METHODS OF SUPPRESSION NON-LINEARITY PRODUCTS IN TERRESTRIAL DIGITAL VIDEO TRANSMITTER

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Abstract - Intention of the paper is to show in reduced form the methods of suppression non-linearity products in terrestrial digital video transmitter with apply of digital precorrection unit and output filter unit.

1 - INTRODUCTION

Standard for digital terrestrial broadcasting DVB-T [1], established in 1997, opened a new era in digital TV technology. Multicarrier techniques, COFDM modulation, digital precorrection GPS synchronisation, are some of the features of a digital transmitter.

COFDM modulation method is very resistant to different disturbances (e.g. reflection and interference), and also spectrally economical, enabling the transmitter network to transmit the digital signal on only one channel (Single Frequency Network). In-band and out-of-band intermodulation products rise limits the efforts to get possibly large amplifier efficiency factor for nominal transmitter output power. A solution is the use of digital precorrection, which, for minimising the intermodulation products, has to accomplish best possible compensation of amplitude and phase transfer characteristics of the amplifier and the use of output filter unit with very high selectivity.

2 - DVB-T TRANSMITTER – LOW POWER STAGE

Input signal to the transmitter is a MPEG2 transport stream, with 5Mbit/s to 34,3 Mbit/s data rate, depending on transmission mode and parameters chosen.

In COFDM encoder redundant bits are added to MPEG2 signal, then time and frequency redistribution of bits are fulfilled (interleaving), building forward error correction (*FEC*). Different code-rates can be chosen (eg. R=1/2, R=2/3, R=3/4, R=5/6, R=7/8). Here is R = (useful bit rate) / (useful bit rate + protected bit rate).

To obtain OFDM signal, transport stream is divided into two (QPSK), four (16QAM) or six (64QAM) bit streams, forming a word of 2, 4 or 6 bits, defining the subcarrier vector. OFDM symbol is in 8K mode formed by 6817 subcarriers, and in 2K mode by 1705 subcarriers. Symbol duration is divided into two parts: useful and guard parts. Guard part can occupy 1/4, 1/8, 1/16 or 1/32 of the whole symbol duration.

In linear precorrection unit the input I/Q stream is treated in amplitude and phase to linearise the power-amplifier transfer characteristics.

Up-converter converts the IF signal to the desired UHF channel, which will be amplified for driving the output stage to the level needed.

3 - DVB-T TRANSMITTER - HIGH POWER STAGE

Output power amplifier is realised in the new LDMOS technology. It is characterised by very high power amplification, and due to AB-class operation, by good efficiency also.

Input multi-carrier signal to the power amplifier is given by:

$$s_{in}(t) = A_{in}\sum_{n=1}^{N}[d_n^I(t)\cos w_n t + d_n^Q(t)\sin w_n t], \quad (1)$$

where A_{in} is amplitude of the *n*-th subcarrier for respective I and Q channels, *N* - number of subcarriers, $d_n^I(t)$ and $d_n^Q(t)$ are the bit streams applied to respective I and Q channels of the *n*-th carrier. Transmission characteristic is not a linear one, and can be approximated by a third-order polynom.

Output signal $s_{out}(t)$ is given by:

$$s_{out}(t) = a_0 s_{in}(t) + a_1 s_{in}^3(t) + \ldots, \quad (2)$$

where a_0, a_1,... are non-linear coefficients.

It follows that at the amplifier output, besides basic signals, appear also sum and difference of their frequencies (intermodulation products) distributed in and out of the channel.

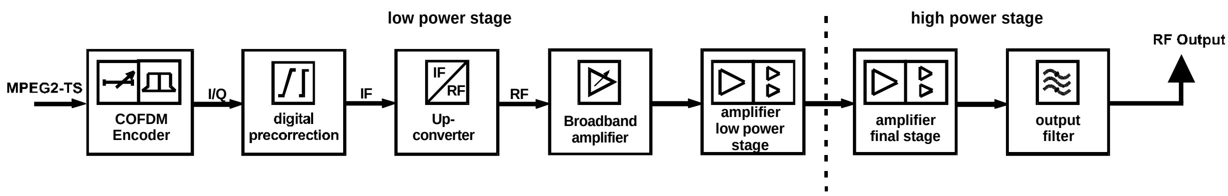

Figure 1. DVB-T Transmitter's chain

Figure 2 shows a typical distribution of DVB-T signal frequency spectrum at the output of power amplifier.

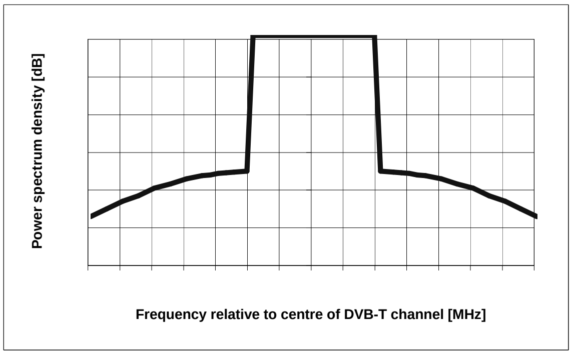

Figure 2. DVB-T signal spectrum at the power amplifier output.

An important operating parameter which determines the efficient usage of a high power amplifier is the output backoff (*OBO*). It is expressed by

$$OBO = 10\log\frac{P_{sat}}{P_{out}}\,, \qquad (3)$$

where P_{sat} is the maximum output power (saturation power) and P_{out} is the mean power of the transmitted signal. It is desirable to have the smallest possible output backoff in order to utilise as much as possible the available power of the amplifier. But, operating the amplifier with small backoffs will tend to generate relatively high IM products in-band and out-of band.

4 - LINEARITY PRECORRECTION UNIT

Linear precorrection has to compensate distortions caused by the nonlinearity of the amplitude- (AM-to-AM) and phase- (AM-to-PM) transmission characteristics of the power amplifier to the point of saturation. DVB-T signal peak values exceedings the amplifier saturation region are compensated by additional methods, depending on realisation called peak reduction, peak preconditioning, etc.

Peak-to-rms value ratio of the signal is expressed by the crest-factor:

$$x = 20\log\frac{U_{\max}}{U_{eff}} = 10\log N\,\cdot \qquad (4)$$

Crest-factor theoretical value in the 8K-mode (6817 subcariers) is 38 dB. Limiting the signal peak values the out-of-band distortion is lowered, but at the same time the C/N ratio inside the channel is lowered too. As the EN 300744 standard prescribes the minimum C/N ratio at the receiver input, a stronger limitation of the signal peak values would lead to the lowering of this minimum C/N ratio. It is the reason why the standard out-of-band distortion lowering, caused by limiting signal peak values, is typically about 3 dB. Approximately in the same amount rises the signal in-band distortion.

In its realisation linear precorrection can be analogue or digital. Analogue precorrection is limited in its action, demanding many adjustments to be controlled in fixed time intervals. Digital precorrection is much precise and stable in time. If realised as adaptive, it automatically takes into account amplifier changes due to ageing or temperature.

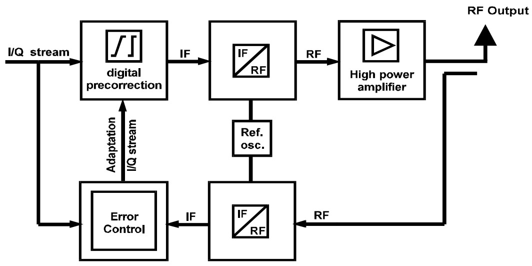

Figure 3. Adaptive precorrection

Recent DVB-T transmitter output stages, realised in LDMOS technology, with very good ageing- and temperature- stability avoid usage of very complex adaptive precorrection, having in mind price lowering of the transmitter and its reliability. Therefore, digital precorrection is used, with adaptive treatment for initialising only. Transfer function of the amplifier output stage and all relevant parameters are precisely measured, put into linear precorrection as reference values, by which the power amplifier realisation is fulfilled.

On Figure 4 the measured data of the power amplifier output stage with and without precorrection are shown. It can be seen that IM products at $f_0\pm$ 4,2 MHz are lowered by 10 dB, what is a typical value realised by linear precorrection, while the rest of IM products attenuation to the level prescribed by DVB-T standard is achieved by output filter unit.

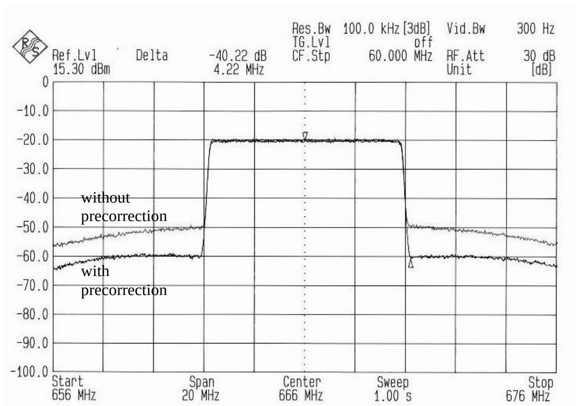

Figure 4 Signal spectrum of a high power amplifier –measured data

5 - DVB-T FILTER UNIT

Standard EN 300 744 prescribes the spectral mask, which has to be filled by digital TV transmitter (Figure 5). Based on the prescribed mask and the frequency spectrum characteristics of the DVB-T signal at the amplifier output, selectivity needed of the filter unit is evaluated. Attenuation:

$$
\begin{aligned}
f_0 &\pm 4{,}2\ \text{MHz}: \geq 15\ \text{dB} \\
f_0 &\pm 6\ \text{MHz}: \geq 30\ \text{dB} \\
f_0 &\pm 12\ \text{MHz}: \geq 50\ \text{dB}
\end{aligned}
\tag{5}
$$

Transmission region is defined in the limits $f_0 \pm 3{,}8$ MHz of UHF frequency band 470 – 862 MHz.

In DVB-T transmitter (1kW) design the maximum insertion loss of the filter unit at f_0 was prescribed by ≤ 0.7 dB.

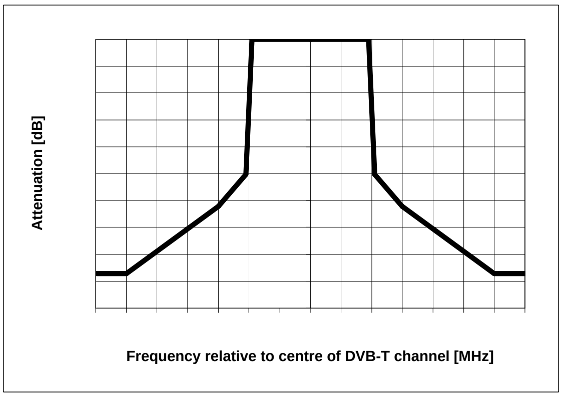

Figure 5. DVB-T spectrum mask

For given parameters the choice of filter is done. In this case it is the Chebyshev-type bandpass filter. Using filter synthesis program filter order is determined, and unloaded resonator-quality Q prediction done, for which filter insertion loss does not exceed the given value of 0,7 dB.

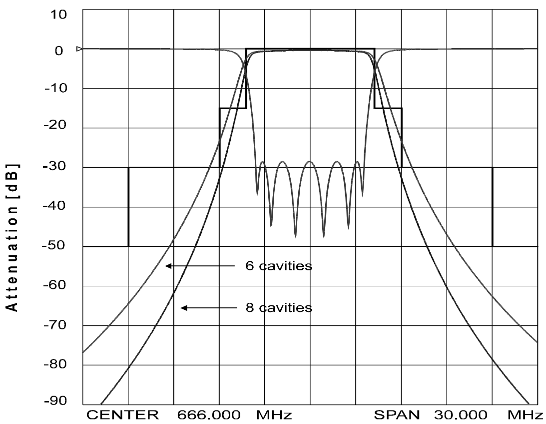

Figure 6. Amplitude-frequency characteristics of 6 and 8 cavities filters

Based on simulation, Figure 6 shows the frequency characteristics of 6 and 8-cavity bandpass filters. It is seen that both filters do not satisfy the desired selectivity, neither the 8-cavity bandpass filter for the insertion loss. For quality factor Q=5000 the insertion loss for a 6-cavity filter is 0,6 dB, and for a 8-cavity one it is 0,85 dB. It can be lowered increasing the resonator diameter, but it is not a satisfying solution having in mind economy and competition on the market.

Using the quality factor

$$
Q = \frac{l}{2d\left(2 + \dfrac{l\left(1 + d/D\right)}{4d\left(\ln\left(D/d\right)\right)}\right)}, \tag{6}
$$

where

$$
d = \frac{1}{\sqrt{p \cdot \mathrm{f} \cdot c \cdot m}} \tag{7}
$$

is the skin effect and the optimum ratio d/D = 0,278, the resonator diameter (cavity) is calculated.

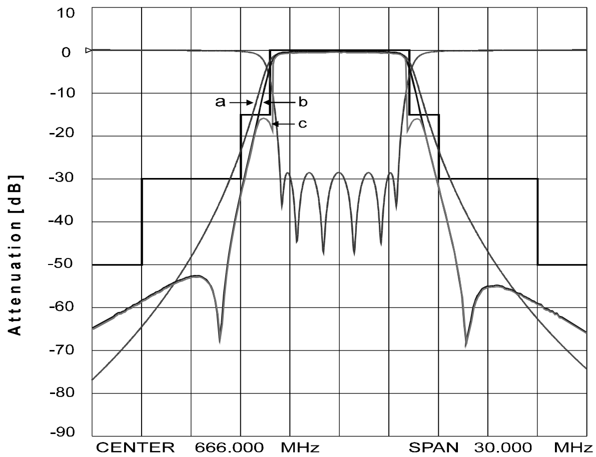

Figure 7. Filter simulation: a) 6-cavity,
b) 6-cavity + overcoupling,
c) 6-cavity + overcoupling + 2 notch cavities

To increase the filter selectivity without changing the dimensions or number of resonators, a solution can be realised by additional coupling (overcoupling) between resonators 2 and 5. It can be approximated by:

$$
K_{25} \approx -K_{23}^2 K_{34} \left(\frac{1}{\Omega_2^2} + \frac{1}{\Omega_4^2}\right), \quad \Omega = 2\frac{f - f_0}{B}, \tag{8}
$$

where $K_{i,j}$ are coupling values between resonators, Ω is the normalised poles frequency, and B is the channel bandwidth.

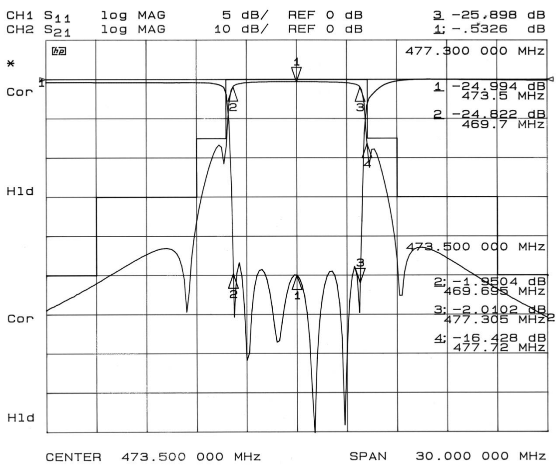

Figure 8. DVB-T filter –measured data

Using the program ADS (Advanced Design System) a 6-cavity filter with additional coupling between cavities 2 and 5, was analysed. At $f_0 \pm 6$ MHz selectivity increased for about 7 dB, and the width of the characteristics in that region became the same as for 8-cavity filter. Insertion loss in the transmission region is lowered about 0,1 dB. To realise the desired selectivity at $f_0 \pm 4{,}2$ MHz (≥ 15 dB), it was necessary to add two notch-cavities. It was finally a "8-cavity" filter again, but filling the prescribed spectrum mask and with lower insertion loss for about 0,25 dB, compared with the 8-cavity filter. The tuning of the filter was simpler also.

Based on simulation results, resonator dimension calculations, coupling factor, minimum voltage isolation for the peak power 10 dB above nominal power, material choice for filter temperature stabilisation, a DVB-T filter unit was realised.

Following values are obtained:

Frequency:	470–862 MHz
Insertion loss:	≤ 0,6 dB
Attenuation:	
$f_0 \pm$ 4,22 MHz	≥ 15,0 dB
$f_0 \pm$ 6,0 MHz	≥ 30,0 dB
$f_0 \pm$ 12,0 MHz	≥ 50,0 dB
Return loss:	≥ 23,0 dB
Input Power (DVB)	≤ 1000 W
Dimensions:	265x330x560 mm
Weight:	22 kg

As it can be seen, measured values apply very good to simulated ones, showing good choice of reduction factors between ideal and practical values in resonator quality, electrical conductivity, surface roughness and resonator coupling calculations.

6 - CONCLUSION

Intermodulation products caused by output power amplifier nonlinearities could be lowered to a great extent using a sufficiently large output backoff. That would mean a considerable amplifier efficiency factor drop, being uneconomical. As a compromise, the output backoff lowering is suggested to the extent, needed for the sum of IM products from output amplifier, of linear precorrection and of output filter unit to reach the value prescribed by EN 300744 standard for output spectral mask.

Figure 9. Practical realisation of DVB-T filter

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