Application Note

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Making EIRP Measurements on 5G Base Stations

Overview

The introduction of active antenna systems on 5G base stations requires engineers installing and maintaining them to use alternative measurement methods, such as effective isotropic radiated power (EIRP) for transmitter power and beam verification. This application note highlights how the Anritsu Field Master Pro™ MS2090A facilitates the "over-the-air" (OTA) measurement of EIRP on active base stations using an accessory dual polarized waveguide antenna. Measurements are performed according to 3GPP specifications and are ideal for product design verification and field installations.

Background

In the past, the majority of radio systems, whether cellular, PMR, broadcast, or military, have all used relatively simple transmitters and antennas. Measuring the transmitter power was simple and could be made with an absorption power meter or by using a direct connection via a “sniffer” port in the antenna feed. However, to achieve the efficiency and speed goals set by the radio industry for 5G, manufacturers and providers have had to rely on vastly more complex transmitter and antenna systems. Using traditional methods to make measurements has become virtually impossible, and even when and where possible, their results have little relationship to the performance of the network.

New methods of measurement have had to be developed that can be performed on any configuration of base station, however complex. These must go beyond a simple measure of input power and provide operators with an indication of how good a connection should possibly be to user equipment (UE) located somewhere in the field. This new basic measurement of transmitter power for a 5G base station is now EIRP. This paper discusses what it is and how it is measured using modern test equipment.

The Need for EIRP

First, let us define what is meant by EIRP. If an antenna could be made that was effectively a point source and it radiated RF energy equally in all directions (in 3D space), then the signal strength measured at a set distance would be same regardless of the direction. This antenna would then be radiating “isotropically”. Such an antenna can also be said to have unity gain, or no gain. A good 2D example of isotropic radiation would be when a pebble is dropped into a pool of water and the waves are equally dispersed in all directions.

Now, if a non-isotropic or directional antenna is used to measure the signal strength at the same distance as before and the input power was varied to get the same reading as before, then it could be said that the radiated power in that specific direction was equivalent to an isotropic antenna with a given input power.

For example, at 1 GHz and a distance of 100 m, the free space path loss is 72 dB. If a signal of 1W (+30 dBm) is fed into the isotropic antenna, the power measurement is –42 dBm (Figure 1A). If a directional antenna is used with a gain of 6 dBi in the intended or “boresight” direction, the result is a reading of –36 dBm (Figure 1B). It could be said that it is +6 dBi or 6 dB more than the isotropic antenna. Taking it further, it can be said that the directional antenna has the effective radiated power of an isotropic antenna fed with +36 dBm or 4W. In short, it has an EIRP of 4W. (Note: when measuring the gain of an antenna, it is typically given in dBi or dBs relative to an isotropic antenna.)

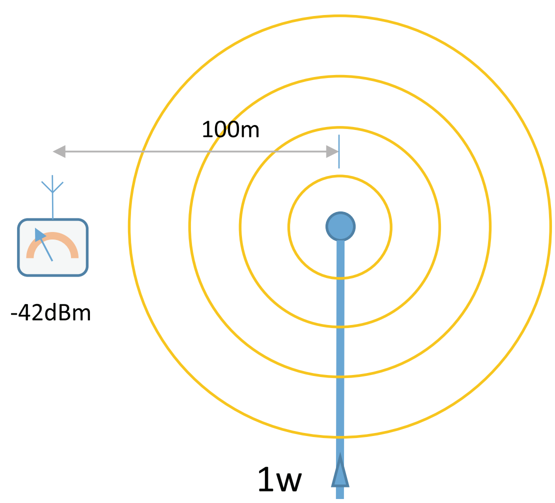


Figure 1A: Omni-directional antenna radiates isotropically – equal power in all directions.

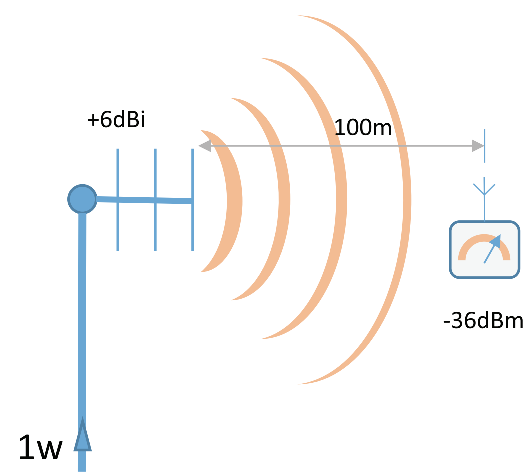


Figure 1B: Directional antenna radiates more energy in the 'forward' direction – has 'gain' over an isotropic antenna.

Before 5G

Directional antennas have been in use for many years, however, their directional characteristics were generally determined by their construction and boresight directions fixed by their mounting. For cellular applications, they would typically be designed to radiate in an arc of 60º to 120º depending on the number of sectors a base station might support. Some electro/mechanical adjustment might be included to allow carriers to optimise coverage, but essentially they were fixed. By knowing the antenna gain and the input power, operators can predict signal strengths in the field and hence estimate performance.

In order to meet all of its design goals, 5G has to use directional antennas that can be steered dynamically and generate beams in multiple directions simultaneously. To achieve this it is necessary to use a matrix or array of antennas, each being fed with different signals. At a minimum distance from the antenna, known as the far field, these signals combine together in or out of phase to create a beam-like pattern (Figure 2). These are commonly known as phased arrays because in their simplest form the beam direction is determined by the phase difference between the signals on each successive antenna element.

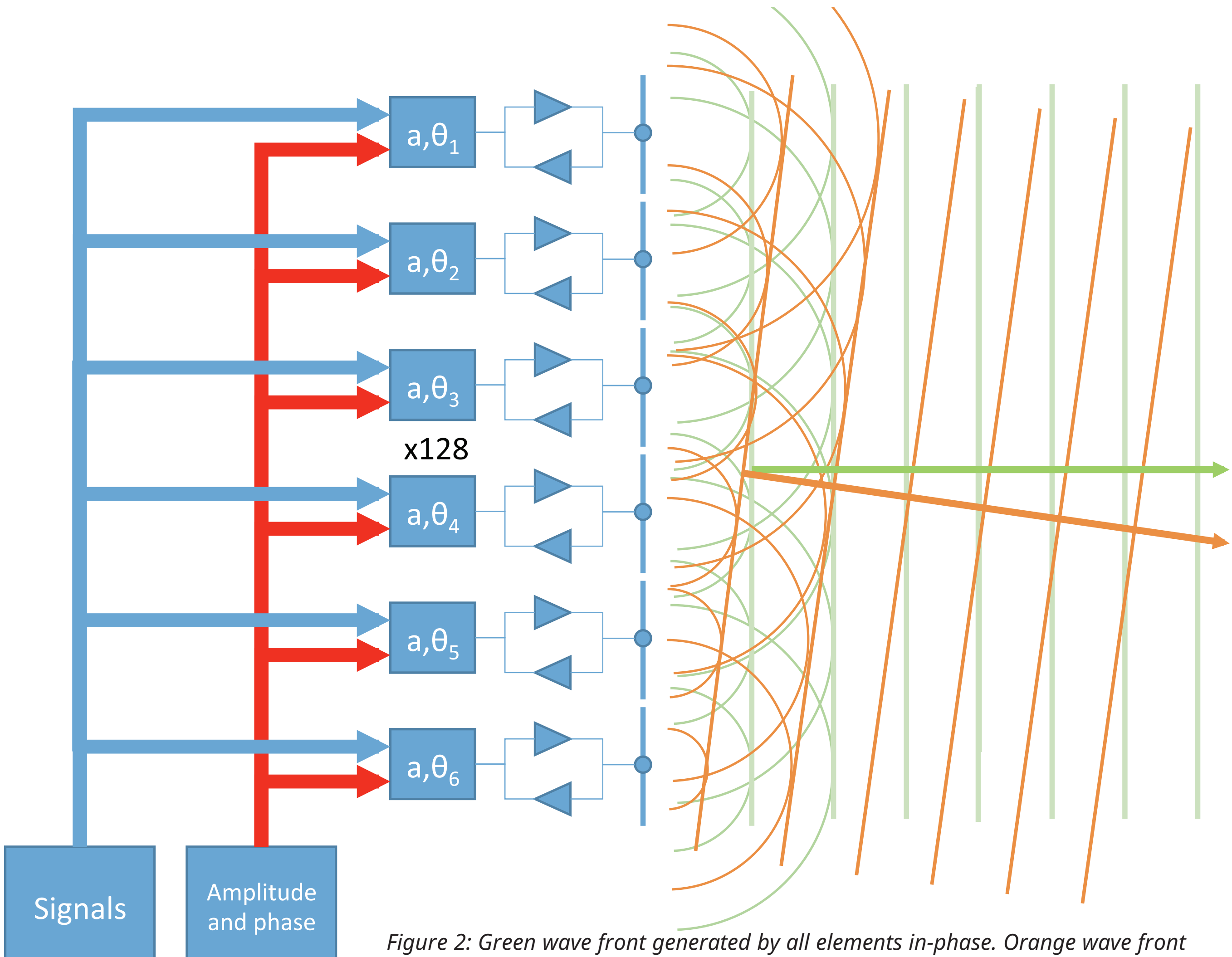


Figure 2: Green wave front generated by all elements in-phase. Orange wave front generated by successive phase shift on each element.

To achieve the complexity required for 5G, these active antennas typically have an individual transceiver associated with each antenna element. Each element will also have two cross-polarized radiators to improve diversity. In all, a 5G antenna could have 128 to 256 individual transceivers all integrated with their own radiating elements. Using the traditional method of measuring antenna input power is therefore impractical at best and a better solution had to be found.

Note: *in some Asian markets the regulators insist on the continued use of a single RF test port. It is unclear how the port should be coupled to the array and can be different for each manufacturer. Assuming all elements are coupled and that the coupling network offers the same path length to each antenna element, then only the boresight power can be measured reliably (Figure 3). Realistically, this can only be used for looking at drift over time and would have to be used off-line with a test signal aimed along the boresight. It does not offer a practical measurement for many network operators.*

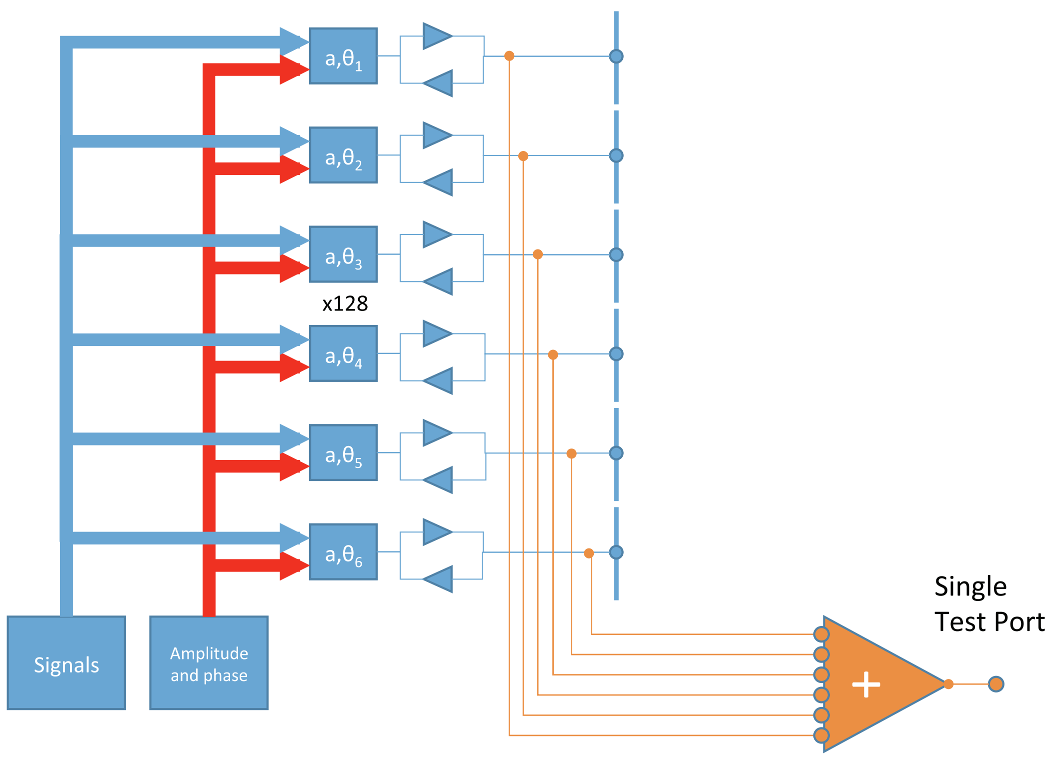


Figure 3: Sampling network must have all same path lengths and attenuation to give boresight power only.

Over-the-Air EIRP Measurements

Not only can active antennas steer their beams dynamically, they can also change the shape of the beam in order to narrow the focus and concentrate energy in the wanted direction towards a single user or spread the beam for more broadcast applications. Doing this changes the gain and hence the required input power. The industry has therefore agreed that in the field the most useful measurement of power is EIRP. As already stated, it provides the operator with a reliable indicator of signal strength anywhere in a cell once path loss is taken into consideration.

Practically, making EIRP measurements in the field is not as straightforward as it might seem. Even sub –6 GHz 5G transmitters have the potential to use bandwidths of up to 100 MHz, therefore any measuring receiver has to be "flat" across the channel bandwidth while adequately rejecting other signals on adjacent channels. (Any lack of flatness in measuring receiver gain translates directly into a power measurement error.) At any reasonable distance from the base station the signal level is going to be quite small. Remember, at 1 GHz and 100 m the path loss is 76 dB. This typically means that a receiver is needed that is more sensitive than a normal spectrum analyser.

If measurements on a live base station are required, then one needs to be able to extract that part of the transmission that is "beamed" in the direction in question and also know the intended EIRP. This means that any instrument has to decode the broadcast signalling and use this to control the measurement timing.

The last part of making an EIRP measurement is to understand the various path loss elements and take them out of the equation. Free-space path loss is a significant one that requires knowledge of the distance between the measuring antenna and the base station itself. This can be determined using various techniques, including GPS, laser/optical rangefinders, and accurate large scale maps. Other factors include the "gain" of the measuring antenna and the insertion loss of any connecting cables.

Utilizing Spectrum Analyzers to Make EIRP Measurements

The Anritsu Field Master Pro MS2090A handheld spectrum analyzer has been designed to meet this new challenge of measuring EIRP directly from a 5G base station. This includes sufficient bandwidth to make accurate measurements on signals occupying 100 MHz or more, as well as enough sensitivity and low noise floor to record EIRP at realistic distances from an active base station. It also has the ability to lock on to the primary and secondary synchronisation signals, using this to measure the EIRP in up to 8 broadcast beams that 5G base stations step sweep across each sector so that mobiles can acquire synchronisation in order to report their presence and location (Figure 4).

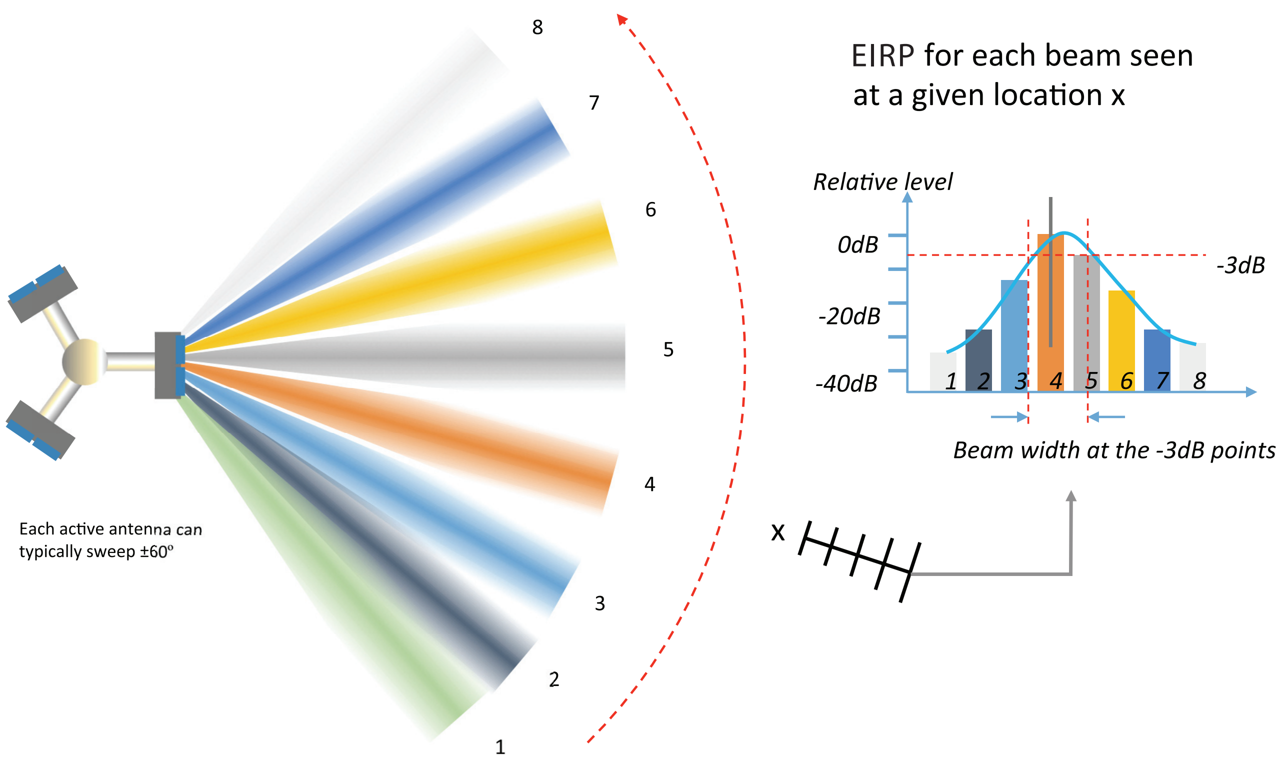


Figure 4: Primary Synchronisation Signal (PSS) step sweeping across the antennas field.

It is also possible for fault finding and commissioning teams to place the base station in a test mode where it transmits a known "test model" signal in a given direction and strength. This allows radiation patterns to be determined and field strength in complex environments to be measured. It also provides a means of using conformance test methods in the field.

To determine EIRP in the field, the Field Master Pro MS2090A takes account of 4 parameters and presents the following calculated results (adjusted for the channel frequency):

1. Power incident at the input to the instrument
2. The channel frequency and bandwidth
3. The gain of the measuring antenna (dBi)
4. The loss in the cables between the antenna and the instrument
5. The distance from the base station antenna (using GPS or input from a laser rangefinder)

In addition to EIRP, there are a number of other parameters that help operators determine the performance and likely coverage achievable with their networks (which relates to the signal quality and therefore the UE ability to acquire it). The Field Master Pro MS2090A reports on these alongside EIRP and includes:

1. RSRP and SINR – provide a ratio between the wanted signal and any unwanted signal and noise in the channel bandwidth used
2. RSRQ – provides a measure of the received signal quality and is derived from detected error rates
3. EVM – another quality measurement but this time looking at the accuracy of the modulation transmitted relative to an idealised waveform

EIRP – The Way Forward

It is clear that with 5G and the arrival of beamforming, traditional methods of measuring the total radiated power of a base station are both impractical and of little use to network operators who want to make field measurements and optimize coverage. The new breed of field testers, like the Anritsu Field Master Pro MS2090A, provide practical and convenient measurements of EIRP in the far field, the only place where the beams are formed from multi-element active antennas. Using EIRP measurements in various directions, operators can determine the beam shapes, the location/angles of the nulls, and safety of field strengths close to the base station. This in turn allows them to minimise interference to their own and other network services. EIRP measurements can be used with any transmitter regardless of the complexity and so provide the way forward for network optimisation for the foreseeable future.

Practical Measurements of EIRP

Virtually all 5G base stations employ two polarised antenna arrays to improve diversity and reduce fading. Typically, they would be angled at ±45° and used in several ways. For SSB beams, the location of the UEs are unknown so it is likely that both antenna arrays would carry the same information transmitted at similar power levels. This would ensure that reception in a random location/orientation would be optimised as the UE's antenna polarisation would be unknown.

For traffic beams, the two antenna arrays can be used in a MIMO fashion to achieve multiple paths to the UE to either maximize reception quality or, under clear signal conditions, data throughput. There may be other reasons why a base station might choose to vary the signals on the two antenna arrays, such as reducing base station to base station interference or optimising reflected signals off nearby buildings.

Therefore, in order to determine the true beam power, the power has to be measured in two orthogonal planes and then added together to give the total EIRP. The 3GPP base station test specification TS38.141 states that the two orthogonal polarisations may be measured simultaneously or separately. Using the latter method simplifies the procedure, reduces the cost of equipment, and reduces the number of elements that need to be calibrated.

Using the Field Master Pro MS2090A to Measure Beam Power

The Field Master Pro MS2090A supports all of the features necessary to measure EIRP according to the 3GPP specification TS38.141, and performs all of the calculations to provide a single beam power measurement. Measurements can be made with any polarised measuring antenna, but the preferred approach is to use a dual antenna where the two elements are arranged at right angles along the boresight axis. This avoids the need to rotate a single antenna through 90° between each measurement. A good antenna choice would be a quad ridged pyramidal horn antenna. A horn antenna offers good gain, directivity, and front-to-back isolation. A quad ridged horn antenna will also provide two orthogonal, well-matched outputs over a wide bandwidth (Figure 5). (Note: if using a single polarisation antenna, care has to be taken to ensure it is rotated exactly through 90° for each measurement.)

Figure 5: A quad ridged horn antenna in use.

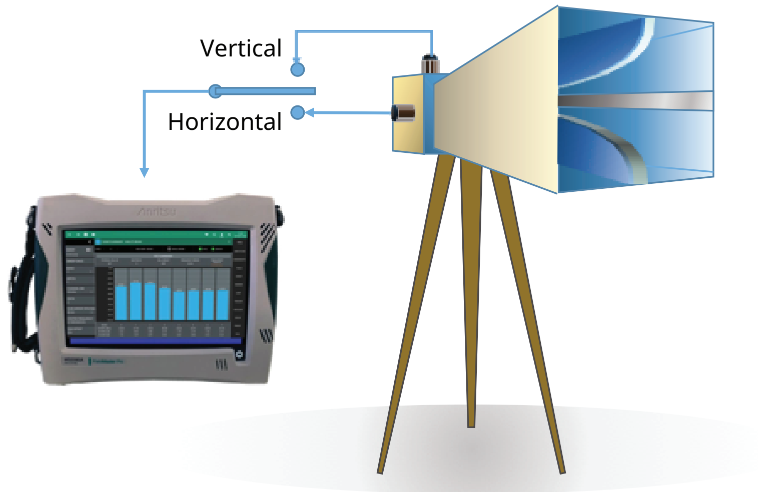


Figure 6: The diagram above shows a typical connection set up using a dual polarized antenna with an RF switch to select each output.

Typical Procedure for Measuring 5G Base Station EIRP

1. Before going into the field, ensure that the RF cabling being used is calibrated for insertion loss at the frequencies/bands to be measured. It is recommended that the RF switch is also included in the loss calibration process. Ideally this should be done using a vector network analyser. If one is not available, then there are other methods that can be used, however, these tend to be less accurate if termination mismatches are not considered.

2. Ensure that the cables connecting the antenna to the switch are the same type and length. It is important that the cable loss is the same along both the horizontal and vertical branches. The cable insertion loss can then be stored in the instrument for later use in the field.

3. The measuring antenna should have a calibrated gain, as a function of frequency, supplied by the manufacturer. This should also be entered in to the instrument for later use.

4. Determine a good safe location from which to make the measurements.

    a. It should have clear sight of the base station antenna

    b. It should be beyond the unsafe working zone of the base station itself and any other co-sited transmitters

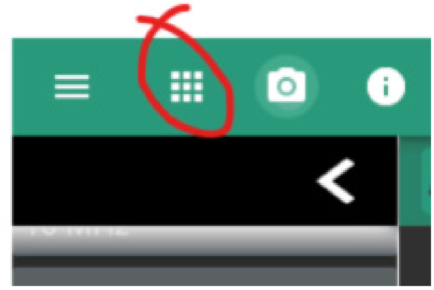
    c. Most countries produce safe working practices documents for working with transmitters, which should be followed at all times

5. Stand the antenna on a tripod and aim it directly at the base station antenna, this includes both azimuth and tilt. (Correct alignment can be confirmed once the “Active EIRP” measurement is available, see step 15. The antenna can be moved to obtain a peak reading.)

6. Connect the antenna to the Field Master Pro MS2090A via the RF switch, ensuring the cabling is the same configuration as used in calibration. Avoiding frequent disconnection/reconnection is recommended, however, if kept connected, please ensure the connectors are protected from mechanical strain and shock during transit. (More consistent results will be achieved if cabling is not disturbed once calibrated and connectors are tightened to the correct torque.)

7. Next, determine the distance from the base station antenna to the measurement antenna. Probably the simplest and most accurate method is to use a laser range finder. There are a number of these devices sold for golfing and cost just a few hundred dollars. Typically they claim to have an accuracy of ±1 m or yard. The distance to the antenna should then be stored in the Field Master Pro MS2090A.

8. From the top level menu select **5G Measurements**.

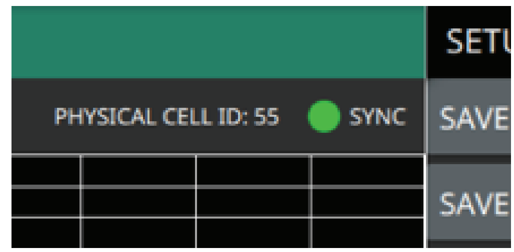


9. Then select **Measure** and then **EIRP**.

10. The **Quick View** menu presents all of the fields in a logical order along with a simple diagram of the set up stage.

11. Ensure the cable loss, distance to the base station antenna, and the measuring antenna gain are all correctly saved in the instrument and shown on the screen.

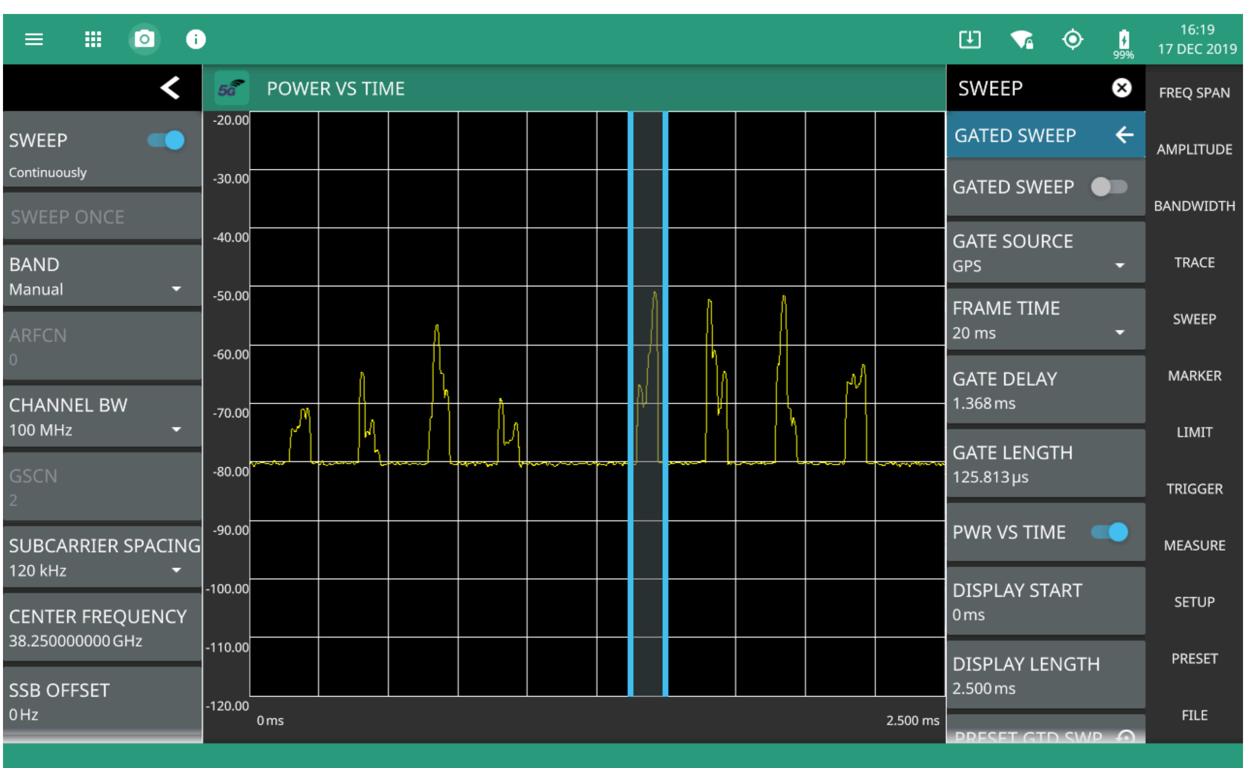
12. Set the band of operation, channel bandwidth, sub-carrier spacing, and SSB offset to the appropriate values for the radio under test.

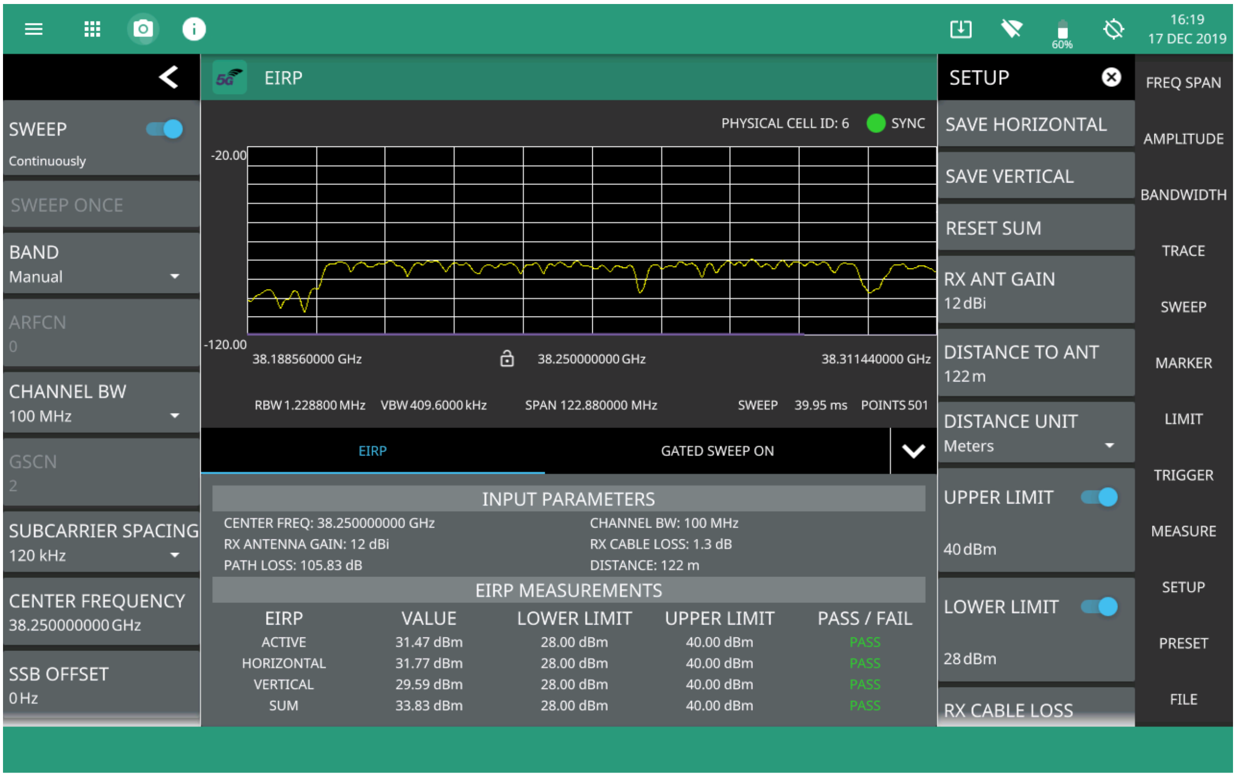


13. Using the EIRP screen, and assuming the base station is transmitting a full 5G standalone specification signal, the instrument should acquire sync within a few seconds and display a green indicator.

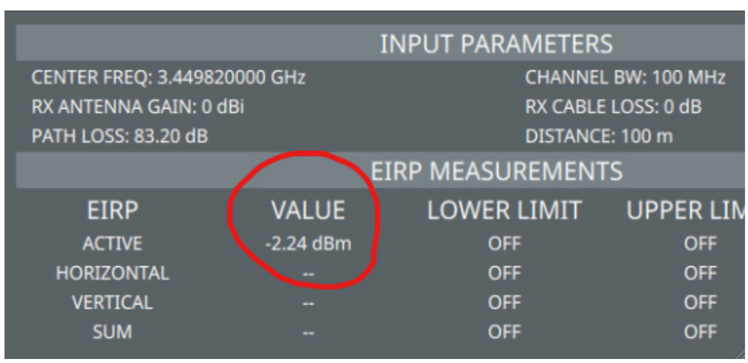
14. If sync is not obtained, use the **AUTO DETECT SSB** feature to confirm the correct SSB offset has been set.

15. For TDD 5G NR EIRP measurements, the use of a gated sweep ensures that the measurement of power is only made when the gNB is actively transmitting. From the **SWEEP** menu, select the **GATED SWEEP** softkey. Then enable the **Power vs Time** display. The screen will now show a full 5G TDD frame. Set a gate around a constant signal in the frame, for example an SSB beam. If the Field Master Pro MS2090A is synchronized to GPS, the SSB signals will be near the frame start, if there is no GPS sync, it is necessary to identify the SSB signals manually. A typical gate around an SSB signal will be 120 µs. When a gate has been set around a SSB signal, turn off the **Power vs Time** display mode and enable GATED SWEEP.



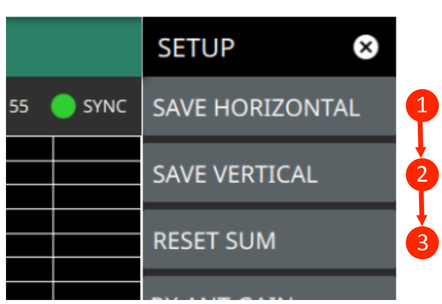


16. Once sync is obtained, the instrument will display the current, active signal's EIRP.



17. Depending on the position of the antenna switch, press **Save Horizontal** or **Save Vertical**. Then throw the switch, wait for the reading to update, and press the other orientation.

18. Pressing **Reset Sum** will cause the calculation to be performed and the results displayed.



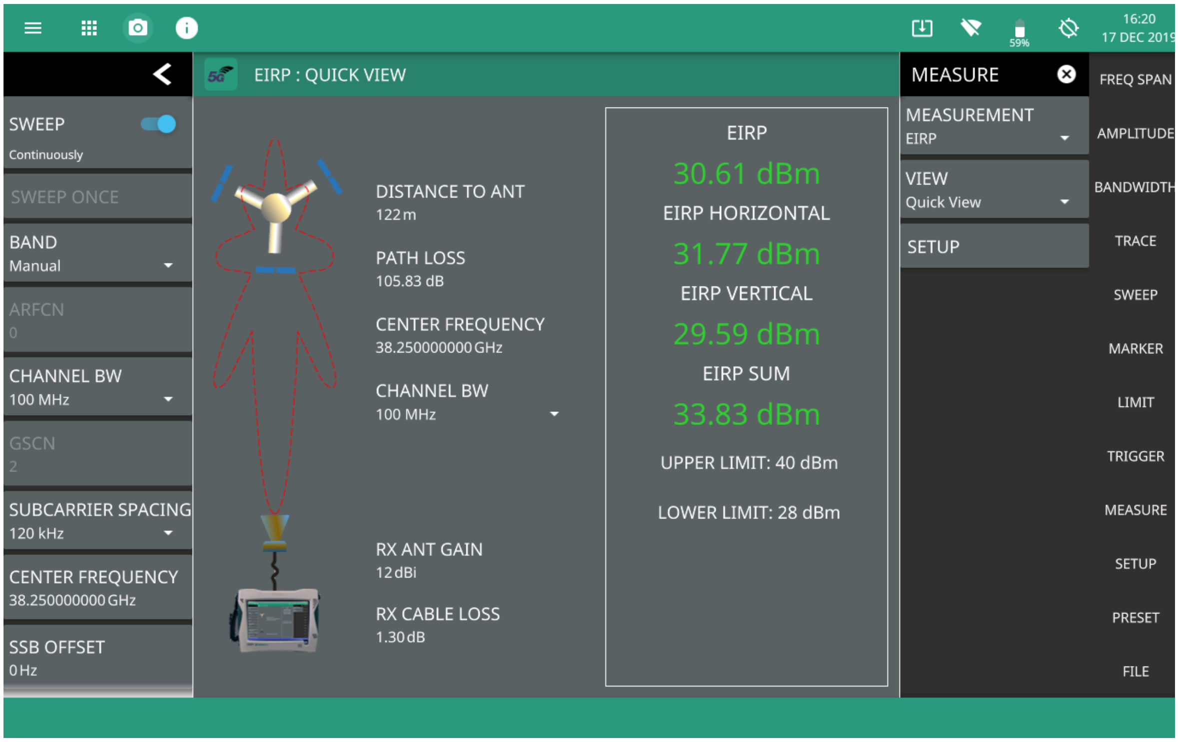
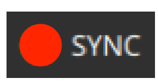


Figure 7: An Example EIRP Screen Showing a Typical 5G Base Station Measurement

Other Things to Consider

If Sync is Not Obtained



- Use the spectrum analyser function to check there is a signal centered on the channel/band number. Peak hold or a slow sweep may help to see the intermittent signals. (The instrument can only decode signals that are visible.)
- With a full specification, 3GPP 5G standalone base station, the synchronisation blocks (SSBs) will be located on specific sub-carriers. These are defined as a raster that does not align with the band/ channel center. By default, the instrument will scan this raster looking for the SSB and will only sync if found. An SSB search facility can be invoked that will look for SSBs anywhere in the channel. This search can take some time but may help with non-standard scenarios.

If Reported Power Level is Too High or Too Low

- If the EIRP measurement is higher than expected, then it is quite possible that another signal is interfering with the reading. Typical sources include co-sited transmitters and/or UEs that are physically close to the measuring antenna or along the axis of measurement. Generally, it will be obvious that there is an interferer when looking at the spectrogram. Check that the signals are centered on the band number and that they are pulsed with a frame repetition rate of 1 ms.
- If the EIRP measurement is lower than expected and a fault is not suspected, then check the following:
  - Is the measuring antenna correctly aligned in azimuth and tilt?
  - Ensure that a gate has been set in the **Power vs Time** sweep menu around an SSB signal.
  - Are you located at a point between SSB beams? Moving a few degrees in either direction around the base station may show a change in power. You can use the 'active' measurement to see the effect of moving in real time. Don't forget to re-check the distance to the BS if you have relocated.
  - Check all of the connectors in the RF cabling to ensure they are not damaged or have become lose.
  - If the horizontal and vertical measurements are significantly different, try rotating the measuring antenna through 90° and ensure that the measurements are replicated but on the alternate polarisations. If not, check the cabling, switch and antenna.

- Changes in the propagation path between the BS and the measuring antenna may affect the readings significantly, especially for mmWave or FR2 signals. Check for the following scenarios:
  - Are there obstructions along the path such as trees, overhead cables, lampposts or tall buildings?
  - Are there objects or buildings that might cause a strong reflection, such as buildings, vehicles, water or tall fences.
  - Rain and fog will attenuate mmWave signals. It is recommended that critical measurements are only made under clear weather conditions.
  - Other transmitters along the axis of measurement, this includes other base stations beyond the base station being measured.
- By law, a base station must limit the total power transmitted in a given direction if people are likely to be regularly exposed to high EMF fields. An example might be an office building located close to a base station. The base station is required to monitor the beam energy directed at the office block and keep the total power to below a safe limit. The safe limit has to take account of all other sources of RF in the neighborhood, including broadcast signals. Therefore, it is possible that although the base station is expected to transmit at full power, it could be being limited by this regulatory mechanism.

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Specifications are subject to change without notice.

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