REPORT ITU-R BT.2018

STUDY OF THE SYSTEM C GHOST CANCELLING REFERENCE SIGNAL FOR THE EVALUATION AND CORRECTION OF LINEAR DISTORTION IN THE TELEVISION CHAIN

(Question ITU-R 55/11)

(1998)

Many countries are interested in improving the operational quality of existing television broadcasting networks.

The automatic correction in receivers of distortions that have accumulated in the TV chain is one of the most effective means of increasing the effective quality of the chain. For this purpose, Recommendation ITU-R BT.1124 defines ghost cancelling reference (GCR) signals for correction of linear distortions in receivers, which can also be used for the correction of distortions in individual sections of complex TV chains, and which can also serve for the evaluation of distortions.

At the present time, various enhancement modules are being implemented in existing TV services. The correction of linear distortion is considered to be one of the most important enhancement modules.

Some countries are currently using analogue systems with 6 MHz video bandwidth and intend in the future to use NICAM digital sound. So two bandwidths for the luminance signal are expected to be in use: 6 MHz (without digital sound) and 5 MHz (when digital sound is used). So the question of 5 MHz and 6 MHz GCR signals is of interest.

In 1996 (Doc. 11A/42) was published presenting some results of studies of the GCR system C signal.

This report brings together the results of further studies (Doc. 11A/80) on this subject.

1 Automatic correction of linear distortions as a part of the concept of enhanced analogue television

The concept of enhanced analogue TV assumes the use of the wide-screen picture aspect ratio of 16:9, digital sound, and improved image quality in comparison with conventional TV.

The realization of this concept is based on the use of digital signal processing.

Principles and some details of the construction of enhanced TV systems are described in ITU-R texts (Recommendation ITU-R BT.1118 – Enhanced compatible wide-screen television based on conventional television systems; Recommendation ITU-R BT.1197 – Enhanced wide-screen PAL TV transmission system (the PALplus system); Recommendation ITU-R BT.1298 – Enhanced wide-screen NTSC TV transmission system, and Doc. 11A/8).

One of the most significant characteristics of enhanced TV is the improvement of image quality. This is achieved by means of:

– use of high quality sources of signal (component digital studios);

– use of intra-frame signal pre-processing and post-processing, allowing more effective separation of luminance and chrominance signals in the decoding process;

– correction in the receiver of linear distortions accumulated in the TV path (referred to in the ITU-R texts as “ghost cancellation”).

The automatic correction of linear distortions has common importance both for conventional and enhanced TV. By including a device for ghost cancellation in the receiver, linear distortions that have accumulated in multi-chain TV paths are removed rapidly, with consequent improvements in displayed luminance and chrominance resolution and in the decoding of teletext.

2 The question of GCR test signal standardization

Recommendation ITU-R BT.1124 (Reference signals for ghost cancelling in analogue television systems) defines three GCR signal systems – A, B and C.

For Europe, and for many other countries, signal C is of interest. The direct purpose of this signal is concerned with the reduction of echo signals accumulated in the TV reception path. The GCR signal has wider application for the rapid estimation and correction of common linear distortions [Gofaizen, 1995a and b] and (Doc. 11A/42).

Correction of distortions is possible both in the television receiver, and at the input to each link in the distribution and transmission chain. Taking into account that linear distortions can result in nonlinear effects and in worsening noise characteristics of the image, the use of automatic correction of nonlinear distortions does not exclude the necessity of controlling these distortions in each link. Thus the estimation of linear distortions is possible on various criteria. Use of computer technologies allows these to be achieved by computing methods.

The studies in the Ukraine (Doc. 11A/80) took into account the following:

– The possible optimization of the system C GCR signal by the use of alternative window functions, suggested in work [O.V. Gofaizen, 1995a and b] and (Doc. 11A/42) with the objective of achieving an improvement in the accuracy of the estimation of distortions.
– Recognizing that the GCR signal is already standardized, any changes would need to be compatible with existing use of the signal in a number of countries; aspects of the compatibility of any modifications would need to be investigated.
– An optimized GCR signal should have higher noise immunity relating to interference from the adjacent channels than the standard GCR signal (noise immunity gain should be appreciated as the result of optimization).
– The introduction of an optimized GCR signal must not result in an increase in the cost of equipment.

Thus, during the course of choosing a GCR signal for some countries, various studies were felt to be appropriate in order to seek to provide the most effective solution bearing in mind these issues.

3 The mathematical description of the GCR signal and analysis of its basic properties

In Koo [1995] has described the properties of what has become known in the ITU-R as the system C GCR signal.

This analysis was continued and is complemented in works [Gofaizen, 1995a and b] and (Doc. 11A/42).

The following is a recent alternative description and analysis of the same system C signal, as derived during the course of latest studies:

In work (Doc. 11A/42) it is shown that the GCR signal may be represented by the formula:

$$g(t) = \frac{A}{2\pi} \int_{-\Omega}^{\Omega} e^{\,j\,\mathrm{sign}(\omega) b \omega^2} W(\omega)\; e^{\,j\omega t} d\omega \qquad (1)$$

where:

$$W(\omega) = \int_{-mT}^{mT} w(t)\; e^{-j\omega t} dt$$

$$w(t) = q(t)\; s(t)$$

$$q(t) = \cos^2 \frac{\pi}{2} \frac{t}{mT}$$

$$s(t) = \frac{m-2}{mT} \,\mathrm{sinc}\, \pi \frac{m-2}{m} \frac{t}{T}$$

$$\mathrm{sign}(\omega) = \begin{cases} -1 & \text{for } \omega < 0 \\ 0 & \text{for } \omega = 0 \\ 1 & \text{for } \omega > 0 \end{cases}$$

$$\mathrm{sinc}\, x = \frac{\sin x}{x}$$

The parameter values of this signal given in Recommendation ITU-R BT.1124 are:

$$A = 0.30358 \times 10^{-6} \text{ V}$$

$$b = 0.2829 \times 10^{-12} \text{ s}^2\text{/rad}$$

$$\Omega = 2\pi \times 5{,}5 \times 10^6 \text{ rad/s}$$

$$\Omega_1 = 2\pi \times 5 \times 10^6 \text{ rad/s}$$

$$c = 0.9121 \times 10^6 \text{ rad/s.}$$

The parameters T and m in equation(1) are:

$$T = \frac{m - 2}{m} \frac{\pi}{\Omega_1}$$

$$m = \frac{\Omega_1}{c} + 2$$

so that $T = 94.5$ ns and $m = 36.4439$.

In this signal there are two window functions:

– $W(\omega)$ in the frequency domain or its Fourier transform $w(t)$, presented in the formulae, and

– $P(\omega)$ in the frequency domain or its Fourier transform $p(t)$. This window function is not seen from the formulae. It is a rectangular function limiting the interval of product $e^{j \,\text{sign}(\omega) b \omega^2} W(\omega)$ when integrated by ω.

The structure of each of these window functions is shown in Figs. 1 and 2 respectively.

The equation for the GCR signal in the time domain may be represented as [Gofaizen, 1995a and b] and (Doc. 11A/42):

$$g(t) = f(t) \otimes w(t) \otimes p(t) \tag{2}$$

where:

$$f(t) = \frac{1}{2\sqrt{\pi b}} \left\{ \cos\left[\omega(t)\, t - \frac{\pi}{4}\right] + \frac{1}{\pi} \sin\left[\omega(t)\, t - \frac{\pi}{4}\right] \otimes \frac{1}{t} \right\}$$

$$p(t) = \frac{\pi}{\Omega} \text{sinc } \Omega t$$

$$\omega(t) = \frac{t}{4b}$$

$\otimes$: convolution sign.

Here, function $\omega(t)$ demonstrates the linear relationship between frequency change and time.

The system C signal has the following inherent characteristics [Koo, 1995]:

– high energy,

– flat amplitude-frequency characteristic within the bandwidth of interest,

– smooth phase characteristic in the bandwidth of interest,

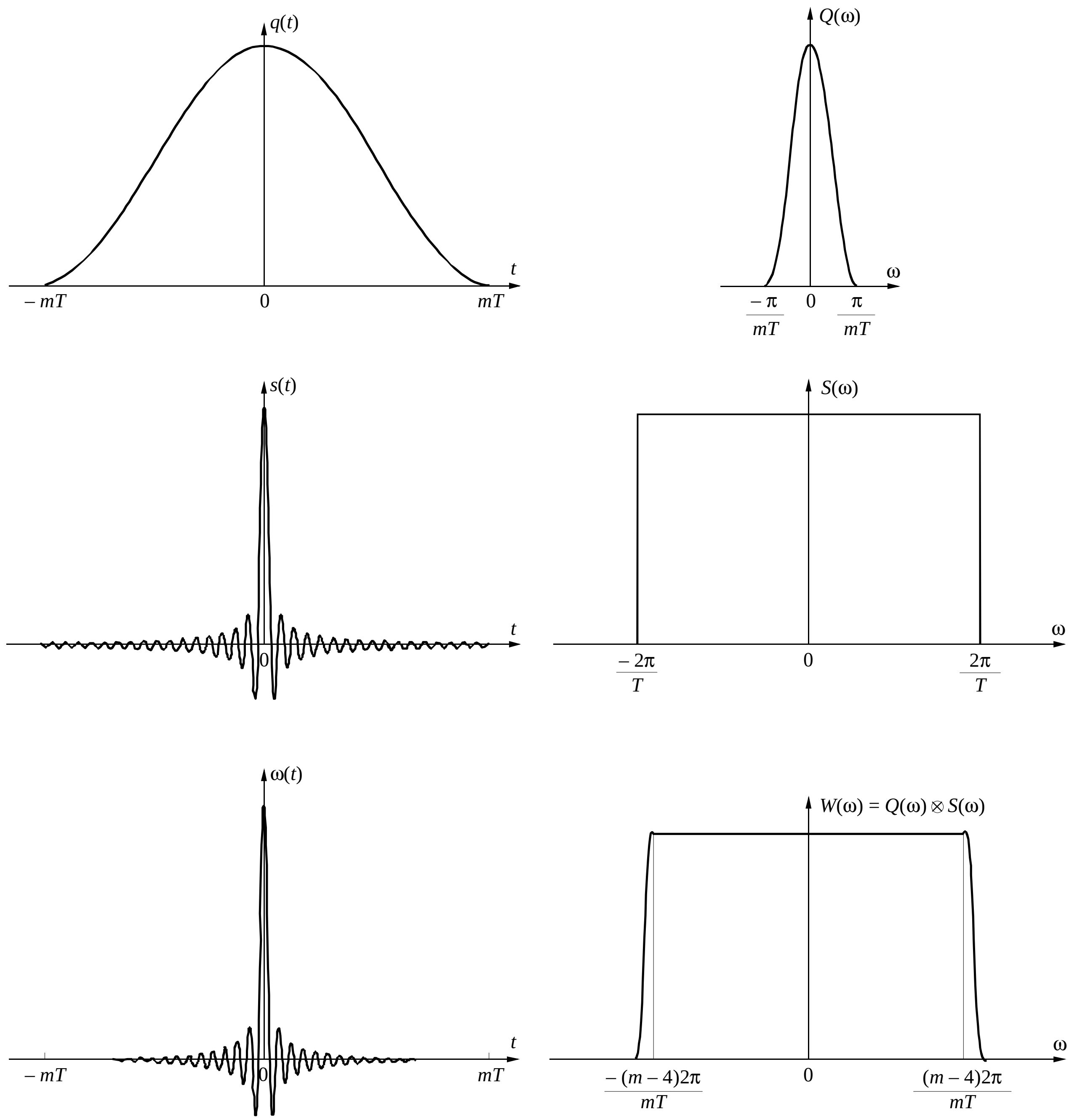
– GCR signal auto correlation characteristic is limited at the expense of convolution by function sinc Ωt,

– at a given energy level the GCR signal duration is minimized,

– GCR signal spectral characteristic is not practically sensitive to change of sampling frequency and word length,

– GCR signal is real-valued, thereby simplifying the equipment needed for its use.

FIGURE 1
The structure of window function *W*(ω) in frequency domain and time domain



Q(ω), *S*(ω), *W*(ω): Fourier transform of *q*(*t*), *s*(*t*), *w*(*t*)

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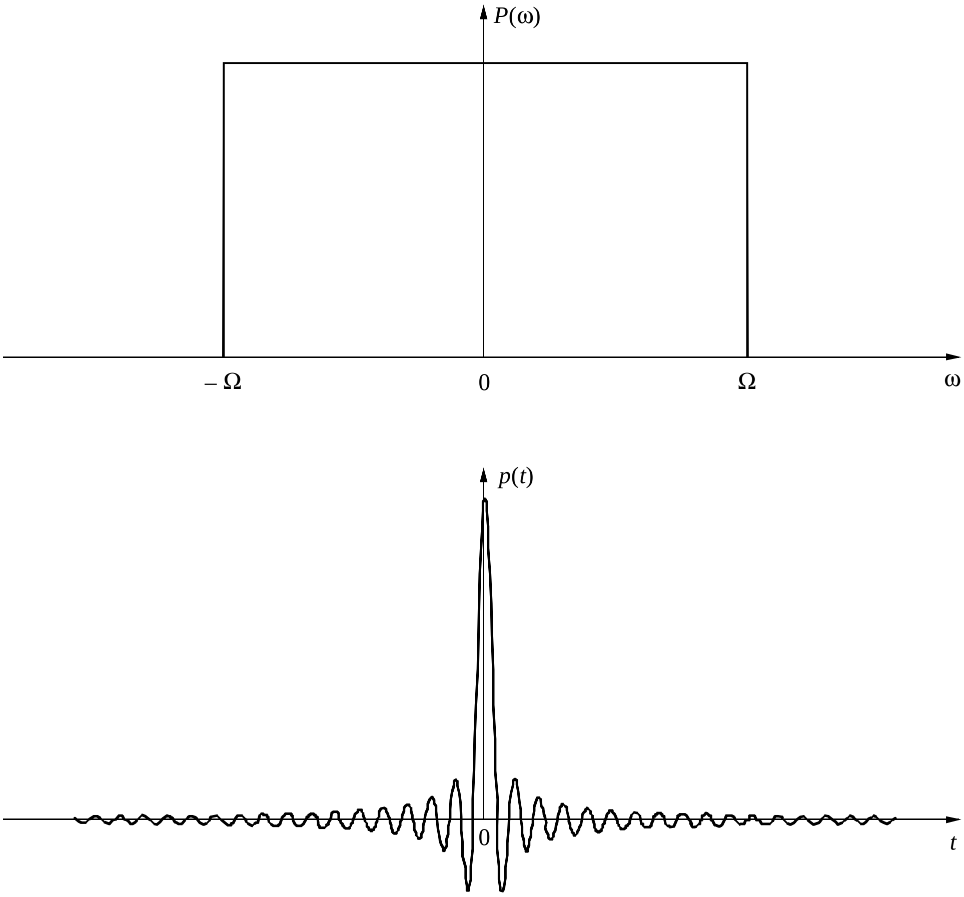
FIGURE 2

The structure of window function *P*(ω) in frequency domain and time domain



P(ω): Fourier transform of *p*(*t*)

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4 Analysis of GCR signal parameters in the frequency and time domains

GCR signal characteristics, evaluated using such model, are presented below.

Figure 3 shows Fourier-prototype of window function *w(t).*

Figures 4 and 5 describe window function *W*(ω) in linear and logarithmic scales. *W*(ω) decays to the following relative levels at the following frequencies:

–6 dB	at 5 MHz
< –60 dB	at 5.5 MHz
< –75 dB	at 6 MHz.

With further increase of frequency a rate of attenuation of about 20 dB/MHz is observed.

Figures 6 and 7 illustrate the two polarities of GCR signals, lines A and B.

FIGURE 3

Fourier-prototype of the window function

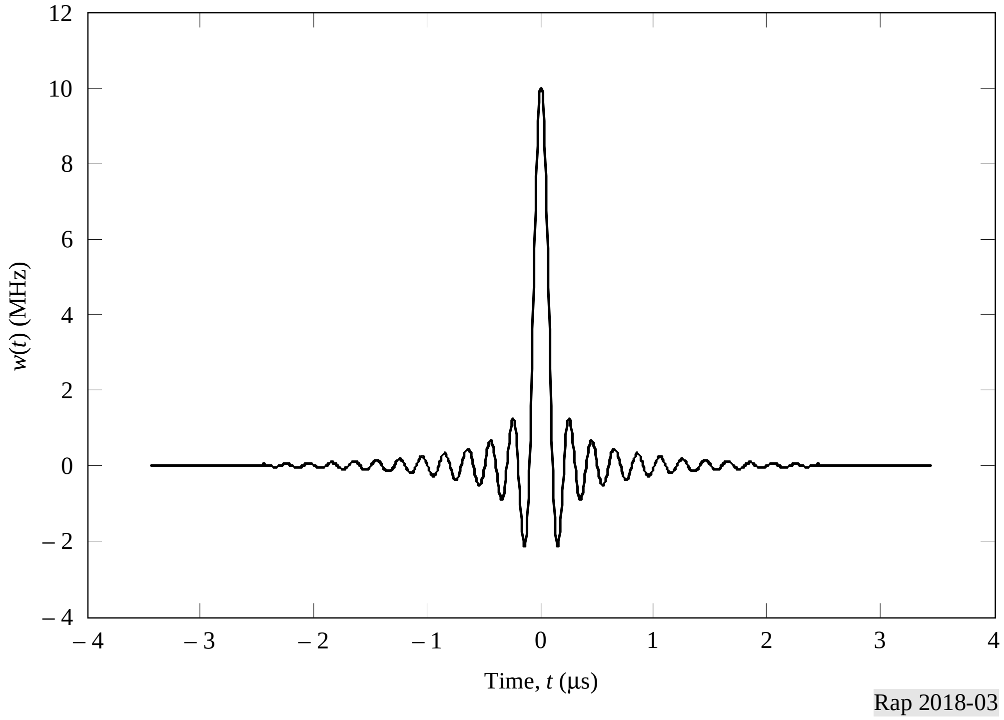

FIGURE 4

Window function in linear scale

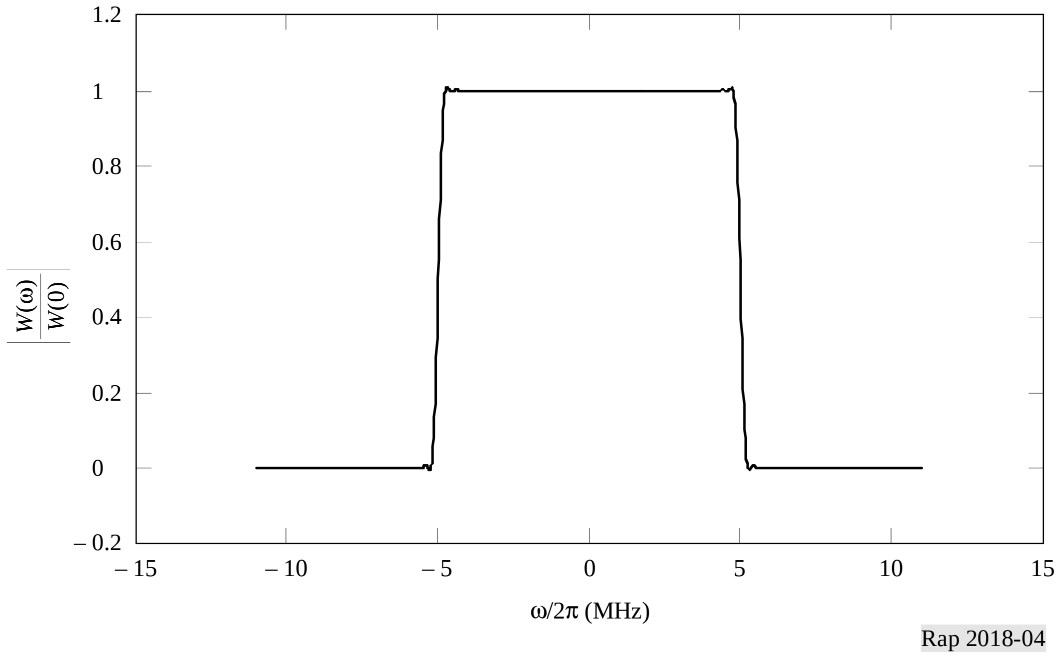

FIGURE 5

Window function in logarithmic scale

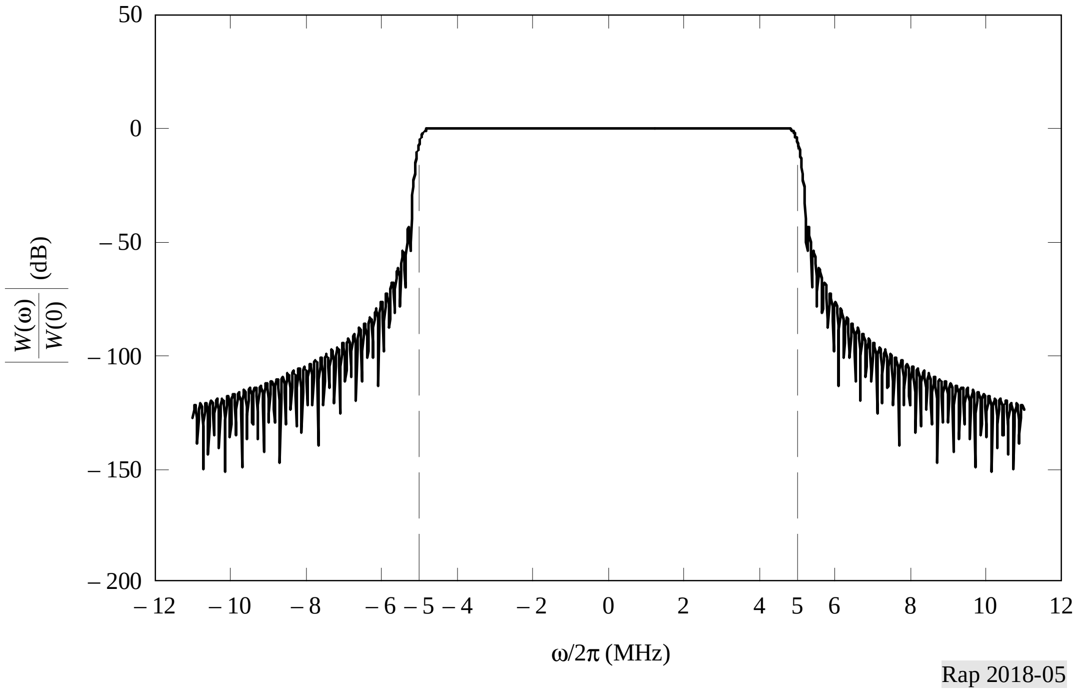

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FIGURE 6

Line A signal, containing GCR signal of positive polarity

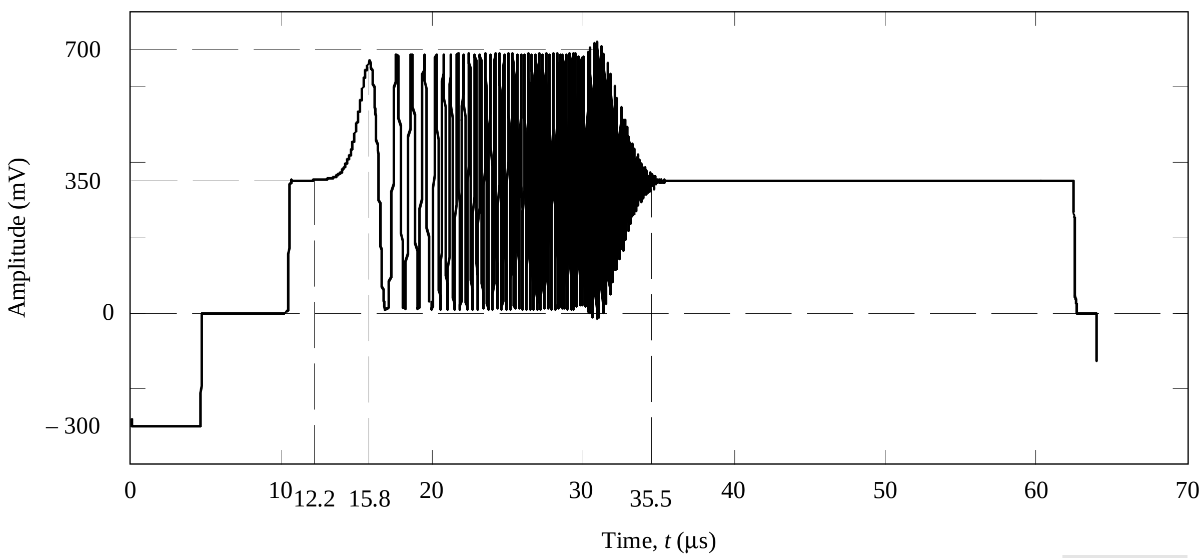

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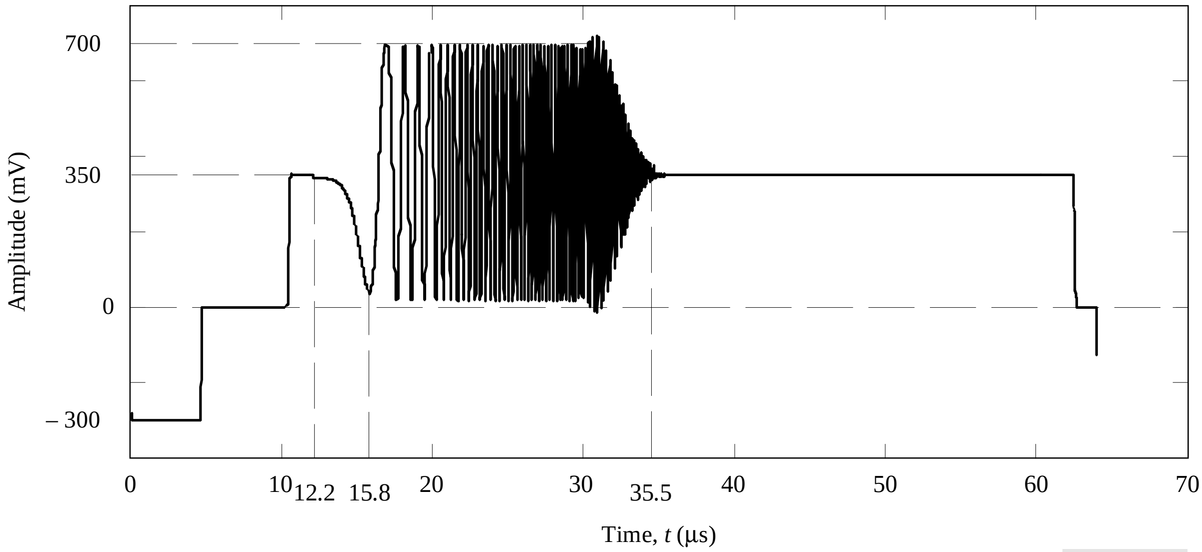
FIGURE 7

Line B signal, containing GCR signal of negative polarity



Figures 8 and 9 illustrate the amplitude-frequency characteristic of the GCR signal using linear and logarithmic scales respectively, normalized to unity level, according to the Recommendation ITU-R BT.1124. The envelope of the signal amplitude, normalized to unity level, reaches the following levels at the following times:

–6 dB at t = 15.1 µs and t = 32,4 µs

–40 dB at t = 12.4 µs and t = 35,7 µs

–60 dB at t = 9.4 µs and t = 37,1 µs.

FIGURE 8

GCR signal magnitude, normalized to unity level in linear scale

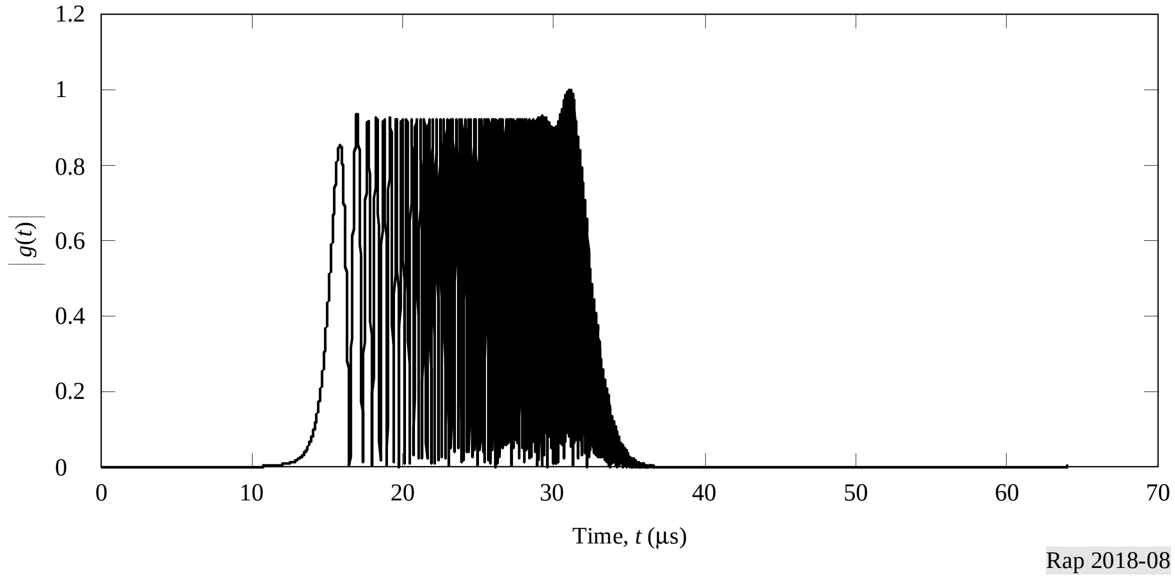
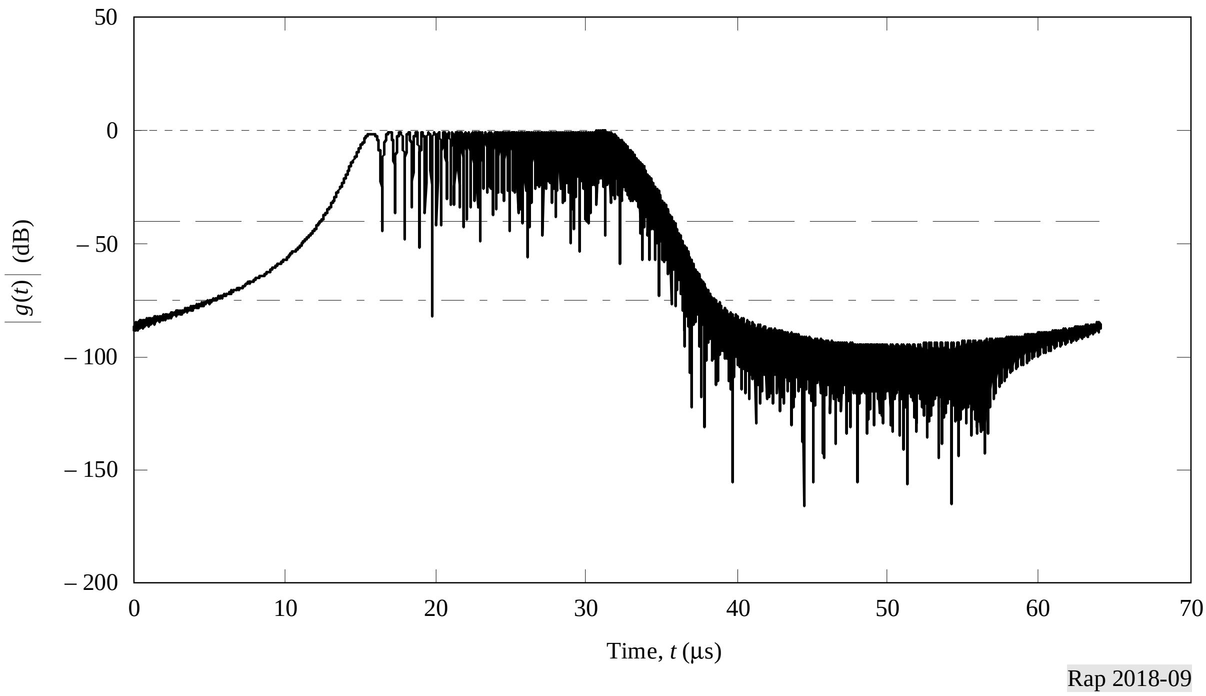


FIGURE 9

GCR signal magnitude, normalized to unity level in logarithmic scale



5 Analysis of the properties of the GCR signal

For practical use of the GCR signal, it is helpful to determine how various factors influence the accuracy of the estimation of distortions, while adjusting parameters of the reference signal.

The GCR signal possesses an important property: its energy outside the specified time and frequency domains is insignificant. In the time domain outside the specified interval (at $t < 12.2$ µs and $t > 35.4$ µs) the residual level is less than –40 dB. Over a slightly wider interval (at $t < 11$ µs and $t > 36$ µs) the residual level is less than –60 dB. In the frequency domain, at $f > 5$ MHz spectral density rapidly becomes insignificant. That is why in practice this signal is tolerant to changes of the frequency characteristic outside the nominal 5 MHz bandwidth. Besides, for these reasons, and also in connection with use of a GCR signal with alternating polarity, the adjacent parts of the TV signal do not influence the measurement of distortions using the GCR signal.

Other evaluations were made to assess the influence of certain factors:

– *Influence of signal restriction in the time domain*

According to the Recommendation ITU-R BT.1124, the signal boundaries shall correspond to temporal samples $t = 12.2$ µs and $t = 35.4$ µs. Estimations show, that the difference of Fourier-transforms of the signal not limited in time, and limited to the specified limits, normalized to $F(0)$ does not exceed 0.005 dB. A similar result is obtained for a wider window area, limited to the temporal samples, between $t < 11$ µs and $t > 36$ µs.

– *Influence of bandwidth restriction of the Fourier-transform of the signal*

The inherent method of derivation of the GCR signal imposes two measures for restricting its bandwidth:

– use of window function $W(\omega)$, restricting the signal to 5 MHz at –6 dB, with rapidly increasing attenuation such that at 5.5 MHz it is less than –60 dB;

– use of integration boundaries $(-\Omega, \Omega)$ for calculating the inverse Fourier-transform, appropriate to frequency range ±5 MHz. This corresponds to multiplication by the appropriate rectangular window, accepting the peak level between these frequencies, and zero level outside their limits.

Use of these two windows results in the following. Spectrum restriction caused by the second window occurs at a very small spectral density level of the signal, owing to its attenuation by the first window. Therefore, the influence of first window function on the GCR signal is insignificant.

Use of the first window with a very narrow transition area leads to the appearance of oscillations with the same amplitude as that of the final part of the signal. This is a shortcoming of the GCR signal, but the compromise accepted ensures the complete control of distortions in the frequency range 0-5 MHz, having sufficient energy reduction above 5.1 MHz. This is very important for an enhanced TV system, since the frequency above 5.1 MHz is available for the transmission of a digital sound signal.

– *On choice of window function W*(ω)

It is clear, considering the aforesaid, that the form of the window function does not have a major effect on the GCR signal properties. Nevertheless, it is desirable to estimate the value of such an effect, taking into account that a number of studies in the world were devoted to a choice of window functions in connection with synthesizing finite impulse response (FIR) filters. For example, it is generally considered that a Hamming window function is better than a $\cos^2$ window. A wider class of windows – the Kaizer window, makes it possible to simulate an almost exact approximation of windows such as Hamming, Blackman, and others, by varying its parameters.

Figure 10 represents two realizations of window *W(ω)* shown on a logarithmic scale. The first was obtained on the basis of a $\cos^2$ window, and the second on the basis of a Hamming window. Figure 11 shows the differences in amplitude-frequency response achieved between these realizations, normalized to zero frequency amplitude. It is clear that, in the range 5-6 MHz, the second realization achieves some 10 dB greater attenuation than the first. At higher frequencies, the second realization is inferior. However, this is not significant, as the relative level of Fourier-transforms appear to be below –60 dB. These estimations may be helpful for the construction of GCR signals for new applications.

FIGURE 10

Hamming and cos² windows on logarithmic scale

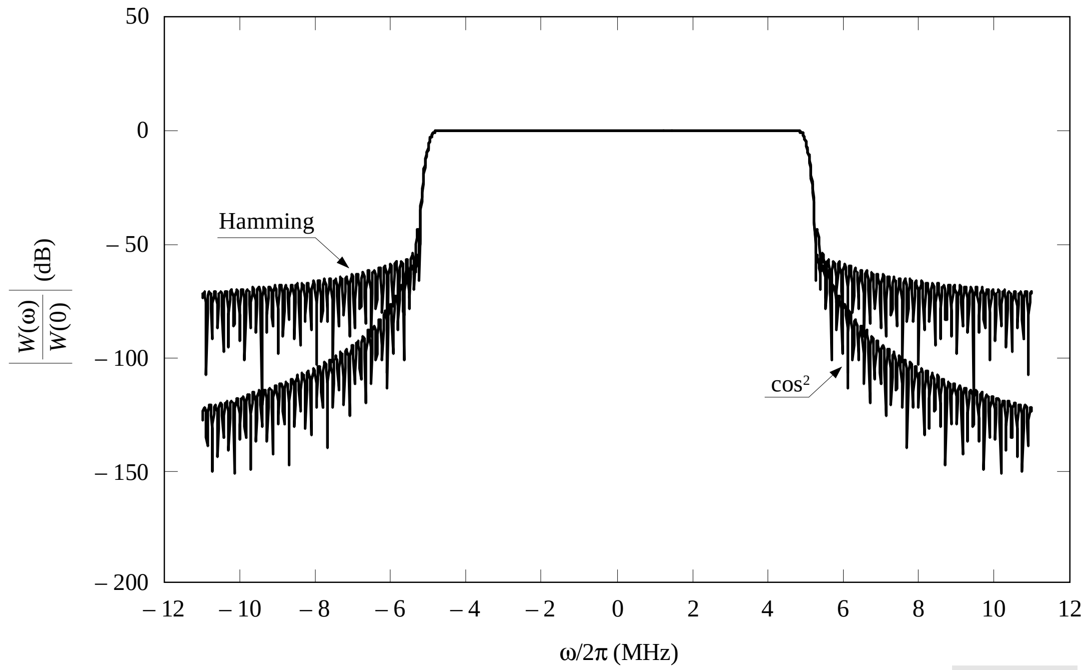


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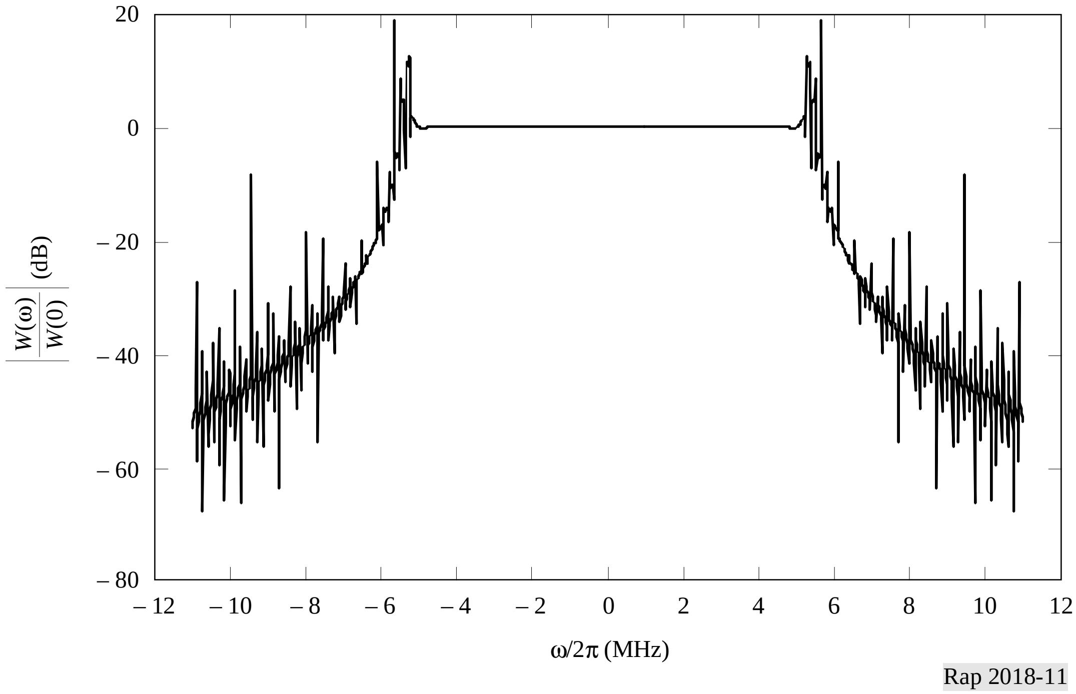
FIGURE 11

Difference of Hamming and cos[2] windows in logarithmic scale



It seems from this analysis that the window function used by the System C GCR signal as described in Recommendation ITU-R BT.1124 is optimal.

6 Parameters of GCR signal for the 6 MHz bandwidth channel

According to the draft report on the enhanced SECAM TV system (Doc. 11A/8) two modes of operation of the enhanced SECAM system are envisaged: transmission of only analogue sound, and transmission of both analogue and digital sound.

In the case of the use of both analogue and digital sound, the video signal bandwidth is nominally 5.1 MHz, and for this purpose the GCR signal as described in Recommendation ITU-R BT.1124 ideally fits.

In the case of the conventional SECAM system or the enhanced SECAM system with only analogue sound, the control and correction of linear (including ghost) distortions should ideally be made in the frequency range up to 6 MHz. In this connection, it is proposed to define the GCR signal for this bandwidth.

The following parameter values are suggested for a system C GCR where it is required to have a bandwidth of 6 MHz:

$$A = 2.7 \times 10^{-7} \text{ V}$$

$$b = 0.23 \times 10^{-12} \text{ s}^2/\text{rad}$$

$$c = 0.9121 \times 10^{6} \text{ rad/s}$$

$$\Omega = 2\pi \times 6{,}25 \times 10^{6} \text{ rad/s}$$

$$\Omega_1 = 2\pi \times 6 \times 10^{6} \text{ rad/s.}$$

Using the above values, *m* and *T* are derived to be:

$$m = 43.332$$

$$T = 79.487 \text{ ns.}$$

Figures 12, 13 and 14 represent the amplitude-frequency characteristic of window function *W(ω)* for 6 MHz bandwidth on linear and logarithmic scales.

FIGURE 12

Amplitude-frequency characteristics of window function *W* (ω) for 6 MHz bandwidth shown on a linear scale

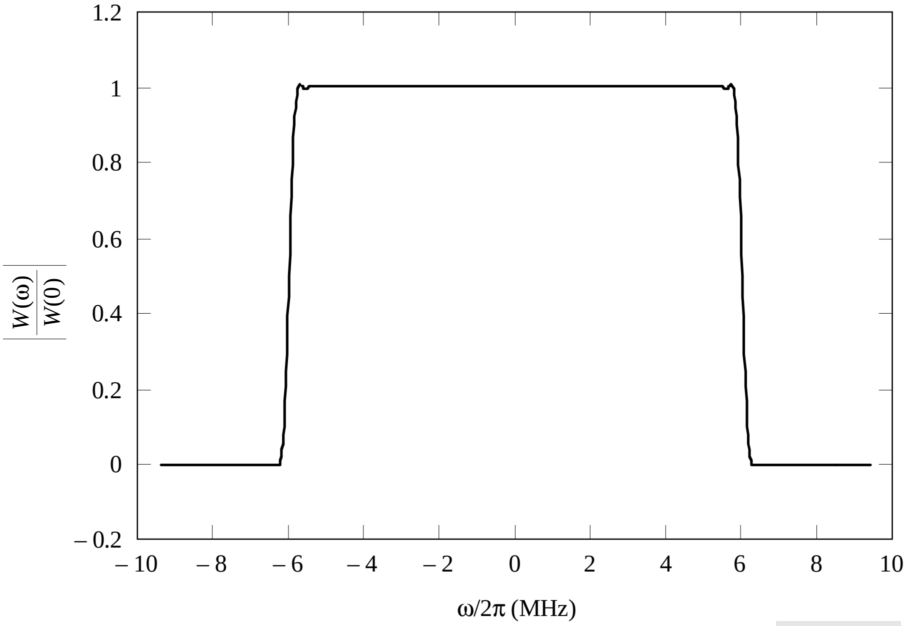


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FIGURE 13

GCR signal spectrum for 6 MHz channel bandwidth
at $\Omega_1 = 2\pi \times 6 \times 10^6$ rad/s, $\Omega = 2\pi \times 6.25 \times 10^6$ rad/s

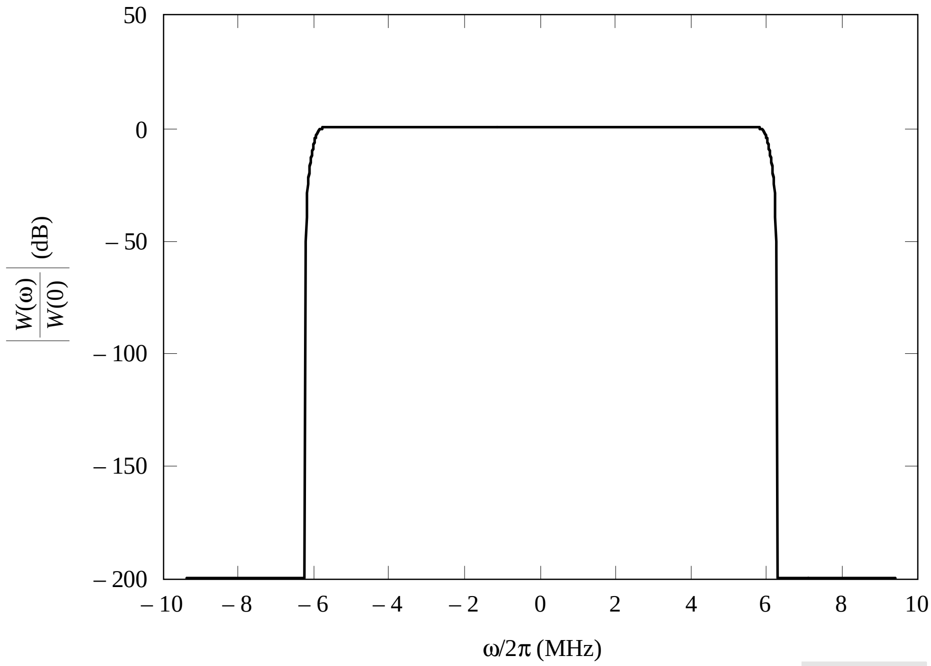

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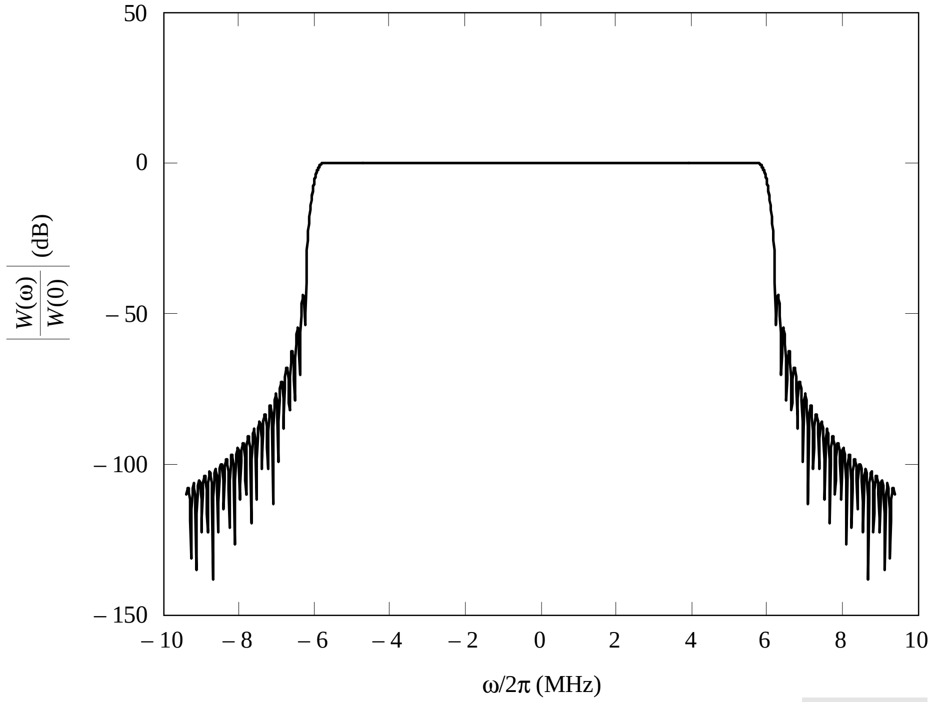
FIGURE 14

GCR signal spectrum for 6 MHz channel bandwidth at $\Omega_1 = 2\pi \times 6 \times 10^6$ rad/s and at unlimited integration



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Figures 15 and 16 illustrate 6 MHz GCR signal lines A and B for positive and negative polarity.

FIGURE 15

GCR line A for 6 MHz bandwidth

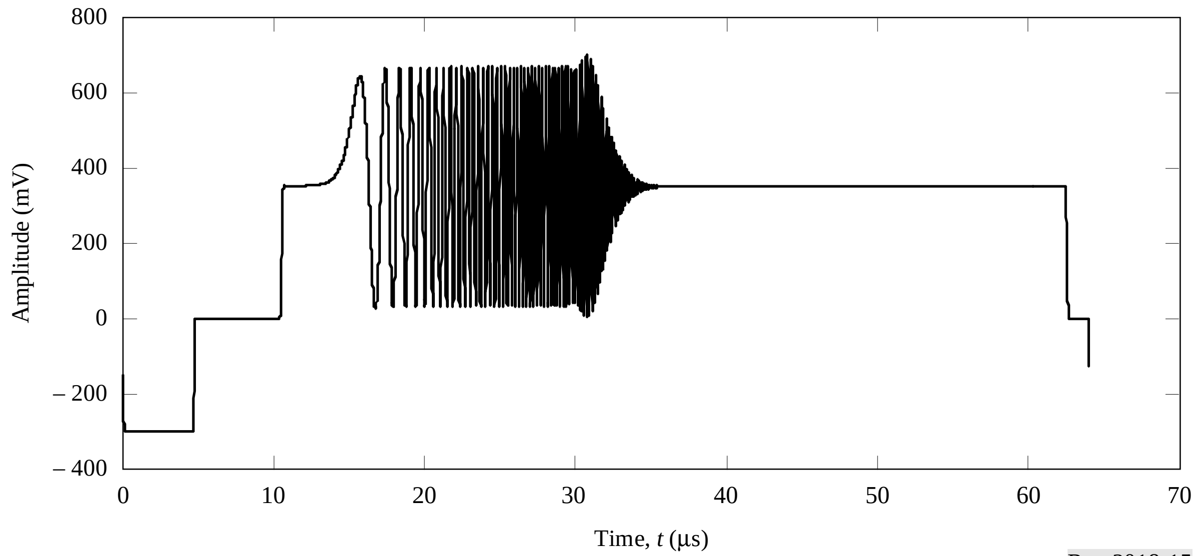

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FIGURE 16

GCR line B for 6 MHz bandwidth

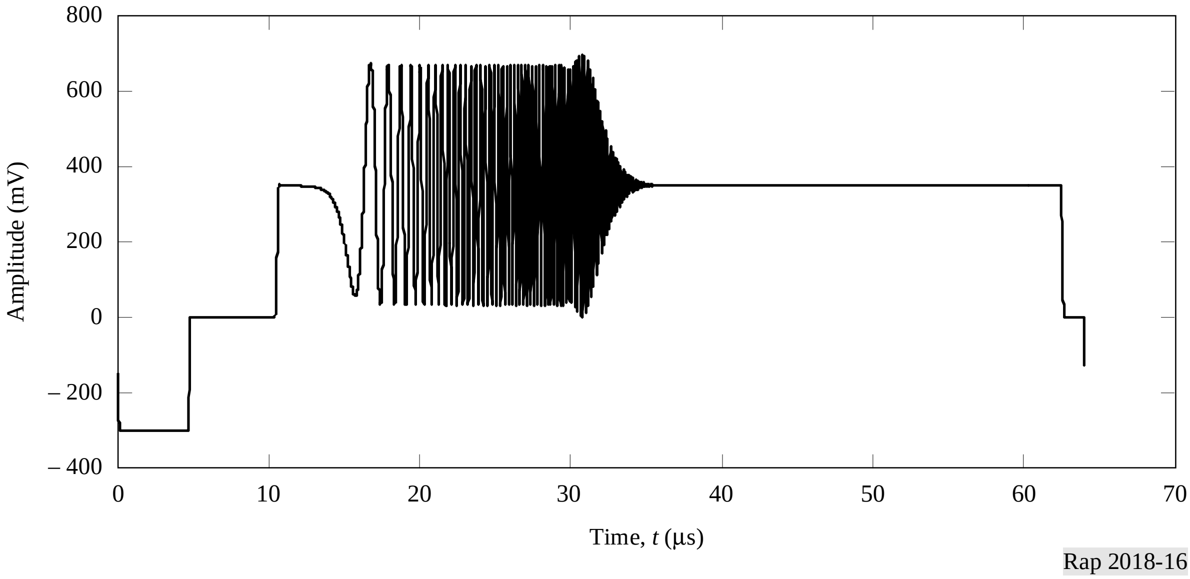
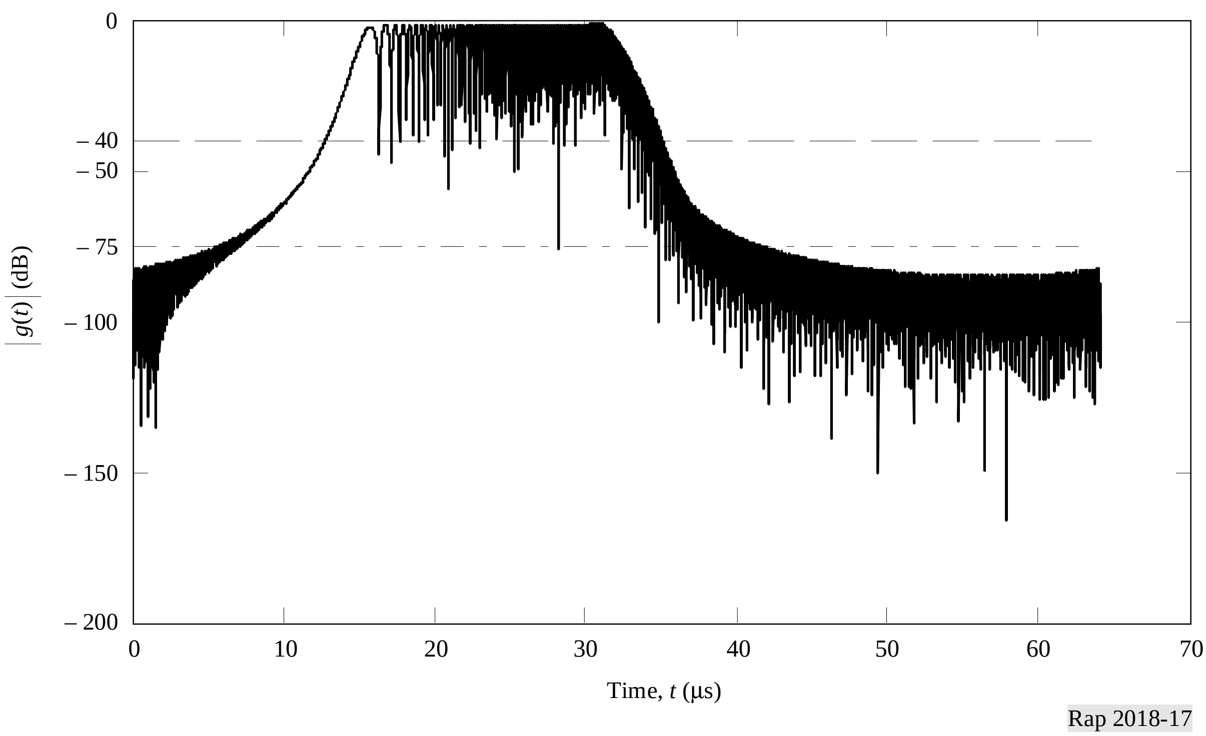


Figure 17 shows a plot of the GCR signal magnitude on a logarithmic scale.

FIGURE 17

GCR signal, normalized to unity level in logarithmic scale



The analysis of these figures shows that other properties of this extended-bandwidth variant of the system C GCR signal are similar to those of the GCR signal as already described in Recommendation ITU-R BT.1124.

7 Conclusion

The results of quantitative evaluations, and the figures presented here that plot the characteristics of the GCR signal in both the time and frequency domains, may be helpful in understanding the behaviour of the signal, and could be useful for future possible development of Recommendation ITU-R BT.1124.

The results of the studies confirm that the chosen parameters of the GCR signal C are optimal for use with systems having a nominal video bandwidth of 5 MHz.

Further studies are planned regarding the possible use for systems D/K of two versions of the GCR signal C, the first as described in Recommendation ITU-R BT.1124 for a 5 MHz video bandwidth, and the second suggested here for a video bandwidth of 6 MHz.

Provided that there is development of the appropriate methods and hardware, the introduction of the GCR signal C as a universal signal for the estimation and correction of distortions in the TV chain, will make it possible to achieve accurate channel characterisation and correction of linear distortions in analogue and analogue-digital TV paths. Consequently, with GCR signal C it is possible to achieve a significant increase in quality offered by analogue television broadcasting.

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UNIIRT [1996] Report: Study on standardization in the Ukraine of GCR test signal for evaluation and correction of linear distortion in analogue TV channel and other video transmitting systems in the sphere of telecommunications. Ukrainian Scientific Research Institute of Radio and Television. Odessa, Ukraine.

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Doc. 11C/22 (Annex 4) – Contributions to a possible Report on GCR signals (President of WG 11C), 23 March 1996.