HF High Frequency Radio Telecommunications

Learn by Simulation

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1 - Introduction

1.1 - Why HF Radio?

In this day and age of instant voice, video and text messaging one might ask the question why one would possibly consider using HF radio, the same technique that Marconi used to transmit from Poldhu in Cornwall to St. John’s Newfoundland in 1901. Our modern telecommunications infrastructure is based on large bandwidth fibre optic cables that span continents and oceans. Local communications within cities is done increasingly over cellular and Wi-Fi networks operating at UHF and microwave frequencies. There is still of course a large network of interconnected standard telephony central offices that connect by landline to subscribers.

HF radio still has a particular niche, however. It is ideal to communicate basic low speed data/voice to remote locations that have no infrastructure or to mobile platforms. In other circumstance, it may be the only means of communication. Recent studies of natural and man-made disasters paint a grizzly picture of how things can rapidly collapse to nothing. One does not have to look far: the earthquake in Haiti in 2010, Hurricane Katrina in 2005, and the tsunami in Thailand in 2004. In all these events HF played a key role. The ITU International Telecommunications Union recognizes the usefulness of HF radio (Ref.1).

A large badly timed solar flare could devastate satellite communications. This in turn could seriously affect GPS and timing circuits used on terrestrial networks. The movie “Gravity” (Ref.2) described another serious situation where an explosion detonated in the GEO satellite belt could knock out all satellite communications and turn the belt into a circulating junk field, all very scary. Lastly all cables whether they are simple telephone twisted pair or fiber optic OC-192 cables suffer from backhoe problems, or the accidental slicing of a cable.

HF radio allows point to point voice and data communications. Although ionospheric propagation is extremely variable, measurement techniques using ionosondes give an accurate daily picture of activity. This data can be used to allow computer propagation analysis of path performance on a real time basis. Using known beacon stations, this performance can be checked as to accuracy. HF radios equipped with ALE (Automatic Link Establishment) choose the optimum frequency with best performance for a particular link. Each HF station can be equipped with a call sign, so that any station within a group can be automatically reached.

Modern HF radios are rugged, solid state and portable. It has been proven in many cases, that when disaster strikes, all conventional infrastructure such as telephone central offices, cell base stations, power and broadcasting, all fail. This currently happens almost on a monthly basis all over the world. HF radio is not linked to any of these systems and can survive to provide close < 100Km and long range >1000Km communications. HF generally provides only one voice channel with option for data at a relatively low speed. This is adequate for many applications.

The table below summarizes some of the important advantages and disadvantages of HF radio.

Advantages HF radio	**Disadvantages HF radio**
Light, rugged, portable, infrastructure independent. Ideal for remote areas or in disaster communications.	Low bandwidth channel <= 9600bps. Not suitable for multimedia transmission. Low bit voice or text type messages.
Near in communication < 100Km via NVIS and long distance nx1000Km via ionospheric reflection	Subject to ionospheric propagation disturbances. This can be mitigated using ALE.
Variety of antennas available to match transmission mode	Solar Flares may cause outages at Poles PCA Polar Cap Absorption
ALE allows increased reliability constant channel monitoring. Selective Call allows station addressability	Trained personnel required. Using ALE & Selective Call reduces need for schedules and rigorous procedures.
Low cost, no bandwidth charge. Cross patching with VHF/UHF/Cell. Voice and data can be encrypted	Specialized communications area. Every country has an amateur radio community that can assist as required.

1.2 - Brief Historical Development

Guillermo Marconi made his first trans-Atlantic communication to Signal Hill in St. John's Newfoundland in 1901. He used long wavelength high frequency radio. HF radio saw extensive use and development in World War I (Ref.3). Radios were built using the spark gap principle and were inductively coupled to the antenna. Detectors were either a type of Branly coherer or magnetic detector or "maggie". Towards the end of the war, the audion or valve made an appearance. Edwin Armstrong invented the super regenerative receiver and the superheterodyne principle. So by the time of World War II, radio equipment used reliable valves or tubes, using continuous wave with superheterodyne operation.

After World War II and up to the mid 1970s, HF was used mostly by amateur radio operators, the military, resource companies and those needing communications in remote areas. Radios used tubes, and were quite large requiring extensive power supplies. Frequency accuracy was either by fixed crystals, or by tuning to a known frequency/time standard transmission such as WWV or CHU (Ref.4).

A significant advancement was made in the late 50's when Dr. Trevor Wadley invented the first synthesized radio using his famous "Wadley Loop". This was sold as the Racal RA-17. Following this, synthesized radios with good frequency accuracy came on the market, featuring solid state designs with good portability.

Figure 1.1 Famous HF Radios - RA17 - XCR30 - SBX11a

The Barlow and Wadley XCR-30 was one of the first units available to the general commercial market. It also had a 1st IF at 45MHz which was revolutionary at the time. Canada was a world leader in rugged portable HF equipment. The famous Spilsbury SBX-11a was sold worldwide up to the late 90's. SSB transmission gradually replaced AM transmission as the frequency accuracy of radios improved

Figure 1.2 shows several generations of HF equipment on the author's radio bench. The Hammarlund HQ-100AC all band shortwave receiver was purchased in 1964. It was a single conversion all tube radio with first IF at 455KHz. The Drake TR-4C was purchased in 1973. It was an all tube transceiver covering all the amateur bands from 80m to 10m. The Sony ICF7600 shortwave receiver came out in the early 1980s and was completely transistorized with a digital synthesizer. The Elecraft K2 purchased in 2003 is a solid state all band transceiver with synthesizer and microcontroller control of all settings. The SDR-IQ purchased in 2006 is a so called SDR or software defined radio where the majority of the receiver functions are performed in software.

Figure 1.2 – Several Generations of Amateur HF Transceivers and Receivers

During the 1980s before small scale portable satellite equipment became available, considerable work was done to improve the performance of HF radio systems. The invention and introduction of ALE (Automatic Link Establishment) MIL-STD-188-141A in 1988 was a huge step forward. ALE continually monitors a set of HF channels spread from 1.6 to 30MHz and chooses the best channel available automatically (Ref.5).

Digital Signal Processing DSP has made extensive inroads into Telecommunications since the advent of the microprocessor in the early 1970s. In HF radio, DSP has seen wide use in several areas such as specialized audio signal processing, filtering and noise blanking. In Software Defined Radio SDR, the basic structure of a receiver or transceiver is constructed using DSP, not just selected audio processing functions. DSP is also used in various digital modems that interface with a transceiver’s SSB input.

A modern amateur radio or commercial HF transceiver will have the following features:

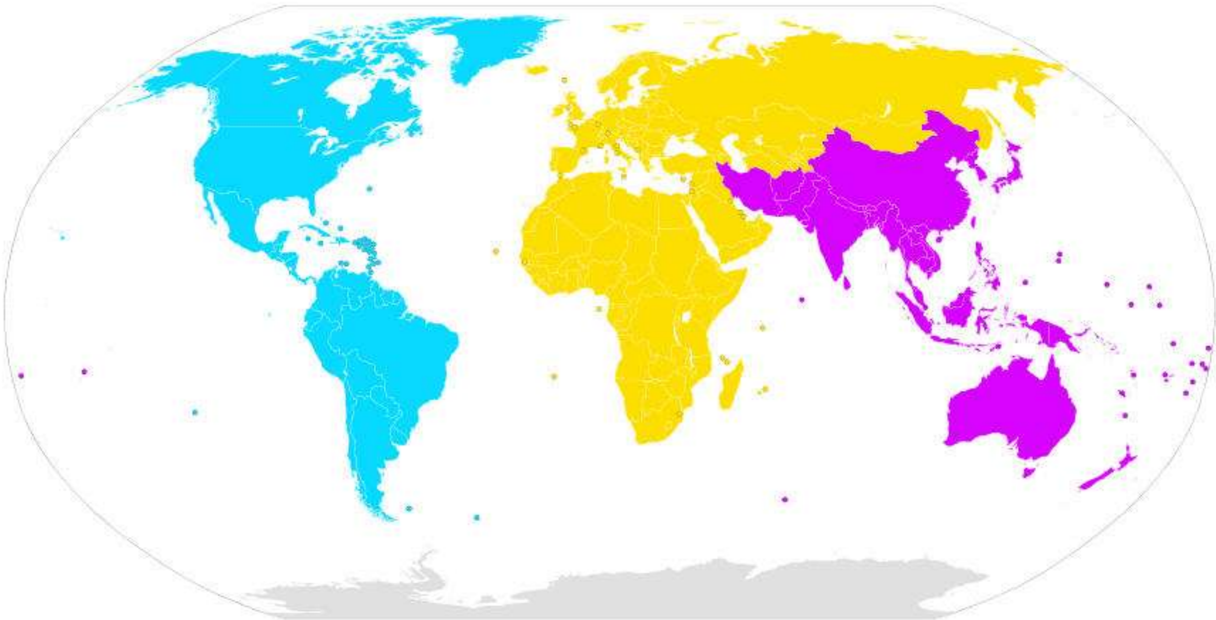
- All solid state, lightweight, rugged, DC powered
- Microcontroller operation of many functions
- HF synthesizer operation
- SSB, CW and interface for digital modes operation via the SSB interface
- ALE and Selective Call capability (PCALE for amateur operation)

1.3 - HF Frequency Bands

Various types of users can be found in the HF frequency bands. The list below is a brief summary:

- Amateur Radio Operators
- Government and Military Agencies
- Nautical Ship to Shore communications
- GMDSS Global Marine Distress & Safety System
- Aircraft Air/Ground communications
- ACARS Aircraft Communications Addressing and Reporting System
- OTH Over the Horizon Radar systems
- Citizens Band Radio
- Short Wave Broadcasting Stations for International and Regional service

All of the above users have their own particular frequency bands within the overall HF bandwidth. The ITU International Telecommunications Union defines HF radio to be Radio Band 7 between 3MHz and 30MHz (Ref.6). Practically HF users start at the edge of the AM broadcast band which can be 1.61MHz to 1.71MHz depending on the ITU region. The ITU defines 3 world regions Figure 1.3 (Ref.7):



ITU Region 1 = Yellow = Europe, Africa, Middle East, Soviet Union
ITU Region 2 = Blue = Americas and Pacific Islands
ITU Region 3 = Purple = Asia, Iran, Oceania

Figure 1.3 ITU Regions

Canadian Amateur Radio HF Bands
2190m = 135.7, 137.8KHz
160m = 1.8 - 2.0MHz
80m = 3.5 - 4.0MHz
60m = 5.332, 5.348, 5.3585, 5.373, 5.405MHz
40m = 7.0 - 7.3MHz
30m = 10.1 - 10.15MHz
20m = 14.0 - 14.35MHz
17m = 18.068 - 18.168MHz
15m = 21.0 - 21.45MHz
12m = 24.89 – 24.99MHz
10m = 28.0 - 29.7MHz

Figure 1.4 Canadian Amateur Radio Band Frequencies

Figure 1.4 gives a list of the Canadian Amateur Radio Frequency bands (Ref.8). This list is representative of frequencies used by HF radio systems both amateur and commercial. Amateur radio bands differ slightly from country to country depending on ITU region.

1.4 - Methodology

In this text I will focus on the basic design and operational aspects of HF radio. The ultimate goal is to be able to plan a link between two points and be able to predict as best as possible what the voice and data performance will be. In all cases a hands-on approach is used. Wherever possible, all block diagrams and circuits will be built in software – either ScicosLab/Scicos (Ref.9 & Ref.10) or LTspice IV (Ref.12). I will follow the same approach as used in "Learn Telecommunications by Simulation" (Ref.11) where I covered analog and digital communications: baseband, AM/SSB, FM/PM, PSK and QAM. All chapters have supporting videos and equipment demonstrations.

Chapter 2 introduces the sampling theorem and the advantages of digital communications for noise removal by signal regeneration. In Chapter 3 we examine various HF receiver and transceiver structures by building and experimenting with the associated block diagrams. In Chapter 4, we cover Frequency Synthesizers that are a crucial component for all modern HF equipment. Various synthesizers are examined such as the Divide by N Phase Locked Loop and the DDS or Direct Digital Synthesis types. Chapter 5 incorporates these ideas into the SDR_U hardware receiver design for Zero IF Direct Conversion.

Chapter 6 looks at HF modulation techniques with the emphasis on the latest digital modems. Chapter 7 examines the celestial navigational principles that apply to HF radio propagation, in particular solving the spherical triangle. Finally Chapter 8 looks at the ultimate goal of link analysis and performance prediction with detailed case studies.

The HF radio channel is one of the most unforgiving channels that exist in modern telecommunications. Pioneering work that has been done in this area has been used and applied in all wireless technologies.

1_intro.mp4 summarizes this introduction.

1.5 - Acknowledgements

My thanks to Ramine Nikoukhah of INRIA for his valuable suggestions in using Scicos and to Nino Porcino I8BLY and Kok Chen W7AY for their help in implementing digital modems.

2 - Basic Analog and Digital Transmission

2.1 - Analog Transmission

The sampling theorem forms the basis of digital transmission. An analog signal is sampled by a sampler and these samples are then converted to numbers, typically by a pulse code modulation process. The PCM samples can then be transmitted or manipulated as desired. In a simple baseband transmission system, the PCM samples are transmitted by a two level data signal. This signal can withstand a fair amount of noise, because it can be regenerated.

An analog signal, however, cannot be regenerated to remove noise. This is one of the great advantages of digital transmission. To illustrate this, we will examine two models. The first model analog_trans.cos in Figure 2.1 is analog baseband transmission. The second digital_trans.cos is digital baseband transmission shown in Figure 2.11. Ref.11 covers baseband signals in detail.

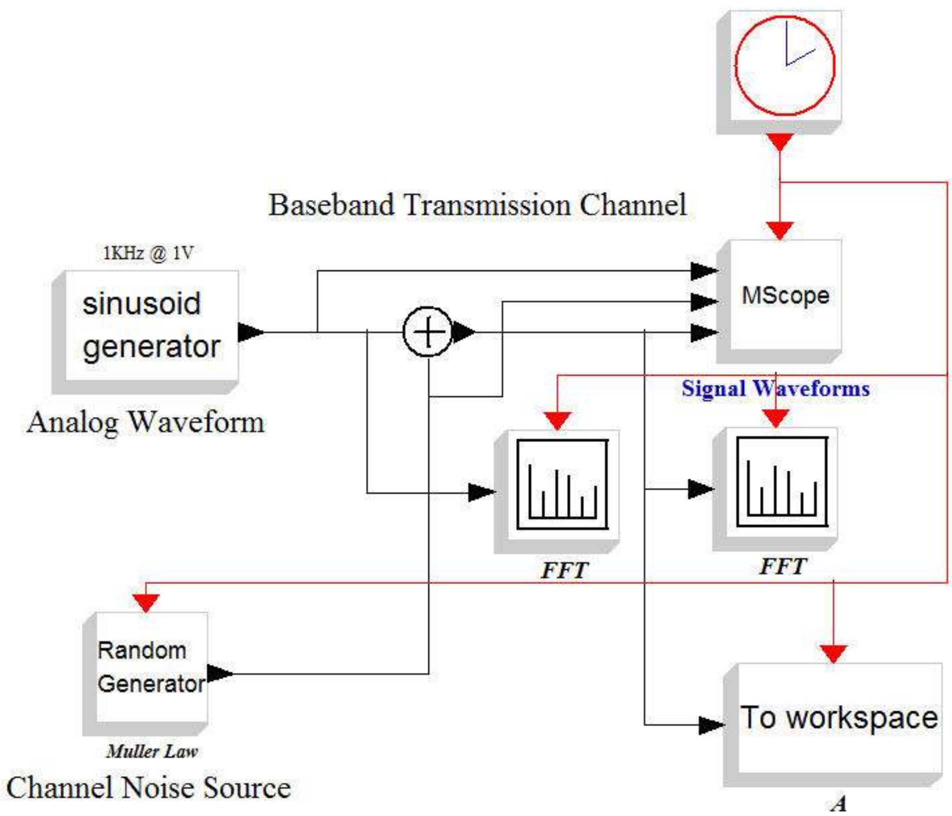


Figure 2.1 Analog Transmission through Baseband channel analog_trans.cos

In Figure 2.1 we have an analog signal represented by a simple 1KHz tone transmitted through a baseband channel where a noise signal (represented by a random generator) is added. We can increase or decrease the amount of noise by adjusting the parameter “n” in the context. The signal spectrum is examined before and after the noise is added. The output is also captured as a structure A(volts_j, time_j), so that we can generate a WAV file and listen to the signal with noise. “n” is set at 0.2.

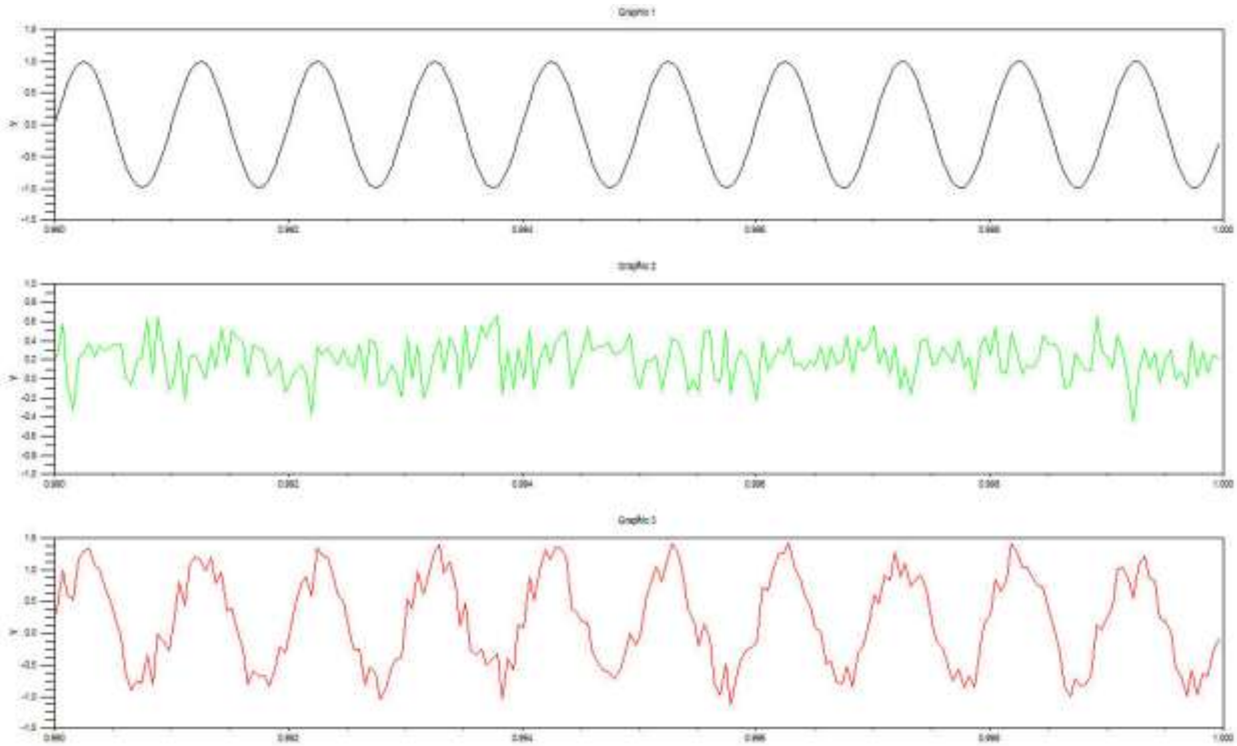


Figure 2.2 Analog Tone, Noise Signal and Analog Tone + Noise

Figure 2.2 shows the tone before and after noise addition. We have approximately +0.5V/-0.5V of noise which is added to the signal. So at the peak of the signal + noise signal we can have as much as 1.5V or as low as -1.5V.