DOHERTY POWER AMPLIFIER

Introduction

Doherty power amplifier was invented by William H. Doherty of Bell Telephone Laboratories in 1936.
In the thirties, the US economy is bankrupt after the crash of 29, also known as the Great Depression. Along these years the transoceanic radio communications take great relevance, very powerful transmitters were required. Amplitude modulation was the main modulation scheme at that time, which meant that the power amplifier must preserve signal fidelity.

Common AB amplifiers achieve an efficiency of 33% due to its operation near compression point. Broadcasting transmitters and transoceanic communication operated approximately with 50kW and 500kW respectively, assuming a huge spending power and consequently poor efficiency economic.

The problem we found with amplitude modulation is that we need power amplifiers with low distortion to keep the fidelity of the signal to be transmitted. Nowadays, the most efficient power amplifier is class C amplifier, but its operation is non-linear, providing large distortion and, therefore, does not keeping the necessary fidelity for AM modulation. Class C amplifiers work well in applications that use constant carriers such as frequency modulation FM.

The Doherty amplifier success is to combine class AB and class C amplifiers which allow us maintain linearity of the amplifier and, at the same time, improving the efficiency operation.

Despite the age of this invention, its use continues in broadcasting, particularly in digital TV transmitters, solid state transistors (e.g. LDMOS) are used for its execution.

In this paper we review the behavior of class AB and class C amplifiers, and then Doherty amplifier operation will be studied in detail.

Class AB and Class C amplifiers

Class AB Amplifier

Class AB amplifiers have their transistors biased with a small gate voltage or base current with or without presence of signal at its inputs. It is the most common design in audio amplifier, because they provide high performance and audio quality.

These amplifiers are named this way, because with large signals its behavior is like a class B amplifier, but with small signals, they have not crossover distortion and its behavior is like Class A amplifiers.

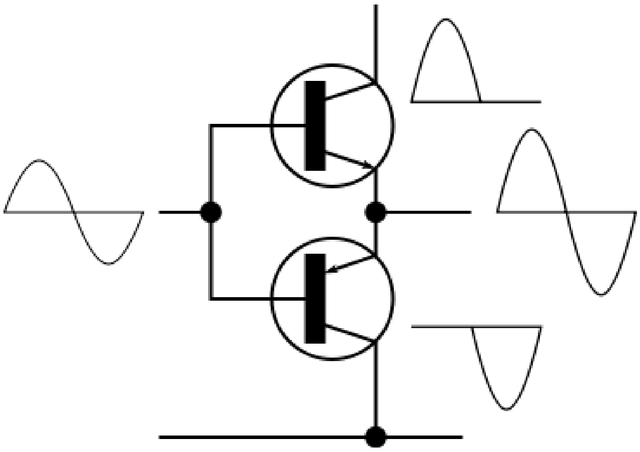

Figure 1: Class-AB push–pull amplifier

They have two output transistors, such as class B, but unlike these, they have a large bias current flowing between the base terminal and the power supply, which however is not as high as in class A.

This current is the minimum necessary to correct the nonlinearity associated with crossover distortion, with a fair value for placing transistors on the edge of driving. This Q point of polarization is between the cutting zone and the driving zone.

Class C amplifier

Class C amplifiers are conceptually similar to class B output stage, which its operating point located at one end of the load line with zero bias current.

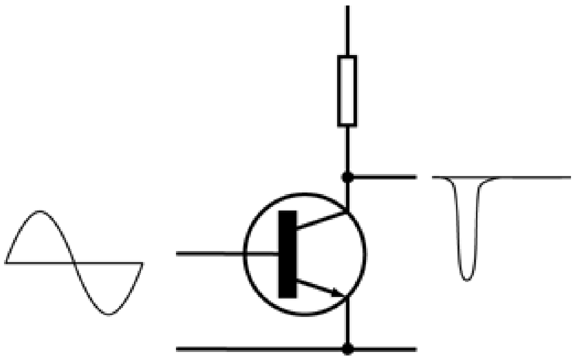

Figure 2: Class-C amplifier

The class C amplifier is unique to "RF" Use as "load" tank circuit. The main feature of this amplifier is that the active element drives less than 180º of a sinusoidal signal applied to its input. That is, it amplifies only a portion of the signal. His other feature, no less important, is its high power output (efficiency).

Doherty power amplifier.

Introduction

The main advantage of the Doherty power amplifier design, is the combination of class AB and class C amplifiers, called "carrier amplifier" and "peaking amplifier" respectively. In this way, we preserve the linearity of the amplifier (Class AB) and we obtain a high efficiency (class C).

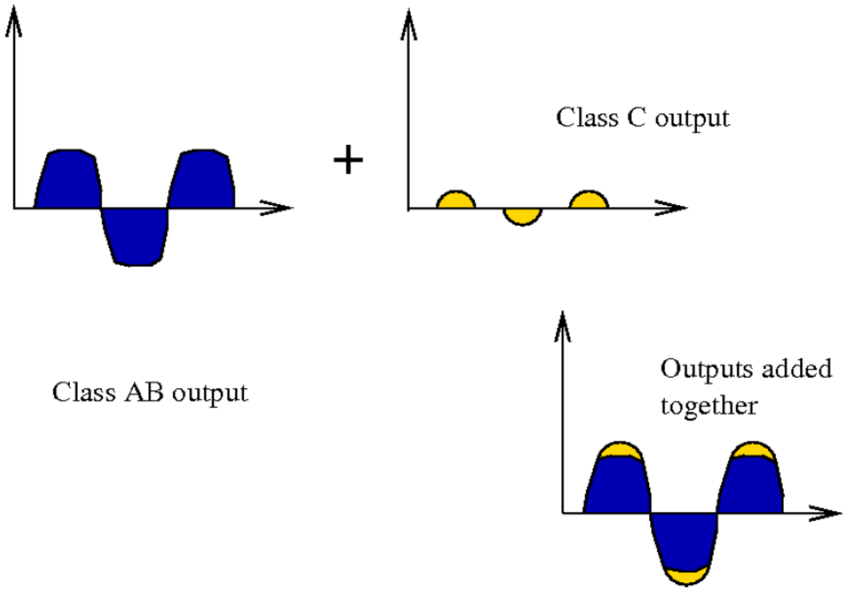

Figure 3: Doherty amplifier design concept. Above the level where the Class AB stage compresses, the Class-C stage "tops-up" the signal, restoring signal fidelity.

The idea is to use the class C amplifier to "top up" signal when the class AB amplifier compresses the signal. When the signal is close to its average value, the stage "peaking amplifier" will not operate; however, the stage "carrier amplifier" is operating near its compression point, achieving a (approached 78%) very efficient performance.

Once a peak appears on the input signal, the "peaking amplifier" stage starts running "tops up" the compressed signal from the "carrier amplifier" stage.

One of the most notable parts of the design are the techniques used to divide the input signal, as well as how to combine the signals from the "carrier amplifier” stage and “peaking amplifier" stage.

The following figure (4) shows the Doherty amplifier architecture.

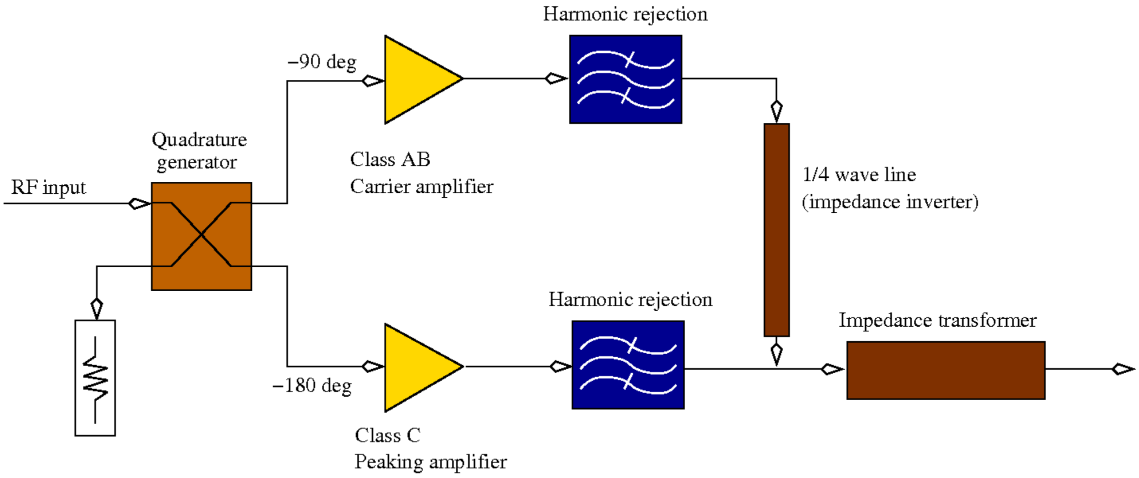

Figure 4: The Doherty amplifier. Not how the outputs of the constituent amplifiers are combined

At the input we have a "hybrid coupled", which divides the power of the input signal equally in two outputs, both phase 90º to each other. The purpose of this block is the distribution of the input signal to the two amplification stages with a suitable phase, to finally merge the amplification result obtained.

Then in the figure 4, "carrier amplifier" and "peaking amplifier" stages, class AB and class C amplifiers respectively, provide power gain design. The output on the "carrier amplifier" stage is driven by a line of ¼ wave, and it is mixed with the output of "peaking amplifier" stage. Finally the result is adapted to an impedance transformer.

These blocks constitute the Doherty amplifier design. In the following sections, we will discuss in detail each of the blocks to build the complete design model.

The input phasing and power split

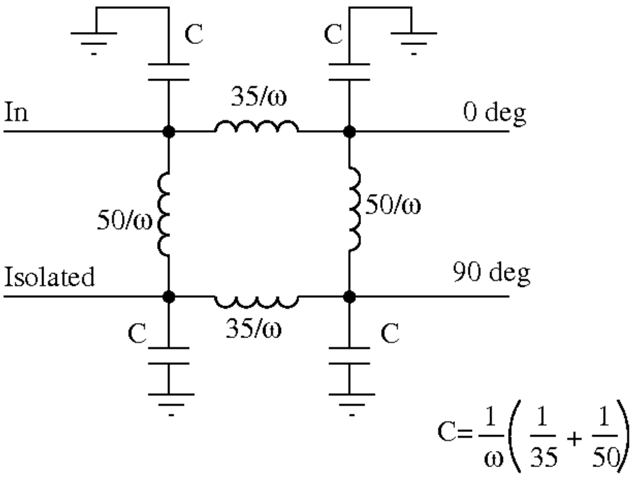

Figure 5: Lumped component version of 3dB quadrature hybrid

The 0º phase branch of the "couple hybrid" is connected to the "carrier amplifier" stage (-90º in figure 4), while the 90º phase branch is connected to the "peaking amplifier" stage (-180º in Figure 4). This phase is suitable for the subsequent combination of the amplified signals at the output of Doherty amplifier.

Therefore, the "hybrid couple" block performs a 3dB power split, half power to the 0º phase branch (-90° in Figure 5), and the remaining half to the 90º phase branch (180º in figure 5). The voltage of the input signal is splitted in two branches ($\frac{1}{\sqrt{2}} = 0.71$).

The voltage sources are specified by their peak sinusoidal value Vs, so the available power at the output of the "couple hybrid" is $Vo = \frac{Vs^2}{2*4*50}$.

- Factor of ½, time averaging of the voltage squared, RMS voltage.
- Factor of ¼, voltage divider effect
- 50, source resistance.

Figure 6, shows the effect on the "couple hybrid" on the voltage presented to the carrier and peaking amplifier inputs.

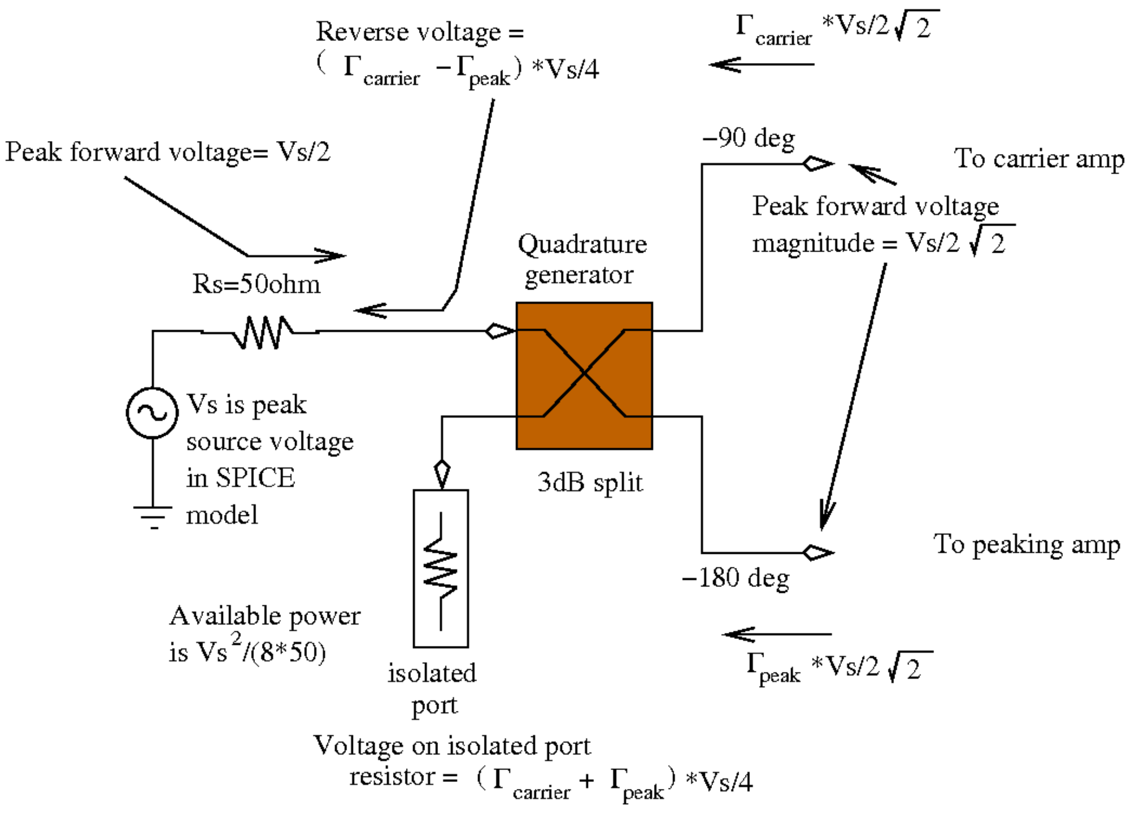

Figure 6: The properties of the power-splitting hybrid.

The reflection coefficient from the carrier amplifier is $\Gamma_{carrier}$ and the reflection from the peaking amplifier is denoted by Γ_{peak}. Using a "couple hybrid" tends to assist with the input matching by routing a large portion of any possible reflected power from the amplifiers to the insolated port resistive. In this way, the input reflection is mostly removed.

In fact, if the reflection coefficients for the carrier and peaking amplifier are almost equal, the input source will see an almost matched load.

In other hand, the reflection from the one amplifier input do not affect the other amplifier because of the insolation provided by the hybrid. This is a common feature of all “balanced” input architectures.

Figure 6, shows the comparison of the reflection coefficient from Doherty example versus Class AB amplifier.

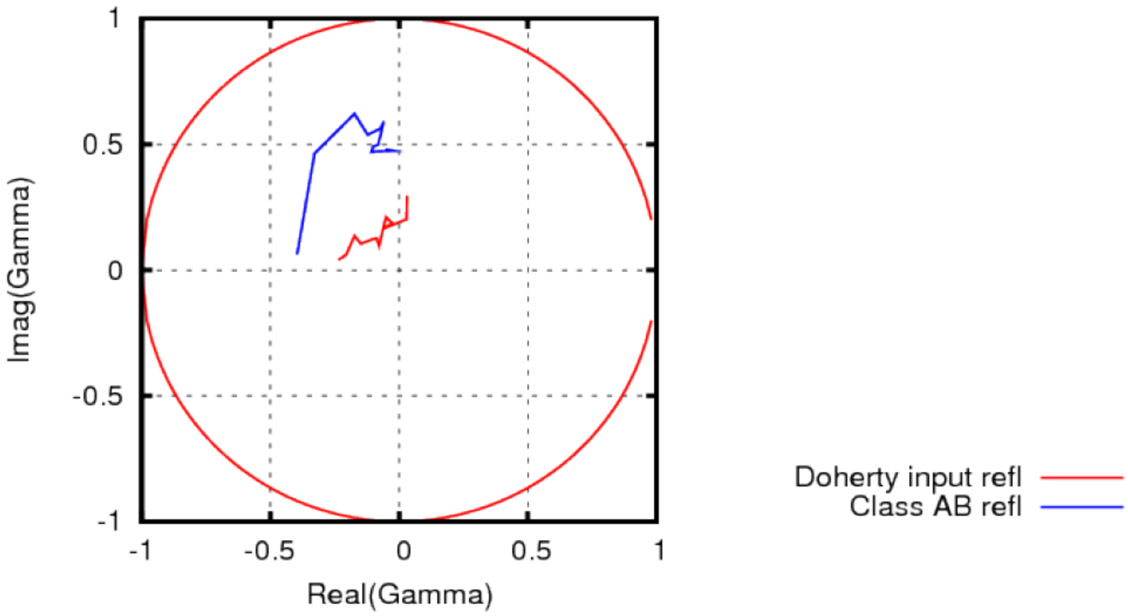

Figure 7: Reflection coefficient versus forward input power for Class AB (blue) and the Doherty (red). Low power is on the left and the reflection coefficient moves clockwise with increasing input power level. The outer circle indicates reflection coefficient magnitude of one

The reflection coefficient of the class AB change depending on input power, while Doherty remains independent of the input. In addition, the reflection coefficient of the Doherty amplifier is lower, consequently, achieve a better input matching for the entire range of input power.

Output combining and phasing.

The key to combining the amplifier output resides in the use of an impedance invert that match the carrier amplifier to the output of the peaking amplifier, and the impedance transformer on the output. An impedance is made with a ¼ wave line, in this case, it will be replaced with a lumped element equivalent (pi network). (See figure 8)

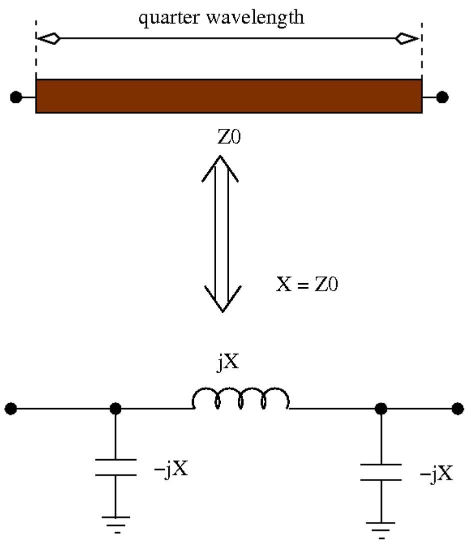

Figure 8: The 1/4 wave line can be replaced with a pi network to make an impedance inverter. The reactance of the discrete components should equal the characteristic impedance of the transmission line for proper operation.

As I mentioned in the introduction, with a low input drive signal, the peaking amplifier is mostly inactive and looks nearly like an open circuit. The impedance transformer converts the 50 ohm load to 25 load on the input side. In turn, the impedance inverter steps up the impedance seen by the carrier amplifier out to nearly 100 ohms. When input drive signal increases, the peaking amplifier begins to conduct more an more, feeding current into the output circuit. The carrier amplifier output, due to its phase relationship with peaking amplifier output is 90º, sees its load impedance drops as input RF power increases. This “impedance modulation” effect allows the carrier amplifier output voltage to remain close to the rail voltage over a wide range of input signal levels. The load-line of the carrier amplifier change dynamically depending on input signal. In other words, the peaking amplifier provides a form of fundamental active load pulling to the carrier amplifier.

Therefore, as the carrier amplifier satures, its output impedance drops as the transistor collectors no longer look like current sources, but voltage sources. The impedance inverter transform the carrier amplifier out impedance to a high value, allowing the peaking amplifier output collector to efficiency pump power into the load, acting as current sources.

In other hand, the impedance inverter transform the saturated carrier amplifier (now looking like a voltage source) into a current source. The peaking amplifier and carrier amplifier behave as two parallel current sources providing power to the output network.

Conclusions

The Doherty amplifier is ideal for maximizing the efficiency and linearity of a power amplifier, in high PAPR signals "Peak-to-Average Power Ratio".

If the modulation scheme is based on some form of multiplexing in frequency or amplitude modulation, the Doherty amplifier design is suitable. However, if the modulation scheme requires a constant carrier (FM, FSK, PSK, etc.), then the Doherty amplifier may not be suitable in our design, being a more appropriate class C amplifier or switching amplifier topology solutions.

Advantages:

- Good way to stretch amplifier efficiency while achieving good signal fidelity.
- Reduces spectral regrowth in signals with high peak to average power ratios when compared to Class AB operating near compression point
- Can be used in low-power (handheld) as well as high power (e.g. broadcast) amplifiers.
- Lots of ways to optimize for various applications (bias, phasing).
- Balanced input circuit reduces return loss variation and magnitude over power range.

Disadvantages:

- Increased circuit complexity over classical Class AB amplifier topology.
- Difficult to tune all parameters to find best operating point (operating sweet spot).
- Device parasitic complicate design of real-world amplifier.
- Input signal levels change operating characteristics (this is true for other large-signal amplifier types as well).
- Doherty amplifier gain is lower (often approximately 3dB lower) than for corresponding Class AB amplifier because of power-splitting at input needed for carrier and peaking amplifiers.

References

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