ACP Measurement according to IS 54 (NADC) using the FSE Spectrum Analyzers

Application Note 1EF32_0L

Subject to change

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Products:

FSEA, FSEB, FSEM

ROHDE&SCHWARZ

Introduction

In digital wireless communication systems one or multiple users are assigned to a physical RF channel. With analog systems only one user per carrier is possible. Output spectrum of the transmitter has to be restricted to the assigned channel in order to avoid interference with the neighbor channels. With the switch over to digital modulation formats more user per channel are possible. They share one channel by using only part of the time for transmission (Time Division Multiplex Access, TDMA) or by coding the transmission by orthogonal sequences for distinction to other users (Code Division Multiples Access, CDMA). Beneath the restriction of modulation spectrum with TDMA systems also time behavior of the transmitted signal is critical. One reason is that in a multi-user situation only one user is allowed to transmit within his assigned time slots. Another reason is that by switching a carrier on and off spectrum of the transmitter splatters and causes additional interference in other RF channels.

Leakage into other channels has to be minimized to assure, that strong signals in adjacent channels do not affect weak signals in the assigned channel.

Both types of spectrum,

- the spectrum due to modulation and
- the spectrum due to switching transients

have to be tested in most communication standards.

For NADC requirements are stated in the North American Electronics Industry Association / Telecommunication Industry Association (EIA/TIA) interim standard IS54.

With the NADC standard each channel is divided in six timeslots, each lasting 6.43 ms. Two of them are assigned to a single user so that three users share a frequency channel. The six timeslots are combined to a frame lasting 40 ms.

The structure of the frame is different for mobile and base stations. Base stations transmit a continuous signal with time slots joined together. Mobile stations transmit only in their assigned time slots. The rest of the time they are in off-mode.

Due to the burst nature of the mobile transmission the spectrum of the transmitted signals can be thought of as two parts, the spectrum due to modulation of the carrier and the spectrum due to switching, i. e. the edge transitions of the bursts.

Spectrum due to switching mainly depends on the speed of edge transitions. The faster the raise or fall time, the higher the spectral power and width. The interference due to switching results in impulsive noise. Tight control of switching speed is necessary to limit the spectrum content of the signal.

Between the two edges of a burst ideally the spectrum has the characteristic of a carrier modulated by random noise. In practice it is distorted by noise and intermodulation of the transmitter.

Adjacent power measurement according to NADC standard

NADC standard defines two limits for out of band power:

- the adjacent and alternate channel power due to modulation and
- out of band power arising from switching transients.

Different methods for detection apply to both types of interference. Measuring power due to modulation mean power has to be used, whereas with measurement of switching transients peak power has to be used.

For both types of emission same limits apply:

Channel	Frequency Offset	Limit
Adjacent channel	±30 kHz	<-26 dB
1st alternate channel	±60 kHz	<-45 dB
2nd alternate channel	±90 kHz	<-45 dB or <-13 dBm

The NADC standard uses distributed filtering, that means part of the filtering is performed on the transmit side of the system and part is performed at the receive side. Both filters are root raised cosine filters with an excess bandwidth of 0.35. The demodulator in the receiver of the base station or the mobile station sees a signal filtered with both filters. In order to measure the signal powers seen by the demodulator, for measurement the root raised cosine filter according to the standard has to be used.

The following picture shows the attenuation vs. frequency of the root raised cosine filter used for baseband filtering. In the RF domain the frequency 0 kHz corresponds to the center frequency of the transmit or neighbour channel. The attenuation curve has to be applied to both sides of the center frequency.

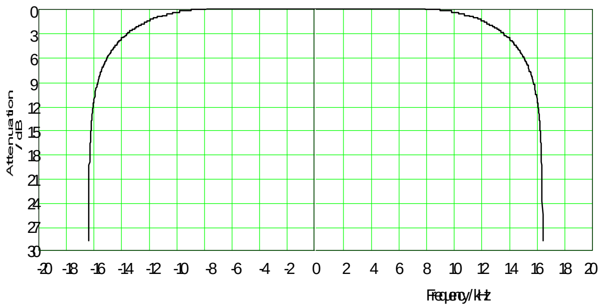

Fig 1 Voltage transfer function of the NADC root raised cosine filter

Channel Power and Adjacent Channel Power Measurement with Spectrum Analyzers

Channel Power or Adjacent Channel Power can be measured using a fixed tuned receiver with an appropriate IF filter and a power detector or a spectrum analyzer with digital signal evaluation and firmware or software for channel power measurement. The receiver solution requires a specialized instrument for the respective standard whereas a spectrum analyzer is a general purpose instrument suitable for many applications.

Two requirements have to be fulfilled by the spectrum analyzer:

- the power of the signal has to be measured and
- measurement has to be performed within the channel defined by the standard using a channel filter.

Power Detector

A spectrum analyzer is not a power detecting instrument. For signal display it converts the RF signal to an IF and uses an envelope detector to rectify the IF signal. The envelope of the IF signal is filtered by a lowpass filter with variable cutoff frequency (Video Filter). Following the Video Filter different detectors are available for display of a trace on screen. A trace contains a fixed number of points (500 in case of the FSE) in frequency axis to be displayed.

When the spectrum analyzer sweeps over the required frequency span, the peak detector catches the peak video voltage of the spectrum represented by a point in frequency axis.

The sample detector uses one (arbitrary) sample per point to be displayed in frequency axis from the digitizing device. If the frequency range of a point is wider than the resolution bandwidth, parts of the spectrum are lost.

With the autopeak detector the maximum and minimum video voltage detected in the frequency range represented by a point are displayed. Both values are connected by a vertical line.

For power detection of noise like signals as the digitally modulated NADC signal only the sample detector is usable. The peak detector would give too high values as only the peaks of the video voltage are displayed. To avoid averaging prior to detection a video filter has to be used, which doesn't affect the video signal. A video bandwidth 3 to 10 times the resolution filter is appropriate.

In addition to the above mentioned detectors the FSE provides an **RMS detector**. Unlike the sample detector it uses the complete signal information represented by a frequency point of a trace and delivers the rms value. Each pixel on screen displays the power of the spectrum represented by the pixel. In contrary to the sample detector no signal is missing even with narrow resolution bandwidths and wide spans.

Channel Power Measurement

When measuring the power in a specific bandwidth (channel) the spectrum analyzer integrates the levels (frequency points) representing the channel according to the following formula:

$$\mathrm{PWR_{CH}/mW} = \frac{\mathrm{CHBW}}{\mathrm{RBW_{noise}}} \cdot \frac{1}{\mathrm{N}} \sum_{i=1}^{N} 10^{\frac{P_i \,/\, \mathrm{dBm}}{10}} ,$$

where

PWR_{CH} = Channel Power
CHBW = Channel Bandwidth
RBW_{noise} = Noise Bandwidth
N = Number of Points (= Pixel)
P_i = Level of Point i

The frequency points used for channel power measurement are antiloged and then summed. The sum is divided by the number of points and multiplied by the factor $\frac{\mathrm{CHBW}}{\mathrm{RBW_{noise}}}$.

RBW_{noise} is the noise bandwidth of the resolution filter used.

When a channel filter is required as with NADC each frequency point has to be weighted by the attenuation of the channel filter before the summation.

For display the level is calculated from the power:

$$\mathrm{LVL_{CH}} = 10 \lg (\mathrm{PWR_{CH}})\ \mathrm{dBm}$$

With adjacent channel power measurement often the relative value to the channel power is needed. In this case the difference between the channel power and the adjacent channel power is displayed.

Following restrictions have to be obeyed when performing channel power measurements.

To meet the channel bandwidth **a minimum number of frequency points** have to be used for summation. As only integer numbers for summation are possible, the channel bandwidth cannot be met exactly. This leads to a maximum span with a given channel bandwidth (e.g. 30 kHz with NADC). The maximum span for < 2 % bandwidth error (results in a error of power of < 0.1 dB) can be calculated from the channel bandwidth (CHBW), the number of points for a complete trace (500 with the FSE):

$$\begin{aligned} Span_{max} &= \text{error x No. of points x CHBW} \\ &= 0.02 \times 500 \times 30\text{ kHz} = 300\text{ kHz} \end{aligned}$$

That means that the measurement of all 7 channels specified in IS 54 or IS 136 is possible with a single sweep (transmit channel, adjacent channels, 1st alternate and 2nd alternate channels).

Resolution bandwidth has to be narrow in order not to influence the channel bandwidth. As a rule of thumb the resolution bandwidth (RBW) should be < 2.5 % of the channel bandwidth. With NADC the 500 Hz bandwidth meets this requirement. Higher bandwidths up to 5 % of channel bandwidth can be used when the spectrum analyzer internally corrects the channel bandwidth due to the resolution bandwidth used. In default setting the FSE uses 1 kHz resolution bandwidth and corrects the error internally.

Using the **sample detector** a minimum number of points have to be used to attain a stable test result. The reason is that the amplitude probability distribution of noise signals filtered by an IF filter is according to the Raleigh distribution. The exact power only can be calculated, if the amplitudes of the frequency points taken for power calculation follow the Raleigh distribution. This is nearly true for more than 1000 points. 20000 points lead to an uncertainty of 0.1 dB. Spectrum analyzers provide 400 to 1000 points on frequency axis. This is not sufficient for stable test results. To stabilize the test result averaging could be assumed to be the appropriate mean. But averaging of noise signals with logarithmic scaling tends to give lower results than the true rms value. Ideal averaging results in a 1.45 dB lower level indication. The reason is that the logarithm of the noise amplitudes are averaged. Additionally the average value of a noise signal is 1.05 dB lower than the rms value. Averaging of impulsive noise gives even lower results. On the other hand averaging of cw signals e.g. spurious doesn't change the amplitude. As the real NADC signal may be thought of all three classes of signals mentioned, no fixed correction factor can be applied.

The FSE provides the **rms detector** in addition to the detectors normally available with spectrum analyzers. With the rms detector all samples from the A/D converter are used for calculation of the rms level at each individual frequency point displayed. The number of samples available depends on sweeptime used. By increasing the sweeptime the number of samples is increased proportionally (see appendix) and the test result is stabilized. No correction factor has to be used to get the true result.

Measurement of Spectrum due to Modulation

The FSE family supports the user by providing firmware routines to carry out the ACP measurement for the NADC standard. The following example shows the operation of the FSE.

Test Setup:

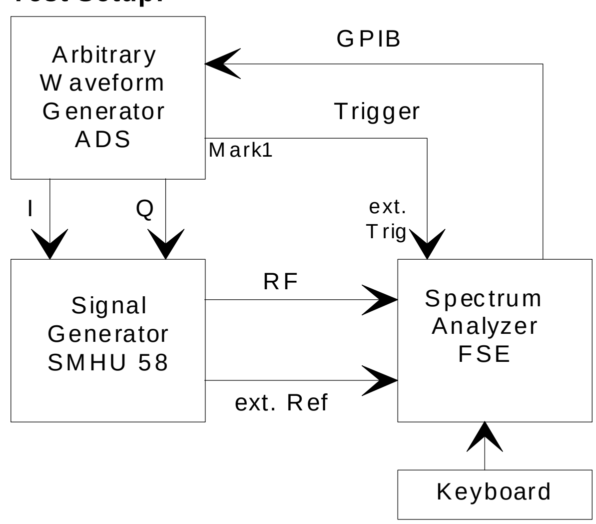

Fig 2 Test Setup for NADC ACP measurement

The Signal Generator SMHU58 delivers a NADC modulated signal to the RF input of the FSE. Modulation is generated via the I/Q inputs of the SMHU58 by the Arbitrary Waveform Generator ADS. The ADS is controlled via the 2nd GPIB bus of the FSE (FSE-B16) by the internal computer function of the FSE (FSE-B15) and the program IQSIM for generation of the data set used in the ADS to produce the NADC baseband signal. For accurate adjacent channel power measurement, the frequencies of the generator and the spectrum analyzer have to be synchronized. For that purpose the external reference output of the SMHU 58 and the EXT REF input of the FSE are connected via a BNC cable. The FSE is set to external reference.

Step 1: Generation of the data set for the ADS

Note: With the following example the program IQSIM.EXE is assumed to be available on the internal harddisk of the FSE (drive C:>:, subdirectory IQSIM)

- Switch the FSE to the computer function [*ALT+SysReq*] on keyboard
- Change the directory to the IQSIM program, e.g. [C:> *cd\IQSIM*]
- Run the program IQSIM.EXE [*iqsim:* **ENTER**]:
- [*File: Load file...: NADC_D1*] This file simulates a NADC Base Station signal with Synchronization word S 1.
- Download the data set to the ADS: [*Transfer: Transfer to ADS64K*]
- Switch over FSE to Spectrum Analyzer [*ALT+SysReq*]

Step 2: Settings on Signal Generator SMHU58

- Set the output frequency to a NADC channel [**FREQ**: *870.03* **MHz**]
- Set the level to 3 dBm [**LEVEL**: *3* **dBm]**

  Note: When the I/Q modulator is modulated by NADC_D1 data file the SMHU 58 delivers about 3 dB less output level as stated in display.
- Switch on the I/Q modulator [**I/Q**]

Step 3: Configuration of Spectrum Analyzer FSE

- Configure FSE to preset settings [**PRESET**]
- Set center frequency to frequency of SMHU58 [**CENTER**: *870.03* **MHz**]
- Set span to 200 kHz [**SPAN**: *200* **kHz**]
- Set reference level to 0 dBm [**REF**: *0* **dBm**: ATTEN AUTO LOW NOISE]
- Set the frequency reference to external: [**SETUP**: REFERENCE EXT]

Note:

Due to the modulation the NADC signal is similar to noise. The sum power of the signal applied to the spectrum analyzer stages in front of the IF filter is the total power of the signal. On display only the part of the signal within the resolution bandwidth used is shown. I.e. the displayed trace is lower than the level applied to the input of the analyzer. The difference is

$$10 \lg \frac{\mathrm{RBW}}{\mathrm{SBW}} \mathrm{dB},$$

where

RBW = Resolution Bandwidth and

SBW = Signal Bandwidth.

Signal bandwidth corresponds to the bandwidth of the transmit filter, i. e. 30 kHz. When 1 kHz RBW is used for measurement the difference is about 15 dB.

Step 4: Configure the FSE for NADC power measurement.

For ACP calculation the FSE provides versatile firmware routines in the left side menu of the marker menu. Operation of different standards as NADC, TETRA are supplied by macros. The user has only to select the standard in order to switch on the appropriate filtering, channel bandwidth and channel spacing.

Configure the ACP settings:
[**MARKER NORMAL**: ⇐ :
ADJACENT CHAN POWER: CP/ACP REL:
POWER MEAS SETTINGS:
SET NO. OF ADJ CHANNELS: 2: *ENTER:*
ACP STANDARD: *Select* NADC *from table*:
⇑ *(Menu Up)*
ADJUST CP SETTINGS *(Span and RBW are set to the default values*)]

The FSE performs the measurement of adjacent channel power and 1st alternate power of the signal. The numbered values are shown as a list on screen.

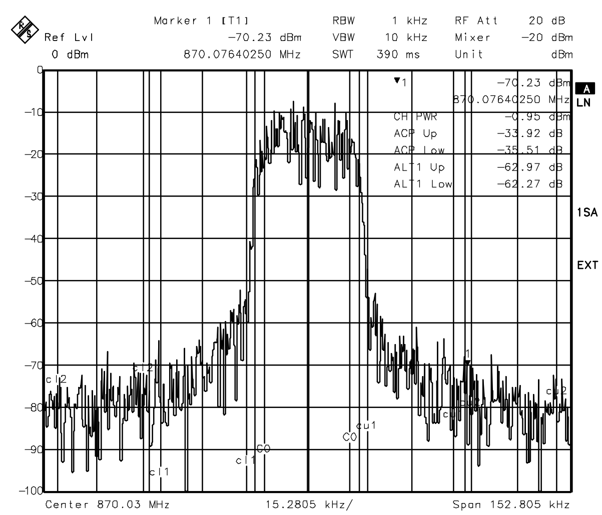

Fig 3 Test result of NADC ACP measurement using the sample detector

If only the adjacent channel power test is required or also the 2nd alternate channels have to be tested, the number of adjacent channels has to be adopted via the following sequence of keystrokes:

[**MARKER**: ⇐ : POWER MEAS SETTINGS: SET NO. OF ADJ CHANNELS: n: *ENTER:* ⇑ *(Menu Up)* ADJUST CP SETTINGS *(Span and RBW are set to the default values according to the modified number of channels*)]

In default settings the FSE uses the sample detector. To use the advantages of the rms detector it has to be switched on in the trace menu.

[**TRACE 1**: DETECTOR: DETECTOR RMS]

In order to stabilize the numbered values for the power measurement, an increase of sweeptime to 2 seconds is recommended:

[**SWEEP**:SWEEPTIME MANUAL: 2 **s**]

Fig. 3 and fig. 4 show a comparison between measurement using the sample detector and the rms detector. The trace in fig. 4 is smoothened due to the higher number of samples used for display of the power (see appendix A). This stabilizes also the test result for the channel power measurement. With the sample detector the test result varies up to 4 dB between different sweeps whereas with the rms detector and 2 seconds sweeptime the variation is well below 1 dB. The instability with the rms detector can also be seen from the different numbers of ACP Up and ACP Low in figure 3.

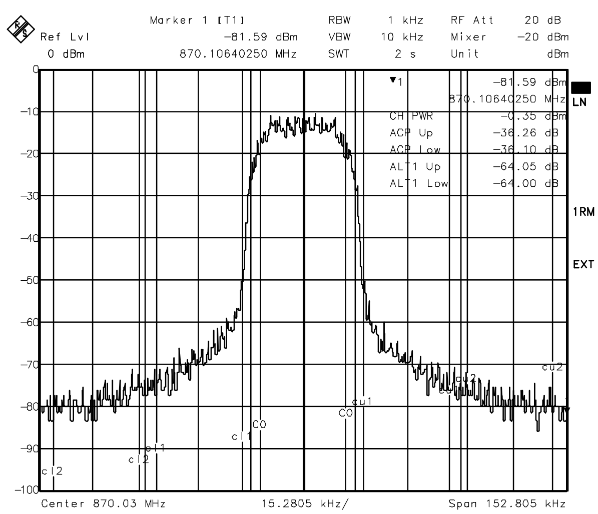

Fig 4 Test result of NADC ACP measurement using the rms detector

By increasing the sweep time the test result can be stabilized with the rms detector. With the sample detector averaging had to be used to get stable numbers for the different channel powers. But averaging leads to wrong test results due to the logarithmic scaling of the display and the random nature of the signal.

Measurement on Burst Signals

With NADC three users share one channel. The Information is transmitted in TDMA frames. When testing a mobile station time selective spectrum measurement has to be performed therefore, i.e. if measuring the modulation spectrum, only during transmission of the burst the FSE sweeps and measures the spectrum. When no transmission occurs between the TDMA frames, the FSE stops sweeping.

The FSE offers the Gated Sweep to perform this measurement. It is gated by an external signal and sweeps only during a user defined gate time. To take into account a delay between the external trigger signal and the sweep start, a gate delay can be defined.

- Switch the FSE to the computer function [*ALT+SysReq*] on keyboard
- [File: Load file...: NADC_U1F] This file simulates a NADC Mobile Station Full Uplink Burst.
- Download the data set to the ADS: [Transfer: Transfer to ADS64k]
- Switch over FSE to Spectrum Analyzer [*ALT+SysReq*]

Following steps are necessary to set up the FSE for gated sweep:

Connect the MARK 1 output of the ADS with the trigger input of the FSE.

Set the FSE for external triggering:

TRIGGER: EXTERNAL: <1> V

Set the FSE for Gated Sweep:

SWEEP:
EXT GATE: ON
EXT GATE SETTINGS:
GATE EXTERN

GATE LEVEL: <1> V:

GATE MODE EDGE:

GATE POL POS:

GATE DELAY <1.2> ms:

GATE LENGTH <5 > ms:

The above values for the gate delay and the gate length are raw numbers derived from the burst specification of IS54 or IS 136. To set both values more accurate the FSE can be switched to zero span mode. The time for the active sweep is shown by two vertical lines the left one showing the gate delay and the time between the two lines showing the gate time. Adjusting the gate delay and gate time both lines are set properly.

SPAN: ZEROSPAN

TRIGGER: EXT 1 **V**
SWEEP: SWEEP TIME MANUAL: <10> ms
EXT GATE SETTINGS:
GATE DELAY: <adjust properly>
GATE TIME: <adjust properly>
SPAN: LAST SPAN

SWEEP: SWEEPTIME 2 s
MARKER NORMAL: ⇐: ADJACENT CHAN POWER

Appendix A:

The RMS detector in the FSE

Due to its novel approach for signal evaluation the FSE has the capability to measure the rms (root mean square) value of a signal without any correction factor and independent of the signal shape.

The linear video signal at the output of the envelope detector of FSE is available with a dynamic range of 100 dB in digital format. The FSE calculates from the digital video samples the rms value for each pixel of the trace using the known formula:

$$V_{rms} = \frac{1}{N} \cdot \sqrt{\sum_{i=1}^{N} V_i^2}$$

whereas

V_{rms} = rms value of voltage
V_i = Sample of linear envelope voltage
i = index
N = number of samples for 1 pixel on screen

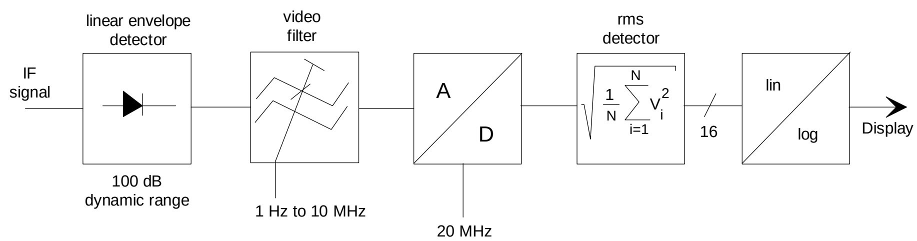

Fig 5 Schematic Diagram of FSE Detector
(only for explanation of the function, i mplementation is R&S proprietary)

After filtering according to the resolution bandwidth set the IF signal is applied to the linear envelope detector. It removes the IF portion of the signal and provides at the output the linear video signal with 100 dB dynamic range. The following video filter has to be set to a bandwidth more than three times the resolution bandwidth set, in order not to average the video signal prior to rms detection. Averaging would introduce errors with power detection as the average value of random signals is lower than the power. The linear video voltage is digitized with 20 MHz sampling rate. That way at the output of the digitizer the linear video voltage is available in digital format.

Beneath the maximum and minimum peak and sample detector the FSE contains an average and a rms detector (fig. 5 shows only the rms detector). They are implemented using digital circuitry instead of analog circuitry in other spectrum analyzers.

Advantage of the all digital peak detectors is their fast acquisition time, their accuracy, their unlimited hold time and their zero discharge time.

But the all digital implementation of the detectors enables the FSE to detect the rms and average value of the signal, too.

With the rms detector each sample from the AD converter is squared. The squared samples are accumulated until the necessary number of samples for one pixel is reached. The sum is divided by the number of accumulated samples and the square root is taken.

For display the logarithm of the linear power of the video signal is taken.

The dynamic range of the rms detector is 96 dB according to the 16 bit resolution at the output of the rms detector.

That way each pixel represents the rms of all signal components represented by a pixel displayed on screen of the FSE.

The number of samples used for detection depends on sweeptime. If the sweeptime is increased the number of samples is increased proportionally. In other words the time for averaging or rms weighting is increased on each individual frequency. This results in a more stable test result. When measuring noise signals or digital modulated signals the trace smoothens by increasing the sweeptime.

The following advantages are attained using the rms detector for power measurements:

- Test result does not depend on characteristic of signal because no correction factors have to be applied, which are only valid for specific classes of signals, e. g. cw signals, impulsive noise or random noise.
- The stability of the test result for channel power measurement does not depend on number of pixels used for calculation of channel power. The trace can be smoothened by increasing the sweeptime leading to stable channel power measurements.
- Test time is reduced up to a factor of ten for measurement in all channels (transmit adjacent and alternate channels) as all channels can be tested in a single sweep with stable and accurate test result.
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Appendix B:

USER Menus for NADC ACP measurement.

The settings described in this application note are available with the file NADC_ACP.EXE. It is a self executable file. By running the file the macros and settings for the NADC ACP measurements are extracted. After running the file the following files are available:

NADC_MAC.MAC

ACP_SA.SET

ACP_RM.SET

ACP_SAB.SET

ACP_RMB.SET

Installation

Copy the file NADC_ACP.EXE on to a floppy disk and run NADC_ACP.EXE.

Operation from floppy disk

Insert the floppy disk into drive A: of the FSE and load the softkey menu according the following steps:

- **RECALL**: EDIT PATH: *A:*

- SELECT ITEMS TO RECALL: ENABLE ALL ITEMS: ⇑
- DATA SET LIST: {*Select NADC_MAC in table*}: **ENTER**
- {*The filename NADC_MAC is entered into the input box*}: Press **ENTER**
- SELECT ITEMS TO RECALL: DEFAULT CONFIG

Operation from internal harddisk
(Computer Function FSE-B15 installed)

- Switch over to computer function [ALT + SysReq] on external keyboard.
- Generate a NADC_ACP directory under C.\user\config directory:
  cd:\user\config
  md nadc_acp
- *Copy the file NADC_ACP.EXE to the FSE hard disk:*
  copy a:\nadc_acp.exe c:\user\config\nadc_acp
- *Run the file nadc_acp.*

Load the soft key menu according the following steps:

- **RECALL**: EDIT PATH: *c:\ user \config\ nadc_acp* **ENTER**
- SELECT ITEMS TO RECALL: ENABLE ALL ITEMS: ⇑
- DATA SET LIST: {*Select nadc_mac in table*}: **ENTER**
- {*The filename nadc_mac is entered into the input box*}: Press **ENTER**
- SELECT ITEMS TO RECALL: DEFAULT CONFIG

Operation of the USER menu:

When pressing the USER key the following menu appears:

USER MENU	
NADC ACP SAMPLE DET	ACP measurement on a non bursted NADC signal using the sample detector (File: ACP_SA.SET)
NADC ACP RMS DET	ACP measurement on a non bursted NADC signal using the rms detector (adjacent and 1st alternate channels) (File: ACP_RM.SET)
NADC ACP BURST SA	Gated ACP measurement on a bursted NADC signal using the sample detector (File: ACP_SAB.SET)
NADC ACP BURST RMS	Gated ACP measurement on a bursted NADC Signal using the rms detector (adjacent and 1st alternate channels) (File: ACP_RMB.SET)

Each menu recalls a specific ACP measurememt.

When the menu is operated from floppy disk the settings are downloaded from the floppy disk in drive A. Therefore the floppy must remain in drive A: when using the NADC_ACP macros.

After recalling a test setting, all parameters for the measurement can be changed manually. Normally the center frequency and the level settings required will be different from the settings stored.

If settings different from the supplied values are needed, they can be updated by storing the changed settings on disk according to the following procedure:

- Recall the setting to be changed using the specific softkey in the user menu.

  Change parameters e.g. CENTER, REF LEVEL, MARKER, ...
- SAVE: {*the name for the specific file has been already entered in the input box*}: ENTER
- The new settings are stored on floppy in drive A or on internal harddisk depending on the path specified.

Warning: If changed settings are stored, the supplied default settings are lost and cannot be recovered. It is recommended to operate the FSE with a copy of the original disk.

Macros may be destroyed if SELECT ITEMS TO SAVE is not set correctly to DEFAULT SETTING.

Josef Wolf, 1ES2
Rohde & Schwarz
8 December 1996