scf(0) open graphic window #0
33 scf(0);
34 plot(0,Vm);
35 title(0,"3 Baseband Tones", "Time Seconds", "Amplitude Volts");
36 //-----
37
38 //Calculate the spectrum with fft
39 //scf(1) open graphic window #1
40 scf(1);
41 y=fft(Vm);
42 sample_rate=1/Ts;

```

Fig 4.4 Baseband Analog Tones
[bb_tones.sce](#)

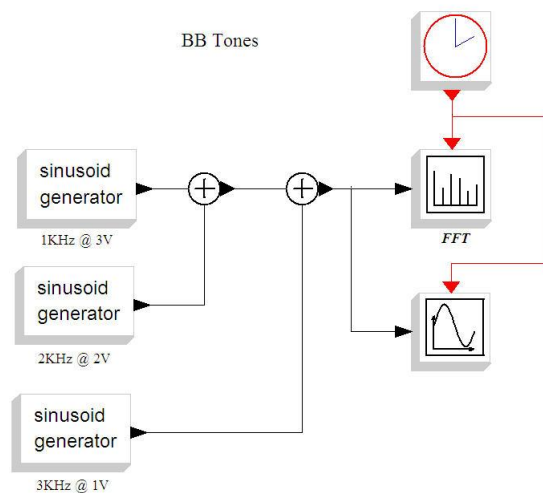


Fig 4.5 Baseband Analog Tones
[bb_tones.cos](#)

In general, the sum of many sinusoids of different amplitudes and phases but the same frequency will give a sinusoid at that frequency with a different amplitude and phase given by the vector addition of each component. However, the addition of sinusoids of different frequencies, amplitudes and phases will give rise to a non-sinusoidal periodic signal. This is further explained in [bb_analog.mp4](#).

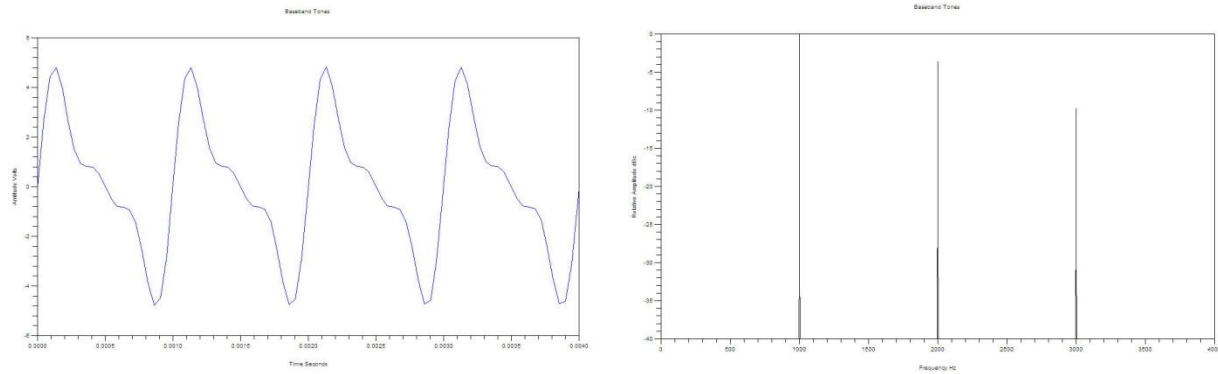


Fig 4.6 Baseband Analog Tones [bb_tones.sce](#) Scope & Spectral Display

From **Fig 4.6** we see that the addition of the 1KHz, 2KHz and 3KHz tones gives rise to a non-sinusoidal periodic wave of 1KHz.

Consider the spectrum of the baseband tones in **Fig 4.6**. Note that there is a discrete line for each component frequency. We can convert the ratio of the voltage of each component and see if the relative spectrum amplitude indicates the same thing:

Component	Relative Amplitude	$\text{dB}=20\log(V/V_{\text{ref}})$	Fig 4.6 Spectrum
1KHz	$3/3 = 1$ reference	0 dBc	0 dBc
2KHz	$2/3$	-3.5dBc	-3.5dBc
3KHz	$1/3$	-9.5dBc	-9.5dBc