Characterization of the ISDB-T critical spectrum mask

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Abstract**—** Non-linearity in the ISDB-T transmission chain causes intermodulation products that widens the spectrum emission and should be taken into account to assign frequency channels.

The characterization of the transmission spectrum mask is one of the most important measurements in order to achieve the best use of the electromagnetic spectrum. The use of critical mask defined in [1] allows allocations of co-site adjacent channels for an efficient use of the electromagnetic spectrum that is a finite and limited resource.

In this paper different test procedure using spectrum analyzer and dedicated digital TV analyzer in order to measure the ISDB-T transmission mask is discussed.

***Key Words* —** ISDB-T, spectrum mask, intermodulation, spectrum analyzer.

1. INTRODUCTION

THE transmission spectrum of ISDB-T signal consists of 13 successive OFDM segments. The nature of OFDM modulation is to send the information parallelized in thousands of modulated carriers very close each other, obtained through an IFFT algorithm. These carriers are then amplified by a power amplifier chain with a non-linear behavior that generates intermodulation products that increase the out of band emission interfering the adjacent channels and also degrading signal quality by the Inter-carrier interference.

Reduce out-of-band emissions demands the incorporation of an external filter [4][5] at the output of the power transmitter to eliminate the intermodulation products generated.

As defined in ABNT NBR 15601, there are three different spectrum mask: non-critical; sub-critical and critical. The difference between them are the attenuation of the out-side emission being the critical the most difficult to achieve and test.

Transmission spectrum mask are commonly tested by spectrum analyzers, but in ISDB-T, the requirements are too high; and more sophisticated measurement test methods must be incorporated in digital TV analyzers.

In this paper the transmission spectrum mask measurement as an alternative methodology is proposed and compared with a multi-propose spectrum analyzer and other dedicated digital TV analyzer, the characteristics of the test equipment required is described and the uncertainty calculation for the proposed method is also included.

2. TEST ANALYSIS

2.1. ISDB-T signal analysis

ISDB-T modulation can be configured to operate in three different modes: Mode 1 or 2k, Mode 2 or 4k and Mode 3 or 8k that modify the number of carriers per OFDM segment. The frequency bandwidth shall be 5.7 MHz when the OFDM carrier bandwidth is 5.572 MHz with 4 kHz spacing between carrier frequencies in Mode 1. This bandwidth shall apply regardless of the mode which is chosen, and selected to ensure that the bandwidth of 5.610 MHz has a gap where each carrier of the uppermost and lowermost in the 5.572MHz bandwidth includes 99 % of energy.

According with ABNT NBR 15601 and ARIB STD-B31 if the spectrum mask is tested with 10kHz of resolution bandwidth, the power density is reduced by

$$10.Log\left(\frac{5.572MHz}{10kHz}\right) = 27.46dB$$

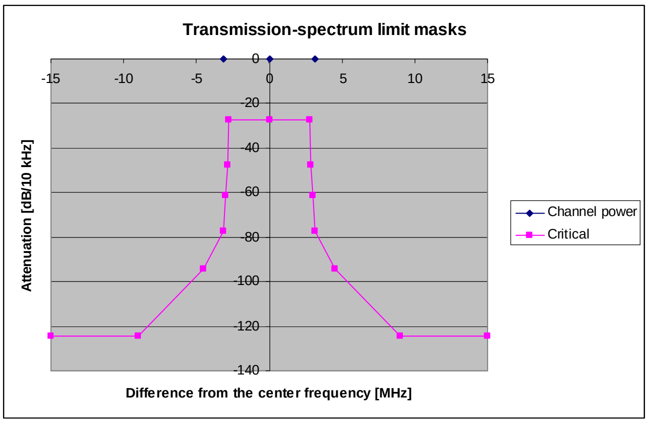

Fig.1 ISDB-T critical mask

ABNT NBR 15601 Table 41 defines the limits of the out-of-band emission indicating the attenuations in relation to the transmitter average power. The final purpose of this test it to characterize the power density distributions, thus the limits given in [1] should be specifies as attenuation in relation to the power density related to 10kHz as show in figure 1.

2.2. Two tone Intermodulation phenomena

A two tone intermodulation phenomena can be observed when two CW sources are combined at the input of an amplifier and their frequencies are inside the passband of the device being tested. Non linearities in the amplifier will give products in the form ($N\omega_1$-$M\omega_2$). The components ($2\omega_1$-ω_2),($2\omega_2$-ω_1) and ($3\omega_1$-$2\omega_2$),($3\omega_2$-$2\omega_1$) are known respectively as third and fifth order intermodulation products and their frequencies and levels are close to the fundamental tones ω_1 and ω_2. Higher order products are generally negligible in comparison.

This phenomenon is also present in the testing equipment and is one of the limits of the available dynamic range. The input mixer of a spectrum analyzer is a non-linear device, so it always generates distortion by itself. Most spectrum analyzers use diode mixers and their current intensity can be expressed as

$$i = Is.\left(e^{\frac{qv}{kt}} - 1\right)$$

Where IS = the diode's saturation current
q = electron charge ($1.60\text{x}10^{-19}$ C)
v = instantaneous voltage
k = Boltzmann's constant ($1.38\ \text{x}10^{-23}$ joule/°K)
T= temperature in degrees Kelvin

Expanding into a power series

$$\mathrm{i} = \mathrm{Is}(\mathrm{k}_1\mathrm{v} + \mathrm{k}_2\mathrm{v}^2 + \mathrm{k}_3\mathrm{v}^3 + \ldots)$$

When two tones and the local oscillator are the input voltage to the mixer

$$\mathrm{v} = \mathrm{V_{LO}}\ \sin(\omega_{\mathrm{LO}}\ \mathrm{t}) + \mathrm{V_1}\ \sin(\omega_1 \mathrm{t}) + \mathrm{V_2}\ \sin(\omega_2 \mathrm{t})$$

The following unwanted mixing products are also generated in the output mixer.

$$(\mathrm{k}_4/8)\mathrm{V_{LO}}\mathrm{V_1}^2\mathrm{V_2}\cos[\omega_{\mathrm{LO}} - (2\,\omega_1 - \omega_2)]\mathrm{t}$$

$$(\mathrm{k}_4/8)\mathrm{V_{LO}}\mathrm{V_1}\mathrm{V_2}^2\cos[\omega_{\mathrm{LO}} - (2\,\omega_2 - \omega_1]\mathrm{t}$$

Where $k_4 = \dfrac{\left(\dfrac{q}{k.T}\right)^4}{4!}$

If V1 and V2 have the same amplitude, their products can be considered as cubic terms. The third order products rise at rate 3dB/dB like Figure 2 shows.

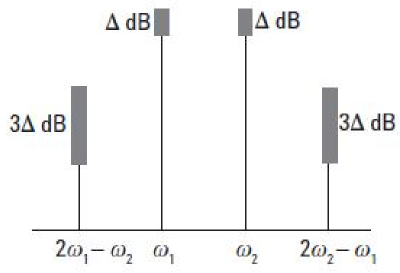

Fig. 2 two tone intermodulation

2.3. Instrument available dynamic range

Dynamic range is the ratio, expressed in dB, of the largest to the smallest signals simultaneously present at the input of the instrument that allows measurement of the smaller signal to a given degree of uncertainty.

There are three factors that limit the dynamic range: internal noise, internal intermodulation performance and the phase noise of a local oscillator.

The instrument internally generates noise and distortion that affects measurement's accuracy. Spectrum analyzers noise floor is described by DANL and signals bellow this level can not be seen. The input attenuator strongly affect the sensitivity of the analyzer to display low level signals by attenuating the input signal and reducing signal to noise ratio . Resolution bandwidth also affects signal-to-noise ratio. The total noise power is determined by the width of the IF filter. The noise level displayed varies following the relation.

$$N_{1,2} = 10.Log\left(\frac{RBW_2}{RBW_1}\right)$$

Like DANL is often referred to a specific IF-filter bandwidth, is easy to obtain the displayed noise for any IF-filter. ISDB-T spectrum mask measurement defines 10kHz IF-filter.

The unwanted distortion products generated by the input mixer fall at the same frequencies as the distortion products under measure on the ISDB-T input signal. The effect of the intermodulation can be seen as a spectral growth or spectrum shoulders shown in figure 3.

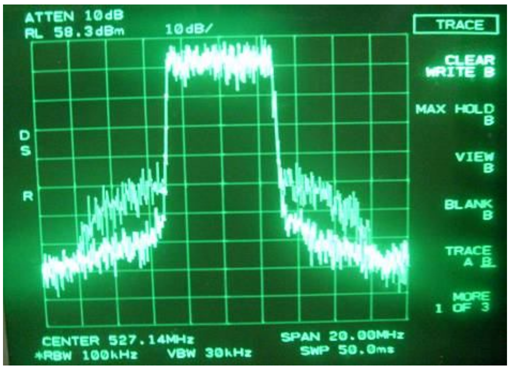

Fig. 3 spectral growth caused by the input mixer level.

The phase relationship generate additions and cancelations between the generated intermodulation products and the signal that we want to measure, so the lack of knowledge of phase relationship between them is a source of uncertainty that also depends on the amplitude relationship of them through the relation.

$$error_{\text{Internal intermodulation}} = 20.\log(1 \pm 10^{\frac{d}{20}})$$

Where d is the difference in dB between the amplitude of the intermodulation products generated internally and the amplitude of the intermodulation of the incoming signal. The probability function distribution can be assumed as rectangular.

The third order performance is given as the Third Order Intercept point (TOI) and represents the mixer level at which the internally generated intermodulation would be equal to the fundamental tones. This point is obtained by sweeping the levels of the fundamentals tone ω_1 and ω_2 and observing the levels of the third order components as a function of the input power level.

The dynamic range can be plotted as a function of the input level, where low levels input reduces the signal to noise ratio and generates low intermodulation, against high levels input, more immune to noise but the intermodulation product are more significant. Figure 4 shows the HP8564 [2] available dynamic rage for ISDB-T spectrum mask, where 78dB is the best condition obtained for an input level of -27 dBm.

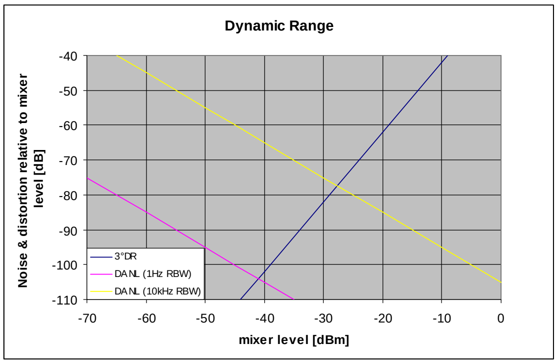

Fig. 4 HP8564 dynamic range.

As was shown in figure 1, the required dynamic range for transmission spectrum mask is obtained by addition of the total power channel to the power density in 10kHz band and the highest attenuation defined in [1]

Required dynamic range [dB]= 27.46dB+97dB= 124,46dB

Actually, there is no spectrum analyzer with 124.46dB of dynamic range available.

Most digital TV analyzer has been equipped to perform the spectrum transmission mask test. Their does not have better TOI level and neither lower DANL, only incorporate the facility of add spectrum emission with the filter mask response.

Table 1 gives a comparison between a spectrum analyzer HP8564 and the digital TV analyzers Anritsu MS8911B and Rohde & Schwarz ETH and ETL

Table 1 Instruments Specifications

Parameter	HP 8564	MS8911B		R&S ETH		R&S ETL	
		pre-amp on	pre-amp off	RF presel on	RF presel off	pre-amp on	pre-amp off
TOI [dBm]	11	---	10	-6	7	---	12
DANL [dBm]	-150	-150	-123	-165	-156	-166	-140

3. TEST PROCEDURE

3.1. Using spectrum analyzer

To solve the excessive dynamic range requirement, out of band emissions can be tested by measuring the ISDB-T signal before filter mask and the filter response separately, and multiply both curves (or addition in dB).

Figure 5a shows the filter characterization block diagram using a tracking generator synchronized with a spectrum analyzer using the same setting defined in ABNT NBR 15601.

The filter characterization should be saved in an internal trace memory as figure 5b shows, where ~~it's~~ necessary that the top of the trace has the same Reference Level value of the spectrum analyzer.

Fig. 5a filter characterization block diagram.

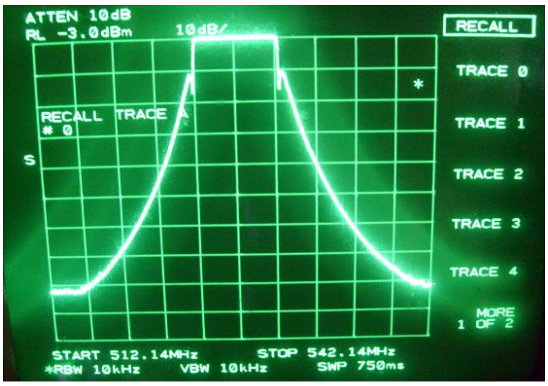

Fig. 5b filter characterization trace.

Figure 6 shows one of the possible block diagrams of the ISDB-T signal measurement taken before the mask filter. It must be done over and directional coupler previously characterized. To obtain the best dynamic range it is necessary to add internal and external attenuation. Insufficient attenuation will cause intermodulation products close to the signal under test and an excessive one will increase the noise level, so in practice, is desirable to adjust in 1dB step being 10dB step too high to obtain the best dynamic range.

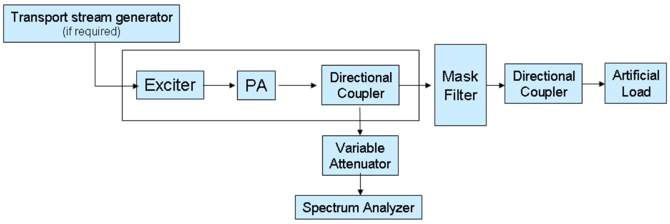

Fig. 6 ISDB-T characterization block diagram.

Most spectrum analyzers have many functions like additions and differences between traces and also with display lines. The peak power density should have the same value as the reference level of the spectrum analyzer.

When emissions can not be measured by the dynamic range, it is possible to recall the filter curve from an auxiliary trace and adding it with the ISDB-T spectrum obtained before the mask filter as has shown in figure 7.

Fig. 7 Transmission spectrum mask result.

Filter correction is much important for frequencies of ± 3MHz form the center frequency.

In offset of ± 3MHz from the center frequency the available dynamic range use to be enough to determine the compliance of the transmission spectrum mask, but results with lower uncertainties can be obtained applying the filter corrections only out of these limits with the configuration shown in figure 6.

Between the ± 3MHz from the center frequency lower uncertainties are obtained applying the block diagram shown in figure 8, without any correction of the filter transference.

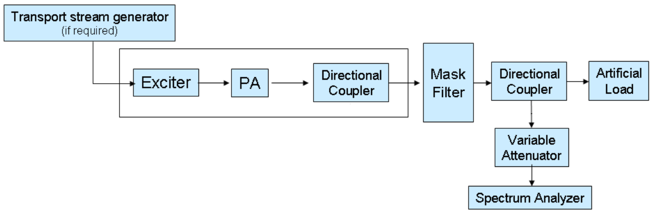

Fig. 8 ISDB-T characterization block diagram between the ± 3MHz from the center frequency

3.2. Using dedicated DTV analyzers

When using Anritsu MS8911B with option 030 for ISDB-T analysis a pre-load default filter response can be used.

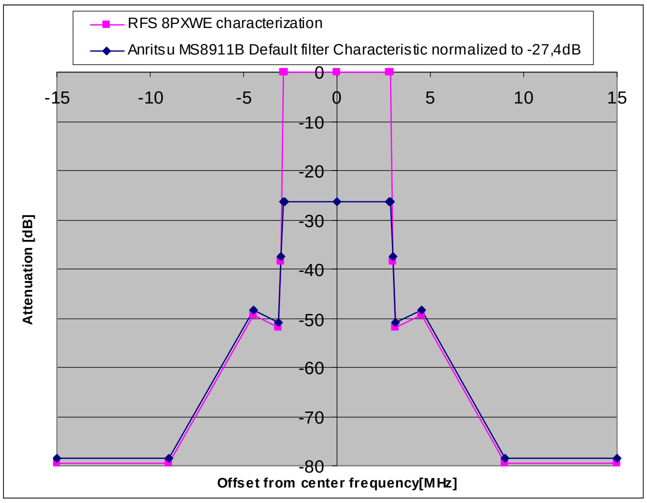

Fig. 9 Anritsu 8911B default filter comparison.

Lab comparison between MS8911B pre-load default filter with a commercial RFS [5] response is shown in figure 9.

The TV analyzer Rohde & Schwarz ETH has an integrated tracking generator for filter characterization that allows saving in an internal trace.

The TV analyzer Rohde & Schwarz ETL also have an integrated tracking generator for filter characterization but the filter response should be manually entered in a traducer register.

3.3. Uncertainty due to amplitude accuracy

When the signal under test is applied to the instrument the first source of uncertainty is given by impedance mismatch causing that the incident and reflected signal vectors add constructively or destructively. Thus the signal received by the analyzer can be larger or smaller than the original one. This measurement is made with the same attenuator settings so the input attenuation switching uncertainty can not be considered. The input signal is mixed with the local oscillator and their flatness contributes to the frequency response uncertainty. Spectrum analyzers have a band switching uncertainty but usually, in measurements of 30MHz span does not be added. After the input signal is converted to an IF, it passes through the IF gain amplifier and the IF attenuator that refer the input signal amplitudes to the reference level.

Reference level accuracy and resolution bandwidth switching do not add uncertainty in relative measurements such as spectrum mask, but the display scale fidelity should be included.

The sources of uncertainties in relative measurement using spectrum analyzer are summarized in table 2.

Table 2 amplitude uncertainty in relative measurements

Source of uncertainty	Probability distribution	Divisor
Impedance mismatch	U-shape	$\sqrt{2}$
Frequency response	rectangular	$\sqrt{3}$
Display scale fidelity	rectangular	$\sqrt{3}$

Uncertainty due to impedance mismatch can be calculated in the same way like power measurements [3]. The systematic error is

$1-|\Gamma_L|^2$ while the limits of mismatch uncertainty are

$\pm 2|\Gamma_G||\Gamma_L|$ caused by the lack of the phase difference

between Γ_G and Γ_L. In most cases, uncertainty due to mismatch is relatively small.

3.4. Uncertainty due to filter characterization

Following the connections described in figure 5a, filter characterization uncertainty will include the same sources described in table 2, in addition with the frequency response of the tracking generator and mismatch in the input and output ports.

That implies that the filter response trace, like figure 5.a shows, is obtained with a certain level of uncertainty that will be carried out until the final result. The attenuation of a filter inserted between a generator and a spectrum analyzer that are not perfectly matched [3], has a standard deviation of mismatch M [dB] is approximated by.

$$M[dB] \approx \frac{8.686}{\sqrt{2}}\left[|\Gamma_G|^2.|S_{11f}|^2 + |\Gamma_L|^2.|S_{22f}|^2 + |\Gamma_G|^2.|\Gamma_L|^2\left(1+|S_{21f}|^4\right)\right]^{0.5}$$

Where S_{11f} and S_{21f} can be obtained from filter specifications [5].

Table 3 shows the uncertainty sources of the filter characterization measurement.

Table 3 amplitude uncertainty in filter characterization

Source of uncertainty	Probability distribution	Divisor
Uncertainty for filter mismatch	rectangular	$\sqrt{3}$
Generator Amplitude linearity	rectangular	$\sqrt{3}$
Display scale fidelity	rectangular	$\sqrt{3}$
Frequency response	rectangular	$\sqrt{3}$

4. RESULTS

The device under test and the instruments used during the test are shown in table 4.

Table 4 devices under test and test instruments

ISDB-T transmitter	NEC DTL-10/1R6P 1kW UHF DIGITAL TV TRANSMITTER SYSTEM
Output filter	RFS 8PXWE
Spectrum analyzer	HP8564E
Sweep generator	R&S SMP02
Variable attenuator 1dB step	HP84904L

4.1. Measuring transmission spectrum mask after filter between ±3.5MHz offset from center frequency using spectrum analyzer

Figure 10a shows the transmission mask measurement measured as figure 8 describes. Figure 10b represents the same information as a function of frequency offset from the center frequency channel. On table 6 the uncertainty budget is shown.

Fig. 10a critical mask measurement

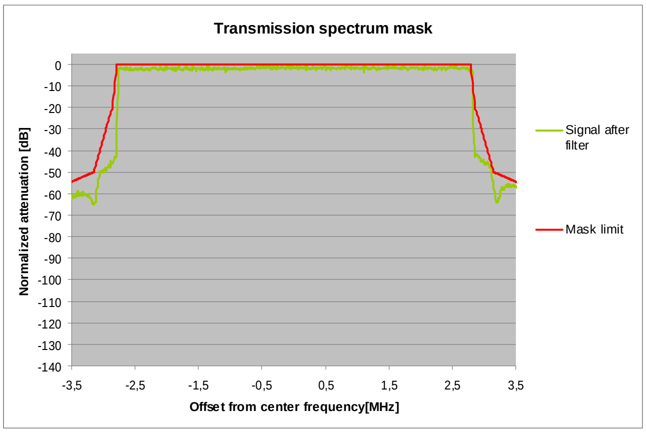

Fig. 10b critical mask measurement between ±3.5MHz from the channel center frequency

The internal intermodulation error shown in table 5 is obtained using the spectrum analyzer settings and the calculated available dynamic range.

Table 5 internal intermodulation error calculation

Reference level [dBm]	-26.7
Internal attenuator [dB]	30
Power/Power Density [dB]	27.46
Mixer level [dBm]	-29.24
Available dynamic range [dB]	-78
d [dB]	18
$\mathrm{error}_{\mathrm{internal\ intermodulation}}$ [dB]	1.1

Uncertainty budget

Table 6 transmission mask measurement uncertainty for ±3.5MHz offset from the center frequency

Source of uncertainty	Value [dB]	Probability distribution	Divisor	u_i [dB]	V_{eff}
Impedance mismatch	0,12	U-shape	$\sqrt{2}$	0,08	∞
Frequency response	0,80	rectangular	$\sqrt{3}$	0,46	∞
Display scale fidelity	0,85	rectangular	$\sqrt{3}$	0,49	∞
Internal intermodulation	1,10	rectangular	$\sqrt{3}$	0,64	∞
Combined standard uncertainty		normal		0,93	> 1000
Expanded uncertainty		K=2		1,86	> 1000

4.2. Measuring transmission spectrum mask before filter beside ±3.5MHz offset from center frequency using spectrum analyzer

For testing the transmission spectrum mask on frequencies offset higher that ±3.5MHz, filter characterization and spectrum emissions must be measured before the mask filter.

The results of filter characterization measurement according to the connections described in figure 5a, and the uncertainty budget are respectively shown in figure11 and table 7.

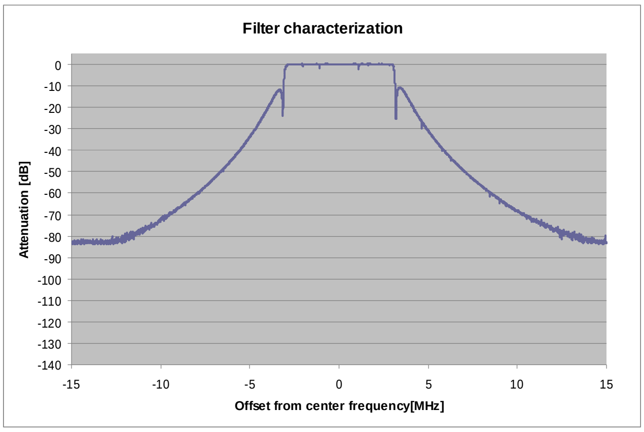

Fig. 11 filter characterization measurement

Filter characterization uncertainty budget

Table 7 filter characterization uncertainty

Source of uncertainty	Value [dB]	Probability distribution	Divisor	u_i [dB]	V_{eff}
Filter Impedance mismatch	0,31	rectangular	$\sqrt{3}$	0,18	∞
Generator Amplitude linearity	0,60	rectangular	$\sqrt{3}$	0,35	∞
Frequency response	0,80	rectangular	$\sqrt{3}$	0,46	∞
Display scale fidelity	0,85	rectangular	$\sqrt{3}$	0,49	∞
Combined standard uncertainty		normal		0,7	> 1000
Expanded uncertainty		K=2		1,4	> 1000

Figure 12 shows the filter characterization trace, the spectrum emission trace measured before the filter and the result obtained as the addition of these two traces. The limits of the critical mask are also included .

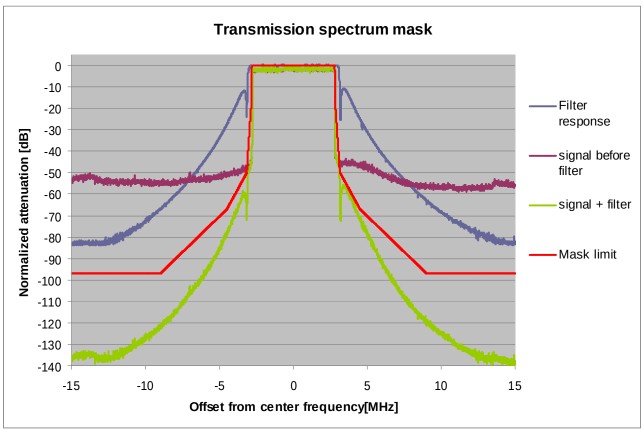

Fig. 12 Transmission spectrum mask measurement results

Uncertainty due to internal intermodulation

To measure the ISDB-T signal before the filter, the available dynamic range is 22dB. Table 8 shows the spectrum analyzer parameters and the obtained error generated by the internal intermodulation.

Table 8 internal intermodulation error calculation

Mixer level [dBm]	-29.24
Available dynamic range [dB]	-78
d [dB]	22
$error_{internal\ intermodulation}$ [dB]	0.7

Table 9 transmission mask measurement uncertainty using filter characterization

Source of uncertainty	Value [dB]	Probability distribution	Divisor	u_i [dB]	v_{eff}
Impedance mismatch	0,12	U-shape	$\sqrt{2}$	0,08	∞
Frequency response	0,80	rectangular	$\sqrt{3}$	0,46	∞
Display scale fidelity	0,85	rectangular	$\sqrt{3}$	0,49	∞
Internal intermodulation	0.7	rectangular	$\sqrt{3}$	0,20	∞
Filter characterization	0,70	normal	1	0,70	> 1000
Combined standard uncertainty		normal		1.07	> 1000
Expanded uncertainty		K=2		2.14	> 1000

4.3. Measuring transmission spectrum using ANRITSU MS8911B.

The results of critical mask transmission measurement using ANRITSU MS8911B are shown in figure 13, where the filter characterization measurement described before was replaced by the default filter response pre-load.

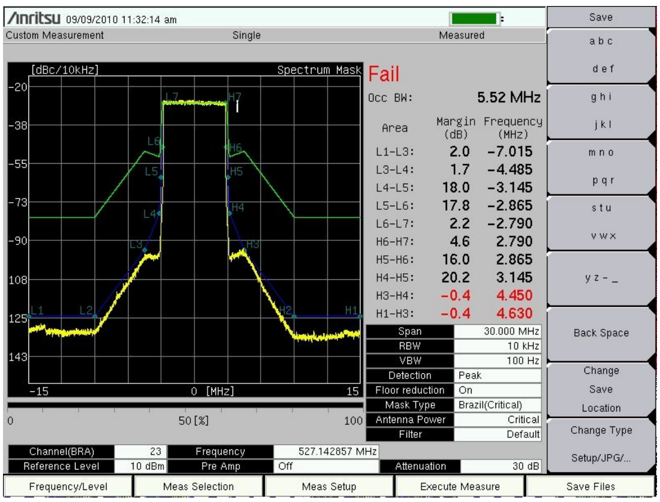

Fig. 13 Transmission spectrum mask measurement results using default filter

5. CONCLUSIONS

It is possible to reduce measurement uncertainty of the transmission spectrum mask between ±3.5MHz from the center frequency using the available dynamic range when the internal intermodulation error is relative low.

When the requirement of dynamic range exceeds the available one, if a filter response correction is applied out of ±3.5MHz from the center frequency and the results are obtained by addition the mask filter response to the ISDB-T signal measured before it, the uncertainty is higher due to the contribution of filter characterization uncertainty.

During measurements, ISDB-T testers have shown the similar performance than multipurpose spectrum analyzer for testing the transmission spectrum mask.

According to the results obtained in this work, the mask filter characterization can be considered as the more accurate method. But, the use of pre-load default filter response gives a good approximation of the final measurement result even when, it should not be used as certifying test for equipments.

The inclusion of devices for adding the mask filter response to the ISDB-T signal in digital TV analyzers, could give additional advantages as the base band analysis, allowing measurement like modulation error ratio (M.E.R.), echo pattern, inbalance I-Q and bit error rate performance, that characterize the signal quality.

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