# DRM Transmitter Requirements
# and
# Applying DRM Modulation to Existing Transmitters

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## DRM OBJECTIVES

"The DRM consortium had from the outset a number of key objectives. These objectives underpinned the work that was carried out to design a digital broadcasting system suitable for all the AM broadcasting bands world-wide.

The main objectives were:

- A significant improvement in audio quality and reliability
- Improved receiver usability and features for the listener
- Compatibility with current and future spectrum usage in the bands
- An assured migration path from analogue to digital broadcasts
- Early availability of receivers at the lowest cost through an open and non-proprietary system specification
- Maximum re-use of existing broadcast infrastructure

The DRM system was designed as an eventual replacement for current analogue AM broadcasting. However the system was also specifically designed to allow these new digital transmissions to co-exist with current AM broadcasts. By this means the changeover from analogue to digital broadcasting can be phased in over a period of years. This allows broadcasters to make the required investment on a timescale which meets their budgetary needs. This will ensure that expensively acquired and perfectly satisfactory transmission equipment is not suddenly made obsolete. Furthermore, unlike some other digital systems, the DRM system has been designed to allow suitable analogue transmitters to be modified to switch easily between digital and analogue broadcasts.

Because the DRM system was designed from the outset to co-exist with current analogue services it received the necessary recommendation from the ITU and this provides the international regulatory basis upon which transmissions may take place. "

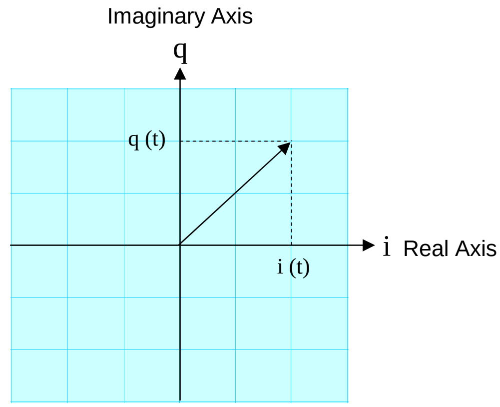
From the DRM Broadcasters' User Manual, 1st edition March 1, 2004

This paper will focus attention to the impact of DRM transmission technology and implementation on transmitters in place, and requirements for future transmitter purchases in line with the stated objective of the DRM consortium. It will deal with what is necessary to make an existing modern AM transmitters capable of transmitting a digital signal accurately. It also discusses what is required in an AM transmitter to meet the transmission requirements as recommended by ITU, and the operating standards established by organizations such as ETSI for countries and regions of the world.

## COFDM MODULATION AND POWER AMPLIFICATION

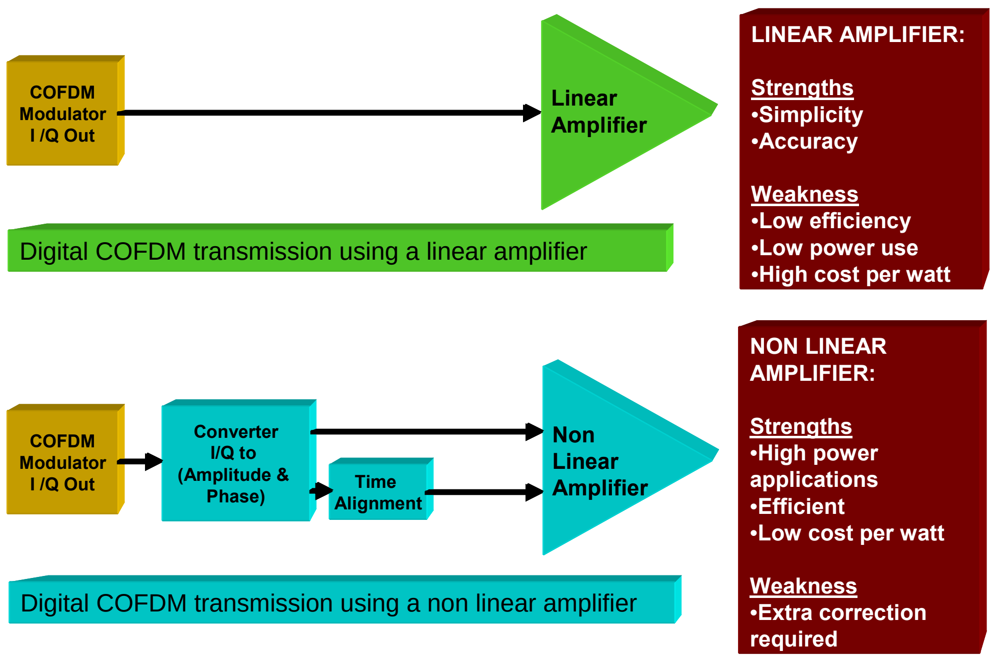
### Vector Modulation

To meet the expectations for DRM, a complex digital modulation method, COFDM or Coded Orthogonal Digital Modulation, is used. This is a vector modulation represented by (**i**) for the in-phase and (**q**) for the quadrature phase component. See fig 1. COFDM allows the transmission of high quality audio, related digital information about the broadcast, and other digital date useful to the listener. The first question is what are the practical equipment requirements for a digital AM transmitter.




### Linear or Non Linear Amplification

There are two approaches to transmitting digital signals as shown below. The advantages of each solution are most apparent depending on the power level required for the transmission.



Linear Amplification

The digitally modulated signal generally requires linear amplification to eliminate the intermodulation components which will result in spectral degradation. The ideal solution for amplifying COFDM would be to use a perfectly linear amplifier. This linear amplifier is practical for lower power transmitters, where efficiency is not a significant cost factor. Unfortunately, in the real world, the high cost and poor efficiency of linear amplifiers makes them impractical. As transmitter size is increased above 1kW another approach is desired.

Non Linear Amplification

The DRM signal is a complex digital signal represented by (**i**) for the in-phase and (**q**) for the quadrature phase component. The optimum solution is "non linear" high efficiency amplifiers which are capable of transmitting an all digital signal. In order to operate with a high efficiency amplifier it is necessary to use EER (Envelope Elimination and Restoration). To carry out the EER approach, it is necessary to convert the (**i**) and (**q**) waveform into an amplitude (**r**) and phase (**φ**) component. This conversion allows a "non linear" AM transmitter to amplify the Amplitude (**r**) and Phase (**φ**) signals separately, and to then reconstructed the (**i**) and (**q**) waveform in the modulation process.

The process of converting the (**i**) and (**q**) waveform to the easier to handle (**r**) and (**φ**) signals results in signals are theoretically of infinite bandwidth. However, in practice the required bandwidth will be set by the nyquist filter which results in a bandwidth of three to four times the bandwidth of the (**i**) and (**q**) signals due to spectral shaping.

The amplitude and phase modulation applied within the transmitter must each be a "linear" to assure the restored modulation is an accurate replication of the original signal. To meet these requirements a transmitter must have minimal amplitude and phase distortion, and have sufficient bandwidth to meet the requirements noted above.

LINEARITY AND BANDWIDTH ISSUES IN AM TRANSMITTERS

Amplitude Distortion Effects

The performance characteristics of a transmitter are directly related to the DRM operation of that transmitter. Intermodulation Distortion (IMD) is caused by a non-linear transfer function (AM to AM distortion) inherent in the amplifier or by an amplitude to phase (AM to PM distortion) conversion error. Both of these non-linearity's cause an increase in undesirable spectral components. In a perfect amplifier the (**r**) and (**φ**) signals will perfectly combine in the power output stage of an AM transmitter with the result being a perfect spectrum with only the desired signal. The accuracy of this combining directly impacts the OBE and the ability of a transmitter to meet the required spectral mask.

Phase Response in Filters

Simulation shows that phase linearity is at least as critical as flat frequency response and amplitude linearity if a transmitter is to have low OBE.

If the amplifier has a non-linear transfer function or amplitude to phase rotation the IMD products will increase. The level of IMD products generated due to phase errors can be better understood by a simple vector representation as shown in Figure 6. It is important in any EER system to align the timing of the (**r**) and (**φ**) to eliminate IMD products due to timing differences through the amplifier. It is also important that the (r) amplitude component be adjusted to 100% negative modulation to eliminate IMD associated with over-modulation.

RF Amplifier and Modulator Effects on Transmitter Bandwidth

This bandwidth requirement is not a problem for the (**φ**) phase channel of a modern solid state transmitter.  Most modern transmitters use an H Bridge RF amplifier design where the RF signal is generated at operating frequency.  These broadband amplifier designs are capable of operating with more than four times the phase modulated signal used by DRM.

However, the bandwidth in most solid state transmitters of the amplitude (**r**) channel is limited by the modulation methods used.

Analog filters in a modulator system (required between the modulator and RF power amplifier) are a source of non-linear phase/frequency characteristic.  Non linearity distorts the modulation waveform and increases the Out of Band Emission (OBE) in both PSM (Pulse Step Modulator and PDM (Pulse Duration Modulated) transmitters. The PDM transmitter filter must have high attenuation of the modulator switching frequency and therefore has greater phase non-linearity problems than the PSM) design.

These distortion characteristics can be controlled by increasing the switching frequency used in the modulation process, thus increasing the audio bandwidth of the modulator.  Moving the switching frequency above 120KHz to 150KHz allow audio bandwidth sufficient for good DRM transmission at a 4.5 to 10KHz transmission bandwidth.

Negative Modulation Effects on Bandwidth Requirements

Another characteristic of the DRM modulation places demands on the amplitude or audio bandwidth and RF bandwidths of a transmitter.  The dynamics of multiple carriers in the OFDM signal means that there will always be opportunity for the negative modulation levels of come carriers to go to zero momentarily, causing wide band noise and a 180 degree instantaneous change in the phase signal.  These wide band responses will cause intermodulation products, and resulting OBE,  if the bandwidth of the amplitude and phase path of the transmitter is not sufficient to handle the signal.

It is possible to softening the abrupt 180 degree phase transitions to enable the phase modulated signal to pass through the PA and also reduces the wideband noise (more than +/- 100 kHz) generated by the transmitter, since the signal is phase continuous. The following graph, Fig 2, show the phase modulation signal during digital processing and at the output frequency (1 MHz in this simulation). Note the desired amplitude signal (solid line) and the amplitude signal which is filtered by any limitations in a transmitters amplitude bandwidth.

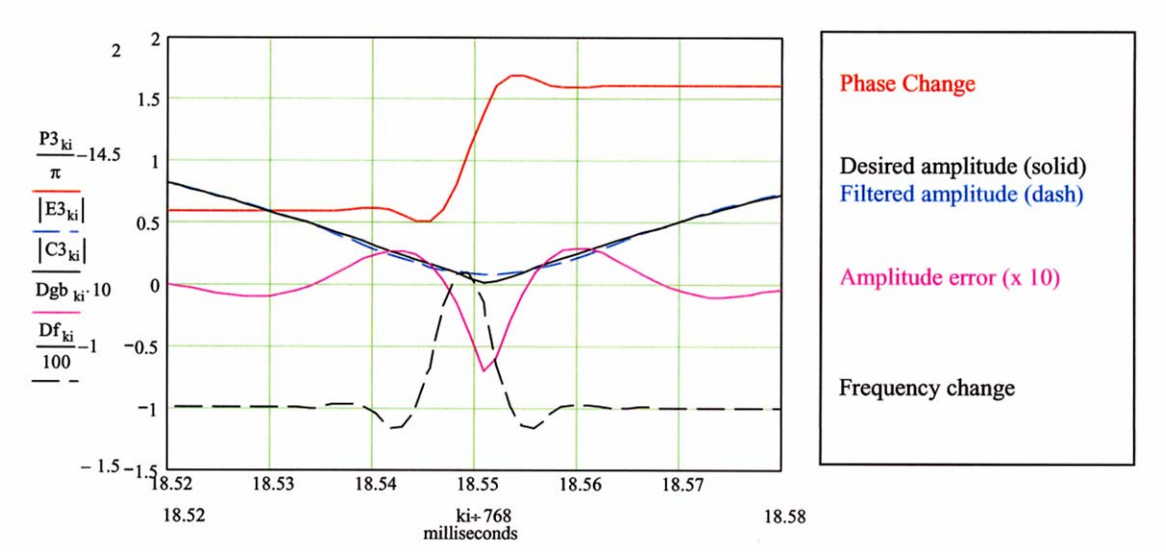
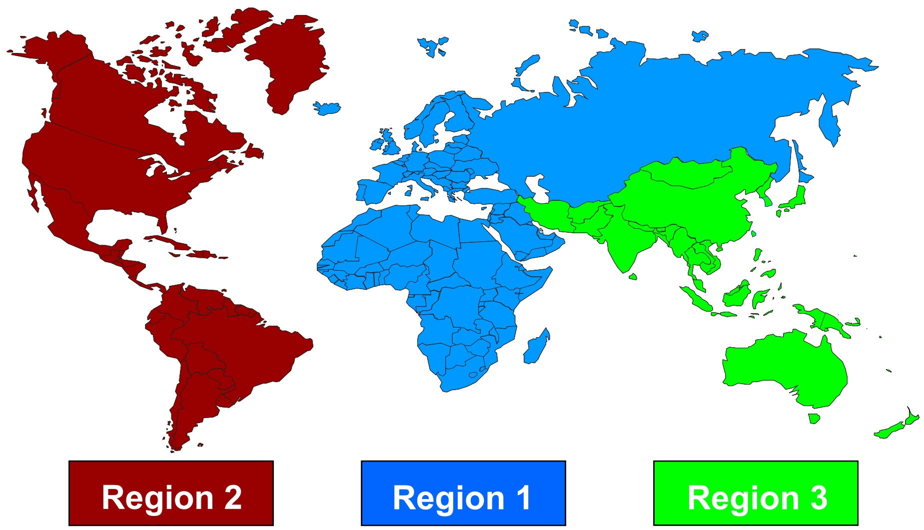



Figure 2 Negative Modulation Effects

Note that the momentary frequency change is of the order of 100 kHz with a duration of about 8 microseconds. With less smoothing of the phase transition the frequency change will be of shorter duration but larger, probably putting the instantaneous frequency outside the pass band of the RF circuitry.

Broadcast Bandwidth Requirements on Amplifier Bandwidth

Regardless of which modulation method is considered, the resulting spectrum of the system will be required to fit into an existing spectral mask. This spectral mask varies depending upon the region of the world in which the service is operated. The map and table in Fig 3 and Table 1 shows the current transmission bandwidths for the 3 ITU regions of the world. As DRM is implemented in some regions, countries may seek approval to expand the transmission bandwidths to allow stereo and increased data transmissions on MW and SW. Wider bandwidths will require the amplitude modulation bandwidths of the transmitter to be wider as shown in Table 2.




| Transmission Bandwidth | | | |
|---|---|---|---|
| Long Wave | Not Used | 4.5KHz, 9KHz | 4.5KHz, 9KHz |
| Medium Wave | 10KHz, 20KHz | 4.5KHz, 9KHz | 9KHz, 18KHz |
| Short Wave | 10KHz | 10KHz | 10KHz |

Fig 3 & Table 1 ITU Recommended Transmission Bandwidths by Region

| Approximate bandwidth required for good digital modulation | | |
|---|---|---|
| Transmission Bandwidth | RF Bandwidth (**φ**) | Amplitude Bandwidth (**r**) |
| 4.5KHz, 5KHz | 20KHz | 15 to 20KHz |
| 9KHz, 10KHz | 40KHz | 30 to 40KHz |
| 18KHz, 20KHz | 80KHz | 60 to 80KHz |

Table 2 Suggested RF bandwidth of a transmitter for accurate DRM transmission

## DIGITAL POWER OUTPUT FROM AM TRANSMITTERS

### Peak to Average Ratio

DRM power is expressed as the power output of the average digital modulation. Since modulation peaks are high for COFDM transmission, the average power is significantly lower than for the same transmitter operating in the analog AM mode. Under ideal conditions a DRM COFDM waveform has a peak to average ratio on the order of 12dB.

The average power for a DRM signal is a function of the peak power capability of the amplifier used and the peak to average ratio of the DRM signal. A transmitter with an analog carrier power output of 100kW and peak power of 400kW would produce 25kW Watts DRM average power with 12 dB of headroom for the modulation peaks. If the digital average power of such a 100kW transmitter were increased even 2 dB, the transmitter would clip the peaks of the amplified signal, causing in-band and out of band intermodulation products. The result is excessive out of band emissions and non-compliant operation of the transmitter. This same effect will be seen in an ideal linear amplifier, as these intermodulation products are produced by the clipping effect. The following graph, Fig 4 & 5, shows the result of 2 dB of peak clipping due to increase of the signal level to the power amplifier. Since peak levels can vary considerably from symbol to symbol, it is difficult to adjust a transmitter to completely eliminate this problem.

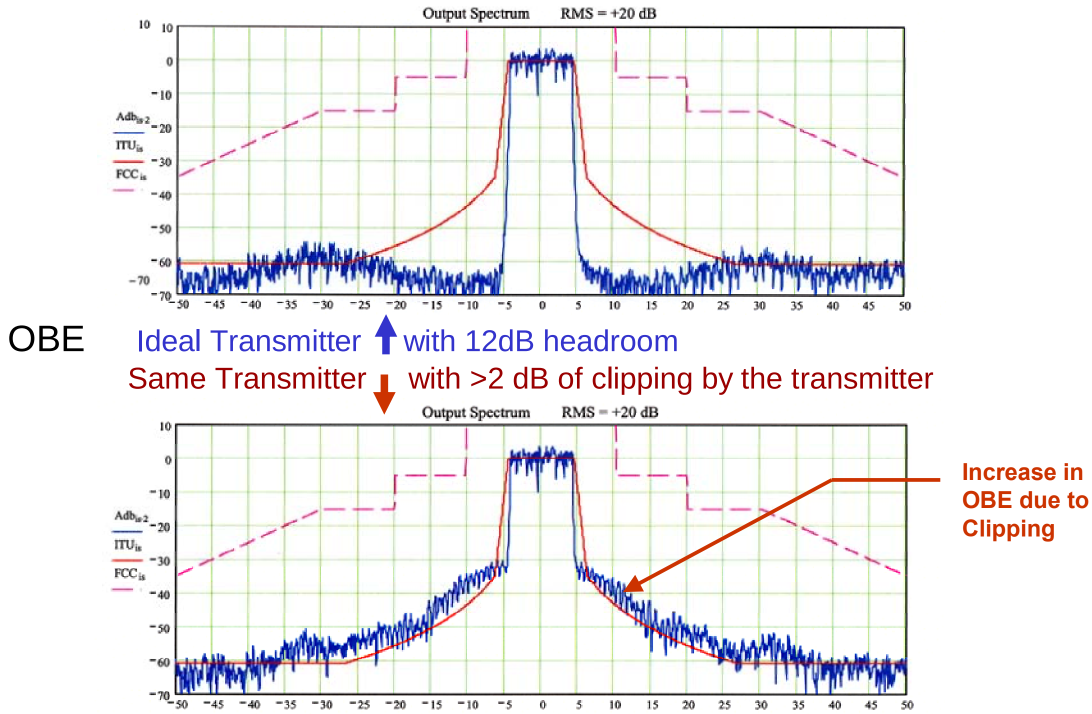



Figure 4 & 5 Out of Band Emission without and with clipping in a transmitter

These intermodulation products cause the creation of shoulders on either side of the transmitted spectrum. This is clearly not acceptable as the signal will interfere with other adjacent channels. Stringent spectrum masks have been produced as part of the ETSI . specification' for DAB and this requirement is the dominant factor determining the linearity requirements of the transmitter. It is therefore necessary to deal with transmitter clipping and its effect on out of band emissions.

Even with proper control of phase shifts, peak clipping in the modulator or power amplifier can also produce severe OOB radiation. A 10 dB backoff (40 kW rms digital from a transmitter rated for 100 kW carrier and 400 kW modulation peak will probably eliminate clipping in 95 to 99 percent of the DRM symbols.

Low-Level Clipping

An alternative to extreme backoff is to clip the **iq** signals in the early stages of the exciter, followed by digital low-pass filtering to attenuate the out-of-band frequencies produced by the clipping as shown in the following two graphs, Fig 6 & 7. This does not eliminate the bit errors at the receiver due to the clipping, but other studies have shown that, in a noise-limited channel, 2 to 3 dB of clipping will give a 1.5 to 2 dB net improvement in the effective signal to noise ratio.

This first graph, Fig 6, shows that low-level clipping without filtering produces the same amount of OBE as high-level clipping.

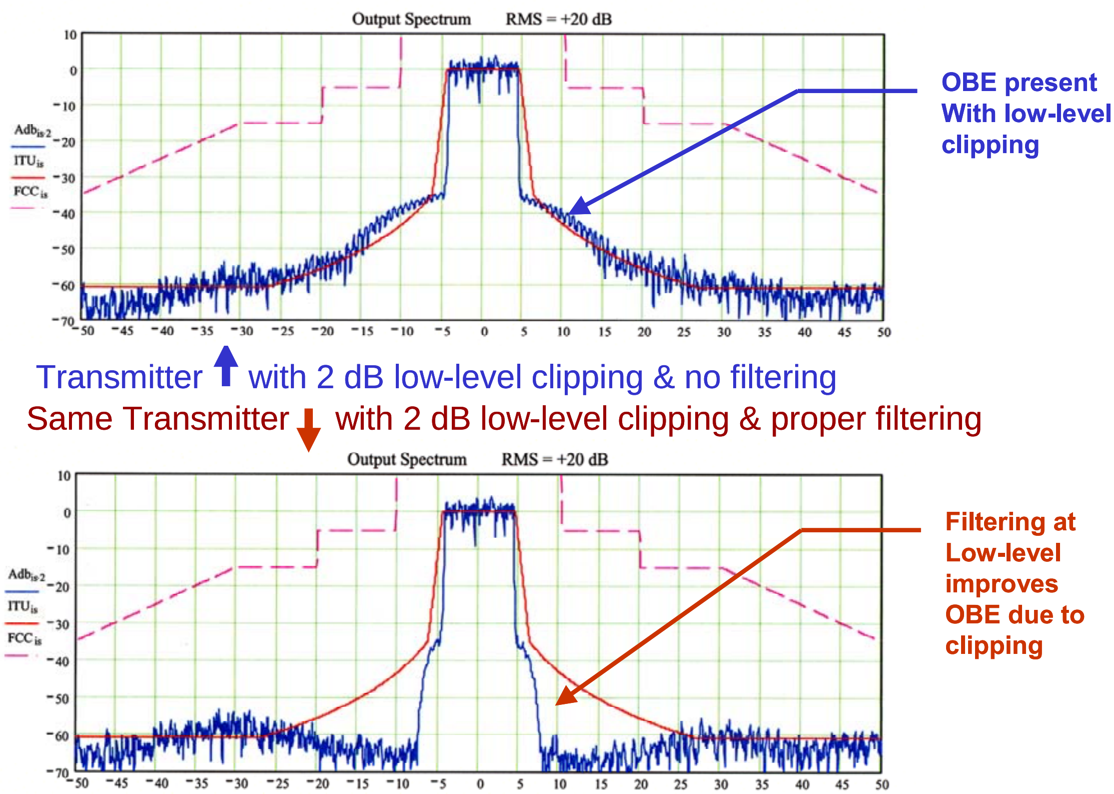



Figure 6 & 7 Out of Band Emission without and with low level clipping and processing

The second graph, Fig 7, shows that with the same amount of clipping, proper filtering confines the additional frequencies within the ITU limits as shown below. Simulations indicate that the peak-to-rms ratio varies from symbol to symbol between 7.5 and 10.5 dB with most values near 8.5 dB. Setting the clip level at 7.5 to 8 dB above the desired rms output results in very light clipping on most symbols but controls the OOB radiation on the infrequent large peaks. In the previous 400 kW PEP transmitter, clipping at +8 dB and filtering will allow an rms output power of 65 kW instead of 40 kW.

The effects of controlling the OBE of a transmitter by low-level clipping by 2 to 4 dB, and filtering will improve the total power output of a digital transmitter without causing significant degradation of the digital signal. Future testing is needed to quantify how far clipping and filtering can be used to improve total average power output in a DRM transmitter.

## TRANSMITTER OUTPUT POWER FOR DRM

The peak power of a transmitter is determined by not only the carrier power level, peak to average of the DRM signal, and low level clipping, but by the positive modulation capability in the transmitter design as well. The following graph, Fig 8, shows the relationship between average carrier (and resulting peak power), positive modulation capability, and clipping on the total average power of a transmission system..

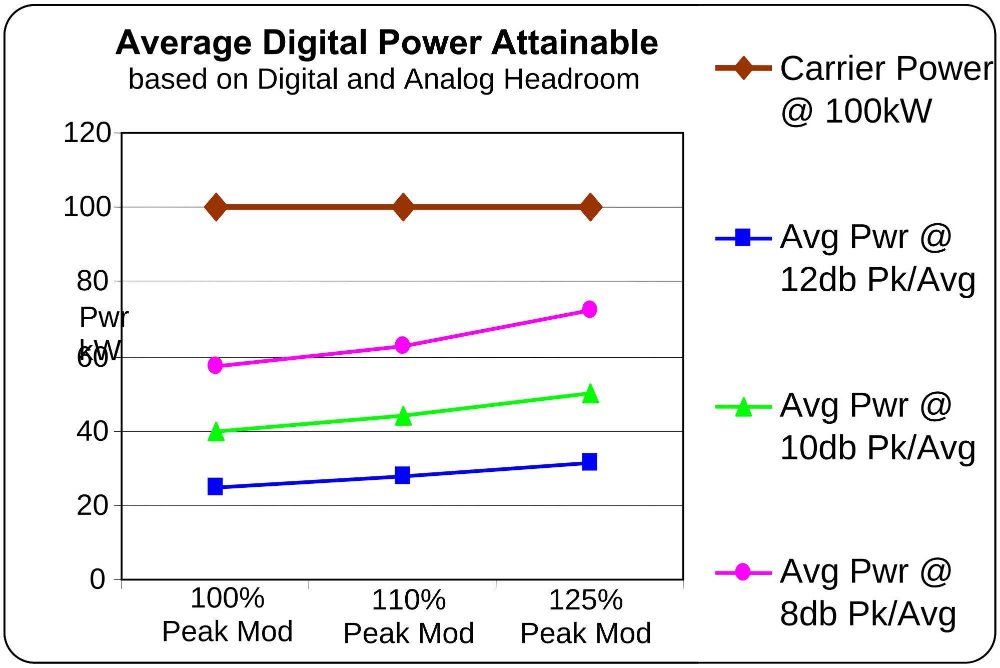



Figure 8 Digital Power Possible based on Peak Modulation capability and Clipping

CONCLUSION

Practical Transmitters

The issues of RF and amplitude bandwidth, distortion, clipping and power covered in this paper are all points of concern when upgrading a transmitter in the field, or when purchasing a transmitter for future use in DRM broadcasting. In some cases significant modifications may be necessary to existing transmitters in order to transmit DRM compliant signals while also complying with TTU requirements. With careful planning these modifications can be made at a reasonable cost.

Current DRM modulators have capabilities to pre-correct the digital signal to compensate for non-linearity in some transmitters. As technology develops, greater compensation will be shifted to the DRM Modulator to correct transmitters for better OBE performance, and ease the work to make older equipment compliant with ever more demanding performance criteria.

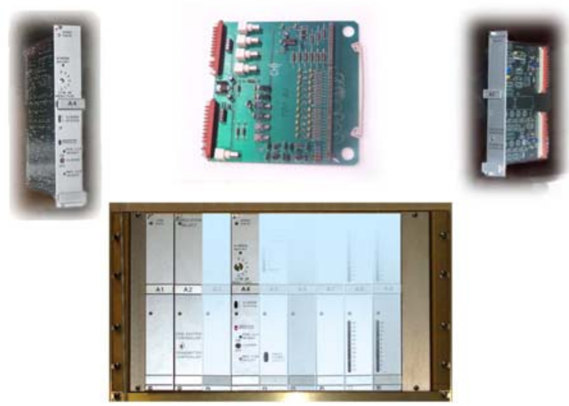
Reverences

Optimizing the Design of an HF Transmitter for DRM -TC_CM_ 175, Herbert P. Jacobson, 2001

Practical Application

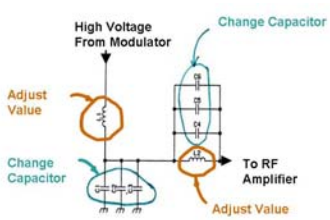
Continental is preparing a DRM upgrade kit for the popular 418F HF transmitter in use around the world. The above principles require improving the bandwidth of the 418F modulator, reducing noise in the transmitter and applying correction to the transmitter for DRM modulation. This is accomplished with changes to the audio filter, screen modulation and using the DRM Exciter to assist in the linearization of the transmitter. The following diagrams and pictures show the process.

The DRM Modulation Upgrade Kit requires replacing some of the solid state modulator control boards with new A1, A2, A4, and I/O board. These boards remove the input audio filter, provide DC coupling, improve modulation control and add automatic / manual switching to DRM



It is also necessary to change the audio filter characteristics for wide band operation.

Adjusting the Inductor




Changing the Capacitor

Completed
Filter
Modifications

And add a DRM Exciter to complete the package.

Contact a Continental Electronics Representative for more details on the DRM Upgrade Kit.