Phasing Quadrature Amplification

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Table of Contents

Introduction

Two things have been over looked with this technology, one is the importance of pulse modulation and the other has been that logic gates are able to be used for analog signal processing. Both of which were new areas to explore, and how far was it possible go with these ideas. There are three types of pulse modulation that can be used to build other waveforms with. There are pulse width modulation (PWM), pulse phase modulation (PPM) and pulse location modulation (PLM). Whereby PPM can used to generate the other two forms, PWM only has amplitude information and PLM only has phase information. So to be able to move from one form to the other depending on what is required Amplitude, Frequency Modulation or both. By using PPM it can do both phase and amplitude, as demonstrated with this new phasing modulator amplifier design. This technique is able to work with both Radio Frequencies (RF) and with light at optical wavelengths.

Over the last three years I have been working on this phase modulation technique, it has been a case test prove and evaluate the findings. Once this is done you start this process over again and again making small improvements as you go. Throughout this research process it was not possible to go on the Internet and see how this technology should work. By being first there is no limitations on what can and can not be done, the down side is it takes a large amount of time to make small amounts of progress. I also had ongoing support from Stephen Nitikman at our local college electronic labs, working through many different ideas though out this process.

Once everything was working in class D, this amplifier was push into class E and replace the low pass filter with a band pass filter. The down sides was poor modulation of 65.536 kHz, it was too low to be receive on an AM broadcast radio. The next step was to increase the frequency again to go above 150 kHz, to fall within the long-wave band. I found that PWM was a limiting factor to modulating the carrier, so it was time to move away from using PWM and to try again with PPM this is how the two unknown classes of switching amplification was found. At this stage there was a I needed to do more research into other forms of switching amplification and I could not find any match to what I was working with.

After these experiments I added in a FPGA into the circuit and used this PPM waveforms as a starting point, it was then possible to modify these pulses with logic gates to build a phasing modulator. Looking at what was done with the Tayloe mixer and taking a new approach this is where the Taylor modulator came from, it is far more than a simple switching RF mixer. The Taylor modulator takes the analog building blocks and converts their analog stages in to logic equivalents. This is an interesting area of discovery that fall between both analog and digital technologies, at the same time letting you take the best parts of both to work with. Once I worked out the required logic blocks and how they go together to build the Analog Digital Modulator (ADM), I soon found it was possible to use it with In-phase and Quadrature (I & Q) inputs.

Requirements

A need to design a transmitter that has lower total harmonic distortion (THD) than any current broadcast transmitter that is currently on the air and a need to build it with higher amplifier efficiency. What is the best way of going about this? with AM there is a number stages that are problematic, with reaching these aims. So the way to move forward is to look at other ways to generate the wanted type of modulation to eliminate many of these short comings. The power amplifier would need to operate in a switching configuration for the highest level of conversion efficiency from the DC input to the RF output stage. The only way this could be done would be using some form of phasing modulator in combination with a switching amplification process.

Current I & Q mixers design

Phasing modulator; version 1

The most common type is made up of two balanced mixers offset by 90° phase shift network, the oscillator is feed into this phase shift network and each of the two inputs are driven via low pass filter. The two outputs are then combined and feed through a band-pass filter, leaving only the wanted frequency.

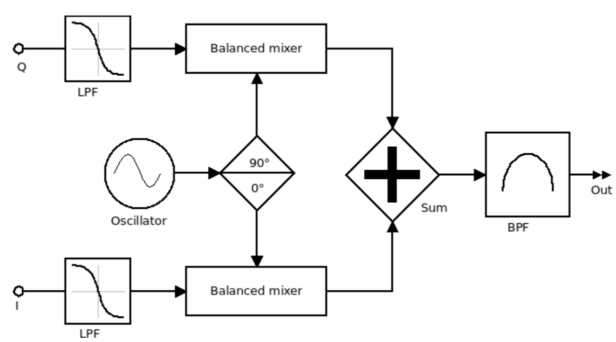


Figure 1, basic phasing modulator

Tayloe Mixer; version 2

The other is the Tayloe mixer, whereby the phase offset is done in logic by a divide by four, generating in this case four phase angles 0°, 90°, 180° and 270°. The mixing is done with an analog switch, rebuilding the wanted output frequency and as before this is then was filtered through a band-pass filer.

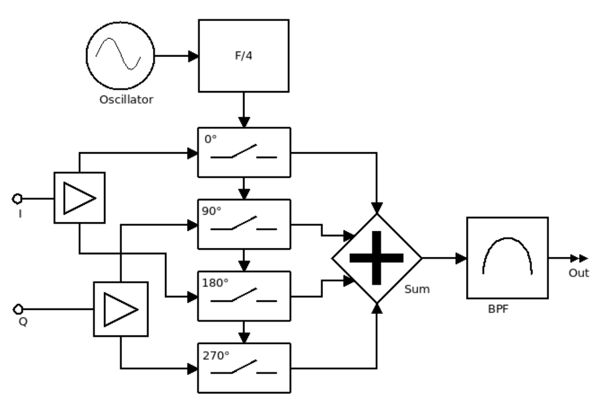


Figure 2, Tayloe mixer

Background

The phasing modulator has been around since the 1940's, in it's early form it was used to generate SSB as a more efficient transmission format over AM that was widely used at that time. This is when we started working with In-phase and Quadrature inputs, to represent each part of the waveform as Phase and Amplitude.

Where AM radio broadcasts have been around for more than 100 years now the basic idea is still the same, with many improvements made over this time and this document will go into another of these improvements. AM radio sound quality has also changed over time, the biggest impact came about with the invention of the super heterodyne receiver and it's limited bandwidth. This is only one of the factors that have an impact, the other is the over processing of in coming audio signal, poor linearity of the modulators and of the RF amplifiers stages.

Up until now we have been generating various wave forms and measuring the effects of the pulse widths to work out the minimum required bandwidth. Where in this process works the opposite way and used pulses to generate various wave forms, this technique is able to works both ways. This type of Quadrature amplification was invented in 2017, after experimenting with an optical road safety system called the Electronic eye project, it was soon discovered that the same process could be modified to work at radio frequencies. This form of switching amplification is made up of two parts, one been a phasing modulator using In-phase and Quadrature inputs, the other is switching output stage that acts as the amplifier. For this process to work it must have minimum of four pulses, two for the In-phase components positive and negative going and same for both Quadrature components.

Classes of amplification

From the beginning of electronic amplification devices there was a requirement to understand how the amplification process is been done. The way this was worked out in the analog classes was by using angles to specify the on time in degrees. So therefore you had Class A, that on for 360° of the cycle, with Class B that was on for 180° x 2 of a cycle. Class C, is on from a few degrees and used a LC tuned circuit combination to generate a full cycle. With switching amplification classification is based on the type of switching and the way the output filtering is being done.

Types of pulse modulation

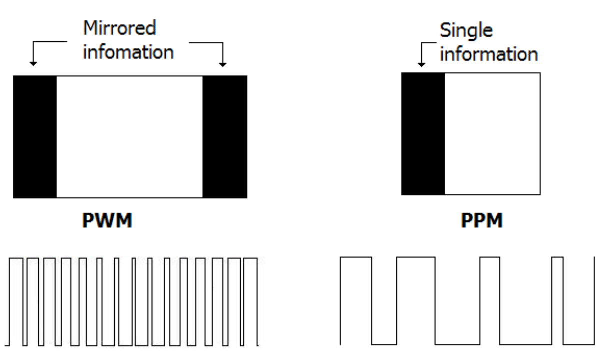


Figure 3; pulse waveforms

Where PWM has the same information on both sides of the pulse, but is mirrored or 180° out of phase, whereby the phase information is canceled out leaving just amplitude information. By converting PWM to PPM by removing one side, by doing this you also keep all the encoded information as well as the all important phase information. This is in a way like what you would get with Amplitude modulation with the side bands on each side of the carrier, where all that is needed is just one of the side bands.

PWM amplification

Class D & I are switching amplifiers, where class D uses PWM this process chops the sine wave into wide or narrow pulses. At the widest point of the pulse is at the peak of the sine wave and the opposite at the minimum point. With Class I there is two in-phase PWM carriers that are connected to a common clock, using a differential process where one input is offset to the other by 180°. This means the audio input needs to be phase shifted by 0° and 180° to drive each PWM input. Both classes of amplification therefore are linear, what goes in comes out with very good efficiency. These are known as switching classes and all require filtering after their output stages to remove unwanted harmonics, in class D & I a low-pass filter is used. The efficiency of these classes comes from the output device been tuned hard on and off, minimizing power been dissipated within this switching device.

Quadrature amplification

Starts out with two signals that have the same frequency and are offset by 90°, which is expanded out to four phase angles that have an offset of 90° (0°, 90°, 180° & 270°). Unlike Class D, Quadrature amplification works at minimum of four times the highest frequency where Class D is a minimum of two times the highest frequency. Another difference between the other switching classes is that quadrature amplification uses PPM not PWM in this case. Where PWM has no phase information, therefore it is used to very the amplitude, however if you remove one side you end up with both the phase and amplitude components. In quadrature amplification the amplitude part is not used, whereby you are able to process the phase information within logic gates and by adding I & Q pulses together it is possible rebuild any type of analog waveform. This is where Nyquist is very miss leading stating you only need two pules to regenerate a sine wave, not true for phase integrity this is where you need minimum of four. This is the key difference between quadrature amplification and what happens in Class D and in many other switching classes.

CLASS-P*TM* and CLASS-Q*TM* :

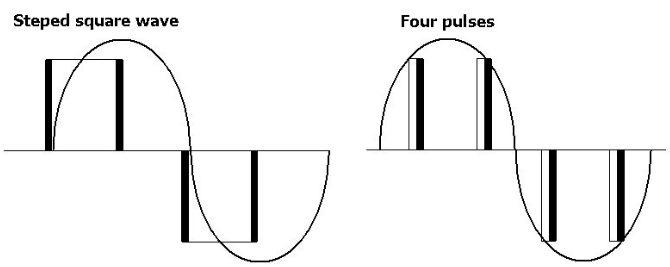
These classes of amplification are unique due to the way that they are based on phasing principles, so you will have a Sine and Cosine parts to the step waveform. Therefore with these amplifiers are made up of four pulses, two positive going and two for negative going, as parts of the generated analog waveform. This approach is used in these new forms of amplification, moving on from the limitations of Class D and the two times clock technique.

There are two forms of Quadrature amplification which I will call Class P and Class Q, in Class P (pulse) you have four PPM pulses that are offset by 90° from each other, in Class Q (quadrature) each side of the pulse has the in-phase and quadrature information.

In class P each pulse must be lass than 25% on time, where you have a gating window that the pulse must fall within. The PPM therefore is between 0% and a maximum of 25%, it must be trigged to start at 0°, 90°, 180° & 270°, with PLM the pulse just needs to be within the gating window. The output waveform therefore has 0° & 90° positive going and 180° & 270° are negative pulses. Possible uses for Class P would be in applications where you need a extra level processing between input / output stages, where Class Q has the higher efficiency of the two.

With class Q the maximum on time is 50% and 50% off, where you will end up moving into Class E (Square wave). Therefore when amplifying a modulated signal you always will be less than the maximum of 50% on the positive and negative going cycles to provide room for modulation. Where there is a sharp cutoff between the linear and nonlinear zones, this starts to have an impact above 25% pulse average until you reach 30% where it mostly becomes nonlinear. Another way to look at Class Q is that it provides the linearity of Class A with the efficiency of Class E, making ideal for many forms of analog and digital modulation systems.

With quadrature amplification it is also possible to be used for audio applications, but there is no real advantage over existing classes like D & I, so therefore my focus has been on RF applications where I & Q inputs are used.



The back lines shows where the modulation is located.

Figure 4; Class Q on the left, with Class P on the right, where the Sine and Cosine swap based on what side band information is required.

The phasing technique used are the same for both classifications, the only difference is in pulse processing stage of the modulator. In Class P you have four time slots for each of the angles, where one side of each pules is modulated (PPM). The location within that time slot can also very, using pulse position modulation. In Class Q each side is modulated, positive side has two parts of the information and the negative side has the other two. With Class Q the 0° & 90° are set in the pulse processing stage, but are not so important in the pulse converter stage.

Both of these classes are based on pules phase modulation.

As with Class D and all the other switches classes output filtering becomes very important to rebuild the analog waveform, both Class P and Q used with low-pass, band-pass or a combination of both. Where you have both positive and negative going pulses that you are working with, as in figure 4.

Amplifier grouping types:

Analog -Classes	PWM -Classes	On/Off switching -Classes	Supply rail -Classes	Quadrature -Classes
A, B, C	D,I	E,F	G,H	P,Q

Class Q, AM broadcast transmitter

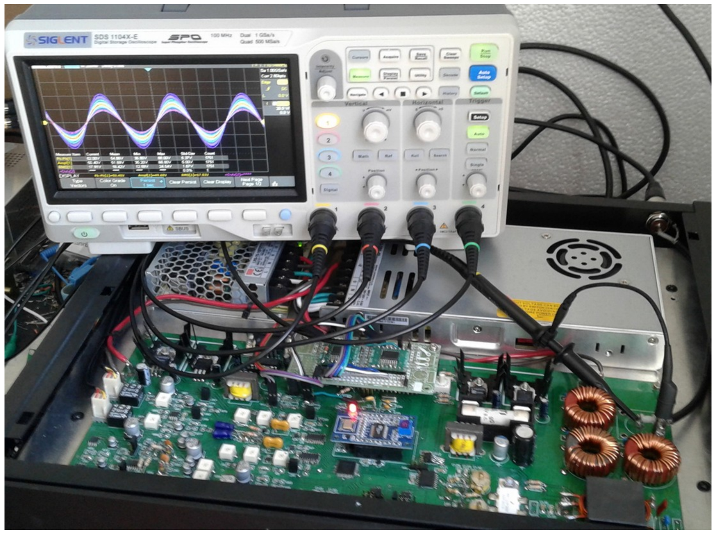


Image 1; Prototype testing with an Oscilloscope.

By using one dual device at twice the frequency and in logic I did a divide by two, bringing the operating frequency back down to 660 kHz from 1.32 MHz. With this version it modulated both digital and analog waveforms with very good linearity, for analog testing I used AM stereo (C-QUAM) and for digital, Digital Radio Mondiale (DRM) was used at 64QAM.

The current prototype has elements of all the others versions as well as new ideas for the first fully working AM transmitter. Whereby in this configuration you are able operate up to the maximum frequency of 10 MHz, this is well within the range of the AM broadcast band from 540 to 1700 kHz. All the testing was done over three frequencies, 660, 1110 and 1500kHz, where there were gaps found between local radio stations. For the output power I was getting a maximum of 200 Watt at 100% modulation, using a LDMOS switching device.

Operating in I & Q mode

Operating in I & Q mode with DRM using an offset of 12 kHz, there is no issue generating any waveform type, regardless of the type information been sent analog or digital. A waveform as complex as COFDM can easily be modulated, the only limitation is the linearity of the phase modulators been used, this is why the THD is so important. Unlike other types of analog RF amplifiers this configuration uses very nonlinear amplification, just two states, on and off. So therefore phase noise and phase distortion affects need to be minimized wherever possible, this is why so much negative feedback was used in various parts of this circuit.

Constellations:

Figure 5; ADM design version 4, modulating QPSK

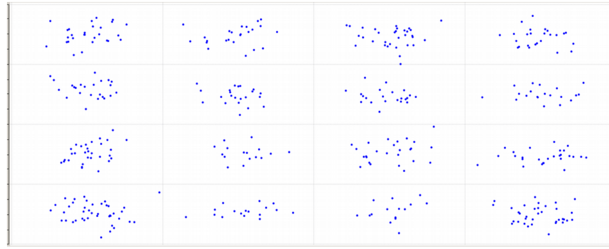


Figure 6; ADM design version 4, modulating 16QAM

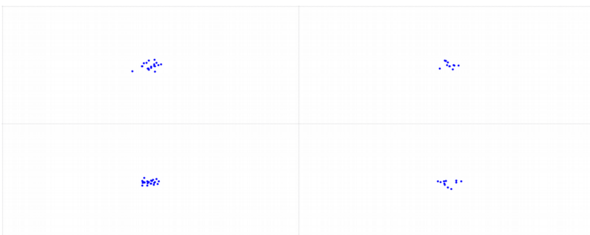


Figure 7; ADM design version 5, modulating QPSK

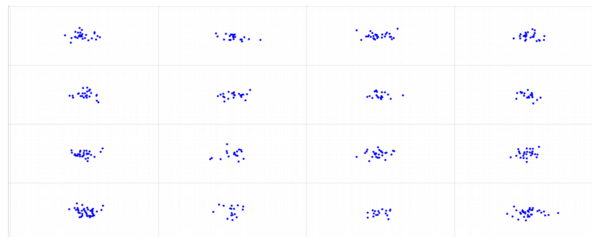


Figure 8; ADM design version 5, modulating 16QAM

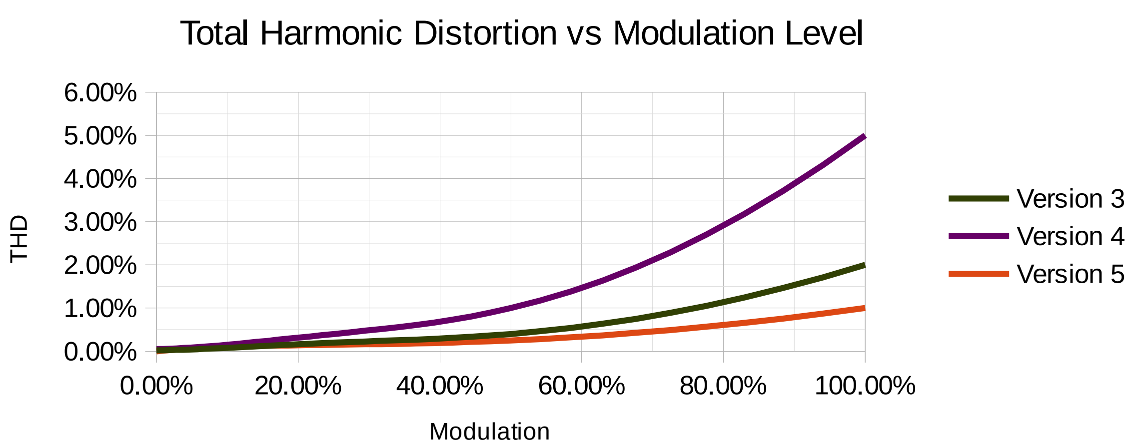


Figure 9; Two tone test

From figure 9 you can see the versions using two phase modulators with better switching output devices made improvement over version 4 using four phase modulator design. This was due the switching power MOSFETs that had a higher amount of phase distortion. In version 5 a newer design was used for the negative feedback path, using two PWM signals through a low-pass filter driving back into each of the inputs of the phase modulators. With quadrature amplification it is an ultra linear process, where most of the distortion takes place in the phase modulator stages (converting the analog inputs to PPM or PWM). With ongoing improvements I am sure it is possible to bring this level of distortion down, closer to 0.5% at 100% modulation.

*Note; The THD in the receiver can be as high as 5% or more, so the aim is to keep the transmitter as low as possible.

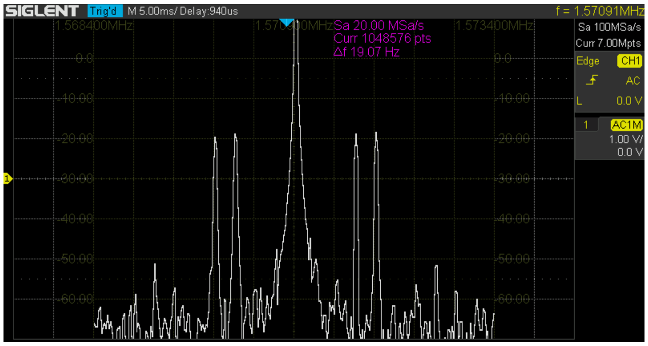


Figure 10; Two tone test a 750 Hz and 1 kHz

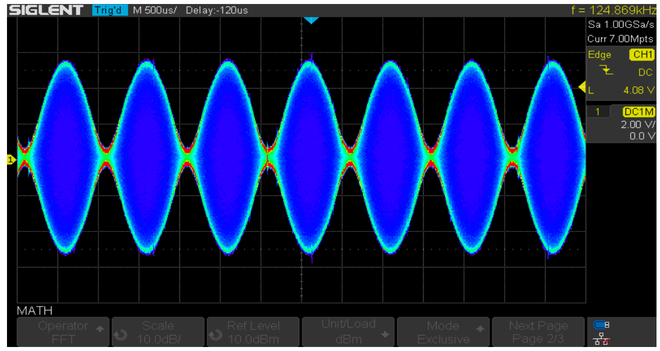


Figure 11; 99% Modulation at 1 kHz

Next version

I now have my first working product based on the experimental work done with all the previous versions. Where the next version is a 100 Watt model that operates in class Q with a small number of improvements. Such as using a new type of phase modulator design, providing a wider frequency range from LF all the way up to HF. Also has a in-build audio compandor stage just before the pre-emphasis, to provide an improved signal to noise on performance on the receive side. The plan is go with this design for on air testing here in Toronto later on in the year.

The 1kW model using the NXP MRFX1K80H device, for higher efficiency I am working with a switching DC power supply rail to operate in class G and Q. Using a combination of techniques from the older versions, with flexibility from a common hardware layout. Quadrature amplification is fully scalable process making for much higher power levels above 1 kW possible, with minimal designed changes.

This transmitter design is lost on your average AM receiver, where I am using a Denon TU-680NAB receiver connected to a Pioneer EX-9000 expander and this is providing good off air performance with this setup. With this renewed interest in AM stereo, I hope manufactures will soon get the message and start making receivers again, it is not that hard to do this in a single DSP chip these days.