Testing and calibration of IoT devices for maximum energy efficiency

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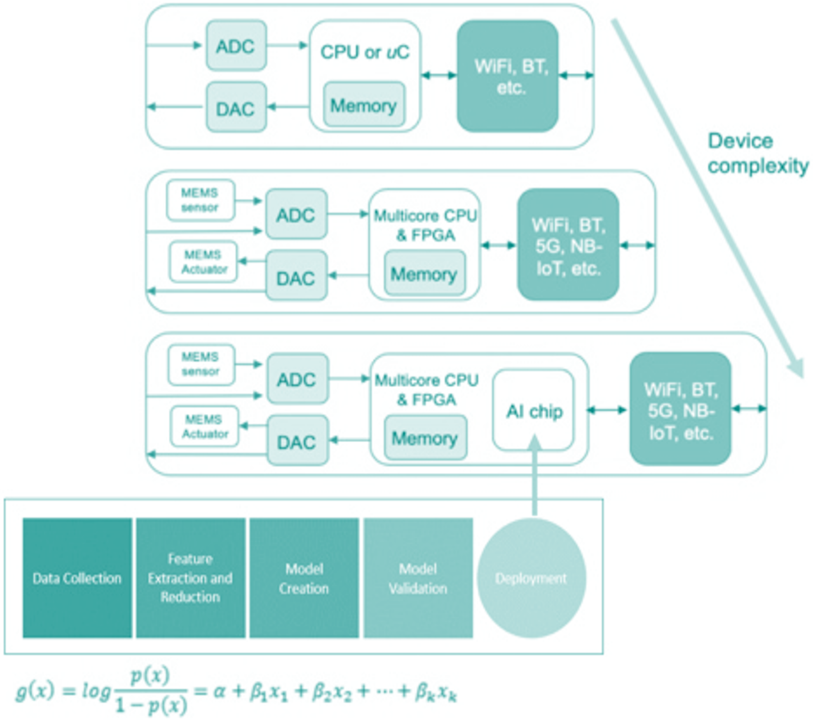
Abstract

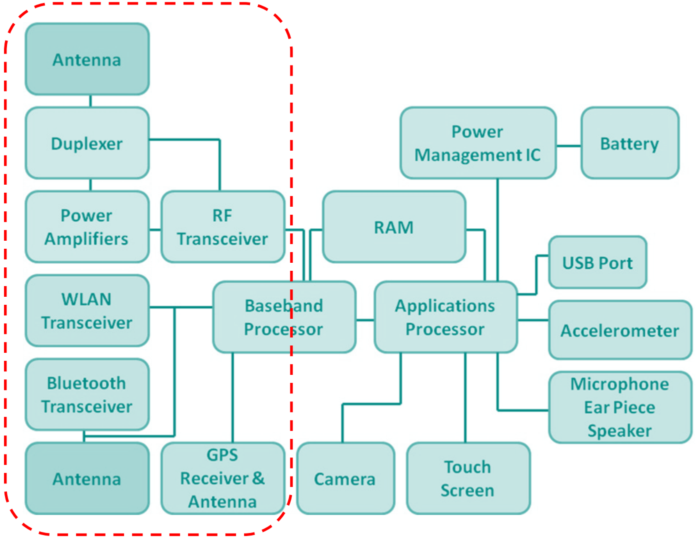
Most Internet of Things (IoT) devices are not designed to be energy efficient out of the box. Such factors as the protocol used by the device, its location (inside a building, in a tunnel, in the battlefield, etc.), environmental and operational conditions, and others can directly affect its performance. Proper configuration, calibration and testing is required to achieve maximum energy efficiency with respect to a minimum baseline. A large network with many connected IoT devices using multiple communications channels and connectivity options (e.g., Bluetooth, WiFi, NB-IoT, LTE-M, eMTC, etc.) and base stations would require multiple test scenarios and procedures to validate its optimal operation. The use of the 3GPP narrowband IoT (NB-IoT) which can reach 200 Kbits/s or eMTC (enhanced machine-type communication which can reach 1 Mbit/s) require key physical layer measurements of the uplink signals such as error vector magnitude (EVM), adjacent channel leakage ratio (ACLR), spectrum emission mask (SEM); calibrated signal power, precision frequency and signal quality measurements are performed. In the case of eMTC, different waveform features such as frequency hopping and guard symbols are tested. In this presentation we review different test cases and procedures that can be used to maximize the energy efficiency of a IoT devices and base stations, and how the use of model-based design techniques and AI/ML can help to improve its overall performance.

Fast Evolving IoT Devices: New Testing and Calibration Needs

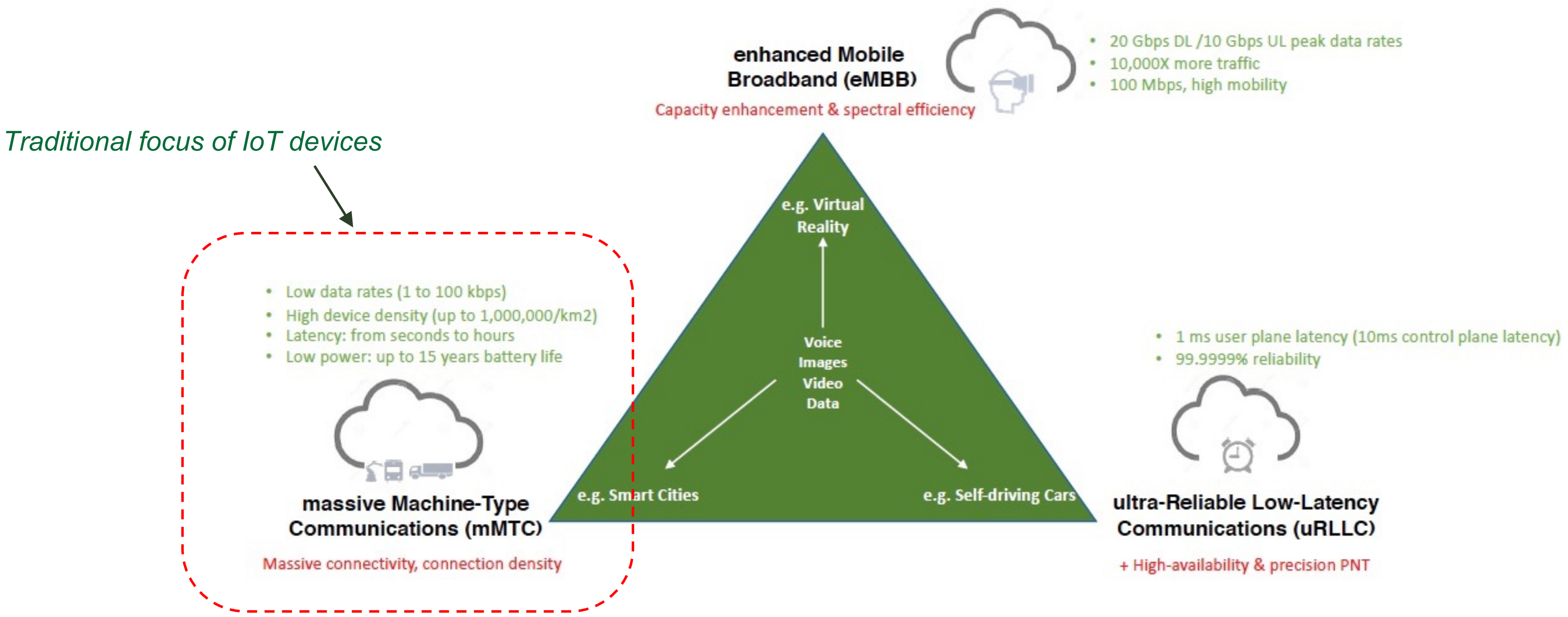
IoT Devices Growing Complexity[5]



RF Front-End Testing[6]

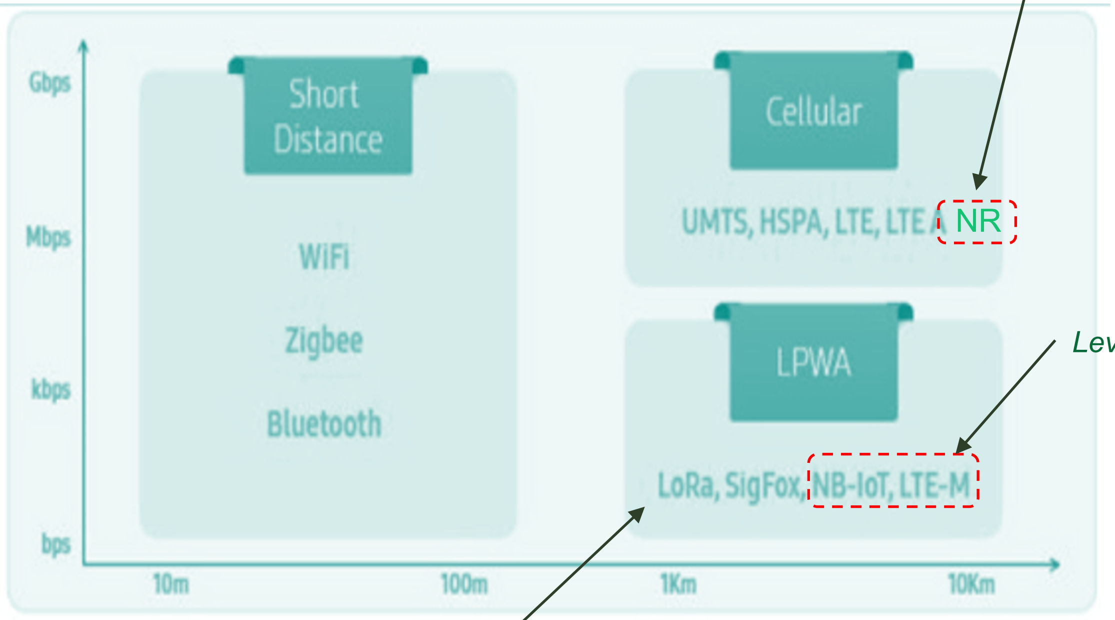


5G Use Cases an IoT[7]



IoT Protocols: Short-Distance vs. Cellular vs. LPWA[5]

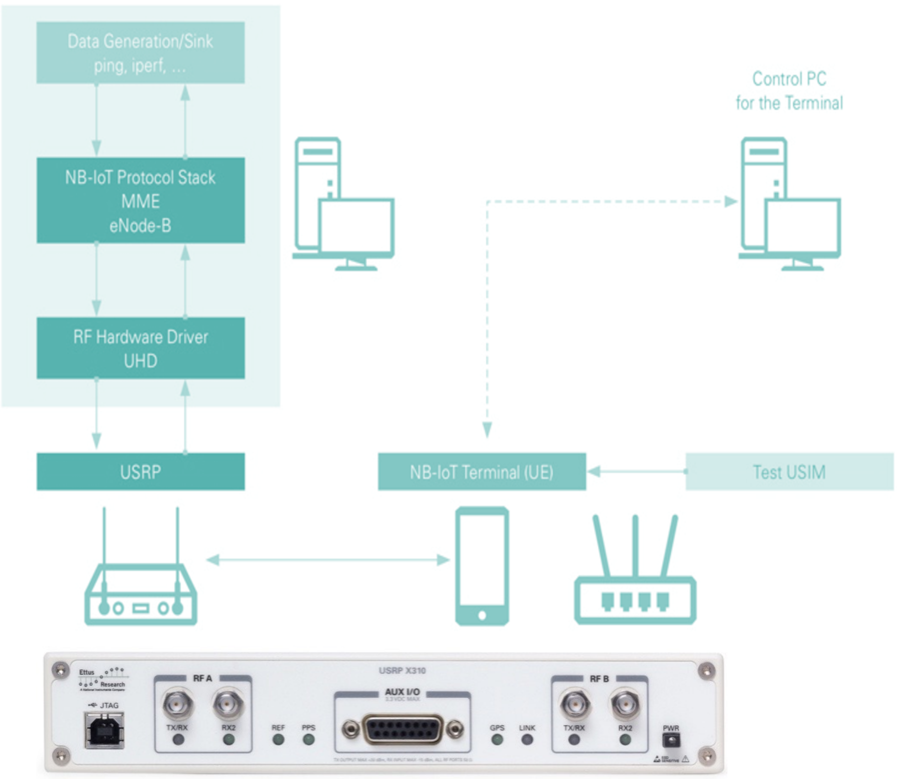
Leverages NR (5G)

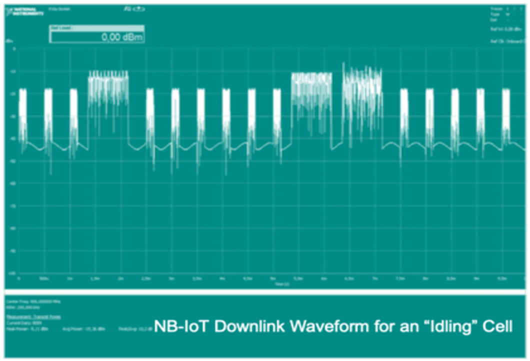


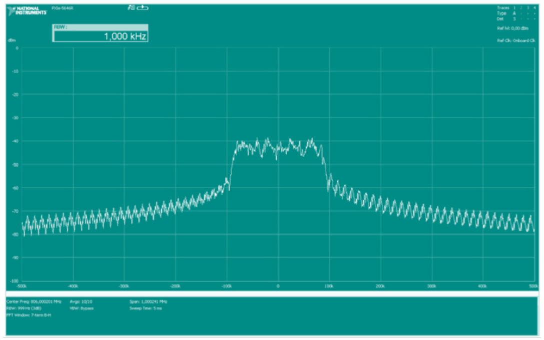
Leverages LTE/LTE-A (4G)

A class of wireless technologies that enables low power consumption and long-range wireless connectivity, that are well suited to the specific needs of machine-to-machine (M2M) and IoT devices.

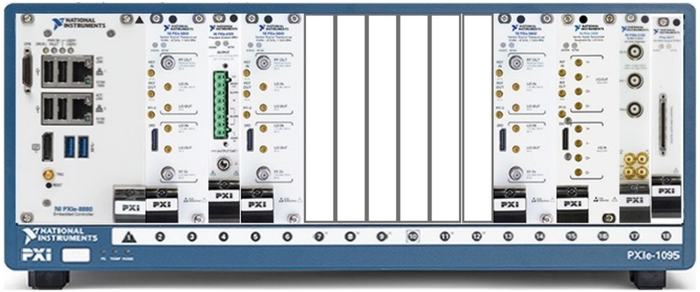
Low-cost NB-IoT DL base station using USRP SDRs[8]

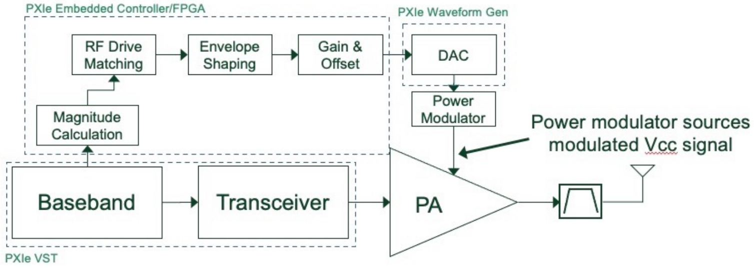


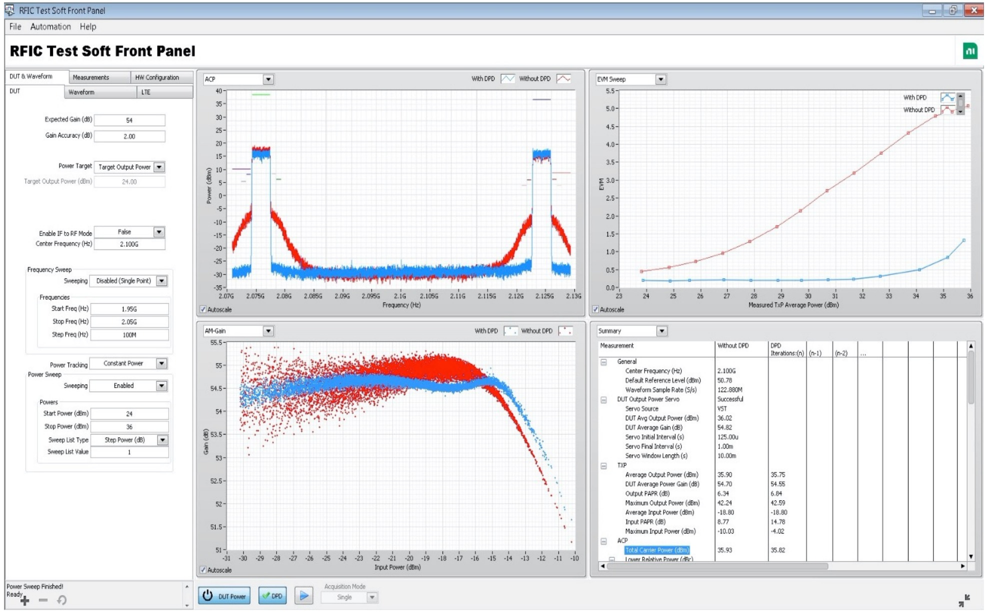




LTE-A/NR: PAs and RF Front-End Testing in IoT Devices[9, 10]







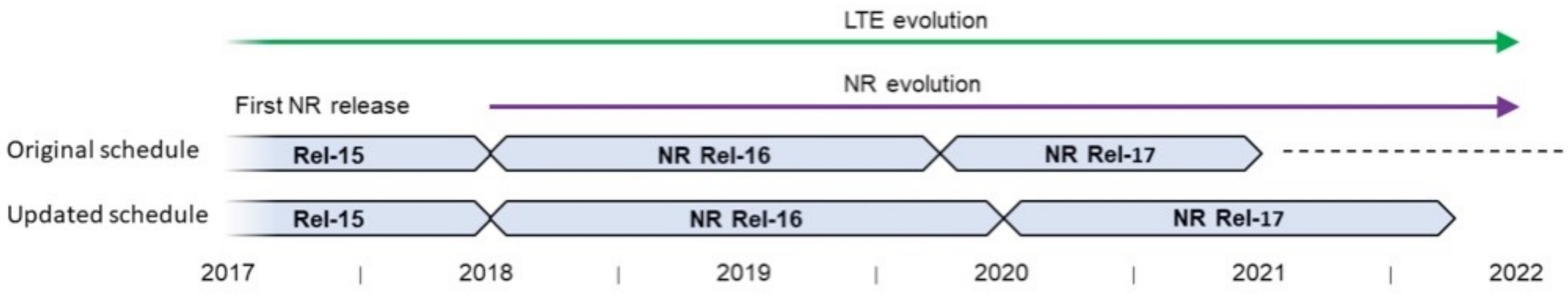
Internet of Things (IoT)

IoT Devices can be based on different wireless protocols and standards:

- LTE-MTC (a.k.a. LTE-M or eMTC)
- NB-IoT
- 5G NR
- WiFi
- SigFox®
- LoRa/LoRaWAN®
- BLE®*
- Etc.

(*) Bluetooth Low Energy

3GPP timeline for Release 15, 16, and 17[1]



3GPP Release 16 Enhancements for IoT[1]

Enhancements for LTE-MTC for reducing energy consumption and increasing spectral efficiency by massive-MTC devices:

- Enhanced mobile-terminated early-data transmission (can be used by idle mode UE to receive a small amount of data without having to transition to connected mode).
- UE-group wake-up signaling (up to 8 groups/wake-up-signal resource), thereby reducing UE energy consumption.
- Uplink transmission using preconfigured resources in idle mode, allowing the UE to avoid time-consuming random-access procedures.
- Multi-transport-block scheduling in both the DL and UL transmission directions (up to 8 DL/UL unicast blocks or 8 multicast blocks using a single DCI*), reducing the control-signaling overhead
- Enhanced DL-quality reporting from the UE in both idle and connected mode, enabling improved link adaptation.
- Relaxed serving-cell measurement requirements for low-mobility devices.
- Use of resynchronization signal to improve performance for intra-frequency neighbor cell measurements

(*) Downlink Control Indication

3GPP Release 16 Enhancements for IoT[1] (Cont'd)

Enhancements for NB-IoT[1]:

- Enhanced mobile-terminated early-data transmission
- Uplink transmission using preconfigured resources in idle mode.
- Multi-transport-block scheduling in both the downlink and uplink transmission directions.
- Enhanced downlink-quality reporting from the device in both idle and connected mode, enabling improved link adaptation.
- Presence of reference signals on non-anchor carrier for paging even when paging is not transmitted. This can be use by the UE for power saving and for improving measurements.
- Enhanced support for network management, including SON support for reporting of Automatic Neighbor Relation measurements, radio link failure reports and random-access configurations.
- Mobility enhancements by means of new system information to assist idle-mode inter-RAT cell selection for NB-IoT to and from LTE, LTE-MTC and GERAN*.

(*) GSM EDGE Radio Access Network

Further LTE Evolution in Release 17 as related to IoT[1]

- Further broadening of the use cases for cellular LPWA and to address lessons drawn from existing deployments and trials.
- Includes supporting 16-QAM modulation for NB-IoT, increasing maximum DL transport block size to 1736 bits (from 1000 bits) for Cat-M1 LTE-MTC UE, and the possibility for14 HARQ processes for half-duplex LTE-MTC where, in all cases, the aim is to enable higher peak data rates.
- Support for faster recovery from radio link failures and enhanced NB-IoT carrier selection.
- out a study on the possibility and required specification updates to support NB-IoT and Separately, 3GPP will carry LTE-MTC on non-terrestrial networks.
- The aim of this possible specification would be to provide IoT connectivity in very remote areas with low or no cellular connectivity.

NR and IIoT[1]: uRLLC and eMBB Use Cases

- Support of NR Industrial Internet of Things to extend the applicability of NR to various verticals, such as further improvements for AR/VR and new uses cases like factory automation, transport industry and electrical power distribution.
- Increase the reliability of the UE interface, increasing resource efficiency with duplication, better handling of high-priority traffic multiplexed with low-priority traffic in the same UE, and more efficient support of TSC*.

(*) Time Sensitive Communications

From ITU-T L.1210[4] and ETSI ES 203[3]

- **5G** is introducing major improvements on Massive MIMO, **IoT**, low latency, unlicensed spectrum, and with V2x for the vehicular market.
- Support of some of these services will have a relevant effect on the power ratings and the **energy consumption** not just at the radio base station but also at the UE or **IoT** device level.
- A major service area of 5G **impacting the powering** and backup will be the **URLLC** (Ultra Reliable Low Latency Communication) as its support will increase the service availability demands by many orders of magnitude.
- Supporting such high availability goals will be partly reached through redundant network coverage, but a main support will have to come through **newly designed powering architectures.** This will be made even more challenging as 5G will require the widespread introduction of **distributed small cells**.
- There is a need to define **sustainable and smart powering solutions**, able to adapt to the present mobile network technologies and able to evolve to adapt to their evolution.
- The flexibility would be needed at level of **power interface, power consumption, architecture tolerant to power delivery point changes** and including control-monitoring.
- This means that it should include from the beginning **appropriate modularity and reconfiguration features for local powering and energy storage and for remote powering solutions including power lines sizing, input and output conversion power and scalable sources.**

Typical Electrical Power Demand for Radio Base Stations and IoT Devices/Concentrators[3]

Macro cell, micro cell and pico or femto cells, with correlation to aggregated RF power, is available in Table 1, together with power needs of IoT, as they could be based on powering paradigms like those of the Small Cells.

Table 1: Powering related characteristics of radio base station, Small Cells and IoT

EQUIPMENT	INSTALLATION			POW. CONSUMPTION		POWERING TYPE					Backhauling connection		Aggregated RF power	
	INDOORS Private premises	INDOORS Public sites and enterprises	OUTDOORS	TYP (W)	MAX (W)	BATTERY Duration (years)	Local mains	Remote power	PoE	mimimum BACKUP time	Wireline / Wireless	Connection flavour	MIN (W)	MAX (W)
WIRELESS														
COMPLEX MACRO BASE STATION (e.g. 2/3/4/5G - multiple freq, massive MIMO and multiple operators)			X	8000	24000		X			YES many hours	Wireline	Optical		many hundreds
SIMPLE MACRO BASE STATION (e.g. 2/3/4G - single freq and single operator)			X	3000	6000		X			YES few hours	Wireline / wireless	Optical / mmWave / high speed broadband		few hundreds
MICROCELLS			X	30	250		X	X		advised minutes	Wireline	Optical / high speed broadband	1	20
PICOCELLS (including FWA nodes)		X		10	50		X		X	advised minutes	Wireline	ETH/Optical	0,1	1
FEMTOCELLS	X			5	20		X			NO	Wireline	Any Broadband	0,01	0,1
WIRELINE														
VDSL2 DSLAMs			Cabinets	150	250		X	X		advised minutes	Wireline	Optical		
G.FAST			Cabinets	25	40			X			Wireline	Optical		
IoT														
Gas & water sensing, metering	X			very low		10					Wireless	LP WAN		
Surveillance camera		X	X	5	20		X	X	X	NO	Wireline	Any Broadband		
Environmental sensing (CO2, NOX, noise, particulate ...)			X	2	10			X		NO	Wireless	LP WAN		

Estimate Radio Base Station Power Site Rating[3]

The Impact of PAs

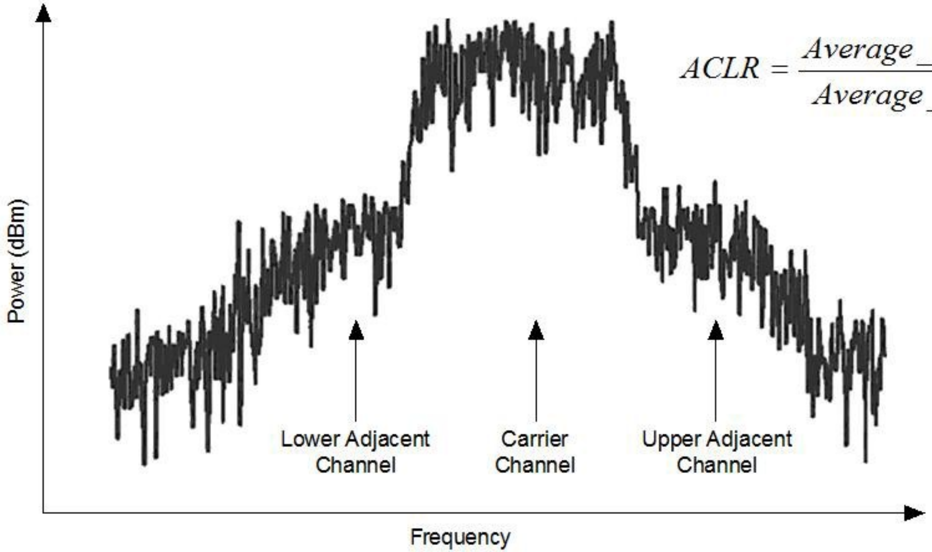
NR IoT and IIoT Devices and Concentrators

Needs for RFIC (PA) Testing

- Validate, and characterize wideband LTE, 5G NR, and Wi-Fi power amplifiers and front-end modules.
- Integrate precision DC, digital, analog, and RF instrumentation for synchronized test bench control of interactive and automated validation of RF front ends.
- Measure and record AM/AM, AM/PM, gain, ACLR, EVM, PAE, etc., with and without various types of digital predistortion (DPD)—including dual-band or custom algorithms.
- Perform power, frequency, and output load sweeps; accurate dynamic measurements with an integrated interface for MIPI RFFE, SPI or other digital protocols; and measure ultra-low EVM for Wi-Fi 7 and 5G NR modulation schemes with cross-correlation algorithms.

Adjacent channel power leakage ratio (ACLR)

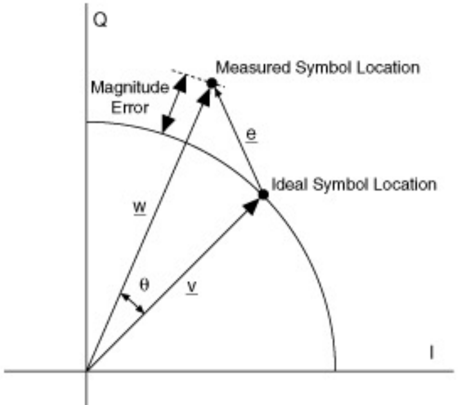
A ratio of the carrier product power to the adjacent channel products power level. Another definition is that "is the ratio of the filtered mean power centered on the assigned channel frequency to the filtered mean power centered on an adjacent channel frequency."



$$ACLR = \frac{Average\_Power\_in\_Adjacent\_Channel}{Average\_Power\_in\_Carrier\_Channel}$$

Error vector magnitude (EVM)

Measurement of demodulator performance in the presence of impairments.



Where:

$\underline{v}$ is the ideal symbol vector
$\underline{w}$ is the measured symbol vector
$\underline{w}$-$\underline{v}$ is the magnitude error
θ is the phase error
$\underline{e}$=$\underline{w}$–$\underline{v}$) is the error vector and
$\underline{e}$/$\underline{v}$ is the EVM.

$$\mathrm{EVM} = \frac{\sqrt{\frac{1}{N}\sum_{j=1}^{N}[(I_j-\tilde{I}_j)^2+(Q_j-\tilde{Q}_j)^2]}}{|\underline{v}_{\max}|}$$

Where:

I_j is the I component of the *j*-th symbol received
Q_j is the Q component of the *j*-th symbol received
$\tilde{I}_j$ is the ideal I component of the *j*-th symbol received
$\tilde{Q}_j$ is the ideal Q component of the *j*-th symbol received.

EVM is related to the modulation error ratio (MER) and *ρ*. There is a one-to-one relationship between EVM and MER. Although EVM measures the vector difference between the measured and ideal signals, *ρ* measures the correlation between the two signals.

The modulation error ratio (MER)

a measure of the signal-to-noise ratio (SNR) in a digitally modulated signal. Like SNR, MER is usually expressed in dB. MER over N number of symbols is defined as the following equation:

$$\mathrm{MER} = \frac{\sum\limits_{j=1} (\tilde{I}_j^2 + \tilde{Q}_j^2)}{\sum\limits_{i=1}^{N} [(I_j - \tilde{I}_j)^2 + (Q_j - \tilde{Q}_j)^2]}$$

Where:

I_j is the I component of the *j*-th symbol received

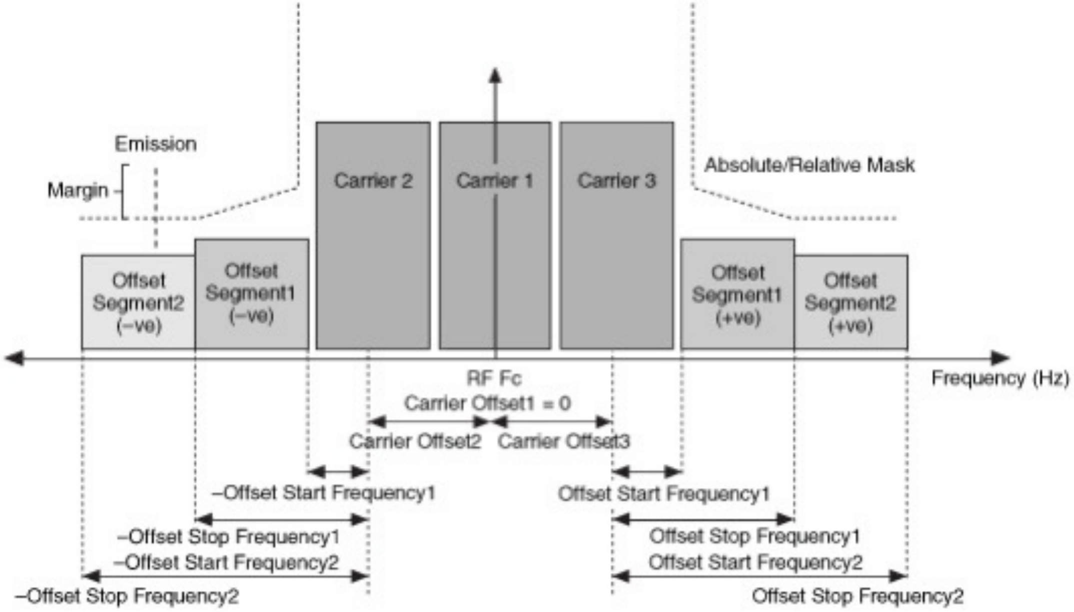
Q_j is the Q component of the *j*-th symbol received

$\tilde{I}_j$ is the ideal I component of the *j*-th symbol received and

$\tilde{Q}_j$ is the ideal Q component of the *j*-th symbol received.

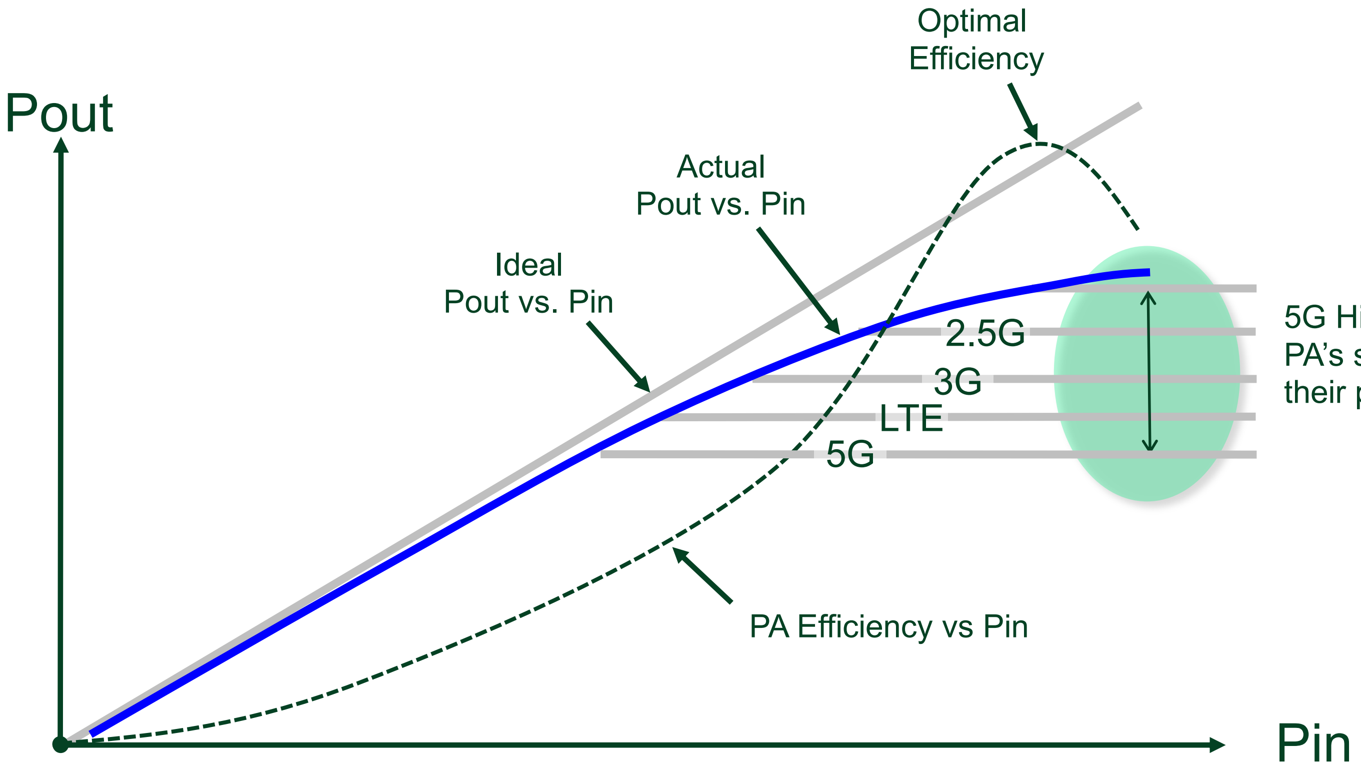
Spectrum Emission Mask (SEM)

Spectral emission mask (SEM) measurements measure out-of-band emissions in the neighboring bands of the carrier. The following figure shows the configuration of SEM carriers and offset segments.



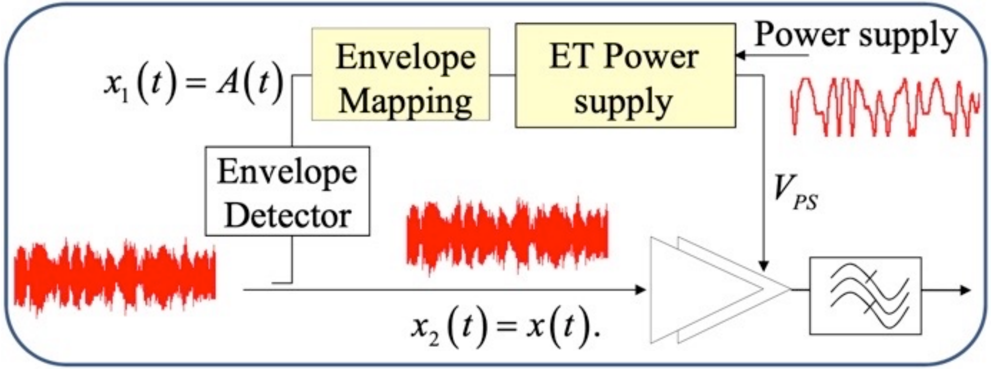
Peak to Average Power Ratio (PAPR)[10]

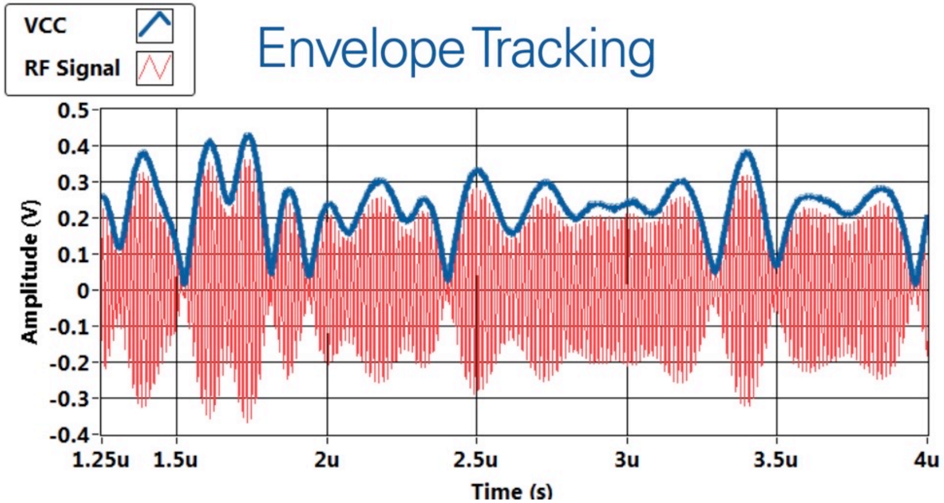
It has a major impact on the efficiency of the PAs in base stations and devices.



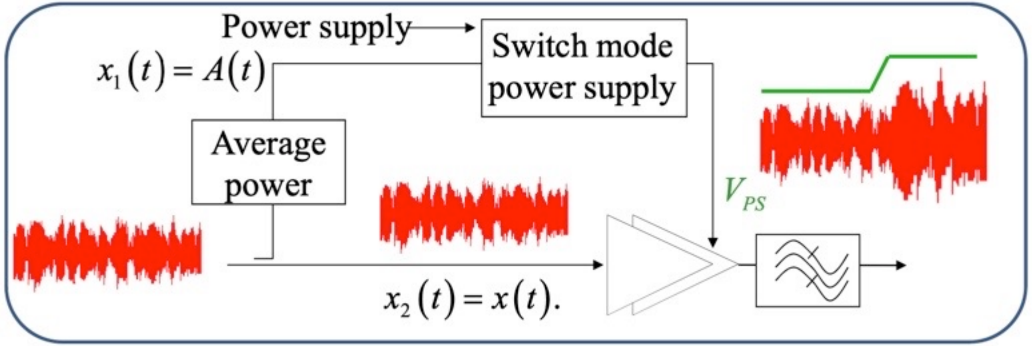
5G High PAPR signals mean that PA's spend less time operating at their point of peak efficiency

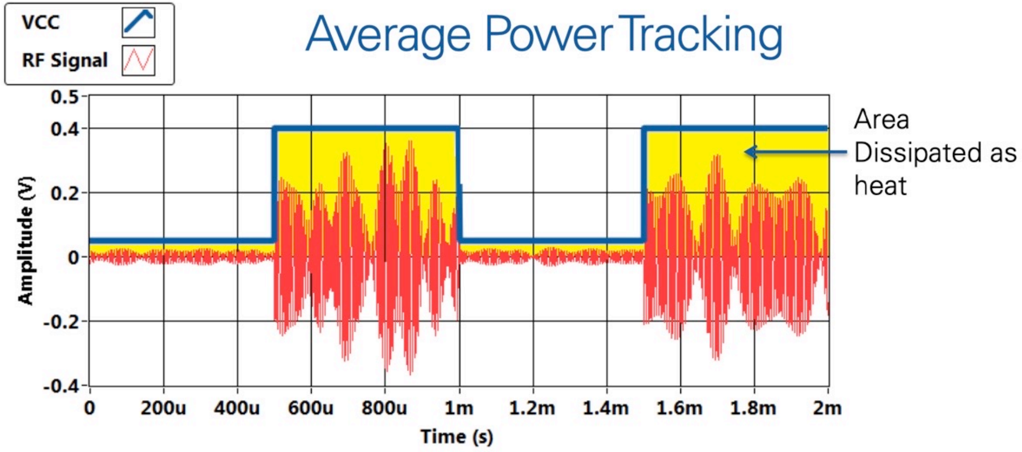
Envelop Tracking (ET) for LTE (4G)

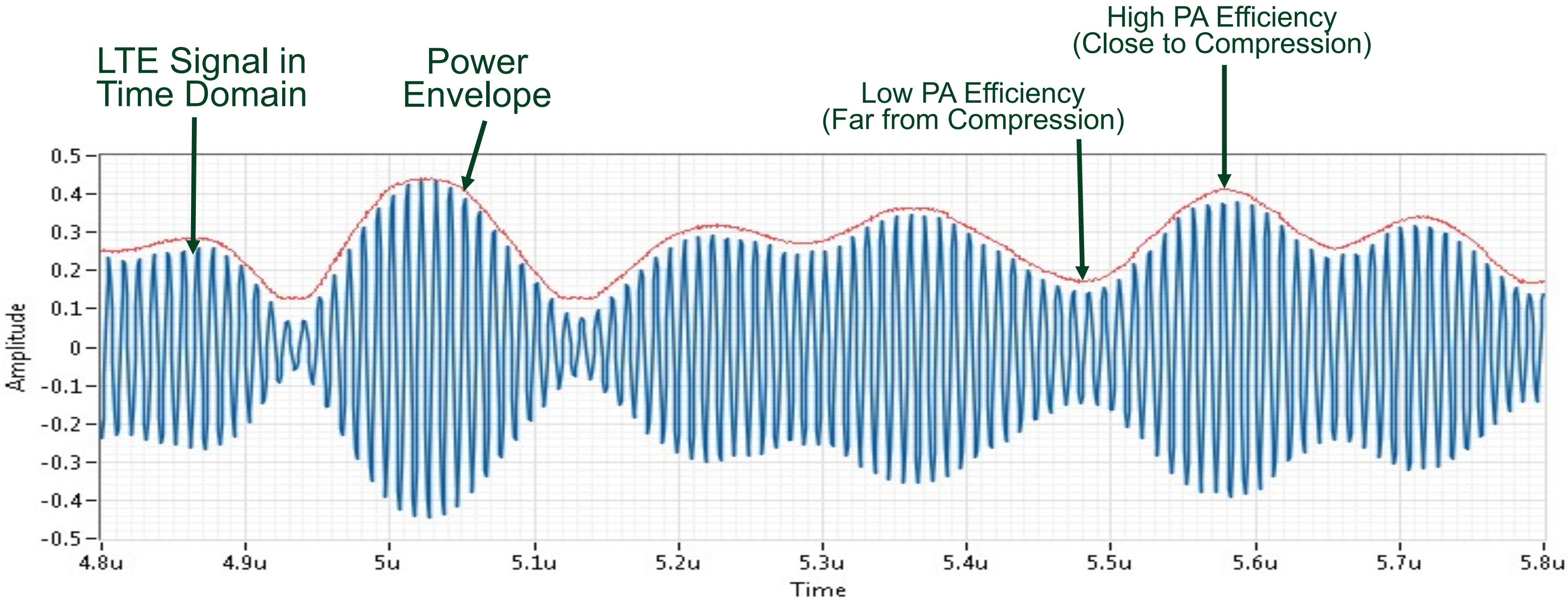




Average Power Tracking (APT) for 5G NR

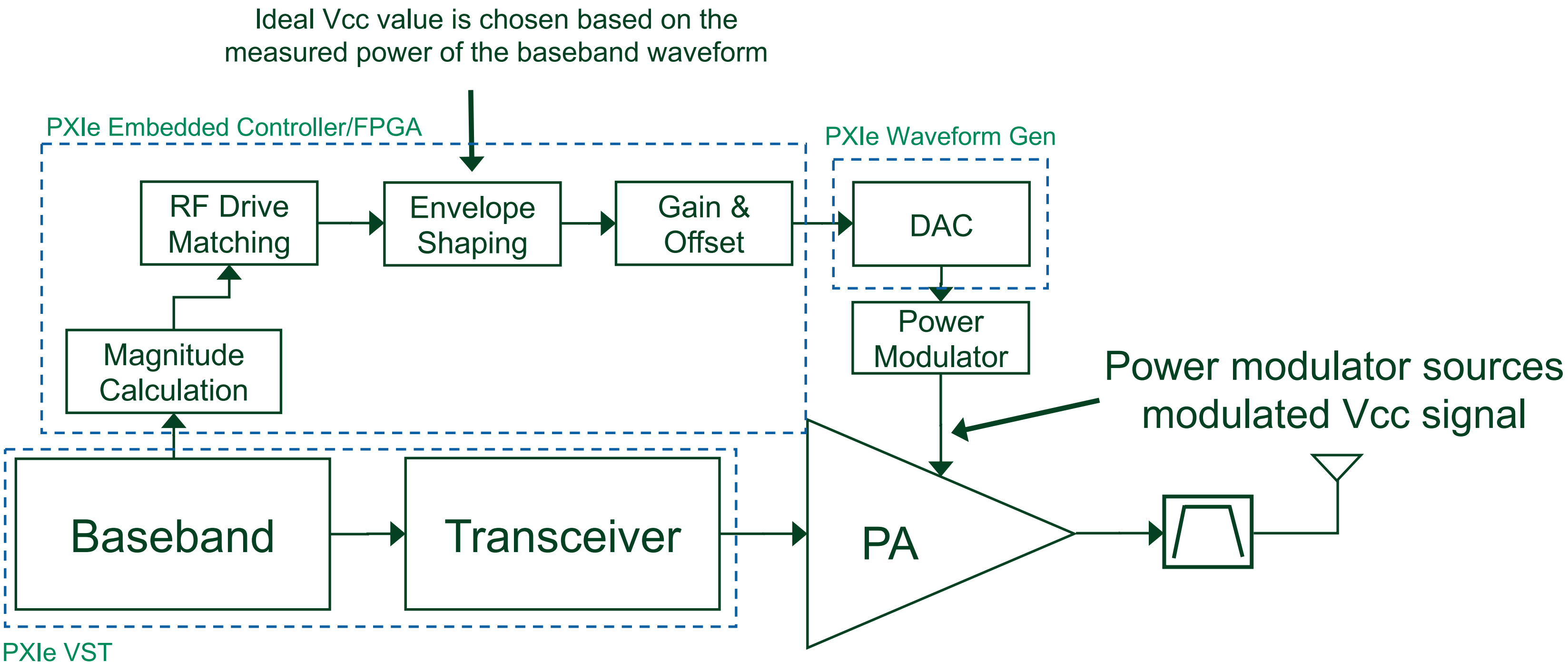






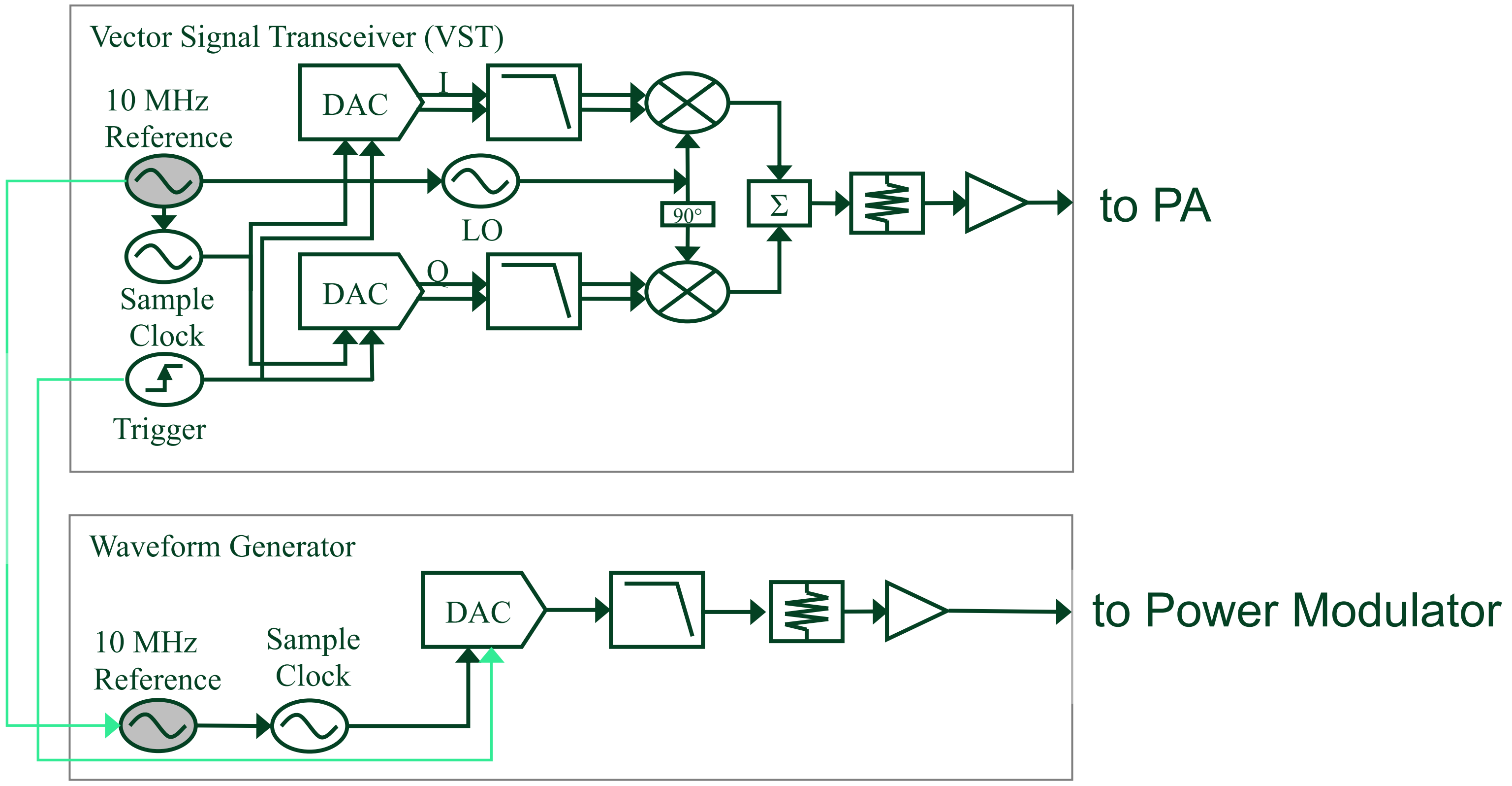
Envelope tracking PA's maximize efficiency by varying the PA's point of peak efficiency (by adjusting Vcc) in accordance with the power envelope of the signal.

Creating a synchronous modulated power supply signal

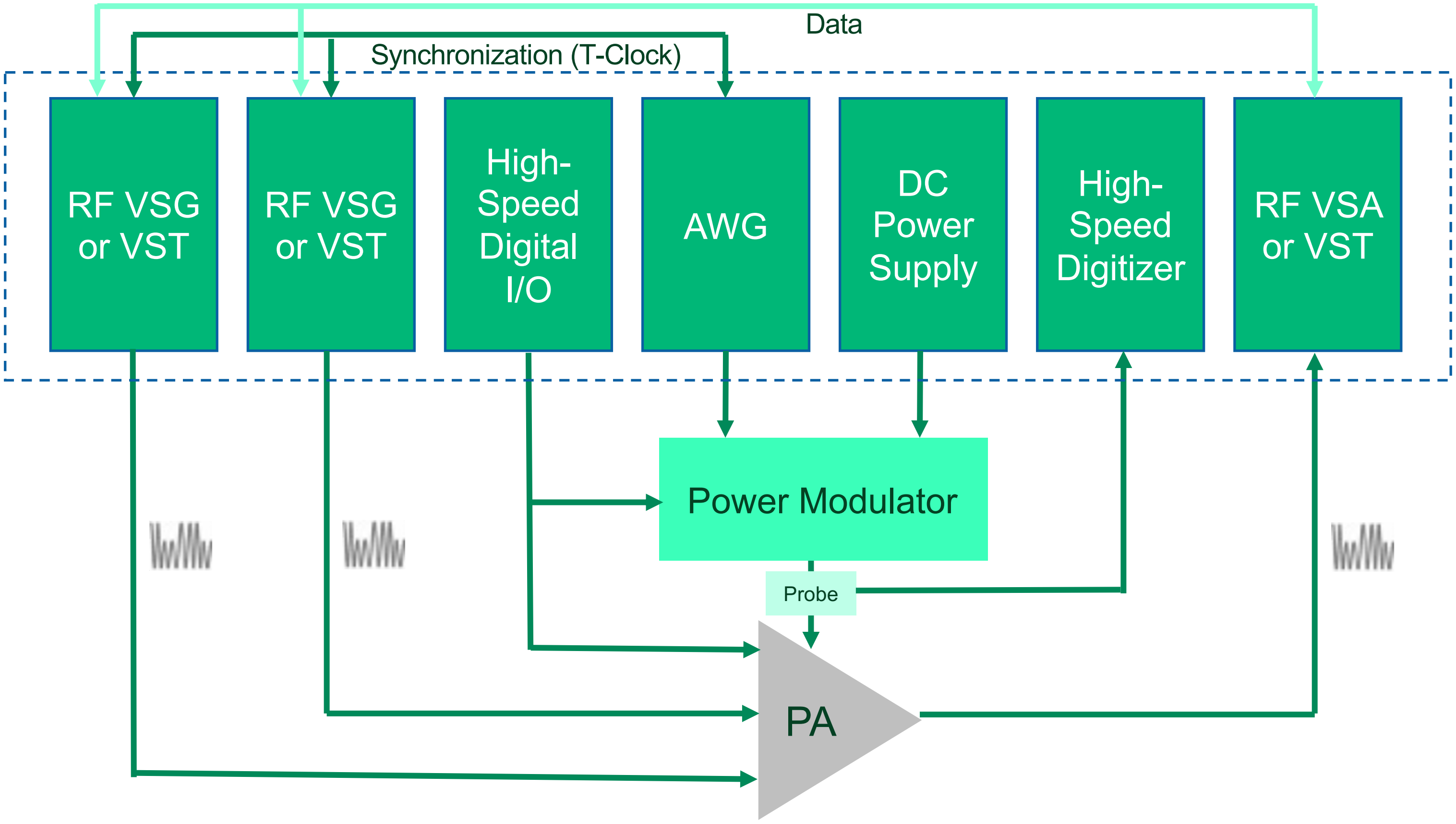


Using a Master Clock for RF to Baseband Synchronization

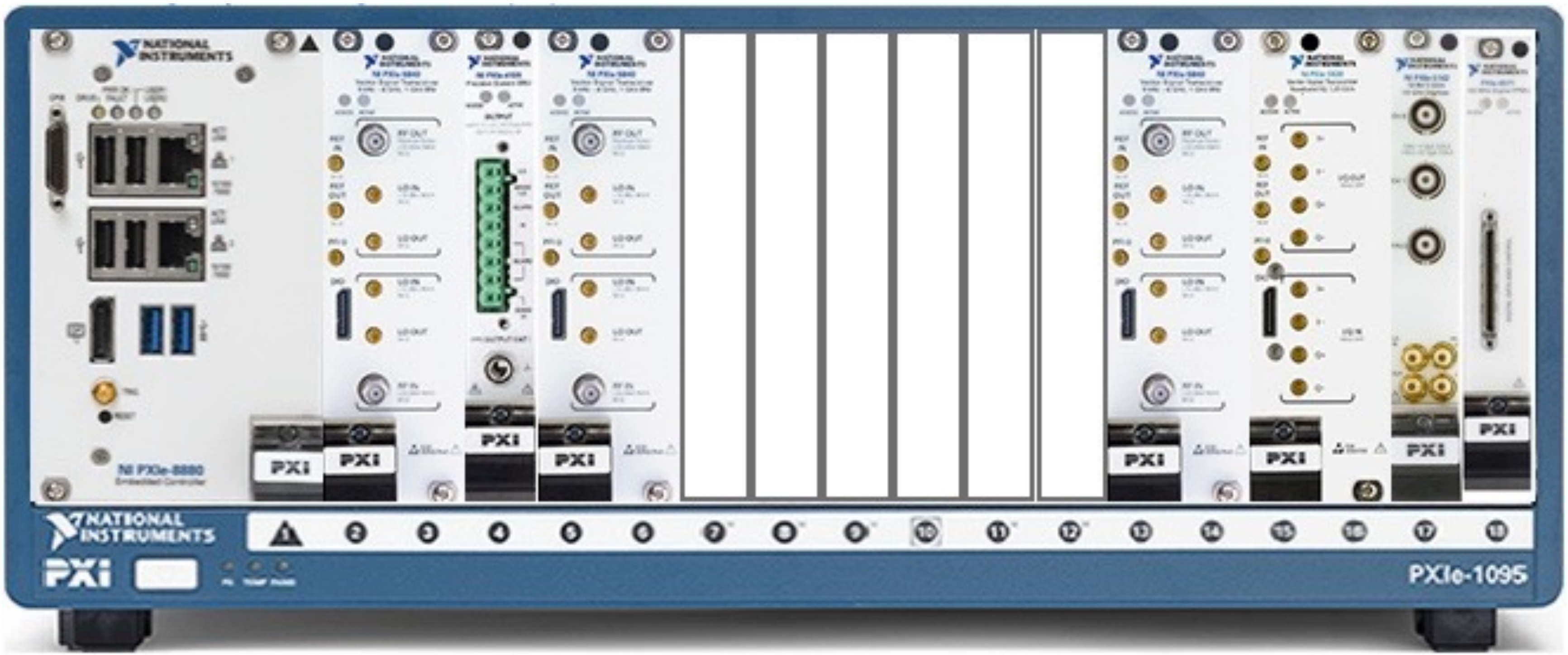
VST shares clock signals internally (using the NI-Tclk supported in the PXIe chassis).



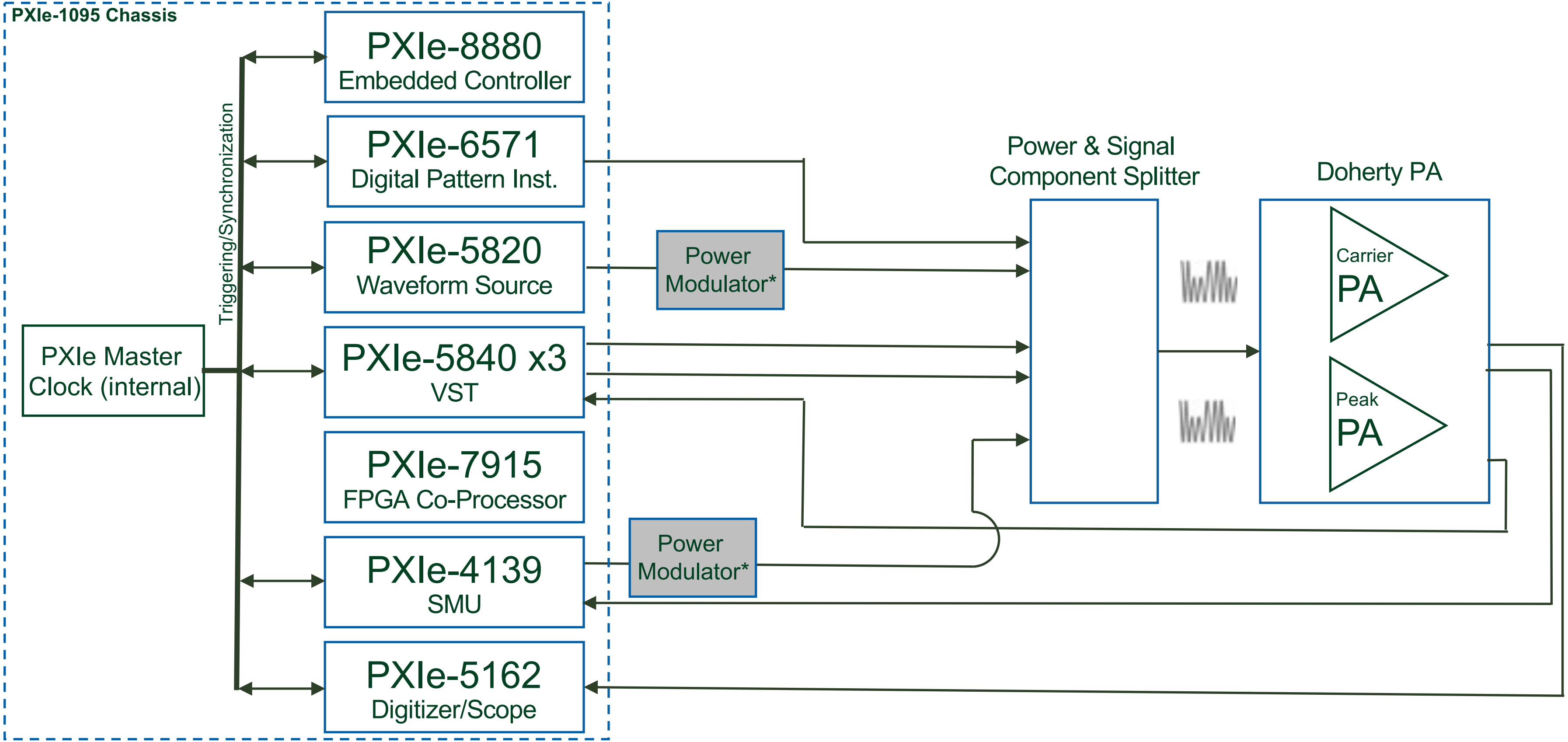
An ET/DPD Dual-Input PA Test System



Test System



ET/DPD Dual-Input PA Test System



(*) Power Modulator not included. It's a power supply amplifier that can give the PA the high current it needs with a wide modulation bandwidth.

(**) Radio heads needed for mmWave frequencies.

References

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Questions?

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