The Digital Linear Amplifier

By

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Abstract. *This paper is the second of two presenting a modern approach to Digital Amplitude Modulation and, now, Digital Linear Amplification. The first paper showed, by example, how full carrier amplitude modulation takes place in a cascade of 3 dB hybrid power combiners by gating the RF drive to power binary related coherent signal sources. The signal sources are added together in the power combiners. The state of these sources, whether on or off, is controlled by the logic one and zero make-up of a straight binary word representation of the sampled modulation wave-form. The signal which is gated is the carrier signal of each amplifier derived from a common signal source. For a ten bit example providing 1024 discrete steps, the carrier is gated in increments as small as one least significant bit (LSB), or 1/1024th of the maximum possible peak envelope power of the system. It is important to appreciate that the relative power levels of the array of ten amplified carrier sources are related in power according to the weighting of each of their places in the binary word sample of the modulating voltage wave-form.*

This paper carries the Digital Amplitude Modulator concept to the general purpose Digital Linear Amplifier. There is no restriction on modulation format except that orthogonal carriers may not be used. The output is a distortion free power reproduction of the driving signal with or without carrier and with or without both sidebands since it is virtually impossible to stray away from a straight-line transfer function. Also the Digital Linear Amplifier is very power efficient since linear amplifiers are not needed. They may be operated in class B or C. The RF linear power amplifier may be designed for any practical power level and any practical carrier frequency. The modulation wave-form is arbitrary, but must be bandlimited to meet the Nyquist criteria for digitally sampled signals.

Finally, practical considerations are presented which make the Modulator or Amplifier far less complex to design by deriving the "partial baseband signal" from the whole to be returned to analog leaving only the three highest significant bits for digital modulation. Previous papers written on these two subjects are listed as references.

Background. It will be shown that the Digital Linear Amplifier offers a new level in transfer function linearity since it becomes virtually impossible to stray away from the digitized linear transfer function. It will also be shown that it offers a very high degree of power efficiency since linear amplifiers are not required. The power signal sources are simply gated on or off and may be operating near or in saturation.

A ten bit example of a Digital Amplitude Modulator was presented in the first of these two papers on the subjects of the Digital Amplitude Modulator and the Digital Linear Amplifier. The 10-bit straight binary representation of the modulating voltage wave-form is used to turn on the drive to ten corresponding binarily related RF carrier power sources which are summed by means of a cascade of isolated 3 dB hybrid power combiners. Figure 10 of the first paper, “The Digital Amplitude Modulator” is reproduced here as Figure 1 for review.

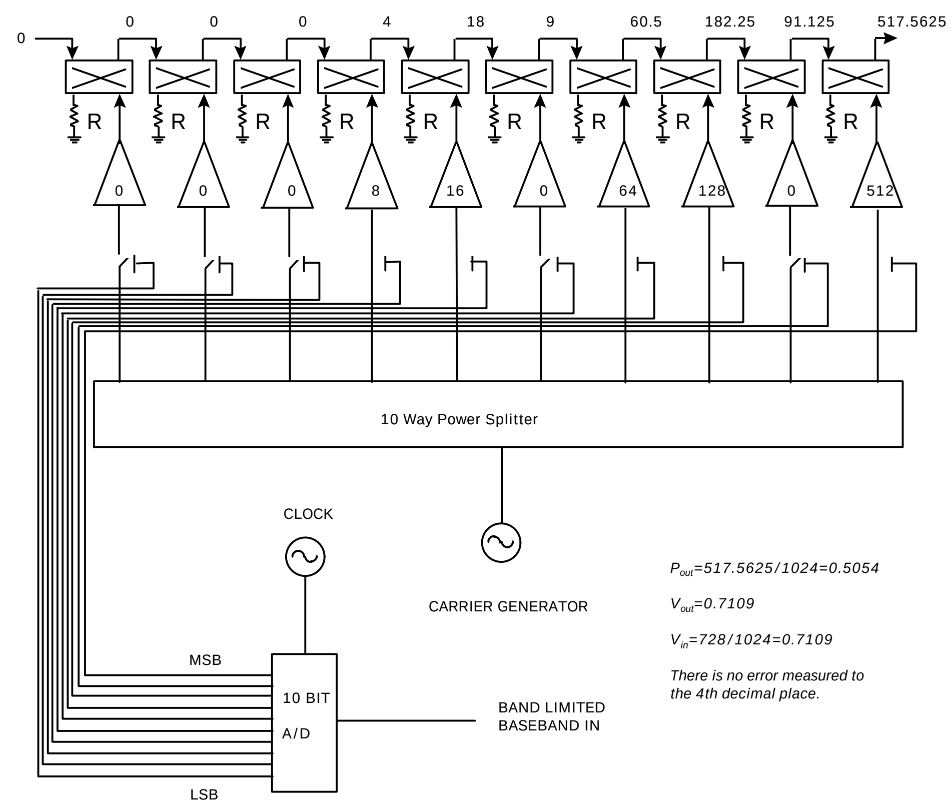

Fig.1 For a ten bit system, there is no measurable error to the fourth decimal place

Obtaining Digital Linear Amplification. A modulated signal may be fully described by the position of its voltage vector, V(t) (or equivalently, its current vector) in the two dimensional plane described by polar coordinates where R(t) represents the vector magnitude as a function of time and θ(t) represents the phase angle as a function of time as shown in (1) below.

$$V(t) = R(t)\cos(\omega t + \theta(t)) \qquad (1)$$

In the case of pure amplitude modulation, θ(t)=0. In the case of pure phase modulation, R(t)=K. In cases involving SSB, VSB, the X-QAMs or the X-VSBs where both amplitude and phase modulation take place, it is not sufficient to simply amplitude modulate as the method of Figure 1 suggests. A means to derive the required simultaneous phase modulation of the carrier generator is also required.

Figure 2 shows an approach where the amplitude and phase modulation is applied to a low signal level modulator designed for the format desired as if it were to be used in an “ordinary scheme” of IF modulation, up-conversion and amplification such as that used for High Definition Television or Digital Television Broadcast, DTV.

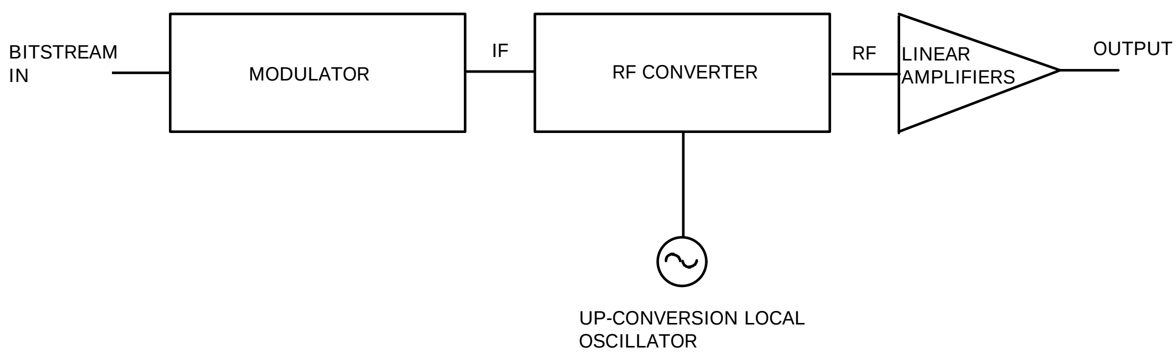

Fig. 2. An ordinary IF modulation and RF Up-conversion transmitter scheme

The signal to be transmitted is complete at the IF stage even though it is not on frequency for transmission. It may also be spectrally inverted if high side RF conversion is the standard, but it is the IF signal that contains all of the amplitude and phase information required to continue with the derivation of the Digital Linear Amplifier.

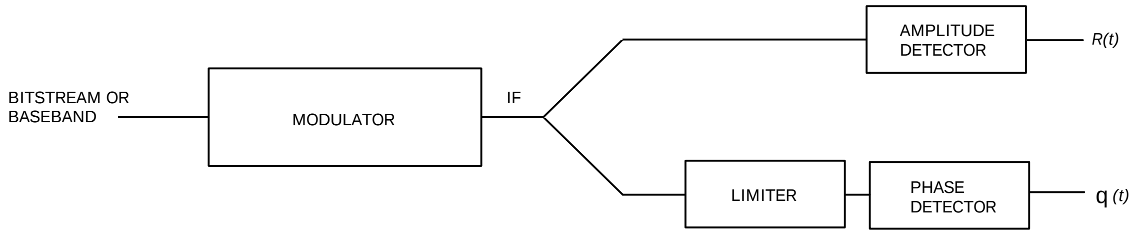

Fig.3. A conventional quality modulator is used to generate the IF signal which is then broken down into its constituent amplitude and phase components, *R(t)* and q *(t)* for application to the Digital Amplitude Modulator for linear amplification.

Figure 3 shows the first step in the derivation of the Digital Linear Amplifier. A baseband signal is modulating an IF carrier as usual for the format and system of choice. The modulated IF signal may be SSB, analog television which is VSB, a digital format such as one of the QAMs or any signal which is planar in R and θ, i.e. does not have orthogonal carriers. The IF signal is split into two paths. One path demodulates the amplitude with no regard to phase such as a simple diode detector. The other is limited or clipped then phase detected with no regard to amplitude. Levels are adjusted according to system needs. Since the IF signal is not yet on the right transmission frequency, the phase detected signal in figure 3 may be up-converted with a mixer and local oscillator. Phase information is not lost during the up-conversion since θ(t) simply adds another term to the argument of the up-conversion oscillator. Figure 4 shows the Digital Linear Amplifier with the amplitude and phase information added back into the system for proper reconstruction of the complete signal at the RF frequency.

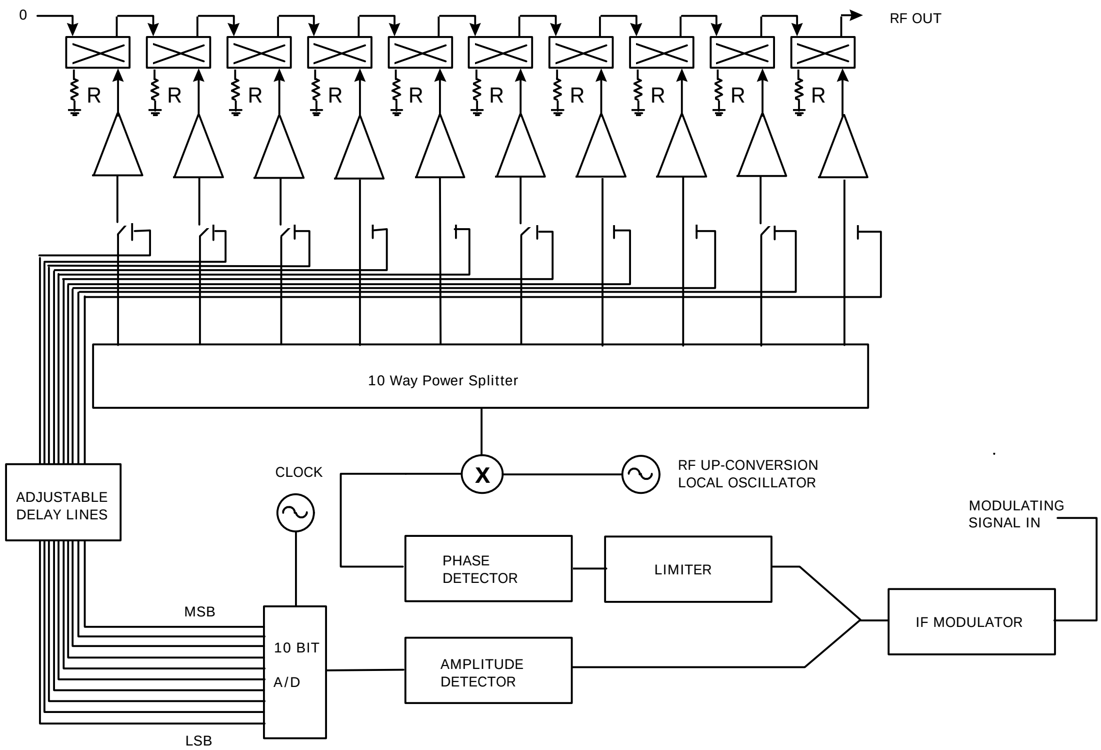

Fig.4. The Digital Linear Amplifier showing up-convrsion to the RF frequency. An If signal is demodulated and split into two paths for amplitude and phase detection. These two signals are then used to remodulate the A/D converter and carrier generator of the Digital Amplitude Modulator as described in Figure 1.

Not shown in figure 4 are leveling circuits. Digital delay lines are necessary in the lines between the A/D converter and the drive switches so that the gated RF power signals arrive at their respective 3 dB hybrid power combiners at the precise required time. It is reasonable to think that the higher power amplifiers have longer delay from the drive switch to power output just because these amplifiers have more stages.

Practical Considerations. It may seem that the Digital Linear Amplifier shown in figure 4 is cumbersome and may be difficult to keep in alignment. Some considerations include:

a. Proper time alignment of the signals arriving at the power combiners.
b. Turn-on turn-off (rise and fall) times of the power amplifiers.
c. Regulation of the output power of all amplifiers.
d. The amplifiers must be designed as if they are gated on all of the time or for a period as short as one sample period.
e. Maintaining ten bit coordination in all ways.

For (a), digital delay lines are available in fractional nanosecond and tens of nanosecond intervals. Generally these devices are switch or logic level selectable and certainly may be controlled by a microprocessor. For (b), rise and fall times required are inversely proportional to modulating bandwidth. An experimental analog television transmitter showed that the bandwidth of each amplifier should be at least 20 times greater than the modulation signal for switching glitches to be lower than 60 dB down from the carrier. This translates to

$$T_{RISE} = T_{FALL} < \frac{1}{20BW_{MODULATION}} \qquad (2)$$

For analog television with a 4.18 MHz bandwidth, the rise and fall times for each amplifier should be less than 12 nS. For SSB voice communication, the rise and fall times need not be nearly as fast, but on the order of 17 uS.

Considerations (c) and (d) are related in that the regulation bandwidth of the power supplies for the amplifiers must be such that as an amplifier generates heat when it is driven, its gain will decline causing the output power to droop. This must be sensed and the power supply voltage automatically adjusted accordingly. Consideration (e) requires that all amplifiers must be connected to a common reference in order to maintain the proper binary power relationship as a function of time. This may be nearly impossible in a ten bit system, but there is a way to greatly reduce the complexity of the Digital Linear Amplifier.

It was mentioned early on that there are several reasons why the Digital Linear Amplifier is superior to the conventional amplifier. One is the inherent reduced intermodulation distortion since it is virtually impossible to deviate from a straight-line transfer curve. The other is power efficiency since none of the amplifiers need to be linear. A look at power efficiency indicates that the Digital Linear Amplifier is most efficient when it is making the highest power. Table 1 of the *Digital Amplitude Modulator* paper shows that the efficiency of the power combiner cascade is theoretically 100% when all amplifiers are gated on. It declines from there, but when less power is required down the slope of the modulating signal, efficiency is a less important issue. Efficiency is the highest when the most power is needed. The overall system power efficiency is then the efficiency of the power amplifiers (assuming that the combiners are lossless) which may be in the eighties of percent if class C amplifiers are used.

Complexity may be greatly reduced with very little sacrifice in power efficiency and no reduction in linearity if it is realized that 87.5% of the power generated by the ten bit Digital Linear Amplifier is generated in the three highest significant bits. These three bits should remain digital for their power efficiency, but the remaining seven may be returned to analog by means of a D/A converter. This partial baseband signal then modulates the carrier through a conventional mixer, is phase adjusted and then added to the first of only three 3 dB hybrid combiners for a ten bit system. Figure 5 shows this practical approach.

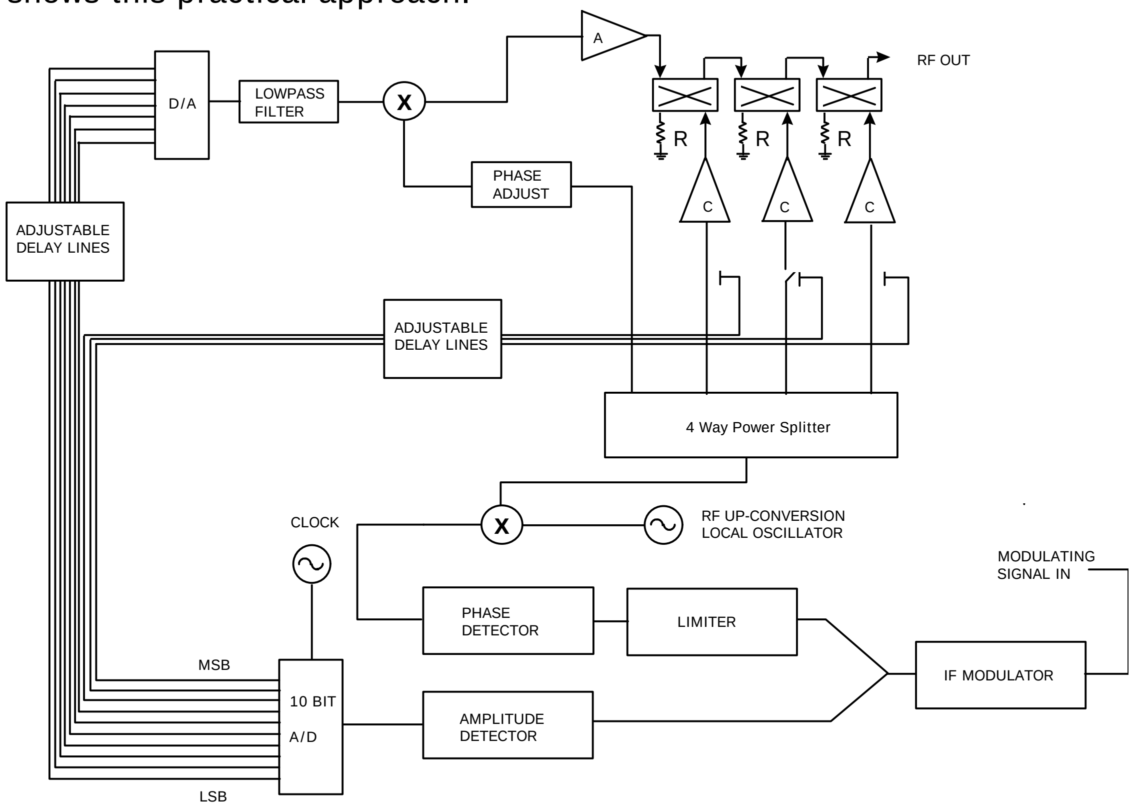

Fig.5. The complexity of the Digital Linear Amplifier is greatly reduced by returning the least seven significant bits to analog form for modulation of a mixer, RF up-conversion, and linear amplification with a class A amplifier. This method is still very power efficient since 87.5% of all power comes from the three most significant bits which remain digital.

The analog RF signal input to the left most power combiner represents the seven least significant bits including the arbitrary carry bit. Although using a class A amplifier for these seven appears to be undesirable and counter to the desire to be all digital, it provides for a much simpler design. If the power efficiency of the class A stage is 10% and it is called upon to provide 12.5% of all the power of the Digital Linear Amplifier (100-87.5=12.5%), it consumes the same power as the eighth bit amplifier provides by itself since it is called upon to make 128/1024=12.5% of the power of the entire amplifier. The eighth bit amplifier is not 100% power efficient, so it actually will consume more power than the class A amplifier. *Not much is lost and the gain in simplicity is enormous.*

Conclusion. The Digital Linear Amplifier concept and theoretical design has been presented with the hope that it will find its rightful place in the digital age of the twenty-first century. It has been proven only in the laboratory for analog television at a peak of sync power of 1000 watts, but the concept is so simple and elegant that it deserves trial in other areas of RF power transmission.

References. For more detailed and theoretical presentations, see the following:

1. Hulick, T.P., “Digital Amplitude Modulation”, Broadcast Engineering, Dec. 1987, pp.66-80.
2. Hulick, T.P., “Digital Amplitude Modulation”, RF Design, Dec. 1989, pp. 39-46.
3. Hulick, T.P., “Inside the Digital Amplitude Modulated TV Transmitter”, World Broadcast News, Feb. 1994.
4. Hulick, T.P., “Digital Amplitude Modulator”, RF Expo West Conference Proceedings, March 1994, pp.7-34.