NIST Unveils Status Of PIM Testing

A series of NIST-monitored tests of signal-distortion measurements on passive components provides necessary measurement assurance to manufacturers.

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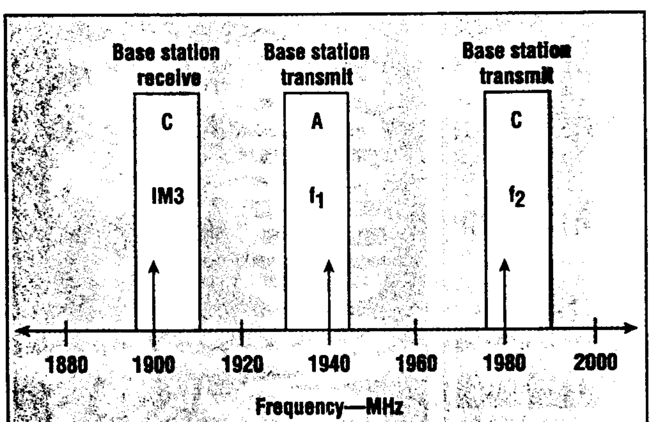
PASSIVE intermodulation (PIM) is a form of signal distortion that occurs whenever signals at two or more frequencies conduct simultaneously in a passive device, such as a cable or connector, which contains some nonlinear response. Requested by US industry and members of the International Electrotechnical Commission, the National Institute of Standards and Technology (NIST) initiated a comparison of measurements of PIM for the US wireless industry. The goal was to determine the level of agreement in measurements of PIM made by US manufacturers and suppliers of passive components for wireless-communication base stations. This study reveals not only the difficulties that industry is experiencing in making PIM measurements, but also provides US companies with a tool to improve their measurement capabilities as they deal with PIM-related trade barriers.

Since August 1998, 10 US companies have participated in the PIM comparison. The participants measured four round-robin test samples and contributed 19 data sets for four different commercial communications bands. No company is singled out, and each can determine how well its measurements compare with the group averages for each of the four test samples in each of the four communication bands. While the majority of participants report PIM levels within one standard deviation of the mean value, some companies report quite significant discrepancies.



1. Potential third-order modulation in broadband PCS results from collocation of two or more transceivers at a single site.

In PIM, the nonlinear behavior produces spurious signals, where the frequencies are linear combinations of the frequencies of the original signals. The lower odd-ordered intermodulation (IM) products [e.g., f (IM3) = $2f_1 - f_2$] are usually the most difficult in the wireless industry since they have the highest potential of falling within the receive band, or uplink, of a base station, creating RF interference (RFI) in the receiver.[1] Although frequency allocations are specifically designed to guard against this problem, collocation of two or more base-station transceivers at a single site substantially increases the risk of PIM interference,[2] as illustrated in Fig. 1.

Base stations built for mobile communications systems such as personal communication services (PCS-1900), Advanced Mobile Phone System (AMPS), Global System for Mobile Communications (GSM), and Digital Communications System (DCS-1800), use DIN (Deutsche Industrinorm) 7-16 and type-N coaxial connectors to handle the high transmit-power requirements. At high power (more than 1 W), nonlinearities in coaxial connectors become apparent and measurable.[3] The many possible causes of IM in coaxial connectors and cables include poor mechanical contact, dissimilar metals in direct contact, ferrous content in the conductors, debris within the connector, poor surface finish, corrosion, vibration, and temperature variations. The sources of PIM have been studied quite extensively at various laboratories.[4-15]

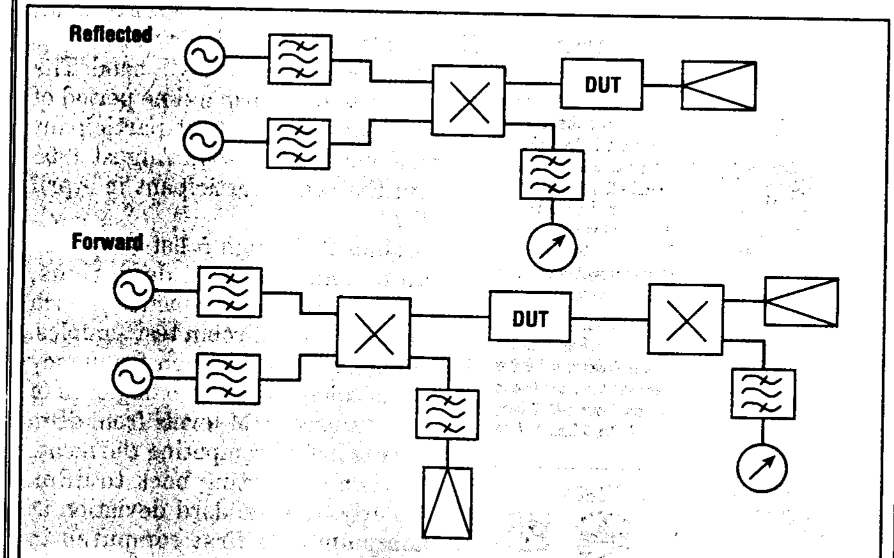
Table 1: Receive and transmit frequencies for four communication bands

Communication band	[illegible]-station [illegible] frequencies (uplink)	[illegible]-station [illegible] frequen-[illegible] (downlink)
AMPS	[illegible] to 849 MHz	[illegible] 894 MHz
PCS-1900	[illegible] 1910 MHz	[illegible] 1990 MHz
GSM	[illegible] 915 MHz	[illegible] 960 MHz
[illegible]CS-1800	[illegible] 1785 MHz	[illegible] 1880 MHz

TEST METHOD

To conduct the comparison, NIST obtained two sets of test samples. One was used as a control test sample, and the other was circulated among the participating companies. The test samples were labeled with different colors to distinguish them: red, white, yellow, and blue. Each test sample had two ports with male and female DIN 7-16 connectors and varying passive nonlinearities. The red, white, and yellow test samples were simply male-to-female adapters with diodes inserted through the outer conductor wall to generate nonlinearities of varying degrees. The blue test sample, which also had a diode inserted in one connector, was a cable assembly whose purpose was to create noticeable frequency-dependent behavior.

Following the International Electrotechnical Commission's guidelines,[16] the power levels for the third-order IM products of each test sample were measured with two continuous-wave (CW) signal sources, each measuring +43 dBm (20 W) at the test ports. Each test sample was measured within the base-station receive (uplink) band of any or all of the four communications bands listed in Table 1, when the two +43-dBm signals were tuned to fall within the corresponding base-station transmit (downlink) band. The minimum



2. Two configurations for measuring passive IM products are reflected and forward. The DUTs can be connectors or a cable assembly.

required data from each participant was a single third-order IM power in one communication band.

Participating companies were asked to measure either or both forward and reflected IM products (Fig. 2). To measure reflected IM, participants were instructed to connect the male connector of the test sample to the active test port of their system and the female connector to a low PIM load. To measure forward intermodulation, they were instructed to connect the male connector of the test sample to the active test port of their system with the female connector being connected to their own cable that was, in turn, connected to the receiving port of their system. Participants who had the ability to make swept-frequency measurements were encouraged to make additional measurements at specified frequencies. Those who had systems that could measure IM products in more than one communication band and those who had multiple systems were encouraged to measure the devices in as many different bands as possible.

The role of NIST in this comparison was to act as a pilot laboratory. Without knowing absolute PIM values, its tasks were to organize the comparison, measure the stability throughout the study, keep a data base of the measurements, and report the results.[17] Its first responsibility was to procure a passive IM analyzer and two sets of test samples, one of which was kept in-house for measuring the long-term stability of the system, and the other was circulated among the participants. After each company measured the set of four test samples, they were returned to NIST along with their data, and test samples were re-measured to ensure that they were still in working order before sending them to the next company. To date, 10 companies have contributed 19 data sets over the past nine months. Each participant's measurements are compared against the group, keeping all companies' identities confidential.

AMPS

Of the 10 participants, five made measurements in the AMPS band, six in the GSM band, six in the PCS band, and two in the DCS band. The data presented span a time period of nine months—the first participant made measurements in August 1998 with the tenth participant in April 1999.

Tables 2 through 5 list the mean values and standard deviations, taken by the 10 participants for each of the four round-robin test samples. The mean value at each frequency was calculated by converting each of the measured PIM levels from dBm to watts before computing the mean, and then converting back to dBm. Similarly, the standard deviation at each point was first computed in watts and then converted to decibels. The following are the results obtained in each of the four communications bands.

Five IM3 frequencies (844, 845, 846, 847, and 848 MHz) were specified for measurements spanning the AMPS band. Measurements at these frequencies could be obtained in two ways: holding source one at 869 MHz and sweeping source two downward from 894 to 890 MHz in steps of 1 MHz, or holding source two at 894 MHz and sweeping source one upward from 869 to 871 MHz in steps of 0.5 MHz. All five participants who made measurements in the AMPS band made swept-frequency measurements in both directions. One participant made reflected measurements, one made forward measurements, and three made forward and reflected measurements. Tables 2 and 3 list the mean values and standard deviations for each test sample at the five measured frequencies.

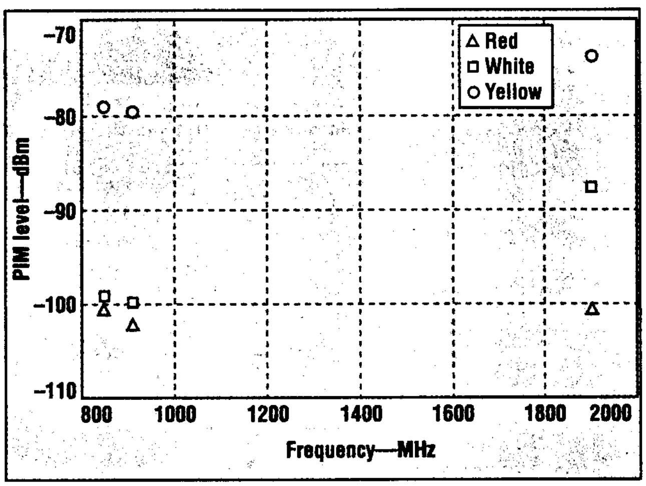
From the data compiled in all bands, including AMPS, it appears there is no significant difference between reflected and forward measurements for the electrically short test samples (red, white, and yellow). However, there were noticeable differences for the electrically long (blue) test sample, so the two measurements were separated when calculating the mean values and standard deviations. Also, the white test sample was less stable than the other test samples in all bands, yet its PIM values were very close to the red test sample. The mean values measured throughout the AMPS band for the red test sample varied between –100.3 and –101.4 dBm, with standard deviations ranging from 1.5 to 1.9 dB; the mean values of the white test sample varied between –98.8 and –99.5 dBm, with standard deviations from 2.8 to 4.8 dB; the mean values of the yellow test sample varied between –79.4 and –79.7 dBm, with standard deviations from 1.3 to 1.9 dB; the mean values of the blue test sample, measured in the reflected configuration, varied between –93.6 and –95.1 dBm, with standard deviations from 3.3 to 4.6 dB; and the mean values of the blue test sample, measured in the forward configuration, varied between –87.9 and –88.3 dBm, with standard deviations ranging from 1.4 to 2.1 dB.

Table 2: Mean values and standard deviations in the AMPS band (red, white, yellow)

IM3	Red test sample		White test sample		Yellow test sample	
Frequency (MHz)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)
844	-100.6	1.9	-98.8	2.8	-79.4	[illegible]
845	-101.4	1.7	-99.5	3.0	-79.7	[illegible]
846	-100.8	1.6	-99.5	2.8	-79.4	[illegible]
847	-100.4	1.6	-98.9	4.8	-79.7	[illegible]
848	-100.3	1.7	-99.2	3.0	-79.4	1.8

Five IM3 frequencies (890, 895, 900, 905, and 910 MHz) were specified for measurements spanning the GSM band. Measurements at these frequencies could be obtained in two ways: holding source one at 925 MHz and sweeping source two downward from 960 to 940 MHz in steps of 5 MHz, or holding source two at 960 MHz and sweeping source one upward from 925 to 935 MHz in steps of 2.5 MHz. Of the six participants who made measurements in the GSM band, two made swept-frequency measurements. The other four made measurements at 910 MHz (source one at 935 MHz and source two at 960 MHz). Three participants made reflected measurements, one made forward measurements, and two made forward and reflected measurements.

Similar to the AMPS band comparison, the GSM measurements showed no difference between reflected and forward measurements for the electrically short test samples (red, white, and yellow) but did so for the electrically long (blue) test sample. And once again, the white test sample was less repeatable than the others. Since only two participants made swept-frequency measurements in the GSM band, statistical calculations were performed only for 910 MHz where all of the participants made measurements. One participant's measurements were more than 30 dB lower



3. The frequency dependence of the red, white, and yellow samples shows that white has the greatest deviation between low (900-MHz) and high (1900-MHz) frequency.

Table 3: Mean values and standard deviations in the AMPS band (blue)

IM3	Blue reflected		Blue forward	
Frequency (MHz)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)
844	-95.1	4.6	-88.2	2.1
845	-94.5	4.4	-88.3	2.1
846	-94.2	3.8	-88.1	1.8
847	-93.7	4.1	-88.0	1.4
848	-93.6	3.3	-87.9	1.8

than the others for all four test samples, so their data were not included in the computations of mean values and standard deviations. Of the remaining five participants, the mean value measured at 910 MHz in the GSM band for the red test sample was −102.3 dBm, with a standard deviation of 2.3 dB; the mean of the white test sample was −99.9 dBm, with a standard deviation of 3.6 dB; the mean of the yellow test sample was −80.1 dBm, with a standard deviation of 0.7 dB; the mean of the blue test sample, measured in the reflected configuration was −93.2 dBm, with a standard deviation of 1.1 dB; and the mean of the blue test sample, measured in the forward configuration, was −88.3 dBm, with a standard deviation of 2.6 dB.

Five IM3 frequencies (1870, 1880, 1890, 1900, and 1910 MHz) were specified for measurements spanning the PCS band. Measurements at these frequencies could be obtained in two ways: holding source one at 1930 MHz and sweeping source two downward from 1990 to 1950 MHz in steps of 10 MHz, or holding source two at 1990 MHz and sweeping source one upward from 1930 to 1950 MHz in steps of 5 MHz. Of the six participants who made measurements in the PCS band, five made swept-frequency measurements in both directions, and one made swept frequency measurements in one direction (source one held constant). One participant made reflected measurements, one made forward measurements, and four made forward and reflected measurements. Tables 4 and 5 list the mean values and standard deviations for each of the test samples at the five measured frequencies.

Overall, measurements in the PCS band showed significantly larger variations than those seen in either the AMPS or GSM bands, which is

Table 4: Mean values and standard deviations in the PCS band (red, white, yellow)

IM3	Red test sample		White test sample		Yellow test sample	
Frequency (MHz)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)
1870	−100.4	2.8	−90.5	7.5	−74.4	3.9
1880	−98.9	7.4	−89.9	7.6	−74.3	3.9
1890	−99.2	6.0	−89.4	8.0	−74.3	3.8
1900	−98.9	5.5	−89.0	8.0	−74.1	4.8
1910	−100.6	3.3	−87.9	8.0	−73.7	3.5

consistent with the results of the European round-robin.[18] Similar to the AMPS and GSM comparisons, the PCS measurements showed no difference between reflected and forward measurements for the electrically short test samples (red, white, and yellow) but did for the electrically long (blue) test sample. Frequency-dependent behavior was observed in the blue test sample when reflected measurements were made, which is predicted by models developed by Deats and Hartman[19] and Jargon *et al.*[17]

This is not to say that the blue test sample is not frequency dependent at lower frequencies, but rather the frequency range of the PCS band is much wider than the AMPS and GSM bands. Thus, the frequency-dependent behavior is more apparent in PCS when swept frequency and reflected measurements are performed. Once again, the white test sample was found to be less stable than the others. The mean values measured throughout the PCS band for the red test sample varied between –98.9 and –100.6 dBm, with standard deviations ranging from 2.3 to 7.4 dB; the mean values of the white test sample varied between –87.9 and –90.5 dBm, with standard deviations from 7.5 to 8.0 dB; the mean values of the yellow test sample varied between –73.7 and –74.4 dBm, with standard deviations from 3.5 to 4.8 dB; the mean values of the blue test sample, measured in the reflected configuration showed a downward trend in PIM from –83.5 dBm at 1870 MHz to –95.1 dBm at 1910 MHz, with standard deviations from 2.5 to 3.7 dB; and the mean values of the blue test sample measured in the forward configuration varied between –84.3 and –85.7 dBm, with standard deviations from 2.5 to 3.2 dB.

DCS

Five IM3 frequencies (1730, 1740, 1750, 1760, and 1770 MHz) were specified for measurements spanning the DCS band. Measurements at these frequencies could be obtained in two ways: holding source one at 1805 MHz and sweeping source two downward from 1880 to 1840 MHz in steps of 10 MHz, or holding source two at 1880 MHz and sweeping source one upward from 1805 to 1825 MHz in steps of 5 MHz. Two participants made measurements in the DCS band. One participant performed forward and reflected measurements, and one effected reflected measurements.

Since only two participants made measurements in the DCS band, no statistical computations were performed. However, similar to the PCS band, frequency-dependent behavior was observed in the blue test sample when reflected measurements were made. And once again, this was attributed to the wide bandwidth of the DCS band.

For the first four months of the

comparison (August to November 1998), stability-check measurements were performed on an AMPS system, and then for the remainder of the comparison (November 1998 to April 1999), measurements were made on a PCS system. If the system showed large variations in the round-robin test samples, the in-house test samples could be used to determine whether the problem was due to the test samples varying or whether something was wrong with the system. Fortunately, this did not happen. The systems and the test samples remained stable throughout the comparison. Table 6 lists the standard deviations of the measurements made at NIST of the round-robin test samples. All of the test samples remained stable within standard deviations of 2.9 dB or less for up to five months on a single system.

Table 5: Mean values and standard deviations in the PCS band (blue)

IM3	Blue reflected		Blue forward	
Frequency (MHz)	Mean (dBm)	Standard deviation (dB)	Mean (dBm)	Standard deviation (dB)
1870	-83.5	2.5	-84.8	3.1
1880	-84.2	2.7	-85.7	3.0
1890	-86.1	2.9	-84.5	2.6
1900	-89.6	3.1	-84.4	3.2
1910	-96.1	3.7	-84.3	2.7

SUMMING UP

Of the 19 data sets received, most companies' measurements fell within two standard deviations of the measured means of each band. In the AMPS band, three of the five participants' measurements fell consistently outside one standard deviation (typically less than 3 dB), although all the measurements fell within three standard deviations. In the GSM band, only two of the six participants' measurements fell consistently outside one standard deviation (typically less than 3 dB), and all were within two standard deviations except for one which was as much as 50 dB from the mean. In the PCS band, not one of the six participants measured consistently outside one standard deviation (between 2 and 8 dB), except for measurements of the yellow test sample where two participants measured outside three standard deviations from the mean.

Several conclusions can be drawn with regard to PIM measurements. First, it appears that there is no significant difference between reflected and forward measurements for electrically short test samples (red, white, and yellow). However, there were noticeable differences for the electrically long (blue) test sample. Second, IM in passive devices is not always frequency independent. This contradicts the findings of the European round-robin performed in 1995.[18] Figure 3 plots PIM versus frequency for the red, white, and yellow test samples. The white and yellow test samples show deviations up to 10 dB between lower frequencies (AMPS and GSM) and higher frequencies (PCS and DCS). Frequency-dependent behavior was observed over a frequency range of 40 MHz in the blue test sample when reflected measurements were made. Measurements in the PCS band showed significantly larger variations than those seen in either the AMPS or GSM bands, due to the higher operating frequencies. This behavior agrees with the findings of the European round-robin. Finally, measurements made by the system on round-robin test samples remained stable within a standard deviation of 2.9 dB over a five-month period.

Table 6: Standard deviations of the NIST measurements

Test sample	AMPS standard deviation (dB)	PCS standard deviation (dB)
Red	2.8	1.3
White	2.9	1.6
Yellow	0.5	2.9
Blue	0.6	2.7

This comparison of passive IM measurements has addressed, in a timely manner, a direct need expressed to NIST by US base-station equipment manufacturers. This comparison allowed each participant to assess its capabilities in an impartial way, while allowing NIST to evaluate the urgency of any PIM measurement problems that may exist within the industry. ●●

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