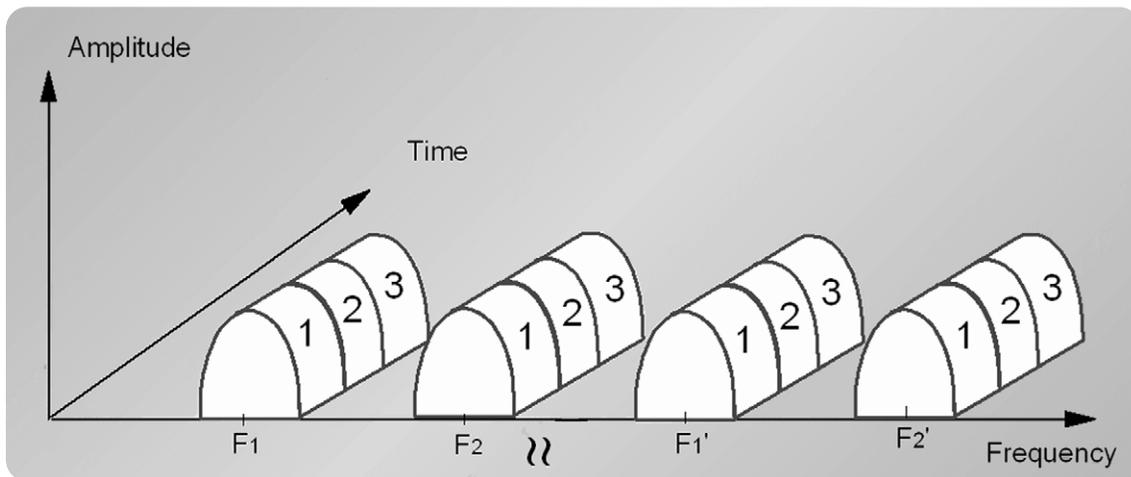


# Agilent Technologies Understanding PDC and NADC Transmitter Measurements for Base Transceiver Stations and Mobile Stations

Application Note 1324



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## **1. Introduction**

This application note describes the key RF parametric measurements necessary to characterize PDC (Personal Digital Cellular) and NADC (North American Digital Cellular) transmitters in both Base Transceiver Stations (BTS) and Mobile Stations (MS). New test instruments are making these measurements easier to perform, faster and more precise.

This paper is meant to enhance the reader's understanding of the requirements of PDC and NADC transmitter RF parametric tests. It is also intended to be a useful reference for engineers in research and development, manufacturing, quality assurance, and field service. However, some modification and optimization of the information provided may be needed to meet the specific requirements of each of these areas.

For each measurement, examples of setup, method, and specification limits are given. These have been derived from the ARIB and EIA/TIA standards.<sup>1</sup>

**1. See Glossary for the meaning of these acronyms**

## Measurement challenges

Digital Cellular and PCS (Personal Communication System) are two of the most popular systems now in use for wireless mobile communications.

One of the major access techniques used to share the available bandwidth is TDMA (Time Division Multiple Access) which was established in the early 90's. In Japan, PDC has grown rapidly. In the United States, the auction of the 1.9 to 2.0 GHz frequency band triggered the popularity of NADC and PCS.

The following factors have accelerated the expansion of PDC and PCS:

### Technical progress

– low-cost, small, and smart MS

### New services

– e-mail, answering service, packet-data

### Strategy of operators

– promotion campaigns, lower charges

### Subscriber desires

– high mobility

The rapid increase in mobile station users has created capacity problems, especially for major metropolitan areas. However, TDMA technology helps reduce these problems.

The analog cellular system allowed only one user per frequency channel (Figure 1a). TDMA systems, however, can permit three users to simultaneously share one channel in the normal operation mode (Figure 1b).

Furthermore, in the higher-capacity mode (Figure 1c), six users can simultaneously use one frequency channel.

In TDMA systems, a BTS sends individual data in different time slots for each MS, using a continuous transmission.

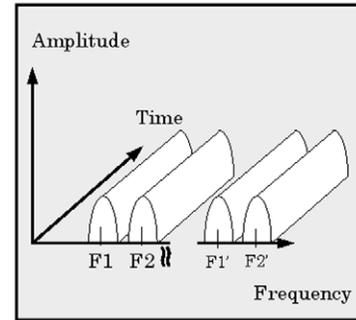
Also, each MS transmits a bursted carrier in a different time slot than other MSs at the same frequency.

The TDMA system has adopted the  $\pi/4$ DQPSK digital modulation format. This is fundamentally different from the techniques used in the analog system, and can provide more information capability, such as more capacity, digital data services, higher data and voice security, and overall better quality communications.

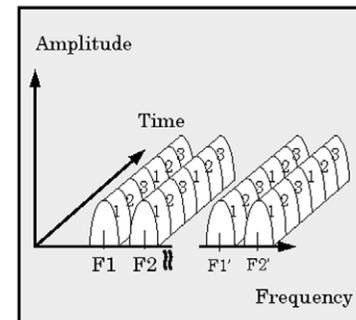
The migration to digital systems has created transmitter testing challenges for the wireless industry. Service providers and network equipment manufacturers (NEMs) converting to digital must use new RF parametric measurement techniques to test the performance of their digital BTS and MS. Test instruments must have higher measurement speed, better accuracy, and more flexibility to adequately test the performance levels of TDMA transmitters. For instance, it is necessary that a transmitter tester have the following new functions:

- Trigger for pulsed carrier
- Carrier power versus time analysis
- Modulation accuracy analysis.

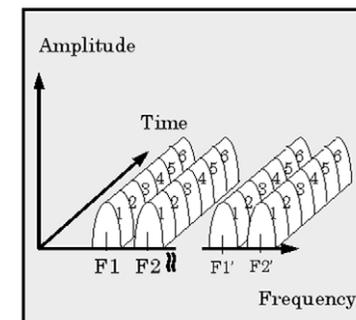
Chapter 2 describes these functions in detail.



1a. Analog



1b. Full rate



1c. Half rate

Figure 1. (a) Analog systems allow only one user per channel. (b) TDMA systems in normal mode allow three simultaneous users. (c) TDMA systems in high-capacity mode permit six simultaneous users.

## Origin of measurements

NADC and PDC transmitter (and other) measurements originate from the following ARIB, TIA and EIA standards.

- ARIB, Association of Radio Industries Businesses, which publishes ARIB RCR STD-27: Personal Digital Cellular Telecommunication System RCR Standard.
- TIA (Telecommunication Industry Association)
- EIA (Electric Industries Association), which publishes:

-TIA/EIA-628 (also called Interim Standard IS-137): 800 MHz Cellular System, TDMA Radio Interface Performance Standards for Dual-Mode Mobile Stations.

-TIA/EIA-629 (also called Interim Standard IS-138): 800 MHz Cellular System, TDMA Radio Interface Performance Standards for Base Stations Supporting Dual-Mode Mobile Stations.

It is worth noting that these standards were written for the purposes of full type approval and are, therefore, extensive. In most application areas, it is not practical to make the whole suite of measurements.

In manufacturing, for example, where throughput and cost are key drivers it is typical to use a subset of the measurements defined in these standards. Optimization is the key here; the objective is to test sufficiently to prove correct assembly, ensure calibration and assure correct field operation, with a minimum expense.

## 2. RF Parametric Transmitter Measurements in PDC and NADC

This chapter describes key RF parametric tests for PDC and NADC transmitter measurements on BTS and MS.

There are three basic categories of measurements for TDMA systems:

1. Power. These measurements check the power in the transmission channel and any power that may be leaking into alternate channels.

To measure the bursted carrier of an MS, instruments need to have a trigger function to properly acquire the burst. Examples are: power versus time, Adjacent Channel Power (ACP), and Occupied Bandwidth (OBW).

2. Power with respect to time. These measurements confirm that each burst in the channel is correctly timed and does not interfere with other bursts. Examples are power versus time and Carrier-Off Power (COP).

3. Error Vector Magnitude (EVM). This measures the modulation quality of the signal.

The block diagram of a typical TDMA MS transmitter is shown in Figure 2.

The operation of this transmitter can be briefly described as follows:

- The vocoder digitizes the user's voice, and the channel coder generates the complete data stream for the cellular system.
- The modulator consists of a digital filter, digital to analog converter (DAC), and I/Q modulator.
- A digital filter (a root Nyquist filter) minimizes the spectrum spreading caused by digital modulation.
- The modulated signal is generated by the I/Q modulation as I and Q data.
- An Upconverter shifts the output frequency to the desired channel.
- An Upconverter shifts the output frequency to the desired channel.

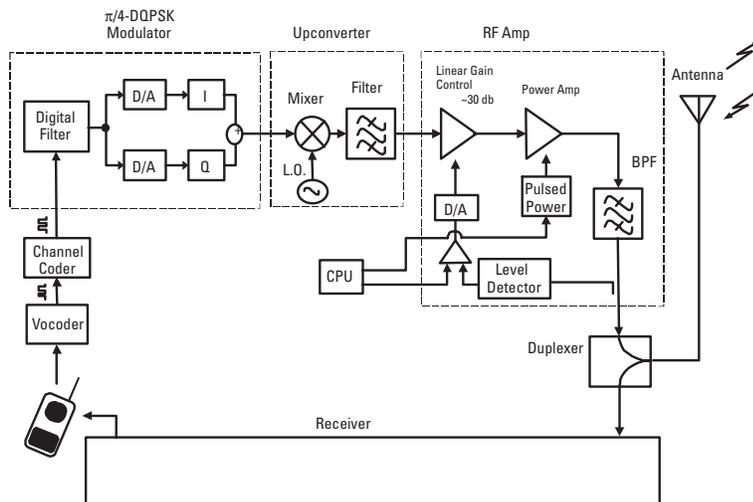


Figure 2. MS transmitter block diagram

## RF Parametric Transmitter Measurements in PDC and NADC (continued)

The RF signal is amplified by the RF Amp. (The MS has a more complicated control circuit than the BTS in this section to realize the burst carrier correctly.)

- The RF signal goes through a bandpass filter before being radiated by the antenna.

The BTS transmitter differs from the MS transmitter in two respects:

1. It has only an ON/OFF function in the RF Amp, instead of bursted power.
2. Several signals (channels) are often combined before being applied to the output amplifier.

The parametric measurements described in the next chapter are affected by specific transmitter components, as shown in Table 1.

**Table 1. Transmitter components and related measurements**

<b>Component</b>	<b>Related measurements</b>
Digital filter	ACP
I/Q modulator	EVM, OBW
Amplifiers	Carrier power, ACP
Pulsed power & gain controls	Power versus time, COP

## **Carrier power**

### **Purpose of measurement**

Output power in the specified time interval is a fundamental characteristic of a TDMA transmitter and is linked directly to its operation range. PDC and NADC systems have the capability for dynamic power control (up to 28 dB in the case of MS in the highest power class) to ensure that each link is maintained sufficiently with a minimum of power. This feature gives two fundamental benefits: 1) it keeps overall system interference at a minimum and 2) it maximizes MS battery life.

The output power level of BTS transmitters is usually entrusted to service providers, but in some cases the maximum output power may be regulated. Adoption of output power control for base stations is generally at the discretion of service providers. The output power of a base station transmitter is usually set to the optimized level corresponding to cell allocation to keep sufficient communication quality within a cell and minimize interference with other cells. A mobile station transmitter typically has output power control capability in 4 dB steps, and its power level is controlled by a linked base station to maintain the link with minimum power consumption by the mobile station.

The output power of each transmitter has to be controlled within tight limits. If a transmitter produces too little power, link performance is compromised. On the other hand, if too much power is produced, interference with others may be too high, and battery life of the MS is shortened. BTS receivers are easily saturated by excessive power from nearby mobile stations.

Practical transmitter implementations (especially for mobile stations) require output power calibration in manufacturing to meet PDC and NADC specifications. This calibration process involves the construction of a table of calibration factors for power steps and frequencies. Power calibration, which is now done with an automated measurement and adjustment system, corrects for the effects of component variation.

Out-of-specification power measurements indicate a fault, usually in the power amplifier and filter circuitry, the carrier/local oscillator circuitry or the calibration table mentioned below. They can also give early indication of a fault with the power supply (in the case of mobile stations, the battery).

### Specifications for maximum power and attenuation control

The BTS transmitter under test is set for continuous transmission, and the data field of the RF carrier must be modulated with a pseudo-random test signal that has a 511-bit code length (PN9 / CCITT-O.153) for all of time slots.

The specifications for maximum power and attenuation control for PDC base station transmitters are shown in Table 2.

**Table 2. PDC BTS specifications**

Maximum power	Power control level	Control error
Not specified	0 dB, -4 dB, -8 dB	+2 dB, -4 dB

The specifications for NADC base station transmitters are given in Table 3.

**Table 3. NADC BTS specifications**

Maximum power	Power control level	Control error
Not specified	Not specified	+1 dB, -3 dB

The MS transmitter under test is set for repetitive transmission. That means it must be set to repeatedly transmit a burst of the RF carrier modulated with PN9 for a specific time slot. The PN9 modulation is set for the user information transfer channel under test. Output power of mobile stations is defined as the average power over the period of a specified transmission burst. The specifications for PDC mobile stations are shown in Table 4.

**Table 4. PDC MS Specifications**

MS class	Max. output power	Power control range (in 4 dB steps)	Control accuracy
1	3.0 W	0 dB to -28 dB	+2 dB, -4 dB (except 0 dB)
2	2.0 W	0 dB to -24 dB	
3	0.8 W	0 dB to -20 dB	
4	0.3 W	0 dB to -16 dB	

Each maximum output power shall be within +20% and -50% of the specified value. Table 5 has specifications for NADC mobile stations. Because all mobile stations and most base stations implement dynamic power control, it is necessary to make multiple power measurements at several power levels and several carrier frequencies to test for proper operation.

**Table 5. NADC MS specifications**

MS class	Max. output power	Power control range (in 4 dB steps)	Control accuracy
1	+6 dBW (4.0 W)	0 dB to -28 dB	+2 dB, -4 dB
2	+2 dBW (1.6 W)	0 dB to -24 dB	
3	-2 dBW (0.6 W)	0 dB to -20 dB	
4	-2 dBW (0.6 W)	0 dB to -16 dB	± 3 dB * ± 6 dB * ± 9 dB *
		-24 dB * -28 dB * -32 dB *	

\* for the dual mode only

## Practical measurements

### BTS output power measurement

The output power measurement of PDC and NADC base station transmitters is relatively easy because BTS transmitters under test are set for continuous transmission—unlike mobile stations, which repeatedly transmit a burst of the RF carrier in a specific time slot. PDC and NADC base station transmitter power measurements are done in a traditional way, except for setting up the units under test to transmit PN9 data.

In practice, several different types of test equipment can be used to make power measurements on PDC and NADC base station transmitters. Accuracy, linearity and repeatability are important, and the measurement performance depends on the power level measured. Either a peak power meter with diode detectors, or an average power meter with diode detectors or thermal sensors can be used, with the traditional attention to potential error. It is also possible to use conventional spectrum analyzers for this measurement, although the measurement uncertainty of spectrum analyzers is usually a bit greater than that of average power meters. (see Figure 3).

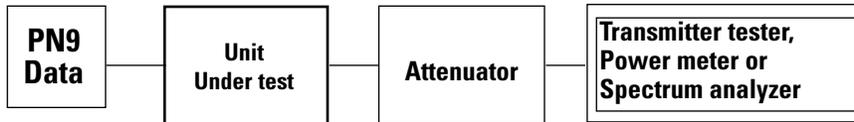


Figure 3. BTS output power measurement setup

Some modern transmitter testers, suitable for R&D, manufacturing, installation, and maintenance of base stations, can make this power measurement easily and accurately at a high speed. Sophisticated digital signal processing with wide-dynamic-range analog-to-digital converters enhances the power measurement accuracy of a modern transmitter tester, providing accuracy close to that of a power meter (see Figure 4).

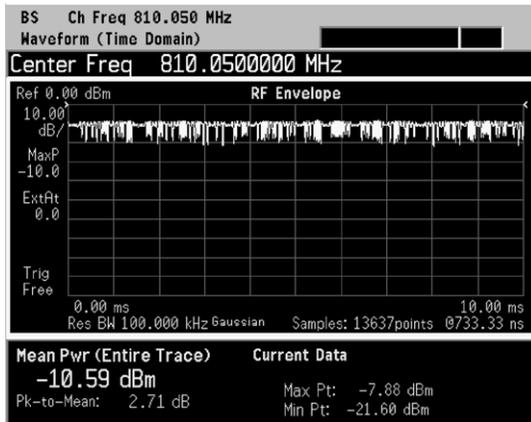


Figure 4. Output power measured by a modern transmitter tester

Power meters or spectrum analyzers (or equivalent testers) are used in free running mode, since the unit under test generates a continuous transmission signal. Sweep time (or data acquisition time) is usually set to about 10 msec or longer to capture at least one time slot of the PN9-modulated signal, so that power measurements can be made with minimum uncertainty.

It should be noted that power measurements are extremely vulnerable to impedance mismatch. Some modern test equipment offers internal attenuation to help minimize errors caused by impedance mismatch.

## MS output power measurement

If conventional average power meters or spectrum analyzers without gated triggering are used for MS output power measurement, careful treatment of the measurement results is required, since an MS transmits carrier bursts as mentioned above. Any measurement results with power meters or equivalents that indicate average power during the measurement period do not correspond to the actual power during the burst period.

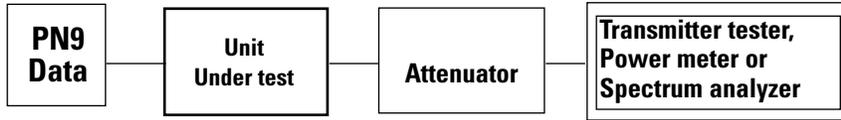


Figure 5. MS output power measurement setup

The average value of repetitive burst power ( $P_m$ ) must be measured for a sufficiently long time (longer than the response time of the power meter) by the power meter. Average power during a burst period ( $P$ ) is calculated from the burst length  $B$  (6.52 msec for PDC, 6.46 msec for NADC) and the burst repetitive period,  $T$  (20 msec for a full-rate system and 40 msec for a half-rate system):  $P = P_m * (T/B)$ . Therefore, if the actual  $T/B$  is different from the assumed  $T/B$ , the power measurement uncertainty will be large (see Figure 6).

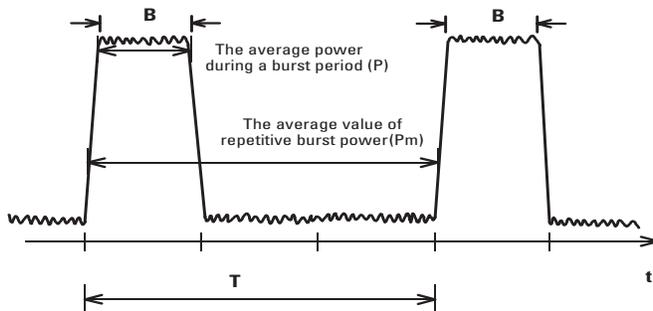


Figure 6. Burst power explanation

Because PDC and NADC MS use digital modulation and carrier bursts, their transmitters should be set up to transmit data field bits filled up with data. The test instrument should capture the burst-on portion of the output signal, then calculate the average power from its sample points using the time-domain mode (similar to spectrum analyzer's zero-span mode).

Some modern test instruments can acquire and hold all waveform information for the specified time interval and calculate power during the user's desired period by post data processing at a significantly high speed. The display example shown in Figure 7 indicates accurate power measurement results corresponding to one focused burst period with sufficient time resolution.

As in the case of BTS output power measurements, it is important that the test instrument plus external pads and cables provide an accurate  $50 \Omega$  load to the device under test.

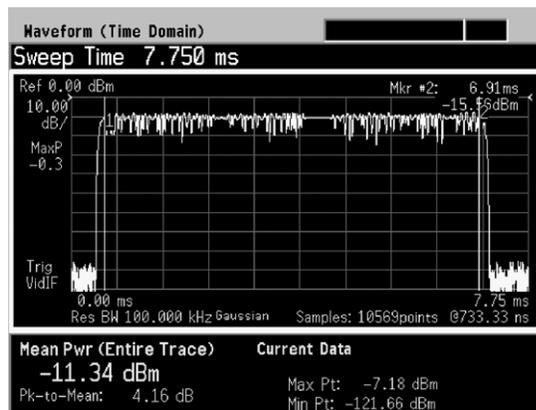


Figure 7. Output power measurement using transmitter tester's waveform mode

## When the measurement is used

Output power measurements are normally performed in every phase of BTS and MS lifecycles. Accuracy, linearity and repeatability requirements are typically more stringent in R&D and less stringent in installation and maintenance. Measurement speed and repeatability are key in manufacturing, where power calibration at multiple points is required and cost reduction is always a consideration.

Maximum output power depends on the gain of the output amplifier, filter shape, the efficiency of the upconverter, the oscillators' signal levels and the I/Q modulator performance (see Figure 8). Burst timing depends on the pulse-shaping (switching) function and timing of the baseband control clock. Well-designed circuitry, which has small drift with environmental changes and is less sensitive to component variation, can reduce power-level calibration points significantly in high-volume manufacturing. However, PDC and NADC mobile stations in mature manufacturing need many power calibration points to cover all nominal power levels (specified by standards) at three carrier frequencies; at a minimum, middle, low-end and high-end points are required within the allowed frequency band. Modern test equipment can make these measurements rapidly and accurately.

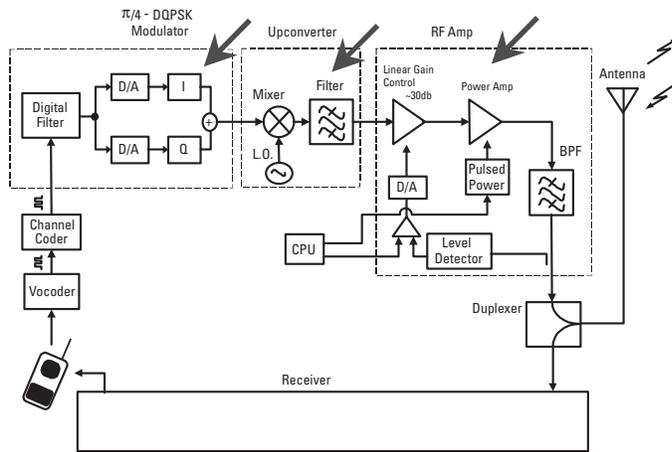


Figure 8. Transmitter components that determine maximum output power

## Adjacent Channel Power (ACP)

### Purpose of measurements

The  $\pi/4$ DQPSK modulation process in PDC and NADC transmitters causes the continuous-wave carrier to spread spectrally, creating the potential for interference with other channels. Spectrum generation due to rapid switching of MS power is another potential source of interference. Spectral re-growth due to intermodulation in the power amplifier is a third cause of degraded adjacent channel power performance. Since PDC and NADC systems use Frequency Division Multiple Access (FDMA) in addition to Time Division Multiple Access (TDMA), it is necessary to ensure that unwanted spectrum due to modulation, switching and excessive system noise floor does not produce interference with other user channels at different frequencies located near the frequency of the channel being used. Adjacent Channel Power (ACP) measurements are made at several adjacent channels to verify that unwanted spectrum is lower than specifications, so that no user can experience significant interference from others.

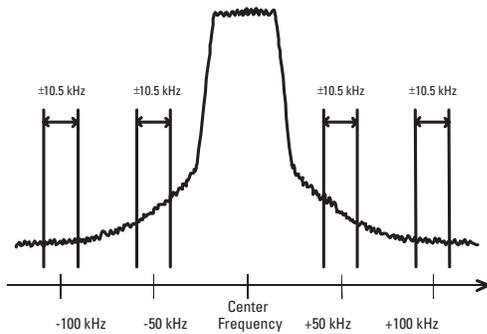
This measurement can reveal many faults in the transmit chain, such as malfunctions of baseband circuitry (code generator, digital filter, digital-to-analog converters, 90-degree phase shifter, and I/Q modulators), high phase noise of oscillators, or an excessive wide-band noise floor of an upconverter, output amplifier or analog filter. The last two faults are the result of poor analog performance.

**Definition and specifications for ACP**

For PDC transmitters, ACP (or adjacent channel interference power, or adjacent channel leakage power) is defined as the average power that is conducted within a bandwidth of  $\pm 10.5$  kHz, where the center frequency of the bandwidth is separated by a specified offset frequency from the focused carrier frequency under the condition that the focused carrier is modulated with PN9 at the same data rate as in actual operation (see Figure 9). ACP specifications are the same for both BTS and MS. ACP values are expressed relative to the carrier power value, which should be measured as described above.

**Table 6. ACP specifications for PDC BTS and MS**

Offset frequency	ACP limit
+50 kHz, -50 kHz	$\leq 45$ dB
+100 kHz, -100 kHz	$\leq 60$ dB

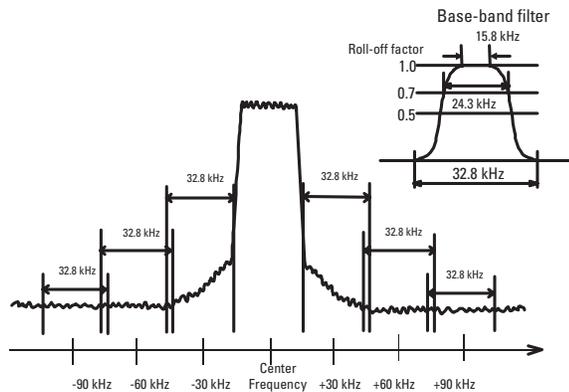


**Figure 9. PDC ACP**

For NADC transmitters, ACP is defined as the average power radiated within a bandwidth of 32.8 kHz at the specified frequency offset, where the test instrument uses the baseband filter (see Figure 10). The focused carrier must be modulated with PN9.

**Table 7. ACP specifications for NADC BTS and MS**

Offset frequency	ACP limit BTS	ACP limit (MS)
+30 kHz, -30 kHz	$\leq 26$ dB	$\leq 26$ dB
+60 kHz, -60 kHz	$\leq 45$ dB	$\leq 45$ dB
+90 kHz, -90 kHz	$\leq 45$ dB or $\leq 13$ dBm (BTS $\leq 50$ W) $\leq 60$ dB (BTS $> 50$ W)	$\leq 45$ dB or $\leq 13$ dB



**Figure 10. NADC ACP**

Except for two points that are defined with absolute power values (in dBm), ACP results should be expressed relative to the mean output power value, which must be determined with the carrier power measurement described above.

## Practical measurements

The measurement of out-of-channel spectrum due to modulation and excessive noise floor can be time consuming if made precisely as standards documents require. Often, some subset of the defined measurement set is performed in most applications for time and cost reasons. However, some modern test instruments can measure ACP exactly as defined in technical standards or type approval specifications much faster than conventional methods, and at a reasonable cost.

The procedure for measuring ACP by the DSP method is:

1. Set UUT to transmit PN9 data.
2. Set UUT amplitude.
3. Set triggering signal bursts.
4. Measure carrier power.
5. Measure ACP at offset frequencies.

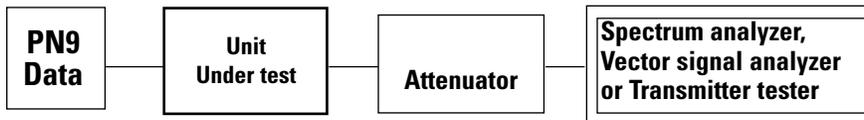


Figure 11. ACP measurement setup

Table 8. Comparison of traditional and DSP methods for measuring ACP

Measurement method	Advantage	Disadvantage
Standard method with conventional spectrum analyzers	Excellent dynamic range	Slow and tedious Calculation software
Modern DSP method	Fast and easy; Calculation software is usually embedded	Good dynamic range

For both PDC and NADC, set up the Unit Under Test (UUT) to transmit its maximum output power with data field bits filled up by the pseudorandom data.

The modern transmitter tester has a one-button measurement function. This function first measures the average power of the carrier frequency, then measures each adjacent or alternate channel by shifting the center frequency.

The transmitter tester makes rapid, highly accurate and consistent ACP measurements using the Fast Fourier Transform (FFT) (see Figure 12). Each measurement takes only a few seconds. This speed contributes to high throughput for equipment manufacturers.

Some transmitter testers have a bar graph display capability. This makes it easier for a user to see adjustment results in real-time (see Figure 13). The display shows both the ACP values of each adjacent/alternative channel relative to the carrier and the absolute values (dBm). A "Fail" message will be displayed if the result exceeds the test limits.

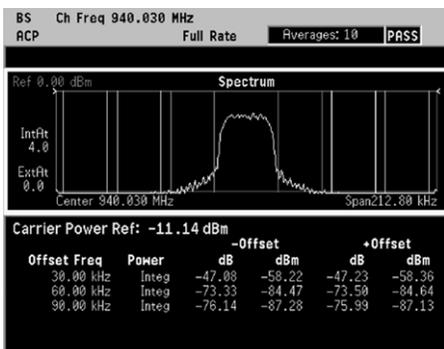


Figure 12. ACP measurement by transmitter tester

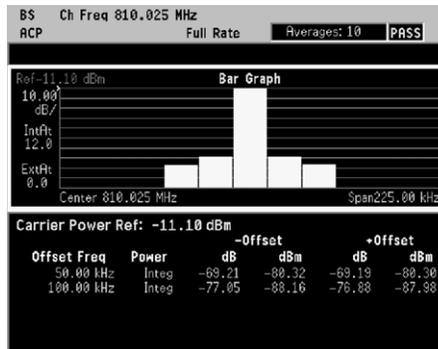


Figure 13. Bar graph display of ACP

### When the measurement is used

Because of the importance of this measurement, ACP must be measured at almost every stage of a transmitter's life cycle, especially for a BTS. Also, equipment must pass the type approval test before being introduced to the market.

The key factor affecting ACP performance is the efficiency of the Digital Filter (root Nyquist filter) in the  $\pi/4$  DQPSK modulator section (see Figure 14). If this filter doesn't work well or is incorrectly designed, undesired spectrum will be spread to adjacent or alternate channels.

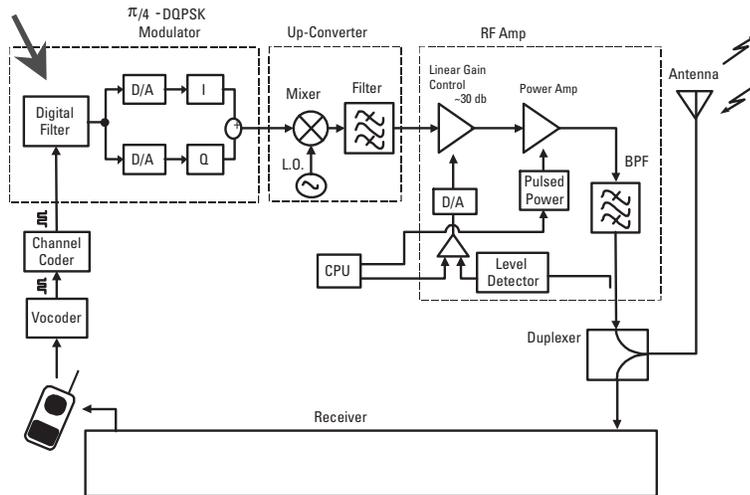


Figure 14. Digital filter efficiency is the key factor in ACP

If an ACP value exceeds the specification, the cellular system will have interference problems. Therefore, ACP measurements are critical for R&D. They are also important at the final test stage in MS manufacturing and QA, since equipment is transferred from manufacturers to service providers after this point.

Service providers typically perform two types of MS tests: a go/no-go test that doesn't check ACP, and a test similar to that of a final production test that does check ACP.

## Occupied Bandwidth

### Purpose of measurement

Occupied Bandwidth (OBW), or permissible occupied frequency bandwidth, is an alternative parameter to ACP. Both parameters indicate how much a transmitter will interfere with users in other channels. OBW is specified only for PDC (in RCR STD-27).

### OBW specifications for PDC

OBW is the frequency bandwidth corresponding to 99% of the total power. It is determined from the formula  $OBW=f_2-f_1$ , where  $f_1$  is the lower-edge frequency below which 0.5% of the total power remains, and  $f_2$  is the higher-edge frequency above which 0.5% of the total power also remains (see Figure 15). The OBW specification for PDC is 32 kHz for both BTS and MS.

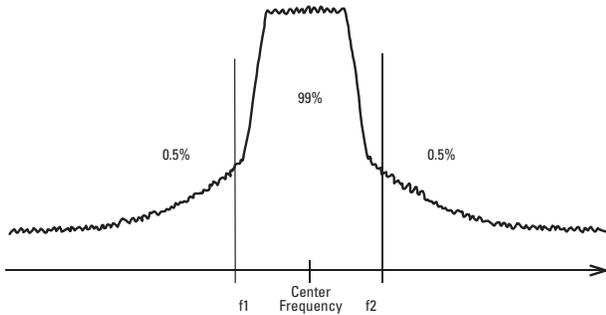


Figure 15. PDC OBW explanation

### Practical measurements

The measurement setup for OBW is the same as for ACP (see Figure 16). When a conventional spectrum analyzer is used for the measurement, the resolution bandwidth and the video bandwidth are recommended to be set at 1 kHz or less, and the input power level of the spectrum analyzer must be 50 dB or more above the instrument noise floor.



Figure 16. OBW measurement setup

Current transmitter testers and some spectrum analyzers have a “one-button” function for measuring OBW. Figure 17 shows the result of this measurement on a transmitter tester. The display shows the OBW value (in kHz) and total power value (in dBm). A “Fail” message is displayed if the result exceeds the test limit.

The procedure for measuring OBW is as follows:

Set up the UUT to transmit its maximum output power with its data field bits filled up by the pseudorandom data. Set the center frequency to the carrier frequency and the span to 100 kHz. Measure the total power. From the total power, calculate the lower-edge 0.5% frequency point ( $f_1$ ) and the upper-edge 0.5% frequency point ( $f_2$ ). The difference,  $f_2 - f_1$  is the OBW value.

If your instrument has a one-button OBW function, use it to find OBW.

### When the measurement is used

Like ACP, OBW is measured for type approval testing and final production testing to ensure that interference between users on different channels is minimized.

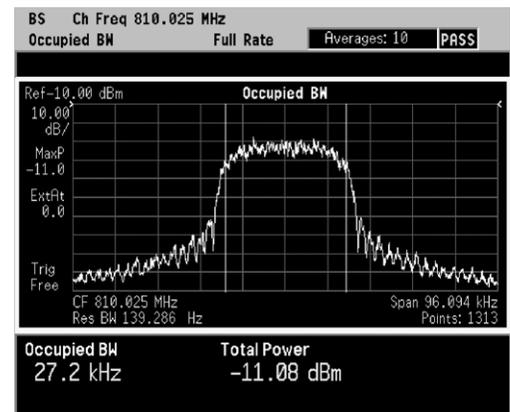


Figure 17. One-button OBW measurement

## Power versus time

### Purpose of measurement

The power versus time measurement is only applicable to mobile stations. Since TDMA BTS output is a continuous transmission, a power versus time measurement is not required.

A TDMA system mobile station is assigned to one of the transmission time slots shared in the time domain with other mobile stations within one channel frequency allocation. The RCR-27 and TIA/EIA-627 standards regulate the time response characteristics of transmitted power. The objective of these regulations is to insure the mobile station's transmitted RF signal does not disturb other mobile stations by restricting the time-domain signal output envelope within the regulated transmission power pattern. If a time response exceeds the boundaries of the regulated time pattern, it will interfere with the user of the adjacent time slot. If a time response is narrower than the regulated pattern, the communication data will be degraded.

Power ramp-up time and power fall time should also be within the regulated power pattern. If the response time is too fast, it will cause the frequency spectrum to spread. This will increase the ACP. If the response time is too slow, it will also result in the violation of the regulated pattern, causing data degradation.

Both RCR-27 and TIA/EIA-628 regulate the power-off level not to exceed -60 dBm. This leads to the requirement that a mobile radio should have an on/off ratio greater than 80 dB. This is challenging to achieve at frequencies higher than 800 MHz. Satisfying the on/off ratio requirement while maintaining adequate rise/fall times is a challenge for both R&D and manufacturing. A combination of DC power supply control of the transmitter power amplifier, RF power control of the pre-power amplifier stage and I/Q control of the baseband stage are used to obtain this high on/off ratio (see Figure 18).

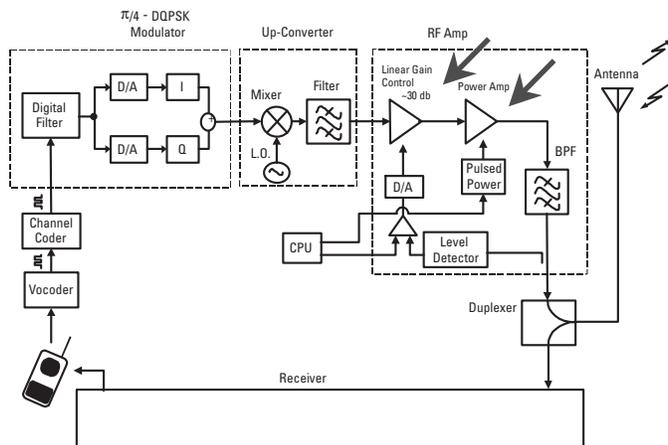
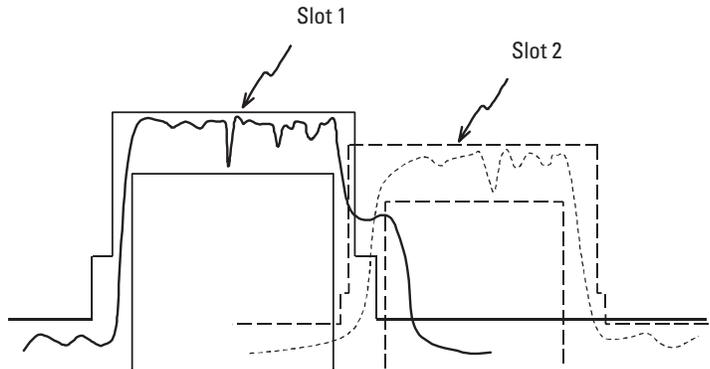


Figure 18. Control of the RF power is essential for maintaining a high on/off ratio

**Purpose of measurement (continued)**

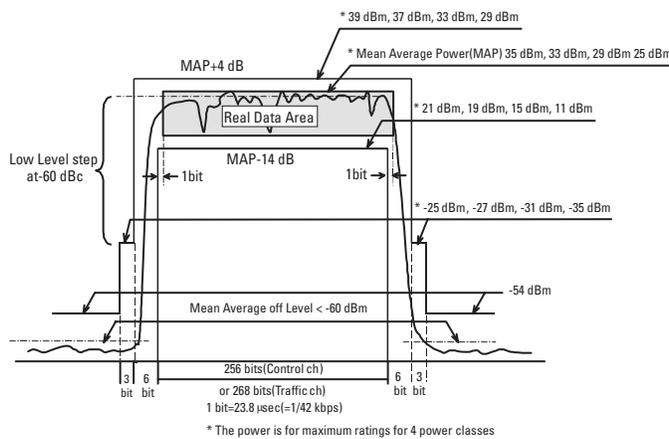
Smooth power ramp-up and fall at the maximum power shoulder areas will produce the minimum frequency spectrum spreading. If the level smoothing occurs only in the low-power area, this will cause a sharp power rise in the maximum power shoulder area. This will degrade the ACP characteristics. Timing mismatch between the linear level control and DC power switching will sometimes lead to a glitch in the nonlinear time response, interfering with the adjacent time slot user, as shown in Figure 19.



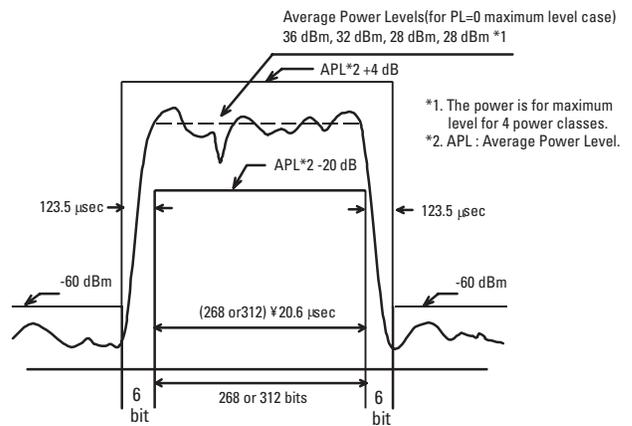
**Figure 19. A nonlinear glitch in slot 1 interferes with the slot 2 signal**

**Graphical view of specified limits**

The mask for the PDC power ramp-up/fall response is shown in Figure 22. The NADC standard only regulates the power transition time, and assumes that the frequency spectrum is measured for ACP. Figure 20 shows the power ramp-up/fall requirement described in TIA/EIA-628. This is the case when the mobile station power level is set to zero; that is, the maximum power setting. The NADC standard also specifies the time for the nominal power level to be within +3 dB, -20 dB of the specified power level as 20.6  $\mu$ sec.



**Figure 20. PDC power-versus-time mask**



**Figure 21. NADC MS power-versus-time mask**

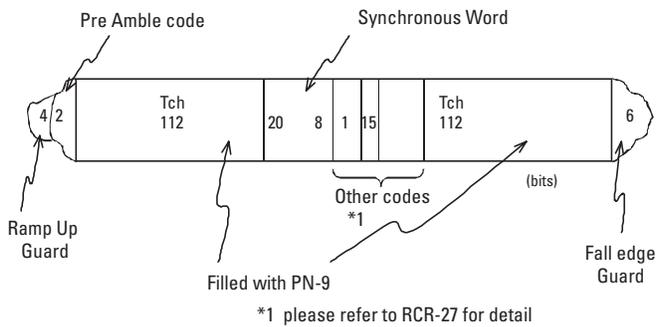
**Practical measurements**

Errors in the power versus time measurement typically occur at the shoulder of the high-power area. Furthermore, the time-response errors in this area are more likely to degrade frequency spectrum characteristics. A calculation shows that the maximum power of a  $\pi/4$  DQPSK-modulated RF signal is higher than the average power level by 3 dB. At about this level, the average input level to the transmitter tester should be approximately 10 dB below the reference level to ensure the maximum level response observation and to provide dynamic range of 80 dB.

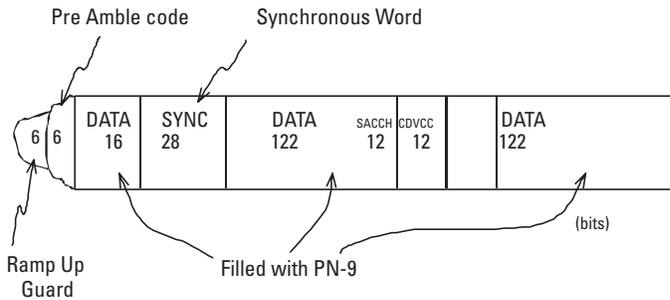
The measurement is done in the time-domain mode by setting the center frequency to the MS carrier frequency. The video trigger of the transmitter tester is normally used for waveform detection. To check all power setting ranges, the maximum power level is set at various levels.

A TDMA radio is set to transmit the physical transmission channel as shown in Figures 22 and 23.

Figure 22 shows the traffic channel (Tch) code filled with the PN-9 pseudorandom pattern for PDC. Figure 23 shows the traffic channel code filled with the PN-9 pseudorandom pattern for NADC's DATA. Please refer to RCR-27 and TIA/EIA 627 for other codes within these figures.



**Figure 22. PDC MS transmission slot format**



**Figure 23. NADC MS transmission slot format**

### Practical measurements (continued)

For systems such as PDC and NADC, in which the synchronization word or the fixed data is clearly defined for the power versus time measurement, trigger-point detection from the decoded synchronization word position will reproduce the precise trigger point.

Figures 24 and 25 are examples of the power versus time measurement using a transmitter tester. Figure 24 shows the ramp-up section of the waveform. Figure 25 displays the entire waveform. The ramp-down portion is shown in Figure 26.

### When the measurement is used

Power versus time measurements are used throughout R&D, manufacturing, QA and service to ensure the characteristics of the digital level control and the DC power switching for the output power amplifier.

For design verification, detailed power versus time measurements are required at various levels for different time slots.

In high-volume manufacturing, the power versus time test is made to verify that the regulation is met, even after test level settings and time slot conditions have been relaxed with the stabilization of product performance.

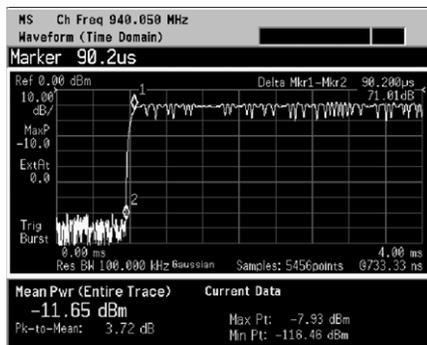


Figure 24. Power versus time (ramp-up portion)

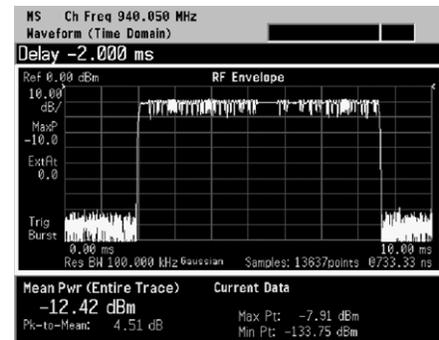


Figure 25. Power versus time (entire waveform)

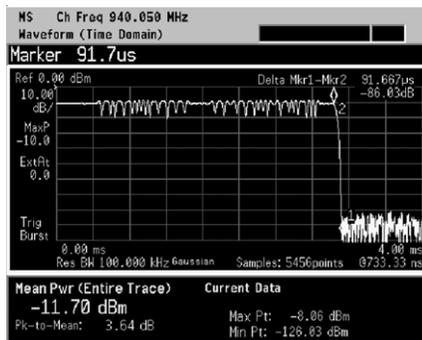


Figure 26. Power versus time (ramp-down portion)

## Carrier-Off Power (COP)

### Purpose of measurement

As described in the section on power versus time measurements, the TDMA method is a time-sharing system. The output power of a mobile station must be “off” during all time slots to prevent interference with other active mobile users.

In mobile phones, the off-state condition is accomplished by turning off the transmission amplifier’s DC power supply and setting the pre-power amplifier to the minimum linear power control. This is essential not only to assure the power-off level but also to minimize the power consumption for maximum phone usage time per battery charge. The DC power supply measurement during the off state is often done in conjunction with the COP measurement.

Designing the MS so that the DC power is turned off and the linear level controller is adjusted to the lowest level is not difficult and circuit behavior is usually stable after final check-out even at high production volumes.

Degradation of the carrier-off state is typically caused by a malfunction of the transmission power amplifier or electromagnetic coupling between components around the switching circuit.

### Graphical view of specified limits

As shown in Figure 27, the COP specification is less than  $-60$  dBm for both PDC and NADC mobile stations. This limit is derived from the power versus time measurement, in which the off-level limit is also  $-60$  dBm. Since the maximum power level is in the range of 20 to 30 dBm, the dynamic range or on/off ratio is more than 80 dB.

The PDC standard also regulates the BTS Carrier-Off-Power at less than  $-60$  dBm (2.5 uW). Given the basic condition of continuous transmission output in a BTS, this measurement is most likely performed only when trouble shooting.

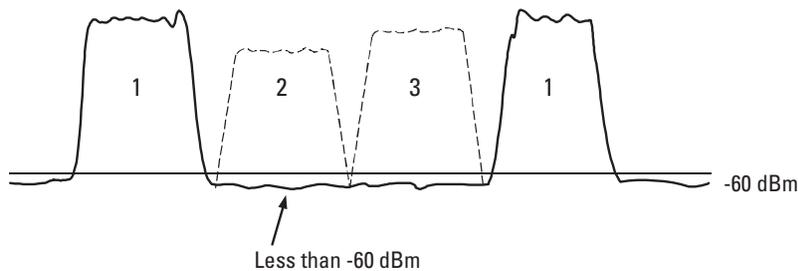


Figure 27. Carrier-off power specification (PDC and NADC MS)

## Practical measurements

The setup for COP measurements is very similar to that for power versus time measurements. For COP measurements, the transmitter tester is used in the time-domain mode with the center frequency set to the carrier frequency. All of the “off” time slots of the burst envelope are displayed. The video trigger is typically used for this measurement. However, if the sync word can be extracted from the decoded data, and the storage and regeneration functions for the sync word of the burst waveform are available for setting the trigger point at the rising edge, more stable COP measurements will result. Figure 28 shows an example of the COP power measurement by a transmitter tester.

## When the measurement is used

COP characteristics are often measured in R&D to check the burst timing control circuit, to test the timing of the RF level control circuit, and to test the condition of the transmitter power amplifier. All time slots are scanned to ensure overall functionality.

In manufacturing, because of the generally stable circuit characteristics, the COP measurement is usually conducted on only one time slot to save test time. This test is usually done with the power versus time test.

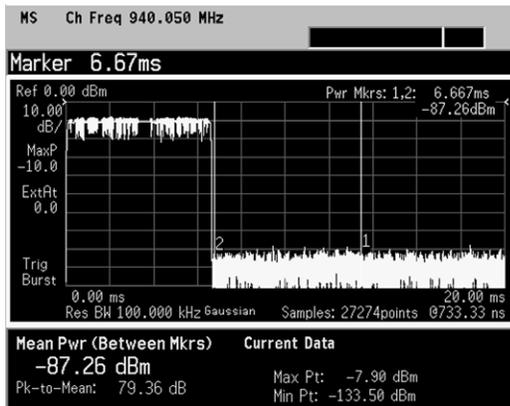


Figure 28. COP measurement by a transmitter tester

## Error Vector Magnitude (EVM)

### Purpose of measurement

In the PDC and NADC systems, BTS and MS are linked by a carrier transmission that is modulated in both phase and amplitude. The accuracy of this modulation is the key to correct operation of the systems. The parameter that indicates modulation accuracy is Error Vector Magnitude (EVM). The error vector is the vector difference at any time between the ideal reference signal and the measured signal (see Figure 29). The tester generates the reference signal by calculating the transmitted data stream, symbol clock timing, and baseband filtering parameters.

EVM is the root-mean-square (rms) value of the error vector over time at the instants of the symbol clock transitions.

A modern transmitter tester can provide magnitude error, phase error, frequency error and I/Q origin offset simultaneously when measuring EVM.

I/Q Origin Offset is defined as the relative attenuation values (dBc) between the ideal signal and the test signal. It is represented by the gap between the measured origin point and the reference origin on the I/Q plane.

Usually EVM should be measured on one or more time slots. However, there are cases in which it is possible to miss the worst peak EVM values by averaging through one time slot. One such case is when the unstable MS transmission occurs during the burst ramp-up period. For MS in the NADC system, it is recommended to measure EVM in the first ten symbols.

A  $\pi/4$  DQPSK modulator consists of a digital filter, phase shifter, D/A converter and I/Q modulator (see Figure 30). EVM measurement results and other related measured values will help to troubleshoot a transmitter when there is an impairment in the modulator section. Some troubleshooting examples are given below.

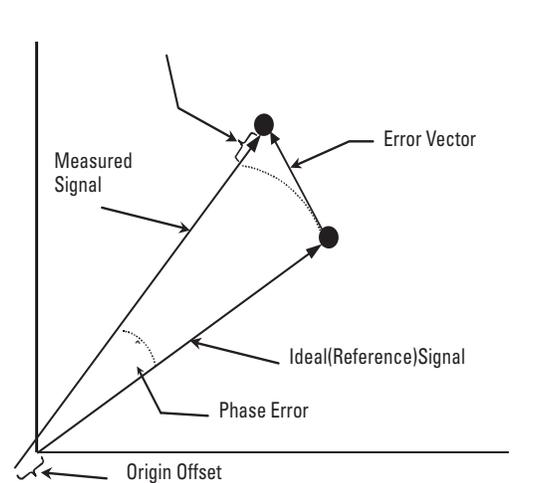


Figure 29. Error vector and related parameters

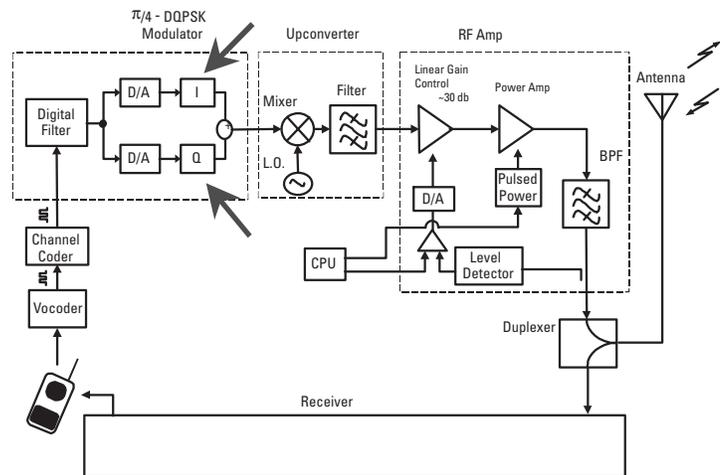


Figure 30. MS transmitter

## Definition and specifications

### PDC definition

The modulation accuracy is the difference in values between the actual transmitted signal and the reference (ideal) signal. The vector error is calculated as the square root of the value that is obtained by dividing the sum of squared errors over a timeslot by the number of symbols.

*PDC specifications (BTS and MS):*

EVM  $\leq 12.5\%$

Origin offset  $\leq -20$  dBc

### NADC definition

The NADC definition is very similar to the PDC definition, but the number of symbols in a slot is different.

*NADC specifications:*

EVM  $\leq 12.5\%$  (BTS and MS)

$\leq 25\%$  (For first ten symbols, MS only)

Origin offset  $\leq -30$  dBc (BTS),  $\leq -20$  dBc (MS)

## Practical measurements

### Trigger timing

TDMA mobile stations use a burst transmission carrier, which presents a challenge for EVM measurements.

The sync word has a particular bit sequence specified by the PDC and NADC standard. To establish a synchronization with the carrier, the tester has to demodulate and capture this word in the burst carrier. This is an automatic function in the modern transmitter tester.

If the EVM measurement result exceeds the expected value, there is a defect in the I/Q modulator section. You can analyze the problem by looking at the EVM and related parameters (phase error, magnitude error and I/Q origin offset), as the following examples illustrate:

1. An I/Q gain imbalance of the modulator causes the I/Q constellation of the measured signal to spread along the I-axis and shrink along the Q-axis, or vice versa, compared to the ideal (reference) I/Q constellation (Figures 31, 32, and 33). This defect causes the magnitude error to increase, also.
2. The phase shifter in the I/Q modulator is required to shift the phase by exactly 90 degrees. A defect in the phase shifter can result in a shift other than 90 degrees, causing a quadrature error on the I/Q plane. In this case, the measured constellation is rotated by some degrees centered at the origin on the I/Q plane (Figure 34). Then, both magnitude error and phase error increase.

If only the phase error increases, there is a possibility of a defect caused by residual FM or phase error in the phase-locked loop circuit.

### When the measurement is used

The EVM measurement is needed in every phase of the lifecycle for both BTS and MS. As mentioned above, the EVM measurement is useful for troubleshooting vector-modulated signals in the R&D phase and for I/Q calibration in the production phase. The key requirements for the transmitter tester are measurement speed and good accuracy.

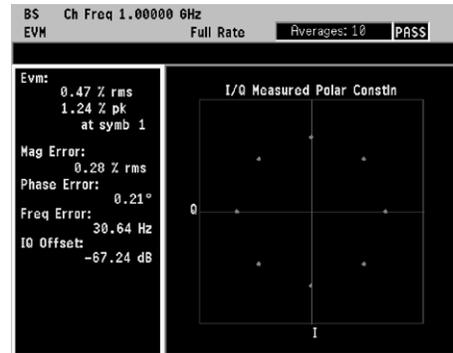


Figure 31. Ideal polar constellation

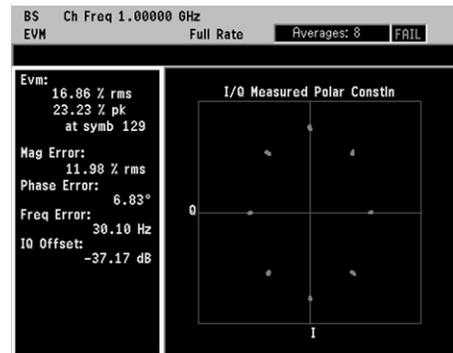


Figure 32. I/Q gain imbalance

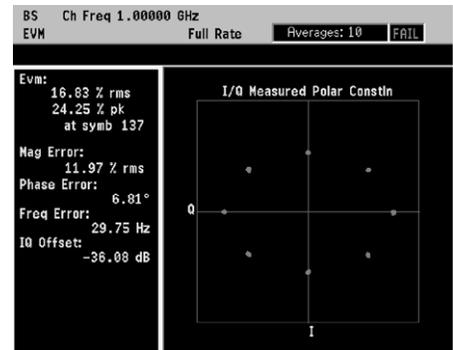


Figure 33. I/Q gain imbalance

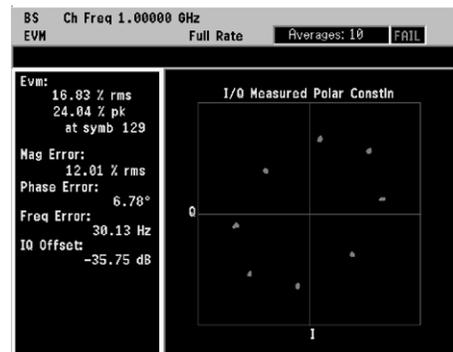


Figure 34. Phase shifter error

### 3. Choosing transmitter measurements for an application

Tables 9 and 10 summarize the test needs at every stage of the BTS and MS lifecycles. These tables are provided only for guidance. The combination of measurements used in each stage may vary depending on a number of factors, such as transmitter design, integration level, and calibration.

The probabilities from Yes to No in Tables 9 and 10 are roughly defined as follows:

- Yes 100%
- Most 75%
- Some 50%
- Few 25%
- No 0%
- N/A Not Applicable

**Table 9. Testing requirements for BTS**

	Carrier power	Adjacent channel power	Occupied band width (PDC only)	Power versus time	Carrier off leakage power (PDC only)	Error vector magnitude	Other transmitter measurements (not described in the application note)
R & D	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Verification	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Type approval	Yes	Yes	Yes	N/A	Yes	Yes	Yes
Module test	Yes	Yes	Some	N/A	Some	Yes	No
Final test	Yes	Yes	Yes	N/A	Most	Yes	Few
QA test	Yes	Yes	Yes	N/A	Some	Yes	Some
Installation	Yes	Yes	Yes	N/A	Some	Yes	Some
Maintenance	Yes	Yes	Yes	N/A	Some	Yes	Some
Depot repair	Yes	Yes	Yes	N/A	Some	Yes	Some

**Table 10. Testing requirements for MS**

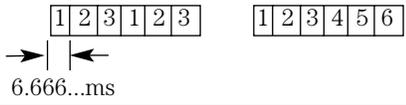
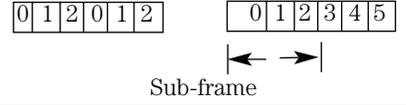
	Carrier power	Adjacent channel power	Occupied band width (PDC only)	Power versus time	Carrier off leakage power (PDC only)	Error vector magnitude	Other transmitter measurements (not described in the application note)
R & D	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Verification	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type approval	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pre test	Yes	Few	Few	Few	Few	Few	No
Final test	Yes	Yes	Most	Most	Most	Yes	Few
QA test	Yes	Yes	Yes	Yes	Yes	Yes	Some
Service	Yes	Yes	Most	Most	Some	Yes	Few

### 4. Summary

This application note describes the importance of transmitter measurements to the testing of BTS and MS for the PDC and NADC systems. The ARIB and TIA/EIA test specifications have been created for type approval purposes, and are therefore extensive. However, they are a good foundation for testing at any stage of BTS and MS lifecycles. It is essential to optimize the transmitter test suite for your specific application. It is also important to find a balance of test coverage, cost, speed, and test system flexibility. This application note should assist in reaching these goals.

Modern test equipment is often designed for one or a few of the select key transmitter measurements. However, some modern instruments are designed for great flexibility, permitting them to be used anywhere from R&D labs to service shops for testing old or new equipment using any radio format.

## 5. Appendix: an overview of PDC and NADC systems

	NADC (TIA/EIA 627, 628, 629) 1996 latest	PDC (RCR STD-27) 1998 latest
Carrier	800 MHz band	800M Hz band, 1.5 GHz band
Forward-LINK	869~894 MHz	810~828 MHz(band1), 1477~1501 MHz 870~885 MHz(band2)
Reverse-LINK	824~849 MHz	940~958 MHz(band1), 1429~1453 MHz 925~940 MHz(band2)
Forward/Reverse Spacing	$\Delta=45$ MHz	$\Delta=130$ MHz(band1) $\Delta=48$ MHz $\Delta= 55$ MHz(band2)
Channel Spacing	30 kHz	50 kHz (25 kHz interleaving)
Channel/Carrier 40 ms/frame	3(full-rate), 6(half-rate) 6 time slots/frame, 40 ms/frame 	3(full-rate), 6(half-rate) 6 time slots/frame, 40 ms/frame 
Access Scheme	TDMA/FDMA	TDMA/FDMA
Duplex Scheme	FDD	FDD
Modulation	$\pi/4$ -DQPSK (2 bits/symbol)	$\pi/4$ -DQPSK (2 bits/symbol)
Filter	SQRT raised cosine ( $\alpha=0.35$ )	SQRT raised cosine ( $\alpha=0.5$ )
Modulation Data Rate	48.6 kbps (2 bits/symbol)	42 Kbps (2 bits/symbol)
Data Rate	13 kbps(full CODEC), 6.5 kbps(half CODEC)	11.2 kbps(full CODEC), 5.6 kbps(half CODEC)
Speech CODEC	VSELP 8 kbps	VSELP 8 kbps

## 6. Glossary

ACP	Adjacent Channel Power
ARIB	Association of Radio Industries and Businesses (Japan)
BTS	Base Transceiver Station
CDMA	Code Division Multiple Access
DQPSK	Differential Quadrature Phase Shift Keying
EIA	Electronic Industry Association (USA)
EVM	Error Vector Magnitude
FFT	Fast Fourier Transform
I/Q	In phase/ Quadrature
MS	Mobile Station (mobile handheld)
NADC	North American Digital Cellular
NEM	Network Equipment Manufacturer
PCS	Personal Communications System
PDC	Pacific Digital Cellular
RMS	Root Mean Square
TDMA	Time Division Multiple Access
TIA	Telecommunications Industry Association (USA)

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2. *TIA/EIA-627: 800 MHz Cellular System, TDMA Radio Interface, Dual-Mode Mobile Station-Base Station Compatibility Standard*.
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9. *Using Error Vector Magnitude Measurements to Analyze and Troubleshoot Vector-Modulated Signals*, Agilent Product Note 89400-14, literature number 5965-2898E.

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(fax) (305) 267 4286

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(tel) 0 800 738 378 (New Zealand)  
(fax) (64 4) 802 6881

### Asia Pacific:

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Taikoo Shing, Hong Kong  
(tel) (852) 3197 7777  
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