CBRS & C-Band

What Radio Engineers need to know

In many countries, the midband -specifically 3.5 GHz to 4 GHz- is a key piece of the 5G spectrum strategy while it is forming a pivotal stage for 4G expansion particularly in private network deployments.

Citizens Broadband Radio Service (CBRS) and C-band spectrum bands have the potential to pour more than 500 MHz for more capacity. And this spectrum has fair propagation characteristics and promising economics. However, this doesn't come without a cost; there are inherent challenges when bands go higher in addition to the higher need-for-speed. And that imposes special considerations when it comes to network planning and associated measurements.

This document is aimed at raising the practical awareness of planning engineers to the propagation behavior at such higher bands and the emerging challenges of 4G and 5G deployment scenarios. Then it sheds light on the growing indoor deployment considerations. And finally, it summarizes the best practices, dos and don'ts that Consultix gathered with professional users of its indoor and outdoor instruments. Some of these factors are usually overlooked by some users, while they are so critical (yet can be easily avoided if adequate attention is paid to).

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Introduction

More than 40 nations around the world have opened up the 3.7 to 3.98 GHz band for 5G wireless. And many other countries are auctioning or planning to auction the C-band. In terms of the number of countries, perhaps it's the most popular 5G band in the world. The ITU sliced C-band into three windows: n77, n78 and n79. Most European and Asian countries currently use n78, which lays from 3.3 to 3.8 GHz. However, the USA will use n77 (a larger band window from 3.3 to 4.2GHz). Japan also already uses n77, so equipment and phones are existing.

Additionally, in the United States, a 150 MHz-wide portion of the 3.5 GHz band known as the Citizens Broadband Radio Service (CBRS) band, has been opened for shared access applications.

CBRS is conceived as a boost for 4G and a key for 5G while the C-band will be exploited merely for 5G. So, lets here explore what each band chunk brings to the cellular ecosystem.

CBRS (3550MHz-3700MHz)

The entire spectrum for bands 42 & 43 now belongs to CBRS, which is also referred to as Band 48.

Fortunately, LTE was designed to work across a wide range of frequency bands (450 MHz up to 3.8GHz) referred to as E-UTRA. Additionally, this band is perfect for services that require ultra-high resources, and hence it is perceived as a key for 5G.

CBRS gave rise to new capabilities and opportunities for a wide range of users such as incumbent users, mobile operators, other service providers, public entities, enterprises etc.

A notable potential for enterprises is deploying private 4G and 5G networks, which can prove especially helpful in implementing mobile edge-computing . And luckily many of the CBRS features stand to specifically benefit the enterprise, hence Private LTE deployments is expected to dominate CBRS indoor deployments during the next five years.

Additionally, CBRS is well suited for enterprises with critical communications requirements spread out over wide geographic areas such as convention centers, sport arenas, mines, ports, farms and factories.

CBRS classes

Category A

CBSD of Class A (or Category A) is a low power base station or a small cell with a maximum transmitted power of 24 dBm/10 MHz and maximum EIRP of 30 dBm (1 watt). They are mainly intended for indoor deployment, however can be deployed outdoor if the antenna height doesn’t exceed 6 meters above average terrain. Installing it outdoor and above 6 meters is classified as CBSD Category B and subject to its operational requirements.

Category B. CBSD falling under class B is a higher power radio intended for outdoor use with a maximum EIRP of 47 dBm (50 watts) per 10 MHz. Category B must be installed by a Certified Professional Installer (CPI).

Unleashing the potential

CBRS will expand the value of mobile networks and give rise to more new use cases bolstering many new services and several types of players.

For large businesses that require a private wireless network, CBRS offers more secure connectivity than Wi-Fi and at the high speeds and quality of LTE. Whether the business exists in a high-rise office building, a college campus or a large remote site (I.E. mining industry), CBRS solutions allow local private LTE networks to be built for the entire enterprise regardless it is indoors or outdoors.

In general, many players to benefit from CBRS in different forms such as:

1. Mobile Network Operators / Capacity Augmentation
2. New Entrants
3. Multiple Service Operators (MSOs)
4. Neutral Host RAN
5. Private LTE Networks
6. Wireless Internet Service Providers (WISPs)/Utilities.

CBRS is economical for mobile coverage and capacity due to the low spectrum acquisition cost, and this brings new business opportunities/models that have been unimagined in the past.

In the USA, with the support of the major operators, in addition to the existing use of 3.5 GHz as an LTE band in other parts of the world, the device ecosystem support for the CBRS band/technology is building momentum, and this will bring scale advantages and accordingly low-cost solutions. Monthly cost to deliver data will almost drop to half compared to a traditional LTE small cell which uses licensed spectrum. A key benefit of CBRS comes from the capability to aggregate up to 40 MHz of low-cost spectrum although CBRS implies extra costs for SAS and integration with mobile operator.

C-Band

For 5G to cover entire cities, it needs to be carried on a band below 6 GHz to travel adequate ranges from base stations. Sitting immediately above CBRS, the US government auctioned this band allowing companies to license and use 280 MHz of radio frequencies in what is known as the C-Band—specifically in the 3.7-3.98 GHz window.

More importantly, in almost every country around the world that has launched 5G networks—except the US—these midband frequencies are at the heart of their 5G networks. Thanks to the great combination of reasonably good coverage and enough open frequency space to enable high-speed.

This band portion wasn’t available for use in the USA when 5G first launched because it had been already assigned to the satellite TV a long while ago. However, with the declined demand for such TV services, there has been increasing calls to reallocate the frequencies for other purposes—most notably 5G-.

It’s a matter of fact, C-Band radios have very robust 5G functionality and would be at a lower deployment cost than its mmWave rival and could still provide 500-1000 Mbps service.

Mid-band Benefits

RF attributes

- Reasonable propagation characteristics that imply reliable coverage. And this is important to provide connectivity for IOT devices, critical communications (that require 99.999% reliability) and applications such as remote control, automotive or smart manufacturing.
- Massive MIMO antennas are practically feasible at 3.5 GHz and this makes the band capacity considerably higher than those of low GHz bands.
- The fair penetration characteristics of this band in buildings, make it a prominent candidate for broadband communication for both worlds; 4G and 5G.
- Wider spectrum bandwidths that are typically available compared to most of sub-3 GHz bands.
- The 3.5 GHz band is characterized by little rain fading. And this allows for robust connection in rainy regions.
- And finally, network deployment can be considerably fast due to its propagation characteristics which open the door to reuse the installed base of macro sites that serve sub-3 GHz bands.

Technology Attributes

From WIFI user perspective, CBRS has the following advantages compared to WIFI:

- Highly predictable performance thanks to limited interference.
- Unlike WiFi and other unlicensed solutions, access to this band will be gated to users to help mitigate interference issues.
- Coverage of large and remote areas that are hard or expensive to serve with Wi-Fi; for example five CBRS radios can cover a venue where more than 100 Wi-Fi access points needed.
- Improved security because data is kept within a private network
- Low-latency connectivity for mission-critical applications
- The technology allows for configurable Quality of Service (QoS). And this allows prioritization of network traffic such as mission-critical and latency-sensitive traffic.
- MNOs may offer roaming capabilities to enable devices to transparently roam between private networks and existing carrier networks.
- Security can be achieved via SIM-based authentication, enabling users' mobile phone accounts to login to online services. One use-case that has been widely addressed involves colleges and universities, which are demanding high-speed private networks covering dormitories, academic buildings and other facilities.
- Push-to-talk (PTT) capability is also vital for many campuses. New PTT over CBRS will provide the higher quality that comes with a broadband voice network in addition to the added security.

Propagation Physics

Initially, lets summarize here how propagation mechanisms such as reflection, attenuation, diffraction and wall penetration in the mid-band differ from low GHz bands and why they have to be accurately quantified. Although these factors can be simulated using techniques such as ray-tracing, in practice they are very sensitive to user inputs and the actual venue details.

Attenuation ↑

It's a matter of fact; the higher the frequency, the higher the free space losses. Figure 1 here illustrates some scenarios and their associated path loss differences between 1.8 GHz band vs. 3.5 GHz. For example, in outdoor environment the difference in path loss is around 6 dB, while the path loss difference varies indoors from 8 to 11 dB depending on the building architecture and materials.

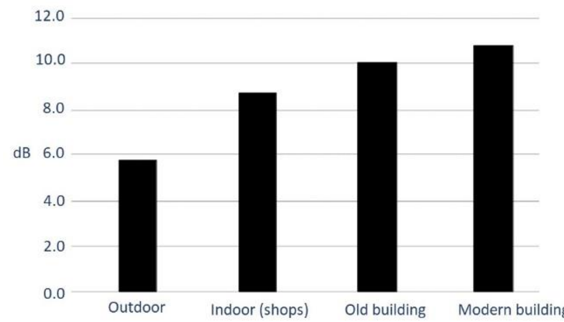


Figure 1. Pathloss difference; 1.8 GHz v. 3.5 GHz

Diffraction ↓

Diffraction played a major role in low GHz propagation, however, its effects considerably decay at higher frequencies as illustrated in figure 2. Experiments showed that the difference in propagation losses can increase up to 10 dB @ 3.5 GHz compared to sub-1GHz bands due to diffraction. And it's worth noting, the diffraction loss would be higher if the receiver is close to the wall of buildings or if shielded by any other obstructions.

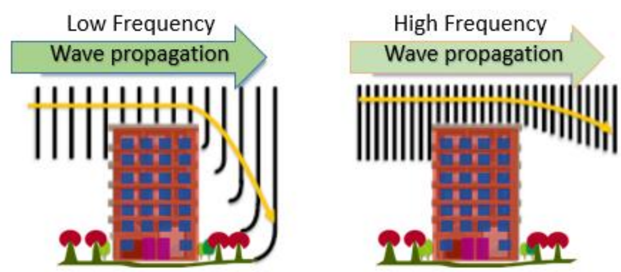


Figure 2. Diffraction @ low and high bands

Materials losses

Different materials commonly used in building construction have a wide diverse of penetration losses. Energy-efficient or tinted glass used in modern buildings introduces additional losses at higher frequencies. Although mid-band spectrum fairs better than mmWave when it comes to going through windows and walls, still its data rate can drop to one fifth if a user moved from outdoor to indoor position. And this requires an increase in radio resource allocation to maintain a given DL/UL bit rate. Losses of materials such as concrete or brick increase rapidly with frequency as per the real measurement shown in figure 3. And propagation of waves into building will mostly be a mix of paths through different materials.

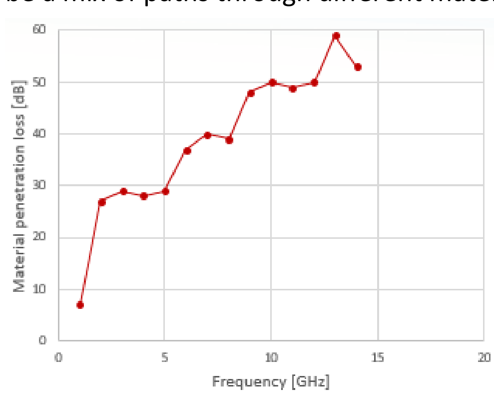


Figure 3. Concrete losses vs. Frequency

Outdoor-to-indoor penetration

Due to the previous factor of material losses, a signal coming from macro site will experience significant attenuation at C-band frequencies compared to low GHz bands. This is explained in figure 4 which shows that the typical difference between 1.8 GHz and 3.5 GHz ranges from -10 to -15 dB. Still C-band frequencies such as 3.5 GHz are better than mmWave bands by a factor up to 50 dB.

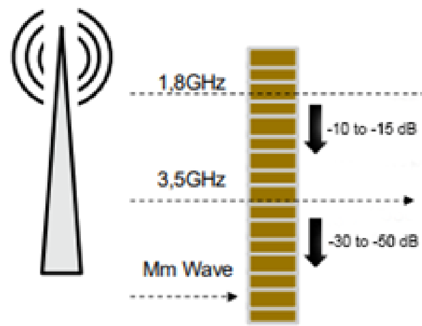


Figure 4. Outdoor to indoor losses

These characteristics shows that the mid-band bridges a gap between low GHz bands and mmWave however on-site testing of different environments and venue types will reveal the actual impact of the above mechanisms and tune the design to each morphology. And the lack of this quantification causes colossal technical and business impacts that are highlighted later in this article.

Planning Challenges

Due to the previously discussed propagation behaviors at such bands, the following considerations have emerged or became of more importance:

1. Dedicated indoor networks are becoming a must in the era of 5G. And when such indoor networks increase, interactions between indoor and outdoor signals become more considerable. In order to realize reliable service and minimize interference between indoor networks and macro sites, indoor and outdoor networks need to be planned and optimized as an integrated environment.
2. Compared to lower frequency bands, the mid-band brings more coverage challenges such physical boundaries on the power handling capabilities of antennas, economical high-power amplifiers and higher attenuation. That’s why network planners have to compensate this by employing massive MIMO antennas to provide higher beamforming gain.
3. 5G networks using 3.5 GHz employ TDD (Time Division Duplex) rather than FDD which is used by most of 4G networks globally. TDD naturally implies some network engineering constraints such as network synchronization and inter-operator coordination. Hence network planners have to consider such factors to mitigate interference between TDD operators and utilize the spectrum efficiently
4. Co-existence of C-band satellite services whose very weak signal might be affected by any uncontrolled, unregulated and unintended emissions of 5G networks operating in the 3.5 GHz band.
5. Outdoor network coverage is uplink bounded because the limited output power of mobile devices (23 dBm maximum) is much lower than the base stations which transmit power in tens of Watts. Accordingly, a 3.5 GHz uplink cannot keep pace with 2100 or 1800 MHz signal propagation. That’s why some solutions such as aggregating 5G at low band with 3.5 GHz or sharing the uplink frequency between 5G and LTE are getting inevitable.
6. To reduce LTE complexity, CBRS vendors offer small cell solutions that work out of the box and do not need a carrier-grade core network. And most enterprises will provision equipment that

they can install and operate without having a dedicated CBRS team. However, they still have work to do such as dealing with RF planning and backhaul.

7. Planning, maintaining and optimizing a private 4G or 5G network is more difficult than a Wi-Fi network. So, enterprise system integrators have to learn how to deal with that, otherwise the private network owner may choose to outsource RAN to a neutral host network or another third-party operator.
8. A likely deployment approach would be to collocate C-band radios on existing macro or small cell towers and densify as needed based on population density, capacity requirements and cell edge performance specs. However, operators have to be aware which sites have existing concealments and of what type as some concealment materials could damp C-Band signals. The concealment materials which have worked fine for the lower bands, could be problematic at higher frequencies specially when carrying 5G.
9. C-Band and 3.4 GHz spectrum regulations allow high power operation. However, CBRS has some power limitation when deployed outdoor. This significant disparity in power levels across the band gave rise to practical concerns and worries that once the 3.45-3.55 GHz band will be activated, its higher power levels will cause interference issue on the lower channels of the CBRS band. And this calls for careful network planning and coordination among spectrum users to limit the harms to CBRS.
10. Passive intermodulation (PIM) hitting C-band. And this is discussed in more details in the next sub-section

Finally, it is so vital to recognize, assess and gauge real-world's RF issues at those new bands. And field measurements are naturally the only mean to gain information, mitigate uncertainties and overcome ambiguities before the network goes live.

PIM @ C-Band

Passive intermodulation (PIM) has always been a concern at low GHz bands and is still a potential threat in the C-band spectrum due to the many IM2, IM3, and IM5 products that can be generated by the existing low and mid-band downlinks at cell sites. These low-order IM products can elevate the noise floor thus reducing the speed and coverage of newly deployed networks.

Accordingly, PIM interference generated by the other transmitters on the platform should be taken into account. As illustrated in figure 5, several combinations of the lower band services can generate intermodulation products that fall in the C-band spectrum. And here low order IM such as IM2, IM3 and IM5 are significantly higher in magnitude than traditional high order IM7 and IM9 which used to be commonly encountered before.

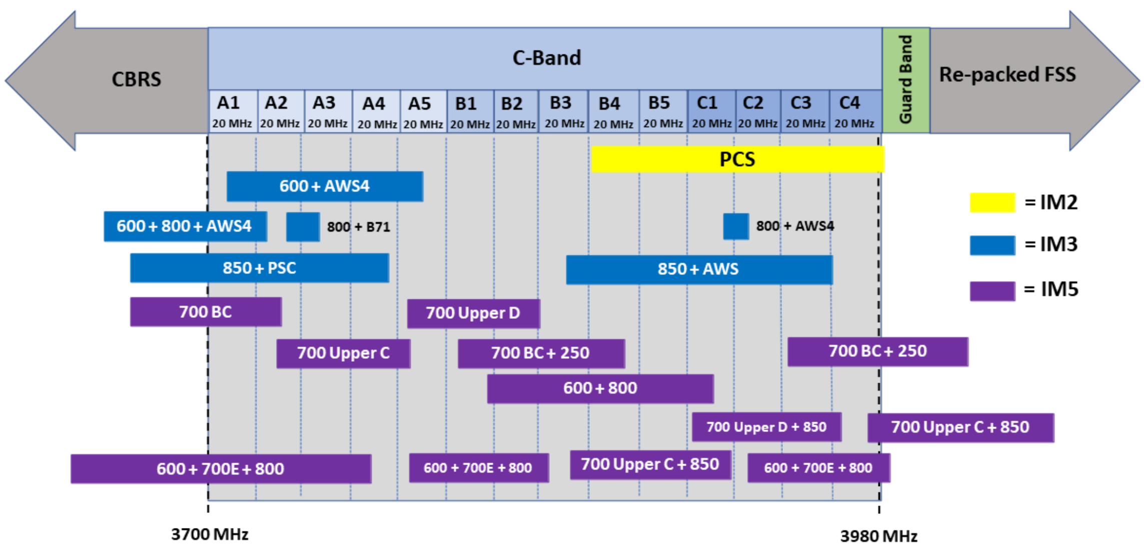


Figure 5. Different PIM possibilities hitting C-band

And since those lower band mainly imply FDD, this means synchronization is not a viable method to mitigate the PIM effect of those bands.

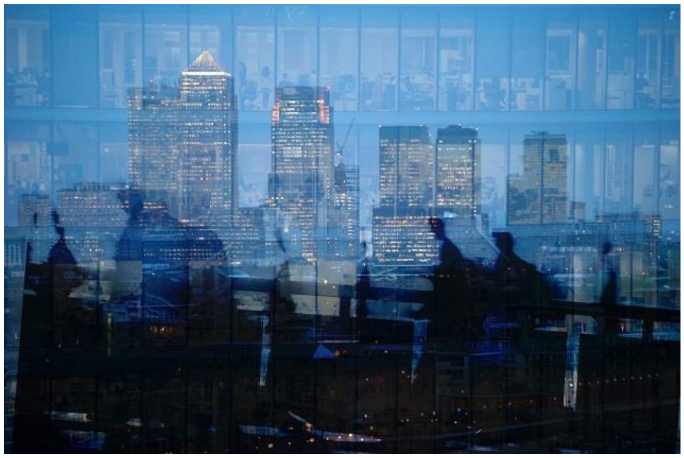
Luckily in most of the cases here, the concerned PIM is characterized by two attributes:

1. Its due to an external source, which means it is stimulated beyond the antennas due to external objects.
2. The highest effective sources typically lie within 10 meters (30 ft) from the antenna.

So, simple countermeasures can be taken economically when collocating 3.5 GHz radio equipment in existing sites. In rooftop sites, this can be achieved by some measures such as moving sectors to building edges, reducing electrical beam tilt, align sectors with the building face and/or deploying RF barrier material on the roof surfaces to block aggressor downlink signals from reaching PIM sources. And generally, for all type of sites, other simple modifications such as antenna skew, or employing low PIM elements (in antenna/radio mounting parts and cable support) can significantly contribute in reducing PIM.

Indoor Network Planning

Radio propagation in indoor environment differs greatly from outdoor, not only because of wall losses but also due to many other factors such as close proximity of reflecting structures (walls, floors …etc.) introducing different fading profile and a totally different RF behavior that varies greatly even from one place to another within the same building.



Three basic propagation mechanisms; Reflection, Diffraction and Scattering influence the propagation of electromagnetic waves. During indoor network planning, RF site measurements should be conducted to examine how these mechanisms aggregate at every venue type. And this is the only method to collect true information about the structure, examine the effect of wall materials on signal strength and reveal any complex propagation mechanisms.

Here we list some of the key considerations growing significantly at such higher bands:

- Solutions like increasing the output power of outdoor small cells indeed increase the throughput/capacity for outdoor users, however this is not the case when they are aimed at serving indoor users.
- To boost the performance of indoor users served from outdoor small cells, high care should be given to balance the transmit power as well as beamforming gains to pass the SINR bottleneck.
- With the expected rise of myriad use cases and technology choices, it can be confusing to pick and employ the optimal architectural choices to bring 5G to each distinct indoor site. For example, in some indoor IOT applications, 5G network planner will be required to plan for 1 connection / square meter.

  And since indoor environment has its unique aspects and considerations, its recommended that the design and deployment approach go with the intended use cases in mind.
- Upgrading existing DAS sites is challenging in most of the cases. Although feeder lines may go beyond 3.5 GHz, this brings extra considerable attenuation. Additionally, components such as couplers, splitters, antennas etc. were primarily supporting frequencies up to 2.7 GHz. And driving those elements beyond 2.7 GHz might bring unacceptable deterioration in their RF behavior represented in insertion losses, VSWR, coupling ratios etc.

- The stringent requirement for indoor 5G networks gave rise to considering network architectures such as Distributed Radio System (DRS). In DRS, the baseband functionality is centralized while the radio and antenna are integrated in one low power module and distributed to ensure high performance throughout the venue. The distribution of several nodes is like DAS & small cells in terms of providing RF signal dominance throughout the building, while the centralized signal processing brings the flexibility and scalability required for 5G deployments.

- CBRS is relatively economical compared to DAS and traditional small cell deployments. A major contributor to this is that a single CBRS radio can support multi-operators in the 3.5 GHz band by default. In comparison, multiple operator-specific small cells are required in a traditional licensed small cell deployment case. Although DAS cost can be brought down with less expensive small cell as a signal source for smaller venues, CBRS still offers a much lower-cost alternative for mobile LTE coverage. On the other hand, while Wi-Fi offers a lower cost solution for in-building wireless coverage, seamless mobile voice service is not possible with Wi-Fi. Additionally, CBRS can be used to provide a quality LTE layer for wireless data services in enterprise venues where the 2.4 GHz and 5 GHz spectrum bands are heavily utilized by Wi-Fi. In addition to providing a neutral host opportunity for building owners and operators, CBRS can also support a private LTE network for critical communications or even internet of things deployments. And CBRS equipment for indoor applications is very similar in form and function to Wi-Fi network equipment. Moreover, CBSD's will be available either stand-alone LTE Access Points or integrated into Wi-Fi APs, with AP controllers on site or in the cloud.
- 5G will bring new network models such as micro-operators. And although 2 indoor micro-operator networks working on mmWave can successfully coexist with a very small separation distance, in sub-6 GHz bands a significantly larger isolation between networks is required (I.E. via adequate spatial separation)
- Extensive coverage is key for mission-critical communication and emerging IOT use cases. Luckily many of such applications demand low data rate. Here operators should consider another layer of sub-1 GHz spectrum as it provides reliable wider coverage, significant indoor penetration and enables the low latency required for ultra-reliable use cases.
- Engineering your indoor network with LBS (location-based service) in mind will be key in the era of 5G. Position aware communication will be natural demand and networks will be required to support indoor positioning with a precision of 1 m to 3m or better. And this should be attainable with 5G's new spectrum that implies wide bandwidth which is greater for positioning calculations.
- Most of today's off-the-shelf Wi-Fi planning tools have the ability to plan and design CBRS networks. These tools typically include coverage prediction (heat maps) and validation. However low-cost tools don't have the capability to calibrate the prediction model using real field measurements.

Experienced planning engineers already built a moderate instinct in lower bands, however accurately characterizing the specific propagation characteristics of each venue at 3.5 GHz band means the difference between premium user experience and disastrous sites particularly in 5G. Radio design and simulation tools are essential elements during planning; however, they can't take into calculations all the parameters of each specific environment. In several cases, the financial and technical risks could be significant if that adaptation is ignored. And this increased the need for real CW measurement in order to optimize the infrastructure cost and achieve operator KPI's.

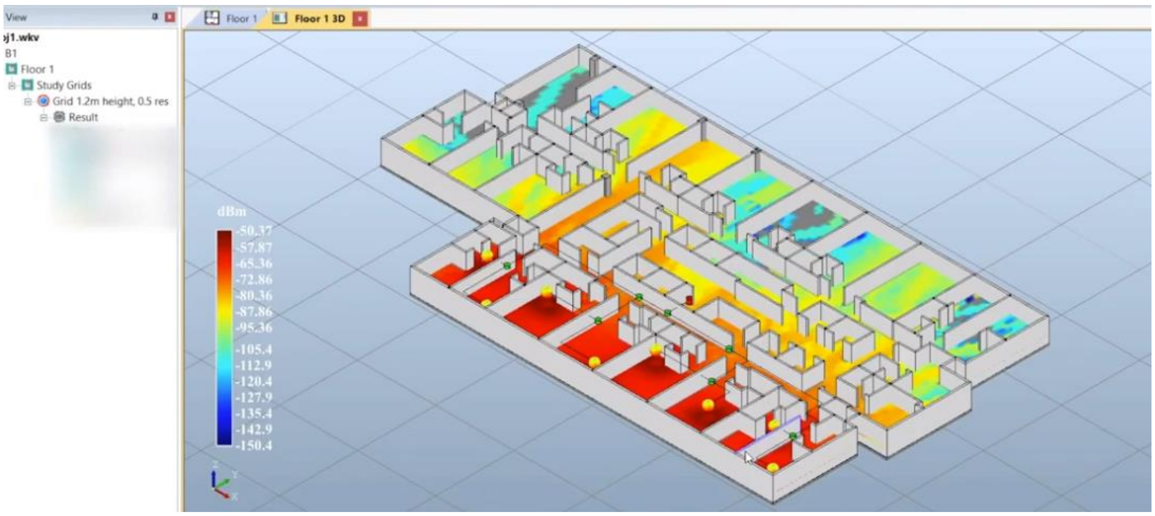


Figure 6. Indoor planning tool; Heatmap

- While leading vendors of indoor planning tools work hardly to make sure materials in their database are as accurate as possible, in fact, the prediction is not always accurate due to the following factors:
  1. Database/Reality dissimilarities
  2. Missing inputs
  3. Wrong material selection
  4. Material is not in DB
  5. Other hidden materials on-site

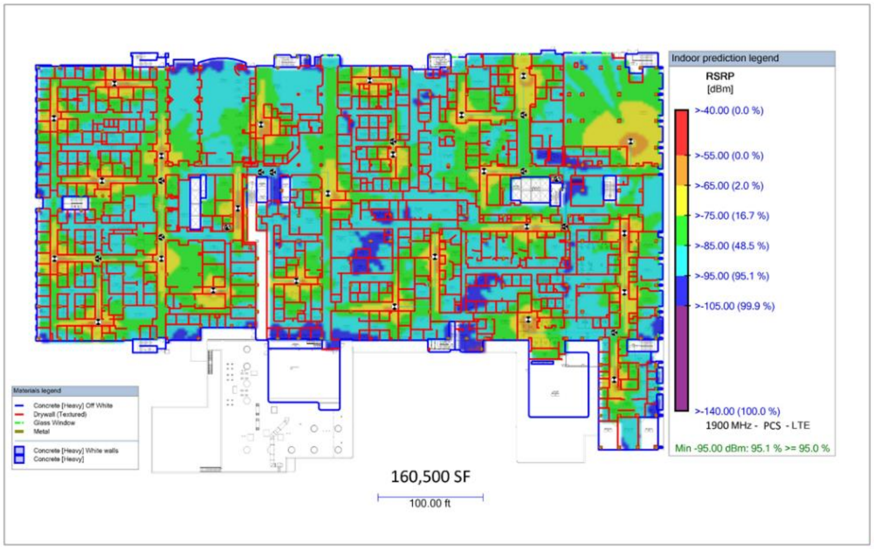
We summarize in the next sub-section a case study explaining the significant effect of wrong material selection or in other words ignoring pre-build site survey and characterization.

Case Study: Wall type mix-up

There are over 70 wall types to choose from. And Many of the wall types look similar by name while it can be hard -especially for a non-construction RF engineer- to select the correct type. Additionally, custom walls can be defined with varying loss parameters. These custom walls might have similar names but greatly different loss figures.

The examples here address a typical case of Drywall and Sheetrock - Light. Most of planning engineers consider Drywall and Sheetrock to mean roughly the same thing. The heatmap in figure 7 is for correct value of Drywall to produce the proper passing scenario using 2* 20 W Remotes and 25 Antennas.

Drywall



(2) 20W Remotes
(25) Antennas

95.1% KPI

Figure 7. Wall type Dry Wall (Correct passing)

Instead, if wall type is mistakenly selected to be Sheet rock Light, then the coverage only requires 2 × 2 Watt remotes and 12 antennas. And this will result in a fake passing heatmap as shown in figure 8. If that flawed design is installed, later the customer will have to choose either to pay a much higher price (more than what's required in the proper case above) or to leave a poor coverage as shown in the next figure below.

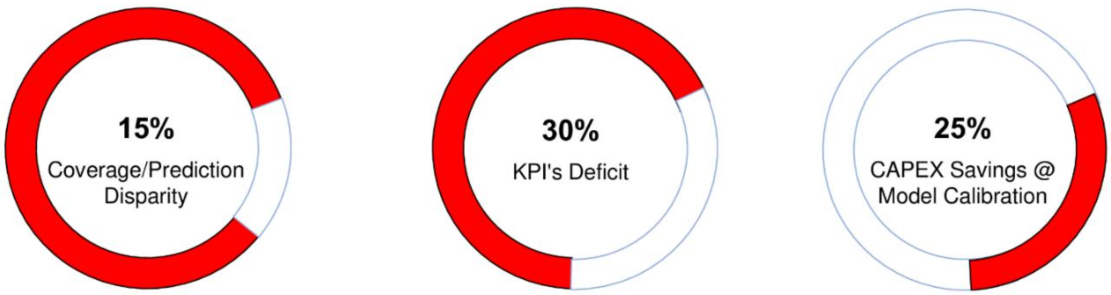
Figure 8. Wall type Sheet rock-Light (incorrect Passing)

Now, if we take the previous incorrect design then correct the selection of wall type from Sheet Rock - Light to be the actual Drywall, we will recognize the dramatic impact it has on performance. Figure 9 here shows the actual failing coverage and KPI's that will take place based on the wrong selected wall type. In other words, the price/performance impacts are extremely out of alignment.

Figure 9. Wall type Dry Wall (Correct failing)

It's worth noting, the price increase illustrated above is the baseline -in case the error is recognized before construction works- however, typically you will realize that in a later phase. Thinking which parameters are correct for a given venue? Accurate predictions require true signal testing (called CW-Testing) in various building morphologies which can then be used to modify prediction parameters. Otherwise, this will eventually lead to a scenario where everybody is blamed!

Post deployment analysis of several projects showed 3 typical numbers sorting out coverage and KPI's deficiencies in case of prediction-only scenarios vs. the cases of CW-augmented modelling.



The 3 above perspectives summarize the financial and technical implications when ignoring to fine tune propagation models to each specific venue or even doing it in a wrong manner.

In this regard, the next section explains the best practices to fetch accurate field measurements that foster propagation model tuning.

Test Practices

In radio planning, it is obvious that underestimating the path loss can lead to coverage gaps. On the other hand, overestimating the path loss is undesired because it leads to excessive infrastructure cost and severe inter-cell interference issues. That's why for an accurate coverage simulation, existing propagation models need to be adjusted for each distinct environment.

Outdoor model calibration is a standard step for macro network planning. And the vital benefits of such step are well known to planning professionals. This is well explained by the figure 10 here which shows more than 25 dB difference between predicted path loss based on a standard propagation model (the upper curve) vs. tuned model after real measurements. Hence bypassing it causes major deficiencies in network coverage.

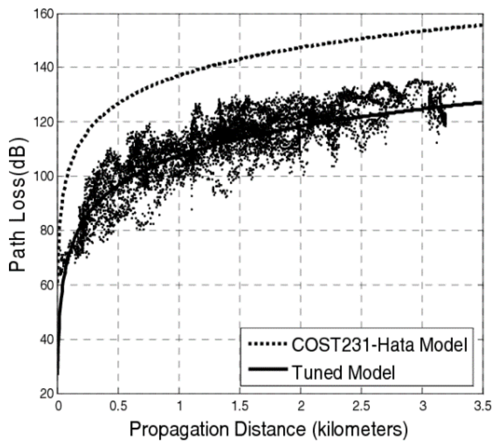


Figure 10. Propagation model before & after tuning

In a similar fashion for indoor network design, field measurements are needed to reveal the actual material characteristics, tune propagation models and overcome uncertainties or risky assumptions. Although it's not yet a standardized step by some operators, many others employ it to avoid underperforming designs or extra network cost due to over-designs.

This is even becoming of high importance with the advent of higher bands such as 3.5 GHz where the instinct of planning engineers is not yet as sharp as it used to be with traditional bands.

Since field testing is aimed at revealing the actual environment characteristics in order to precisely tune the propagation simulation, a high degree of accuracy is required. Otherwise, the model calibration process has less effect.

In this section, we summarize the key considerations and best practices Consultix gathered with top-class users of its indoor and outdoor instruments. Some of these factors are usually overlooked by other users, while they are so critical (yet can be easily avoided if adequate attention is paid to).

First of all, there are general considerations regardless the setup is for outdoor or indoor test.

General Considerations

Cable losses

Cable loss could be a significant factor specially at high frequency such as 3.5 GHz. If adequate attention is not paid to the employed cable length and attenuation, some dB's can be lost from the overall radiated power and adversely affect the test outcome. Remember 3 dB lost from the power means half of the power is lost.

Signal BW

Transmitted CW signal is unmodulated (continuous Wave), hence theoretically it has no BW. Practically you can see it as just few Hz on a spectrum analyzer with low phase noise and careful settings.

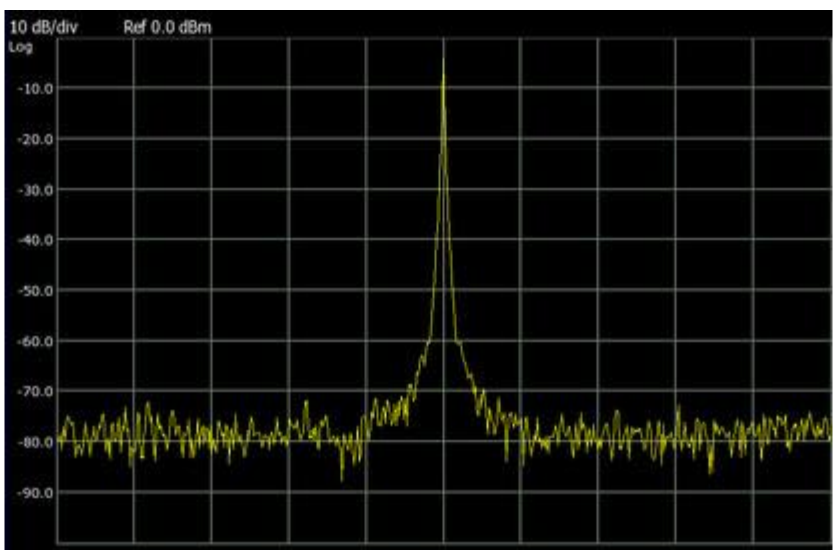


Figure 11. CW Signal Spectrum

Using such a narrow CW signal is intentional in order to allow setting the counterpart CW receiver/scanner to a fairly narrow RBW and hence keeping its noise floor at the lowest possible value. This allows increasing the test link budget in order to maximize the measurement distance. On the other side, another important tip here is to open the RBW of the scanner to tolerate signal drifts due to any reason.

The proper value for receiver RBW varies according to the band. Typically 25 KHz is ok for 3.5 GHz band while 50 KHz might be needed in bands such as mmWave. A transmitter with high frequency accuracy is required here to always maintain its signal confined within the receiver's filter bandwidth.

In all cases, before testing, user has to check that the RF environment is clear in this frequency window. You can verify this by checking that your receiver is not picking up any signal while the transmitter is off.

Tripods

In general, metal objects close to the test antenna cause pattern deformation by some dB's. Which in turn reflects in the measurement accuracy. And metal objects should be kept at least 2 wavelength from the antenna neighborhood to not cause practical pattern distortion.

So, usually for test purposes, a non-metal tripod or a mast is mandatory.

Test Route

- The measurement route must be well selected and planned prior to performing the test.
- Avoid testing in a close proximity to the TX as this saturates your receiver and gives false results.
- Consider that a significant amount of data represents each area or clutter category.

Equipment

- Make sure you are using calibrated equipment
- Test instrument should have a relevant accuracy and resolution (of both level and frequency)
- Make sure your RF equipment is maintained and operated as instructed by its vendor
- Use a transmitter with a screen to recognize the setting values during the test
- Visually check your testers, antennas and cables for any defect in the RF connectors.
- Any electronic device has a kind of unintended emissions. Make sure this conforms to the allowable limits in your country. This may be expressed in general standards such as FCC or CE, or specific EMC standards such as CISPR 22 or EN55022. Additionally, since this is an intentional RF radiator, there could be other specs that should be accounted such has harmonics & spurious
- Avoid excessive heating, don't expose the equipment to direct sun ray
- Avoid any fluids to come into the instrument. Some transmitters are specified for their ingress protection against dust and water. Fetch such information prior to usage.

On-site Calibration

Prior to starting your test and wasting several hours, check the integrity of your overall setup to early recognize if there is any issue in the equipment, settings, connections, cables and antennas. This is achieved by measuring the path loss at a distance 3 meters (~10ft) from the transmitter.

Note : This step is valid for both outdoor and indoor tests.

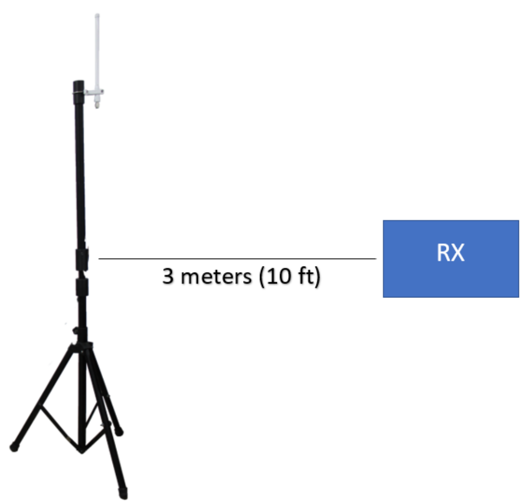


Figure 12. Setup for 3-meter calibration

Reception settings

If you are using a spectrum analyzer rather than a CW receiver/scanner, special attention should be given when setting its parameters to avoid inaccurate readings:

- Transmitter frequency to be chosen as the central frequency of the spectrum analyzer
- The span of your spectrum analyzer to be adequately wider than the test signal. However, too wide span affects frequency accuracy.
- Reference Level should be configured relevant to the expected power levels along the test path.
- Recognize the type of detectors of your tester whether RMS, Peak or Quasi peak detector and select it as per your measurement needs and the post processing procedures.
- Select a relevant channel bandwidth if you are using the "channel power measurement" mode.

Usually these settings are not strictly required when using a specialized CW receiver or scanner.

Warm Up

Warming up is always a good idea before any activity. And the same applies to RF measurements.

All RF devices have resistance and capacitance whose electrical properties change with temperature. For the measurement equipment to be able to properly operate and provide accurate and consistent results, these instruments must warm up and stabilize thermally. This is of more importance when using high power transmitters or complex circuitry receivers/analyzers.

Data Averaging

Averaging always yields to more reliable estimate of the local average power independent of the test signal bandwidth and mitigates fluctuations over a small area due to multipath fading.

Some collection tools have data averaging algorithm, make sure you recognize if this is the case with your tool and configure its parameters adequately.

If you will do averaging manually pay attention if its linear averaging or dB averaging. As dB averaging tends to deemphasize the large variations from the mean, whereas linear averaging may be significantly skewed by one or two extreme values.

Preliminary steps

Interference on channel

Information about available free channels should be fetched before commencing your measurement campaign. Nevertheless, prior to your test, make sure the RF environment along the whole test path is clear from interference on the same channel that will be used for testing.

For this purpose, you may use the same CW receiver/scanner set to scan the candidate test channel (and preferably some other candidate channels for plan B), or you may use a spectrum analyzer set to maximum hold tracing. In both cases, during this pre-survey, switch off your test transmitter.

Equipment settings

Make sure your test equipment is set to its normal settings without any offsets.

Outdoor Measurement Tips

Figure 13. Typical Outdoor CW setup

Test Transmitter

Electrical Supply

For outdoor setup, some users employ normal high-capacity batteries to power the high-power transmitter.

Battery is not recommended as its voltage might drop after a while and affect the output level of the amplifier.

Its highly recommended to use AC generators (like the upper photo in figure 14). This can be a fuel-based generator (make sure to use a stabilized inverter generator) or a battery station with AC output (like the lower photo)

And in all such cases, you just plug the AC/DC adapter of the test transmitter to the AC output socket of that electrical source.

Figure 14. Kinds of power sources for transmitters

Harmonics & spurious

A smooth and flawless CW drive-test, requires minimum interference from the high-power test transmitter onto other operational bands that might coincide with the 2nd or 3rd harmonics of the CW test signal. Pay attention to your unintended harmonic/spurious content and mind their levels compared to the allowable emissions at those frequencies.

EIRP requirements

Outdoor CW testing typically requires EIRP of 12 to 20 Watts according to the planning tool or customer requirements. And some scenarios require even much higher power up to 50 or 80 Watts most notably at 3.5 GHz.

However, the test conditions at some sites require using long cables to connect the test transmitter to the antenna. Question the actual cable loss of the planned cable at the test frequency and take it into account ahead of commencing your field measurements.

Monitoring the transmitted power

Its highly recommended to continuously know the actual power that is eventually injected into the test antenna. Track / record the actual radiated power and consider this in the planning software.

The power value of the transmitter will be altered after passing through cables and connections. It's not only about losses but also the VSWR of each element and temperature variations after several hours.

If you have a jumper after the power meter don't ignore it. Its loss has to be considered at this frequency.

Figure 15. Inline Power measurement

Scanner/Receiver

Sampling Speed

A receiver with high sampling rate is required for outdoor CW drive-testing. Typically, hundreds of samples are required per second to mitigate fast fading effects which illude the characterization process. This is comprehensively explained in Annex 1 (Lee criteria). Moreover, if the user will test multiple bands/channels in parallel, it's important to question the capability of the receiver/scanner if able to switch between channels at an adequate speed that allows a decent car speed while still conforming to Lee criteria.

Car Speed calculation

Maximum car speed should be identified before starting your test. And some receivers come with a car speed calculator that can be used on the spot during the test drive. This is of a great benefit specially when testing multiple bands simultaneously and the receivers' speed will be split across them.

Interference Rejections

Outdoor environment is full of other operational bands that vary in their strength along the test route. And it's a common experience that those signals -although apart from your test signal- might block some receivers or drive others into non-linear regions. A receiver with high rejection filtration maintains its accuracy along the whole test route and under severe interference conditions. Make sure to use a receiver with good performance in terms of parameters such as: maximum input signal, input related spurious, blocking, image rejection etc.

Saturation

In case the interfering signal is wideband or coincidently there are 2 strong interferences at some location along the test route, this might generate intermodulation products inside your receiver which mask or deteriorate your main channel readings.

To avoid such situations, a receiver with high input limits, good saturation point is recommended. This can be also figured out by checking its specs in terms of 3rd order IM Products.

Positioning accuracy

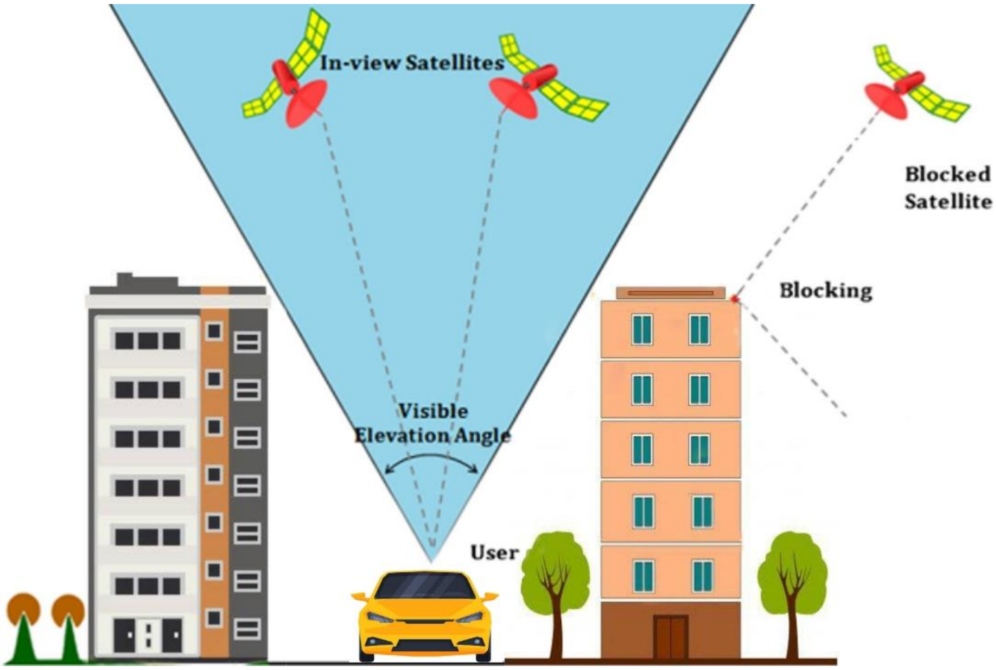


Figure 16. Lack of enough satellite signals

GPS-based positioning for wireless measurements might not be sufficient for 2 reasons:

1. GPS signal could be lost or inaccurate due to situations such as shadowing by buildings, urban canyons, tunnels, etc. And in general, the following factors greatly affect GPS accuracy:
   - Lack of Satellite visibility
   - Poor satellite geometry DOP (Dilution of precision)
   - Multipath
2. To conform with Lee criteria, a precise marking of samples is needed at equidistant distribution.

Hence, for a high-class and risk-free job, some users employ GPS and a dead-reckoning system to increase location accuracy in GPS challenged areas. That dead-reckoning system comprises an odometer and INS (Inertial Navigation system). The distance travelled by the vehicle's wheels since the last known location is sensed using optical or other encoders attached to the vehicle's axles. Odometry is fairly simple to implement, but if used alone the position errors accumulate rapidly as the distance of travel increases. So, the distance measured by the odometer is then complemented by a direction measured using a gyroscope. Odometers are commercially available in the market for affordable prices. Just make sure you provision a CW receiver with odometer interface option.

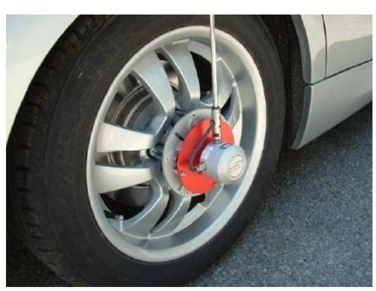


Figure 17. Car Odometer for CW drive-testing

Sampling schemes

In coverage measurement or CW testing its needed to eliminate fast fading and retain slower terrain-based fading, and here comes the Lee criteria which is a criterion for removing that fast fading by averaging the data each 40 lambda distance.

In this distance you should gather 36 to 50 samples and these samples should be equidistant.

Most of the scanning receivers use time sampling or assume fixed car speed across that 40 lambda distance, however to excel the process, samples should be triggered using an external odometer to assure equidistance sampling, while the direction and location of the samples are still geotagged using GPS.

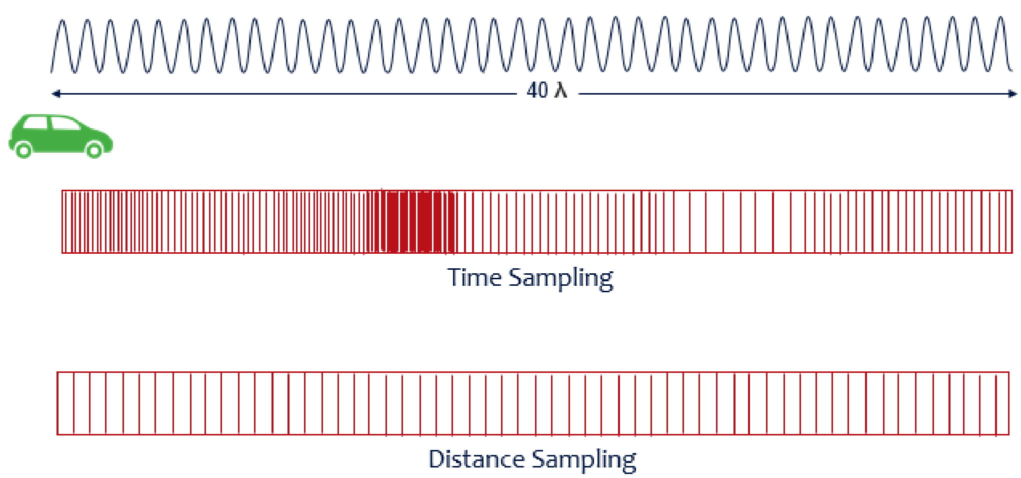


Figure 18. Sample distribution in time sampling vs odometer-based sampling

Test Antennas

TX antenna selection.

Typically, CW test antenna is of omni directional type, however here is a simple checklist to consider when selecting the transmitter antenna:

1. Avoid omni-antenna with high vertical gain such as 10 or 11 dBi as this means a quite narrow vertical beamwidth and hence no stable reach to all test points. On the other hand, antennas with low gain such as 1 or 2 dBi do not contribute considerably to the EIRP, yet they are still better than 10 dBi if they are the only solution.
2. Make sure the power handling rating of your test antenna supports the planned transmitter power
3. Better provision a rugged antenna to avoid damage due to field handling. Nevertheless, Since CW test setup is not for permanent installation, choose the antenna with the relatively lighter weight to make it easy for field crews.
4. Its good idea to select the outdoor test antenna with high Profile as this is less affected by near-by objects and provides a more stable pattern. However, pay attention that higher profile is usually associated with the antenna gain. So, this should still obey the first point above.
5. Remember to include mounting plate or brackets with the antenna for a smooth experience on-site. Not all antennas come with such accessories as standard.

TX antenna pattern

1. Prior to purchasing a test antenna, make sure its radiation pattern files are available and supporting the same format of your planning tool.
2. Test antennas should be provisioned from a trusted supplier as not all declared patterns are accurate.
3. Some claimed omni-directional antennas are not really omni. Check or verify this early ahead.
4. Make sure radiation patterns are available at all the bands you are planning to test.

TX antenna placement

For outdoor CW testing, the height of the test antenna is recommended to be greater than 20m.

And it should be at least 5m higher than the obstacles nearby (within 50-meter neighborhood).

Note: Here the obstacle mainly refers to the highest building around the rooftop of the transmitter. I.E. The building where the site is located should be higher than average height of surrounding buildings.

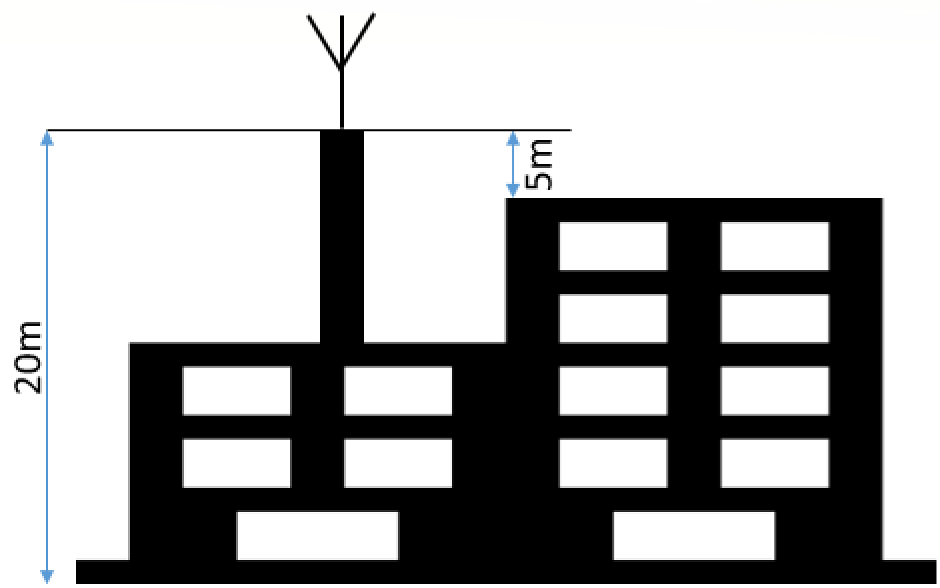


Figure 19. Recommended TX antenna height for outdoor CW Testing

The antenna should be far away from any metal object by at least 2 wavelengths to not deform the radiation pattern.

RX antenna selection

In general, CW drive testing requires the antenna to be vehicle-mount. However, there are some considerations for a smooth operation:

- Select the antenna with moderate profile to avoid blockage by small objects in order to get stable measurements at all directions
- It's always good idea to have antenna with an elegant design yet rugged and suitable for outdoor environmental conditions.
- If more than a band will be tested, ensure the antenna covers them with no tuning required
- Most of car mount antennas do not come as a standard with their magnetic base or mounting plate and pigtail cable. Remember to add such items when selecting a vehicle-mount antenna.
- Select high-quality elements to avoid scratching/marring the vehicle surface.

Data filtration

After your test, filter any point where:

- GPS is unable to locate accurately
- Distance to antenna is too near or too far
- Too weak signals
- Data with a loss exceed over 15-30 dB with no reasonable reason
- Data inconsistent with the requirements defined during route planning
- Clutters with low number of samples

Indoor Measurement Tips

Test Transmitter

Electrical Supply

Usually, indoor test transmitters are low power and have a built-in battery, however in some scenarios that require relatively higher power signal, a high-power transmitter needs external electrical source. Some users employ normal high-capacity batteries to power such high-power transmitters.

Battery is not recommended as its voltage might drop after a while and affect the output level of the amplifier.

Its highly recommended to use a battery station with AC output (like the one in figure 20).

And user just plug the AC/DC adapter of the test transmitter to the AC output socket of that station.

Figure 20. Power Bank for Test Transmitter

Scanner/Receiver

Positioning accuracy

Typically, indoor walk tests imply just marking your walking steps on the floor map, however the 40 λ criteria is still applicable indoors for flawless outcome. And since this requires a precise marking of samples at equidistant distribution, it’s a good idea to use a speed sensor which generates pulses timely along the walking path. In this case, you need a CW receiver with distance sampling & odometer interface.

Figure 21. Odometer for indoor sampling

Test Antennas

TX antenna selection.

- Preferably the test antenna to be the same type of the actual antenna
- Provision a test antenna from a trusted vendor to ensure reliable pattern & gain. Experience revealed that not all omni-antennas are really omni and not all declared patterns are accurate.

TX antenna placement

- The antenna should be apart from any metal object by at least 2 λ to not affect the radiation pattern. Ensure no obstructions around the antenna
- Place the test antenna as close as possible to the intended final installation position, orientation and Hight. Usually a tripod or a mast with a variable hight is a helpful tool here.

Figure 22. Indoor Test antenna setup

RX antenna selection

No much to say here. However to reduce cabling and conections, try o choose an antenna matching your receiver RF connector type if to be attached directly.

RX antenna placement

Care should be given to the receiver antenna placement. Sometimes, especially in CW walk-testing, users ignore the right antenna placement of the receiver. For example, it might happen that they hold it in their hands and so.

Please note that field experience and statistical modelling indicated that body blockage could be considerable. Hence, the location of the antenna is critical during walk testing. Hence, user has to hold the receiver antenna at an average person’s height.

Ask your supplier for the shoulder holder accessory of your indoor receiver for optimum experience and a convenient task.

Figure 23. Shoulder holder for indoor test

Gather LOS & NLOS

To improve the calibrated model, you need a mix of LOS and NLOS data. As lacking a plenty of LOS samples significantly degrades the model calibration process. On the other hand, a remarkable enhancement could be achieved in case the prediction software is fed with adequate LOS as well as NLOS measurements.

Data filtration

Filter all points which were too low and far from the TX.

Sampling manner

Attention should be paid to sampling points in terms of quantity and quality. And this is explained here:

- The left plot in figure 24 represents the ideal scenario. The user here captured an adequate number of samples and calibrated his propagation model to produce the solid curve. Consider this as the ideal reference curve and compare it to the next improper scenarios.
- The middle plot is what happens to the plot when insufficient number of samples is taken. The calibrated plot tends to higher values at most of the points.
- The plot on the right illustrates the case when the samples represent only areas close to the transmitter. So, the plot is extrapolated along its extension and tends to values lower than the ideal curve.

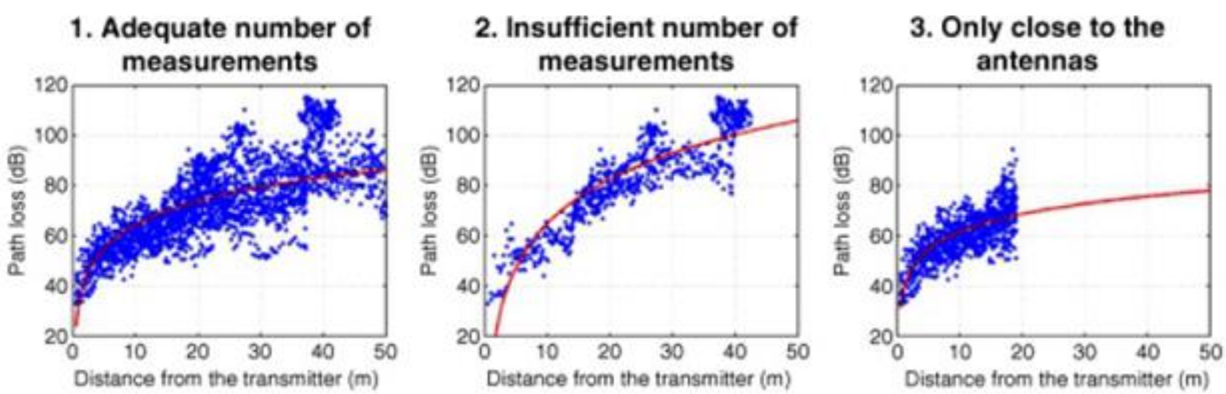
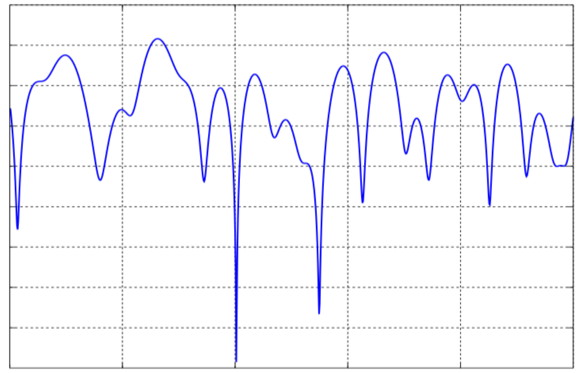


Figure 24. Effect of sampling manner on quality of calibration

Annex 1. Lee Criteria

Fading is a natural phenomenon that causes variations in received signal level and it occurs due to changes in the transmission channel or propagation paths.

There are two types of fading:



1- Slow fading

- Also called large scale fading or terrain-based fading
- Happens due to path-loss and shadowing effects.
- This is the parameter that we're ultimately looking to characterize by CW testing.

2- Fast fading (or Rayleigh fading)

- Causes rapid (hence fast) variations of the received signal strength over short distance and short time periods
- This is the component that we seek to filter out in order to accurately measure the path loss

To avoid the effects of fast fading, William C. Lee proposed a method for obtaining the local mean values of the received signal along a route, this method has since been recommended and adopted by ITU and CEPT among others. It is based on an averaging process (commonly referred to as 40 Lambda averaging) applied to the envelope of the received signal.

Simply a number of samples (N) collected along the route over a certain distance (L) are all averaged together to produce a single point. The number of samples (N) and the distance (L) are essential parameters to ensure that the averaged value:

- Filters out fast fading effects
- Remain, representative of the real signal / within acceptable error limits.

Lee obtained the values of the parameters as follows:

- Distance L = 40 x Wavelengths (40 Lambdas)
- N = 36-50 points

In other words, in order to remove the effects of fast fading in compliance with Lee's criteria, your receiver must be capable of collecting a minimum of 36-50 points in the time, it takes the test car to cover a distance of 40 lambdas. Then, all the samples belonging to this 40-lambda distance are averaged together to produce a single point.

<u>**How to calculate the maximum driving speed?**</u>

Maximum Car speed = $40\lambda/36 \times S/N$

Where,

λ is the wavelength for the highest scanned band.

S is the receiver sampling speed/s.

N is the number of simultaneous bands.

Remember that car speed here is in meter/s, so remember to convert it to Km/h or miles/hour

If more stringent result is needed, replace the factor "36" in the equation with "50".

Annex 2: Why accurate indoor planning is so essential?

“>70% of commercial buildings & hospitals have insufficient mobile coverage indoors”
“49% of architects see that the cost of provisioning for IBW is the greatest challenge”
“77% increase in workforce productivity due to better connectivity”
“28% average increase in property’s value in case of reliable indoor coverage”
“32% of the cases, warehouse distribution workers have to go outside to make calls”
“83% of healthcare workers claim poor cellular coverage at least some of the time”
“40% of warehouse distribution workers blame the carrier when they had a call trouble”

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About Consultix

Consultix is a leading vendor of portable RF test equipment. The company is remarkably known for its comprehensive portfolio of RF analyzers, CW equipment and monitoring solutions serving the Small cells and DAS market worldwide

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