White Paper

A New Technique for Measuring Passive Intermodulation Over Fiber Optic Cables

Background

Passive intermodulation (PIM) continues to be a growing issue for cellular network operators. As mobile technology has progressed, cellular networks have drastically increased the complexity of the communication link. This complexity has necessitated that transmit powers increase as the noise floor of receivers decrease. Due to the greater demands on the entire communication network, the quality of all aspects of the network have had to improve including mobile devices and base stations. All interference signals related to the mobile network have increasingly affected the quality of the network. Interfering signals can be generated by passive intermodulation, active modulation, rouge communication signals, known low-level interfering sources, adjacent channel noise, as well as many others.

PIM is an interfering signal that can be generated internally or externally to the communication system. PIM measurement equipment is designed to locate and help mitigate these interfering sources.

PIM is created via three primary mechanisms

1 – Poor quality base station construction – including: loose or poorly constructed connectors; pinched or damaged cables; poor quality or damaged antennas; or just bad cell site configuration (e.g., how the antennas are positioned relative to other antennas/co-located at cell sites)

2 – External physical effects – for example, if the antennas radiate into a PIM reflective material such as a rusty roof or rusty chains. With densification efforts ongoing, it is increasingly difficult to find “clean” cell sites that are PIM free. Even tower-mounted antennas commonly suffer from PIM due to the equipment mountings themselves.

3 – Co-located adjacent RF bands transmissions – carrier aggregation is a key requirement of 4.5 (LTE Advanced) and 5G networks, and yet doing this (transmitting and combining multiple frequency bands) invites the risk that the aggregated spectrum will mix and create PIM.

As we increase the density of cellular solutions, PIM effects will increase. It is important to note that while PIM is mostly seen in high-power cell sites, PIM is also present at lower transmit powers (such as used in distributed antenna system [DAS]) and its effects will grow as more RF bands are added. This is particularly significant in 5G with the growth of seamless integration of multiple base station technologies to service user needs.

PIM has been viewed as an installation problem. It is true that good site installation will minimize PIM, but PIM by its very nature is an ongoing and evolving problem. Today, PIM is more likely to occur due to changes in frequency content or the physical environment in the vicinity of the cell site. For example, a new RF band is added to an existing cell site, a new physical structure is added within the range of a cell site, or over time the cell site connectors corrode or become loose.

A short summary of PIM — What is it?

PIM is a form of intermodulation distortion that occurs when multiple frequencies combine in a non-linear fashion to produce undesired mixing products. This can even take place in components normally thought of as linear, such as cables, connectors, and antennas. If subjected to the high RF powers found in cellular systems, these devices can generate intermodulation signals at –80 dBm or higher. When passive intermodulation signals are generated late in the signal path, they cannot be filtered out and may have a more damaging impact on cell site performance than the stronger, but filtered, IM products from active components.

A PIM test is a comprehensive measure of linearity and construction quality. PIM shows up as a set of unwanted signals created by the mixing of two or more strong RF signals in a nonlinear device, such as a loose or corroded connector or nearby rust. Other names for PIM include the diode effect and the rusty bolt effect. This pair of formulas can predict PIM frequencies for two carriers:

$$nF1 - mF2 \quad \text{Equation 1}$$

$$nF2 - mF1 \quad \text{Equation 2}$$

F1 and F2 are carrier frequencies and the constants n and m are +/- integers. When referring to PIM products, the sum of n + m is called the product order, so if m is 2 and n is 1, the result is referred to as a third-order product (Figure 1). Typically, the third-order product is the strongest with the potential to cause the most harm, followed by the fifth- and seventh-order products.

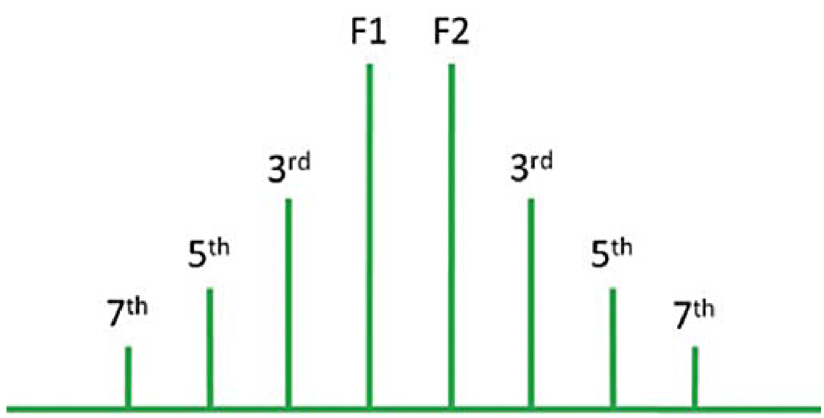


Figure 1. Carriers F1 and F2 with 3rd through 7th order products

Modern mobile communication systems have wide transmit signals, which will mix with themselves to generate wide intermodulation signals centered at the same frequencies and predicted by the intermodulation equations. These patterns can overlap with other intermodulation signals created as a result of different intermodulation orders (Figure 2). By using PIM test equipment to detect and locate PIM sources, the wide spectral pattern of the intermodulation source will decrease and not interfere with the wanted received mobile signal.

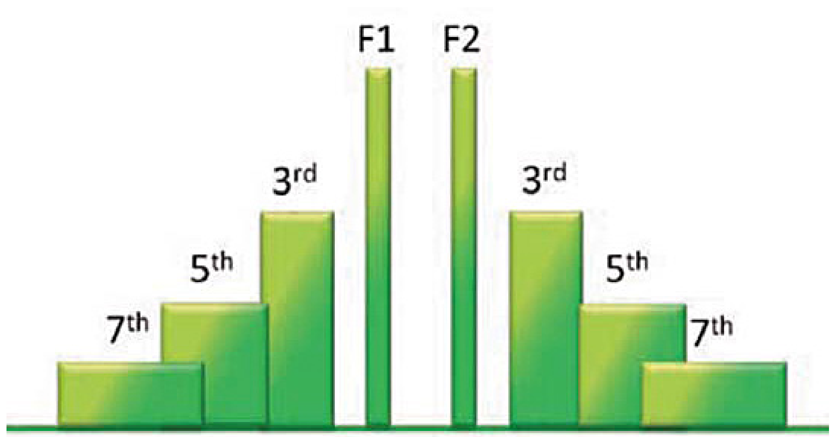


Figure 2. PIM bandwidth increases with the order of the product

Current test methods to tackle PIM, how they fit into testing PIM, and why do we need new PIM test methods?

There currently are three primary methods to measure PIM:

RF-based PIM testers – The Anritsu PIM Master™ MW82119B is a portable test solution that allow the engineer to generate two 40W RF tones at a set of RF frequencies (F1 and F2) to measure the effects of PIM.

Spectral analysis over CPRI – A relatively new method where using spectral analysis of I/Q data on the fiber interface between the baseband unit (BBU) and remote radio head (RRH). The user can look for the telltale profile of PIM.

Noise rise monitoring – Using the installed cellular equipment, set OCNS/AILG (OCNS = Orthogonal Channel Noise Simulator; AILG = Air Interface Load Generator) on all carriers under test and measure RSSI (Receive Signal Strength Indicator) per carrier/resource block where possible in each potential victim uplink (UL).

These methods have been instrumental in helping to reduce the effects of PIM but they do have limitations where the industry needs new solutions to support current and future 4 and 5G networks.

RF-Based PIM Tester	**Positives**
	Test sites that run coax from ground to top of tower
	Rooftop installations
	DAS systems (coax, hybrid) – low power
	New site installations
	Distance-to-PIM (DTP) – PIM location
	Negatives
	Frequency-specific RF test box
	Fiber DAS systems
	RF connections broken to test for PIM
Spectral Analysis over CPRI	**Positives**
	Frequency-agnostic test equipment
	Measurements taken at ground level
	Negatives
	Tends to work with strong PIM signals
	Used to indicate potential for PIM (additional test needed)
	No location of PIM problem
	Requires optical tap
Noise Rise Monitoring	**Positives**
	Requires no additional equipment or software at cell site
	Measurement taken remotely from active cell site
	Negatives
	Requires creation of scripts to test and analysis tools to review data
	Tends to work with strong PIM signals
	Used to indicate potential for PIM (additional testing needed)

What is needed is a strategy that incorporates the solutions we have today and can build upon these so that operators have a comprehensive and cost-effective tool kit to deal with the PIM problems of today and tomorrow. To define such a strategy, there are some key factors that need to be considered:

- Cost: Test equipment, training, support teams and network downtime.
- Cell site considerations: Is this a new cell site in commissioning phase or existing installation? Is this a tower cell site or rooftop cell site with easy access?
- PIM Scenario: PIM is complex and there are number of ways PIM can occur, are we looking at:

Single-band PIM	PIM created from a single RF frequency band (IM product/Carrier BW)
Harmonics	2nd & 3rd Harmonics
On-site PIM	PIM created on the physical cell site
Off-site PIM	PIM created remotely to the cell site

New PIM over CPRI Method

A new method has been developed to provide additional insight into PIM. This new method, PIM over CPRI, allows the user to:

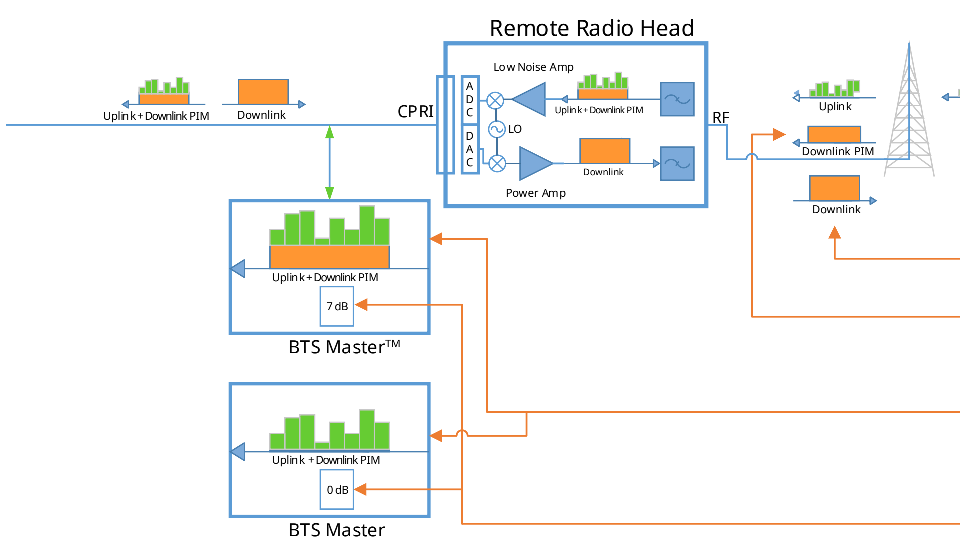
- Have a powerful view into all of the scenarios measured above including how all the IM products that fall in the uplink and all harmonic scenarios in a single measurement instrument
- Monitor live traffic remotely without disturbing cell site RF equipment
- Accurately identify on-site/off-site PIM location
- Accurately measure PIM level near or below the RRH noise floor and/or in the presence of a busy uplink
- Measure PIM for single-band or harmonic scenarios
- Predict the viability of using third-party/OEM PIM mitigation solutions

How PIM over CPRI works

The CPRI optical link contains both downlink and uplink signals transmitted via RF signal path and received via RF signal path.

The remote radio head (RRH) converts downlink data into an RF signal that is transmitted to users. The RRH also receives uplink RF signal and convers it to CPRI data.

By having knowledge of the downlink RF signal pattern-one can predict what that intermodulated interfering signal pattern would be like in the uplink spectrum.



1. Using the downlink signal pattern
2. One can determine what the Interference signal would look like in the uplink spectrum
3. One can then compare the predicted interference signal with the measured received signal to determine if any component of that signal has the interference pattern present
4. One can then separate the uplink signal from the interference signal to quantify the quantity of PIM in the RF link

The CPRI link carries complex baseband data representing the downlink (DL) and uplink (UL) signals as transmitted and received at RF by the remote radio unit. As such, the data on the CPRI uplink will show the signals received from user equipment (UE) and any interference suffered by the RF signal. By tapping into the CPRI link, we can observe the transmitted and received signals real time in an operational cell site. However, observing the received spectrum gives us only a limited understanding of those impairments because we cannot easily differentiate between wanted UE signals and PIM. Even when PIM is quite severe, it can be very hard to identify within the spectrum. Some network OEMs will ask UEs to lower the transmit power to reduce the noise floor, while others will ask them to increase their transmit power to overcome a high noise floor. However, both methods will cause a reduction of capacity and/or coverage area.

PIM over CPRI employs a new innovative algorithm to differentiate PIM from wanted UE signals. With knowledge of downlink signals, the algorithm uses that knowledge to build a detailed mathematical model of the PIM affecting the uplink. By correlating the modelled PIM with the received uplink signal, any actual PIM present within the uplink can be identified.

Because the algorithm works on the baseband signals, the instrument is band agnostic. To configure the mathematical model it requires knowledge of the center frequency as well as the bandwidths of the downlink and the uplink carriers. The signals used for the mathematical model are flexible enough to allow inter-band and cross-sector PIM to be measured. The algorithm measures PIM by modelling all of the MIMO downlink transmissions in real time against the individual MIMO uplink signals to isolate PIM created from each antenna or a combination.

A full MIMO model is also essential to identifying whether the primary PIM source lies within the antenna line or external to the antenna system. In practice, external PIM sources can appear stronger from one antenna versus another due to their position or polarization. This information helps the algorithm determine whether the PIM source is located internal or external to the antenna location.

Benefits and Key Characteristics of CPRI PIM Measurements

One of the major benefits of CPRI PIM detection over traditional RF PIM detection is that it can do a non-invasive measurement on a cell site that is in service. Basic PIM surveys can be done without a tower climb and during office hours. As the PIM source is illuminated by real cellular traffic, the PIM measured is directly applicable to UL desensitization and the real PIM impact on the network.

The algorithm requires a minimum DL power level to create the mathematical model. Real-time downlink traffic may or may not generate enough power for the algorithm. In the case that there isn’t enough downlink traffic, a method can be employed to increase DL power for the algorithm. This requires an adjustment to the sector under test. The best way to ensure adequate DL activity is to enable OCNS/AILG (or equivalent) on the system to populate any empty resource blocks (RBs). This method does not affect active users on the system. The measurement also provides a check on the transmit signal strength to insure minimum signal level.

Implementation of PIM Over CPRI in Anritsu’s BTS Master™ MT8220T

The PIM analysis software measures optical levels in dB Full Scale (dBFS, which is the full scale of the digitized data stream from the RRH to BBU). These can also be displayed as dBm based on user preference. The conversion factor from dBFS to dBm is a characteristic of the RRH and is normally a standard value for any one class of RRH. The instrument provides a dialogue box for setting the conversion factor, with suitable default values based on any RRH vendor profile selected.

The software calculates a desensitization metric in dB that indicates by how much the UL channel noise floor has been raised by PIM. This is a key figure of merit that is directly relatable to cell performance. If the desensitization metric exceeds a preconfigured threshold (typically 3 dB), the cell degradation will be too high to tolerate and the test is considered a FAIL. Measurements that exceed this threshold will significantly impact data throughput and UE capacity on the uplink.

Example from Anritsu BTS Master™ MT8220T with PIM Over CPRI Analyzer Option

The plots below are for a Band 13 2T2R RRH with LTE10 downlinks at 751 MHz and uplinks at 782 MHz. The BTS Master MT8220T base station analyzer is set to alternately measure both ULs: Figure 3 shows the results for UL1 (with PIM) and Figure 2 shows the results for UL2 (no PIM).

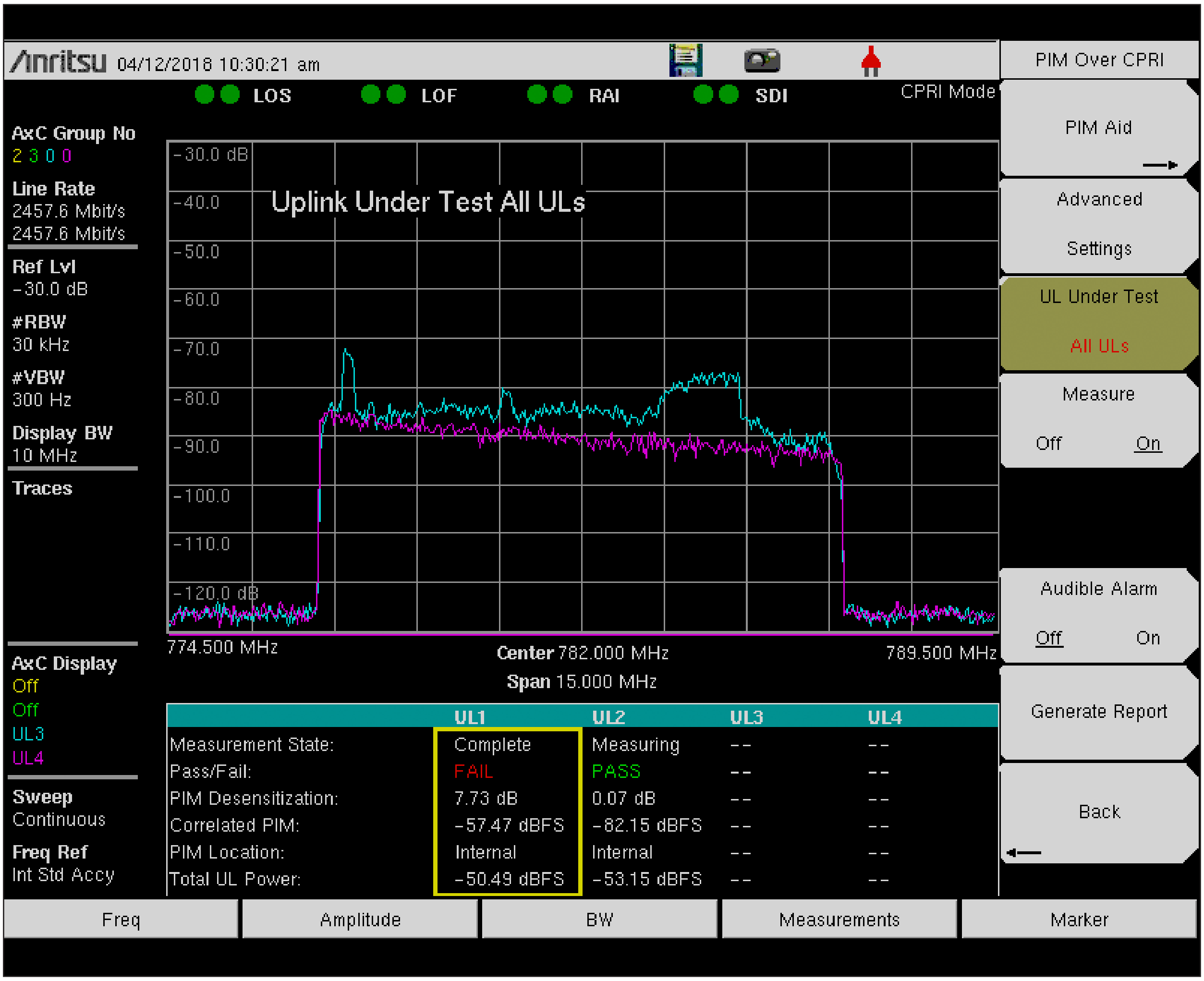


Figure 3. Example of Measurement, active UL1 with PIM

Referring to Figure 3:

- The traces shown and the results highlighted in the yellow box both relate to UL1
- The cyan trace is a spectrum of the UL signal capture on which the PIM measurement is performed and therefore contains both PIM and UE activity
- The magenta trace is the spectrum of the PIM signal component present in the same capture. As we can see from the traces and measurement values, it is approximately 7 dB below the total UL power in this case. It is therefore almost entirely masked by UE activity
- As seen in the results in yellow highlighted box, UL1 is showing a serious internal PIM problem. A repair on the Port 1 antenna line should be considered.

Figure 4. Example of Measurement, active UL2 with NO PIM present

Referring to Figure 4, there is essentially no PIM on the UL2 antenna line. The residual correlated PIM is over 17 dB below thermal noise at -64.4 dBFS and the desensitization is negligible. UL2 is therefore a PASS.

For a more detailed explanation of the BTS Master MT8220T base station analyzer's PIM over CPRI measurement, please take a look at the PIM over CPRI application note (P/N 11410-01078) at anritsu.com.

Conclusions

This white paper outlines how PIM over CPRI works and how to get the most of out of this measurement technique. PIM over CPRI is your first step in determining if a site has PIM issues before calling in PIM mitigation team. PIM over CPRI allows testing at ground level without turning down service and disconnecting any antenna connection like traditional RF PIM testing, saving carriers on capital and expenditure expense costs.

PIM over CPRI has been designed from the outset to offer a simple and easy means to test and locate highly complex PIM problems. This method is complementary to the traditional RF PIM testing that is used to troubleshoot PIM issues. PIM over CPRI represents the next step in arming operators to tackle PIM. By using non-intrusive tools and methods, the BTS Master MT8220T with the PIM over CPRI option is able to provide far greater insight into the nature of PIM in the network and how best to tackle it.

As wireless systems continue to add RF bands, more complex modulation, carrier aggregation, increased cell density, and increased RF power, PIM will increasingly affect wireless KPI's. Anritsu is determined to equip the wireless communications market with best tools and advanced methods to combat PIM now and in the future.

Anritsu envision : ensure

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• United States
Anritsu Company
450 Century Parkway, Suite 190, Allen,
TX 75013 U.S.A.
Phone: +1-800-Anritsu (1-800-267-4878)

• 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 - Sao Paulo - SP - Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• Mexico
Anritsu Company, S.A. de C.V.
Blvd Miguel de Cervantes Saavedra #169 Piso 1, Col. Granada
Mexico, Ciudad de Mexico, 11520, MEXICO
Phone: +52-55-4169-7104

• United Kingdom
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

• France
Anritsu S.A.
12 avenue du Québec, Batiment Iris 1-Silic 612,
91140 VILLEBON-SUR-YETTE, 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: +49-89-442308-0
Fax: +49-89-442308-55

• Italy
Anritsu S.r.l.
Via Elio Vittorini 129, 00144 Roma Italy
Phone: +39-06-509-9711
Fax: +39-6-502-2425

• Sweden
Anritsu AB
Isafjordsgatan 32C, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00

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

• Denmark
Anritsu A/S
Torveporten 2, 2500 Valby, 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.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• Spain
Anritsu EMEA Ltd.
Representation Office in Spain
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 5
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

• United Arab Emirates
Anritsu EMEA Ltd.
Dubai Liaison Office
902, Aurora Tower,
P O Box: 500311- Dubai Internet City
Dubai, United Arab Emirates
Phone: +971-4-3758479
Fax: +971-4-4249036

• India
Anritsu India Pvt Ltd.
6th Floor, Indiqube ETA, No.38/4, Adjacent to EMC2,
Doddanekundi, Outer Ring Road, Bengaluru – 560048, India
Phone: +91-80-6728-1300
Fax: +91-80-6728-1301

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

• P. R. China (Shanghai)
Anritsu (China) Co., Ltd.
Room 2701-2705, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road 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: +81-46-296-6509
Fax: +81-46-225-8352

• Korea
Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• Australia
Anritsu Pty Ltd.
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, 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

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