

Introduction to GSM and GSM mobile RF transceiver derivation

The GSM system works properly only when its component parts operate within precise limits. Learn the key measurements required for testing GSM transceivers.

By Paul Kimuli

The GSM system was specified by the European Telecommunications Standards Institute (ETSI at www.etsi.org). GSM has evolved into GSM900, DCS1800 (also known as PCN) and PCS1900 (in the USA). GSM is now a global system for mobile communications, spanning Europe, Asia, Africa and much of South America.

The GSM standards define a radio communications system that works properly only if each component part operates within precise limits. Essentially, mobiles and base stations must transmit enough power with sufficient fidelity to maintain a call of acceptable quality, without transmitting excessive power into the frequency channels and timeslots allocated to others. Similarly, receivers must have adequate sensitivity and selectivity to acquire and demodulate a low level signal.

This document provides an overview of the key measurements required for testing GSM transceivers. It also discusses GSM mobile performance derivation. It is intended to help an RF designer with no GSM RF system knowledge get up to speed with the GSM system.

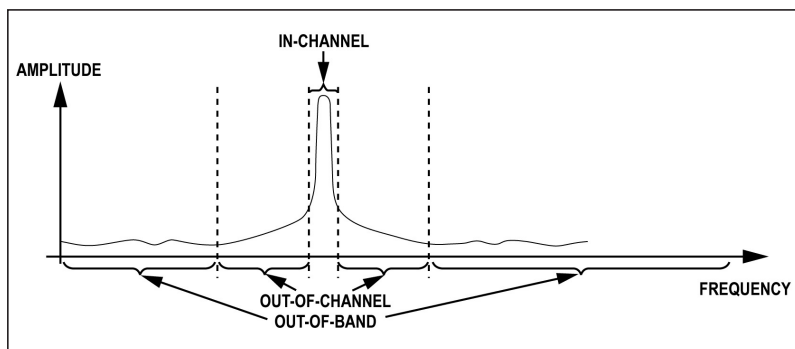


Figure 1. Visualization of the three areas of concern in the spectrum

GSM modulation

GSM900 is the original GSM system. It uses frequencies in the 900 MHz band (numbered one to 124), and is designed for wide area cellular operation with maximum output powers of 1 W to 8 W allowed for mobile applications.

GSM uses a digital modulation format called *0.3 Gaussian minimum shift keying*, or *0.3 GMSK*. The 0.3 describes the bandwidth of the Gaussian filter in relation to the bit rate.

GMSK is a special type of digital FM modulation. Ones and zeroes are represented by shifting the RF carrier by plus or minus 67.708 kHz. Modulation techniques that use two frequencies to represent ones and zeroes are called *frequency shift keying* (FSK). In the case of GSM, the data rate of 270.833 kbps is chosen to be exactly four times the RF frequency shift. This has the effect of minimizing the modulation spectrum and improving channel efficiency. FSK modulation where the bit rate is exactly four times the frequency shift is called *minimum shift keying* (MSK). In GSM, the modulation spectrum is further reduced by applying a gaussian pre-modulation filter. This slows down the rapid frequency transitions, which would otherwise spread energy into adjacent channels.

0.3 GMSK is not phase modulation. It is the frequency shift, or change of phase state, that conveys information. GMSK can be visualised from an in-phase and quadrature (I/Q) diagram. Without the Gaussian filter, if a constant stream of ones is being transmitted, MSK will effectively stay 67.708 kHz above the carrier center frequency. If the carrier center frequency is taken as a stationary phase reference, the 67.708 kHz signal will cause a steady increase in phase. The phase will rotate 360 degrees at a rate of 67,708 revolutions per second. In one bit period (1/270.833 kHz), the phase will get a quarter of the way round the I/Q diagram, or 90 degrees. Ones are seen as a phase increase of 90 degrees. Two ones cause a phase increase of 180 degrees, three ones 270 degrees and so on. Zeroes cause the same phase change in the opposite direction.

The exact phase trajectory is tightly controlled. GSM radios need to use digital filters and I/Q or digital FM modulators to accurately generate the correct trajectory. The GSM specification allows no more than 5 degrees RMS and 20 degrees peak deviation from the ideal trajectory.

GSM transceiver measurements

GSM mobile transmitter and receiver measurements originate from section 05.05.V8.12.0 ("Radio Access Network: Radio Transmission and Reception," Release 1999) of the ETSI 3GPP standards.

Performance is critical in three areas; in-channel, out-of-channel, and out-of-band. An example of a spectrum of the three areas is shown in figure 1.

In-channel measurements determine the link quality seen by the user in question. Measurements include phase error and mean frequency error, mean transmitted RF carrier power, and transmitted RF carrier power versus time.

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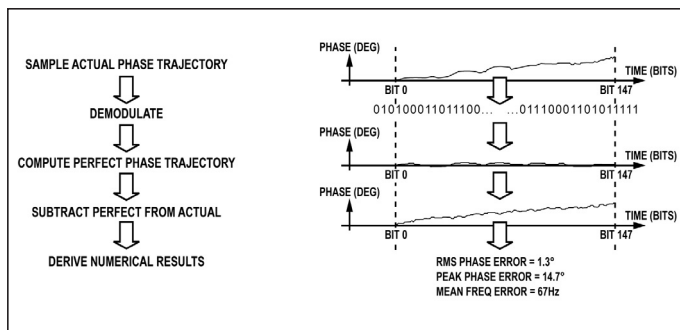


Figure 2. Test procedure to derive phase error

Out-of-channel measurements determine how much interference the user causes other GSM users. These measurements include spectrum due to modulation and wideband noise, spectrum due to switching, and Tx and Rx band spurious.

Out-of-band measurements determine how much interference the user causes other non GSM users of the radio spectrum, such as the military, police, and aviation. All other spurious (such as harmonics and wideband) are included here.

Phase error and frequency error

Phase error is one of the parameters used in GSM to characterize modulation accuracy. Poor phase error usually indicates problems with I/Q baseband generators, filters, modulators, or amplifiers in the transmitter circuitry.

Frequency error measurements indicate poor synthesizer/phase lock loop performance (such as if synthesizers may not settle quickly enough as they shift frequencies between transmissions). In GSM systems, poor frequency error can cause target receivers to fail to gain lock to transmitted signals. Also the transmitter could cause interference with other users.

To measure phase and frequency error, test sets can be used to sample transmitted output of the devices under test to capture the actual phase trajectory. This is then demodulated and the ideal phase trajectory is derived mathematically. Subtracting one from the other gives error signals. The mean gradient of these signals gives frequency error. The variation of this signal is the phase error and is expressed in terms of root mean square (rms) and peak. Figure 2 demonstrates this test procedure.

Figure 3 shows a measurement of the phase error on one transmitted burst and how it relates to the limits set by the GSM standard.

Mean transmitted output power

GSM systems use dynamic power control to ensure that each link is

maintained sufficiently with a minimum of power. This allows overall system interference to be kept to a minimum, and in the case of an MS, battery life is maximized.

Power measurements outside of specifications usually indicate a fault in the power amplifier circuitry, the calibration tables or the power supply.

The mean output power is measured during the useful part of the GSM burst. When performing this measurement, the GSM test equipment derives the correct timing reference by demodulating incoming signals and gating over the useful part of the GSM burst.

The transmitters of the GSM systems must ramp up and down within the time division multiple access (TDMA) structure to prevent adjacent timeslot interference. If transmitters turn on too slowly, data at the beginning of the burst might be lost, degrading link quality. If the transmitters turn off too slowly, the user of the next time slot in the TDMA frame will experience interference.

Therefore, transmitted RF carrier power versus time measurements are performed to assess the envelope of carrier power in the time domain against a prescribed mask. The measurements also check that the transmitters' turn offs are complete. If a transmitter fails this measurement, it usually indicates a problem with the units PA or power control loop.

Adjacent channel power

As part of the out-of-channel measurements, the adjacent channel power (ACP) is defined by two measurements: spectrum due to modulation and wideband noise, and spectrum due to switching. These two measurements are usually grouped together and referred to as *output RF spectrum* (ORFS).

The modulation process in a transmitter causes continuous wave carriers to spread spectrally. The spectrum due to modulation and wideband noise

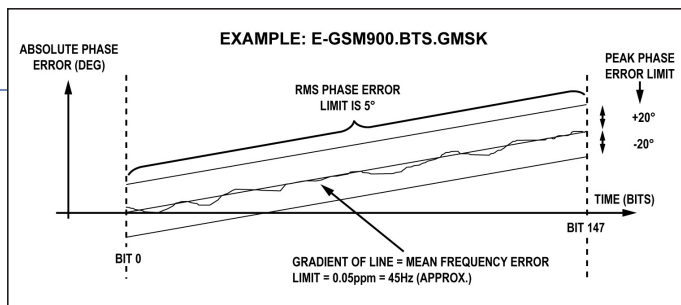


Figure 3. Example of an absolute phase error in one burst in relation to GSM standards

measurement is used to ensure that the modulation process does not cause excessive spread. This would cause interference to adjacent channel users.

To perform these measurements, analyzers are tuned to spot frequencies and time gated across part of the modulated burst. Using this mode, the power is measured. The analyzer is then returned to the next frequency or another offset of interest. This process continues until all offsets are measured and verified against permissible limits. The result of these measurements is a set of frequency versus power points that define the spectrum of the signals. However, spectral components that result from the effect of bursting do not appear because the ramps are gated out.

The test limits for these measurements are expressed in dBc (power below carrier). It follows that the first step of the measurement is to take a reading of the center frequency to which the transmitter is tuned.

Spectrum due to switching

GSM transmitters ramp RF power rapidly. The transmitted RF carrier power versus time measurements described earlier ensure that this process happens at the correct times and is fast enough. However, if RF power is ramped too quickly, undesirable spectral components exist in the transmission. This measurement also ensures that these components stay below the acceptable level.

To perform spectrum due to switching measurements, the analyzers are tuned to and measure multiple offset frequencies in zero span mode with no time gating.

Spurious measurements

The out-of-channel measurements are necessary to ensure GSM transmitters do not place energy into the incorrect parts of the spectrum. This would cause interference to other users of the spectrum. These anomalies are referred to as *spurious transmissions*.

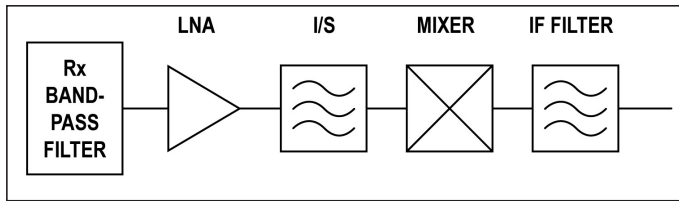


Figure 4. Single LNA with active mixer

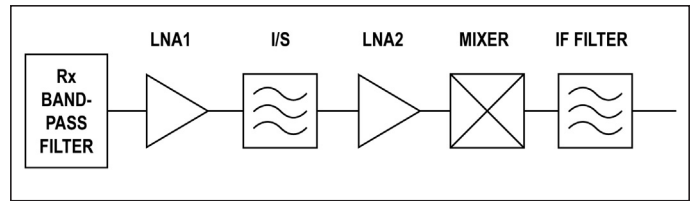


Figure 5. Dual LNA with active mixer

The spurious transmissions are measured by connecting test sets directly to the antenna connectors of the MS. Due to the antennas direct connection to the test sets, these measurements are referred to as the *conducted spurious measurements*. Measurements of this parameter include Tx/Rx band spurious, cross band spurious, and out-of-band spurious.

The spurious measurements can be categorized as Tx or Rx depending on the band they inhabit. The Tx band spurious measurements relate to spurious that fall within the 925 MHz to 960 MHz GSM Tx band. The Rx band spurious measurements, however, are measures of how much energy the transmitters put in the Rx band (880 MHz to 915 MHz). This test ensures that Tx spurious don't "jam" or desensitize adjacent receivers. The specifications of the measurements are based on 1 m average distance between mobiles.

For the purpose of attenuating the Tx band signals during these measurements, the test setups usually include Rx band pass filters in front of the analyzer inputs.

In some countries GSM900 and DCS1800 systems co-exist. For this reason the ETSI 3GPP standards require specific cross-band performance capability. This is to ensure the GSM transmitters place the minimum energy required into both the DCS1800 and GSM9000 bands.

The out-of-band spurious is a series of spectrum analyzer measurements over a large frequency range — from 100 kHz through 12.75 GHz. The 3GPP standards were written to include wideband spurious limits to which an MS must conform.

Receivers

Sensitivity is the fundamental measure of receiver performance. It specifies the minimum signal level for a specified percentage of errors in the demodulated information. The reported value for all receiver measurements is bit error rate (BER) or one of the following variations:

- Frame erasure rate (FER) — The percentage of erased frames compared to the total number of frames sent during an observation period.
- Residual bit error rate (RBER) — When frames are erased, the BER of the remaining frames is measured. The RBER parameter defines this measurement.

BER is a ratio of bits received erroneously versus total number of bits received. It is measured as follows: The test systems output signals carrying known bit patterns (usually pseudo random bit sequences or PRBS). PRBS signals are usually labeled PN_x, where x is the number of bits being permuted in the sequence (such as PN₉ = 2⁹ - 1 or 511 bits).

During the measurements, the receivers under test attempt to demodulate and decode these patterns. By return paths (using a method known as *loop back*), the receivers send the resultant bits back to the test systems for comparison. The test systems then calculate the required metrics. GSM handsets are tested using this loop-back method.

Most receivers are required to maintain a specified BER in the presence of interfering signals within the channel. For GSM, the performance is measured as follows: Digitally modulated signals power levels are set 20 dBs above receiver sensitivity at the center of the receivers' passband. These signals are combined with GMSK modulated interferers. Combined signals are then injected into the antenna ports of the receivers. The power levels of the GMSK interfering signals are then set to nominal levels at which the receiver BERs must not exceed the receiver sensitivity specifications. The difference in power levels between the two signals is the interference ratio.

Receiver blocking constitutes one of the out-of-channel receiver tests. Blocking tests verify correct receiver operation in the presence of out-of-channel signals and monitor the receivers' susceptibility to internally generated spurious responses. There

are three key tests that define the receivers blocking performance: spurious immunity, intermodulation immunity, and adjacent channel selectivity.

Spurious immunity is the ability of the receivers to prevent single, out-of-channel interference signals from causing undesired in-channel responses at the output of the receivers. Spurious may be generated within the receivers from power supply harmonics, system clock harmonics or LO spurious.

Intermodulation immunity is a measure of the receivers' performance in the presence of distortion products due to intermodulation products. These intermodulation products are generated when more than one tone is present at the input of the receivers. The tones non-linearly mix to form third-order intermodulation products. The products of concern lie within the receivers' passband.

Adjacent channel selectivity is a measure of the receivers' ability to process the desired modulated signals in the presence of strong signals in the adjacent channels. Alternate channel selectivity is a similar test in which the interfering signals are two RF channels away from the receivers' passband.

GSM mobile RF transceiver derivation

Receiver sensitivity is related to receiver noise figure according to:

$$S = -174 + 10 \log B_i + \frac{S}{N} + G_{imp} + NF$$

Where the receivers' bandwidth (180 kHz for GSM), is the baseband signal-to-noise-ratio and the RF and broadband implementation gain.

The GSM standard specifies a minimum -102 dBm sensitivity requirement. Given a worst-case baseband ratio of 9 dB and a 2 dB implementation margin, we calculate the noise figure as:

$$NF = -174 + 10 \log(180,000) + 9 + 2 - (-102) = 8.5 \text{ dB}$$

Given this worst-case NF, the receivers' designers can then investi-

Frequency band	MS Blocking signal level	Description
600 kHz ≤ f-fo < 800 kHz	-43 dBm	In band blocking
800 kHz ≤ f-fo < 1.6 MHz	-43 dBm	
1.6 MHz ≤ f-fo < 3 MHz	-33 dBm	
3 MHz ≤ f-fo	-23 dBm	
900 MHz to 915 MHz	-5 dBm	Out of band blocking
980 MHz to 12750 MHz	0 dBm	

Table 1: Blocking signal levels where GSM is expected to perform

gate various front end gain and NF partition options according to the equation:

$$NF = 10 \log \left[F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_2} + \frac{(F_3 - 1)}{G_1 \cdot G_2} + \dots \right]$$

Where F_i is the noise factor of the i 'th block in the partition ($i = 1, 2, 3 \dots$).

Although the second equation shows that the higher the gain of the first active stage, the lower the NF of the system would be, the receivers' designers need to ensure that the first active stage does not compress the subsequent stages. This would degrade receiver linearity. This shows that system sensitivity is a compromise between receiver NF (dominated by choice of front end components) and receiver linearity.

The receivers' front end low noise amplifier (LNA) options typically investigated are shown in figures 4 and 5.

The main benefit of the dual LNA option — when compared with the first option — is that the individual LNA noise figure and gain requirements are significantly relaxed. With the single LNA option, the front end LNA would need to be tightly specified

to achieve the same system NF as the dual LNA option.

The main disadvantage of the dual LNA option typically is increased cost and (potentially) the extra supply current required due to addition of a second LNA.

Rx blocking analysis

Table 1 shows the blocking signal levels with which a GSM mobile is expected to perform without dropping a call. GSM receiver designers specify the receive strips' compression points based on the above listed in-band blocking signal level specifications, and uses the out-of-band blocking signal levels to define the filter rejection specifications to avoid signal path compression.

For example, in-band blocking at 3 MHz offset (such as -23 dBm) sets the compression point required for the front end. Assuming a 1 dB loss switch and a 2.5 dB loss filter prior to a LNA stage in the receive strip, it places a total 3.5 dB loss prior to the LNA stage. This means the LNA compression point must, in the worst case, be -26.5 dBm (such as -23 dBm to 3.5 dBm).

Offset frequency	dBc/BW	Derived Phase noise
±200 kHz	-30 kHz/30 kHz	-75 dBc/Hz
±250 kHz	-33 kHz/30 kHz	-78 dBc/Hz
±400 kHz	-60 kHz/30 kHz	-105 dBc/Hz
±600 kHz - 1200 kHz	-60 kHz/30 kHz	-105 dBc/Hz
±1200 kHz - 1800 kHz	-60 kHz/30 kHz	-105 dBc/Hz
±1800 kHz - 3000 kHz	-63 kHz/100 kHz	-113 dBc/Hz
±3000 kHz - 6000 kHz	-65 kHz/100 kHz	-115 dBc/Hz
> ±6000 kHz	-71 kHz/100 kHz	-121 dBc/Hz

Table 2: ETSI 05.05 specifications for spectrum due to modulation

Rx intermodulation

GSM receiver intermodulation performance is predominantly affected by the front end circuitry. The intermodulation performance is affected if the IF filter chosen has good enough attenuation at +/-800 kHz and +/-1600 kHz (the offset frequencies for which this parameter is tested as specified by the GSM 05.05 standard).

The equation typically used to determine system IP3 requirement is:

$$IP3(\text{min}) = P_i + \frac{(P_i - P_u + \frac{C}{I})}{2}$$

where

P_i

is the interference signal level (-49 dBm from GSM 05.05 spec),

P_u

is the useful signal and

$\frac{C}{I}$

is the carrier-to-interference ratio for which the receiver is designed. The useful signal level can be determined from the GSM sensitivity level by adding 3 dB. So, for an 8 dB carrier interference ratio, the minimum GSM receiver input intercept is -20 dBm.

Conclusion

This article is meant to only be an overview of the key measurements required for testing GSM transceivers, and GSM mobile performance derivation. It is intended to help an RF designer with no GSM RF system knowledge get a better appreciation of GSM module specifications and how they can affect system performance.

RF

About the Author

Paul Kimuli is a senior RF field applications engineer for Maxim Integrated Products Inc. (www.maxim-ic.com) based in the United Kingdom. He has a first class degree with Honours in electronic and electrical engineering, from the University of Leeds. Kimuli can be reached at pserukenya@hotmail.com.