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4M Modulation

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1 Document Overview

The digital age has arrived for the radio broadcasting industry, with the adoption of such standards as HD Radio™ and Digital Radio Mondiale™ (DRM™). These modulation standards impose new demands on both FM and AM transmitters, requiring more linear reproduction than current analog FM and AM transmission techniques can provide. Legacy modulation designs in AM products have been and continue to be of major interest during development, testing, and implementation of these emerging digital transmission standards. In particular, both Pulse Width Modulation (PWM) and digital modulation have been the subject of discussions and papers focusing on their spectral performance and efficiency in the face of new digital transmission schemes.

This paper presents the latest innovation in AM transmitter technology, 4M Modulation™, developed by Broadcast Electronics and the benefits that can be derived from this unique design. 4M Modulation provides many advantages in both spectral performance and efficiency for digital and analog transmission. The 4MX 50, BE's first transmitter using this modulation scheme, is a fraction of the footprint and weight of comparable modules due to the component-efficiency of 4M Modulation and associated technologies. It is the only 50 kW AM transmitter that, when tipped on its side, can be moved through a standard doorway.

In addition to these key performance criteria, 4M Modulation provides the advantages discussed here.

2 Existing Modulation Schemes

To understand 4M Modulation and its advantages, it is important to review existing modulation schemes and understand the limitations and key features of each as they relate to standard analog AM, HD Radio, and DRM. The two dominant modulation designs used today are PWM and digital.

2.1 PWM Technology

PWM Overview

PWM is one of the most common modulation schemes and is also the modulation design used in all AM transmitters produced by Broadcast Electronics before the advent of the 4MX product line. A block diagram of a PWM transmission system in shown below in Figure 1. The PWM transmitter design encompasses six major blocks:

1. audio low pass filter,
2. PWM generator,
3. power supply,
4. low pass filter,
5. RF amplifier, and
6. bandpass filter.

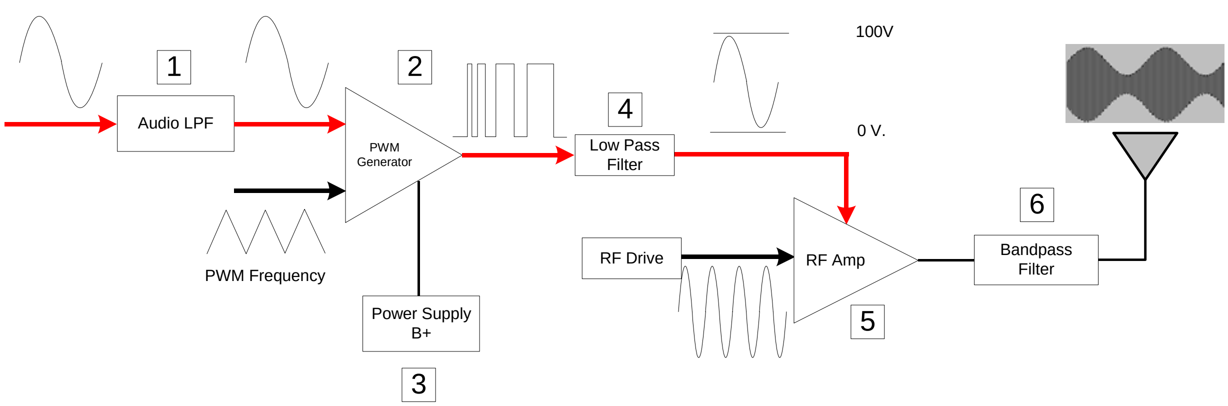

Figure 1: PWM Transmitter Diagram

1. The audio input filter limits the higher-frequency audio of the incoming signal. The high end limiting usually occurs between 10 kHz and 15 kHz. The filter also prevents unwanted high-frequency noise that might be injected into the system.

2. The PWM generator is a comparator whose two inputs are the filtered audio input and a triangle wave that is generated internally. The triangle waveform has a frequency usually between 70 kHz and 150 kHz, known as the PWM frequency. These two signals are compared and produce an output signal whose duty cycle is proportional to the audio level (i.e., when audio amplitude is high, the duty cycle increases, and as the amplitude is lowered, the duty cycle decreases). This output, known as a pulse train, is shown in Figure 2, below. The PWM generator also produces an amplified pulse train based on the DC voltage from the bulk power supply.

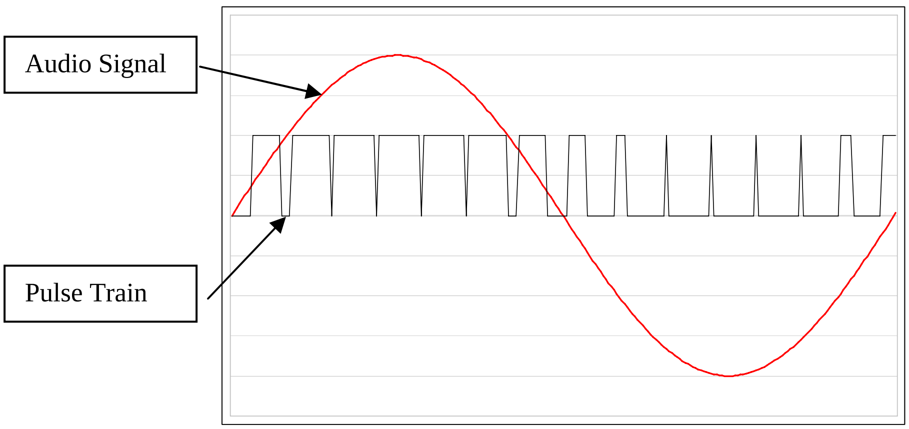

Figure 2: PWM Generator Pulse Train

3. The power supply takes energy from the AC mains and converts it to the desired DC voltage. This voltage, typically around 100V, is one of the inputs to the PWM modulator.

4. The PWM generator output is then passed through a low pass filter (LPF) to regain the original audio signal at an amplified voltage. The DC output of this LPF has a voltage proportional to the audio input. The LPF must be capable of filtering the PWM switching frequency and harmonics to levels that comply with the regulatory emission mask requirements.

5. The RF amplifier switches at the carrier frequency, which is amplified by the voltage coming from the modulator LPF. This yields an RF signal whose amplitude varies in proportion to the original input audio signal.

6) The bandpass filter then attenuates any harmonics of the carrier frequency to an acceptable level.

Effects on HD Radio

For HD Radio, the input filter is removed or modified to allow the higher-frequency amplitude signal to pass unobstructed into the PWM generator. The HD Radio audio bandwidth is 15 kHz. Therefore, this filter must be sufficiently wide and have a bandpass characteristic that limits any phase and amplitude distortions caused by the filtering. Widening of this filter can cause problems for the transmitter because it now passes higher-frequency components other than the audio.

The phase information for the HD Radio signal is injected directly into the exciter and sent to the RF amplifiers. The internal oscillator is disabled (usually by a relay), and the carrier signal with HD Radio phase information replaces it. The injection of the phase information in this manner poses no bandwidth limitations, since the RF amplifiers and the bandpass filter have more than acceptable bandwidth to pass HD Radio phase information.

The frequency of the PWM is critical to HD Radio performance. The PWM low pass filter must limit the spurious products generated by the modulator. As the frequency gets lower, it becomes increasingly difficult to reduce these spurious emissions and still maintain enough bandwidth to pass the higher-frequency HD Radio signal without introducing phase and amplitude distortion. If the switching frequency is high, the LPF can be designed to minimize these distortions and still maintain acceptable spurious levels. It is important to note that increasing the PWM switching frequency has a negative impact on overall transmitter efficiency because of switching losses in the modulator. As the switching frequency increases, the losses in the FETs in the modulator increase, thus lowering the overall efficiency of the system.

If the phase and amplitude of the signal passing through the PWM filter are distorted, then the resulting output signal will have intermodulation distortion products. These intermodulation products yield a spectrum that may not meet the required spectral emissions mask. Also, the receiver may not decode the resulting broadcast signal properly (i.e., with high bit error rates).

2.2 Digital Technology

Digital Overview

Digital modulation technology has been incorporated at high power levels for many years. This technology works like a high-power digital-to-analog converter (DAC). As the audio input level increases, more modules are turned on, and, conversely, the number of modules turned on decreases as the audio input level decreases.

The digital AM system comprises five major blocks:
1. audio low pass filter,
2. audio/PA controller,
3. power supply,
4. series of RF amplifiers, and
5. bandpass filter.

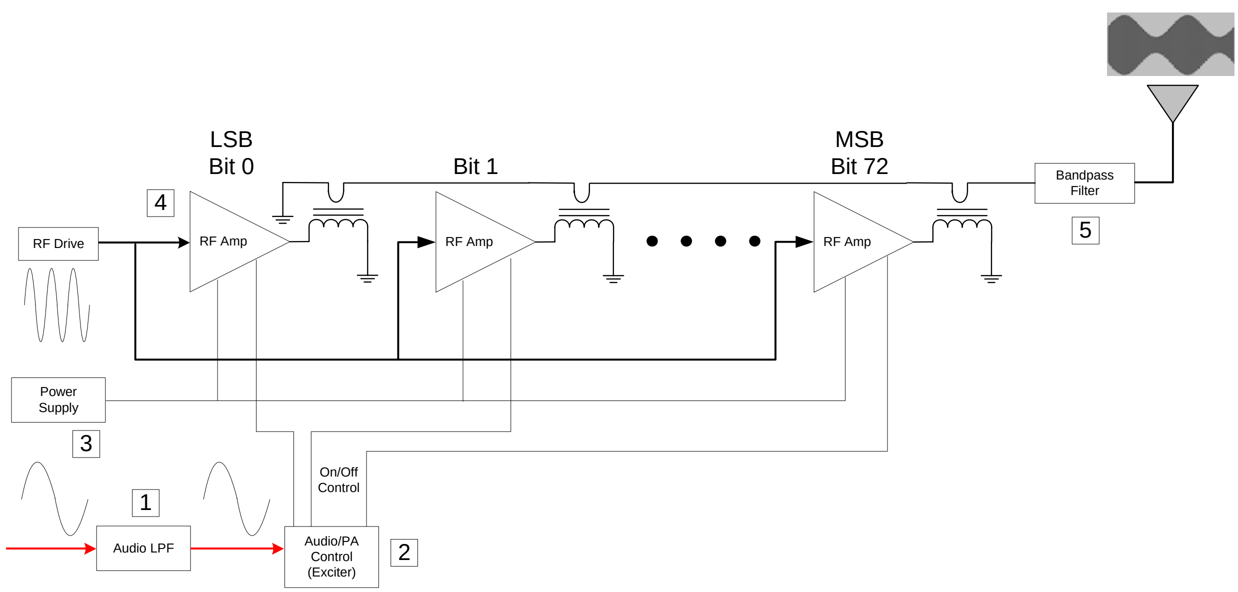

Figure 3: Digital Modulation Transmitter Diagram

1. The audio input filter provides the same function as it does for the PWM transmitter: it removes any unwanted high-frequency audio and noise before sending the audio to be amplified.

2. The audio/PA controller receives the audio signal and determines the number of amplifiers that are to be turned on to mirror the audio signal at the output of the bandpass filter. It also determines the gain of the variable gain amplifier used to eliminate any quantization noise resulting from the finite number of amplifier steps.

3. The power supply creates a voltage from the AC mains and feeds the RF amplifier directly. This is different from the PWM transmitter, where this voltage is used by the modulator stage.

4. The digital system incorporates a series of amplifiers that can be turned on or off at the command of the audio/PA controller. As the amplitude of the audio rises, more amplifiers are turned on. As the amplitude of the audio lowers, amplifiers are turned off. This modulation scheme works well at power levels when there are enough modules to accurately reproduce the desired audio waveform. However, performance degrades lower power levels due to limitations in the number of modules available to reproduce the audio signal. In addition, as amplifiers are turned on and off, quantization noise occurs, just as it does with a DAC—an additional cause of performance degradation.

5. The bandpass filter provides much the same function as the filter used in the PWM design: it reduces the level of harmonics of the carrier to an acceptable level.

Effects on HD Radio

The digital modulation scheme eliminates the need for the PWM generator, modulator, and the associated LPF. Eliminating these parts causes an efficiency advantage over a PWM transmitter, with efficiencies in the high 80s. In addition to the efficiency advantage, eliminating the modulator and associated LPF is important to HD Radio broadcast because the LPF is the major bandwidth-limiting portion of the PWM transmitter system. In its place is a controller system that determines, from the audio input signal, which RF amplifiers are turned on. This modulation scheme is not bandwidth limited.

For HD Radio, the input filter is removed or modified to allow the higher-frequency amplitude signal to pass unobstructed. This is the same as with the PWM transmitter.

Like the PWM transmitter system, the digital transmitter injects the phase information of the HD Radio signal directly into the exciter. The internal oscillator is disabled with a relay circuit, and the carrier signal with HD Radio phase information replaces it. Injection of phase information in this manner poses no bandwidth limitations.

Because the system is not band limited, the resulting spectrum fits well within iBiquity's recommended mask.

3 4M Modulation

4MX Overview

The background information on the modulation techniques that have been incorporated in AM transmitters over the years assists in illustrating the distinctive technologies in 4MX transmitters and 4M Modulation. The 4MX transmitter provides clear advantages in efficiency, power range, analog performance, and performance in the digital transmission era.

The 4MX transmitter consists of six major blocks:
1. audio low pass filter for analog,
2. I and Q or Ethernet data input for HD Radio operation,
3. exciter,
4. power supply,
5. power amplifier, and
6. bandpass filter.

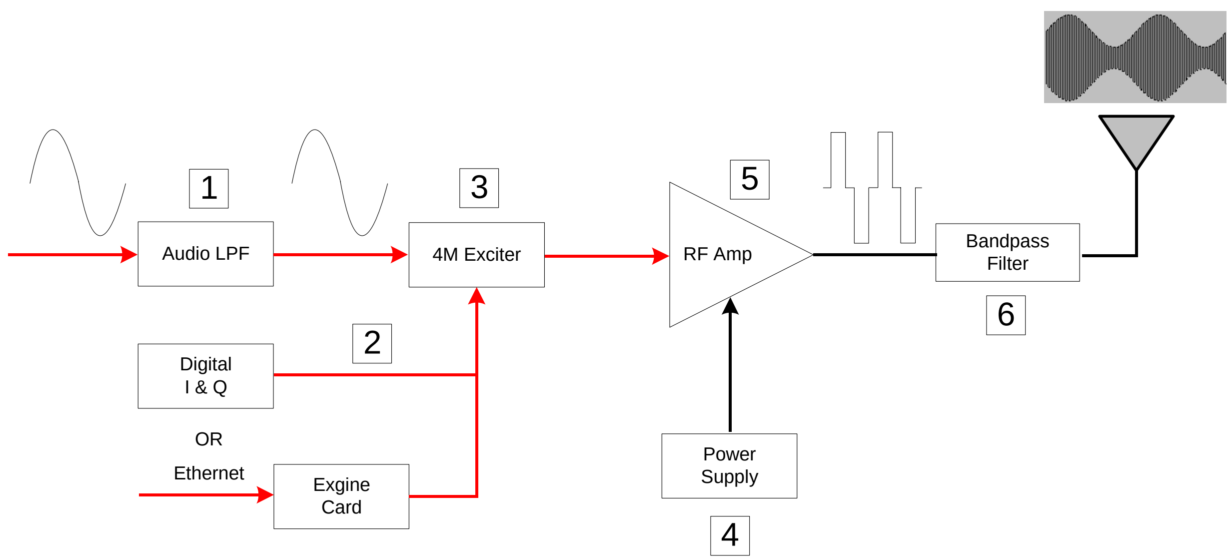

Figure 4: 4MX Transmitter Diagram

1. The audio input filter for the analog signal limits the bandwidth for analog operation by protecting against unwanted high-frequency signals and noise.

2. The I and Q or Ethernet data input provides a path for the HD Radio signals to pass directly into the processor in front of the exciter to be summed with the analog signal. It is important to note that the usual path for entering the HD Radio amplitude signal is through the standard analog input. For PWM and digitally modulated transmitters, the analog filter has to be removed or modified in some way, which leaves the transmitter unprotected against undesirable audio or noise that may enter through this port during HD Radio operation.

3. The exciter provides the drive signal to each PA to create the amplified output waveform. The drive characteristics determine the duty cycle of the amplified waveform.

4. The power supplies are an important feature of the 4MX transmitter design. They run as efficiently as the state-of-the-art will allow at 400 VDC. A power factor corrector supply creates this voltage easily and efficiently.

The supplies were overdesigned for efficiency and reliability. Two input diode bridges are used, even though the design requires only one. The FET used in the power factor corrector circuit delivers 2.85 kW maximum, even though it still operates at the stresses created by as much as a 6 kW output power. The power factor correction inductor was designed for twice the actual current to keep loses at a minimum. The catch diode is the latest silicon-carbide diode, which improves the efficiency of the supply by half a percent. All these design implementations yield an efficient (97%) and reliable power supply.

BE provides a one-to-one relationship between the power supplies and the power amplifiers. Each power supply operates only one PA with no busing of power supplies. This scheme provides optimum redundancy for the system.

5. Each power amplifier has an H-Bridge topology; each runs independently of the other amplifiers in the transmitter, and the output of each amplifier is in phase with all other modules. This is important because it allows the 4MX to operate on a single supply and power amplifier combination, resulting in excellent operation at very low powers. In addition, the same drive signal is applied to all PA modules. The drive to the power amplifier is key to the 4MX operation. The details of this drive circuitry are currently in the patent process and cannot be described in detail here; however, the system's results and benefits are described in the conclusion.

6. The bandpass filter was designed to reduce the harmonics of the carrier to an acceptable level. The 4MX transmitter uses a bandpass filter designed to be broadband, with approximately 180 degrees of phase shift between devices and the output port. The bandpass filter also matches the ideal PA load impedance of 10 ohms to the 50 ohm output impedance.

Effects on HD Radio

The 4M Modulation and 4MX technologies eliminate the need for a modulator stage and the LPF. This offers a tremendous efficiency advantage without limiting the bandwidth of the system. Unlike all other transmitter designs, the 4MX transmitters allow the I and Q or Ethernet data signal for HD Radio to be fed directly into the processor. Feeding the HD Radio signal via a separate path allows the analog input audio to be passed through its protective and noise-reducing filter. The I and Q or Ethernet data signals can then be added at the processor stage. This means that no modifications are needed to operate in the HD Radio mode. The Ethernet data signals are applied directly to the exciter via the Exgine card.

Why the Name, 4M Modulation?

Rarely are engineers allowed input on how the product model is identified. Using 4M Modulation to designate the name of the modulation scheme developed by BE is has a meaning related to how the system works. The “4” in 4M is a play on the mathematical term “Fourier”.

In 4M Modulation, the amplitude of the filtered output carrier is determined by calculating the coefficient of the first term of the Fourier expansion of the waveform presented to the combiner transformer. This is very different from the waveform produced by filtering a PWM signal, where the amplitude of the filtered output carrier is a linear function.

4 Conclusion

The information below compares the 4MX transmitter and the other systems.

- In a PWM transmitter, the modulator uses a duty-cycle modulated waveform to create a DC voltage proportional to the audio input signal. This audio-modulated DC is then sent to the PA to produce the final AM signal. In a 4MX transmitter, the duty cycle of the RF waveform is modulated directly, without the use of a modulator.
- The PWM transmitter performs modulation at some intermediate frequency (70 kHz to 150 kHz); the 4MX transmitter modulates at the carrier frequency.
- For HD Radio, the PWM transmitter is band limited; the 4MX transmitter is not.
- The PWM transmitter has one audio input for the amplitude portion of the HD Radio signal. This requires modification or removal of the audio input circuit during HD Radio operation. The 4MX transmitter has the Ethernet data sent directly to the processor, so no modification of the audio input filter is required.
- The digitally modulated transmitter requires many PAs and turns them off and on to create modulation. The 4MX transmitter requires only one PA to achieve modulation. This allows the 4MX transmitter to produce high-quality audio at low power.
- A transmitter using digital modulation has one audio input for the amplitude portion of the HD Radio signal. This requires modification or removal of the audio input circuit during HD Radio operation. The 4MX transmitter has the Ethernet data signals sent directly to the processor, so no modification of the audio input filter is required.
- The 4M Modulation design results in a more compact design that is a fraction of the footprint and weight of comparable designs.

The table below summarizes the advantages of the 4MX transmitter over other AM systems. The benefits to broadcasters include providing the highest-efficiency, reliability, and analog audio and HD Radio spectral performance on the market today.

Modulation Method	Efficiency	Power Range	HD Radio Spectrum	Spurious/Noise	Modulation Capability	Audio	Size	Weight
4M	89%	High and low	Excellent	Excellent	Excellent: 145% to -100%	Excellent	45"W x 25"D x 87"H	Less than 1,000 lbs
Digital	87%	High	Excellent	Good; quantization and switching products associated with frequency modules are turned off and on	Excellent: 145% to -100%	Excellent	102"W x 54"D x 78" H	More than 3,500 lbs
PWM	75%	Low, due to efficiency limitations	Good; only if PWM switching frequency is high (> 120 kHz)	Good: dependent on PWM switching frequency	Limitations at negative modulation due to nipple effect	Good; limited by PWM frequency	108"W x 48"D x 73"H	More than 3,500 lbs

Table 1: Performance Comparison (available 50 kW models)