Mitigating external sources of Passive Intermodulation (PIM)

By Thomas Bell

Table of Contents

1.0 Introduction

Passive Intermodulation (PIM) is a growing problem in communications systems. PIM appears as new frequencies created by the mixing of two or more signals in a passive, non-linear device such as a loose RF connector or rusty bolt. When these unwanted signals fall inside an operator's uplink band they raise the system noise floor which causes reduced coverage and increased dropped call rates. In LTE networks, PIM interference causes the system to invoke higher error protection and decreased modulation complexity, resulting in significantly lower data throughput.

RF equipment manufacturers have learned to control Passive Intermodulation over the years by eliminating non-linear materials and by assuring high contact pressure at all mechanical interconnects in the RF path. Soldered or welded connections are preferred, but when not practical can be replaced by properly torqued screws equipped with lock washers to prevent loosening. When high contact pressure cannot be assured, a common practice is to insulate the mating surfaces with a dielectric material to prevent metal-to-metal contact altogether. Even with stringent design features in place, RF equipment manufacturers still require a PIM test on the final product to guarantee low PIM performance.

Since the introduction of portable PIM test equipment in 2005, installation contractors are also learning to control Passive Intermodulation in the RF systems they construct. Proper workmanship in the preparation of coaxial cable has a very large impact on the PIM performance of the completed system. Foam and adhesives must be removed from all contact areas, metal flakes left over from the cutting process must be removed, jagged metal edges should be avoided by using only sharp cutting tools and proper assembly torque must be applied to all connections. This is no small chore considering that these connections are often made at the top of a tower under adverse weather conditions. Even with these measures in place, the only way to assure low PIM construction is to test the final system in the field using portable PIM test equipment.

The final challenge in reducing Passive Intermodulation at cell sites is to eliminate PIM sources in the RF path occurring beyond the antenna aperture. If a non-linear object beyond the antenna is excited with sufficient RF power, PIM is generated and re-radiated back into the antenna system. This is a big challenge since cell sites are no longer dominated by tall, isolated towers with a clear view of the sector being served. Rather, cell sites are being deployed on rooftops for improved aesthetics, at street level for localized coverage, and inside buildings for increased capacity. These environments are filled with potential PIM sources such as sheet metal vents, metal flashing, ceiling tile frames and street lamps that may be outside of the control of the network operator. While the non-linearities themselves are relatively similar, different techniques must be deployed in each environment to minimize external PIM generation.

2.0 Roof-top installations

Roof-top sites, as shown in Figure 1, are primarily macro sites designed to cover a wide geographic area. Directional panel antennas with 65° azimuth beamwidth and 5° to 15° elevation beamwidth are typically deployed. The most effective way to minimize external PIM in rooftop applications is to avoid metal objects within the antenna's half-power beamwidths (Figure 2). This can be achieved by placing antennas near the edge of the rooftop with a clear view of the sector being served. Recessing antennas away from the building edge increases the number of metal objects illuminated and increases the probability of external PIM issues.

Figure 1. *Rooftop antenna installation*

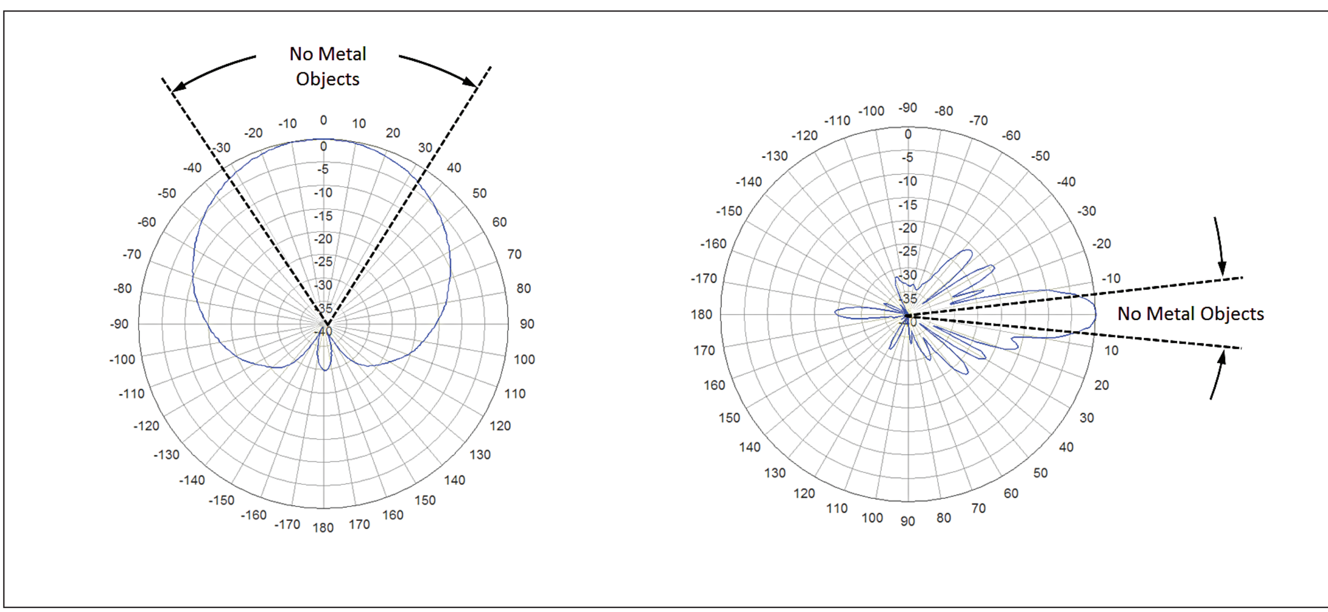

Figure 2. *Azimuth and Elevation patterns for typical sector antenna with "No Metal" zones identified*

Antennas can also be mounted on pipes attached to the exterior surface of the building. This mounting style eliminates metal objects directly in front of the antenna but increases exposure of objects to the side of the antenna as it is rotated to its required azimuth orientation. Efforts should be taken to avoid rotating an antenna more than 60° relative to the building surface to minimize illumination of the building structure.

Figure 3. *Concealment panels in front of antennas*

Placing antennas in locations that minimize external PIM often makes the antennas highly visible from the street. In many cases plastic or fiberglass "concealment" panels are installed in front of or around these antennas to hide them from view, as shown in Figure 3. Care must be taken when constructing concealments to make sure that only non-metallic materials (including concealment panels, supporting structures and fasteners) are used so that PIM is minimized. In addition, any material placed in front of an antenna may change the radiation pattern of that antenna. Improperly designed concealments can spread the antenna beam, causing unintended external metal objects to be illuminated or causing reduced isolation between adjacent bands. If a concealment is suspected to be exciting external PIM sources, try removing the components, one at a time, to isolate the source of the interference.

3.0 External PIM sources

Reducing exposure of metallic objects within the antenna's half power beamwidth is a good start, but may not eliminate all external PIM problems at a site. In the near field of the antenna, radiation patterns are not fully formed. Depending on location, metal objects in the near field may couple energy more strongly than the same object will when located in the antenna's far field. Figure 4 shows this effect on an assortment of external PIM sources placed varying distances from a 0.6 m "small cell" antenna mounted inside an anechoic chamber.

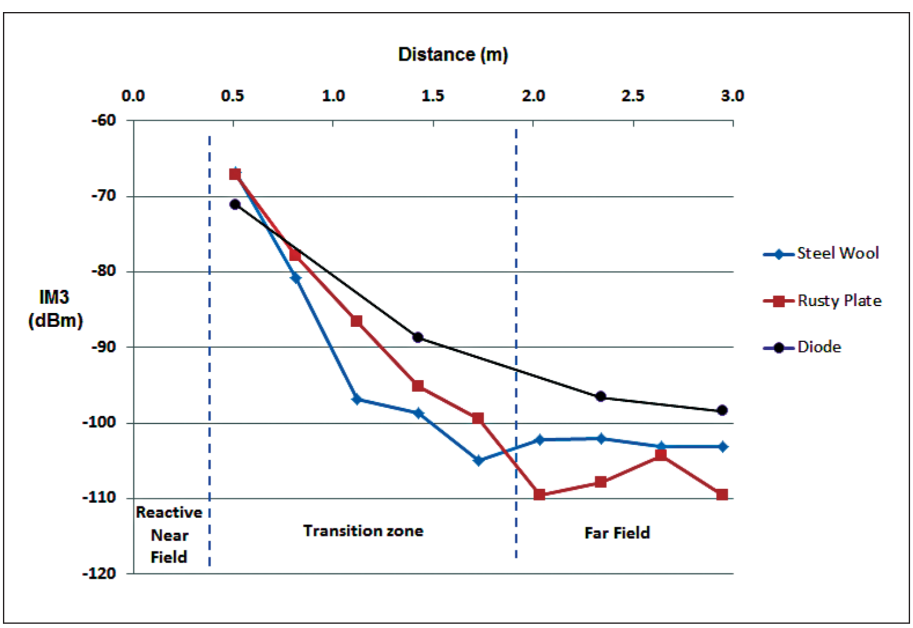

Figure 4. *PIM vs. Distance for objects placed in front of an antenna*

An approximation of the near field to far field transition (where D>>λ) is a distance of $2D^2/\lambda$, where D = the antenna's longest dimension and λ = wavelength of operation. Using this equation with typical indoor, small cell and macro cell antenna dimensions shows that objects within 7 m and as far away as 37 m (depending on frequency and antenna size) are within the antenna's near field for a typical rooftop site (Figure 5). Highly non-linear objects, such as metal safety chains or loosely overlapping sheet metal, should be avoided as much as possible in the antenna's near field and especially avoided within one wavelength (reactive near field) of the antenna aperture.

Common name	E-UTRA operating band	Downlink band			Antenna length (m)					
					Indoor	Small cell		Macro cell		
		Upper limit (MHz)	Lower limit (MHz)	Mid-band λ (m)	0.15	0.3	0.6	1.2	1.5	2.4
					Far Field (m)					
LTE 700 (lower)	Band 12	729	746	0.41	0.11	0.5	1.8	7.3	11.4	29.3
LTE 700 (upper)	Band 13	746	756	0.40	0.12	0.5	1.9	7.4	11.6	29.8
LTE 800	Band 20	791	821	0.37	0.12	0.5	2.0	8.0	12.5	32.0
850 MHz	Band 5	869	894	0.34	0.14	0.5	2.2	8.7	13.7	35.0
E-GSM 900	Band 8	925	960	0.32	0.15	0.6	2.3	9.3	14.6	37.4
DCS 1800	Band 3	1805	1880	0.16	0.29	1.1	4.6	18.3	28.5	-
PCS 1900	Band 2	1930	1990	0.15	0.30	1.2	4.9	19.4	30.4	-
UMTS 2100	Band 1	2110	2170	0.14	0.33	1.3	5.3	21.2	33.2	-
LTE 2600	Band 7	2620	2690	0.11	0.41	1.6	6.6	26.3	41.1	-

Figure 5. *Far Field approximation vs. frequency for various an antenna lengths*

It is interesting to note that polarization also has an impact on how strongly energy couples into a non-linear junction. It is not uncommon for an external PIM source to generate high levels of PIM when illuminated by one polarization and not generate any significant PIM when illuminated by an opposite polarization. This effect can be seen in Figure 6, where Anritsu's Distance-to-PIM™ feature was used at a site to measure both the +45° and –45° polarization feed lines. Overlapping layers of metal flashing at a distance of 4.3 m (14 ft) in front of the antenna generated IM3 at a level of –82 dBm when illuminated by 2x 20W test tones at +45° polarization. The same external PIM source generated very little PIM when illuminated by test tones at –45° polarization. This information could be useful when optimizing site performance. If only one downlink path were required on this sector, site performance could be improved by placing the downlink signals on the –45° port, which is not impacted by PIM interference.

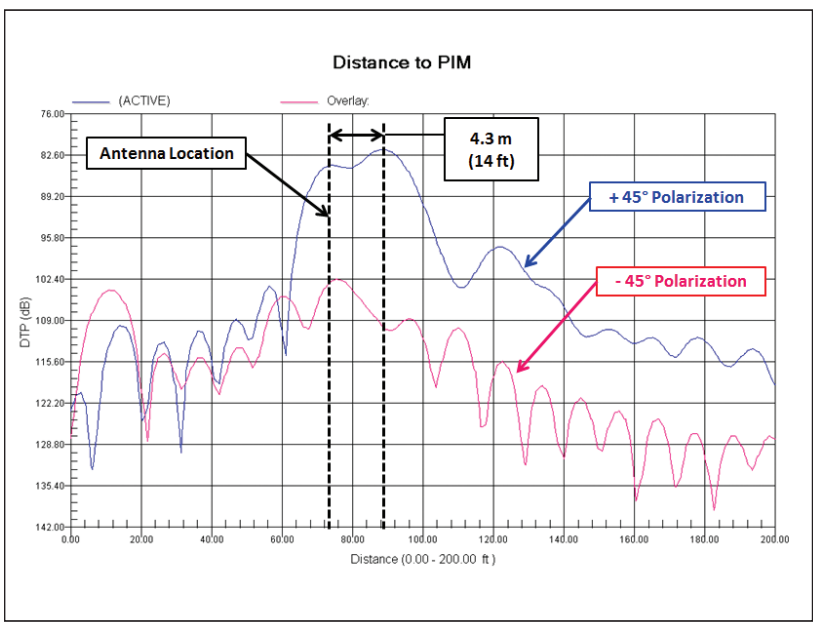

Figure 6. *Overlay of +45° and -45° Distance-to-PIM™ plots*

4.0 Indoor installations

Indoor antennas are typically installed as part of a Distributed Antenna System (DAS) to provide localized coverage inside a building or venue. Most indoor antennas are omni-directional (360° azimuth beamwidth) with very wide elevation beamwidth (>80°), as shown in Figure 7, due to the antenna's small physical size (0.15 m diameter.) With these wide beamwidths, it is virtually impossible to avoid illuminating metal objects when installed inside a building.

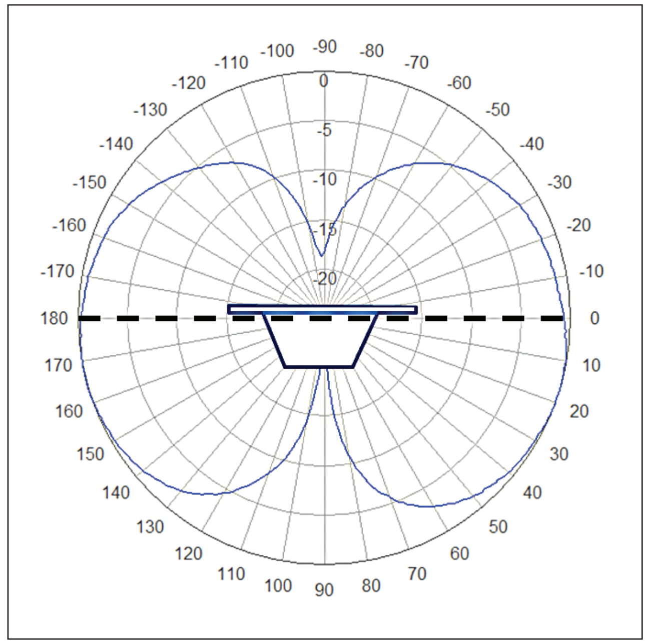

Figure 7. *Indoor antenna, elevation pattern at 700 MHz*

Luckily, the RF power radiated by individual indoor antennas is significantly lower than the power radiated by macro site antennas. Power levels on the order of 15 dBm are typical for indoor antennas compared to power levels >40 dBm at macro site antennas. Since PIM magnitude typically changes 2.5 dB for every 1 dB change in transmitted power, one should expect PIM levels generated near an indoor antenna to be more than 60 dB lower than PIM levels generated near a macro site antenna. This has led many to assume that PIM sources around indoor antennas can be ignored. Unfortunately, this is not the case. Even with reduced power levels, highly non-linear objects are often present in indoor environments, generating PIM levels high enough to degrade system performance.

While "pointing" the antenna away from PIM sources is not a viable option, re-positioning the antennas a small distance can be very effective at reducing PIM. Due to the small size of indoor antennas, and the correspondingly small near field region (Figure 5), small antenna movements can have a large impact on the energy coupled into nearby PIM sources. Movements as small as 0.5 m can reduce PIM levels significantly.

Some network operators now require a "PIM survey" to evaluate environmental PIM at the planned antenna location prior to installation. An indoor antenna is installed on a fiberglass mast and placed as close as possible to the design position (Figure 8). If the measured PIM level exceeds the specification, the antenna is moved within an agreed radius while under test to look for a better location. Once identified, the location is marked and the site plans updated to document the new position. This method has proven very effective at identifying and correcting external PIM problems early in the project cycle rather than waiting to find these problems after construction when changes are expensive and isolating the faulty location may be difficult

Figure 8. *Indoor antenna on mast performing PIM survey test*

5.0 Street level installations

Figure 9. *Small cell antenna installation*

Outdoor DAS as well as "Small cell" deployments often utilize existing structures such as street lamps and telephone poles to provide coverage at street level. These low sites can provide increased capacity in a small area or provide fill-in coverage in areas not served by macro sites.

Small, omni-directional antennas (0.3 m to 0.6 m tall) are often used for these applications due to restrictions imposed by the municipality that owns the structure. Depending on frequency, the near field region extends 0.5 m to 6 m from the antenna mounting location (Figure 5). Typical metal objects that are encountered in this zone include lamp fixtures, power lines and metal support structures. With an omni-directional pattern and almost no ability to re-locate the antenna away from external PIM sources, other techniques must be deployed to mitigate external PIM. One such solution involves the use of quasi-omni antennas.

A quasi-omni antenna is made by phasing three panel antennas together inside a cylinder, 120° apart. The radiation pattern for this style antenna has maximum gain on the boresite of each panel and reduced gain between panels (Figure 10). Due to the large amount of scattering in the street level environment, the nulls in the azimuth pattern have little impact on site coverage. However, rotating this style antenna after installation provides a method to "steer" the azimuth nulls in the direction of external PIM sources and improve site performance.

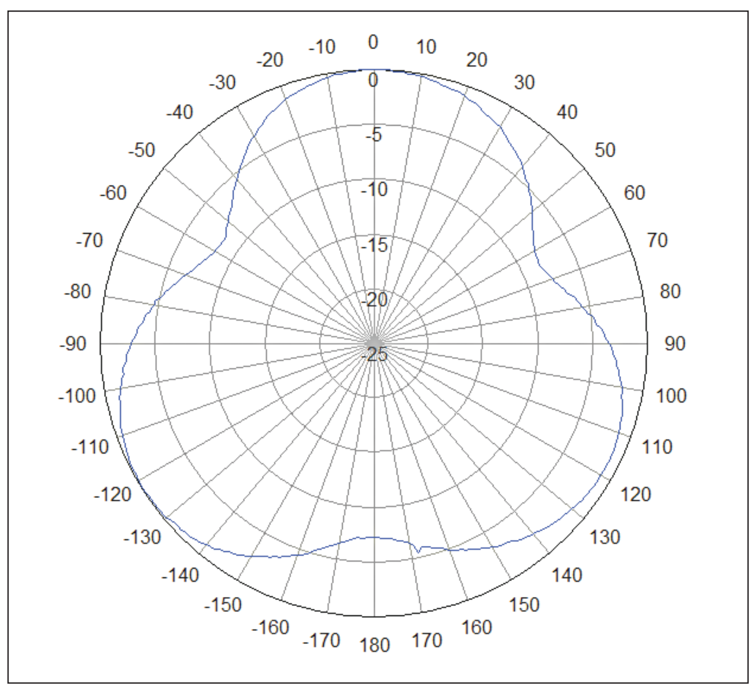

Figure 10. *Quasi-omni antenna azimuth pattern at 700 MHz*

To test this concept a 0.3 m quasi-omni antenna was mounted on an azimuth positioner inside an anechoic test chamber. A PVC structure was constructed inside the chamber to allow controlled movement of an external PIM source with respect to the antenna. PIM vs. time measurements were made at 15 different external PIM source locations while the antenna was rotated 360°. A sample PIM vs. time measurement, while the antenna is rotating, is shown in Figure 11.

At the worst PIM source locations (on boresite, near the antenna) the PIM level was able to be reduced >30dB when the null in the azimuth pattern was directed at the external PIM source. More importantly, a passing PIM test result was able to be obtained at all 15 external PIM locations simply by rotating the antenna. This technique should prove very useful for minimizing external PIM in the typical small cell environment.

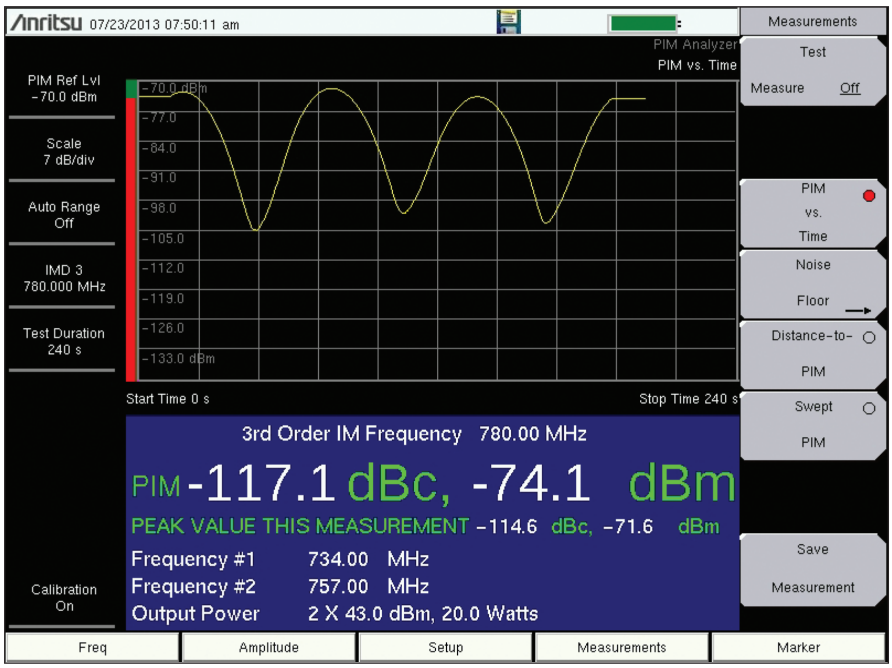

Figure 11. *PIM vs. time plot of Quasi-omni antenna as it is rotated 360 degrees*

6.0 Conclusion

External PIM sources can be a challenge regardless of the environment in which they are encountered. As discussed in this paper, the most effective method to mitigate external PIM is to adjust the antenna location. Changing the antenna's position or orientation to move nearby metal objects outside of the antenna's main beam is effective for both rooftop installations as well as street level installations. Changing the antenna position to move highly non-linear objects outside the antenna's near field is effective for indoor installations. Though each installation type presents its own unique challenges, mitigation techniques are available to reduce external PIM and improve site performance.

7.0 Acknowledgements

I would like to acknowledge Nicholas Cordaro at Verizon Wireless for proposing quasi-omni antennas as a solution for reducing PIM in small cell deployments and CSS Antennas for providing the antennas and the measurement range to enable evaluation of the concept.

I would also like to acknowledge Phillip Chan, John Beadles and Marc Beranger at Rogers Communications for developing the antenna location PIM survey as a means to optimize PIM performance in indoor wireless systems.

• United States
Anritsu Company
1155 East Collins Boulevard, Suite 100,
Richardson, TX, 75081 U.S.A.
Toll Free: 1-800-ANRITSU (267-4878)
Phone: +1-972-644-1777
Fax: +1-972-671-1877

• Canada
Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120,
Kanata, Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• Brazil
Anritsu Electrônica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - São Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• Mexico
Anritsu Company, S.A. de C.V.
Av. Ejército Nacional No. 579 Piso 9, Col. Granada
11520 México, D.F., México
Phone: +52-55-1101-2370
Fax: +52-55-5254-3147

• United Kingdom
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433280
Fax: +44-1582-731303

• France
Anritsu S.A.
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 VILLEBON SUR YVETTE, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

• Germany
Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49 (0) 89 442308-0
Fax: +49 (0) 89 442308-55

• Italy
Anritsu S.r.l.
Via Elio Vittorini 129 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-06-502-2425

• Sweden
Anritsu AB
Kistagangen 20B, 164 40 KISTA Sweden
Phone: +46-8-534-707-00
Fax: +46-8-534-707-30

• Finland
Anritsu AB
Teknobulevardi 3-5, FI-01530 Vantaa, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

• Denmark
Anritsu A/S (for Service Assurance)
Anritsu AB (for Test & Measurement)
Kay Fiskers Plads 9, 2300 Copenhagen S, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

• Russia
Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor.
Russia, 125009, Moscow
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• United Arab Emirates
Anritsu EMEA Ltd.
Dubai Liaison Office
P O Box 500413 - Dubai Internet City
Al Thuraya Building, Tower 1, Suite 701, 7th Floor
Dubai, United Arab Emirates
Phone: +971-4-3670352
Fax: +971-4-3688460

• Singapore
Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• India
Anritsu Pte. Ltd.
India Branch Office
2nd & 3rd Floor, #837/1, Binnamangla 1st Stage,
Indiranagar, 100ft Road, Bangalore - 560038, India
Phone: +91-80-4058-1300
Fax: +91-80-4058-1301

• P. R. China (Shanghai)
Anritsu (China) Co., Ltd.
27th Floor, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, Xu Hui Di District,
Shanghai 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• P. R. China (Hong Kong)
Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P. R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• Japan
Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi,
Kanagawa, 243-0016 Japan
Phone: +81-46-296-1221
Fax: +81-46-296-1238

• Korea
Anritsu Corporation, Ltd.
502, 5FL H-Square N B/D, 681,
Sampyeong-dong, Bundang-gu, Seongnam-si,
Gyeonggi-do, 463-400 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• Australia
Anritsu Pty Ltd.
Unit 21/270 Ferntree Gully Road,
Notting Hill, Victoria 3168, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• Taiwan
Anritsu Company Inc.
7F, No. 316, Sec. 1, Neihu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

11410-0756, Rev. A Printed in United States 2013-9