

Test of DME/TACAN Transponders

Application Note

Products:

- | R&S®SMA100A
- | R&S®NRP-Z81

This Application Note describes the operating principle of DME (Distance Measurement Equipment) that is used for distance measurement in aviation. It also describes various test scenarios for the maintenance of a DME transponder. These tests require an R&S®SMA100A signal generator with R&S®SMA-K26 DME modulation option, and an R&S®NRP-Z81 wideband power sensor.



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Application Note

J. Ostermeier
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1 Abbreviations

BITE:	Built-In Test Equipment Test and measurement equipment installed in the DME transponder to allow the system to perform a self-test
DME:	Distance Measurement Equipment Distance measurement method in aviation
DME/N:	DME narrow spectrum characteristic Standard DME method that is used almost exclusively in civil aviation for distance measurement
DME/P:	DME precise More precise DME method that is seldom used at present
DOC 8071:	ICAO test specification for testing navigation aids
EUROCAE:	European Organisation For Civil Aviation Electronics European authority that defines civil navigation standards
GPS:	Global positioning system
ICAO:	International Civil Aviation Organization International authority that defines civil navigation standards
ID Code:	Identification code
ILS:	Instrument Landing System Navigation aid used during aircraft landing approach
MKR BCN:	Marker Beacon Navigation aid used during aircraft landing approach
MLS:	Microwave Landing System Successor system for ILS, but has not gained acceptance.
NM:	Nautical mile; 1NM = 1805.02 m
pp/s:	Pulse pairs per second
TACAN:	Tactical Air Navigation Military DME variant that also enables azimuthal direction determination.
VOR:	VHF Omnidirectional Radio Range Navigation aid for azimuthal direction determination

2 DME (Distance Measurement Equipment)

2.1 Overview

VHF omnidirectional radio range (VOR), the instrument landing system (ILS), marker beacon (MKR BCN) and DME / TACAN continue to be used as analog navigation aids in international civil and military air traffic.

- VOR is used for route navigation and determines the azimuthal direction between the aircraft and ground station.
- ILS is used during the landing approach and monitors the correct approach path to the runway.
- DME is used to determine the distance between the aircraft and ground station.
- MKR BCN uses 3 radio beacons located at a defined distance from the runway in order to check the approach altitude during the landing approach. In future, the majority of MKR BCN stations will be replaced by DME systems that are positioned at the beginning of the runway and allow the pilot to precisely determine the distance between the aircraft and runway.
- TACAN is the military version of DME. The method used for distance measurement is identical to DME, except that additional pulses for azimuthal direction determination are sent by a TACAN ground station.

DME is a radar system used to determine the slant distance of an aircraft (= DME interrogator) to a ground station (= DME transponder). For this purpose, shaped RF double pulses are transmitted by the aircraft to the ground station and, after a defined delay (= reply delay), the ground station sends the pulses back again. The receiver in the aircraft uses the round trip time of the double pulses to determine the distance to the ground station.

The method is defined in ICAO (International Civil Aviation Organization) Annex 10 to the Convention on International Civil Aviation [1] and also in EUROCAE (European Organisation For Civil Aviation Electronics) ED-54 [2] and EUROCAE ED-57 [3].

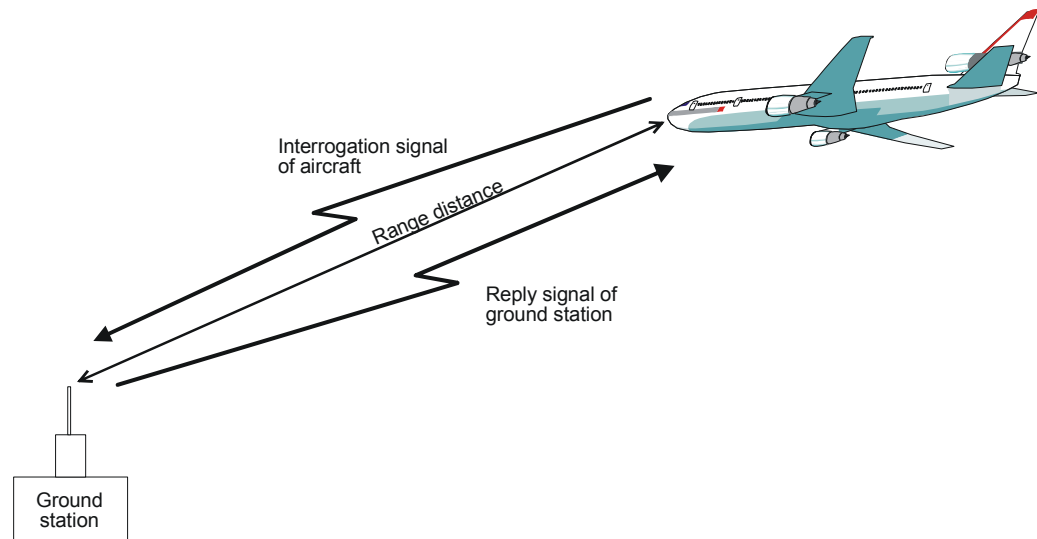


Figure 1: DME principle

Most DME ground stations are combined with a VOR system in order to allow an aircraft to determine its precise position relative to this station. The DME channels are paired with the VOR channels and range from 1025 MHz to 1150 MHz for the aircraft transmitter and 962 MHz to 1213 MHz for the ground stations. The frequency delta between received and transmitted signal is always 63 MHz. The channel spacing between the various DME channels is always 1 MHz. Each channel has two different codings (X and Y) that differ with regard to their pulse spacing. The assignment of a channel and coding to a ground station always remains the same during operation and is determined by the respective national ATC authority.

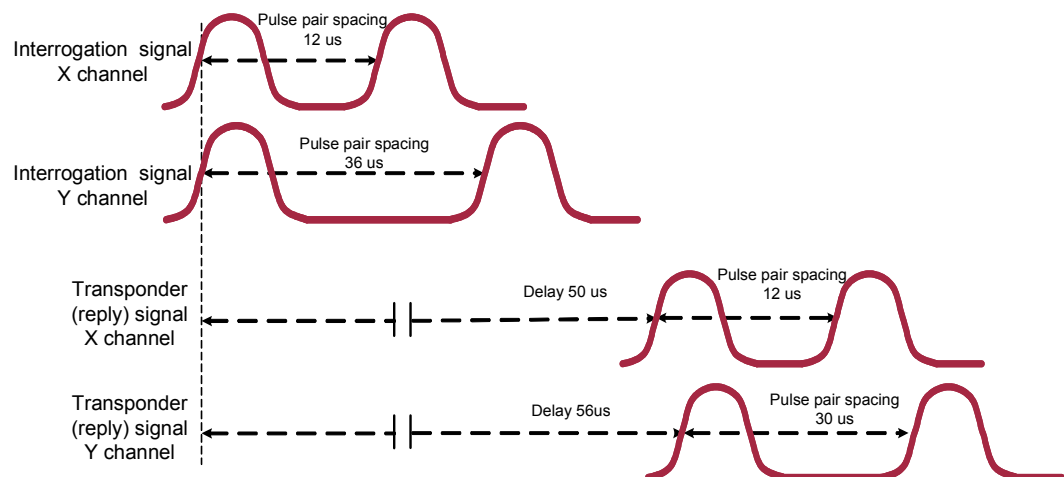


Figure 2: Time characteristic of DME signal envelope for X and Y channel.

Figure 2 shows the time characteristic of the envelope of the DME interrogation pulses from the aircraft (interrogation signal) and the reply pulses from the ground station (transponder reply signal). The table below gives the pulse spacing and delay times for the two channels X and Y.

DME/N pulse spacing and delay times				
Channel	Pulse spacing of interrogation pulses from aircraft	Pulse spacing of reply pulses from transponder	Delay of 1st pulse	Delay of 2 nd pulse
X	12 μ s	12 μ s	50 μ s	50 μ s
Y	36 μ s	30 μ s	56 μ s	50 μ s

Table 1: Pulse spacing and delay times

The table below gives the other DME pulse parameters.

DME/N pulse parameters	
Pulse width (50% amplitude)	3.5 μ s \pm 0.5 μ s
Rise time (10% \rightarrow 90% of amplitude)	0.8 μ s to 3 μ s
Fall time (90% \rightarrow 10% of amplitude)	<3.5 μ s
ON/OFF ratio	80 dB

Table 2: DME/N pulse parameters

In order to limit the bandwidth of the DME signal to the channel width of 1 MHz, the envelope of the pulses is shaped taking the specified rise and fall times into consideration.

There are two different DME standards (DME/N and DME/P) that mainly differ with respect to the rise time of the pulse edge, whereby DME/N is the standard that is almost always used at present. DME/P was defined in the 1980s with the objective of increasing the accuracy of the system. It was intended to be used in combination with MLS (Microwave Landing System = successor system for ILS) and to replace DME/N in the long term. However, owing to the advent of satellite navigation (GPS), DME/P and MLS never gained acceptance and are now no longer being pursued. Therefore, only DME/N will be referred to below.

The overall accuracy of the DME/N system is approx. ± 0.1 NM (± 185 m) (1 NM = 1 nautical mile = 1852.02 m).

2.2 TACAN

TACAN (Tactical Air Navigation) is the military version of DME and, in addition to distance measurement (which is identical to DME), also enables an aircraft to determine the azimuthal direction between the aircraft and ground station. The accuracy of azimuthal direction determination is higher than that of the VOR method used in civil aviation.

To allow a TACAN receiver onboard an aircraft to determine the direction, a TACAN ground station sends 900 specially coded pulse pairs per second in addition to the DME pulses. All pulses are transmitted by a rotating antenna owing a special formed radiation pattern, generating a two tone (15 Hz and 135 Hz) amplitude modulation to the envelope of the DME pulses received from a TACAN aircraft interrogator. The TACAN receiver determines the azimuthal direction by evaluating the phase relation between the amplitude modulation and the 900 specially coded TACAN pulses.

Since the amplitude modulation is generated by a rotating antenna, the pulse peak amplitude at the transponder output (or antenna input) is, like for a DME transponder, constant.

All correlations, features and measurement methods mentioned below therefore also largely apply to a TACAN ground station.

2.3 DME Interrogator

The aircraft's DME interrogator sends a sequence of pulses that are received at the ground station and, after a defined delay time, are returned at a different frequency. The frequency offset between the sent and received signal is always 63 MHz. The receiver in the aircraft filters its own pulse sequence out of all received pulses and in this way determines the time difference between the transmitted and received pulse. It then uses this time to calculate the slant range to the ground station. The distance is usually indicated in nautical miles (NM), where 1 NM corresponds to 1852.02 m and a signal round trip time of 12.359 μ s. As a result, by taking the flight altitude above ground as well as the azimuth angle between the aircraft and ground station (VOR system) into consideration, it is possible to determine the precise position of the aircraft.

With the interrogator, a distinction is made between "search mode" and "track mode". In search mode, the interrogator attempts to set up a connection to a ground station and to synchronize to this ground station. In this mode, the pulse repetition rate can be increased up to 150 pp/s (pp/s = pulse pairs per second).

When the interrogator has synchronized to a ground station, it changes to track mode and performs its distance measurements at regular intervals. The pulse repetition rate in track mode is maximum 16 pp/s.

The transmit power of an aircraft interrogator is minimum 250 W.

2.4 DME Transponder

The principal processes inside a DME ground station are described below.

2.4.1 Checking Receive Pulses

In the receiver, the validity of all received pulses (i.e. the pulse spacing must be consistent with the channel) is checked in the "decoder". A single pulse, for example, is filtered out as an invalid interrogation and no reply to this pulse is sent.

2.4.2 Dead Time of Receiver

After a valid DME double pulse is received (i.e. after the 2nd pulse is received), the receiver at first does not react to any further interrogations for 60 μ s (= dead time) to ensure that it does not trigger again to its own transmitted reply. The receiver is therefore not ready to process new interrogation pulses until the reply double pulse has been fully transmitted. All pulse interrogations that are received at the DME ground station during the dead time are not answered. This ensures that the gap between two consecutive pulses is always at least 60 μ s.

2.4.3 Reply Delay

A reply pulse is sent after a defined delay time (= reply delay) after a valid interrogation pulse has been received.

The "reply delay" of a DME ground station is an important parameter determining the accuracy of the distance measurement. For this reason, this delay time is continuously checked in the transponder by an internal monitor and an alarm is output immediately if an error is detected. However, it is also necessary to check regularly whether the alarm function of this monitoring system is responding correctly. For this purpose, the reply delay is varied and an external device checks the actual delay time when the alarm is triggered. Until now, at least one monitor output (detected output) of the DME ground station together with an oscilloscope has been used. Here there is always a risk of the reply delay being incorrectly measured due to errors at this monitor output.

2.4.4 Reply Efficiency

The "reply efficiency" of a DME system is the ratio of the number of sent pulses to the number of received interrogation pulses from aircraft.

A reply efficiency of 100 % is very rarely achieved since, as described below, there are several reasons why no reply pulse is sent for an interrogation pulse.

- Interrogation pulse occurs in the dead time (see above) of the receiver
→ The efficiency drops as the number of aircraft that are sending interrogation pulses to a ground station increases.
- Interrogation pulse occurs in the key down time of an ID sequence (see chapter 2.4.6)
→ The efficiency drops to 0 % during these times.
- Level of the interrogation pulse drops below the receiver sensitivity of the ground station
→ The efficiency drops dramatically when the maximum distance to the ground station is reached.

The reply efficiency is also often used as the limit for certain tests at the receiver.

When the receiver sensitivity is tested, the minimum input level for a reply efficiency of 70 %, for example, is checked (see chapter 3.4).

2.4.5 Squitter Pulses

If the average transmit pulse rate at a DME ground station drops to values below 700 pp/s (pp/s = pulse pairs per second) due to, for example, a low number of aircraft, the ground station adds random "squitter pulses" to ensure that a minimum pulse rate is provided. This minimum pulse rate is necessary in order to facilitate synchronization of the automatic gain control of an aircraft receiver to the signal of a ground station. Furthermore, the most important pulse parameters of a ground station (e.g. rise and fall time, pulse width and spacing, pulse delay and pulse peak power) are continuously monitored and adjusted by a "BITE" (BITE = Built-In Test Equipment) while the system is in operation. However, this monitoring and regulation loop only works correctly if there is an adequate number of test pulses.

These random squitter pulses are generated by an internal interrogator and fed to the receiver. There, these pulses are then processed in exactly the same way as pulse interrogations from aircraft.

The random distribution of the pulse spacing of the squitter pulses is specified in EUROCAE ED-54.

2.4.6 Identification Code

For identification purposes, a DME ground station transmits a morsed ID code (e.g. MUC for Munich) which is sent approx. every 40 seconds instead of the reply or squitter pulses. The letters are sent in Morse code as shown in the table below. (See also Figure 4)

ID morse codes			
Letter	Morse Code	Letter	Morse Code
A	. -	N	- .
B	- . . .	O	- - -
C	- . - .	P	. - - .
D	- . .	Q	- - . -
E	.	R	. - .
F	. . - .	S	. . .
G	- - .	T	-
H	U	. . -
I	. .	V	. . . -
J	. - - -	W	. - -
K	- . -	X	- . . -
L	. - . .	Y	- . - -
M	- -	Z	- - . .

Figure 3: Morse codes

The dot length is 100 ms and the dash length is 300 ms. The gap between two Morse characters is 100 ms and the gap between two Morse letters is 300 ms.

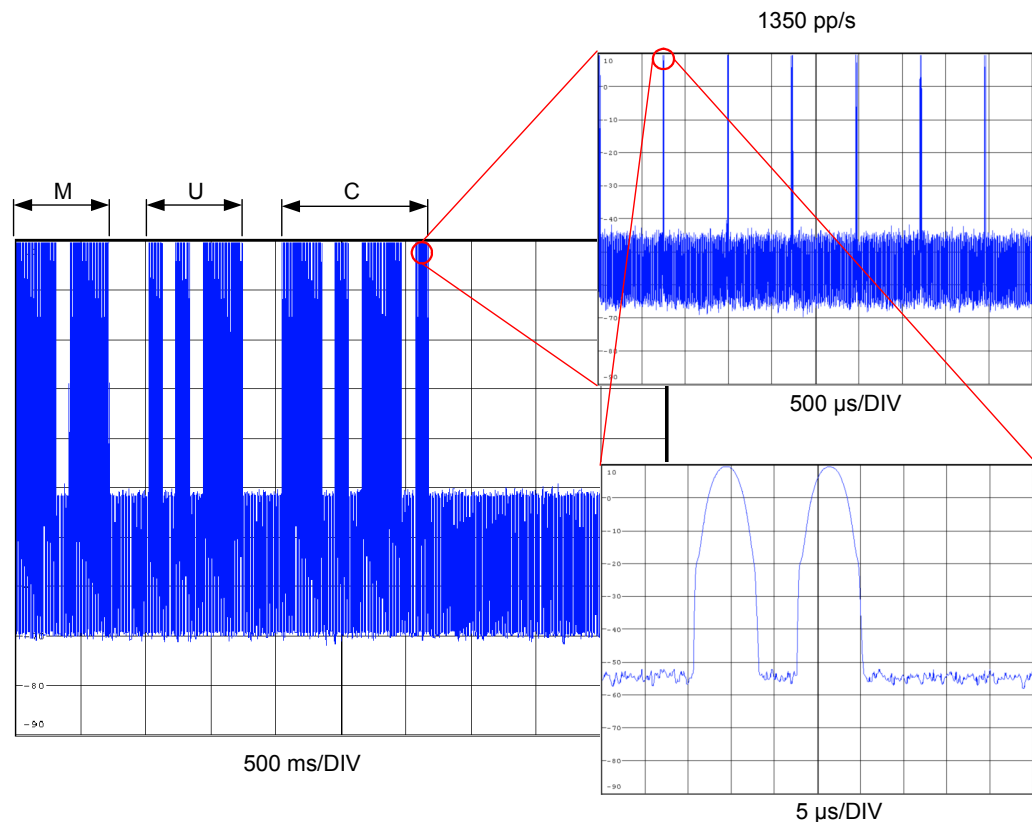


Figure 4: Example of ID code for MUC

Figure 4 shows an example of an ID sequence for the code MUC. To illustrate the sequence more clearly, the squitter, interrogation and reply pulses that are actually sent in the pauses have been omitted here.

Double pulses with a fixed pulse repetition rate of 1350 pp/s are sent during the dot or dash times. During these times, a station does not react to any interrogation pulses, which is why these times are also referred to as "key down times". Reply or squitter pulses are sent as normal between the key down times. An identification sequence must not be longer than 10 seconds and the key down time must not exceed 5 seconds.

2.4.7 Transmit Power

DME ground stations are divided into two power classes.

- "DME enroute transponders" with 1 kW pulse power are used for route navigation over large distances with a maximum range of approx. 200 NM (approx. 370 km)
- "DME terminal transponders" with 100 W pulse power are used for landing approach and therefore over short distances of up to 60 NM (approx. 110 km).

3 DME Analysis with R&S®SMA100A Signal Generator and R&S®NRP-Z81 Power Sensor

DOC 8071 Manual Testing of Radio Navigation Aids, Volume 1 from the ICAO [4] specifies all parameters of a DME station that have to be checked at regular intervals. A distinction is made between various intervals (3 months, 6 months or 12 months). Furthermore, the manufacturers of the DME systems and the operators of the station (i.e. usually the national air traffic control authorities) also specify additional parameters which have to be checked during these regular maintenance intervals.

As already mentioned above, most parameters of a DME station are currently only checked using one internal BITE (Built-In Test Equipment) or with the aid of monitor outputs that are provided by a DME station. A fault at these function blocks may therefore lead to false measurement results and can in extreme cases lead to malfunctioning of the system.

The R&S®SMA100A [5] signal generator, together with the directly connected R&S®NRP-Z81 [6] wideband power sensor, makes it possible to check the most important parameters of a DME ground station using external measuring instruments. For this purpose, the signal generator feeds its DME interrogation pulses via a coupler to the receiver of a DME ground station (as shown in Figure 5) and, using the power sensor, detects via an additional coupler the reply pulses sent from the transponder. The generator software analyzes the detected pulses and indicates the determined parameters in the display. This allows an aircraft interrogation to be simulated and the ground station's reply to this interrogation to be evaluated while the system is in operation.

The following parameters can be measured.

- Reply delay (system delay within the ground station)
- Reply efficiency (ratio of reply to interrogation pulses)
- Monitor alarm
- Pulse repetition rate of the ground station
- Pulse power of the transmit pulse
- Pulse shape (rise/fall time, pulse width and amplitude difference)
- Pulse spacing
- Receiver sensitivity
- Decoder function
- Receiver bandwidth

If a second R&S®SMA100A is available, the following parameters of a ground station can also be checked.

- Receiver recovery time
- Receiver sensitivity with load

As a result, it is possible to verify most DME transponder parameters specified in DOC 8071 using an external measuring instrument.

All of the measurements on a DME transponder which are described in this chapter can also be performed in exactly the same way on a TACAN ground station.

3.1 Measurement of Transponder Time Delay (Reply Delay) and Reply Efficiency

3.1.1 Test Setup for DME Analysis

The illustration below shows a possible setup for testing a DME transponder. This setup allows the DME parameters to be measured while the system is in normal operation. The individual steps for the DME analysis are described in chapter 3.1.2 with reference to the numbered items 1 to 5 shown in Figure 5.

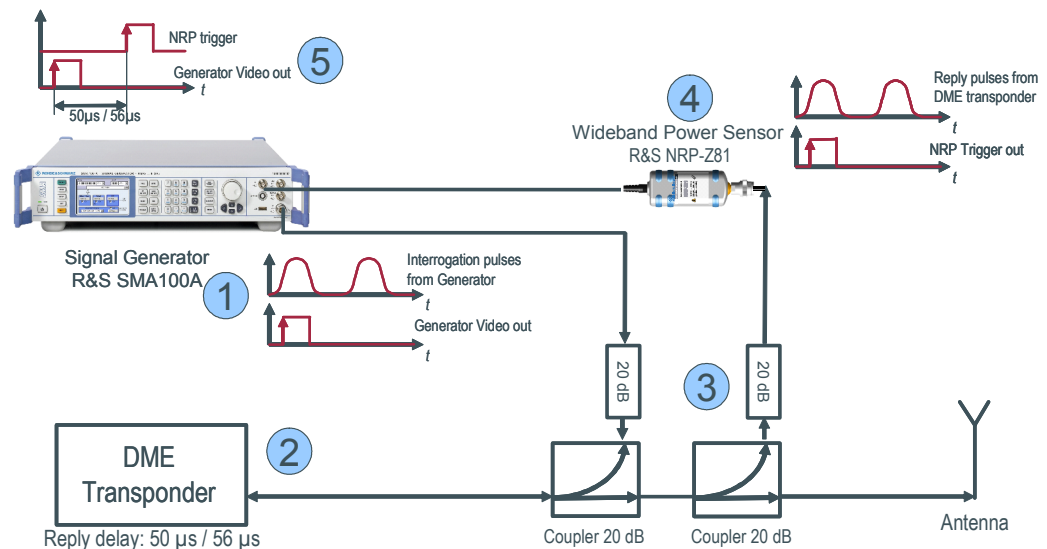


Figure 5: Test setup for DME analysis

The DME signal from the signal generator is fed to the DME ground station via an attenuator and a 20 dB directional coupler, thereby simulating the signal from an aircraft. A 2nd directional coupler decouples the signal sent by the ground station, and this signal is fed to the R&S®NRP-Z81 power sensor via an attenuator.

In order to minimize the effect of the cable between the coupler and antenna on the measurement result (see chapters 3.1.5 and 3.3.1), the directional couplers should be positioned as closely as possible to the antenna.

The attenuator protects the signal generator from the peak transmit power of up to 1 kW produced by the transponder. The coupling attenuation of the coupler (approx. 20 dB) and the 20 dB attenuator attenuate the transmit signal from the ground station by 40 dB and a maximum peak level of approx. +20 dBm is fed to the generator output, which does not pose a problem for the R&S®SMA100A. If higher peak powers are fed to the generator (e.g. as a result of an incorrect setup), the generator is protected by the built-in overvoltage protection for reverse power feeds of up to 50 W¹.

The same conditions also apply to the power decoupled to the power sensor, since the maximum decoupled power for a 1 kW system is approx. +20 dBm and therefore lies

¹ Applies to R&S®SMA100A with R&S®SMA-B103 or R&S®SMA-B106 options installed

within the measurement range for the R&S®NRP-Z81. If levels at the sensor are above +20 dBm, an additional 6 dB attenuator should be used.

3.1.2 Sequence of Steps of DME Analysis

At the beginning of the measurement sequence, the signal generator and power sensor are put in a defined state, the DME modulation is switched on and the peak pulse level of the transmitted pulses of the transponder are measured first using the power sensor. Ten measurements are taken and the average of these ten measurements is checked to establish whether it is within the permissible level window of -13 dBm to +20 dBm. Furthermore, the level difference between the maximum and minimum measured level is checked to establish whether it is below 0.2 dB. If one of the two conditions is not met, an error message or warning is output. The power sensor is then set to a special trigger mode and the trigger threshold is set to 50 % of the measured pulse voltage amplitude. In this mode, the power sensor delivers trigger pulses in realtime when the applied RF voltage exceeds the set trigger threshold. This process of setting the trigger threshold is performed once at the start of each measurement sequence (see chapter 3.1.3).

The basic DME analysis procedure within a measurement sequence is explained below with reference to Figure 5. Steps 1 to 5 are repeated according to the set number of measurements (= measurement count).

- 1) The signal generator generates an interrogation pulse pair and outputs this at the RF output. At the same time, an internal video signal is generated which is active within the pulse width (= 50 % of amplitude value) of the 1st pulse and starts a delay time measurement counter in the generator. Figure 6 below shows the time characteristics of the two signals.

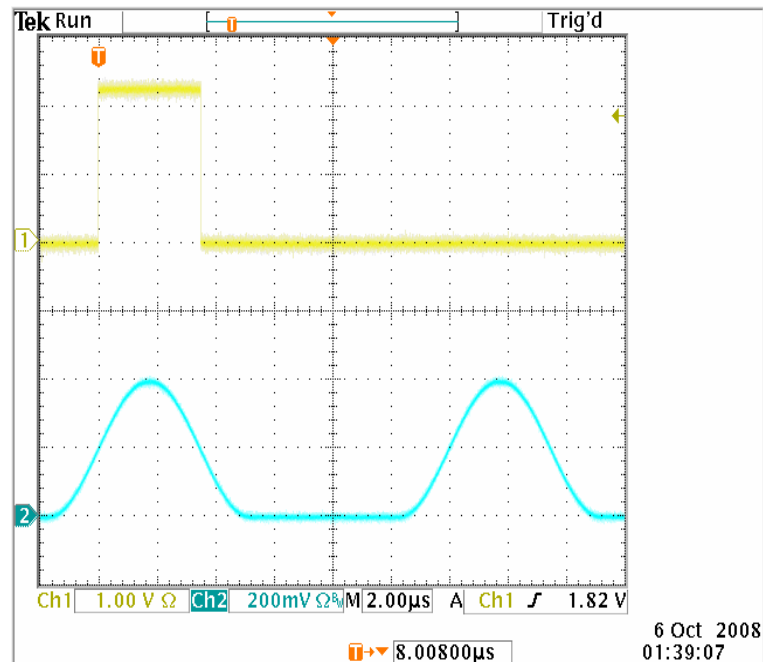


Figure 6: DME signals at SMA100A signal generator

Trace 1: Video signal

Trace 2: DME signal at RF output (rectified with detector)

- 2) The interrogation pulse pair is received by the DME transponder and a reply pulse pair is transmitted with a delay of 50 μs (X channel) or 56 μs (Y channel).
- 3) A second directional coupler decouples part of the power of the reply pulse pair from the transponder, and this power is fed to the R&S®NRP-Z81 wideband power sensor.
- 4) The decoupled reply pulse pair is received and detected at the power sensor. A trigger pulse is generated when the 50 % threshold of the rising pulse edge of the 1st pulse is reached, and is fed to the R&S®SMA100A signal generator via a dedicated trigger line.
- 5) The trigger pulse from the power sensor stops the counter for delay time measurement.

At the end of the measurement sequence, the counter in the generator is reconfigured and used as a pulse counter which counts all trigger pulses from the power sensor over a certain period of time. This is used to calculate the pulse rate of the DME transponder (see chapter 3.2). If necessary, pulse rate measurement can be disabled, thereby reducing the time required for a measurement sequence and for updating the other measurement values (peak power, reply delay and reply efficiency).

The measurement results are then calculated and shown in the generator display (see Figure 7).

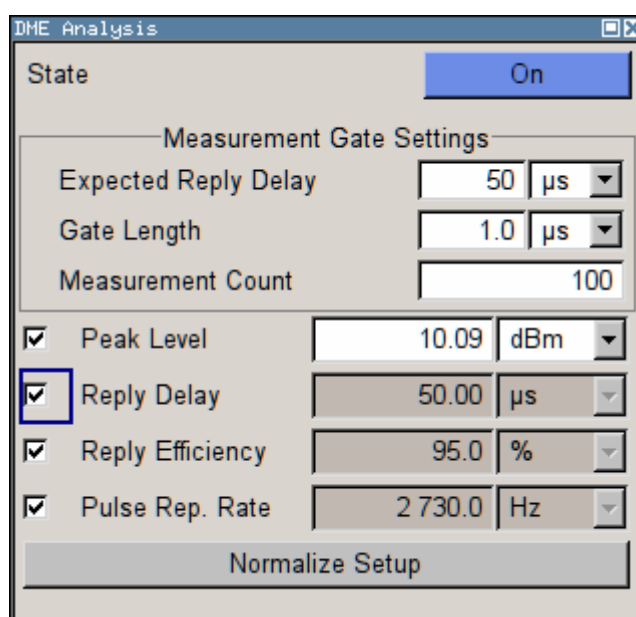


Figure 7: Display of measurement values in DME Analysis menu

The transponder time delay (reply delay) must also be checked with various receiver input levels. For some tests DOC 8071 requires a level range from the receiver threshold up to 80 dB higher.

To be able to set the level at the receiver input precisely, the attenuation of the setup between the generator and receiver input must be determined beforehand in the way described in chapter 3.4.2.

3.1.3 Measurement Window and Measurement Sequence

In order to filter out the correct reply pulses to the sent interrogations from the large number of received pulses (squitter pulses, ID pulses, reply pulses for other aircraft), it is necessary to define a measurement window inside which a valid reply pulse must lie. The settings for window length (= gate length) and the expected delay time (= expected reply delay) in the user interface of the generator define a measurement window within which a reply pulse from a ground station must lie in order to be used as a valid pulse for the measurement.

The expected reply delay must therefore always be identical to the system delay, i.e. 50 μs for a station that operates in the X channel and 56 μs for a DME station that operates in the Y channel.

The gate length is set to 1 μs by default as this setting covers the permissible delay time tolerance of $\pm 0.5 \mu\text{s}$.

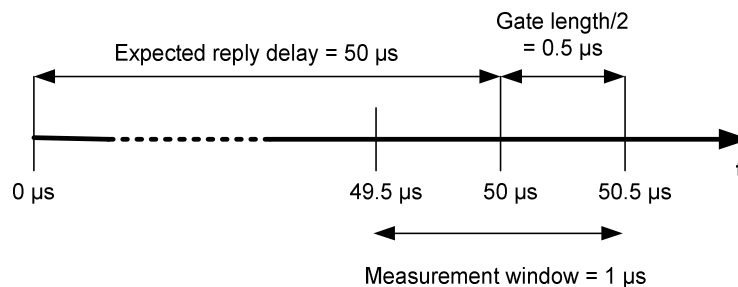


Figure 8: Diagram showing measurement window

The third parameter for defining the measurement window specifies the number of measurements (= measurement count) per measurement sequence and is set to 100 measurements by default. This means that the R&S®SMA100A sends 100 pulses to the DME ground station during each measurement sequence and filters out the valid pulses within the measurement window from all received pulses and from this calculates the delay time and efficiency of the system. The system delay is determined by calculating the average from the number of valid measurements.

The reply efficiency is determined by calculating the ratio of the number of valid pulses to the number of supplied interrogation pulses per measurement sequence.

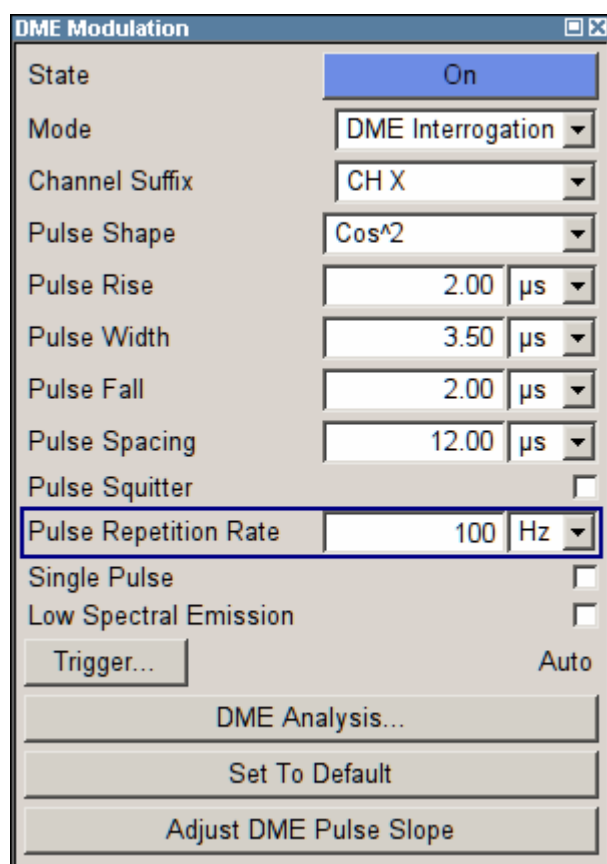


Figure 9: DME menu for setting interrogator parameters

The pulse repetition rate of the interrogator pulses supplied from the R&S®SMA100A can be varied in the DME menu of the generator (see Figure 9) from 10 Hz to 6 kHz. To prevent an increased measurement time for a measurement cycle (100 measurements by default), it is recommended to select a value of approx. 100 Hz (unless a different value is mentioned). A measurement sequence with these settings then takes exactly 1 second. If the pulse repetition rate is also measured, this measurement adds an additional second to the total measurement time.

By varying the measurement window, it is also possible to check the stability of the system delay. To do so, the expected reply delay is first set to the currently measured system delay value, e.g. 50.1 µs, and then the measurement window is continuously narrowed until the efficiency drops. If, for example, this is the case for a gate length of < 500 ns, this means that the system delay fluctuates by more than ±250 ns.

3.1.4 Normalization of Test Setup

With the configuration shown in Figure 10, the test setup must be normalized before starting the measurement by executing "Normalize Setup" in the DME Analysis menu (see Figure 7). The correction factor for the delay time measurement is then determined automatically using a software algorithm and stored.

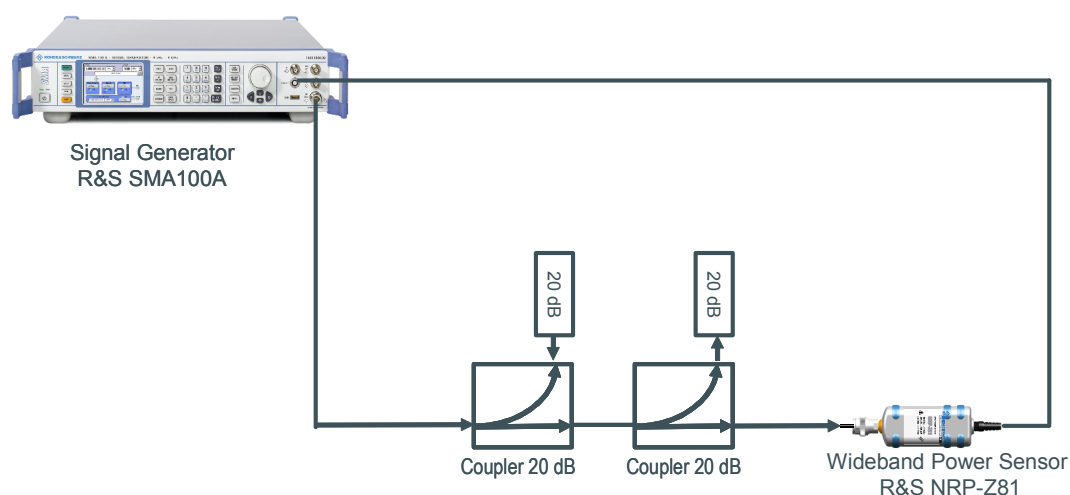


Figure 10: Normalization of test setup

With this test setup, the internal propagation time and delays of the components involved are measured and then taken into consideration when the reply delay is calculated.

This compensates the following errors:

- Delay between 50 % RF amplitude of generator RF signal and rising edge of generator video signal
- Signal propagation time for DME RF pulse from generator to directional coupler
- Delay between rising edge of trigger signal of power sensor and 50 % RF amplitude of received pulse
- Propagation time of trigger signal between power sensor and generator
- Delay time in generator between sensor trigger input and stop signal for delay time measurement counter

3.1.5 Correction of Cable Propagation Time

With the reply delay measurement, it is important to note that the propagation time of the signal in the cable between coupler and antenna for the setup shown in Figure 5 is not measured and therefore the measurement value must be corrected by adding the double antenna-to-coupler cable propagation time. The propagation time must be added twice: once for the signal received by the aircraft (propagation time from antenna to coupler) and again for the signal sent to the aircraft (propagation time from coupler to antenna). Typically the cable length is approx. 5 m to 10 m, whereby the (double) propagation time for a cable measuring 10 m in length will be approx. 100 ns. The propagation time of the cable can be determined using measuring instruments [7] or, if the length and cable type is known, can be calculated using the following formula.

$$\Delta t = \frac{l \cdot \sqrt{\epsilon_r}}{c}$$

where:

Δt :	Signal propagation time (one direction)
l :	Mechanical length of cable
ϵ_r :	Relative dielectric constant of cable e.g. 2.25 for Polyethylene or 2.1 for Teflon
c :	Speed of light = $3 \cdot 10^8$ m/s

3.1.6 Checking Monitor Alarm

As described in chapter 2.4.3, the delay time of a DME station is monitored continuously while the system is in operation, and an alarm is triggered if an error occurs. This alarm function can be checked using the setup described above by adjusting the system delay of the station until the alarm is triggered, and then checking the actual delay time at the point of alarm triggering using the R&S®SMA100A. For this test, the system-internal limit at which the monitor alarm is triggered must be set independently of the set transponder time delay. The alarm would otherwise not trigger if there is a variation in delay time.

3.2 Measurement of Pulse Repetition Rate

3.2.1 Test Setup

See Figure 5

3.2.2 Measurement Procedure

Measurement of the pulse repetition rate is a separate measurement routine which is performed alternately with measurement of the other parameters (peak level, reply delay and reply efficiency). During this measurement, the power sensor is operated in a "trigger mode" (see chapter 3.1.2) in which the sensor generates a trigger signal each time a pulse that is greater than the trigger level is detected. The trigger level is redetermined for each measurement sequence and is set to 6 dB below the measured peak level. To prevent a DME double pulse from being counted as two pulses, the dropout time of the power sensor is set to 40 μ s. This means that with pulses that lie within an interval of 40 μ s only the first pulse supplies a trigger pulse. All other pulses within this dropout time do not deliver a trigger signal and, therefore, are not counted. Since the dead time of 60 μ s (see chapter 2.4.2) means that the DME pulses have a gap of at least 60 μ s, none of the pulses from the ground station are ignored. In the signal generator, all trigger pulses generated by the power sensor within one second of measurement time are counted and this count is used to calculate the pulse repetition rate.

If the pulse repetition rate only is to be measured, it is recommended to disable the other measurements as then the pulse repetition rate measurement will be updated more quickly.

3.3 Measurement of Transmit Power, Pulse Shape and Pulse Spacing

3.3.1 Test Setup

As described in chapter 2.4.7, DME stations can have a transmit power of 100 W or 1 kW. The setup shown in Figure 5 can be used to measure the transmit power of both system types.

The transmit power of a DME system is measured continuously during operation by a detector located at the input of the antenna directly and regulated in the station. This means that, for example, the cable attenuation between the DME station and transmit antenna or the transmission loss of the two directional couplers shown in the setup in Figure 5 is compensated and the DME system must deliver correspondingly more power. For this reason, the transmit power should not be measured directly at the output of the DME station for this measurement, but instead as closely as possible to the antenna. The transmit power at the output of the last directional coupler is determined by gathering the correction value as described below.

3.3.2 Determining Correction Value for Measurement of Transmit Power

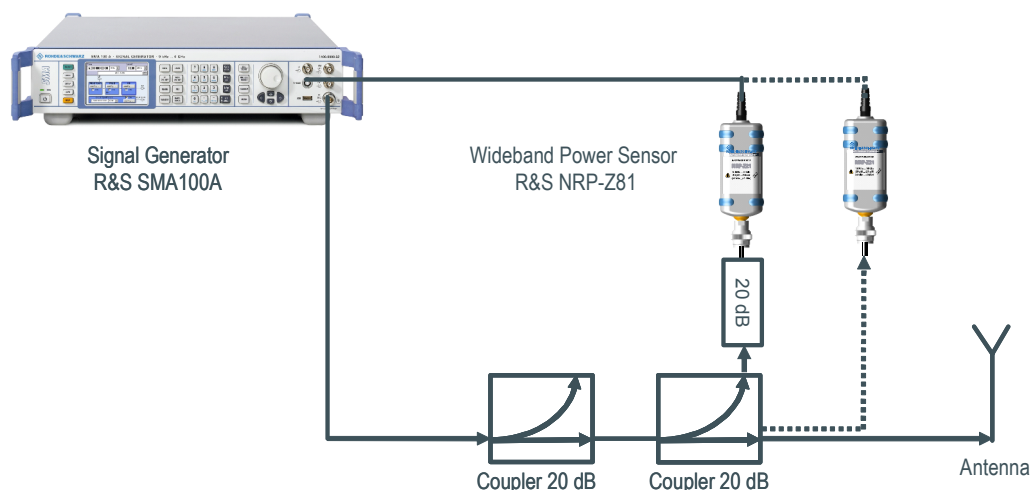


Figure 11: Setup for determining coupler attenuation when measuring transmit power

To be able to determine the transmit power at the antenna, the coupling attenuation of the directional coupler as well as the attenuation of the 20 dB attenuator must be determined beforehand. For this purpose, the R&S®SMA100A feeds a CW signal (as shown in Figure 11) to the directional couplers, and the level at the output of the 20 dB attenuator following the 2nd directional coupler is measured, whereby the antenna must be connected to the through path of the directional coupler during this measurement. The power sensor must then be connected in place of the antenna so that the attenuation on the transmit path can be determined. The difference between these two measurement levels now serves as the correction factor between the power measured via the directional coupler and 20 dB attenuator, and the actual transmit power of the system.

Since the attenuation between the generator and receiver is approx. 40 dB and the dynamic range of the R&S®NRP-Z81 power sensor is higher for CW signals than for pulsed DME signals, it is recommended to perform this measurement using a CW signal with a high level at the generator (e.g. +18 dBm). The transmit frequency of the DME transponder should be selected as measurement frequency.

Example:

To determine the correction value, R&S®SMA100A feeds +18 dBm to the directional couplers.

Level at output of directional coupler + 20 dB attenuator	-22.5 dBm
Level at through path of directional coupler	+17.6 dBm
Correction factor for measurement of transmit power	+40.1 dB

Table 3: Example showing determination of correction value

3.3.3 Measurement Procedure

The transmit power can be measured with the R&S®SMA100A in three different ways.

3.3.3.1 Measurement in DME Analysis Menu

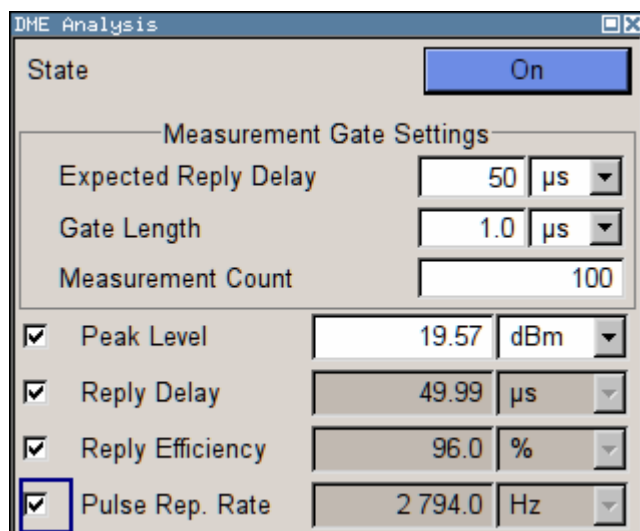


Figure 12: Measurement of transmit power in DME Analysis menu

The DME Analysis menu (see Figure 12) displays the peak power measured at the power sensor. The peak power reading is the average of 10 consecutive peak power measurements. The set RF frequency of the signal generator which, however, is always offset by 63 MHz relative to the transmit frequency of the DME station is used as the correction value for frequency response correction of the power sensor (see chapter 2.3). The resulting systematic measurement error is typically some hundredths of a dB and can therefore usually be disregarded. In order to determine the transmit power of the DME station, the correction factor for the attenuation of the test setup (determined above) must now be included in the calculations.

Example:

Level at output of directional coupler + 20 dB attenuator	+19.57 dBm
Correction factor for measurement of transmit power	+40.1 dB
Calculated transmit power of DME station	59.67 dBm = 927 W

Table 4: Determination of transmit power

At the same time, this menu also shows the values for system delay (reply delay), reply efficiency and pulse repetition rate.

3.3.3.2 Measurement Using NRP-Z Power Viewer

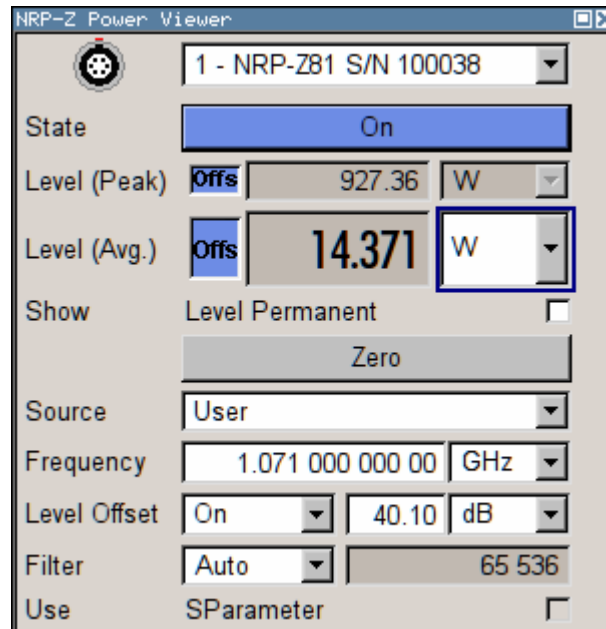


Figure 13: Measurement of transmit power in DME Analysis menu

Measurement of the power using the NRP-Z Power Viewer menu (as shown in Figure 13) allows the correction value to be included automatically as the Level Offset (e.g. 40.1 dB) and the power average (Level Avg.) to be displayed in addition to the peak power level (Level Peak) in watts. If "User" is selected in the menu item "Source", the transmit frequency of the DME station can be entered in the "Frequency" field. The exact frequency response correction value for the power sensor is then used for the measurement.

If necessary, the number of averages can be adapted in the menu item "Filter", whereby the "Auto" mode usually provides the best compromise between measurement time and measurement accuracy.

3.3.3.3 Measurement of Transmit Power and Pulse Shape with SMA-K28 NRP-Z Power Analysis Option

The R&S®SMA-K28 NRP-Z power analysis option allows to display and evaluate the pulse power envelope versus time graphically. The pulse peak power of both DME pulses can be determined by use of two measurement gates, as shown in Figure 14. A gated power measurement provides more accurate and stable results compared to a measurement using markers, since the complete trace within the gate is evaluated for the measurement. Therefore the maximum peak power is measured correctly as long as the pulse peak falls within the defined gate.

In contrast, if the pulse peak power is measured by use of a marker, the power is determined at the position of the marker only, and therefore the result may vary strongly if e.g. the signal is noisy or the timing of the pulse changes slightly due to a variation of the trigger point.

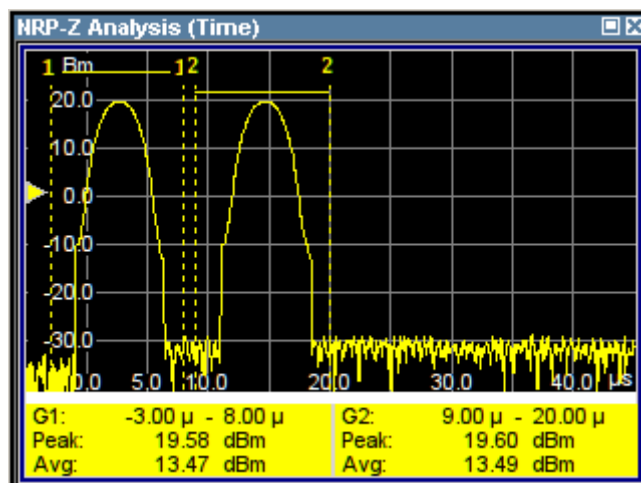


Figure 14: Measurement of transmit power of both pulses using gate mode

Furthermore it is possible to determine the level difference of two consecutive pulses exactly, by use of two measurement gates.

In order to verify the pulse shape of a DME pulse, the R&S®SMA-K28 option is able to analyze all required pulse parameters automatically.

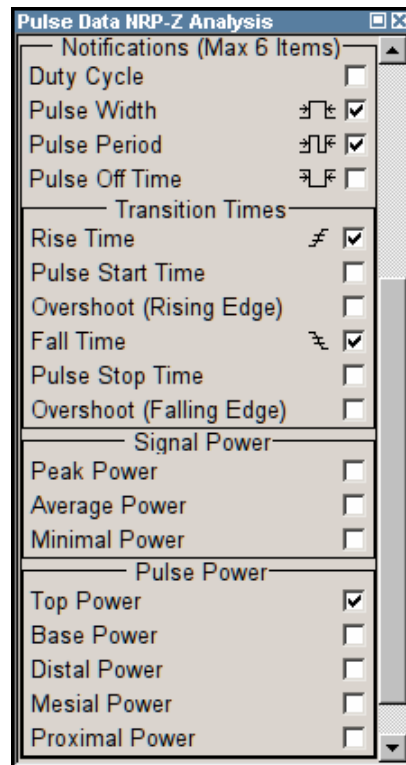


Figure 15: Selection of pulse parameters for pulse analysis

It is possible to select up to 6 parameters, which are reported in the display as shown in Figure 16.

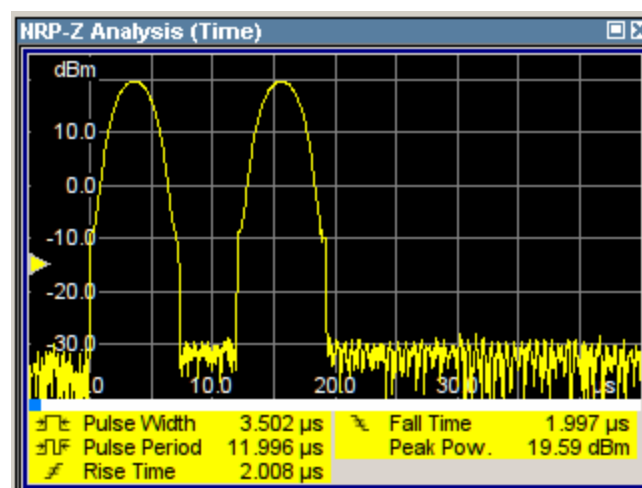


Figure 16: Analysis of pulse parameters

3.4 Measurement of Receiver Sensitivity

3.4.1 Test Setup

See Figure 5

A typical DME transponder is specified for a input level range from -95 dBm to 0 dBm, whereby an efficiency of 70 % is usually guaranteed for the minimum specified level (= receiver sensitivity). The test setup shown in Figure 5 can be used to test a level range from approx. -160 dBm to -20 dBm in cases where the attenuation of the coupler and attenuator have been determined as shown in Figure 17 below.

If the receiver sensitivity is also to be determined for levels above -20 dBm, the 20 dB attenuator between the generator and directional coupler must be replaced by a 20 dB isolator (e.g. JCC0962T1213N15 from JQL), otherwise the output level of the R&S®SMA100A would not be high enough. The isolator has a transmission loss of approx. 0.5 dB in forward direction (s21) and an isolation of approx. 20 dB in reverse direction (s12). Thus the generator is protected sufficiently against the transmit power of the DME transponder, but can feed its signals into the test setup with minimum attenuation. With an output power of approx. +21 dBm from the signal generator, the receiver sensitivity can then be tested for input level up to 0 dBm. Since at this high output power the R&S®SMA100A is operated approximately 3 dB above its specified maximum level, the determination of correction values described in chapter 3.4.2 should also be performed with this high output level. This second correction value must then be taken into consideration at high output powers above 18 dBm.

As a result, it is possible to measure the receiver sensitivity with high accuracy across a wide dynamic range.

3.4.2 Correction Values for Receiver Sensitivity Measurement

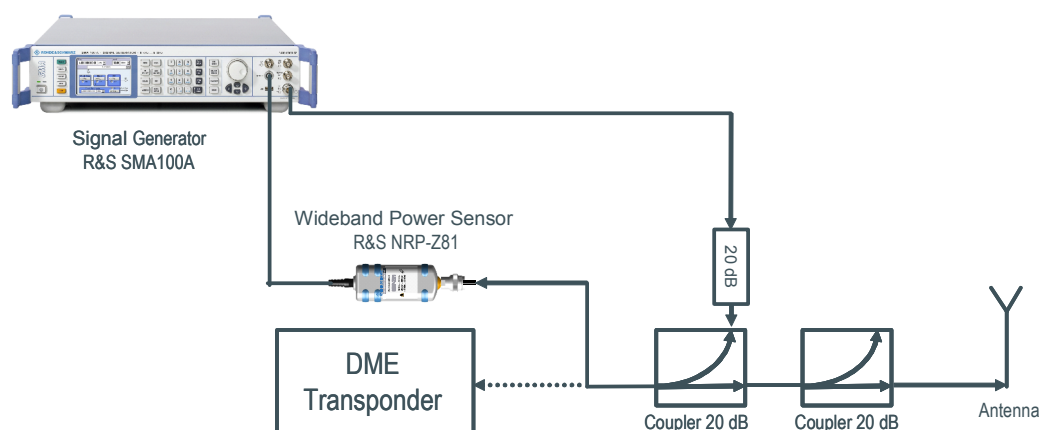


Figure 17: Setup for determining coupler attenuation when measuring receiver sensitivity

In order to take the attenuation of the setup into consideration correctly for a receiver sensitivity measurement, the attenuation of the path from the generator output to the DME receiver input must be determined using the setup shown in Figure 17.

1. Connect the sensor directly to the signal generator and measure the power.
2. Connect the signal generator to the coupler output using a cable and a 20 dB attenuator/isolator and measure the power at the output of the cable normally connected to the DME receiver input (see the setup in Figure 17).
3. The difference between the two measurements gives the attenuation between the generator output level and receiver input level.

As already described in chapter 3.3.2, determination of correction values should also be performed with a CW signal of, for example, +18 dBm. The receive frequency of the DME station should be used as measurement frequency.

The 20 dB attenuator at the output of the generator eliminates level errors due to incorrect matching between generator and DME transponder.

3.4.3 Measurement Procedure

The measurement procedure is identical to the procedure for measuring the transponder time delay and efficiency described under 3.1. The level at the generator is, however, reduced until the receiver is operated at its minimum specified input level (e.g. -95 dBm). In this state, the efficiency is measured and checked to establish whether it exceeds the permissible limit (e.g. >70 %).

3.4.4 Decoder Test

As a further test scenario, DOC 8071 prescribes testing of the decoder that checks the pulse spacing of the interrogation pulses. For this purpose, the sensitivity of the receiver is measured while the pulse spacing of the interrogation pulse is varied. The following three test cases are mentioned in DOC 8071.

- a) The receiver sensitivity must not change in the case of a shift in pulse spacing of interrogation signal of up to 0.4 μs .
- b) The sensitivity is permitted to drop by max. 1 dB in the case of shift in pulse spacing of interrogation signal between 0.5 μs to 1 μs .
- c) No reply should be sent for a interrogation signal which has a pulse spacing that deviates from the nominal value by more than 2 μs .

These scenarios can be tested very simply using the R&S®SMA100A since the pulse spacing of the DME pulses can be varied in the operating menu over a wide range at a resolution of 20 ns and the receiver sensitivity can be measured simultaneously as described above.

3.5 Measurement of Receiver Bandwidth

In order to check the receiver bandwidth of a DME transponder, the receiver sensitivity must be determined as described in chapter 3.3 for two test cases.

- a) The frequency at the R&S®SMA100A is varied by ± 100 kHz from the nominal receive frequency, thereby determining the reduction in input sensitivity.
- b) The frequency at the R&S®SMA100A is varied by ± 900 kHz from the nominal receive frequency and the level at the DME receiver input is set to 80 dB above the minimum receiver threshold (e.g. -15 dBm). The efficiency is measured in this case and must be below the required limit of, for example, 3 %, i.e. the DME station must not transmit any replies to these interrogations.

To be able to perform this measurement using the setup shown in Figure 5, the 20 dB attenuator between generator and directional coupler (as described in chapter 3.4.1) must be replaced by a 20 dB isolator, otherwise the output level of the R&S®SMA100A may not be high enough. With such a setup, an output power of approximately +6 dBm from the signal generator is sufficient for this test.

3.6 Extended DME Analysis Using Two R&S®SMA100A Signal Generators

If two R&S®SMA100A signal generators are available, the setup shown in Figure 18 can be used to test further scenarios at a DME transponder. The receiver sensitivity variation with load can be measured as well as the receiver recovery time.

3.6.1 Test Setup for Extended DME Analysis

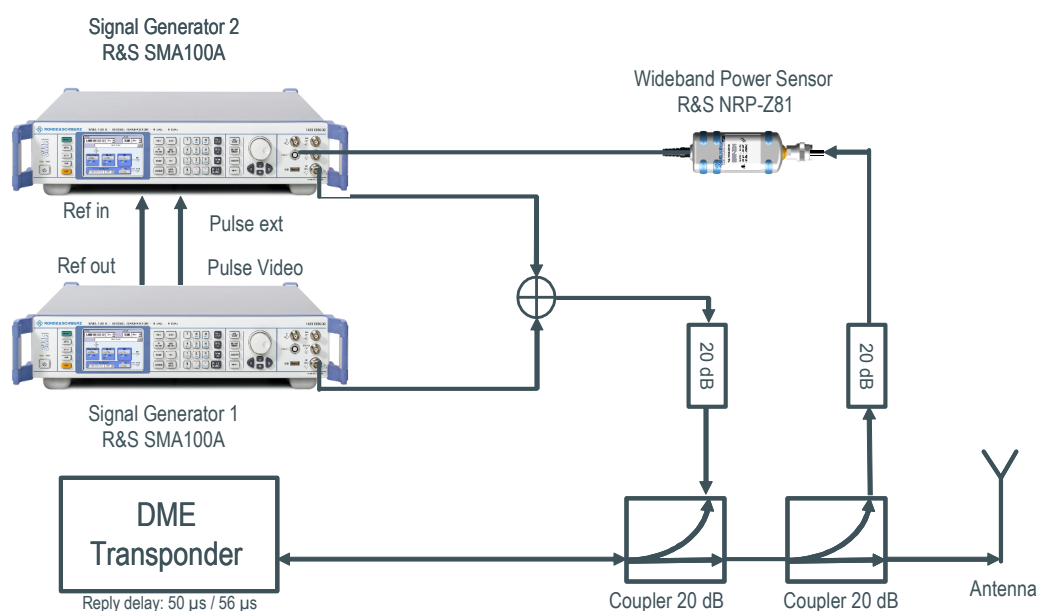


Figure 18: Test setup with two R&S®SMA100A signal generators for extended DME analysis

A second signal generator is added to the setup shown in Figure 5 by using a power combiner and the sum signal is applied to the DME transponder.

The two signal generators are each set to the receive frequency of the DME station and are synchronized with each other by means of the 10 MHz reference signal. To enable triggering, the Pulse Video output of generator 1 must be connected to the Pulse External input of generator 2.

3.6.2 Measurement of Receiver Sensitivity Variation With Load

For this measurement, the receiver sensitivity variation of a DME transponder is checked with the maximum specified load (= number of interrogation pulses). To generate a random sequence of interrogation pulses, generator 1 applies randomly distributed squitter pulses to the DME transponder. For this test the rate of squitter pulses is set to 90 % of the maximum specified load of the DME station (e.g. 3500 pp/s).

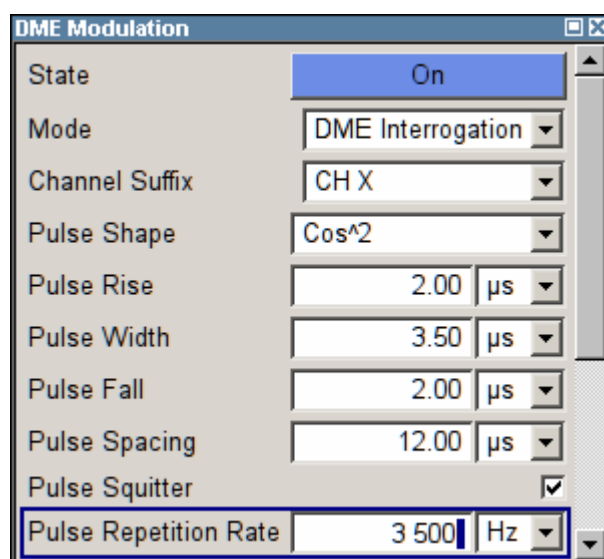


Figure 19: Settings for Squitter mode at generator 1

If only one R&S®SMA100A signal generator is available, the internal BITE squitter generator of the transponder can also be used to generate the external load (interrogation pulses) and to feed it to the receiver.

Generator 2 applies DME pulses with a rate of approximately 40 Hz to the DME transponder and the receiver sensitivity can be determined as described in chapter 3.4. The specification of the DME transponder can be verified very easily, using this external test equipment.

3.6.3 Measurement of Receiver Recovery Time

With this test, the receiver sensitivity is checked with an invalid pulse (e.g. single pulse) which arrives at the receiver up to 8 μs before the valid interrogation pulse pair. In such a case, the level of the invalid pulse is permitted to be up to 60 dB above the receiver threshold. The loss in sensitivity for this scenario must be less than 3 dB.

For this test, both generators are operated in the DME interrogator mode, whereby generator 1 generates an invalid single pulse with a level 60 dB higher than the receiver threshold, and applies this pulse to the DME station.

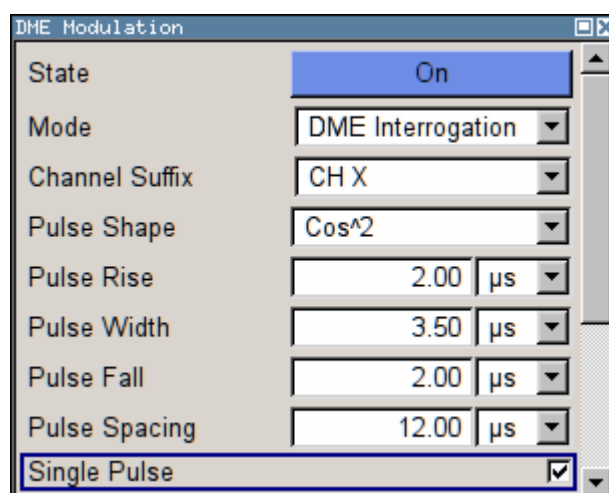


Figure 20: "Single Pulse" setting on generator 1

Generator 2 is operated with external triggering and a trigger delay of 8 μs (see Figure 21), sends valid DME pulse pairs to the station and measures the efficiency of the transponder. By varying the level of generator 2, the receiver sensitivity of the DME transponder is verified as described in chapter 3.4.

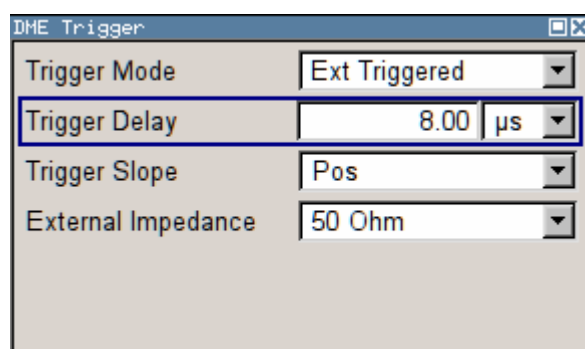


Figure 21: "Trigger Delay" setting on generator 2

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- [7] Application Note 1EF52_0E "Testing Mobile Radio Antenna Systems Using R&S®FSH
http://www2.rohde-schwarz.com/file_1535/1EF52_0E.pdf

5 Ordering Information

Signal Generator	R&S®SMA100A	1400.0000.02
RF Path 9 kHz to 3 GHz with electronic attenuator	R&S®SMA-B103	1405.0209.02
DME Modulation	R&S®SMA-K26	1405.3408.02
Power Analysis	R&S®SMA-K28	1405.3950.02
Wideband Power Sensor	R&S®NRP-Z81	1137.9009.02

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Regional contact

Europe, Africa, Middle East

+49 1805 12 42 42* or +49 89 4129 137 74

customersupport@rohde-schwarz.com

North America

1-888-TEST-RSA (1-888-837-8772)

customer.support@rsa.rohde-schwarz.com

Latin America

+1-410-910-7988

customersupport.la@rohde-schwarz.com

Asia/Pacific

+65 65 13 04 88

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ROHDE & SCHWARZ GmbH & Co. KG

Mühlendorfstrasse 15 | D - 81671 München, Germany

Phone + 49 89 4129 - 0 | Fax + 49 89 4129 - 13777

www.rohde-schwarz.com