The 29th Annual ARRL and TAPR Digital Communications Conference

DSP Short Course

Session 3: How to use DSP

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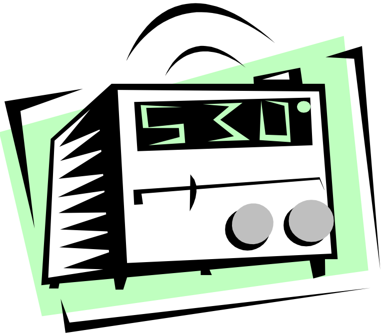
Half Time Recap

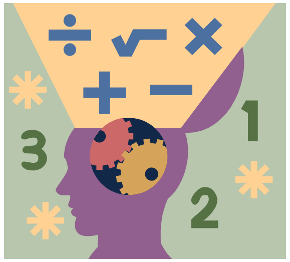
- **We've surveyed the roots of DSP and some of the tools we'll need to work with DSP.**
- **We've looked at how to implement filtering using DSP (FIR, IIR and frequency selective filters)**
- **Now its time to look at how DSP is used to make "components" and how to put these together and implement something useful!**
- **The next two sessions will cover the more popular DSP "components" and techniques and some of the "tricks of the trade" of DSP**

Session 3 Overview

- "Radio Math"
- Common Trig Identities
- DSP "Flow Chart"
- Common DSP "Components"
- Filtering
- Oscillators ,Mixers
- Modulators
- Tone Detectors
- Example 1 "DSP Crystal Radio"
- Example 2 HF Channel Simulator
- Example 3 RTTY Decoder using PC Sound Card



"Radio Math"



- We all know traditional radios use components (inductors, capacitors, transistors, Xtals etc)
- These components are arranged in "circuits" to perform some operation on the signal at the antenna.
- The operations we do (tuning, detection, mixing, amplification, filtering etc) all can be expressed mathematically (not always simple math!)
- In DSP we will do something equivalent:
  - Use DSP to make components …we've already looked at filter "components" in Session 2
  - Use the digital computer and DSP techniques to perform the math operations.

Important Trig Identities

$$\sin\theta \quad = \quad \pm\sqrt{1-\cos^2\theta}$$

$$\tan\theta = \frac{\sin\theta}{\cos\theta}.$$

Modulation and Phase Detection

$$\sin(\alpha \pm \beta) = \sin\alpha\cos\beta \pm \cos\alpha\sin\beta$$

Mixing

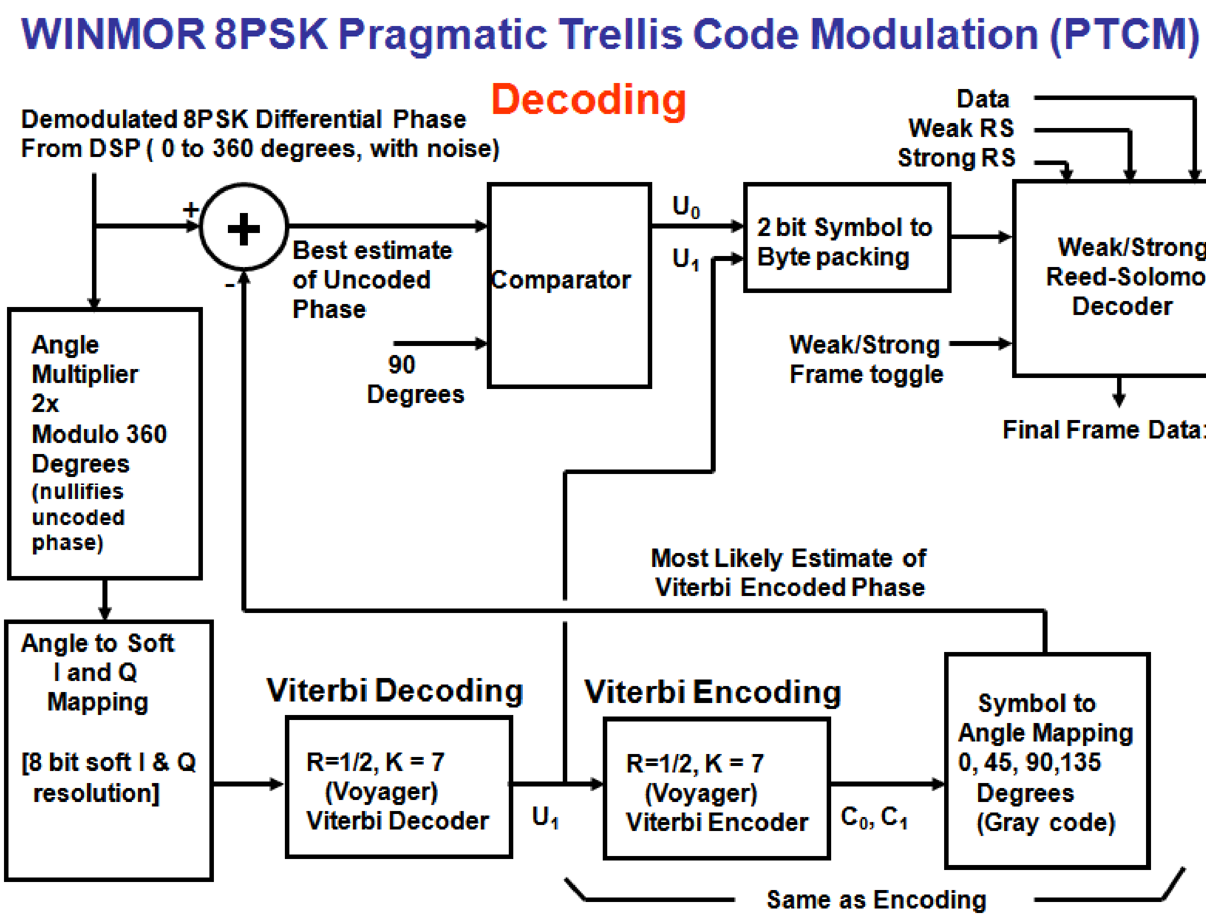
Trig Identities ad nauseum at:

http://en.wikipedia.org/wiki/List_of_trigonometric_identities

DSP Flow Charts

- Just like a radio has a block diagram and a schematic showing the function and interconnections of its various components we need a similar DSP Signal Flow chart for DSP implementations.
- The DSP Flow chart shows:
  - what DSP components are used
  - How data flows between these components
  - May also have some information about the sequence of some DSP operations

Example DSP Flow Chart



This chart describes how data flows and interacts with various DSP components and processes to implement an 8PSK Pragmatic Trellis Code Modulation Decoder

Continuous or "Batch" DSP Flow

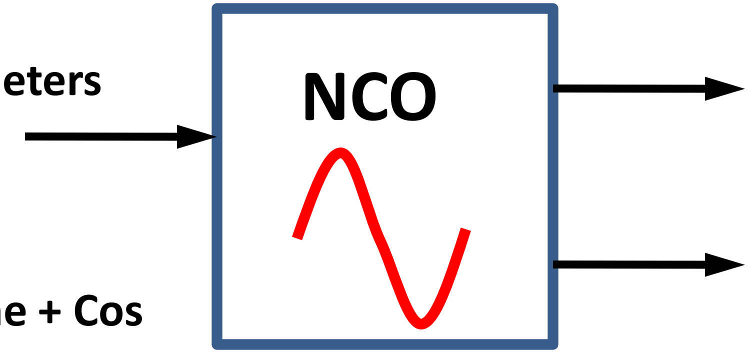
- Often in DSP implementations we must trade off continuous processing vs. batch processing. The type of processing done may be dictated by the application, the hardware or the DSP routines used.
- The DSP Flow chart should help identify which operations are done in batches (e.g. Typical FFT or Read Solomon decode) and which are done "continuously" on the data stream (e.g. Filtering).

Common DSP Components

In Session Two we surveyed Filters: FIR, IIR, Frequency Sampling
There are other specialized filters but most work similar to these.
Some other important DSP Components:

Numerically Controlled Oscillator

Oscillator Parameters
- **Starting Phase**
- **Sample Rate**
- **Frequency**
- **Sine only or Sine + Cos**



Sine Out samples

Cos Out samples (optional)

Important note: With double precision floating point we get oscillators with fine frequency resolution and accuracy!

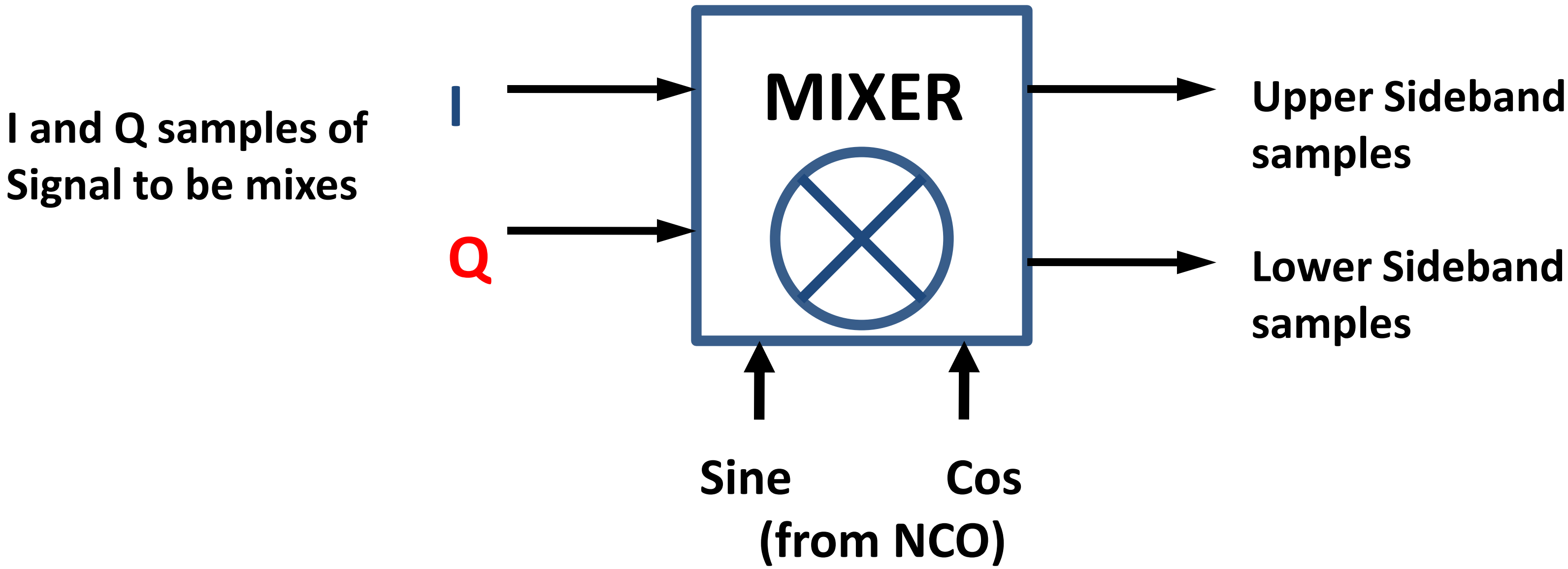
Typical NCO Code:

```
For i  = 0 to Number of Samples -1
    SineOut(i) = Sin(i * 2 * Pi * Freq /Sample Rate + Starting Phase)
    CosOut(i) = Cos(i * 2 * Pi * Freq/Sample Rate + Starting Phase)
Next I
```

http://en.wikipedia.org/wiki/Numerically-controlled_oscillator

Common DSP Components

Balanced Mixer



The Trig identities are used to generate these sum and difference functions.

Typical Balanced Mixer Code:

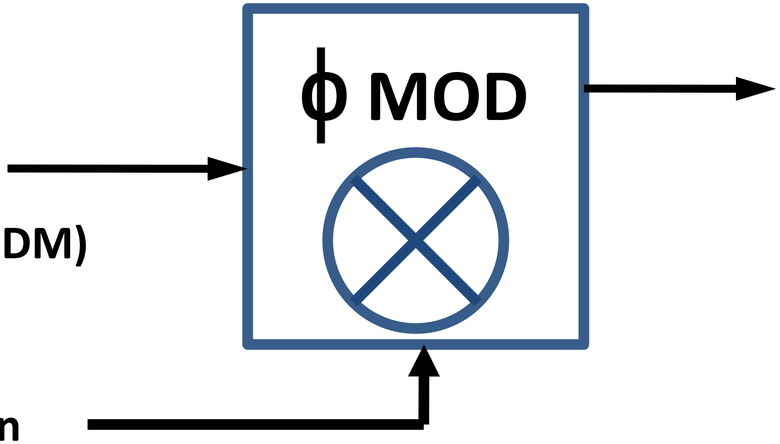
```
For j  = 0 to Number of Samples -1
    USB Out I (j) = NCOCos(j) * I(j) – NCOSine(j) * Q(j)
    USB Out Q(j) = NCOSin(j) * I(j) + NCOCos(j) * Q(j)
Next j
```

Reverse Signs for opposite sideband!

Common DSP Components

Phase Modulator

Sample Rate,
Samples/symbol,
Number of carriers (OFDM)



Phase Modulated samples

Phase Modulation Data

Clever use of FFT can generate multiple carrier Modulation (frequency bins I,j, …) Simultaneously With just ONE inverse FFT !

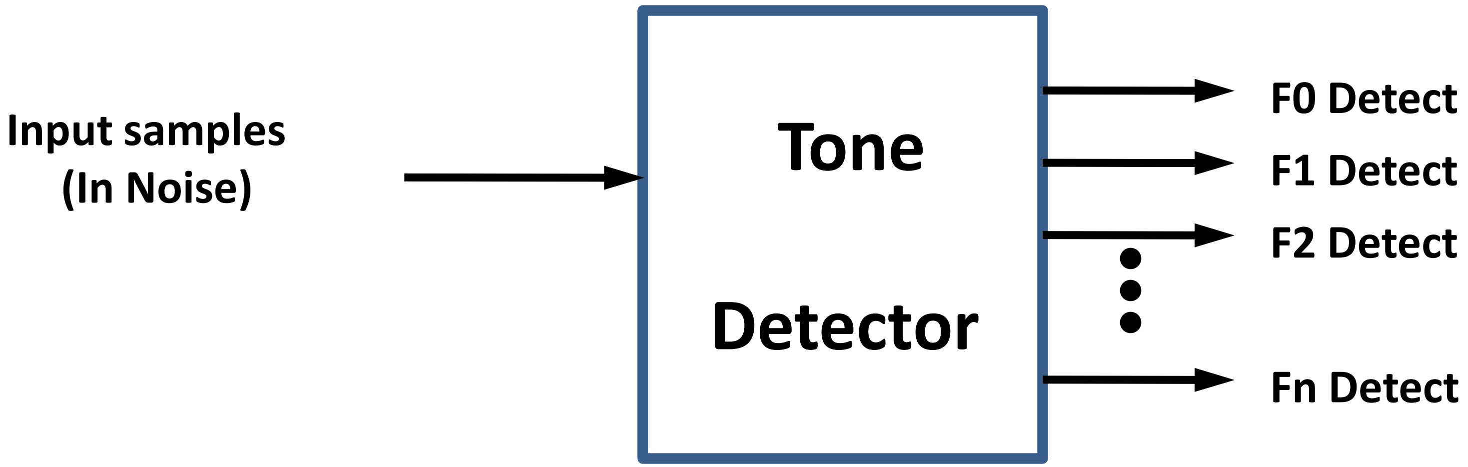
Typical Phase Modulator Code:

RealFFT Freq(i) = Cos (Phase Angle)
ImagFFTFreq(i) = Sin (Phase Angle)
Do INVERSE FFT to get time samples (I and Q)

Remember the FFT can go back and forth from Time to Frequency!!!

Common DSP Components

Tone Detector



The more input samples we process the better the S/N

Typical Phase Modulator Code:

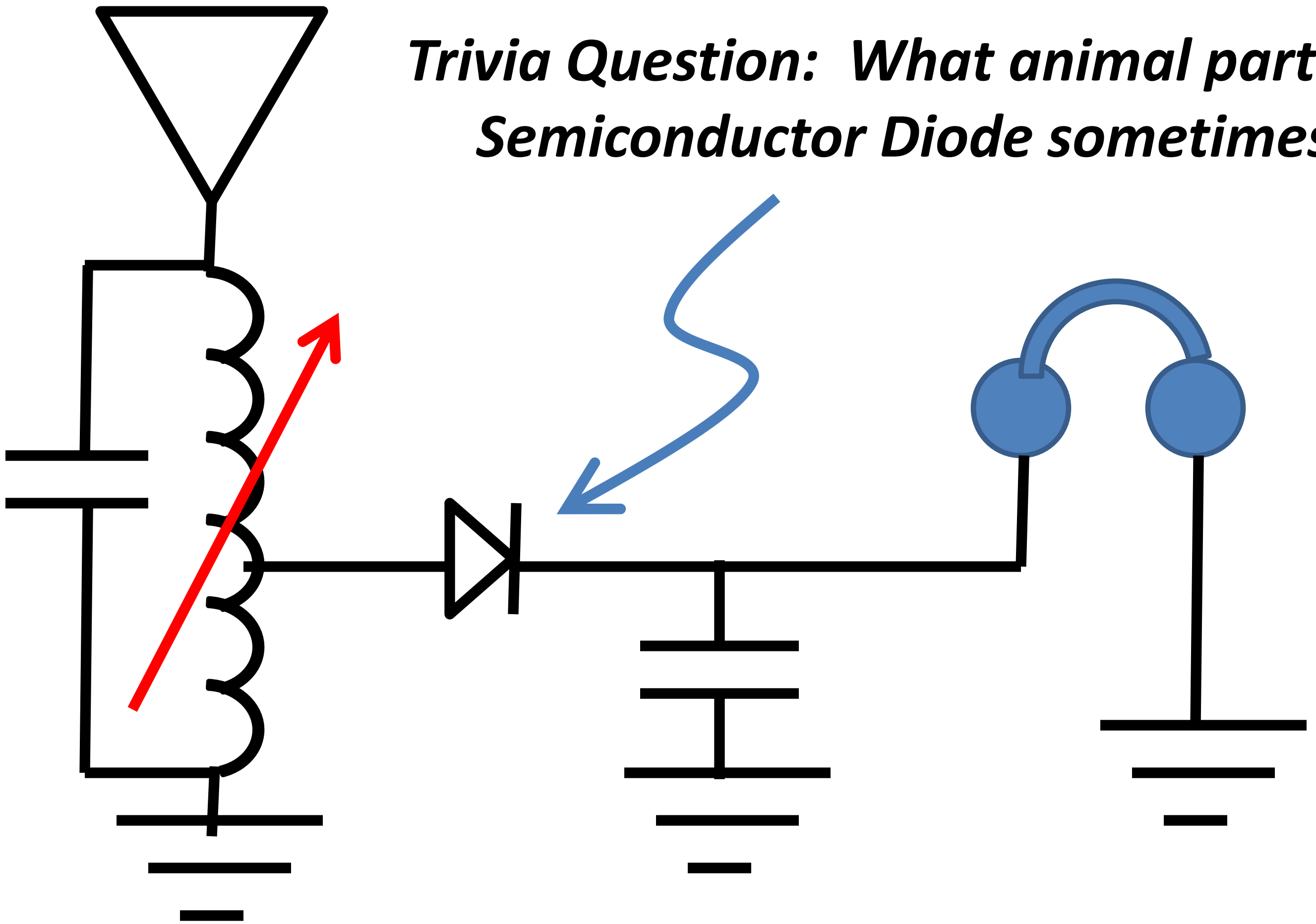
```
Compute FFT of (Input samples)
For j as integer = 0 to n
    Mag(j) = Sqrt( RealF(j) ^2 + ImF(j) ^2)
    If Mag(j) > MaxMag then ToneDetect = j
next j
```

How could we easily reduce the CPU load of this simple routine?

Simple DSP "Crystal Radio" Project

For Many of us …. The schematic of our first radio!

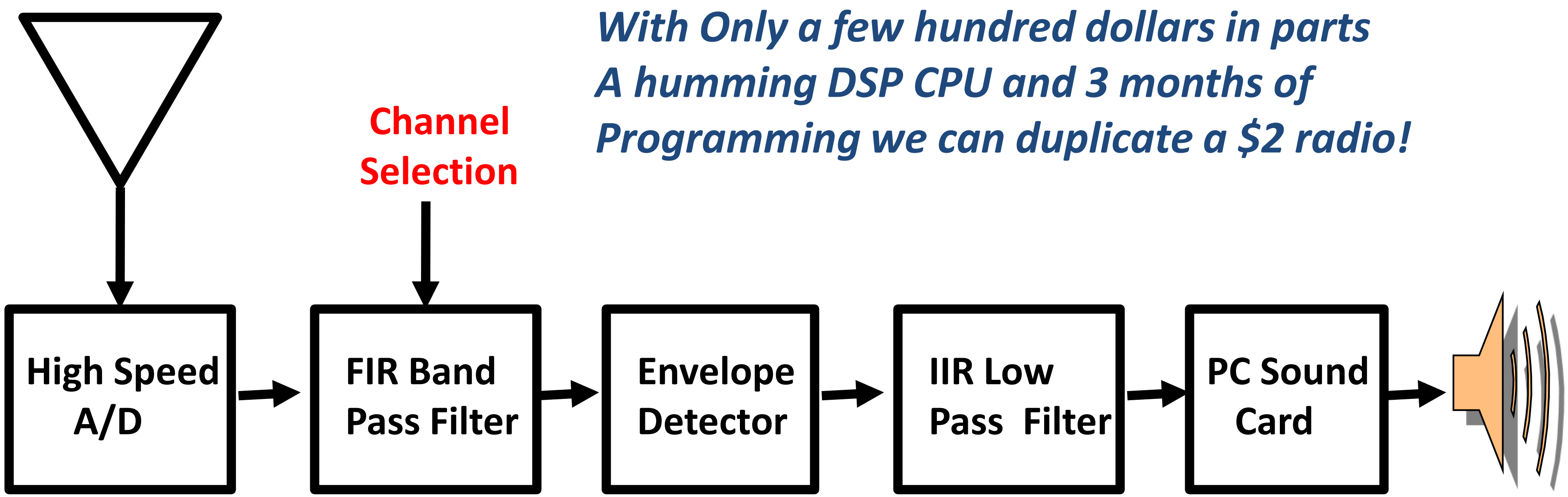
Trivia Question: What animal part was this Semiconductor Diode sometimes called?



Simple DSP “Crystal Radio” Project

Now the DSP Radio!

With Only a few hundred dollars in parts
A humming DSP CPU and 3 months of
Programming we can duplicate a $2 radio!



Sample at Minimum of 2x highest Freq

Number of Taps a function of selectivity and bandwidth desired

Env = Sqrt(I^2 + Q^2)

Simple IIR low pass will suffice

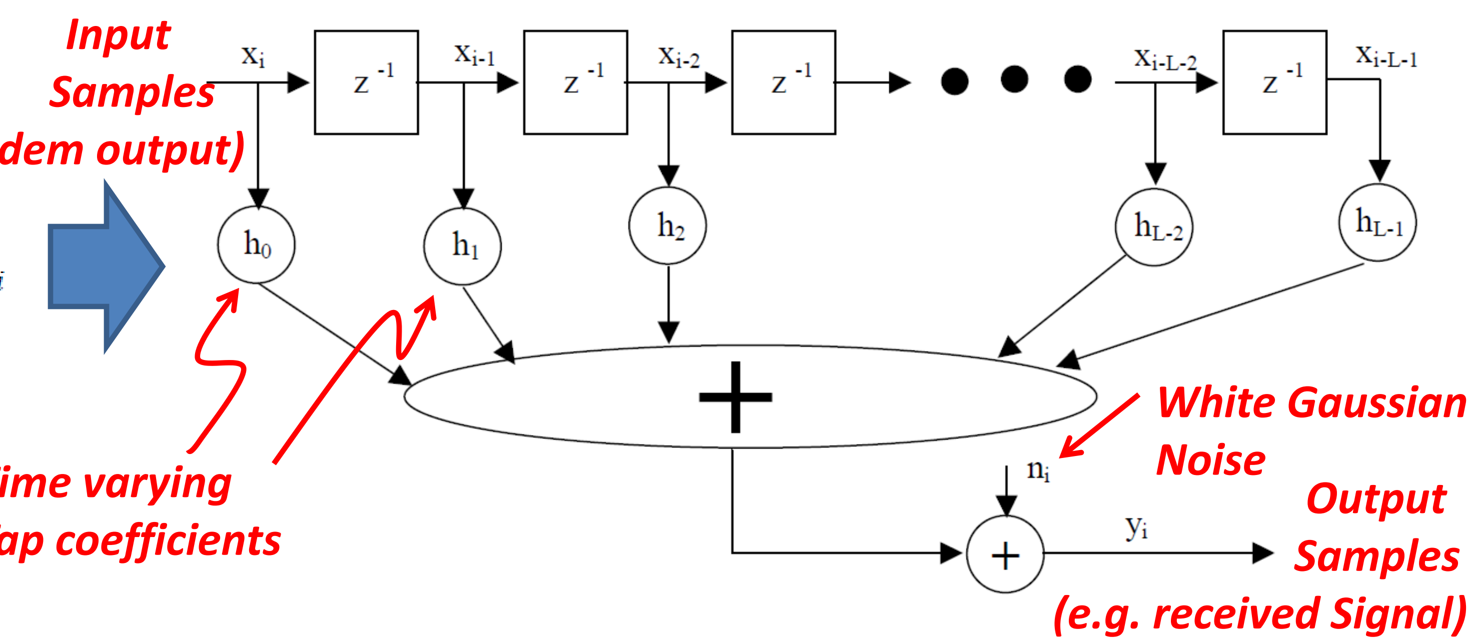
It works…but what are some of the challenges with this approach???

HF Channel Simulator

In working with HF/VHF channel propagation a channel simulator is an invaluable Tool that allows measurement and comparison of modems and performance.

C.C. Watterson developed a HF channel model that is fairly easy to implement Using DSP. (The Watterson Model)

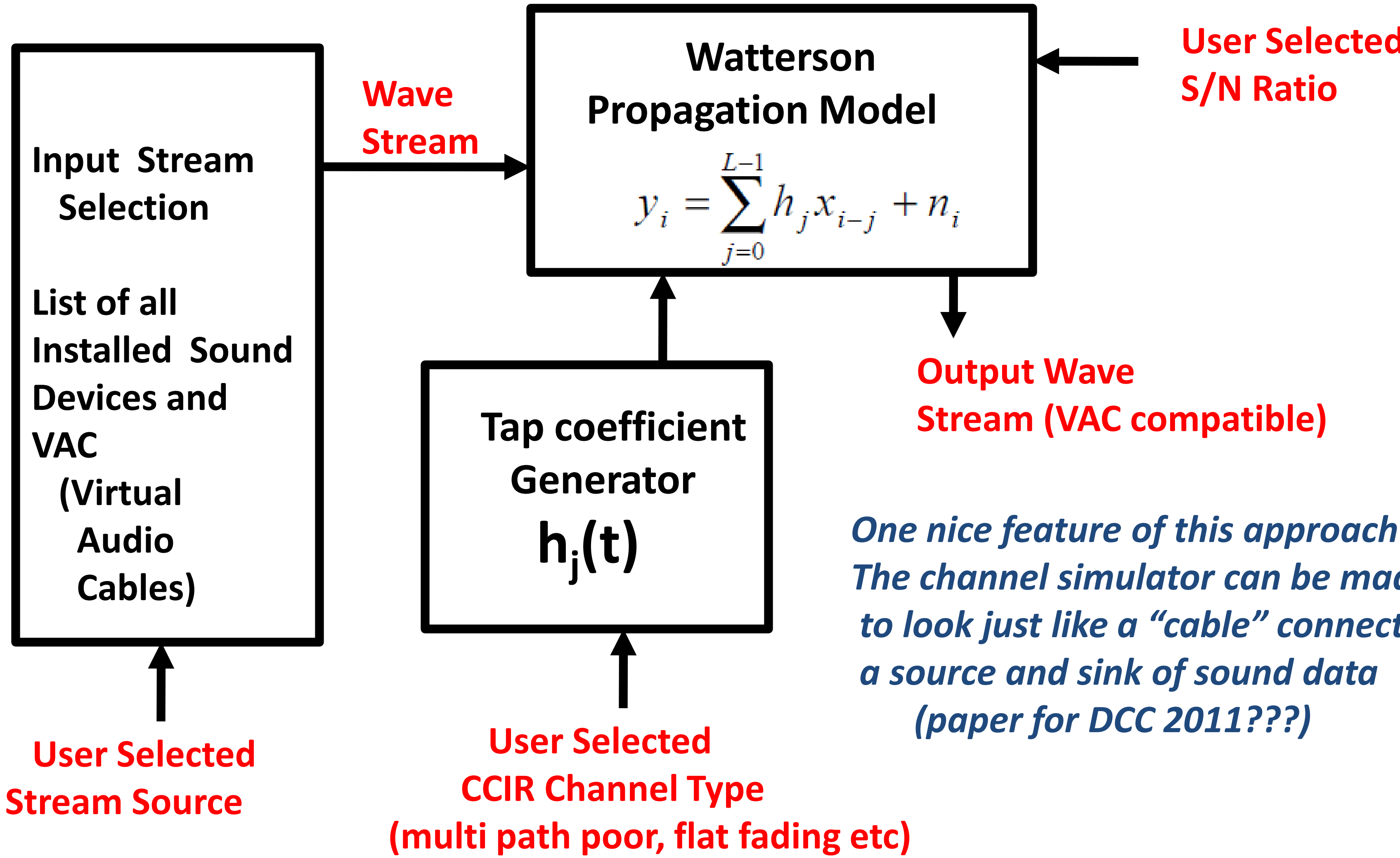
$$y_i = \sum_{j=0}^{L-1} h_j x_{i-j} + n_i$$



We can use this model and standard CCIR channel definitions to build A very useful DSP based channel simulator application on a PC.

http://www.hfindustry.com/HF%20Simulator/chansim.pdf

VAC HF/VHF Channel Simulator



One nice feature of this approach is The channel simulator can be made to look just like a "cable" connecting a source and sink of sound data (paper for DCC 2011???)

RTTY Decoder Using PC Sound Card (Nominal 45.5 baud, 170Hz shift)

Some challenges here! (not uncommon with DSP!)
For true synchronous detection we would like the shift to be an integral number of the baud rate. 170/45.5 = 3.736
Since we can't change these #s we'll have to compromise here!

The sound card only samples at certain standard rates…
(most common: 8000, 11025, 12000, 44,100, 48000, 96000)
Our sample rate should be an integer multiple of the baud rate
None of the standard rates is an exact multiple of 45.5
48000/45.5 = 1054.94 1055 samples/symbol is close enough.

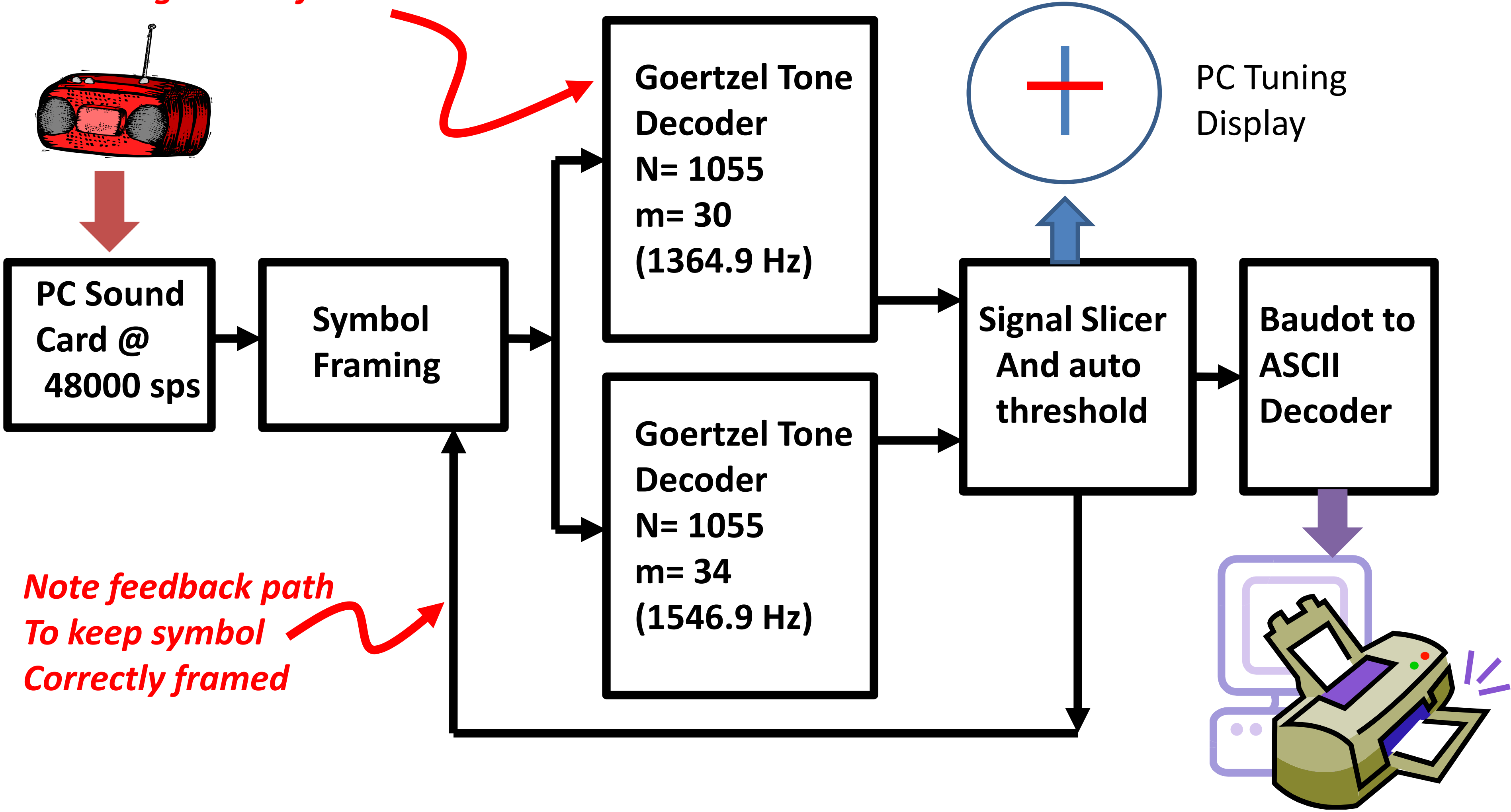
But 1055 is not a power of 2 so we'll have to handle that somehow!

But if it were always easy everyone could do it!

RTTY Decoder Using PC Sound Card

Note trick using Goertzel Tone Detector which can Implement arbitrary Length transform

Real world DSP solutions often involve hardware And user interface issues and require "tricks of the trade" to make them practical!



Session 3 Summary

- We saw that DSP uses math functions to model the familiar functions of radio components and circuits.
- We examined Common Trig Identities with links to many more.
- We saw how the DSP “Flow Chart” is analogous to the familiar schematic diagram.
- Several Common DSP “Components” were described in addition to the filters covered in session 2.
- Example 1 “DSP Crystal Radio”
- Example 2 HF Channel Simulator
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- Now in Session 4 we’ll look into some of the finer points of DSP and some of the necessary “Tricks of the Trade” as the way we make DSP really practical!