# Whip Antenna Guide for Chinese AMR Band

## 1. Introduction

This document provides guidelines for selecting whip antenna in 490M band. It also describes the performance of three different 50 Ω single-ended antennas which are used in the 470–510 MHz Chinese AMR band and are dedicated to the EZRadio and EZRadioPRO family.

Section "2. Basic Antenna Parameters" describes the antenna concept and parameters (such as gain, direction, etc.,) that are related to the antenna performance when selecting an antenna.

Section "3. Antenna Classifications and Their Applications" introduces the antenna classification and application case of the PCB antenna, chip ceramic antenna, and whip antenna according to their performances.

Section "4. Whip Antenna Performance Test" describes the performance evaluation for the three selected whip antennas.

The antennas are selected for 470–510 MHz band. The antennas are optimized and tuned under the antenna PCB + Pico Board + Motherboard (MSC-WMB930 Wireless Motherboard) structure (see Figure 1).

**Figure 1. Typical Measurement Configuration—Antenna, Pico Board, and Wireless Motherboard**

The input impedance and antenna gain of all whip antennas are measured with the above configuration. The outdoor range is also checked using two identical antenna modules.

# 2. Basic Antenna Parameters

## 2.1. Input Impedance

Input impedance is defined as the impedance presented by the antenna at its terminals or the ratio of the voltage to current at its terminals. If the antenna is not matched to the feed line, a standing wave is induced along the feed line. The ratio of the maximum voltage to the minimum voltage along the line is called the Voltage Standing Wave Ratio (VSWR). The impedance can also be expressed in another format as S11 if it is normalized to 50 $\Omega$.

## 2.2. Directivity

The directivity is a measurement that describes the directional transmitting properties of the antenna. It is defined as the ratio of the antenna radiation intensity in a specific direction in space over the radiation intensity of an isotropic source for the same radiated power. There are cases in which the term directivity is implied to refer to its maximum value.

## 2.3. Antenna Gain

Antenna gain is closely related to the directivity, but includes the losses in the antenna as well as its directional capabilities. Antenna gain has the following characteristics:

- Refers to the direction of maximum radiation.
- Is a dimension-less factor related to power and usually expressed in decibels.
- Gi "Isotropic Power Gain" is a theoretical concept; the reference antenna is isotropic.
- Gd of the reference antenna is a half-wave dipole.

## 2.4. Efficiency

The antenna efficiency is the ratio of directivity to gain. It accounts for all the power lost before radiation. The losses may be due to mismatch at the input terminals, conduction losses, dielectric losses and spill-over losses.

The radiation efficiency, directivity, and gain are calculated as follows:

$$G = \eta \times D$$

Where G is the gain, D is the directivity, and $\eta$ is the efficiency.

## 2.5. Polarization

Polarization is the property of the electric field vector that defines variation in direction and magnitude with time. If we observe the field in a plane perpendicular to the direction of propagation at a fixed location in space, the end point of the arrow representing the instantaneous electric field magnitude traces a curve. Generally, this curve is an ellipse (Figure 2). The ellipse can be characterized by the axial ratio (AR), which is the ratio of the two major axes and its tilt angle, t. Polarization may be classified as linear, circular or elliptical according to the shape of the curve. Linear and circular polarizations are special cases of elliptical polarization, when the ellipse becomes a straight line or circle, respectively. Clockwise rotation of the electric field vector is designated as right-hand polarization (RH) and counter-clockwise rotation is left-hand polarization (LH), for an observer looking in the direction of propagation.

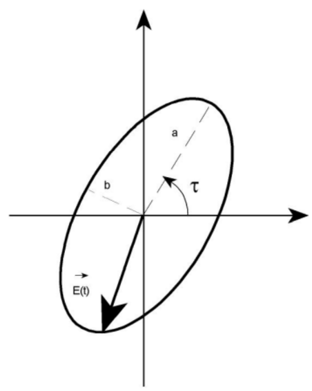



**Figure 2. Elliptical Polarization**

## 2.6. Effective Isotropically Radiated Power (EIRP)

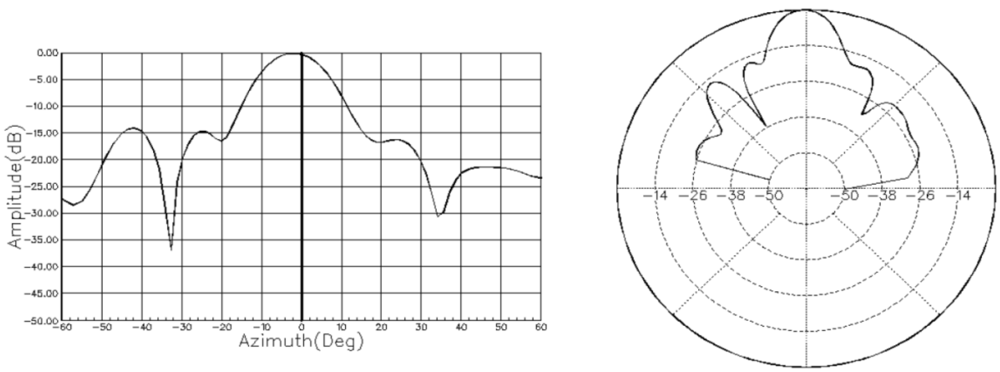
The Effective Isotropically Radiated Power (EIRP) is a figure of merit for the net radiated power in a given direction. It is equal to the product of the net power accepted by the antenna and the antenna gain. EIRP is calculated with the following equation:

$$EIRP = P \times Gi$$

Where P is the power inject to the antenna, Gi is the antenna isotropic power gain.

## 2.7. Radiation Pattern

The antenna radiation pattern is the display of the radiation properties of the antenna as a function of the spherical coordinates ($\theta$,$\varphi$). In most cases, the radiation pattern is determined in the far-field region for constant radial distance and frequency. A typical radiation pattern is characterized by a main beam with 3 dB beam-width and side-lobes at different levels (Figure 3). The antenna performance is often described in terms of its principal E- and H-plane patterns. For a linearly polarized antenna, the E- and H-planes are defined as the planes containing the direction of maximum radiation and the electric and magnetic field vectors, respectively.




**(a) Rectangular Form** **(b) Polar Form**

**Figure 3. Radiation Patterns**

In the antenna parameters described in section “2. Basic Antenna Parameters” , the input impedance is not critical because it can be matched to 50 Ω by using external match circuits. The most significant parameters are antenna gain, polarization, and radiation pattern, with antenna gain as the most important parameter because it directly describes the antenna performance. The polarization of Tx and Rx antennas should be aligned, otherwise the path loss will worsen. An omni-directional antenna is needed in most application cases.

In Section “4. Whip Antenna Performance Test” , the input impedance, EIRP, and gain are measured or calculated. Other antenna parameters are not measured in this document. The range of DUT is also investigated with whip antennas.

# 3. Antenna Classifications and Their Applications

## 3.1. PCB Antenna

The PCB antenna is an antenna that is composed of etched copper on PCB surface. There are several types of PCB antenna such as ILA, IFA, and BIFA antennas. These antennas are low-cost, printed PCB trace antennas which use narrow PCB strips around the PCB circumference as the antenna area, thereby saving significant space. The drawback is the reduced gain. This is especially true if the antenna trace is close to the ground metal of the circuitry. These antenna types are sensitive to hand effect, so bench tuning with hand in place is required. However, the hand effect can also improve the radiation if the hand covers most of the circuit area.

Due to these properties, this antenna type is frequently used in key fobs, where the range requirement is usually moderate.

## 3.2. Chip Ceramic Antenna

The chip antenna is usually realized on high epsilon dielectric, and is a relative high-gain, smaller alternative to any PCB printed antenna. However, this type of antenna is usually soldered on the PCB, and thus needs bare PCB space because it requires either relatively large gaps from ground metal or a large ground metal like the monopole.

Chip ceramic antennas are not generally used in key fobs due to their relatively higher price and the need for bare PCB space. Instead, chip antennas are typically used in set top boxes where the slight additional cost can be tolerated. Their radiation performance may be affected by the outer case of the product if the case is not properly designed, since it is placed inside the product.

## 3.3. Whip Antenna

The whip antenna is typically made of a spring wire antenna and plastic coat, as shown in Figure 4:

**Figure 4. Whip Antenna**

This type of antenna has a higher gain compared to any PCB printed antenna as it has larger dimensions and is usually perpendicular to a large GND metal plane (case, PCB, etc.). It can be placed outside the outer case of a product. If the case is large (i.e., at least lambda/4 or higher), it improves the antenna radiation performance. The whip antenna is also typically used in the AMR band, which requires better range.

The whip antenna does not require extra PCB space and uses the existing circuit area as a GND plane, thereby reducing PCB cost compared to chip ceramic and PCB antennas.This document covers only the whip antenna performance evaluation and test.

# 4. Whip Antenna Performance Test

In this document, three types of whip antennas are evaluated for Chinese AMR band. Information on the antennas is as follows:

- 1# whip antenna:
  Supplier：Shenzhen Hwatle Electronic Co., Ltd.
  Website: http://www.hwatle.com.cn
  Antenna Type：HT-A-450-6100

  This kind of antenna is included in the 4438-490-PDK EZRadioPRO Development Kit

- 2# whip antenna:
  Supplier：Shenzhen Hytera Communications Co., Ltd.
  Website: http://www.hytera.com.cn/
  Antenna Type：16010495W0050

- 3# whip antenna:
  Supplier：Shenzhen Chaoshi Communication Limited.
  Website: http://www.chaoshi.net.cn
  Antenna Type：FA-SC72U

## 4.1. Antenna Input Impedance Test

Figure 5 shows the input impedance test setup for the selected whip antennas. The performance of a whip antenna depends on its reference ground. Since these antennas are selected for using with 4438-PCE20D490 pico board, the performance is tested with 4438-PCE20D490 Pico Board on MSC-WMB930 platform. A pigtail is stretched out to VNA for impedance measurement, thus the antenna uses the GND plane of the test platform as a reference GND plane. The VNA is calibrated and the reference plane is shifted to the input of the antenna. Figure 6, Figure 7, and Figure 8 are the tested S11s of the above three whip antennas.

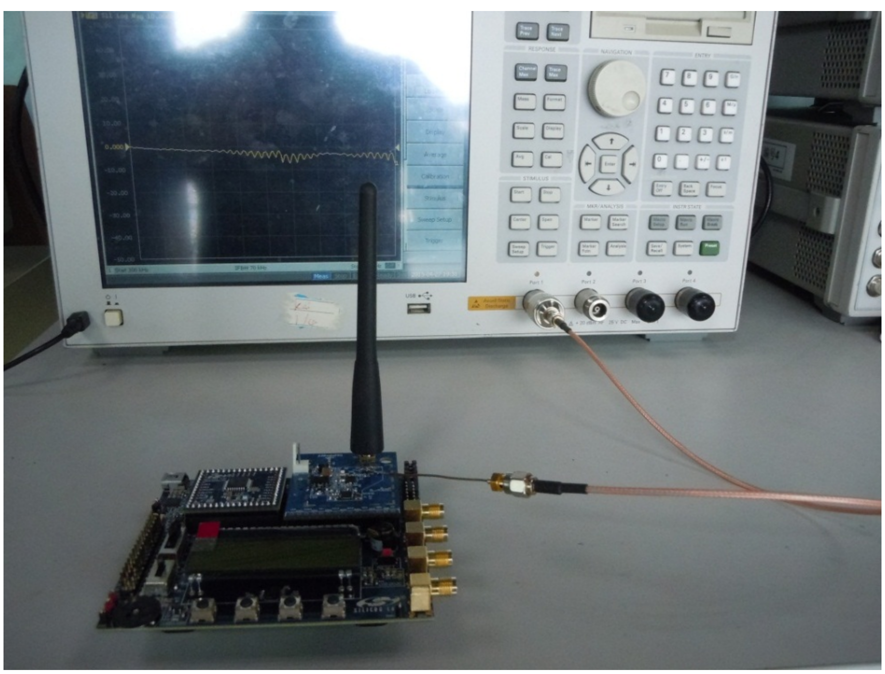


**Figure 5. Input Impedance Measurements Setup**

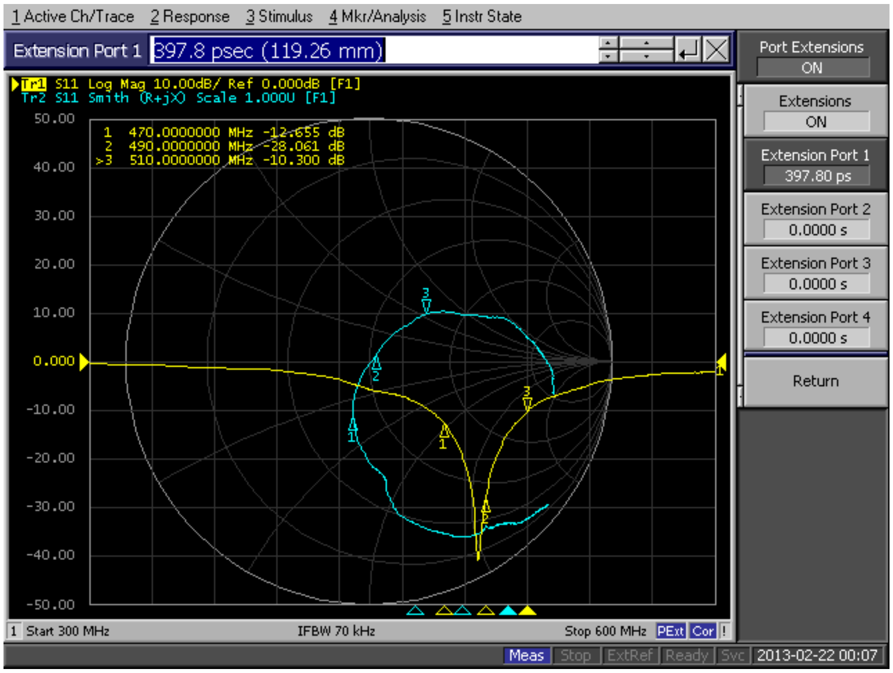



**Figure 6. S11 of the 1# Antenna**

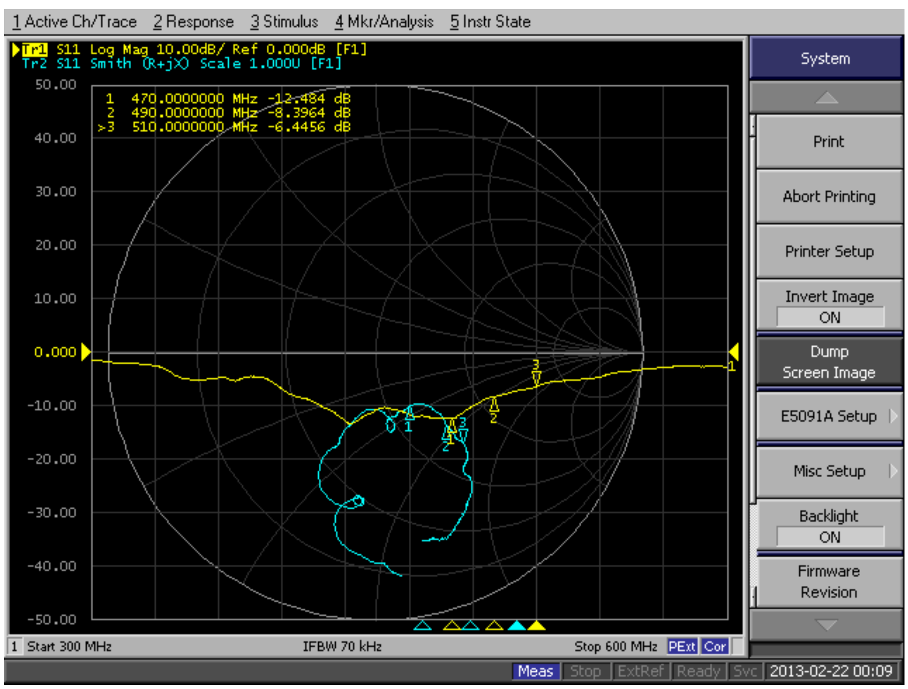



**Figure 7. S11 of the 2# Antenna**

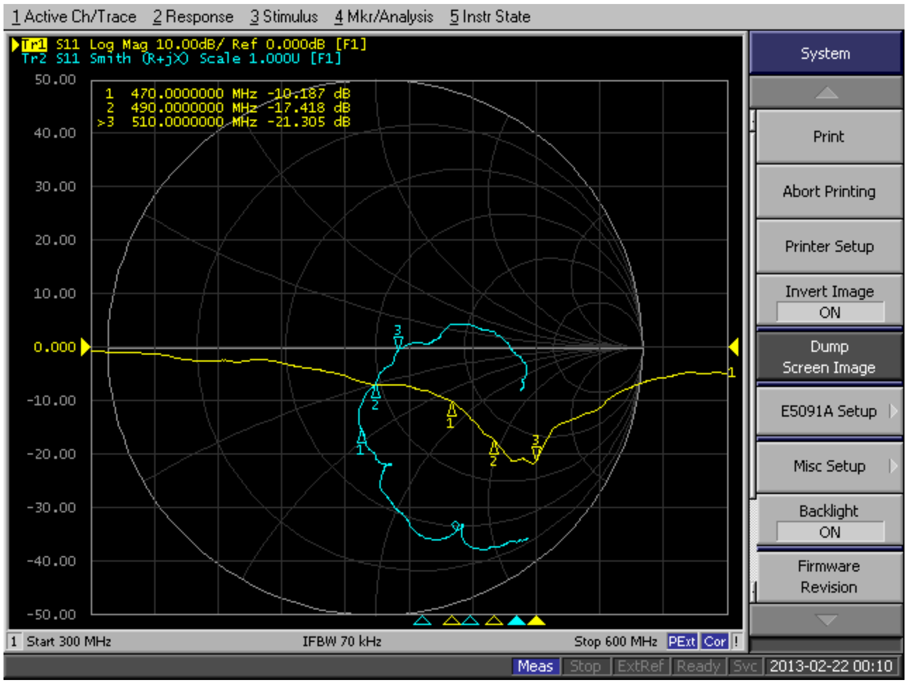



**Figure 8. S11 of the 3# Antenna**

The antenna is considered well-matched to 50 Ω if S11 is below –10 dB. For the results shown in Figures 6-8, the S11 of 1# and 3# antenna is very good in the whole frequency band. The S11 of antenna 2# at some frequency points is not good, but the antenna can be matched to 50 Ω by using external match circuits. If the impedance is not well-matched to the antenna input impedance, it will be lead to a higher VSWR and a reduced radiated power from the antenna. Furthermore, the antenna could damage the PA as a result of not being well-matched; however, the RF output is very robust against high VSWR using the matching circuit provided on the 4438–PCE20D490 picoboard. Refer to the Si4438 PCE20D490 schematics under the Tools tab at http://www.silabs.com/products/wireless/EZRadioPRO/Pages/Si4438.aspx. No damage has been seen by removing the antenna or terminating the output by a short.

## 4.2. EIRP and Gain Test

EIRP of the whip antenna were measured in an antenna chamber using the 4438-PCE20D490 Pico Board. The output power of the pico board is set to be 17 dBm at 470 MHz, 490 MHz, and 510 MHz separately. The antenna is connected on 4438-PCE20D490 via the SMA connector, which constructs the DUT. The spectrum analyzer records the EIRP while the DUT table is rotating 360°. Because the whip antenna has a vertical polarization, the polarization of reference RX antenna is only set to vertical to get EIRP. Figure 9 shows the DUT with a coordinate system under the radiated measurements.

**Figure 9. EIRP Test Chamber**

Before measuring the EIRP and Harmonics, the RF performance of the pico board is measured with conducted way. The output power of 4438-PCE20D490 Pico Board is set to be 17 dBm at 470M, 490M and 510M separately according to Chinese AMR regulation. Three antennas are used to test EIRP and harmonics separately. The conduct power is measured with an Anritsu MS2692 spectrum analyzer. Figure 10, Figure 11, and Figure 12 are the conducted power measurements at 470 MHz, 490 MHz, and 510 MHz separately. From the results, the harmonics are well below their limits at different operating frequencies.

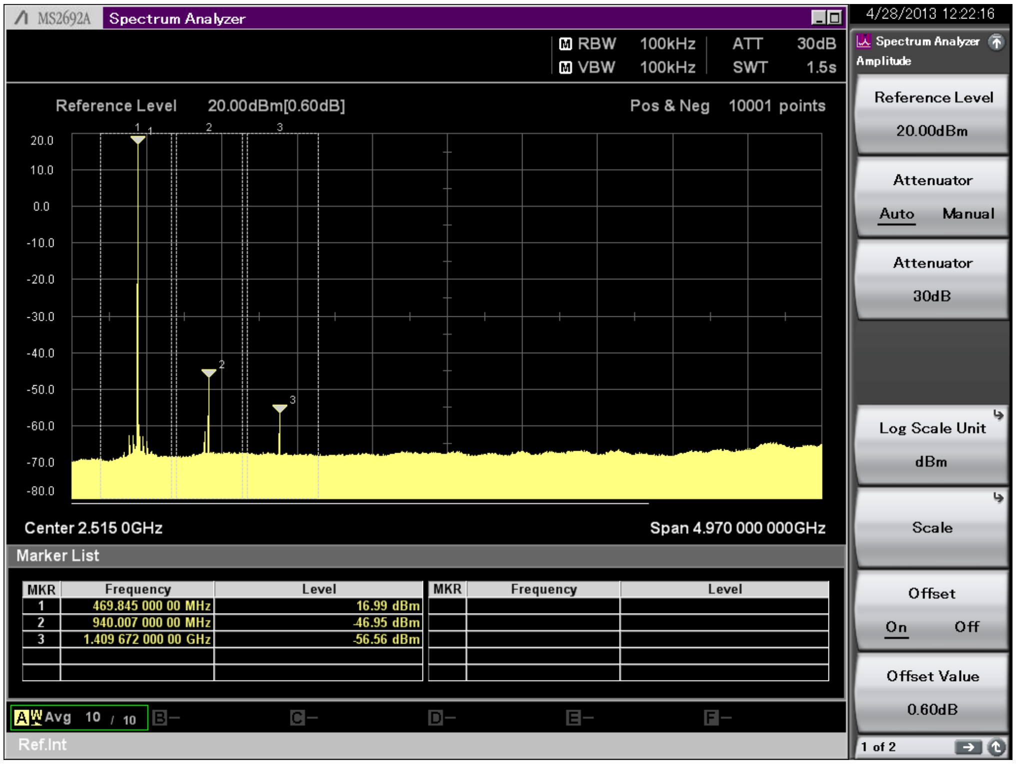



Figure 10. Output Power at 470 MHz

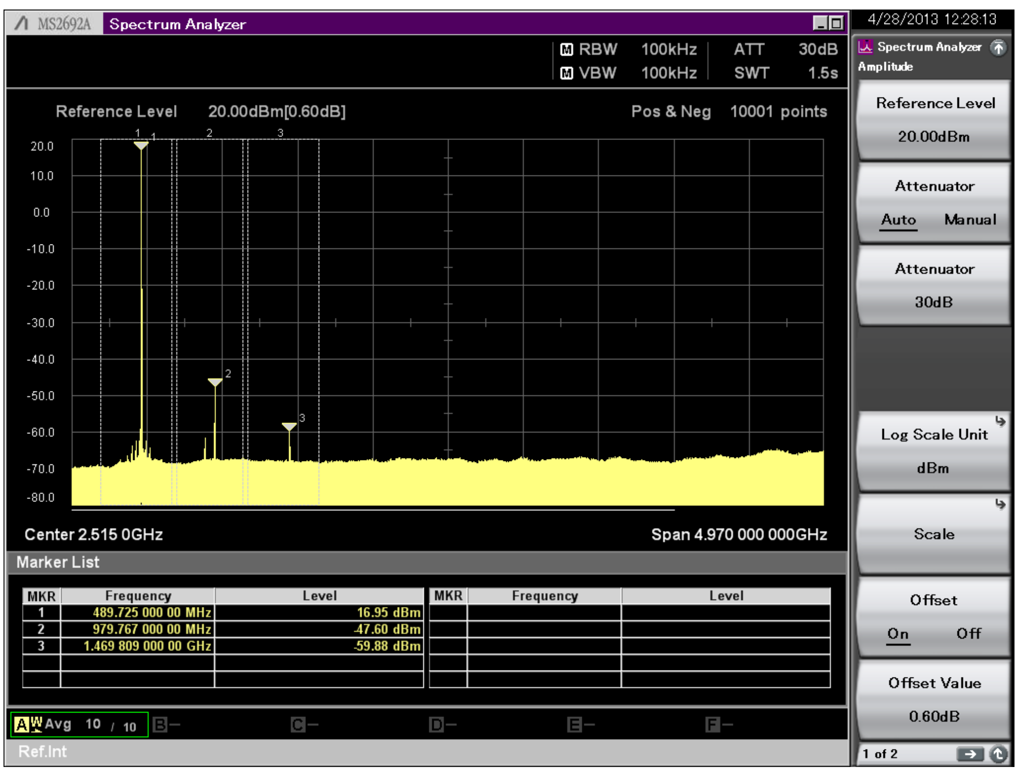



Figure 11. Output Power at 490 MHz

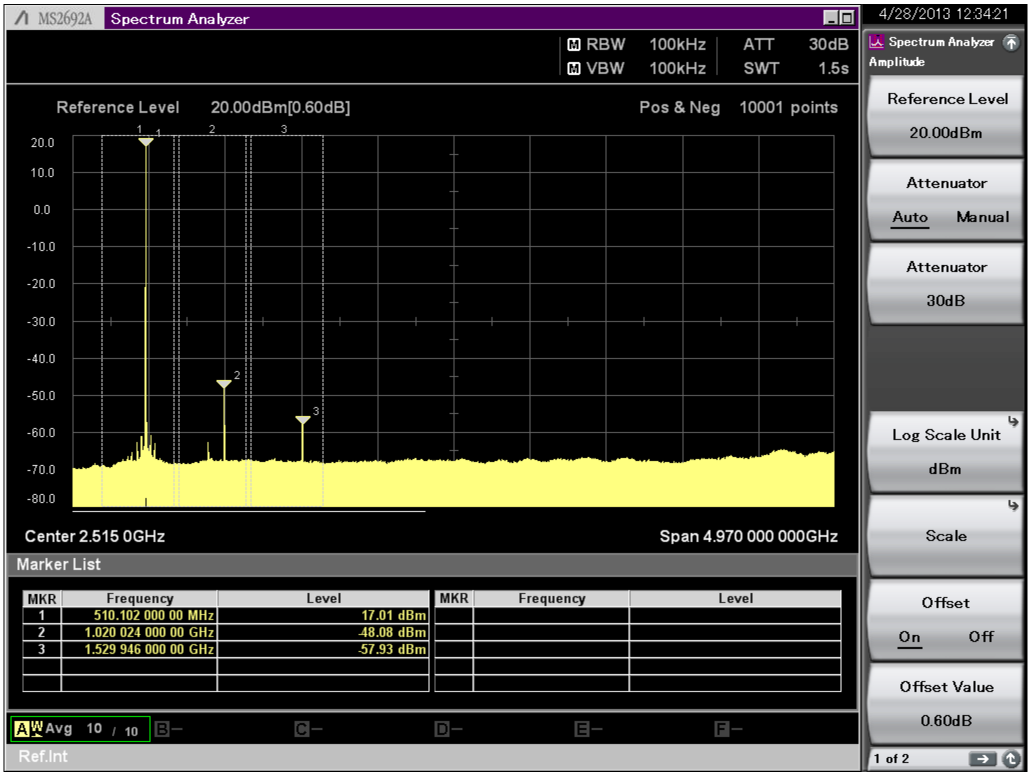
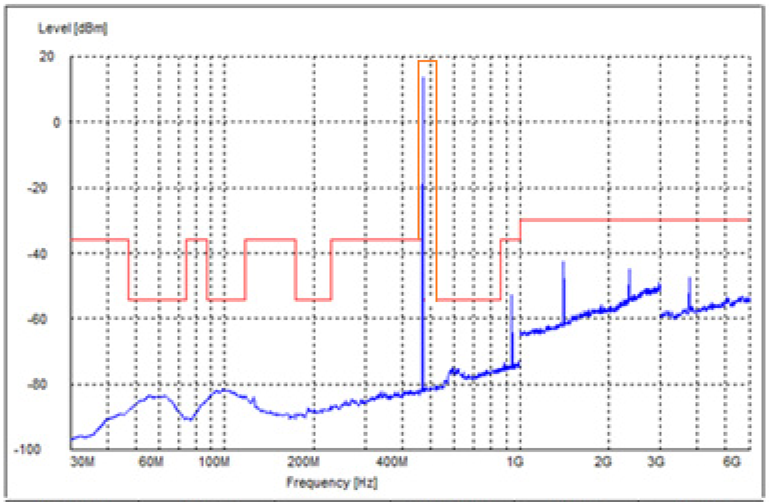



**Figure 12. Output Power at 510 MHz**

The EIRP and harmonic measurement of the whip antenna were measured in the antenna chamber. The 17 dBm output power from 4438-PCE20D490 Pico Board is injected to the antenna. The max radiated power and harmonics are recorded while the DUT antenna is rotating 360 degrees. Figures 13 to 21 are the measured results.




| Frequency | Antenna | TX/RX | Test Values | Limit | Result |
|---|---|---|---|---|---|
| (MHz) | Polarization | | (dBm) | (dBm) | Pass/Fail |
| 469.32 | Vertical | TX | 13.64 | 19.14 | Pass |
| 941.68 | Vertical | TX | -52.64 | -36 | Pass |
| 1408.82 | Vertical | TX | -42.42 | -30 | Pass |
| 2350.70 | Vertical | TX | -44.79 | -30 | Pass |
| 3757.51 | Vertical | TX | -47.47 | -30 | Pass |
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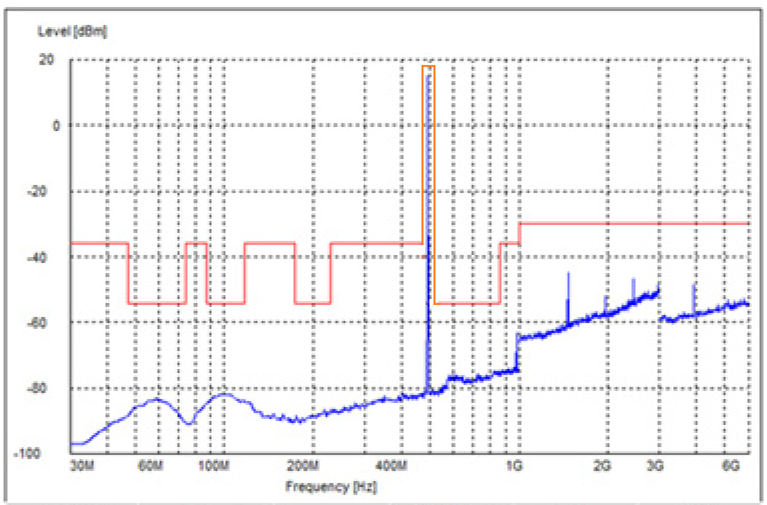
**Figure 13. EIRP and Harmonics of 1# Antenna at 470 MHz**




| Frequency | Antenna | TX/RX | Test Values | Limit | Result |
|---|---|---|---|---|---|
| (MHz) | Polarization | | (dBm) | (dBm) | Pass/Fail |
| 490.70 | Vertical | TX | 14.98 | 19.14 | Pass |
| 980.56 | Vertical | TX | -63.19 | -36 | Pass |
| 1468.94 | Vertical | TX | -45.00 | -30 | Pass |
| 1961.92 | Vertical | TX | -52.10 | -30 | Pass |
| 2450.90 | Vertical | TX | -46.55 | -30 | Pass |
| 3919.84 | Vertical | | -48.66 | -30 | Pass |
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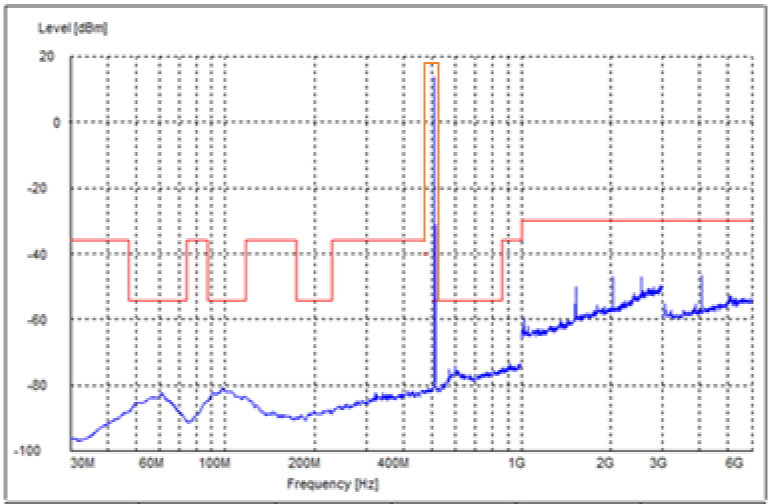
**Figure 14. EIRP and Harmonics of 1# Antenna at 490 MHz**




| Frequency (MHz) | Antenna Polarization | TX/RX | Test Values (dBm) | Limit (dBm) | Result Pass/Fail |
|---|---|---|---|---|---|
| 510.14 | Vertical | TX | 13.77 | 19.14 | Pass |
| 1020.04 | Vertical | TX | -59.34 | -30 | Pass |
| 1529.06 | Vertical | TX | -49.90 | -30 | Pass |
| 2042.08 | Vertical | TX | -47.08 | -30 | Pass |
| 2551.10 | Vertical | TX | -47.06 | -30 | Pass |
| 4082.16 | Vertical | TX | -46.83 | -30 | Pass |
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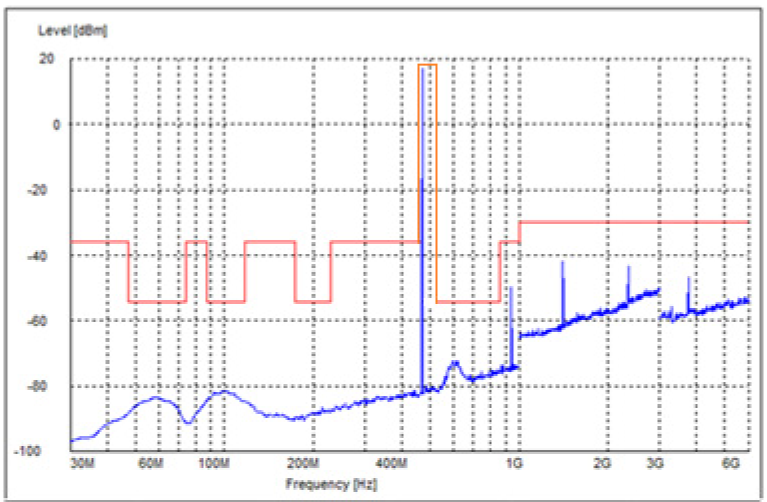
**Figure 15. EIRP and Harmonics of 1# Antenna at 510 MHz**




| Frequency (MHz) | Antenna Polarization | TX/RX | Test Values (dBm) | Limit (dBm) | Result Pass/Fail |
|---|---|---|---|---|---|
| 469.32 | Vertical | TX | 16.92 | 19.14 | Pass |
| 941.68 | Vertical | TX | -49.80 | -36 | Pass |
| 1408.82 | Vertical | TX | -41.62 | -30 | Pass |
| 2350.70 | Vertical | TX | -43.15 | -30 | Pass |
| 3757.51 | Vertical | TX | -46.64 | -30 | Pass |
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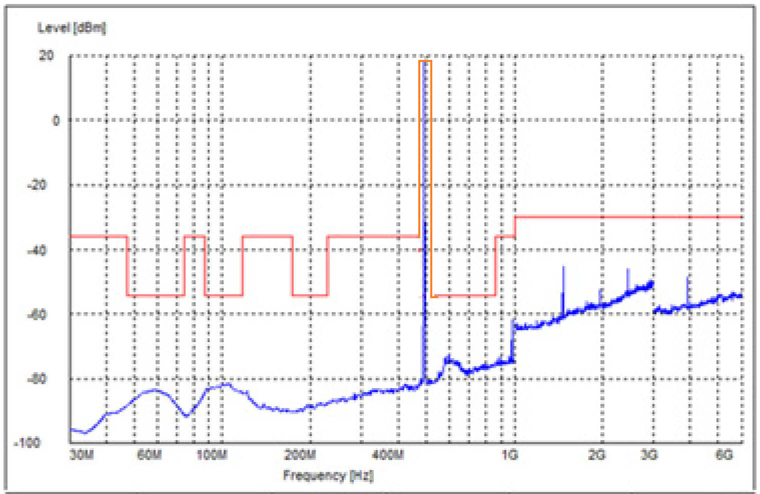
**Figure 16. EIRP and Harmonics of 2# Antenna at 470 MHz**




| Frequency (MHz) | Antenna Polarization | TX/RX | Test Values (dBm) | Limit (dBm) | Result Pass/Fail |
|---|---|---|---|---|---|
| 490.70 | Vertical | TX | 18.20 | 19.14 | Pass |
| 980.56 | Vertical | TX | -61.66 | -36 | Pass |
| 1468.94 | Vertical | TX | -45.19 | -30 | Pass |
| 1961.92 | Vertical | TX | -52.44 | -30 | Pass |
| 2450.90 | Vertical | TX | -45.92 | -30 | Pass |
| 3919.84 | Vertical | TX | -48.48 | -30 | Pass |
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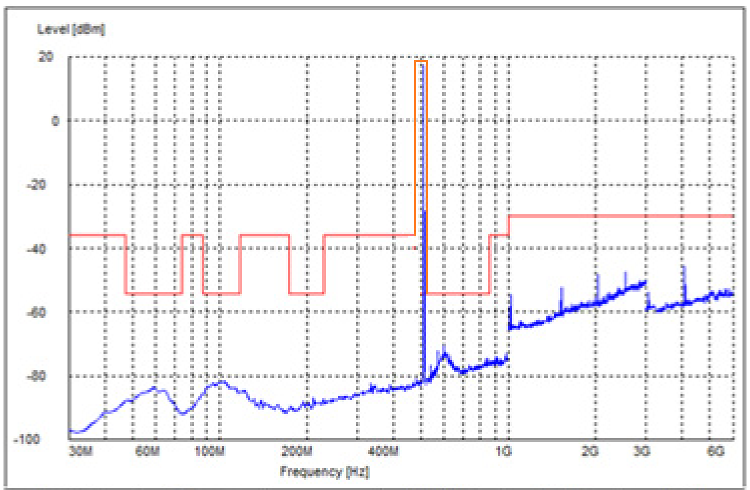
**Figure 17. EIRP and Harmonics of 2# Antenna at 490 MHz**




| Frequency (MHz) | Antenna Polarization | TX/RX | Test Values (dBm) | Limit (dBm) | Result Pass/Fail |
|---|---|---|---|---|---|
| 510.14 | Vertical | TX | 17.37 | 19.14 | Pass |
| 1020.04 | Vertical | TX | -54.59 | -30 | Pass |
| 1529.06 | Vertical | TX | -52.45 | -30 | Pass |
| 2042.08 | Vertical | TX | -48.34 | -30 | Pass |
| 2551.10 | Vertical | TX | -47.55 | -30 | Pass |
| 4082.16 | Vertical | TX | -45.47 | -30 | Pass |
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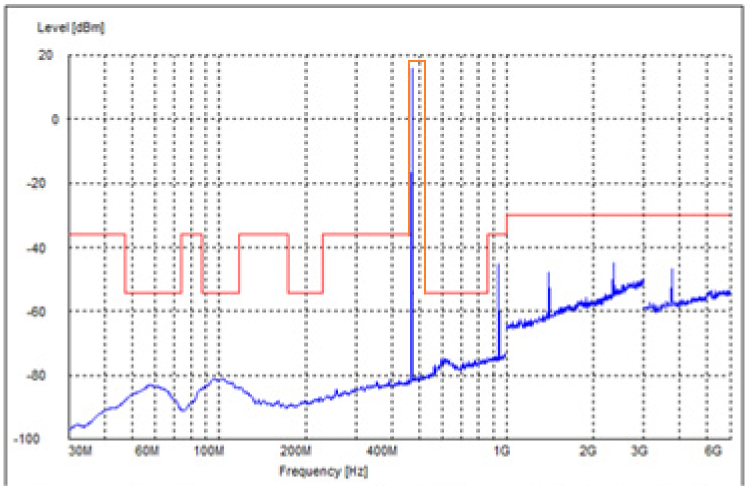
**Figure 18. EIRP and Harmonics of 2# Antenna at 510 MHz**




| Frequency | Antenna | TX/RX | Test Values | Limit | Result |
|---|---|---|---|---|---|
| (MHz) | Polarization | | (dBm) | (dBm) | Pass/Fail |
| 469.32 | Vertical | TX | 16.01 | 19.14 | Pass |
| 941.68 | Vertical | TX | -45.14 | -36 | Pass |
| 1408.82 | Vertical | TX | -47.57 | -30 | Pass |
| 2350.70 | Vertical | TX | -44.78 | -30 | Pass |
| 3757.51 | Vertical | TX | -46.75 | -30 | Pass |
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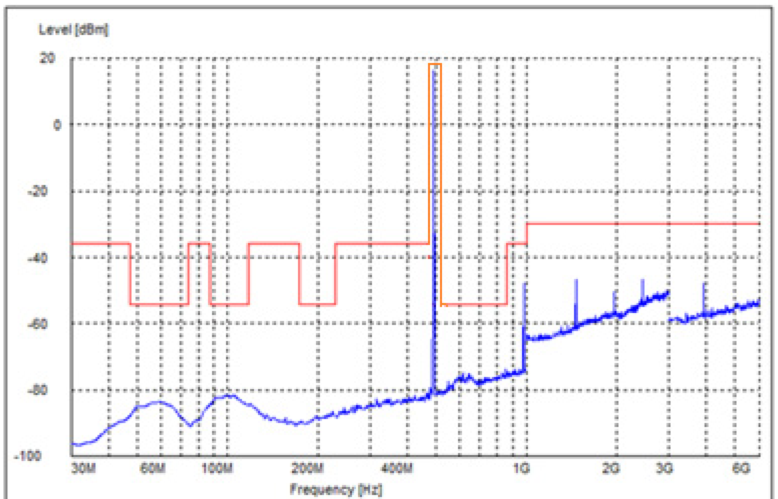
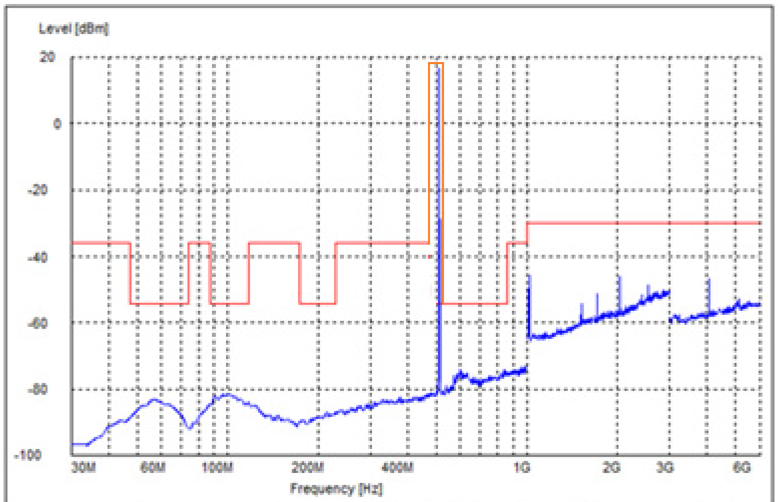
**Figure 19. EIRP and Harmonics of 3# Antenna at 470 MHz**




| Frequency | Antenna | TX/RX | Test Values | Limit | Result |
|---|---|---|---|---|---|
| (MHz) | Polarization | | (dBm) | (dBm) | Pass/Fail |
| 490.70 | Vertical | TX | 16.15 | 19.14 | Pass |
| 980.56 | Vertical | TX | -47.79 | -36 | Pass |
| 1468.94 | Vertical | TX | -46.66 | -30 | Pass |
| 1961.92 | Vertical | TX | -50.39 | -30 | Pass |
| 2450.90 | Vertical | TX | -46.88 | -30 | Pass |
| 3919.84 | Vertical | TX | -47.81 | -30 | Pass |
| | | | | | |
| | | | | | |

**Figure 20. EIRP and Harmonics of 3# Antenna at 490 MHz**




| Frequency (MHz) | Antenna Polarization | TX/RX | Test Values (dBm) | Limit (dBm) | Result Pass/Fail |
|---|---|---|---|---|---|
| 510.14 | Vertical | TX | 16.45 | 19.14 | Pass |
| 1020.04 | Vertical | TX | -45.72 | -30 | Pass |
| 1529.06 | Vertical | TX | -54.22 | -30 | Pass |
| 2042.08 | Vertical | TX | -45.92 | -30 | Pass |
| 2551.10 | Vertical | TX | -48.72 | -30 | Pass |
| 4082.16 | Vertical | TX | -46.87 | -30 | Pass |
| | | | | | |
| | | | | | |

**Figure 21. EIRP and Harmonics of 3# Antenna at 510 MHz**

From the above results, all radiated harmonics are below their limits by at least 9 dB margin. In Chinese AMR band regulation, the fundamental power is limited to 17 dBm ERP, which corresponds to 19.14 dBm EIRP. All of the fundamental radiation power is below the regulation limit.

The antenna gain can be calculated from the measured fundamental EIRP and the delivered power to the antenna (from conducted SA measurements). Calculated antenna gain = EIRP-17 dBm. The antenna gains for different whip antennas at different frequencies are shown in Table 1.

**Table 1. Gains for Different Antenna Samples at Different Frequency**

| Antenna Sample | Gain at Different Frequency (dBi) | | |
|---|---|---|---|
| | 470 MHz | 490 MHz | 510 MHz |
| 1# | –3.36 | –2.02 | –3.23 |
| 2# | –0.08 | 1.2 | 0.37 |
| 3# | –0.99 | –0.85 | –0.55 |

### 4.3. Range Test

The outdoor range is tested using two identical whip antennas on both TX and RX side. The output power at the TX side is set to its maximum. Data rate is set to 500 kbps, frequency deviation is set to250 kHz (GFSK, H=1), and carrier frequency is set to 490 MHz. The sensitivity at RX side is –94 dBm (1e-3 BER at 500 kbps data rate and 250 kHz deviation). The range is recorded with 1% packet error rate.

**Figure 22. Range Test Sets**

The range results are the values in [km] with Google map distance plot. The ranges are tested outside with 500 kbps data rate. Figure 23, Figure 24, and Figure 25 are the range test results.

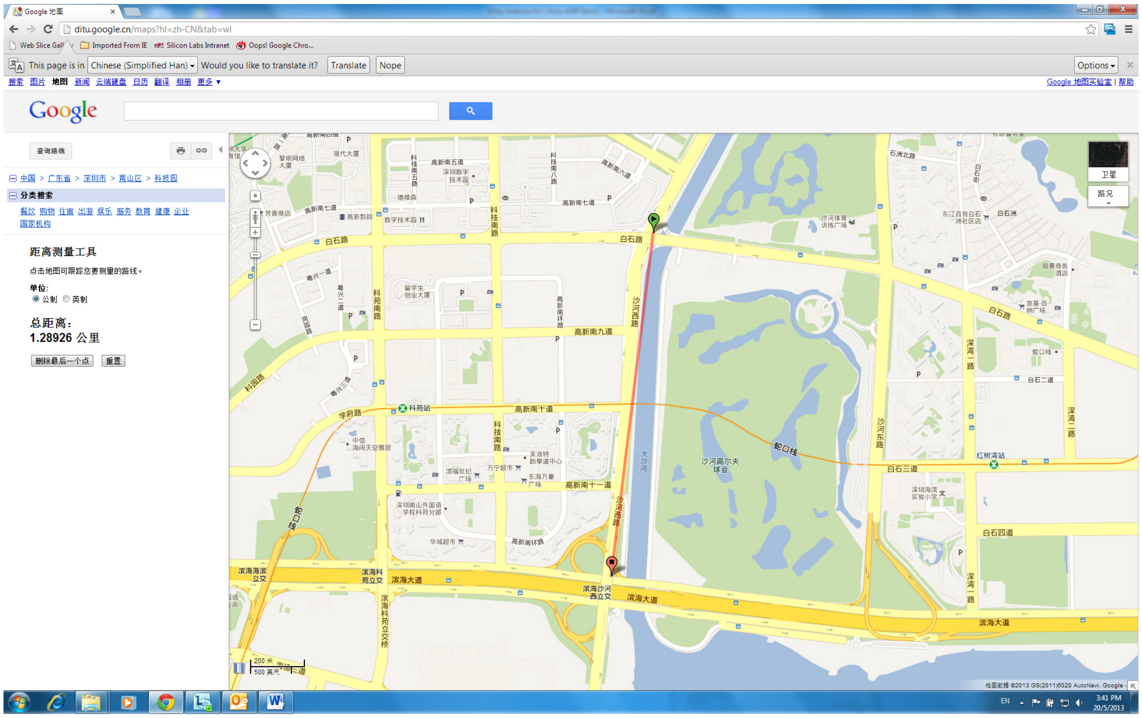



Figure 23. 1# Antenna Outdoor Range Test Result—1.29 km

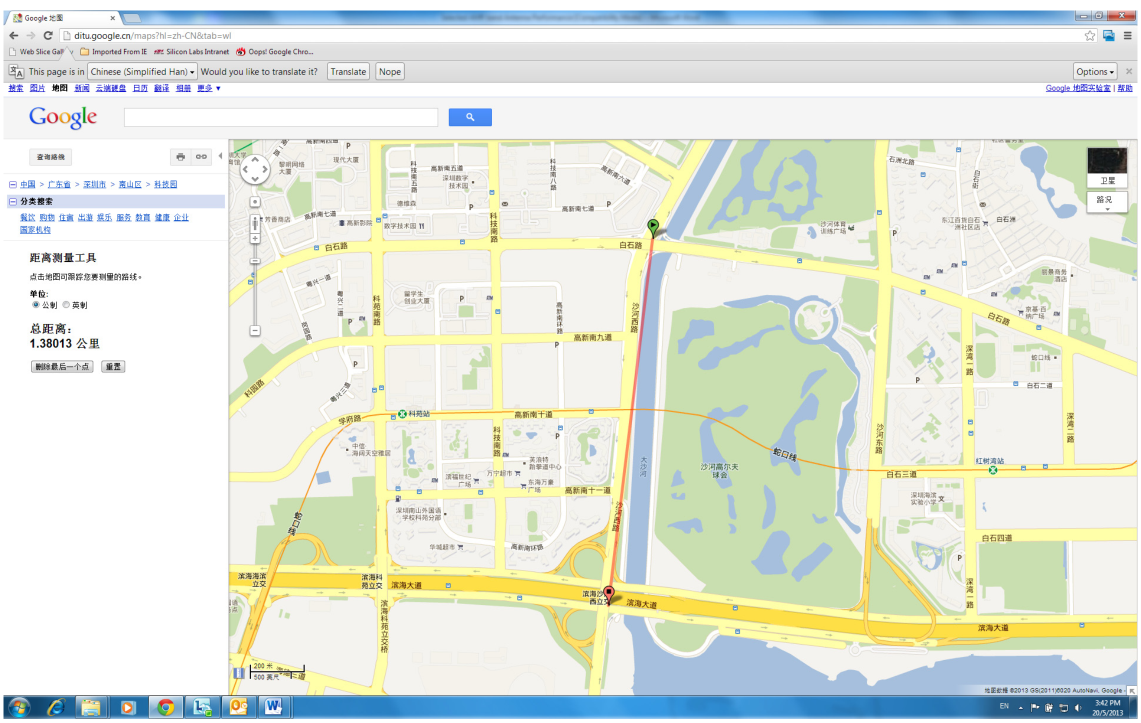



Figure 24. 2# Antenna Outdoor Range Test Result—1.38 km

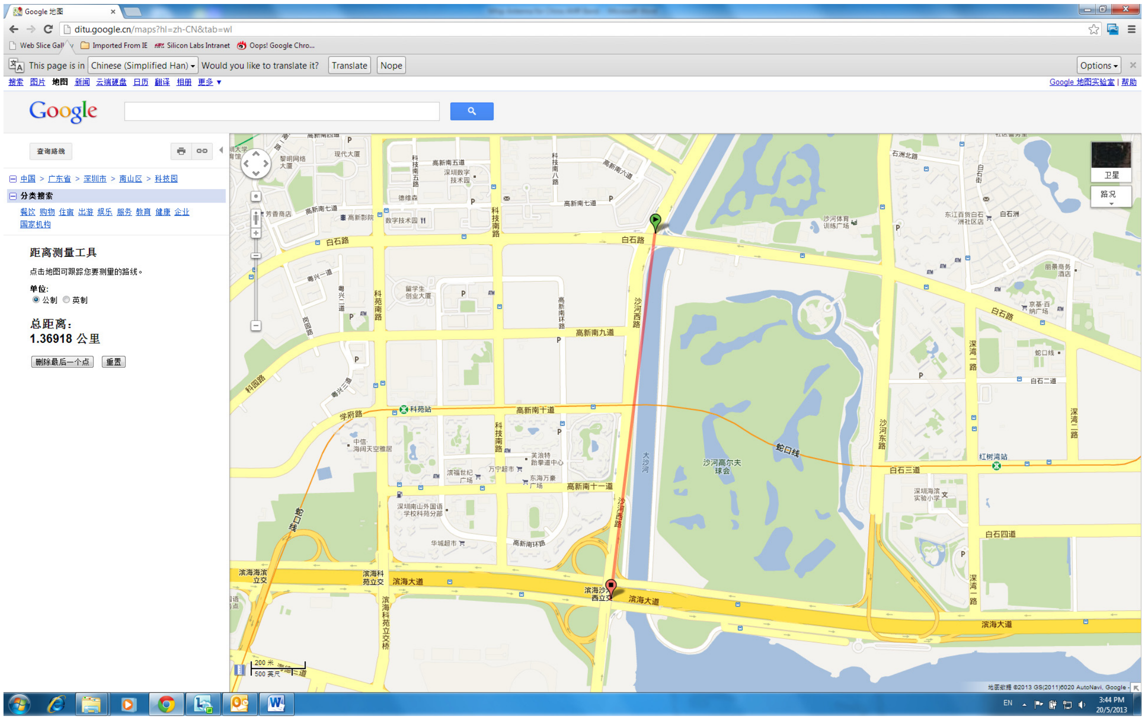



**Figure 25. 3# Antenna Outdoor Range Test Result—1.37 km**

The measured ranges above show that the propagation properties are good in the test site (open field along a river bank without significant obstacles). The propagation exponent is around 2.7…2. 8. In a real urban environment with high buildings and obstacles the propagation is much worse, with a typical exponent of 4.5. In this case, the expected range degrades to 120…130 m with this link budget (~110…114 dB).

For the lower data rates such as 100 kbps,10 kbps, and 1 kbps, the link budgets will be improved and the range will be greater. Table 2 shows the link budgets and estimated ranges both for the above open site and for a heavy urban area at the lower data rates. Figure 22 shows the test sets for range test.

**Table 2. Link Budget and Range Improvements at Lower Data Rates**

| Data Rates (kbps) | Link Budget (dB) | Link Budget Improved (dB) | Expect Improved Range in an Open Site (km) | Expected Range in a Heavy Urban Area (km) |
|---|---|---|---|---|
| 100 | -123 | 9 | 2.8 | 0.18 |
| 10 | -134 | 20 | 6.8 | 0.31 |
| 1 | -142 | 28 | 12.9 | 0.47 |

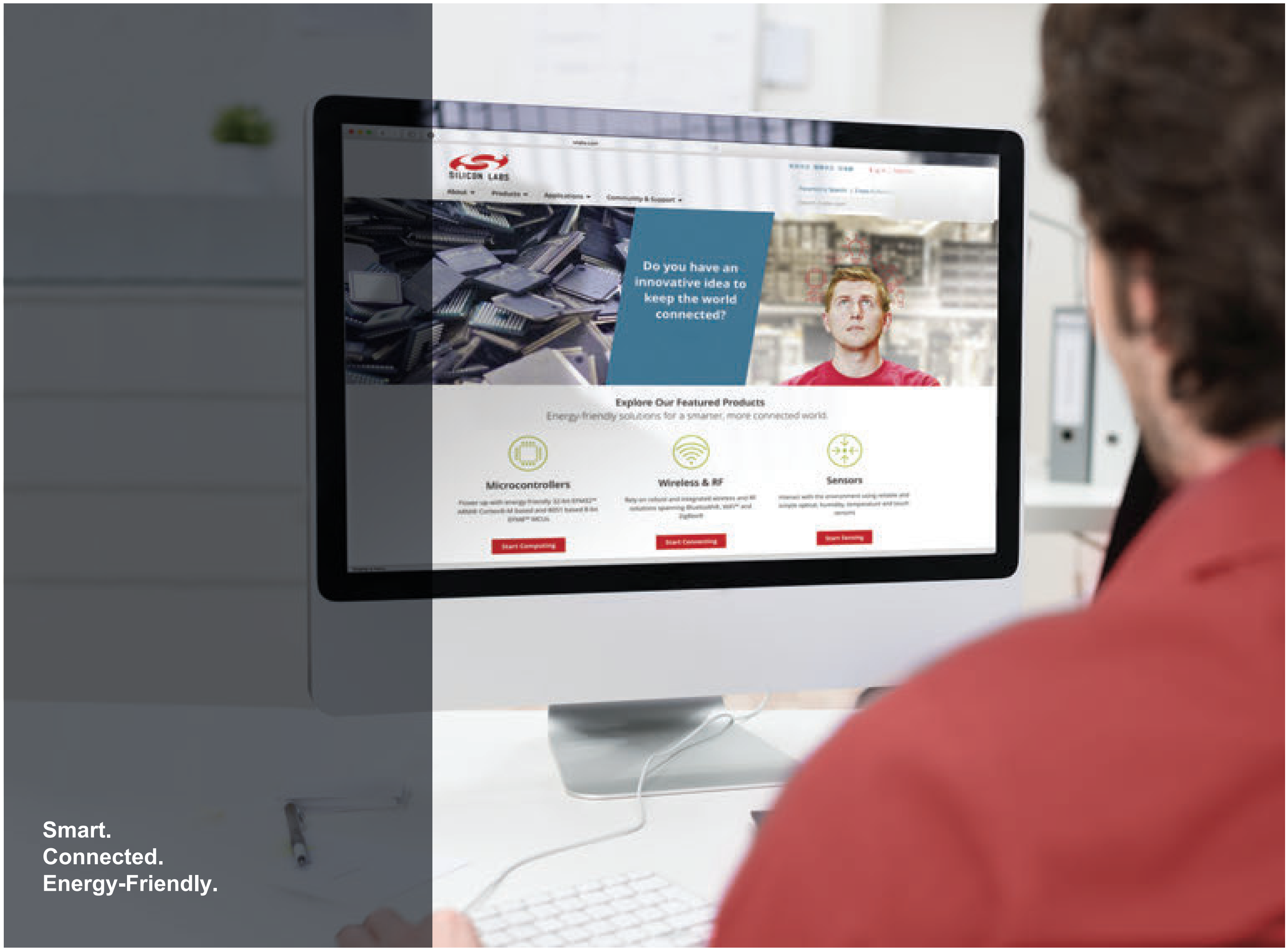
**Notes:**
1. Modulation Index H = 1, Link Budget Improved compared to 500 kbps data rate, assuming antenna gain is 0 dBi.
2. The RF range calculator is used in the above range estimation. Refer to the RF range calculator under Tool tab at http://www.silabs.com/products/wireless/EZRadioPRO/Pages/Si446x.aspx.

## 4.4. Summary of Whip Antenna Performance

Based on the range test results, the performance of these whip antennas are summarized in Table 3. The radiation pattern of the antennas is not measured in this document, and during range test the radiation pattern is not investigated or considered.

**Table 3. Measured Whip Antenna Performance**

| Antenna Samples | Input Impedance or S11(dB) | Gain(dBi) | EIRP(dBm) | Harmonics Margin to Limit(dB) | Range (km) | Price (USD) | Need External Match Circuits |
|---|---|---|---|---|---|---|---|
| 1# | Best (Below –10.3 in whole bandwidth) | Low (–2.02 at 490MHz) | Low (14.98 at 490 MHz) | Good (above 12) | Good (1.29) | Medium (1.0) | NO |
| 2# | Acceptable (Below –6.4 in whole bandwidth) | High (1.2 at 490 MHz) | High (18.20 at 490 MHz) | Good (above 11) | Good (1.38) | High (1.5) | Need L type match circuit |
| 3# | Good (Below –10.2 in whole bandwidth) | Medium (–0.85 at 490 MHz) | Medium (16.15 at 490 MHz) | Good (above 9) | Good (1.37) | Low (0.9) | NO |

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