Application Note

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Using image filtering to improve 2310 TETRA wideband noise measurements

The TETRA conformance specification ETS EN 300 394-1 V3.1.1 (2007-11) defines minimum performance requirements for mobile terminal equipment and base stations. This application note describes a practical method for checking that TETRA transmitters conform to the wideband noise specification.

Introduction

The TETRA standard is designed to share spectrum allocation with analog systems and in order to minimize interference the performance criteria for TETRA transmitters are necessarily onerous. This, in turn, places high demands on equipment designed to the transmitters' performance. Of particular interest here are the requirements for wideband noise emissions far from the carrier.

A companion application note, [1], discusses an apparent shortcoming in the 2310 that impinges upon its suitability for measuring wideband noise and then describes a method of obtaining accurate results. This application note briefly introduces the shortcoming and then details a potentially simpler method of making wideband noise measurements that, although not gaining from all the benefits described in [1], are still valid.

Wideband noise requirements for TETRA transmitters

ETS EN 300 394-1, [2], defines the technical characteristics of both mobiles and base stations together with the radio test methods to be used in type testing. For each parameter, the specification includes a definition for the minimum performance, the test method to be used and the acceptable uncertainty level of the measurement equipment.

The following wideband noise levels measured through the TETRA filter[1] shall not exceed the limits shown in Tables 1.1 and 1.2 for the power classes as stated and at the listed offsets from the nominal carrier frequency. The requirements apply symmetrically to both sides of the transmitter band and shall be measured under normal conditions.

If a discrete spurious lies in one of these bands, then the closest discrete spurious-free frequency which is higher shall be chosen. For each selected frequency offset the test system shall calculate the average power over at least 200 bursts, timed to occur only during the useful part of the burst and covering at least 200 symbols in each phase-modulated burst.

The measured average transmitter power level will be used as the 0 dB reference for the wideband noise measurements.

The conformance specification for acceptable uncertainty introduced by the measurement equipment used to test wideband noise is:

RF power relative to 0 dB reference

0 dBc to -45 dBc:	±1.0 dB
<-45 dBc to -105 dBc:	±1.5 dB

Limitations of Conventional Test Methods

A general-purpose spectrum analyzer is often considered appropriate for making measurements such as wideband noise. However, spectrum analyzers suffer a number of deficiencies as a result of their basic design which make them unsuitable for this measurement.

Some of these deficiencies are shown as follows:

- General purpose spectrum analyzers do not incorporate a square root raised cosine filter.
- The dynamic range of measurement must be greater than 100 dBc. This requirement presents a significant challenge for any spectrum analyzer.
- TETRA requires that wideband noise measurement is performed while synchronized to the bursted carrier. A conventional spectrum analyzer is unable to maintain synchronization with the carrier while tuned to the offset frequency.

For a more detailed description, see [1].

Summarizing, these problems make general-purpose spectrum analyzers unsuitable for TETRA wideband noise measurement.

Freqency offset	Maximum wideband noise level		
	MS Nominal power level <= PL4 (1 W)	**MS Nominal power level = PL 3 (3 W) or PL 3L (1.8 W)**	**MS Nominal power level >= PL 2L (5.6 W) BS (all classes)**
100 kHz to 250 kHz	-75 dBc	-78 dBc	-80 dBc
250 kHz to 500 kHz	-80 dBc	-83 dBc	-85 dBc
500 kHz to *frb*	-80 dBc	-85 dBc	-90 dBc
> *frb*	-100 dBc	-100 dBc	-100 dBc
NOTE: *frb* denotes the frequency offset corresponding to the near edge of the received band or 5 MHz (10 MHz for frequencies above 520 MHz) whichever is the greater. All levels are expressed in dBc relative to the actual transmitted power level, and in any case no limit higher than –55 dBm for offsets <= *frb* or –70 dBm for offsets > *frb* shall apply.			

Table 1.1 - Wideband noise limits for frequencies below 700 MHz

Freqency offset	Maximum wideband noise level		
	MS Nominal power level <= PL4 (1 W)	**MS Nominal power levels from 1.8 W to 10 W and BS Nominal power levels <= 10 W**	**MS and BS Nominal power levels from 15 W to 40 W**
100 kHz to 250 kHz	-74 dBc	-74 dBc	-80 dBc
250 kHz to 500 kHz	-80 dBc	-80 dBc	-85 dBc
500 kHz to *frb*	-80 dBc	-85 dBc	-90 dBc
> *frb*	-100 dBc	-100 dBc	-100 dBc
NOTE: *frb* denotes the frequency offset corresponding to the near edge of the received band or 10 MHz whichever is the greater. All levels are expressed in dBc relative to the actual transmitted power level, and in any case no limit higher than –55 dBm for offsets <= *frb* or –70 dBm for offsets > *frb* shall apply.			

Table 1.2 - Wideband noise limits for frequencies above 700 MHz

An Overview of the 2310 analyzer

A simplified block diagram of 2310 is shown in Fig. 1. The 2310 has a high power and a low power input selected from RF input switch. High power TETRA transmitter classes in the range +3 dBm to +46 dBm are catered for on the high power input and low power TETRA transmitter classes in the range –20 dBm to +27 dBm are catered for on the low power input.

A variable attenuator is used to condition the TETRA carrier to be within a desired power band before it is mixed to an intermediate frequency of 10.71 MHz. The IF signal is amplified to match the operating point of the instrument analog to digital converter. The 2310 uses a novel converter architecture, which is described with more detail in [1].

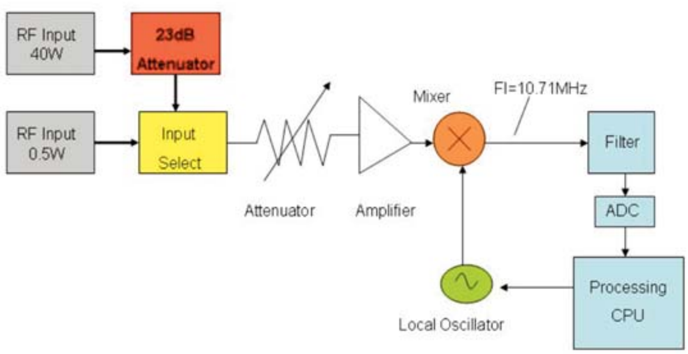

Fig 1 – -2310 basic block diagram

When a mixer is used to frequency convert an RF signal to an IF there are two RF frequencies that will equally well convert to the same IF. Both RF frequencies are separated from the local oscillator by a frequency separation equal to the IF frequency. So, in Fig 2, any signal (or noise) at the wanted TETRA carrier frequency (fc) will be shifted down to the 10.71 MHz IF but, so too will any signal (or noise) at the Image Frequency (Fim).

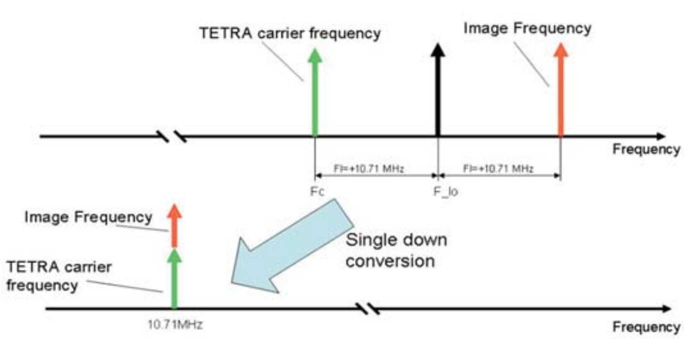

Fig 2 – Derivation of image frequency

With the 2310's receiver architecture it is difficult to determine whether the signal on the mixer's IF port originates from the RF band of interest or whether it is an image response. For most testing with the 2310 this is of little consequence. However, in the specific case of Wideband Noise Measurement, if the transmitter under test has a flat noise floor extending into the Image Frequency zone, then the resultant noise measurement would be double the correct amount, i.e. pessimistic by 3 dB. (The lack of image rejection can easily be demonstrated; see Appendix 1.)

Table 2 shows that the 2310's residual noise floor is consistently lower than the limits listed in Table 1.

Offset frequency	2310 residual noise floor (18 kHz b/w)	
	Fc < 500 MHz	500 MHz < Fc < 1 GHz
100 kHz – 250 kHz	-88 dBc	-88 dBc
250 kHz – 500 kHz	-98 dBc	-98 dBc
500 kHz – 5 MHz	-100 dBc	-98 dBc
> 5MHz	-105 dBc	-103.5 dBc

Table 2 – 2310 residual noise floor

However the margin between the specification limits and the 2310's performance is uncomfortably tight after the noise image component is taken into account:

- Below 500 MHz, the narrowest margin (i.e. for offsets over 5 MHz) is -100 + (-105 + 3) = 2 dB.
- At 500 MHz and above, the narrowest margin becomes –100 + (-103.5 + 3) = 0.5 dB.

This latter figure, in particular, means that marginal transmitters could fail the Wideband Noise Measurement unnecessarily.

[1] discusses this whole subject in greater detail and gives a method of introducing a second IF stage that, in effect, overcomes the problem. Below is a description of a considerably simpler method that, although not able to match the full benefits described in [1], still significantly reduces the risk of a good transmitter failing. In practice, a transmitter with a flat noise floor, when tested with this method, has its 3 dB "pessimism" typically reduced to 1 dB, thus increasing the worst-case margins to 4.5 dB (below 500 MHz) and 2.5 dB (at 500 MHz and above).

Method

As discussed above, ideally the test equipment would ignore any noise generated by the Device Under Test that falls outside the particular frequency offsets specified in Table 1. However, the simple single-IF design of the 2310 that makes it so suitable for the majority of TETRA measurements, is unable to ignore DUT-generated noise in the region of the Image Frequency. There is no reason, though, why that noise cannot be removed before it even reaches the 2310. The methodology is:

- to insert a notch (band-stop) filter, tuned to the Image Frequency (and having a bandwidth of at least 18 kHz), between the DUT and the 2310's input, and …
- to use the points made in [1] about driving the 2310 at its maximum dynamic range.

The set-up is as follows:

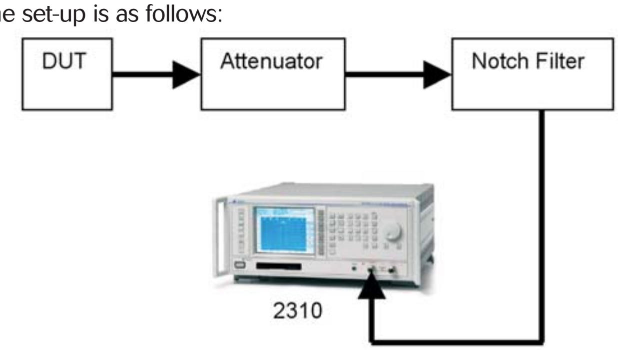

Fig 3 – Configuration to measure wideband noise

The role of the attenuator is to reduce the output power from the DUT so that the 2310 can be fed through its low-power input at maximum sensitivity (i.e. a signal level around 15 dBm). Naturally, the attenuator must be rated for the DUT's output power. For a typical 2 W (33 dBm) mobile, a 20 dB attenuator should be used.

Example equipment list:

Attenuator

Manufacturer: Aeroflex Inmet. (www.aeroflex-inmet.com)

Part Number: 6NxxW-yy, where:

xx = power rating in Watts. Values: 5, 10, 20 or 50.

yy = attenuation in dB. Values: 10, 20, 30 or 40. (Some power ratings are available in additional attenuation values, see manufacturer's website.)

Notch filter

Manufacturer: Telonic Berkeley Inc. (www.telonicberkeley.com)

Part Number:

TTR 375-3EE (250-500 MHz)

TTR 750-3EE (500-1000 MHz)

Signal generator (see below)

Manufacturer: Aeroflex. (www.aeroflex.com)

Model: 2023B

Notch filter tuning and path loss determination

The 2310 has its own Wideband Noise measurement screen that, in normal operation, shows you the wideband noise measurements at up to 20 offsets automatically. However, before taking a measurement at each offset frequency using the notch filter technique, it is necessary that (a) the notch filter should be tuned to the corresponding image frequency and (b) the path loss between the DUT output and 2310 input should be established. To determine the image frequency, see Appendix 2.

Tuning the notch filter is achieved by replacing the DUT with a simple analog signal generator producing an unmodulated carrier at the required frequency at a level of around +10 dBm. The 2310 is set to Spectrum Analyzer mode, tuned to the same frequency and the notch filter is tuned for a minimum on the 2310's display.

To establish the path loss, tune the signal generator and the 2310's center frequency to the offset frequency where the noise is being measured. The path loss is the difference between the signal generator's output level and the level displayed on the 2310.

Measuring wideband noise

On the 2310, set the DUT's channel frequency (FREQ, Channel Frequency).

Select the TETRA Wideband Noise Emissions screen (MEASURE, Wideband).

Set the number of bursts to measure over (MEASURE, Bursts to Average, 200, ENTER).

Please note that the 2310's low-power input is being used. Damage may result if more than 0.5 W is applied so, before proceeding, check the attenuator is of the appropriate value!

For each offset frequency shown on the 2310's screen:

- Perform the notch filter tuning and path loss determination procedure described above.
- Reset the 2310 to TETRA mode and enter the path loss (press LEVEL, select Maximum Sensitivity, press Input Level Offsets, System Loss, enter the path loss and check that Offsets ON is 'illuminated').
- Press SINGLE and wait for a Measured Value to appear against the appropriate Offset Frequency.
- Note that the Measured Value is shown in dBm. Subtracting the Average Tx Power measurement (e.g. +15.6 dBm) from the Measured Value (e.g. –80.7 dBm) gives the result in dBc (-80.7 - +15.6 = -96.3 dBc).

With most radios it will probably be necessary only to notch-out the image at the outermost Offset Frequencies (i.e. the first and last rows on the 2310's screen).

Results

To illustrate the benefits of the method described above, Fig 4 graphs the results of a test performed on a conventional 2 W TETRA mobile on the 800 MHz band, once with the external notch filter in use and once without. Note that without the improvement of 2 dB at the worst case offsets of ±(frb + 12.5 kHz), the DUT would have failed the Wideband Noise test.

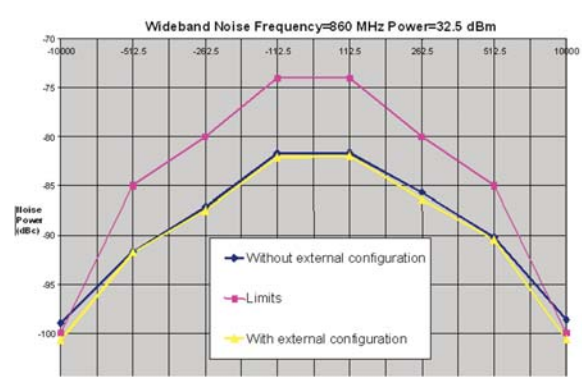

Fig 4 – Improvement through using the external notch filter

[1]The TETRA filter is a square root raised cosine filter with a roll-off factor (alpha) of 0.35 and with 3 dB bandwidth of 18 kHz.

Acknowledgement

The method described in this Application Note was proposed and developed by Teltronic S.A. Unipersonal who also provided the example results shown above. (www.teltronic.es)

References

[1] Application Note. "Using 2310 with Option 01 to make Wideband Noise Measurements on Tetra Transmitters." (www.aeroflex.com)

[2] ETSI 300 394-1 V 3.1.1 (2007-11). Terrestrial Trunked Radio (TETRA); Conformance testing specification.

Appendix 1. Checking the 2310's image rejection

Using a simple analog signal generator, it is simple to confirm that the image rejection of the 2310 is as low as described earlier in this application note. The following example uses a channel frequency of 460 MHz, but any other value can be used.

1. Connect the output of the signal generator to the high-power input of the 2310.

2. Configure the 2310 as follows:

- Select TETRA mode.
- Press Select DUT, BS Tx (Cont), Select Burst Type, PRBS.
- Press LEVEL, High Power Input, Input Level and enter 30 dBm.
- Press MEASURE, Bursts to Average and enter 20.
- Press Wideband Noise, DISPLAY, Numeric Only.

3. Set the signal generator to produce an unmodulated carrier, level –40 dBm, frequency 465.0125 MHz. This simulates noise in an offset of +(frb + 12.5 kHz) where frb = 5 MHz.

4. On the 2310, press the SINGLE button and wait for the measurements to finish. Note the Measured Value corresponding to frb + 12.5 kHz.

5. Repeat the last two steps but with the signal generator frequency set to 486.4325 MHz. This simulates the same amount of noise applied at the image frequency of 460 MHz + (frb + 12.5 kHz) + (2 x 10.71 MHz).

6. In practice, the two Measured Values (corresponding to the direct and image frequencies) will be very similar. Typical differences are less than 0.5 dB.

Appendix 2. Calculating image frequencies

Image frequencies can be calculated as follows:

Positive offset ($F_{offset} > 0$):

$$F_{image} = F_{carrier} + F_{offset} + 21.42$$

Negative offset ($F_{offset} < 0$):

$$F_{image} = F_{carrier} + F_{offset} - 21.42$$

where:

F_{image} = Image frequency (MHz)

F_{offset} = Offset frequency where the Wideband Noise will be measured

$F_{carrier}$ = TETRA carrier frequency

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