# Radio Interoperability in 5G and 6G Multiradio Base Station

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*Abstract* — The 5G system enables flexible and high data rate communication between nearby vehicles, infrastructure nodes, or pedestrians to enable smart traffic use-cases. However, fully autonomous driving vehicles supporting real-time, high-quality, and high data rate sensor data sharing will require data rates beyond 5G, which a future 6G system will support. Mobile devices (UE) and base stations (BTS) supporting the 5G and the future 6G are implemented as multi-mode devices, where multiple radios supporting different systems are integrated into one. The highest 5G data rates are enabled with 5G millimeter wave (mmW) radios, but those face interoperability challenges of harmonic transmissions (TXs) of Long Term Evolution (LTE) and Wi-Fi radios. The 6G radios will suffer co-channel interference from the fundamental TXs of legacy cellular systems since an analog baseband signal of 6G radio will be wider than the frequency allocations of current wireless systems. Similarly, the fundamental TXs of LTE and Wi-Fi may introduce co-channel interference to the analog intermediate frequency (IF) interface of 5G mmW.

A minimum 111 dB isolation requirement is calculated for the co-channel interference from the LTE antenna to the 5G mmW analog IF interface. The measured isolation in the 5G mmW proof-of-concept radio was 67 dB, which is significantly lower than the requirement. The 5G mmW OTA link measurements show that a narrow interference can block the 5G mmW operation if the IF signal has co-channel interference distorting the 5G synchronization signals. The 5G mmW analog interface measurement verifies that the future 6G multi-mode UEs and BTSs will face severe radio interoperability challenges with 5G, LTE, and Wi-Fi transmissions.

*Keywords* — Base station. Error Vector Magnitude, Interface, Interference, Mobile device

## I. Introduction

Fifth-generation (5G) mobile networks will offer ten-fold data rates compared with the current Long Term Evolution (LTE) system. The 5G system will offer 20 Gbps and 10 Gbps peak data rates for downlink (DL) and uplink, respectively. The highest data rates require wide signal bandwidths (BWs) available at millimeter-wave (mmW) frequency bands. Current third generation partnership project (3GPP) 5G new radio (NR) standard supports signal BWs up to 400 MHz at mmW frequencies [1], [2]. The widest supported intra-band carrier aggregation combination in the current mobile terminal standard is 1200 MHz [2], and future 5G releases will enhance data rates. Wireless communication standards beyond 5G towards 6G will require significantly wider signal BWs to support continuously growing data rate demand. A lower THz frequency band between 200 - 300 GHz is one of the candidate bands for future 6G high data rate communication. It has been envisioned that the data rates of the 6G system can reach up to

1 Tbps [3]. Even though no official 6G standard exists, the first proposal for the low-THz wireless standard IEEE 802.15.3d is available, where the widest carrier aggregated signal BW is 69.2 GHz [4]. A one-meter wireless link operating at a 100 Gbps data rate at 230 GHz frequency with a single carrier 16-QAM modulation has been demonstrated in [5]. One of the first use-cases which have been envisioned for 6G relates to autonomous driving and vehicles [3]. The 5G standard has addressed the autonomous driving with a standard [6], which specifies minimum requirements for use-cases. The highest data rates are needed for an imminent collision scenario, where fully automated vehicles are sharing real-time sensor data directly between vehicles or to the network via a roadside unit. The maximum currently specified data rate, such as 5G use-case is 1 Gbps, but it will be enhanced, when higher data rates are widely available in the 5G and future 6G networks. Current vehicle to vehicle communication utilizes additional Wi-Fi communication path based on IEEE 802.11p with 5G and LTE communications to enhance overall data rate and reliability [7]

Current 5G mobile terminals (UEs) and small cell base stations (BTSs) support multiple wireless technologies simultaneously. A trend for 5G mmW UE receivers (Rx) is that they will not utilize filters [8], [9] in mmW RF front end. Implementation of 5G UE with multiple mmW antenna arrays has been studied in [10]. Interoperability requirements between different radio systems, e.g., Wi-Fi, LTE, and 5G, has not been standardized by 3GPP or by any other standardization body. An interference scenario, where the interference signals are coupled from the LTE or Wi-Fi antennas to the 5G mmW antenna, is studied in [11].

A wideband analog signal interface (i/f) is vulnerable to narrow interference signals, as shown in the example in Fig. 1. It can be seen that the 5G mmW radio suffers from the co-channel interferences of LTE and Wi-Fi transmissions (TXs) at an intermediate frequency (IF) or from their harmonic interferences at mmW frequency. The 6G analog BB reception (RX) will suffer co-channel interference from fundamental frequency TX of 5G, LTE, and Wi-Fi and harmonic TXs of LTE and Wi-Fi. The analog BB signal is present in the interconnection cable, at the signal trace or inside of the IC, depending on the system partitioning and architecture.

It can be seen from Fig. 1 that radio interoperability can be implemented by optimizing the RX IF frequency of the 5G mmW radio towards LTE interference. However, when
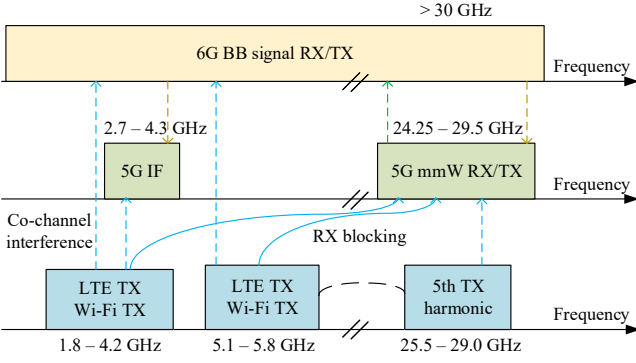
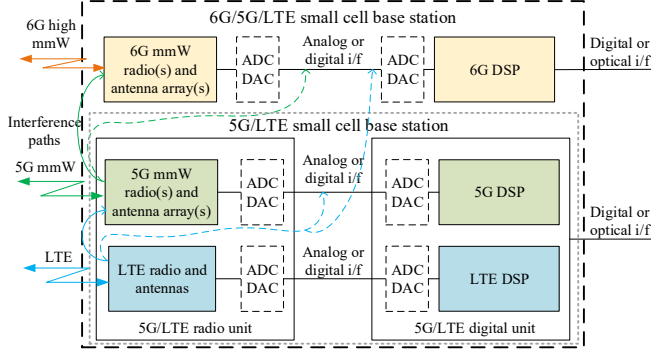Fig. 1. 6G, 5G, LTE and Wi-Fi interference scenarios.



Fig. 2. Block diagram of 6G multi-mode base station with interference paths.

the supported BWs of 5G systems get wider, the frequency planning of non-overlapping frequency allocations becomes more demanding or even impossible. For this reason, the interference scenarios in the analog interconnection between LTE, Wi-Fi, 5G, and 6G need to be studied. This paper shows that more than 110 dB isolation is needed from the LTE transmission antenna to the 5G mmW analog interface to enable seamless concurrent operation between 5G mmW and LTE. The same analysis can be extended to the 6G radio system, as well.

## II. INTERFERENCE SCENARIO IN 6G MULTIRADIO BTS

A block diagram of the future 6G multi-mode small cell BTS, which can be used, for example, as a road-side unit in the traffic use-case, is shown in Fig. 2. The 6G BTS can be divided into two main parts: 6G radio and 5G multi-mode small cell BTS, which has similar functionalities as currently deployed units. The 6G radio will have a dedicated digital interface to the core network since the supported data rates are significantly higher than 5G data rates. It can be seen from the block diagram that the LTE and 5G TXs may couple to the analog i/f of the 6G radio, and similarly, the LTE or Wi-Fi TX may interfere with the analog i/f of the 5G mmW radio. The digital signal processing (DSP) unit may be a separate unit or integrated within the radio unit. In the former case, the analog i/f may locate between radio and DPS units or within the radio unit depending on the locations of the analog to digital (ADCs) and digital to analog converters (DACs).
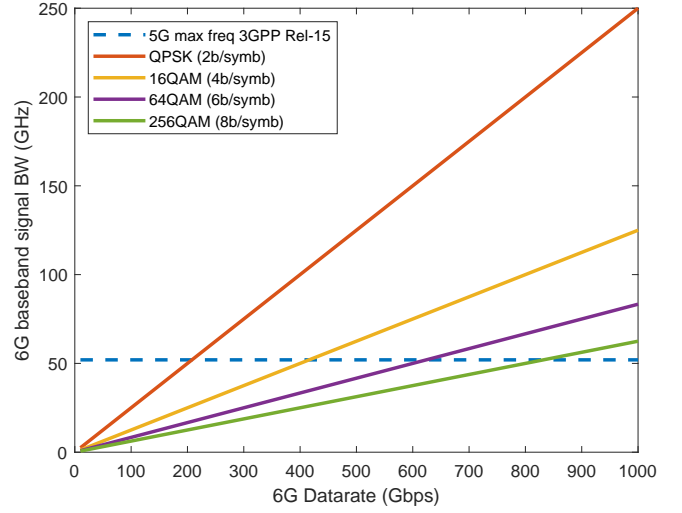


Fig. 3. Real analog 6G baseband signal BW with different modulations.

The signal BWs in the 6G analog and digital interfaces are considerably wider than in 5G or LTE radios. Thus, co-channel interference from other radios is easily coupled to the 6G RX signal. It can be seen from Fig. 3, that the higher the modulation order is, the more narrow analog BB signal BW can be used. High order modulations e.g., 64-QAM and 256-QAM, require a high signal to noise ratio for successful communication, which is difficult to achieve with currently used 200 GHz technologies. The maximum 5G frequency of 52.6 GHz from the 3GPP 5G NR standard is marked with a dotted line in Fig. 3, which indicates that 5G and LTE TXs will have significant overlap with the 6G BB RX signal with all data rates. There is no successful 6G communication with most of the modulations, if overlapping interference frequencies are low-pass filtered from the 6G BB signal. The real analog BB signal BW calculated as

$$BW_{BB} = \frac{BW_{Mod}}{2} = \frac{BW_{data}}{2M} \qquad (1)$$

where $BW_{data}$ is the data rate and M is number of the bits per symbol, which depends on used modulation.

The interference scenarios within the 6G BTS can be analyzed separately for 6G, 5G, and LTE operations. The co-channel interference scenario in the analog i/f is analyzed in the scenario where the sub-6 GHz LTE Tx overlaps with the 5G mmW Rx signal at IF frequency. The isolation between LTE and 5G mmW operations in the developed 5G mmW proof-of-concept (PoC) radio unit has been analyzed in Table 1. It is assumed that the maximum LTE transmission level is 23 dBm [12]. The antenna gain of the LTE antenna is assumed to be 0 dBi for omnidirectional cell coverage. The noise figure (NF) of the 5G mmW receiver is assumed to be 5.0 dB and the gain of the Rx from the antenna to the IF port of the radio 17.0 dB, as described in [13]. Only 0.1 dB deterioration of the 5G mmW RX IF signal is allowed due to the co-channel LTE signal interference since the interference is introduced into the

Table 1. Calculation of maximum interference in 5G mmW IF interface.

|   | Variable | Value | unit |
|---|----------|-------|------|
| A | 5G mmW signal BW | 100 | MHz |
| B | Thermal noise (ktB) | -174 | dBm/Hz |
| C | NF of array Rx | 5.0 | dB |
| D | Noise level in antenna input (A*B+C) | -89.0 | dBm |
| E | RX gain from mmW to IF port | 17.0 | dB |
| F | Noise level in IF cable (D+E) | -72.0 | dBm |
| G | Max noise raise due to interference | 0.1 | dB |
| H | Noise + interference level (F+G) | -71.9 | dBm |
| I | Max interference level Eq. (2) | -88.3 | dBm |
| J | Max LTE TX level with 0 dBi antenna | 23.0 | dBm |
| K | Isolation from LTE to 5G cable (J-I) | 111.3 | dB |



Fig. 4. 5G mmW OTA interoperability measurement setup.



Fig. 5. Photograph of 5G and LTE interference measurement arrangement.

back-end of the RF signal chain. The maximum interference level in the 5G mmW i/f cable can be calculated

$$I_{max} = 10\log_{10}\left(10^{(H/10)} - 10^{(F/10)}\right) \qquad (2)$$

where H is combined noise and interference level, as shown at row H in Table 1, and the F is the noise level in the cable as shown at row F in Table 1. It can be concluded that at least 111 dB isolation is needed from the LTE antenna inside of the 5G mmW i/f cable. The isolation can be improved by optimizing the location of the LTE antenna, by using shielding around the i/f coaxial cable, by selecting a high isolation coaxial cable or by using optical interconnections.

The same method, as shown in Table 1, can be applied for the 6G co-channel interference and isolation calculations. Ratios of the signal BWs attenuate the co-channel interference from the 6G BB TX signal to the 5G RX signal. For example, an co-channel interference from 30 GHz wide 6G signal to 100 MHz 5G signal is attenuated by 24.8 dB, and thus the 6G RX is the most prone for co-channel interferences.

## III. NARROW BAND SYSTEM GENERATED CO-CHANNEL INTERFERENCE TO WIDE BAND SYSTEM

A narrow band interference scenario of a local oscillator leakage of 230 GHz transceiver is analysed in [14], where the narrow band interference is 17 dB higher than average signal power of the communication signal. The 6G capable radio devices are not available, yet, and thus a narrow-band co-channel interference scenario and effect to a wider signal is studied with a 5G mmW and LTE scenario, which is validated with implemented 5G mmW PoC unit [13].

Over-the-air (OTA) interference measurement between the LTE and 5G mmW systems has been performed based on the block diagram shown in Fig. 4. The interference measurement emulates a real use-case where the 5G mmW radio communicates with another 5G mmW unit by using a 5G NR 100 MHz wide Cyclic-Prefix Orthogonal Frequency Division Multiplexing (CP-OFDM) modulated signal. The interfering continuous wave (CW) signal was transmitted, via a wideband test antenna, to emulate a narrow-band interference, such as LTE or Wi-Fi, whose BW varies from 200 kHz
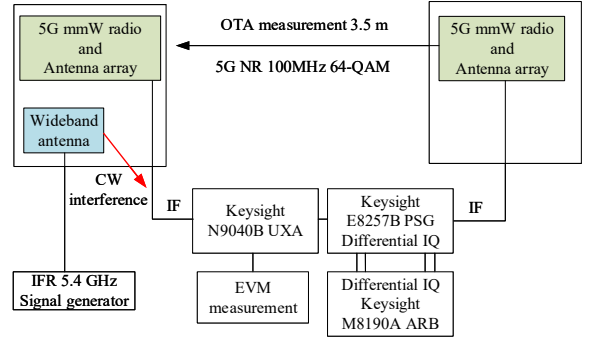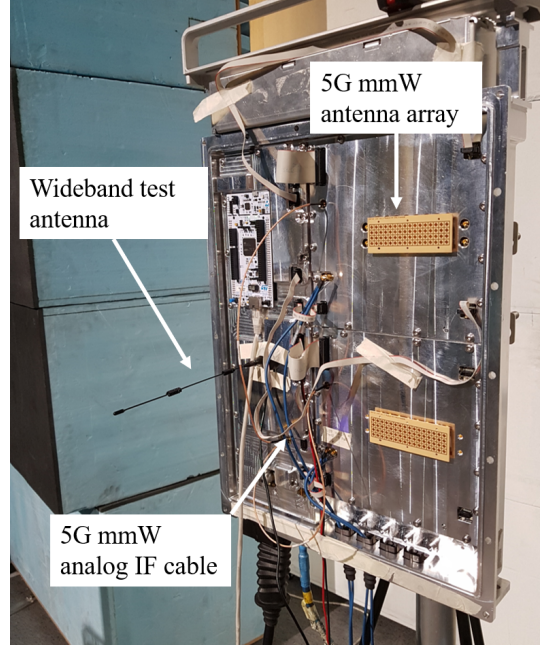
up to 20 MHz. The CW interference was used in the interference measurement since it is the worst-case interferer where all RF power is concentrated on a single frequency. The OFDM signal is composed of multiple narrow sub-carriers, which are individually modulated and demodulated. Thus, the OFDM signal should be by nature, resistant to the CW-like interference.

The photograph of the measurement arrangement is shown in Fig. 5. The interference signal antenna is located next to two 5G mmW array Rxs in the radio unit. Both 5G mmW radio Rxs have own analog i/f connected to measurement equipment. The 5G mmW Rx operates on 4 GHz IF frequency in all measurements. The interfering TX signal level was set to +13 dBm.

### A. Interference Measurements at IF frequency of 5G mmW

The interfering CW signal was swept from 2.6 GHz to 5.4 GHz by 100 MHz steps to cover high-frequency LTE bands. The coupling of interference signal to the coaxial cable
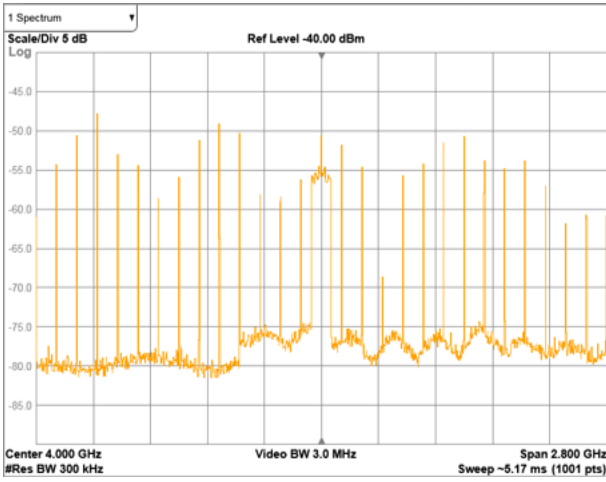
Fig. 6. OTA coupled interference signal levels in 5G mmW analog interface coaxial cable.
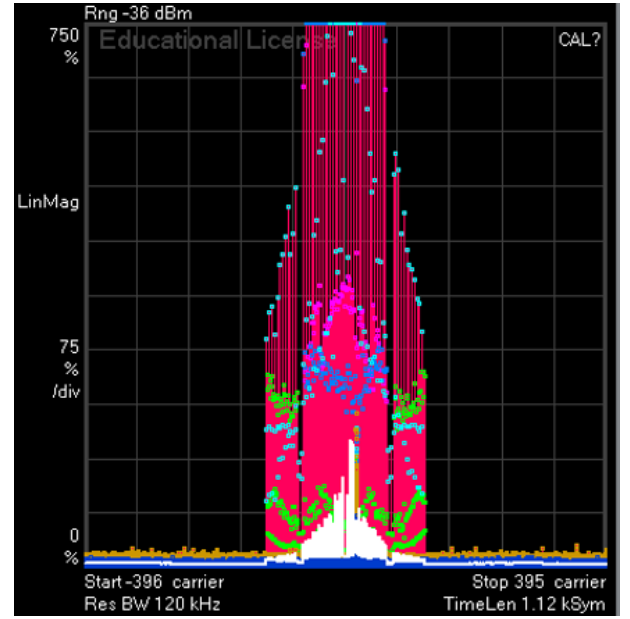


Fig. 7. Sub-carrier EVM plot of 100 MHz 5G NR signal with co-channel CW interference at 2.0 MHz apart from the RF channel center frequency.

Table 2. 5G NR EVM measurements with co-channel CW interference.

| Channel name | EVM (%rms) | Modulation | Number |
|---|---|---|---|
| PSS (Primary Sync. Signal) | 275.58 | BPSK | 48 |
| SSS (Secondary Sync. Signal) | 321.53 | BPSK | 48 |
| PBCH (Physical Broadcast Ch.) | 38.83 | QPSK | 80 |
| PBCH DMRS (Demod. Reference Signal) | 166.6 | BPSK | 80 |
| PDSCH (Physical DL Shared Ch.) | 5.64 | 64QAM | 520 |
| PDSCH DMRS | 4.96 | QPSK | 520 |

was measured with a spectrum analyzer with a max hold setting. It can be seen from Fig. 6 that the interference signal is strongly coupled to the coaxial interface, since the interference signal level is 5 dB higher than the received 5G mmW signal at IF frequency. The measured radiated isolation from the measurement antenna to the coaxial cable at IF frequency was 13 dBm - (-50 dBm) = 63 dB, which is 48 dB lower than the calculated isolation requirement in Table 1.

The coupling mechanism was studied by placing a finger over the cable and coaxial connector. The finger placement over the coaxial connector improved the measured isolation by 7 to 15 dB depending on the frequency. The coaxial connectors need to be adequately shielded to improve radio interoperability.

### B. Measured 5G mmW Performance with Presence of Narrow Band Co-channel Interference

The 5G mmW link performance with presence of the narrow band interference at IF frequency was measured with the error vector magnitude (EVM). The EVM measurement was performed with multiple CW interference signal offsets from the center of the 5G mmW IF frequency. An example EVM measurement is shown in Fig. 7, where the CW frequency is set 2.0 MHz above the center of the used 5G mmW IF frequency.

It can be seen from Fig. 7 that even CW interference may ultimately stop the 5G mmW communication, since more than 200 adjacent sub-carriers were affected by the interference. Results were similar when the frequency of the CW interferer was shifted within the BW of the 100 MHz wide 5G NR signal. The CW signal can completely distort the synchronization and the pilot signals, as shown in Fig. 6 and in Table 2.

Thus, any CW interference source e.g. clock harmonics of digital processors or converters may introduce new interoperability problems with 5G and future 6G wideband communication signals. Interference signals may couple to the baseband communication signal either over-the-air

or conductively via ground or operational voltage planes or control signals. These topics need to be taken into consideration in the 6G RF IC and the printed board designs.

### IV. CONCLUSION

The introduction of the 5G mmW system with LTE and Wi-Fi generates new radio interoperability problems. The fundamental frequency LTE TX creates co-channel interference at the IF frequency of the 5G mmW radio. Future BB signal of the 6G system will suffer the co-channel interference from all previous 5G, LTE, and Wi-Fi systems. It was calculated that 111 dB isolation from the LTE TX to the 5G mmW coaxial cable analog interface is needed to guarantee simultaneous operation. The measured isolation in the 5G mmW PoC system from the LTE antenna to 5G mmW interface was 63 dB indicating that design improvements are needed. Additionally, it was demonstrated that the CW co-channel interference may disrupt the 5G mmW connection by distorting the synchronization signals.

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