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Measurement Comparison of a Low-Intermodulation Termination for the U.S. Wireless Industry

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After the recent, successful completion of a passive intermodulation measurement comparison for nonlinear two-port devices, the National Institute of Standards and Technology was requested to perform a second comparison for a one-port termination. Whereas the first comparison allowed participants to determine the level of agreement in measurements of varying levels of passive intermodulation (–110 dBm to –70 dBm), this comparison allows companies to check their systems at or near the noise floor level of most instruments (nominally –130 dBm). Since March 2000, five U.S. companies have participated in this intercomparison and have contributed ten data sets for four different commercial communications bands. This report preserves company anonymity, and allows participants to determine how well their measurements compare to ensemble averages. The study shows that the majority of the participants report PIM levels within two standard deviations of the mean values, and none of the participants' measurements fall outside of three standard deviations.

Key Words: communications, comparison, intermodulation, measurement, passive, termination, third-order, wireless.

1. Introduction

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 that contains some nonlinear response. The nonlinear behavior produces spurious signals whose 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 problematic in the wireless industry since their signal levels are usually stronger and have the highest potential of falling within the receive band, or up-link, of a base station, creating rf interference 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 possibility of PIM interference [2], as illustrated in Figure 1.

Base stations built for mobile communications systems such as Personal Communication Service (PCS 1900), Advance 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 (above 1 W) power, nonlinearities in coaxial connectors become apparent and measurable [3]. The many possible causes of intermodulation 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 extensively at various laboratories [4-18].

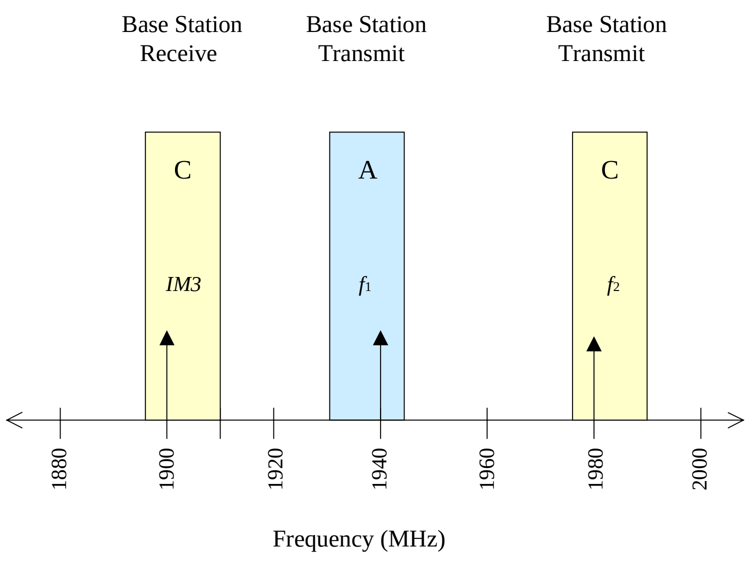

Figure 1. Potential third-order intermodulation in broadband PCS.

In 1998, the National Institute of Standards and Technology (NIST) initiated a PIM measurement comparison [19-21] for the U.S. wireless industry, in response to requests by industry and members of the International Electrotechnical Commission (IEC). The goal of this comparison was to determine the level of agreement in measurements of PIM by U.S. manufacturers and suppliers of passive components for wireless-communication base stations. The study revealed not only the difficulties industry was having in measuring PIM, but also provided U.S. companies with a tool to improve their measurement capabilities. Ten companies participated in the PIM intercomparison, measuring four round-robin artifacts and contributing nineteen data sets for four different commercial communications bands. The study showed that the majority of the participants reported PIM levels within one standard deviation of the mean values, but also revealed significant discrepancies reported by some participants.

After the successful completion of the first comparison for two-port devices, NIST was requested to perform a second comparison for a one-port termination. Whereas the first comparison allowed participants to determine the level of agreement in measurements of varying levels of passive intermodulation (–110 dBm to –70 dBm), this comparison allows companies to check their systems at or near the noise floor level of most instruments (nominally –130 dBm). (Note that dBm is defined as decibels relative to 1 mW.) As in the previous study, this report preserves company anonymity, and allows participants to determine how well their measurements compare to ensemble averages.

2. Methodology

To conduct the comparison, NIST obtained a low-PIM 50 Ω termination with a female DIN 7-16 connector to be circulated among the participating companies. Following the International Electrotechnical Commission's guidelines [22], the power levels for the third-order IM products of the termination were measured with two cw signal sources, each measuring +43 dBm (20 W) at the test ports. The termination was measured within the base station receive (up-link) 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 (down-link) band. The minimum required data from each participant was a single third-order intermodulation power in one communication band.

Participating companies were asked to measure the reflected intermodulation products, as illustrated in Figure 2. They were instructed to connect the female connector of the termination to the active test port of their systems by either a direct connection or a short cable or adapter. 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 intermodulation 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. Appendix A contains the *Instructions for Participants*, and Appendix B includes the *Artifact Measurement Form* that each participant completed.

Table 1. Base-station receive and transmit frequencies for four communications bands.

Communication band	Base station receive frequencies (MHz)	Base station transmit frequencies (MHz)
AMPS	824-849	869-894
PCS 1900	1850-1910	1930-1990
GSM	890-915	935-960
DCS 1800	1710-1785	1805-1880

The role of NIST in this comparison was to act as a pilot laboratory. Without knowing absolute PIM values, our tasks were to organize the comparison, measure the stability throughout the study, keep a database of the measurements, and report the results. After each company measured the termination, they sent it back to us, along with their data, and we re-measured it to ensure that it was still in working order, before sending it to the next company. Now that 5 companies have contributed 10 data sets over the past 14 months, we show how each of the participants' measurements compare with the ensemble, keeping all companies' identities confidential.

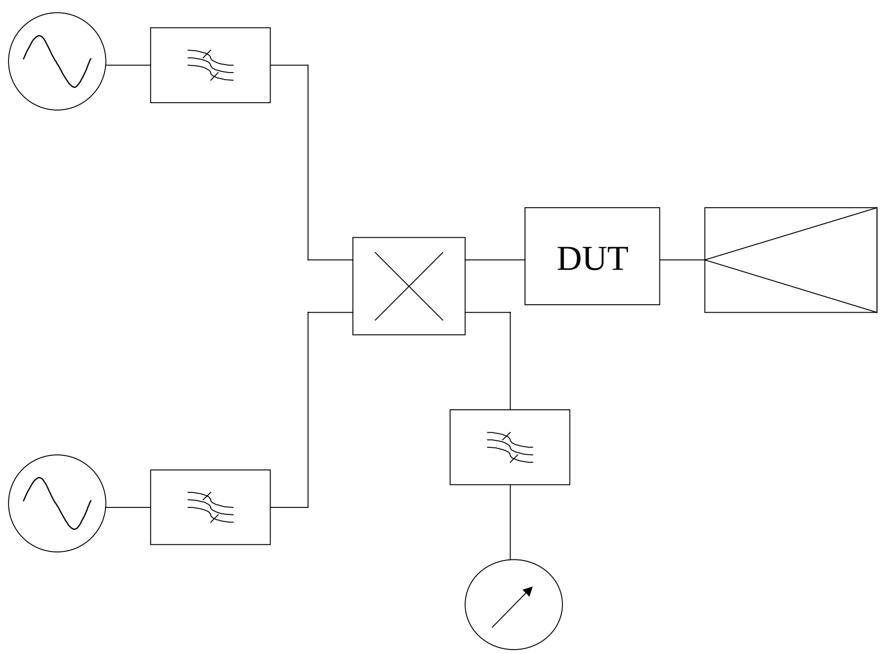

Figure 2. Configuration for measuring reflected passive intermodulation products.

3. Results

Of the five participants, one made measurements in the AMPS band, three in the GSM band, four in the PCS band, and one in the DCS band. The data presented in this report span a time period of 14 months from March 2000 to May 2001.

Tables 2 through 6 list the measured data, along with the mean values and standard deviations, taken by the five participants. These data are also plotted in Figures 3 through 6, where solid lines between measurement points indicate a sweep with source 1 held constant, and dashed lines between measurement points indicate a sweep with source 2 held constant. 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. Likewise, the standard deviation at each point was first computed in watts and then converted to decibels. Below, we discuss the results obtained in each of the four communications bands.

3.1. PCS Band

We specified five particular IM3 frequencies (1870, 1880, 1890, 1900, and 1910 MHz) for measurements spanning the PCS band. Measurements at these frequencies could be obtained in two ways: (1) holding source 1 at 1930 MHz and sweeping source 2 downward from 1990 MHz to 1950 MHz in steps of 10 MHz, or (2) holding source 2 at 1990 MHz and sweeping source 1 upward from 1930 MHz to 1950 MHz in steps of 5 MHz.

All four participants who made measurements in the PCS band made swept-frequency measurements in both directions. Participant D made measurements on two separate systems, so they are designated separately as D1 and D2. Table 2 lists the measured data taken by the four participants, and Table 3 lists the mean values and standard deviations calculated at each of the five measured frequencies. These data are also plotted in Figure 3. The mean values measured throughout the PCS band varied between –126.2 dBm and –129.8 dBm, with standard deviations ranging from 3.9 dB to 5.5 dB.

3.2. DCS Band

We specified five particular IM3 frequencies (1730, 1740, 1750, 1760, and 1770 MHz) for measurements spanning the DCS band. Measurements at these frequencies could be obtained in two ways: (1) holding source 1 at 1805 MHz and sweeping source 2 downward from 1880 MHz to 1840 MHz in steps of 10 MHz, or (2) holding source 2 at 1880 MHz and sweeping source 1 upward from 1805 MHz to 1825 MHz in steps of 5 MHz.

Participant B, the only one to measure the termination in the DCS band, made swept-frequency measurements in both directions. Table 4 lists the measured data taken by Participant B. Statistical computations were not performed since we received data from only one participant, but measurements varied from –126.7 dBm to –134.8 dBm.

3.3. GSM Band

We specified five particular IM3 frequencies (890, 895, 900, 905, and 910 MHz) for measurements spanning the GSM band. Measurements at these frequencies could be obtained in two ways: (1) holding source 1 at 925 MHz and sweeping source 2 downward from 960 MHz to 940 MHz in steps of 5 MHz, or (2) holding source 2 at 960 MHz and sweeping source 1 upward from 925 MHz to 935 MHz in steps of 2.5 MHz.

Of the three participants who made measurements in the GSM band, one made swept-frequency measurements in both directions, one made measurements at 890 and 895 MHz, and the other made a measurement at 910 MHz. Table 5 lists the measured data taken by the three participants. Statistical computations were not performed since we did not have adequate data at any one frequency, but measurements varied from –127.0 dBm to –138.5 dBm.

3.4. AMPS Band

We specified five particular IM3 frequencies (844, 845, 846, 847 and 848 MHz) for measurements spanning the AMPS band. Measurements at these frequencies could be obtained in two ways: (1) holding source 1 at 869 MHz and sweeping source 2 downward from 894 MHz to 890 MHz in steps of 1 MHz, or (2) holding source 2 at 894 MHz and sweeping source 1 upward from 869 MHz to 871 MHz in steps of 0.5 MHz.

Participant E, the only one to measure the termination in the AMPS band, made swept-frequency measurements in both directions. Table 6 lists the measured data taken by Participant E. Statistical computations were not performed since we received data from only one participant, but measurements did range from –130.5 dBm to –133.7 dBm.

3.5. Long-Term Stability

Throughout the period of the comparison (March 2000 through May 2001), we made stability-check measurements on a PCS system. Prior to sending out the termination to each participant, we measured it each time to make sure it was in working order and to verify the long-term stability of the artifact and our system. The measurements of the termination have remained stable to within a standard deviation of 2.6 dB on our system.

4. Discussion and Conclusions

Of the five PCS data sets received, most companies’ measurements fell within 2 standard deviations of the measured means, and none of the participants’ measurements fell outside of three standard deviations. And although we did not receive adequate data in the other communications bands to warrant statistical analysis, none of the measurements we received in those bands indicated significant discrepancies. We also found that measurements made by our system on the termination remained stable to within a standard deviation of 2.6 dB over a 14-month period.

This comparison of passive intermodulation measurements has addressed a direct request by U.S. base-station equipment manufacturers to check their systems at or near the noise floor level of most instruments in an impartial manner while preserving each company's anonymity.

The author thanks Donald DeGroot, Charlie Spellman and David Weinstein for their helpful comments regarding the preparation of this document.

5. References

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Table 2. Measurements of the low-PIM termination in the PCS band, by participant.

Src. 1 Freq (MHz)	Src. 2 Freq (MHz)	IM3 Freq (MHz)	A PIM (dBm)	B PIM (dBm)	D1 PIM (dBm)	D2 PIM (dBm)	E PIM (dBm)
1930	1990	1870	–129.8	–135.8	–123.0	–136.0	–131.7
1930	1980	1880	–131.3	–130.7	–134.0	–135.0	–126.9
1930	1970	1890	–126.3	–127.8	–135.0	–137.0	–126.3
1930	1960	1900	–132.0	–135.0	–130.0	–129.0	–126.2
1930	1950	1910	–129.8	–127.9	–129.0	–133.0	–124.1
1930	1990	1870	–130.4	–138.1	–127.0	–135.0	–130.5
1935	1990	1880	–132.7	–133.8	–125.0	–134.0	–127.7
1940	1990	1890	–128.5	–135.7	–136.0	–128.0	–123.0
1945	1990	1900	–132.5	–140.5	–126.0	–131.0	–122.1
1950	1990	1910	–126.5	–134.1	–122.0	–133.0	–121.9

Table 3. Mean values and standard deviations of the low-PIM termination in the PCS band.

IM3 Freq (MHz)	Mean (dBm)	Std. Dev. (dB)
1870	–129.4	5.5
1880	–129.8	3.9
1890	–128.1	4.2
1900	–128.0	5.0
1910	–126.2	4.2

Table 4. Measurements of the low-PIM termination in the DCS band, by participant.

Src. 1 Freq (MHz)	Src. 2 Freq (MHz)	IM3 Freq (MHz)	B PIM (dBm)
1805	1880	1730	–134.5
1805	1870	1740	–133.6
1805	1860	1750	–131.3
1805	1850	1760	–129.5
1805	1840	1770	–126.7
1805	1880	1730	–134.8
1810	1880	1740	–131.8
1815	1880	1750	–129.9
1820	1880	1760	–127.2
1825	1880	1770	–128.2

Table 5. Measurements of the low-PIM termination in the GSM band, by participant.

Src. 1 Freq (MHz)	Src. 2 Freq (MHz)	IM3 Freq (MHz)	B PIM (dBm)	C PIM (dBm)	D PIM (dBm)
925.0	960.0	890.0	–130.4	–133.2	---
925.0	955.0	895.0	–137.8	–134.3	---
925.0	950.0	900.0	–132.3	---	---
925.0	945.0	905.0	–134.5	---	---
925.0	940.0	910.0	–131.0	---	---
925.0	960.0	890.0	–127.0	---	---
927.5	960.0	895.0	–133.9	---	---
930.0	960.0	900.0	–129.6	---	---
932.5	960.0	905.0	–132.1	---	---
935.0	960.0	910.0	–138.5	---	–131.7

Table 6. Measurements of the low-PIM termination in the AMPS band, by participant.

Src. 1 Freq (MHz)	Src. 2 Freq (MHz)	IM3 Freq (MHz)	E PIM (dBm)
869.0	894.0	844.0	–130.5
869.0	893.0	845.0	–130.7
869.0	892.0	846.0	–132.5
869.0	891.0	847.0	–133.7
869.0	890.0	848.0	–131.5
869.0	894.0	844.0	–131.1
869.5	894.0	845.0	–130.8
870.0	894.0	846.0	–131.8
870.5	894.0	847.0	–132.9
871.0	894.0	848.0	–131.2

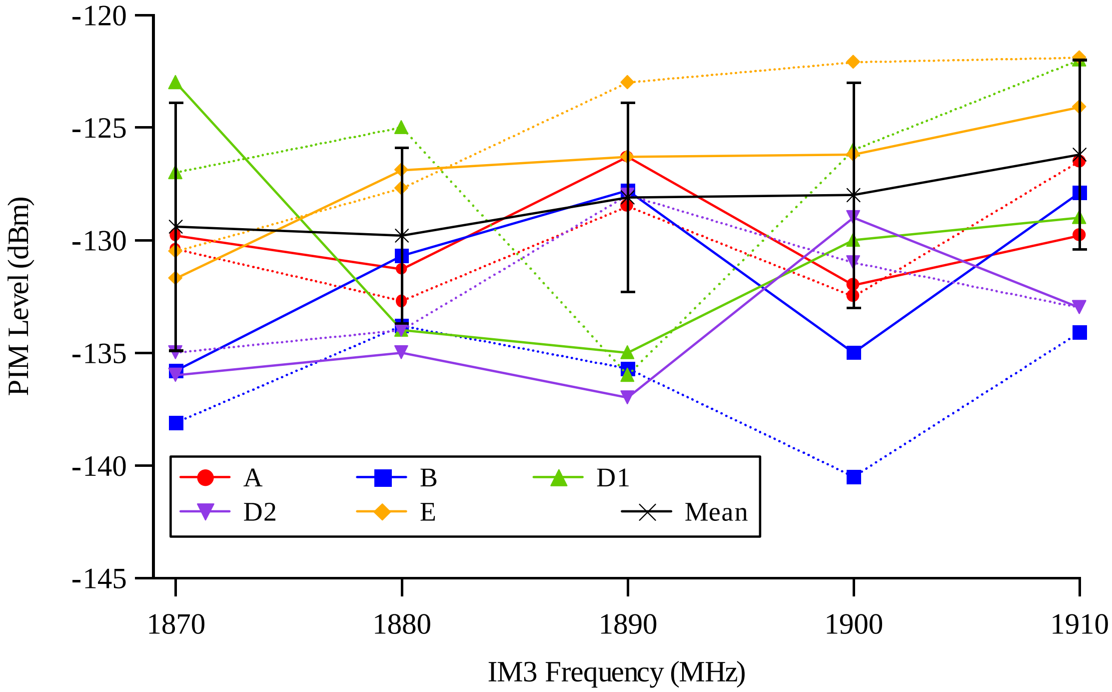

Figure 3. Measurements of the low-PIM termination in the PCS band, along with the means and standards deviations.

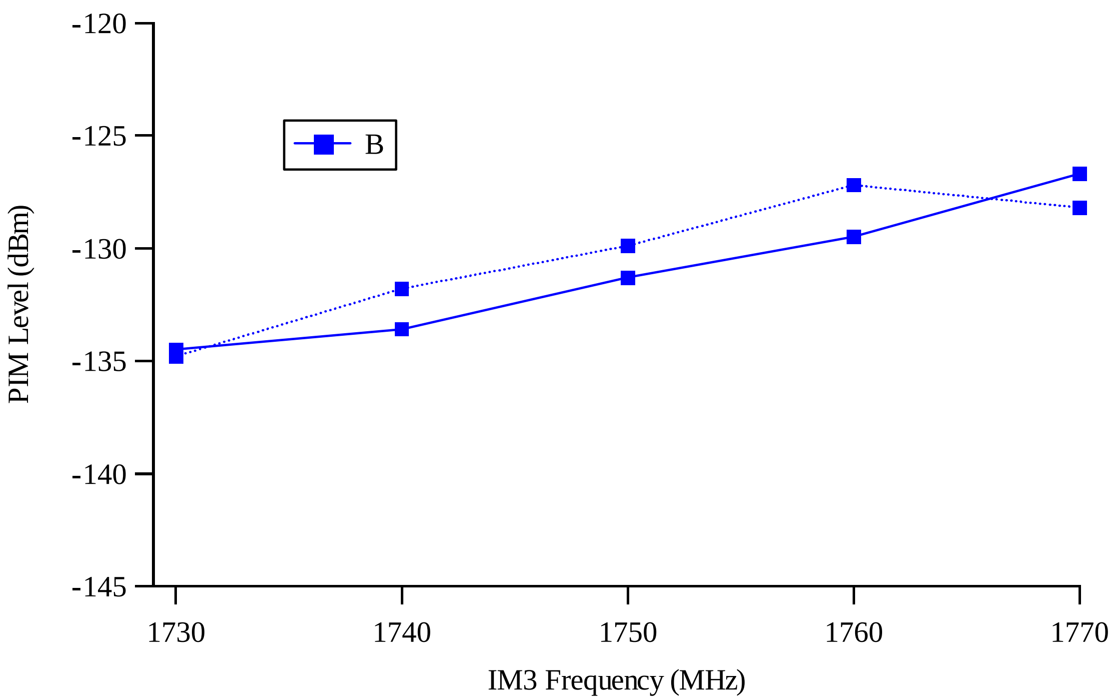

Figure 4. Measurements of the low-PIM termination in the DCS band.

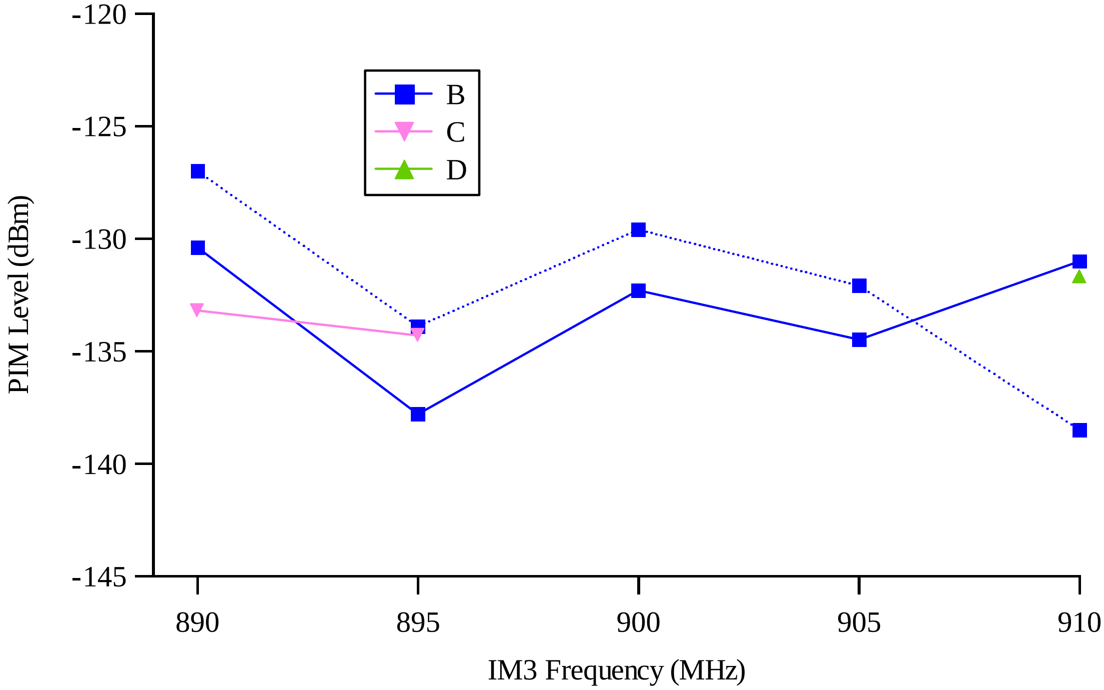

Figure 5. Measurements of the low-PIM termination in the GSM band.

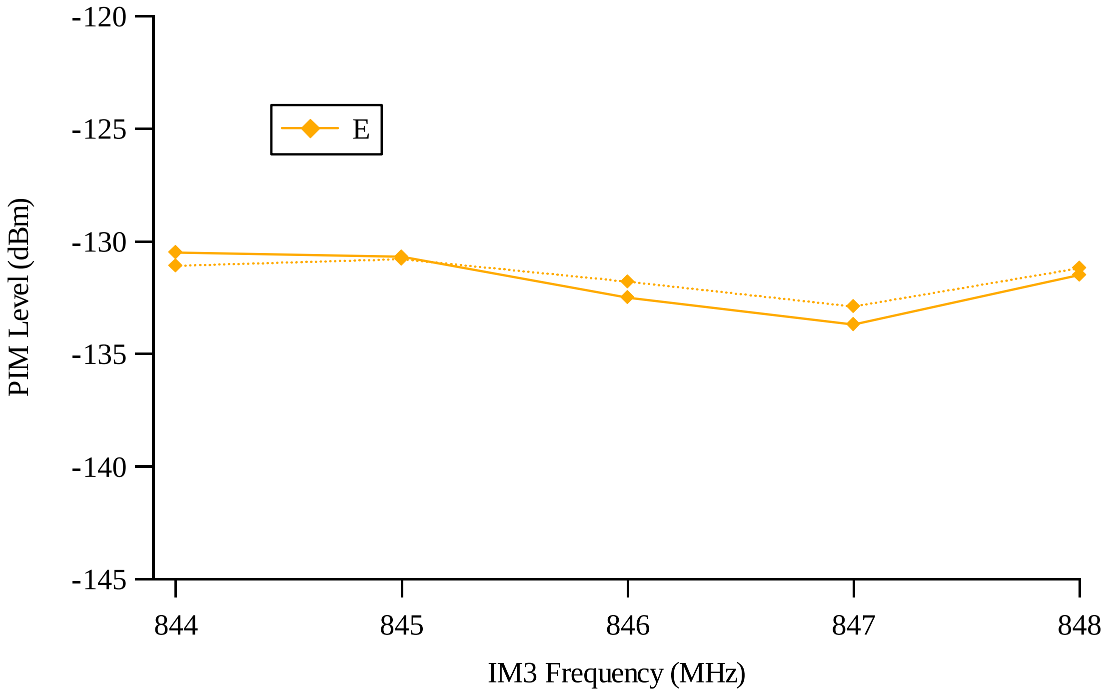

Figure 6. Measurements of the low-PIM termination in the AMPS band.

Appendix A. Instructions for Participants

NIST Passive Intermodulation Measurement Comparison for Wireless Base-Station Equipment

Instructions for Participants

Low-PIM Termination

You will find enclosed a one-port low-PIM termination with a female DIN 7-16 connector to be measured. Please make every effort to perform the measurements described below, and to send the artifact along with the data back to NIST within one calendar week after receiving it. If for some reason your laboratory cannot meet this deadline, contact us immediately so we can make alternative arrangements.

Measurements

The power of the third order intermodulation products of this artifact are to be measured in a system with two cw signal sources, following the International Electrotechnical Commission=s guidelines (IEC Technical Committee 46, Working Group 6). The two test signals should each measure +43 dBm (20 W) at the test ports of your measurement system. All measurements should be reported in dBm.

The third order intermodulation products of this artifact are to be measured within the receive (up-link) band of any or all of the communication bands listed below when the two +43 dBm signals are tuned to fall within the corresponding transmit (down-link) band. The minimum required data is a single third order intermodulation power in one communication band. If your system has the ability to make swept frequency measurements, please perform additional measurements at the frequencies listed on the attached Artifact Measurement Form. In either case, please provide an overall intermodulation value for the entire band in the space provided.

Measure the reflected intermodulation product by connecting the female connector of the termination to the active test port of your system by either a direct connection or by using a short cable or adapter.

If your system has the capability of measuring intermodulation products in more than one communication band, or if you have multiple systems, we encourage you to measure the devices in as many of the different bands as possible.

Communication band	Receive frequencies (MHz)	Transmit frequencies (MHz)
AMPS	824-849	869-894
PCS 1900	1850-1910	1930-1990
GSM	890-915	935-960
DCS 1800	1710-1785	1805-1880

Reporting the Results

When you have finished your measurements, enter your measured data (in dBm) into the provided Artifact Measurement Form replacing the zeroes with your data. Where you do not make measurements, do not replace the zeroes. On the form, your contact information and any comments you would like to share with us relating to your measurements, such as environmental conditions, measurement system and termination used, uncertainty bounds, and anything else you think appropriate.

Returning the Devices

Once you have completed the Artifact Measurement Form for this measured artifact, e-mail it to jjargon@nist.gov, and return the device with a hard copy of the data to:

NIST
c/o Puanani DeLara
325 Broadway, Mail Stop 813
Boulder, CO 80305

Contact Information

If you have any questions regarding these measurements, contact:

Jeffrey Jargon
NIST
325 Broadway, Mail Stop 813.01
Boulder, CO 80305

Tel: (303)497-3596
Fax: (303)497-3970
E-Mail: jjargon@nist.gov

Thank you for your participation. We will contact you in the near future showing you how your measurements compared with everybody elses=, keeping other companies= identities confidential. Likewise, your identity will remain confidential in the reports we send to other companies.

Appendix B. Artifact Measurement Form

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! ARTIFACT MEASUREMENT FORM
! Artifact:
! Date:
! Organization:
! Contact:
! Address (Line 1):
! Address (Line 2):
! Tel:
! Fax:
! E-Mail:
! Comments (Line 1):
! Comments (Line 2):
! Comments (Line 3):
!
! AMPS (824-894 MHz) - Overall PIM level: 0 dBm
! Freq1(MHz)  Freq2(MHz)  IM3Freq(MHz)  Reflected PIM(dBm)
   869.0       894.0         844.0          0
   869.0       893.0         845.0          0
   869.0       892.0         846.0          0
   869.0       891.0         847.0          0
   869.0       890.0         848.0          0
   869.0       894.0         844.0          0
   869.5       894.0         845.0          0
   870.0       894.0         846.0          0
   870.5       894.0         847.0          0
   871.0       894.0         848.0          0
! PCS 1900 (1850-1990 MHz) - Overall PIM level: 0 dBm
! Freq1(MHz)  Freq2(MHz)  IM3Freq(MHz)  Reflected PIM(dBm)
   1930.0      1990.0        1870.0         0
   1930.0      1980.0        1880.0         0
   1930.0      1970.0        1890.0         0
   1930.0      1960.0        1900.0         0
   1930.0      1950.0        1910.0         0
   1930.0      1990.0        1870.0         0
   1935.0      1990.0        1880.0         0
   1940.0      1990.0        1890.0         0
   1945.0      1990.0        1900.0         0
   1950.0      1990.0        1910.0         0
! GSM (880-960 MHz) - Overall PIM level: 0 dBm
! Freq1(MHz)  Freq2(MHz)  IM3Freq(MHz)  Reflected PIM(dBm)
   925.0       960.0         890.0          0
   925.0       955.0         895.0          0
   925.0       950.0         900.0          0
   925.0       945.0         905.0          0
   925.0       940.0         910.0          0
   925.0       960.0         890.0          0
   927.5       960.0         895.0          0
   930.0       960.0         900.0          0
   932.5       960.0         905.0          0
   935.0       960.0         910.0          0
! DCS 1800 (1710-1880 MHz) - Overall PIM level: 0 dBm
! Freq1(MHz)  Freq2(MHz)  IM3Freq(MHz)  Reflected PIM(dBm)
   1805.0      1880.0        1730.0         0
   1805.0      1870.0        1740.0         0
   1805.0      1860.0        1750.0         0
   1805.0      1850.0        1760.0         0
   1805.0      1840.0        1770.0         0
   1805.0      1880.0        1730.0         0
   1810.0      1880.0        1740.0         0
   1815.0      1880.0        1750.0         0
   1820.0      1880.0        1760.0         0
   1825.0      1880.0        1770.0         0
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