

APPLICATION NOTE

This Application Note describes how to configure the Calnex Sentinel with an Over-the-Air (OTA) module to determine the absolute timing accuracy of a 5G NR gNodeB or 4G LTE eNodeB. Sentinel OTA does this by examining the timing signals within the Radio-Frequency (RF) spectrum.



Making Over-the-Air sync measurements with Calnex Sentinel



Introduction

3GPP standards require the phase alignment of transmitted frames between adjacent 5G NR gNodeBs and 4G LTE eNodeBs to be within $3 \mu\text{s}$. If the phase alignment exceeds this limit, then there may be interference between adjacent cells leading to degradation in voice and data performance at the cell boundary. Additionally, 5G and 4G advanced features e.g. enhanced Inter-cell Interference Co-ordination, rely on this alignment to allow additional localized cells to be added to supplement the macro cell's performance. The Calnex Sentinel can be used to examine the quality of the PTP flow to the radio unit and time error of the recovered clock to determine if the frames being transmitted on the air interface meet the 3GPP alignment criteria. However, obtaining physical access to a live radio site can be problematic and, in many cases, it is not possible to access the PTP flow or there is no recovered clock available. Further, the actual frame alignment on the air interface can only be inferred from these measurements.

The intended application of the Sentinel OTA is to measure the timing accuracy of a gNodeB or eNodeB without requiring access to the PTP flow or the recovered clock. The relative timing accuracy of adjacent cells can be determined by making separate measurements of different transmitters in the network.

Sentinel OTA does this by finding and decoding the Primary Synchronization Signal closest in time to the 1pps reference – and compensating for the time between this signal and the start of frame. The measurement assumes that the gNodeB or eNodeB is synchronised to 1pps. Typically, the cells in a network are synchronised to a 1pps reference from a common PTP Grand Master that uses GNSS for time and phase alignment. If that is not the case, then you will need to compensate accordingly.

Sentinel OTA is designed to work between the frequencies of 350 MHz and 6 GHz. Most FR1 5G and 4G cells can be found within this range.

For additional information on the 4G and 5G frame structures, see appendix A or other references.

Setting up for measurements

Location

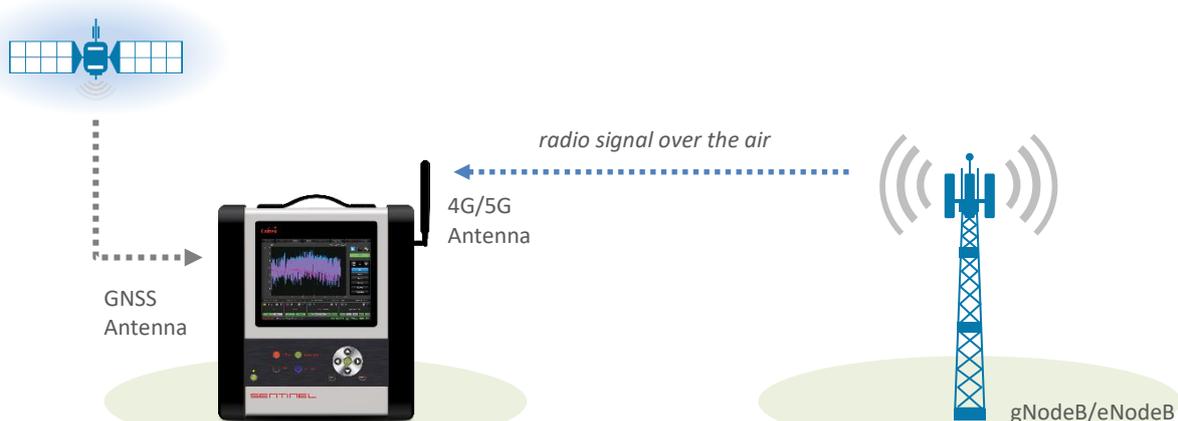
You need to be within sight of the transmitting antenna of interest – the closer the better. In particular you need to have enough signal power at the receiving antenna for the OTA card in the Sentinel to be able to reliably find and decode the signal

Hardware

You will need a Calnex Sentinel with the OTA card installed, along with the appropriate software (R14.0 or later).

You will also need an antenna to receive the RF signal from the transmitter being measured to the Sentinel OTA card. It is also possible to use a suitable cable to connect directly to the transmitter. A cable measurement will always be more reliable, however be careful not to exceed the maximum allowed input power for the OTA card (0 dBm) as you could damage it.

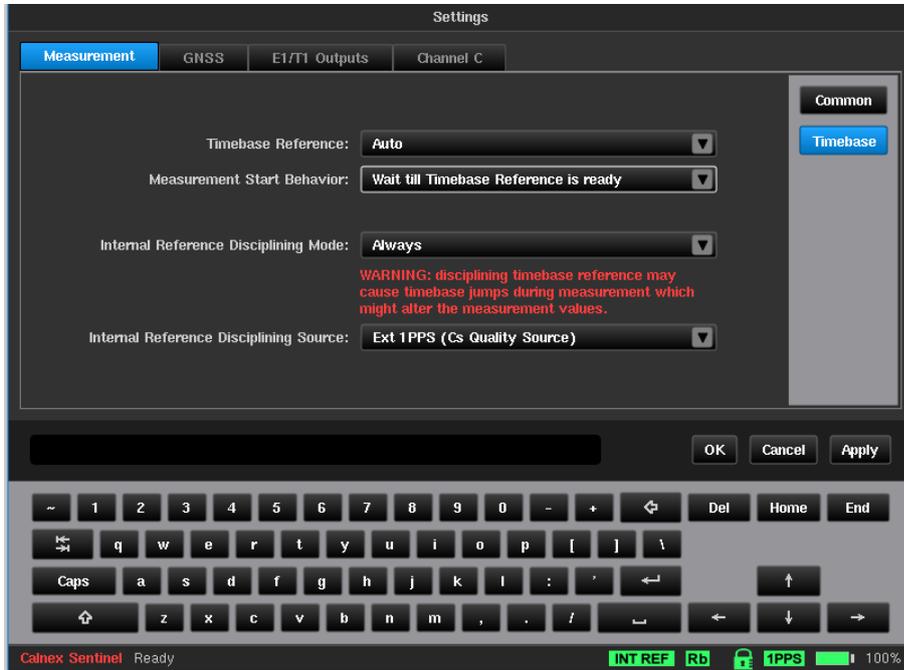
Measurements require that Sentinel is aligned to the same reference as the transmitter being measured. This is achieved by disciplining Sentinel to GNSS prior to starting the measurement. If GNSS is not available at the test site then Sentinel can be put into transport mode after being disciplined at another location which will retain the reference alignment while being moved to the test site.



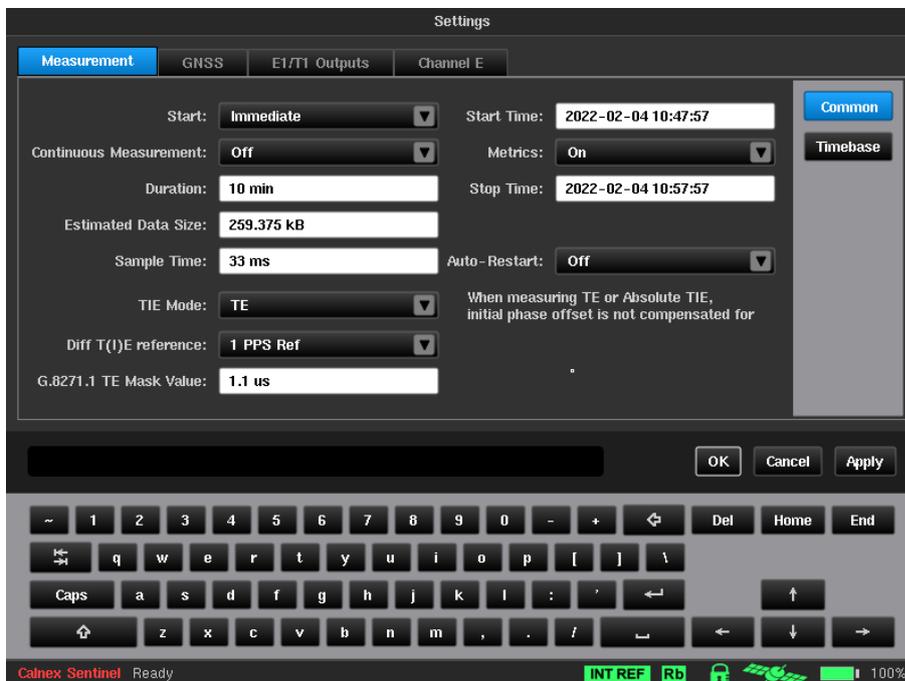
Sentinel setup

Hardware configuration

1. Connect the 4G/5G antenna or cable to the OTA card input port 1.
2. If using an external reference e.g. GNSS or 1pps, then connect it to the Sentinel and select the appropriate reference on the Settings > Measurement > Timebase screen.

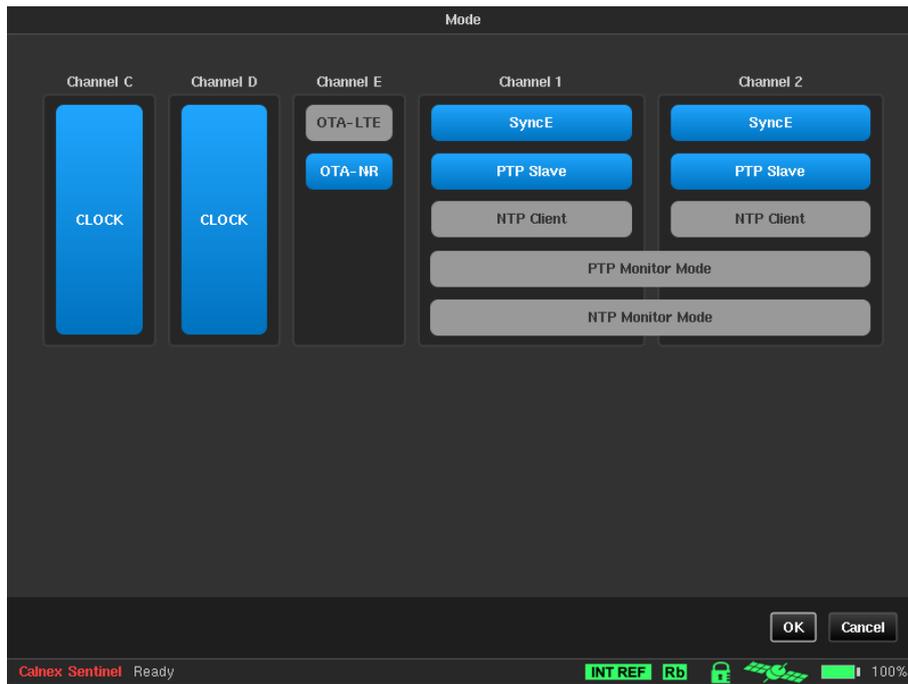


3. Set up the required measurement duration on the Settings > Measurement > Common screen.



Select transmission type

From the main menu, select the **Mode** tab

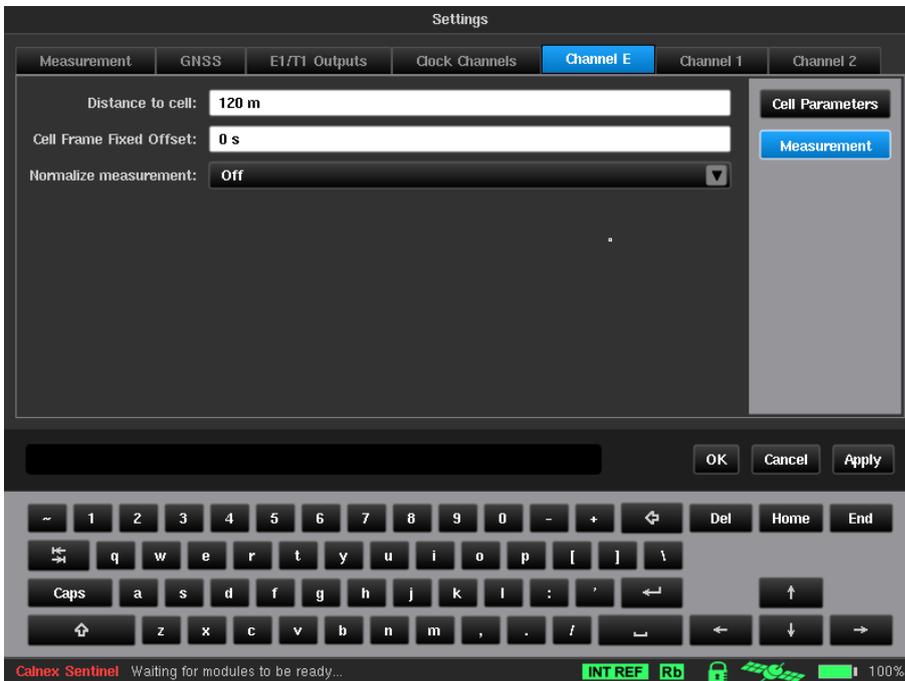


1. On the **Mode** screen, select **OTA-LTE** for 4G transmissions or **OTA-NR** for 5G.
2. Click on **OK**. From this point in the process, the measurement setup varies depending on the transmission selected.

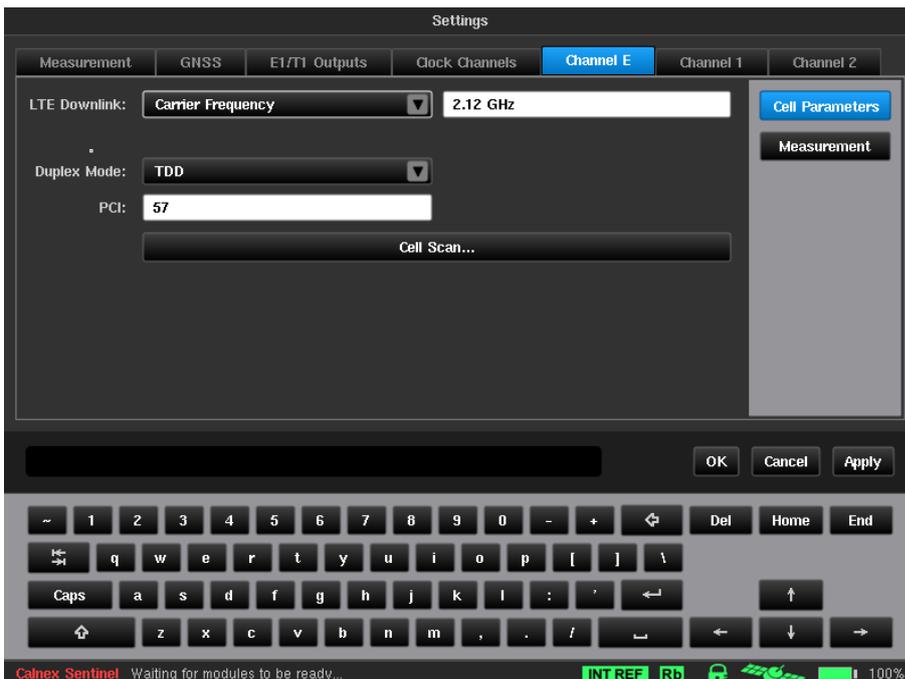
4G LTE Software Configuration

The OTA measurement parameters need to be configured as follows:

1. Go to the Settings screen and select the channel of interest.
2. Click on the **Measurement** button on the right side of the screen.



3. Enter the distance from the eNodeB antenna in the **Distance to cell** field. This is used to compensate for the signal time of flight based on the speed of light through air.
4. To compensate for a known offset from 1pps (e.g. due to internal eNodeB cable delay between the RF generation point and the antenna) then enter this in the **Cell Frame Fixed Offset** field.
5. For phase measurements of TDD cells, **Normalize measurement** should be **Off**. For FDD you may wish to turn it **On** to get a clearer picture of any frequency offset.
6. Click on the **Cell Parameters** button.

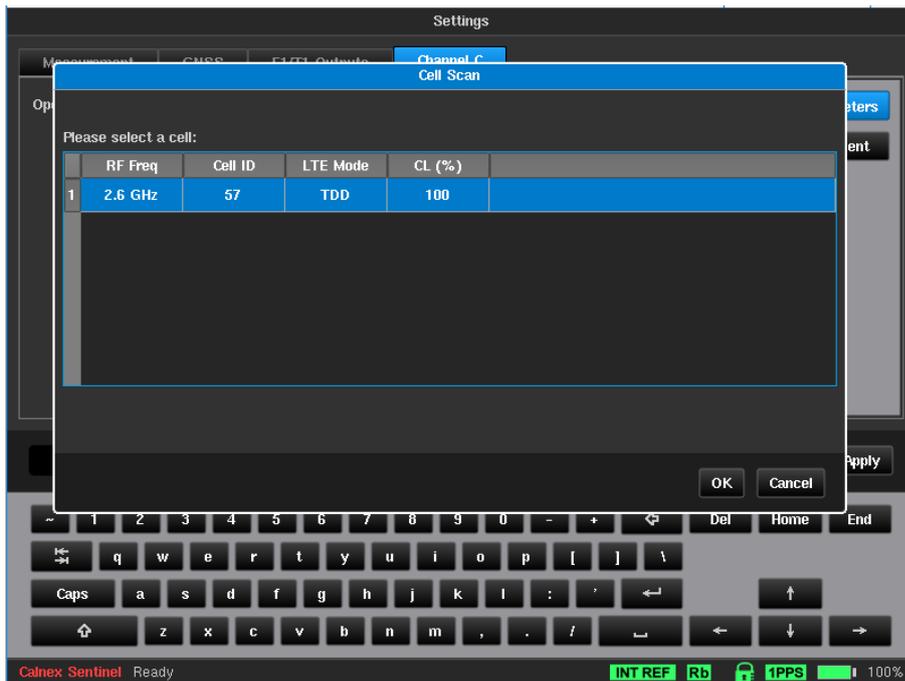


7. Enter the carrier frequency or EARFCN of the signal. If you select EARFCN and tick the LTE Mode tracks EARFCN box, then the system will set the LTE Mode (FDD or TDD) based on the standard.
If you leave this unticked then you can override this setting.

8. If the other parameters (cell ID and TDD or FDD) are known, these can be entered directly.

If these parameters are not known, the scan facility can be used to detect the signal by clicking the **Cell Scan...** button. This will search the selected frequency/EARFCN for a cell ID. It takes about 25 seconds to complete the process and a progress bar shows how far along it is. On completion, it will display the strongest signal it finds.

The CL(%) field indicates the confidence level. A score of 70% or above should be sought. Below this score suggests that Sentinel has not found the specified signal, or the cell ID has not been decoded successfully. In this case check the selected frequency or EARFCN is the correct one, try repositioning the antenna or moving closer to the eNodeB.



9. Once the signal is found, highlight the desired cell, and click **OK** to set these as the measurement parameters.

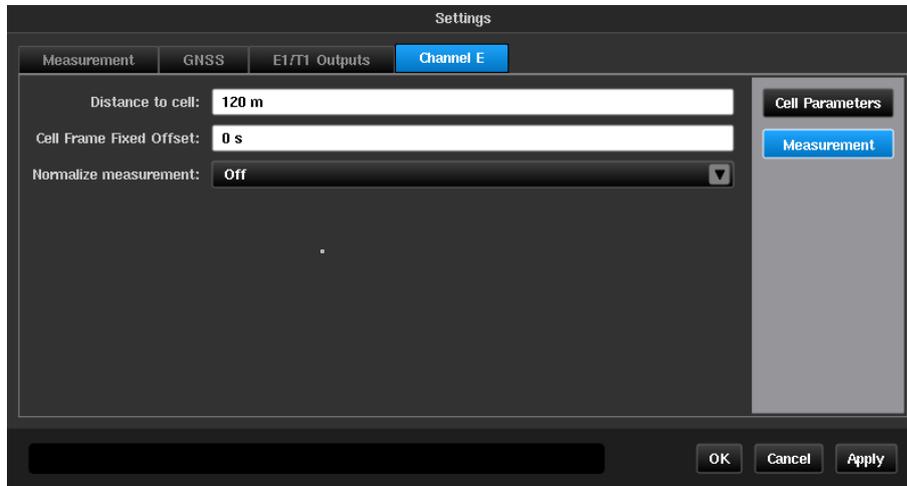
If no signal is found, see the Troubleshooting section of this application note for some hints and tips.

5G NR software Configuration

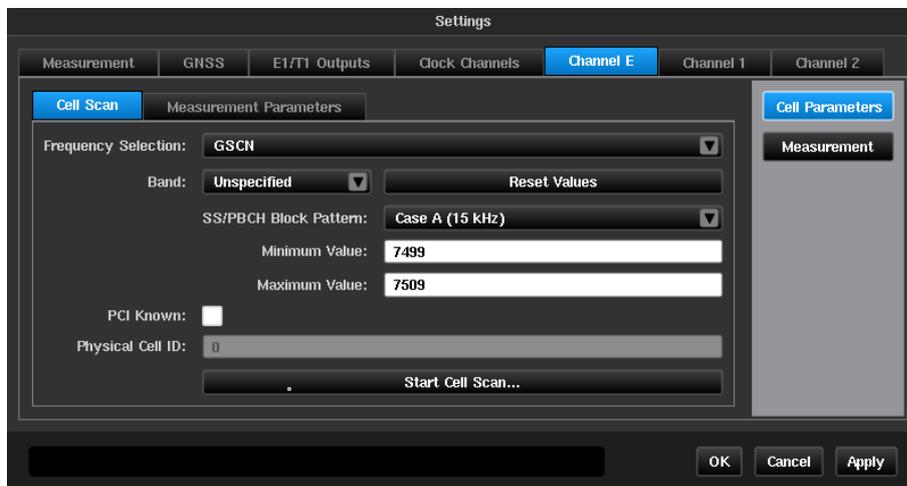
The OTA measurement parameters need to be configured as follows.

Go to the **Settings** screen and select the channel of interest.

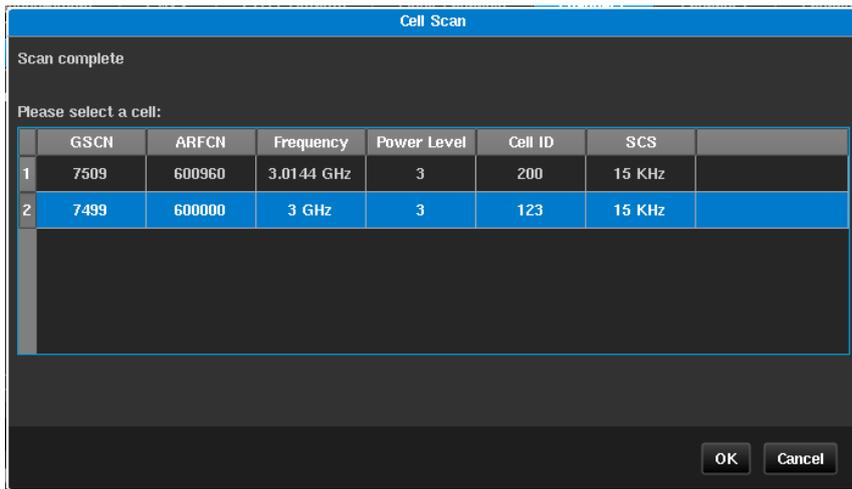
1. Click on the **Measurement** button on the right side of the screen.



2. Enter the distance you are from the gNodeB antenna in the **Distance to cell** field. This is used to compensate for the signal time of flight based on the speed of light.
3. If you need to compensate for a known offset for 1pps (e.g. due to internal gNodeB cable delay between the RU and antenna) then enter this in the **Cell Frame Fixed Offset** field.
4. Turn **Normalize measurement** off.
5. Select the **Cell Parameters** button and **Cell Scan** tab.



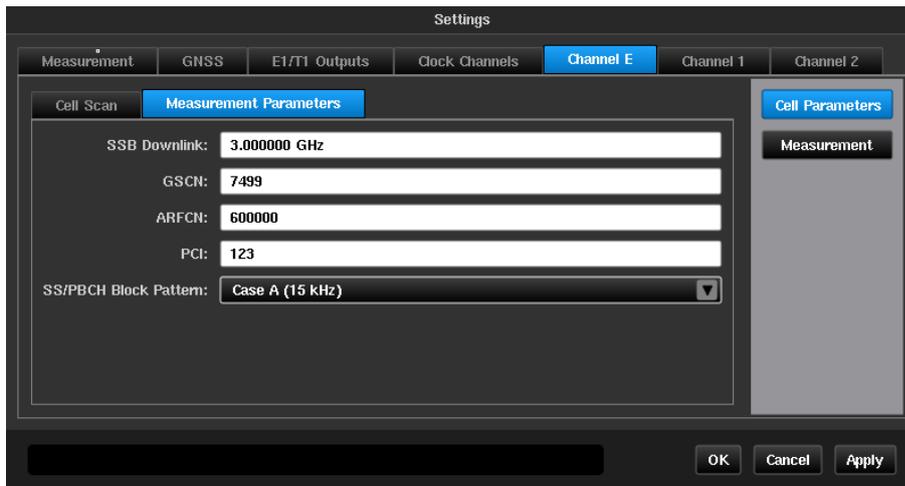
- a. Specify the **synchronization block downlink frequency**. Note that this may not be the same as the channel center frequency. This can be entered as the absolute frequency, the NR absolute radio-frequency channel number (nrARFCN) or the Global Synchronization Channel Number (GSCN). Enter one of these values and the other two will self-populate.
 - b. Enter the **SS/PBCH Block Pattern**. This specifies the subcarrier spacing.
 - c. Enter the **PCI** (Physical Cell ID), if known.
6. Click on **Start Cell Scan...** to scan the selected frequency and display a selectable list of possible Cell IDs for OTA-NR measurement.



7. Once the signal is found, highlight the desired cell, and click **OK** to set these as the measurement parameters.

If no signal is found, see the Troubleshooting section of this application note for some hints and tips.

8. Alternatively, signal parameters can be manually entered under the **Measurement Parameters** tab, without a cell scan being required. If manually entering parameters, only one of the three frequency parameters is required – **SSB Downlink**, **GSCN** or **ARFCN**. When one of these is entered, the other two will automatically populate. One of these frequency parameters, along with **PCI** (Physical Cell ID) and **SS/PBCH Block Pattern** are required fields.



TIPS:

1. **Subcarrier spacing** – When Case B or Case C is used by a Cell, Sentinel is able to detect and decode the Synchronization Signal Block (SSB) using either setting, since both Cases use the same SSB Sub-Carrier Spacing of 30 kHz. However, if the wrong case is selected in the instrument settings, the measurement will have an offset of approximately 70µs.
2. **Disciplining of the internal reference** – Be sure that the internal reference is disciplined to either a stable 1pps reference such as from an atomic clock or to GNSS. If the internal Rubidium clock is used in holdover then be sure that power has been maintained since it was last disciplined either by maintaining mains power to the instrument or by putting the unit in holdover and using the internal battery (if fitted). If holdover is being maintained for an extended period then note that the internal reference will drift by up to 1×10^{-12} per day.

Note, if power is lost to the Rubidium clock, an arbitrary and potentially large phase error of many milliseconds will be introduced until the Rubidium clock is disciplined to a suitable reference. This can happen if the Sentinel is turned off without putting it in holdover mode or if Sentinel is in holdover but the internal battery, if fitted, is allowed to completely discharge.

3. **SSB Downlink Frequency** – In 5G NR, the synchronization block (SSB) is not necessarily at the center frequency of the transmission as it is in 4G LTE. Therefore, the frequency, ARFCN or GSCN of the synchronization signal block should be entered in the SSB downlink field and NOT the center frequency of the transmission.

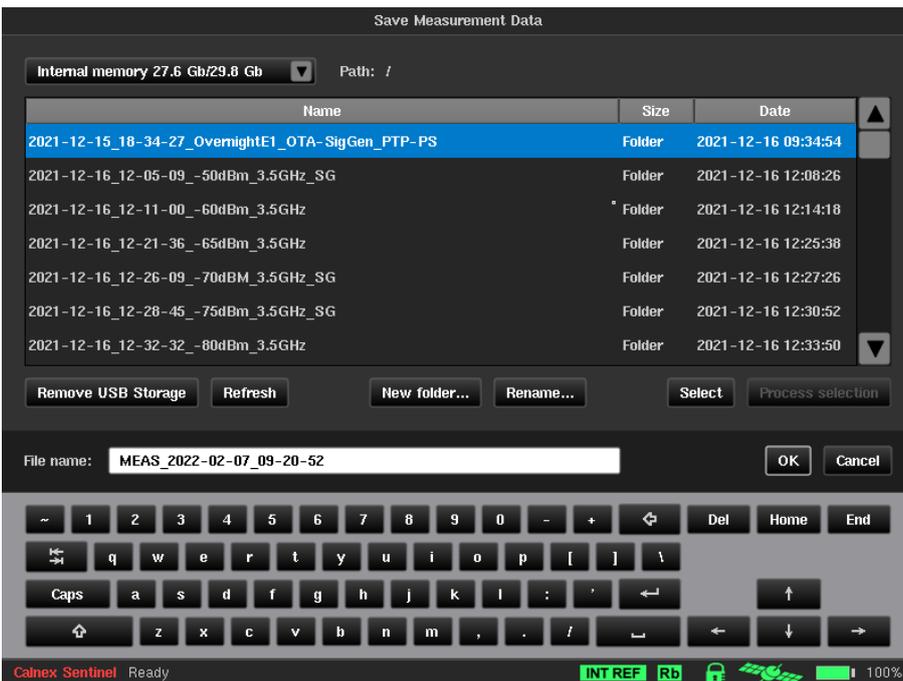
Making measurements

Once Sentinel has detected the cell, it will start the process of locking onto the signal for the purposes of making a measurement. When the measurement is out of lock, the lock LED will be red. When it is in lock the LED will be green. (If during a measurement it goes out of and then regains lock the LED will be yellow.) The power bar graph indicator on the main screen gives an indication of how much power is detected. Ideally all 5 bars should be illuminated, however, the measurement will usually still work with fewer.

When the LED is green, you can press the **Start** button to begin the measurement.



When the **Start** button is clicked, Sentinel will ask to select a file name and storage location. Either select the default given name or enter a custom one, then press **OK**.



The Sentinel OTA card will start measuring the signal timing.



If Sentinel fails to make a sufficient number of successful measurements within a particular time window, then the measurement is deemed to have gone out of lock – this will be indicated by a red Lock LED.



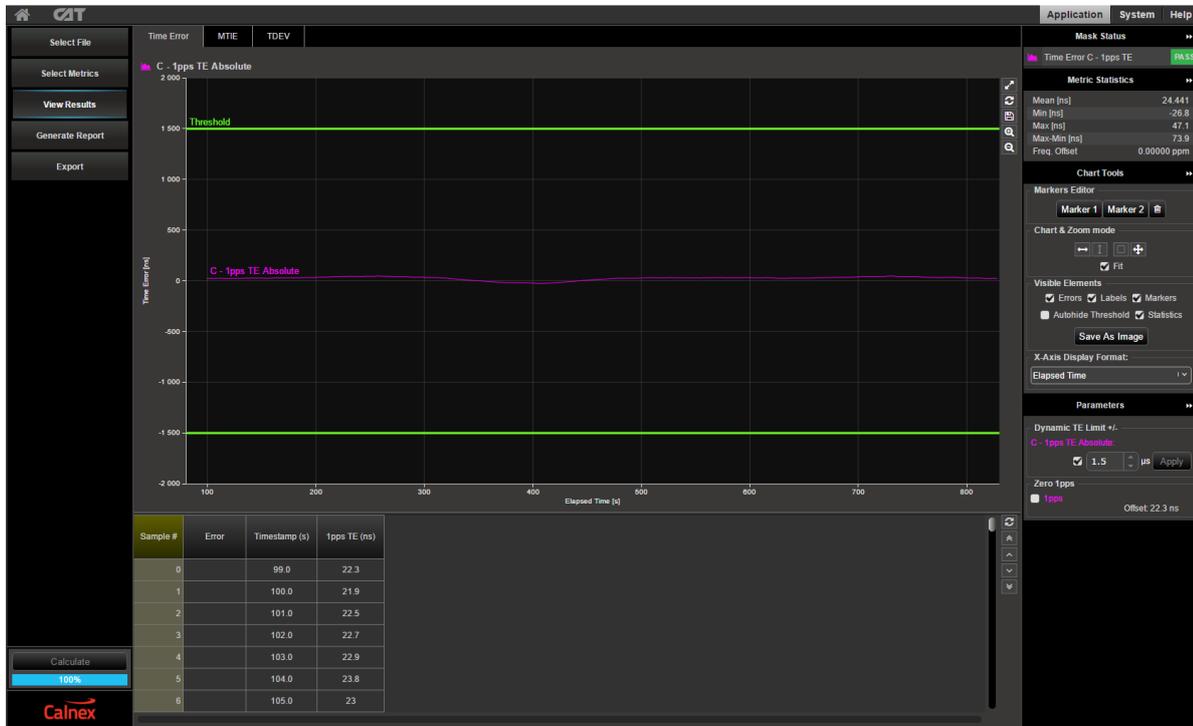
In this case Sentinel will initiate a new search to try and find the signal again before continuing the measurement. When successful, the lock LED will turn yellow to indicate that lock was lost during the measurement. It will turn green again when the measurement is completed.

Using the CAT to review results

The Calnex Analysis Tool (CAT), versions 23 and later, can be used to examine the OTA results in more detail.

Extract the measurement files of interest from the Sentinel and transfer them to a PC where the CAT is available. On opening these files within CAT you will be able to select the OTA metric and view the results.

The frequency offset is shown in the metric statistics on the right hand panel.



Troubleshooting

RF measurements by their nature tend to be more difficult to make than low frequency measurements over a cable. The LTE air interface is very dynamic and can vary a lot from second to second. In particular, the amount of power available at the antenna is affected by various environmental factors as well as the distance between the antenna and the eNodeB.

Tips on how to troubleshoot the set up and measurement:

- If using an antenna, is it properly connected to the Sentinel OTA card?
- If using a cable, is it properly connected to both the eNodeB/gNodeB and the Sentinel?
- Is the radio unit transmitting with sufficient power? (Note: maximum power input to the Sentinel antenna port is 0dBm.)
- If using an antenna, is the Sentinel close enough to the base station to ensure that it is receiving sufficient RF power?
- Does the antenna have a good line of sight view of the base station?
- For LTE transmissions, are the carrier frequency and cell type (FDD or TDD) correctly entered?
- For NR transmissions are the subcarrier spacing, SSB downlink frequency and PCI correctly entered?
- Are there other interfering signals on the same frequency nearby?
- Is the physical cell ID correctly entered? On an LTE transmission, you can use the cell scan facility. Alternatively a suitable cell phone application can assist.
- If using GNSS or an external 1pps as a reference, check that the Sentinel correct reference is selected and is present.
1PPS / 
- Check that the Rubidium status is green **Rb**. The timebase should be running from the Internal Reference **INT REF**.

You may find it useful to use a mobile phone application such as Network Cell Info <http://wilysis.com/networkcellinfo> to identify the cell ID and available cell power.

You may also find it useful to make use of a portable RF spectrum analyzer to identify possible interfering signals.

Appendix A

Information about the LTE Air Interface

The LTE Air Interface downlink is an Orthogonal Frequency Division Multiple Access (OFDMA) system. This means that it consists of a number of subcarriers, each of which is independently digitally modulated and then combined with the other subcarriers for transmission. The center frequencies of these subcarriers are spaced 15 kHz apart.

The bandwidth of a cell can be one of 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz or 20 MHz. The wider the bandwidth the more data can be sent.

In the time domain there is a frame structure. Each frame is 10 ms long and divided into 10 subframes, each of which consists of 2 timeslots, each of which contains 6 or 7 symbols. The structure can be thought of as a two-dimensional matrix, with the subcarriers on one axis and time on the other. Reference signals, control information and data are placed within this matrix and combined together for transmission.

Two particular signals, the Primary Synchronization Signal (PSS) and the Secondary Synchronization Signal (SSS) are the ones of interest for the measurement. They each consist of a sequence of 62 symbols and are transmitted twice in each frame, spread across the central sub-carriers. They provide a timing signal that the mobile phone uses to synchronize its timing to the eNodeB. Taken together, the PSS and SSS also provide the physical cell identification – a number between 0 and 503.

There are two duplexing schemes available – Frequency Division Duplex (FDD), where the downlink and uplink are both on all the time but on different frequencies, and Time Division Duplex (TDD) where the downlink and uplink share the same frequency but at different times.

There are 100 frames transmitted every second. The measurement assumes that the frame structure timing is aligned with 1pps, and finds the time difference between top of second and the start of the radio frame closest to the top of second.

5G NR Frame Structure

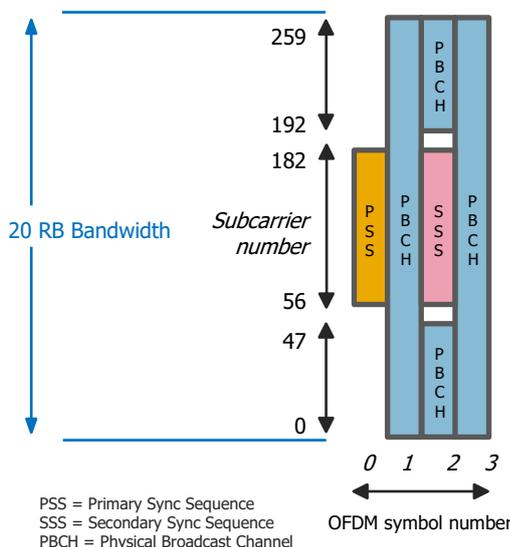
5G NR is similar in many ways to 4G OTA as both use OFDMA. However, in addition to the other modulation schemes used in 4G, radio conditions allowing, it can use 256-state quadrature amplitude modulation (256QAM)

Like 4G, the frame is 10 ms long with 1 ms subframes, but it is a lot more flexible but also more complex. There are differences in the frame structure allowing more symbols per frame.

Cell bandwidths up to 100 MHz are possible in 5G NR frequency range 1 (FR1) and up to 400 MHz in FR2.

Like with 4G, the PSS and SSS are of particular interest in 5G and it is by detecting these signals that we can determine the synchronization of the overall 5G signal. In 5G the PSS and SSS signals are 127 symbols wide and also carry the physical channel ID which in 5G is between 0 and 1007.

The PSS and SSS are in what is called the Synchronization Signal Block (SSB). These SSBs are transmitted in bursts with multiple SSBs per burst. By coding each SSB slightly differently, the user equipment can determine which beam it is in and the base station can optimise the transmission. An additional complication in 5G compared to 4G is the frequency where the synchronization signals are transmitted. In 4G, these are transmitted on the central subcarrier. However, in 5G, sync signals can be positioned on another subcarrier within the cell bandwidth. This makes them harder to find but does lead to less chance of interference from adjacent cells that might be on the same frequency.



The 5G NR Synchronization Signal Block is larger than 4G but this improves the correlation and makes synchronization more reliable.



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