Measurement of relative phase for 5G NR digitally modulated signal using cumulative distribution function

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This letter proposes a measurement technique for the relative phase of a 5G new radio (NR) signal. The total radiated power (TRP) is measured to evaluate wireless equipment. However, this cannot be implemented using the near-field measurement system owing to the digitally modulated signal. The relative phase detected by using a vector network analyser (VNA) changes significantly owing to the fast change in the signal in the time domain and the imperfect synchronisation of internal receivers of VNA. This study calculated the cumulative distribution function and medium value for the signal from the multi-probe measurement system. The detected phase agreed well with the exact value obtained from the continuous wave signal. The proposed technique can be used for TRP calculations using the near-to-far field transformation.

INTRODUCTION: With the growing need for high-rate and large-volume data links, fifth-generation (5G) new radio (NR) services have been commercialised. For the evaluation of wireless equipment such as a base station, the total radiated power (TRP) among the test items of the over-the-air (OTA) is required [1]. The spherical near-field measurement system [2] adopting multiple probes [3] is a good candidate because it can rapidly determine the far-field pattern. However, the phase information is difficult to obtain because the 5G NR digitally modulated signal changes significantly in the time domain. Previous research proved phase detection using a vector network analyser (VNA) [4, 5], but it is only available for the sinusoidal continuous waveform (CW).

This letter proposes a measurement technique for the relative phase of a 5G NR digitally modulated signal. The signal detected using the VNA converted into a two-channel receiver was utilised. The cumulative distribution function and medium value were calculated and compared with the exact values from the continuous wave signal.

SYSTEM CONFIGURATION: Figure 1 shows the near-field measurement setup characterising the TRP, or radiation pattern, of the wireless

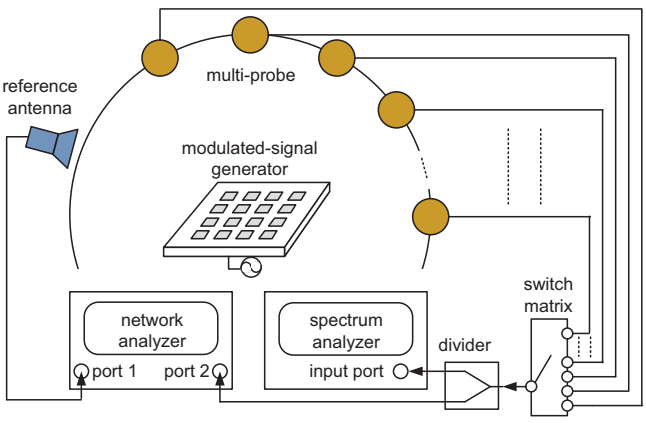
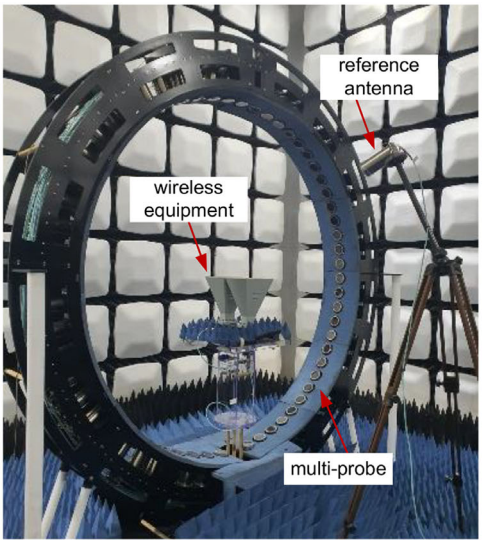


Fig 1 *Multi-probe near-field measurement setup characterizing TRP of wireless equipment radiating digitally modulated signal*



a

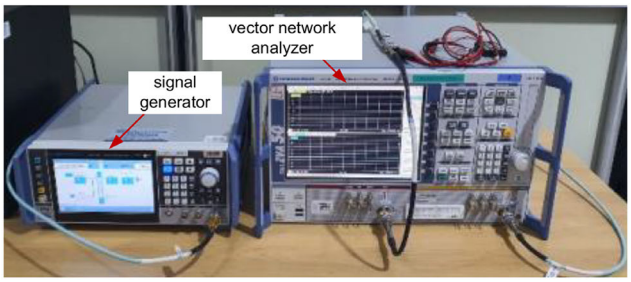


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Fig 2 *Multi-probe near-field measurement system demonstrating the proposed technique. (a) Multi-probe arch and reference antenna; (b) signal generator and network analyser*

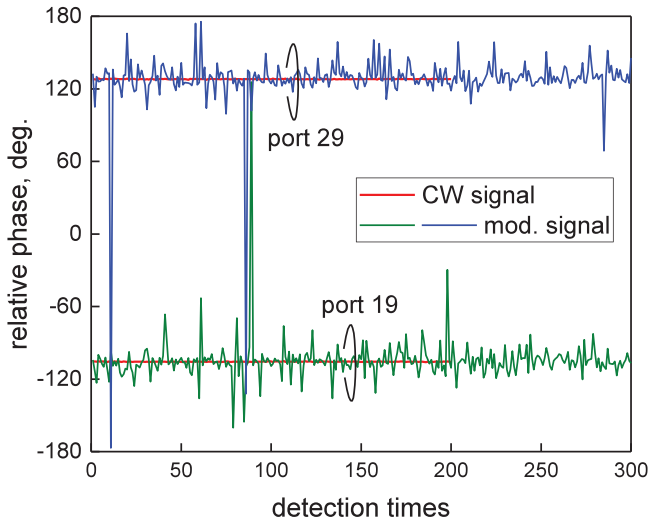

Fig 3 *Recorded relative phase in time of two internal receivers for CW and modulated signals*

equipment. The digitally modulated signal radiated from the wireless terminal or base station is captured by multiple probes and then selected successively by controlling the switch matrix. The chosen signal is split into a spectrum analyser and a vector network analyser by the divider. The radiating signal is also captured by the reference probe and enters another port of the network analyser (NA).

The spectrum analyser can detect the amplitude of the channel power by decoding the 5G NR modulated signal [6]. The network analyser is utilised to acquire the relative phase by removing the power of the internal source and then measuring the signal flowing into the internal receiver at port 1 and port 2 acting on the two-channel receiver [4, 5].

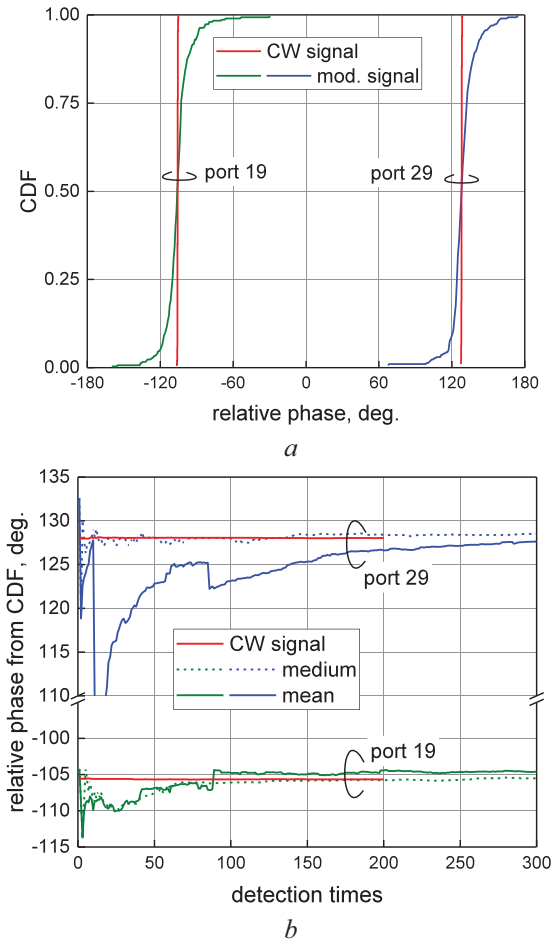

Fig 4 *Extraction of relative phase by probability processing: (a) cumulative distribution function (CDF) after 300 times; (b) medium and mean value after each accumulated detection time*

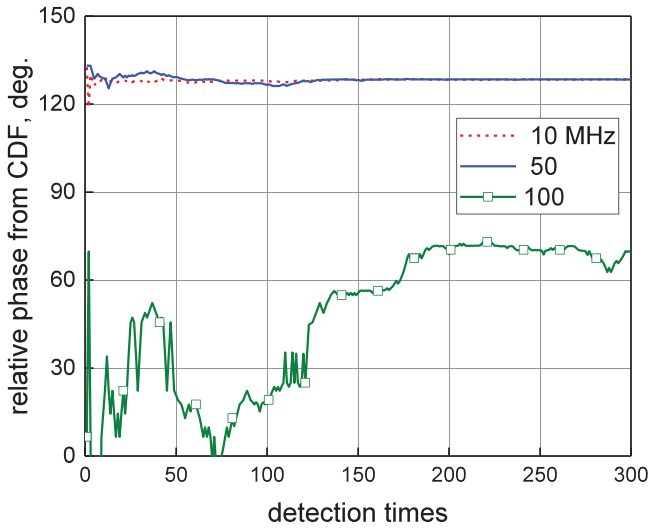

Fig 5 *Extracted relative phase for the 5G NR digitally modulated signal with the RF bandwidth of 10, 50 and 100 MHz*

One port is connected to the reference probe and the other is connected to the receiving probe to record the differential phase.

A realistic multi-probe near-field measurement system demonstrating the proposed technique is shown in Figure 2a. The digitally modulated 5G NR signal is generated from the signal generator shown in Figure 2b, and radiated from the horn array antenna emulating the wireless equipment. The physical channel of the 5G NR digitally modulated signal is based on the NR FR1 test models [7], and the central frequency is set to be 3.5 GHz. The signal is detected by the 57 multi-probes and enters

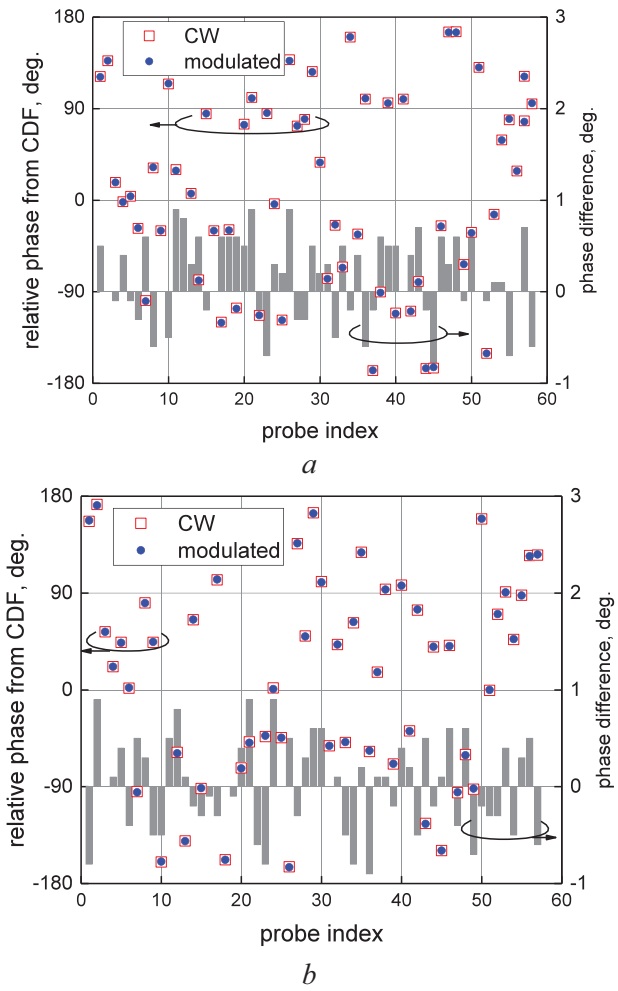

Fig 6 *Extracted relative phase of 5G NR digitally modulated signal received by each probe of near-field measurement system: (a) azimuthal angle of 0° (b) azimuthal angle of 90°*

the port of the network analyser, as shown in Figure 2b. The reference antenna is shown in Figure 2a., which was connected to another port of the network analyser. Here, the spectrum analyser was not configured because the detection of the channel power is originally provided by the commercial instrument, so the demonstration is unnecessary.

The wave quantities of B1 and B2 of the VNA receiver [8] were recorded after triggering them by using the external controller. However, the internal synchronisation is not perfect, so two internal receivers of NA measure the signal at different instantaneous times. Since the 5G NR modulated-signal has a waveform variation of a few microseconds, the relative phase varies with wide values, as shown in Figure 3, during the 300 detection. If the two internal receivers are perfectly synchronised with the accuracy of nanoseconds, the variation of the relative phase will be very small, similar to that of the CW case.

PHASE MEASUREMENT RESULT: Compared with the CW signal, the digitally modulated signal has a variant phase; therefore, this letter proposes probability processing with a median value with a cumulative distribution function (CDF). Figure 4a shows the CDF plot of the time-domain signal 300 times. The 50% of CDF is −105.9° and 128.0° for probe indices of 19 and 29, respectively. The results for the CW signal and modulated signal were agreed very well. Figure 4b shows the medium and mean values after each accumulated detection time from starting number 1 to ending number 300. As the data is accumulated, the medium value rapidly approaches the exact value of 128.0° from the CW signal. However, the mean value was not. The reason is that the fluctuation of the phase is wider than −180° to 180°. The usefulness of the medium value (50% of CDF) was also found for a probe index of 19, as shown in Figure 4b.

The proposed technique was also verified based on the RF bandwidth, as shown in Figure 5. The 5G NR digitally modulated signal with bandwidths of 10 and 50 MHz was recorded, and the medium value quickly converged to the exact value (CW case). Meanwhile, the signal with 100 MHz bandwidth fails to converge even after 300 times, and shows a significant difference. Thus, the usefulness of the proposed technique is dependent on the RF bandwidth.

The proposed technique was also verified based on the RF bandwidth. For the bandwidth of 50 MHz, the medium value quickly converged to the exact value (CW case). Meanwhile, the signal with 100 MHz bandwidth fails to converge even after 300 times. Thus, the usefulness of the proposed technique is dependent on the RF bandwidth.

Figure 6 shows the relative phase of the 5G NR digitally modulated signal received by each probe of the near-field measurement system. For further verification, the azimuthal angles of 0° and 90° were tested by rotating the turntable holding the wireless equipment. The relative phase using the proposed technique agreed very well with the exact value within 1°.

CONCLUSION: This letter proposes a measurement technique for the relative phase of a 5G NR digitally modulated signal radiated from wireless equipment. A demonstration was performed for the multi-probe near-field measurement system. The vector network analyser acting on the two-channel receiver was utilised, which originally had imperfect synchronisation. The cumulative distribution function and medium value (50% CDF) were calculated. The relative phase of the signal received by the 57 probes agreed with that of the CW signal. The proposed technique also indicated good validation up to a 50 MHz signal. The relative phase retrieved by the proposed technique can be used for the near-to-far field transformation with the magnitude of the channel power from the spectrum analyser, and the resultant TRP can be calculated.

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CONFLICT OF INTEREST STATEMENT: The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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