



Analysis Of Specific Absorption Rate (SAR) Test Parameters For Optimization Of 5G Device Evaluation

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ABSTRACT

Specific Absorption Rate (SAR) is used to evaluate the safety of human exposure to electromagnetic fields, particularly from mobile devices. In Indonesia, based on the Decree of the Minister of Communication and Information No. 177 of 2024, all phones and tablets sold must undergo SAR testing in domestic laboratories. However, 5G device SAR testing is time-consuming due to the large number of configurations required, delaying product launches and new technology adoption. This study conducted measurement trials using a Base Station Simulator (BSS), dipole antenna, and SAR Test System to propose a more efficient SAR testing method for 5G. The configuration involved fixed parameters (transmit power and resource block) and varied parameters (frequency, bandwidth, and modulation) to examine their effect on SAR values. The proposed configuration of high frequency, QPSK modulation, and the largest bandwidth proved optimal. By implementing this configuration, SAR testing time was reduced by 98.74%, and the testing process became 69.33 times more efficient.

1. Introduction

Specific Absorption Rate (SAR) is used to assess the safety of electromagnetic field (EMF) exposure to the human body, particularly from mobile devices. Regulatory SAR standards are established to protect public health by limiting the amount of radiofrequency energy absorbed by the body. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Federal Communications Commission (FCC) have set guidelines for the maximum permissible SAR levels, namely 1.6 W/kg averaged over 1 g of tissues (FCC, 2021) and 2.0 W/kg averaged over 10 g of tissues (ICNIRP, 2020). Furthermore, SAR measurement procedures are conducted in accordance with IEC/IEEE 62209-1528 standards and FCC regulations.

Not all countries require SAR testing for products circulating in their country. In Indonesia, with the enactment of the Decree of the Minister of Communication and Information Technology Number 177 of 2024 concerning Specific Absorption Rate Limits on Telecommunications Devices for Cellular Phones and Tablet Computers, as of April 1, 2024 all cellular phones and tablet computers circulating and traded in Indonesia must be tested for SAR in a domestic laboratory (Indonesia, 2024a). The long duration of SAR testing is about 2 (two) weeks to 2 (two) months because there are many configurations in cellular phones that must be tested. The number of parameters such as frequency, bandwidth, modulation, Resource Block (RB) (Indonesia, 2024b) is the reason that not all countries for product certification must require SAR testing, simply by evaluating the test result report document from the laboratory of the country of origin. The long duration of testing results in product launches being delayed so that the adoption of new technologies takes longer.

Therefore, a method is needed to reduce the testing time. IEC/IEEE 62209-1528 and FCC regulate the reduction of SAR measurements, but only for 4G / Long Term Evolution (LTE), namely "Conducted power shall be measured for the largest channel bandwidth supported by the LTE modes in each frequency band,

using QPSK modulation with 1 RB allocation”(IEC/IEEE 62209-1528, 2020), “QPSK modulation with 1 RB allocation generally produces the highest psSAR”(IEC/IEEE 62209-1528, 2020) and in the FCC “Start with the largest channel bandwidth then measure SAR for QPSK with 1 RB allocation, using the RB offset and required test channel combination with the highest maximum output power”(Federal Communications Commission, 2015), while for 5G there are no standard rules yet. The FCC document only says “For 5G-FR1 SAR evaluations are being generally based on adapting the existing LTE SAR procedures (KDB Pub 941225 D05A)”(Tarditi, 2021).

In this research, a series of measurement trials will be conducted to obtain a SAR testing method for 5G devices as a proposed solution in reducing SAR testing time.

2. Literature review

In everyday life, humans are surrounded by various types of electromagnetic radiation (e.g. light, microwaves, X-rays, or cell phone transmissions). Mohamed Abdul-Al et al. in their research summarized the hazards of electromagnetic radiation exposure to the human body from various journals published from 1978 to 2021(Abdul-Al et al., 2022). Therefore, all radio products require Radio Frequency (RF) exposure assessment to ensure safe use. This assessment can be done by RF exposure evaluation, Electromagnetic Field (EMF) measurement, or Specific Absorption Rate (SAR) testing(Jarvis & McDaniel, 2024).

SAR is an important measure used to assess the safety of exposure to electromagnetic fields, particularly from mobile devices on human subjects as users. SAR regulatory standards are designed to protect public health by limiting the amount of radio frequency energy absorbed by the body. Like the research conducted by the Peruvian government assisted by researchers from laboratories and universities, SAR measurements were made on the 5 (five) most widely used cellular phones in the country. Measurements were made on the 900 MHz frequency band Global System for Mobile Communication (GSM) technology using the MVG ComoSAR measuring instrument with the results of the 5 (five) cell phones SAR value is still below the limit of the SAR standard used in the USA and Europe(Vargas-Cuentas et al., 2020).

Another study to determine the impact of radiation emitted by cellular phones on the human body was conducted by Sagar Mahmud, but with different methods, namely by using mathematical equations to evaluate SAR values and temperature changes and using Multisim simulation software to create a circuit diagram that functions to detect and measure the strength of electromagnetic radiation on cellular phones. In addition, the simulation also explains the relationship between measurement distance and output power to the SAR value(Mahmud, 2022).

However, recent studies have shown that current standards do not fully address new technologies and the complexity of human tissue interactions with electromagnetic radiation. Many countries, including Canada, have updated their regulations to reflect technological advances, as seen in the revision of Radio Specification Standard (RSS) 102, which now includes wireless applications and new measurement techniques(Lacombe et al., 2004).

The higher the cellular technology, the more parameters there are to test. The more that must be tested, the longer the test duration. Therefore, a method is needed to reduce SAR testing parameters. Ovidiu Bejenaru et al. conducted research on SAR testing positions (Right-Cheek, Right-Tilt, Left-Cheek, Left-Tilt) and working frequency on SAR values. Measurements were made using Satimo-ComoSAR measuring instruments on GSM technology frequency bands 900 MHz and 1800 MHz. The study also found that the results of the cheek position had a greater value than tilt and the 900 MHz frequency had a greater value than 1800 MHz(Ovidiu Bejenaru, Catalin Lazarescu, Alexandru Salceanu, 2019).

Research to find solutions to speed up testing was also conducted by Mark Douglas et al. Using the vector array probe method, the cSAR3D fast SAR measuring instrument evaluated up to 515 test cases with various

configurations of frequency, distance, modulation, and SAR value. The deviation result obtained from all measured differences was 0.2 dB ($\pm 5\%$) and all measured results were within ± 1.0 dB ($\pm 26\%$). The expanded uncertainty ($k=2$) has been evaluated at $\pm 29\%$ (Douglas et al., 2016).

2.1. 5G New Radio Technology

5G technology is the fifth generation mobile communication technology standard formulated by the International Telecommunication Union (ITU), where 5G technology provides greater bandwidth capacity than 4G, thus enabling higher density of broadband mobile users and supporting three main features namely enhanced Mobile Broadband (eMBB), Ultra-reliable and Low Latency Communication (uRLLC), and Massive Machine-Type Communication (mMTC) (Agelliza, 2023). Table 2.1 shows the differences in technical performance requirements in LTE-Advanced and 5G technologies.

Table 1. Differences in Technical Performance Requirements of LTE-Advanced and 5G Technologies

Parameter	LTE-Advanced	5G
<i>Peak data rate</i>	500 Mbps (UL) 1000 Mbps (DL)	10 Gbps (UL) 20 Gbps (DL)
<i>Typical spectral efficiency</i>	0.7-2.25 bits/s.Hz (UL) 1.1-3 bits/s.Hz (DL)	1.6-6.75 bits/s.Hz (UL) 3.3-9 bits/s.Hz (DL)
<i>Bandwidth</i>	1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz	5 MHz, 10 MHz, 15 Mhz, 20 Mhz, 25 MHz, 30 MHz, 40 MHz, 50 MHz, 60 MHz, 80 MHz, 90 MHz, 100 MHz
<i>Modulation</i>	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM, 256 QAM, F-QAM, FSK-QAM
<i>Energy efficiency</i>	n/a	Maximize
<i>Maximum UE speed</i>	350 km/h	500 km/h
<i>User plan latency</i>	5 ms	0.5 ms
<i>User plan reliability</i>	n/a	99.999%

2.2. 5G New Radio Architecture

There are two types of options used in the network architecture of 5G technology, namely 5G Non-Stand Alone (NSA) and 5G Stand Alone (SA) (Agelliza, 2023).

The 5G NSA architecture allows 5G networks to be supported using 4G LTE infrastructure. The access network is supported using Evolved Packet Core (EPC). EPC is used for coverage by adding a 5G carrier. The 5G NSA architecture allows for lower implementation costs. The 5G SA architecture type is a new core network from the architecture defined by 3GPP that separates various network functions. The 5G SA architecture is suitable for implementing large data rates and does not use the existing 4G LTE network.

2.3. 5G Frequency Band Allocation

5G technology can operate in two types of frequency ranges, namely frequency range 1 (FR1), which runs at frequencies of 410 to 7125 MHz (Committee, 2020), and frequency range 2 (FR2), which runs at frequencies of 24.25 to 52.6 GHz (99, 2021). With this range of values, the 3GPP specification can support most frequency bands, as can be seen in Table 2 and Table 3.

Table 2. Frequency allocation in Frequency Range 1 (FR 1)

Band	Uplink band (MHz)	Downlink band (MHz)	Duplex Mode
n1	1920-1980	2110-2170	FDD
n2	1850-1910	1930-1990	FDD
n3	1710-1785	1805-1880	FDD
n5	824-849	869-894	FDD
n7	2500-2570	2620-2690	FDD
n8	880-915	925-960	FDD
n12	699-716	729-746	FDD
n14	7888-798	758-768	FDD
n18	815-830	860-875	FDD
n20	832-862	791-821	FDD
n25	1850-1915	1930-1995	FDD
n28	703-748	758-803	FDD
n29	-	717-728	SDL
n30	2305-2315	2350-2360	FDD
n34	2010-2025	2010-2025	TDD
n38	2570-2620	2570-2620	TDD
n39	1880-1920	1880-1920	TDD
n40	2300-2400	2300-2400	TDD
n41	2496-2690	2496-2690	TDD
n48	3550-3700	3550-3700	TDD
n50	1432-1517	1432-1517	TDD
n51	1427-1432	1427-1432	TDD
n65	1920-2010	2110-2200	FDD
n66	1710-1780	2110-2200	FDD
n70	1695-1710	1995-2020	FDD
n71	663-698	617-652	FDD
n74	1427-1470	1475-1518	FDD
n75	-	1432-1517	SDL
n76	-	1427-1432	SDL
n77	3300-4200	3300-4200	TDD
n78	3300-3800	3300-3800	TDD
n79	4400-5000	4400-5000	TDD
n80	1710-1785	-	SUL
n81	880-915	-	SUL
n82	832-862	-	SUL
n83	703-748	-	SUL
n84	1920-1980	-	SUL
n86	1710-1780	-	SUL
n89	824-849	-	SUL
n90	2496-2690	2496-2690	TDD
n91	832-862	1427-1432	FDD
n92	832-862	1432-1517	FDD
n93	880-915	1427-1432	FDD
n94	880-915	1432-1517	FDD
n95	2010-2025	-	SUL

Source: (3GPP, 2020)

Table 3. Frequency allocation in Frequency Range 2 (FR 2)

Band	Frequency band (GHz)	Duplex Mode
n257	26,5-29,5	TDD
n258	24,25-27,5	TDD
n260	37-40	TDD
n261	27,5-28,35	TDD

Source: (Metrology for 5G, 2021)

In Indonesia 5G FR1 can operate in bands n1, n3, n5, n8, n28 and n40(Indonesia, 2024b).

2.4. Specific Absorption Rate

Specific Absorption Rate (SAR) is a measure of how much energy is absorbed per unit mass by the human body in each volume and time period when exposed to radio frequency (RF) electromagnetic fields. It is defined as the power absorbed per mass of tissue and has units of watts per kilogram [W/kg](IEC/IEEE 62209-1528, 2020).

SAR is averaged either over the whole body or over a small sample (e.g., 1 gram or 10 grams of tissue). The SAR value can be calculated from the electric field (E) in the body tissue (when exposed to RF energy) using equation 1.

$$SAR = \frac{\sigma|E|^2}{\rho} \dots\dots\dots 1)$$

With:

SAR is Specific Absorption Rate, which is the amount of electromagnetic radiation energy absorbed by biological tissue per unit mass in unit time (expressed in watts per kilogram, W/kg)

σ is the electrical conductivity of biological tissue exposed to radiation (expressed in Siemens per meter, S/m)

E is the magnitude of the electromagnetic field intensity (expressed in volts per meter, V/m)

ρ is the density of biological tissue (expressed in kilograms per cubic meter, kg/m³)

2.5. SAR Regulation

Common regulations used by many countries including Indonesia related to SAR testing are:

- a. IEC/IEEE 62209-1 : SAR testing method for Hand Held and Body-Mounted Wireless used near the ear in the range of 300 MHz - 6 GHz(62209-1, 2005);
- b. IEC/IEEE 62209-2 : SAR test method for Hand Held and Body-Mounted Wireless used near the body in the range of 300 MHz - 6 GHz(62209-2, 2010);
- c. IEC/IEEE 62209-1528 : This is the latest method from IEC used to conduct SAR testing on Hand Held and Body-Mounted Wireless with frequencies of 4 MHz - 10 Ghz(IEC/IEEE 62209-1528, 2020);
- d. KDB 941225 D05A : This is a method published by the FCC as a guide for SAR testing in 4G and 5G technologies(Federal Communications Commission, 2015).

2.6. SAR Exposure Limits

SAR exposure limits for frequency bands from 100 kHz to 300 GHz, for an average interval of ≥ 6 minutes according to ICNIRP guidelines (2020)(ICNIRP, 2020) and standard SAR test methods that are the reference, as can be seen in Table 4.

Table 4. SAR Exposure Limits

Exposure Scenario	Frequency Range	Local Head SAR (W/kg)	Local Torso SAR (W/kg)	Local Limb SAR (W/kg)
Occupational	100 kHz to 6 GHz	10	10	20
	> 6 to 300 GHz	NA	NA	NA
General Public	100 kHz to 6 GHz	2	2	4
	> 6 to 300 GHz	NA	NA	NA

Source: (ICNIRP, 2020)

Occupational is required for devices worn on the body for work purposes (e.g. in the manufacturing industry), while General Public is required for devices used on or near the body for the general public.

2.7. SAR Test System

SAR test system is a system used to measure the level of absorption of radio frequency (RF) radiation energy by the human body. The SAR test system used in this research is SPEAG DASY8(AG, 2021). The DASY8 system combines a measurement system with a high-precision 6-axis robot probe and positioner. The combination allows for fully automated measurement scanning and evaluation with the addition of measured device information and measurement position. The SAR test system SPEAG DASY8 consists of several components(AG, 2021), namely:

a. SAR Probe

The SAR probe serves to measure the electromagnetic field (E-Field) distribution in the phantom. The SAR distribution, and psSAR (peak spatial average SAR) are obtained from the E-field measurements.

b. Phantom

Phantom SAR is a physical model with human-like anatomy. Specific Anthropomorphic Mannequin (SAM) Head is usually used for handheld devices, and Flat Phantom for body-worn devices.

c. Tissue Simulating Liquid

Tissue Simulating Liquid (TSL) is a liquid that represents the dielectric properties of body tissues.

d. Base Station Simulator

Base station simulator is a device used to simulate the function of a base transceiver station (BTS), which is to send and receive frequency signals whether it is 2G, 3G, 4G, 5G, WLAN, and Bluetooth technology.

e. Antena Dipole

A dipole antenna is a radio antenna made of two parallel and collinearly oriented wires or metal conductors. This antenna has a small gap in the center and functions to drain the electromagnetic field. Dipole antennas have a directional radiation pattern and are used to validate SAR probes before SAR measurements are taken.

f. Data Acquisition Electronics

Data Acquisition Electronics (DAE) reads the probe voltage and sends it to the DASY8 computer.

g. Electrical to Optical Converter

Electrical to Optical Converter (EOC) serves to convert electrical signals from DAE into light signals that are delivered through optical media before being sent to the Measurement Server.

h. 6-Axis Robot Arm

A 6-axis robotic arm is used to position the probe.

i. Measurement Server

Measurement Server serves to handle important round-the-clock tasks such as measuring data acquisition and supervision of safety features.

j. SAR Computer

The SAR computer runs the DASY8 software which is used by the operator to determine or carry out measurements.

3. Method

The methodology used in this research is the experimental method, which is a research method used to find the effect of certain treatments on others under controlled conditions (Dr Sudaryono, 2017).

The following is an explanation of the general work process, the base station simulator generates a 5G frequency signal with configured parameters, then through the dipole antenna the 5G frequency signal is

The interpretation of the Z' score(Nasional, 2016) is as follows:

$|Z'| \leq 2,0$ considered acceptable

$2,0 < |Z'| < 3,0$ considered to be able to be given a warning signal

$|Z'| > 3,0$ considered unacceptable

For Z' score values that fall into the warning signal category, the data can still be used, but be aware that there is a potential contribution of uncertainty or error that needs to be prevented before it further affects the validity of the results.

3.2. Research Process

Figure 2 shows the flow chart for this research process:

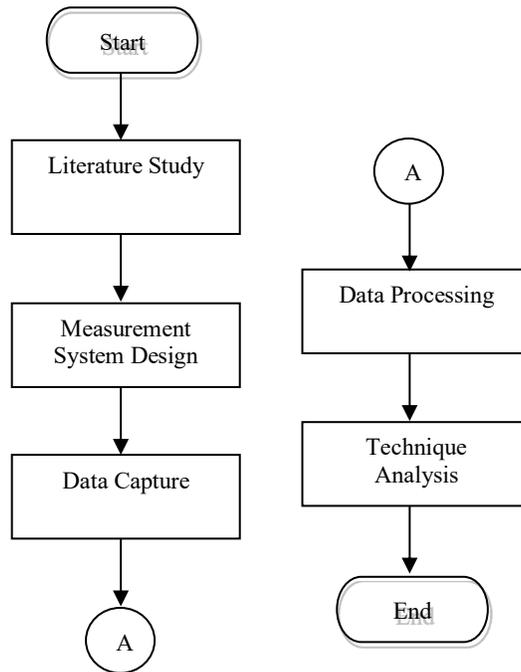


Figure 2. Research Process

4. Results and Discussion

4.1. Measurement Data

The 5G SAR test results are shown in Table 5 for the 900 MHz frequency and Table 6 for the 2100 MHz frequency.

Table 5. 5G SAR Testing Results for 900 MHz Frequency

No	Band Freq	Freq (MHz)	Power (dBm)	BW (MHz)	RB	Mod	SAR Value (W/Kg)										Avg
							1	2	3	4	5	6	7	8	9	10	
1	Band 8 (900 MHz)	885	23	10	1	QPSK	0.908	0.904	0.903	0.903	0.917	0.911	0.908	0.911	0.913	0.917	0.910
		897.5	23	10	1	QPSK	0.929	0.929	0.924	0.925	0.929	0.931	0.933	0.930	0.935	0.932	0.930
		910	23	10	1	QPSK	0.935	0.935	0.937	0.937	0.936	0.937	0.936	0.937	0.938	0.939	0.937
2	Band 8 (900 MHz)	885	23	10	1	16QAM	0.909	0.909	0.906	0.910	0.909	0.912	0.909	0.911	0.912	0.906	0.909
		897.5	23	10	1	16QAM	0.918	0.918	0.916	0.917	0.916	0.917	0.917	0.913	0.915	0.915	0.916

No	Band Freq	Freq (MHz)	Power (dBm)	BW (MHz)	RB	Mod	SAR Value (W/Kg)										Avg
							1	2	3	4	5	6	7	8	9	10	
3	Band 8 (900 MHz)	910	23	10	1	16QAM	0.920	0.924	0.924	0.918	0.920	0.918	0.920	0.920	0.918	0.917	0.920
		885	23	10	1	64QAM	0.887	0.892	0.890	0.888	0.892	0.890	0.893	0.886	0.890	0.888	0.890
		897.5	23	10	1	64QAM	0.910	0.912	0.913	0.908	0.906	0.909	0.914	0.913	0.912	0.911	0.911
		910	23	10	1	64QAM	0.917	0.919	0.919	0.919	0.919	0.919	0.916	0.916	0.919	0.917	0.918
4	Band 8 (900 MHz)	890	23	20	1	QPSK	0.935	0.936	0.938	0.937	0.937	0.939	0.935	0.942	0.945	0.943	0.939
		897.5	23	20	1	QPSK	0.952	0.949	0.946	0.936	0.936	0.937	0.936	0.933	0.932	0.940	0.940
		905	23	20	1	QPSK	0.946	0.948	0.946	0.952	0.952	0.948	0.949	0.948	0.944	0.948	0.948
5	Band 8 (900 MHz)	890	23	20	1	16QAM	0.928	0.928	0.928	0.928	0.917	0.918	0.917	0.917	0.923	0.917	0.922
		897.5	23	20	1	16QAM	0.933	0.931	0.939	0.941	0.938	0.939	0.940	0.934	0.933	0.938	0.937
		905	23	20	1	16QAM	0.936	0.937	0.941	0.934	0.943	0.938	0.940	0.943	0.941	0.946	0.940
6	Band 8 (900 MHz)	890	23	20	1	64QAM	0.920	0.925	0.921	0.921	0.919	0.918	0.919	0.918	0.917	0.924	0.920
		897.5	23	20	1	64QAM	0.930	0.930	0.929	0.937	0.934	0.931	0.936	0.935	0.939	0.935	0.934
		905	23	20	1	64QAM	0.936	0.938	0.938	0.937	0.938	0.939	0.939	0.941	0.941	0.940	0.939

Table 6. 5G SAR Testing Results for 2100 MHz Frequency

No	Band Freq	Freq (MHz)	Power (dBm)	BW (MHz)	RB	Mod	SAR Value (W/Kg)										Avg
							1	2	3	4	5	6	7	8	9	10	
7	Band 1 (2100 MHz)	1930	23	20	1	QPSK	1.75	1.72	1.71	1.72	1.74	1.73	1.71	1.74	1.75	1.75	1.732
		1950	23	20	1	QPSK	1.79	1.78	1.79	1.78	1.77	1.76	1.74	1.76	1.76	1.75	1.768
		1970	23	20	1	QPSK	1.83	1.83	1.84	1.85	1.86	1.85	1.85	1.86	1.86	1.85	1.848
8	Band 1 (2100 MHz)	1930	23	20	1	16QAM	1.70	1.73	1.74	1.75	1.70	1.70	1.71	1.71	1.71	1.71	1.716
		1950	23	20	1	16QAM	1.75	1.75	1.74	1.73	1.73	1.70	1.71	1.71	1.70	1.70	1.722
		1970	23	20	1	16QAM	1.79	1.79	1.79	1.79	1.79	1.80	1.80	1.79	1.79	1.80	1.793
9	Band 1 (2100 MHz)	1930	23	20	1	64QAM	1.68	1.68	1.68	1.68	1.69	1.70	1.69	1.69	1.69	1.70	1.688
		1950	23	20	1	64QAM	1.73	1.71	1.71	1.72	1.72	1.72	1.71	1.72	1.72	1.70	1.716
		1970	23	20	1	64QAM	1.77	1.78	1.80	1.80	1.79	1.79	1.79	1.79	1.80	1.80	1.791
10	Band 1 (2100 MHz)	1945	23	50	1	QPSK	1.81	1.80	1.81	1.80	1.80	1.80	1.79	1.80	1.79	1.79	1.799
		1950	23	50	1	QPSK	1.79	1.80	1.79	1.79	1.84	1.81	1.81	1.82	1.83	1.83	1.811
		1955	23	50	1	QPSK	1.85	1.85	1.87	1.89	1.89	1.89	1.93	1.93	1.92	1.92	1.894
11	Band 1 (2100 MHz)	1945	23	50	1	16QAM	1.77	1.76	1.75	1.76	1.75	1.74	1.74	1.75	1.75	1.74	1.751
		1950	23	50	1	16QAM	1.80	1.78	1.79	1.79	1.76	1.78	1.78	1.77	1.77	1.76	1.778
		1955	23	50	1	16QAM	1.87	1.88	1.88	1.88	1.87	1.88	1.88	1.90	1.90	1.90	1.884
12	Band 1 (2100 MHz)	1945	23	50	1	64QAM	1.75	1.75	1.73	1.75	1.73	1.72	1.71	1.71	1.73	1.71	1.729
		1950	23	50	1	64QAM	1.75	1.75	1.74	1.74	1.79	1.78	1.79	1.79	1.79	1.80	1.772
		1955	23	50	1	64QAM	1.81	1.81	1.81	1.82	1.83	1.80	1.82	1.84	1.85	1.86	1.825

4.2. Z' Score Test

All test data that has been taken is then carried out the Z 'score test with the following results:

- a. Band 8 900 MHz frequency, QPSK modulation, 10 MHz bandwidth with 80% acceptable, 20% warning results. As shown in Table 7;

Table 7. Z' score results 900 MHz frequency, QPSK modulation, 10 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 10 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.908	-0.25	Acceptable	0.929	-0.23	Acceptable	0.935	-2.56	Warning
P2	0.904	-0.92	Acceptable	0.929	-0.23	Acceptable	0.935	-2.56	Warning
P3	0.903	-1.09	Acceptable	0.924	-2.56	Warning	0.937	0.00	Acceptable
P4	0.903	-1.09	Acceptable	0.925	-2.09	Warning	0.937	0.00	Acceptable
P5	0.917	1.25	Acceptable	0.929	-0.23	Acceptable	0.936	-1.28	Acceptable
P6	0.911	0.25	Acceptable	0.931	0.70	Acceptable	0.937	0.00	Acceptable
P7	0.908	-0.25	Acceptable	0.933	1.63	Acceptable	0.936	-1.28	Acceptable
P8	0.911	0.25	Acceptable	0.93	0.23	Acceptable	0.937	0.00	Acceptable
P9	0.913	0.59	Acceptable	0.935	2.56	Warning	0.938	1.28	Acceptable
P10	0.917	1.25	Acceptable	0.932	1.16	Acceptable	0.939	2.56	Warning

b. Band 8 frequency 900 MHz, 16QAM modulation, bandwidth 10 MHz with results 76.67% acceptable, 23.33% warning. As shown in Table 8;

Table 8. Z' score results 900 MHz frequency, 16QAM modulation, 10 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 10 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.909	0.00	Acceptable	0.918	1.10	Acceptable	0.92	0.00	Acceptable
P2	0.909	0.00	Acceptable	0.918	1.10	Acceptable	0.924	2.56	Warning
P3	0.906	-2.15	Warning	0.916	-0.37	Acceptable	0.924	2.56	Warning
P4	0.91	0.72	Acceptable	0.917	0.37	Acceptable	0.918	-1.28	Acceptable
P5	0.909	0.00	Acceptable	0.916	-0.37	Acceptable	0.92	0.00	Acceptable
P6	0.912	2.15	Warning	0.917	0.37	Acceptable	0.918	-1.28	Acceptable
P7	0.909	0.00	Acceptable	0.917	0.37	Acceptable	0.92	0.00	Acceptable
P8	0.911	1.43	Acceptable	0.913	-2.56	Warning	0.92	0.00	Acceptable
P9	0.912	2.15	Warning	0.915	-1.10	Acceptable	0.918	-1.28	Acceptable
P10	0.906	-2.15	Warning	0.915	-1.10	Acceptable	0.917	-1.92	Acceptable

c. Band 8 frequency 900 MHz, 64QAM modulation, bandwidth 10 MHz with results 96.67% acceptable, 3.33% warning. As shown in Table 9;

Table 9. Z' score results 900 MHz frequency, 64QAM modulation, 10 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 10 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.887	-1.08	Acceptable	0.91	-0.55	Acceptable	0.917	-1.28	Acceptable
P2	0.892	0.72	Acceptable	0.912	0.18	Acceptable	0.919	0.00	Acceptable
P3	0.89	0.00	Acceptable	0.913	0.55	Acceptable	0.919	0.00	Acceptable
P4	0.888	-0.72	Acceptable	0.908	-1.28	Acceptable	0.919	0.00	Acceptable
P5	0.892	0.72	Acceptable	0.906	-2.01	Warning	0.919	0.00	Acceptable
P6	0.89	0.00	Acceptable	0.909	-0.91	Acceptable	0.919	0.00	Acceptable
P7	0.893	1.08	Acceptable	0.914	0.91	Acceptable	0.916	-1.92	Acceptable

Measure	SAR (W/Kg), Freq 900 MHz BW 10 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P8	0.886	-1.43	Acceptable	0.913	0.55	Acceptable	0.916	-1.92	Acceptable
P9	0.89	0.00	Acceptable	0.912	0.18	Acceptable	0.919	0.00	Acceptable
P10	0.888	-0.72	Acceptable	0.911	-0.18	Acceptable	0.917	-1.28	Acceptable

d. Band 8 frequency 900 MHz, QPSK modulation, 20 MHz bandwidth with results of 86.67% acceptable, 13.33% warning. As shown in Table 10;

Table 10. Z' score results 900 MHz frequency, QPSK modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.935	-0.63	Acceptable	0.952	2.33	Warning	0.946	-1.14	Acceptable
P2	0.936	-0.38	Acceptable	0.949	1.88	Acceptable	0.948	0.00	Acceptable
P3	0.938	0.13	Acceptable	0.946	1.43	Acceptable	0.946	-1.14	Acceptable
P4	0.937	-0.13	Acceptable	0.936	-0.08	Acceptable	0.952	2.27	Warning
P5	0.937	-0.13	Acceptable	0.936	-0.08	Acceptable	0.952	2.27	Warning
P6	0.939	0.38	Acceptable	0.937	0.08	Acceptable	0.948	0.00	Acceptable
P7	0.935	-0.63	Acceptable	0.936	-0.08	Acceptable	0.949	0.57	Acceptable
P8	0.942	1.13	Acceptable	0.933	-0.53	Acceptable	0.948	0.00	Acceptable
P9	0.945	1.88	Acceptable	0.932	-0.68	Acceptable	0.944	-2.27	Warning
P10	0.943	1.38	Acceptable	0.94	0.53	Acceptable	0.948	0.00	Acceptable

e. Band 8 frequency 900 MHz, 16QAM modulation, bandwidth 20 MHz with 100% acceptable results. As shown in Table 11;

Table 11. Z' score results 900 MHz frequency, 16QAM modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.928	0.86	Acceptable	0.933	-1.11	Acceptable	0.936	-1.10	Acceptable
P2	0.928	0.86	Acceptable	0.931	-1.56	Acceptable	0.937	-0.85	Acceptable
P3	0.928	0.86	Acceptable	0.939	0.22	Acceptable	0.941	0.12	Acceptable
P4	0.928	0.86	Acceptable	0.941	0.67	Acceptable	0.934	-1.58	Acceptable
P5	0.917	-0.40	Acceptable	0.938	0.00	Acceptable	0.943	0.61	Acceptable
P6	0.918	-0.29	Acceptable	0.939	0.22	Acceptable	0.938	-0.61	Acceptable
P7	0.917	-0.40	Acceptable	0.940	0.45	Acceptable	0.940	-0.12	Acceptable
P8	0.917	-0.40	Acceptable	0.934	-0.89	Acceptable	0.943	0.61	Acceptable
P9	0.923	0.29	Acceptable	0.933	-1.11	Acceptable	0.941	0.12	Acceptable
P10	0.917	-0.40	Acceptable	0.938	0.00	Acceptable	0.946	1.34	Acceptable

f. Band 8 frequency 900 MHz, 64QAM modulation, bandwidth 20 MHz with results of 93.33% acceptable, 6.67% warning. As shown in Table 12;

Table 12. Z' score results 900 MHz frequency, 64QAM modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 900 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	0.92	0.23	Acceptable	0.93	-1.05	Acceptable	0.936	-1.83	Acceptable
P2	0.925	2.51	Warning	0.93	-1.05	Acceptable	0.938	-0.37	Acceptable
P3	0.921	0.68	Acceptable	0.929	-1.28	Acceptable	0.938	-0.37	Acceptable
P4	0.921	0.68	Acceptable	0.937	0.58	Acceptable	0.937	-1.10	Acceptable
P5	0.919	-0.23	Acceptable	0.934	-0.12	Acceptable	0.938	-0.37	Acceptable
P6	0.918	-0.68	Acceptable	0.931	-0.81	Acceptable	0.939	0.37	Acceptable
P7	0.919	-0.23	Acceptable	0.936	0.35	Acceptable	0.939	0.37	Acceptable
P8	0.918	-0.68	Acceptable	0.935	0.12	Acceptable	0.941	1.83	Acceptable
P9	0.917	-1.14	Acceptable	0.939	1.05	Acceptable	0.941	1.83	Acceptable
P10	0.924	2.05	Warning	0.935	0.12	Acceptable	0.94	1.10	Acceptable

g. Band 1 frequency 2100 MHz, QPSK modulation, bandwidth 20 MHz with 100% acceptable results. As shown in Table 13;

Table 13. Z' score results 2100 MHz frequency, QPSK modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.75	0.68	Acceptable	1.79	1.60	Acceptable	1.83	-1.71	Acceptable
P2	1.72	-0.68	Acceptable	1.78	0.96	Acceptable	1.83	-1.71	Acceptable
P3	1.71	-1.14	Acceptable	1.79	1.60	Acceptable	1.84	-0.85	Acceptable
P4	1.72	-0.68	Acceptable	1.78	0.96	Acceptable	1.85	0.00	Acceptable
P5	1.74	0.23	Acceptable	1.77	0.32	Acceptable	1.86	0.85	Acceptable
P6	1.73	-0.23	Acceptable	1.76	-0.32	Acceptable	1.85	0.00	Acceptable
P7	1.71	-1.14	Acceptable	1.740	-1.60	Acceptable	1.850	0.00	Acceptable
P8	1.74	0.23	Acceptable	1.76	-0.32	Acceptable	1.86	0.85	Acceptable
P9	1.75	0.68	Acceptable	1.76	-0.32	Acceptable	1.86	0.85	Acceptable
P10	1.75	0.68	Acceptable	1.75	-0.96	Acceptable	1.85	0.00	Acceptable

h. Band 1 frequency 2100 MHz, 16QAM modulation, 20 MHz bandwidth with results of 96.67% acceptable, 3.33% warning. As shown in Table 14;

Table 14. Z' score results 2100 MHz frequency, 16QAM modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.7	-0.56	Acceptable	1.75	1.10	Acceptable	1.79	0.00	Acceptable
P2	1.73	1.12	Acceptable	1.75	1.10	Acceptable	1.79	0.00	Acceptable
P3	1.74	1.67	Acceptable	1.74	0.73	Acceptable	1.79	0.00	Acceptable
P4	1.75	2.23	Warning	1.73	0.37	Acceptable	1.79	0.00	Acceptable
P5	1.7	-0.56	Acceptable	1.73	0.37	Acceptable	1.79	0.00	Acceptable
P6	1.7	-0.56	Acceptable	1.7	-0.73	Acceptable	1.8	1.71	Acceptable
P7	1.71	0.00	Acceptable	1.710	-0.37	Acceptable	1.800	1.71	Acceptable
P8	1.71	0.00	Acceptable	1.71	-0.37	Acceptable	1.79	0.00	Acceptable

Measure	SAR (W/Kg), Freq 2100 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P9	1.71	0.00	Acceptable	1.7	-0.73	Acceptable	1.79	0.00	Acceptable
P10	1.71	0.00	Acceptable	1.7	-0.73	Acceptable	1.8	1.71	Acceptable

i. Band 1 frequency 2100 MHz, 64QAM modulation, bandwidth 20 MHz with results of 93.33% acceptable, 6.67% warning. As shown in Table 15;

Table 15. Z' score results 2100 MHz frequency, 64QAM modulation, 20 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 20 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.68	-1.25	Acceptable	1.73	1.28	Acceptable	1.77	-2.56	Warning
P2	1.68	-1.25	Acceptable	1.71	-1.28	Acceptable	1.78	-1.28	Acceptable
P3	1.68	-1.25	Acceptable	1.71	-1.28	Acceptable	1.8	1.28	Acceptable
P4	1.68	-1.25	Acceptable	1.72	0.00	Acceptable	1.8	1.28	Acceptable
P5	1.69	0.00	Acceptable	1.72	0.00	Acceptable	1.79	0.00	Acceptable
P6	1.7	1.25	Acceptable	1.72	0.00	Acceptable	1.79	0.00	Acceptable
P7	1.69	0.00	Acceptable	1.710	-1.28	Acceptable	1.790	0.00	Acceptable
P8	1.69	0.00	Acceptable	1.72	0.00	Acceptable	1.79	0.00	Acceptable
P9	1.69	0.00	Acceptable	1.72	0.00	Acceptable	1.8	1.28	Acceptable
P10	1.7	1.25	Acceptable	1.7	-2.56	Warning	1.8	1.28	Acceptable

j. Band 1 frequency 2100 MHz, QPSK modulation, bandwidth 50 MHz with 100% acceptable results. As shown in Table 16;

Table 16. Z' score results 2100 MHz frequency, QPSK modulation, 50 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 50 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.81	1.67	Acceptable	1.79	-0.73	Acceptable	1.85	-1.14	Acceptable
P2	1.8	0.00	Acceptable	1.8	-0.37	Acceptable	1.85	-1.14	Acceptable
P3	1.81	1.67	Acceptable	1.79	-0.73	Acceptable	1.87	-0.57	Acceptable
P4	1.8	0.00	Acceptable	1.79	-0.73	Acceptable	1.89	0.00	Acceptable
P5	1.8	0.00	Acceptable	1.84	1.10	Acceptable	1.89	0.00	Acceptable
P6	1.8	0.00	Acceptable	1.81	0.00	Acceptable	1.89	0.00	Acceptable
P7	1.79	-1.67	Acceptable	1.810	0.00	Acceptable	1.930	1.14	Acceptable
P8	1.8	0.00	Acceptable	1.82	0.37	Acceptable	1.93	1.14	Acceptable
P9	1.79	-1.67	Acceptable	1.83	0.73	Acceptable	1.92	0.85	Acceptable
P10	1.79	-1.67	Acceptable	1.83	0.73	Acceptable	1.92	0.85	Acceptable

k. Band 1 frequency 2100 MHz, 16QAM modulation, bandwidth 50 MHz with 100% acceptable results. As shown in Table 17;

Table 17. Z' score results 2100 MHz frequency, 16QAM modulation, 50 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 50 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result

Measure	SAR (W/Kg), Freq 2100 MHz BW 50 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.77	1.67	Acceptable	1.8	1.46	Acceptable	1.87	-0.85	Acceptable
P2	1.76	0.84	Acceptable	1.78	0.00	Acceptable	1.88	0.00	Acceptable
P3	1.75	0.00	Acceptable	1.79	0.73	Acceptable	1.88	0.00	Acceptable
P4	1.76	0.84	Acceptable	1.79	0.73	Acceptable	1.88	0.00	Acceptable
P5	1.75	0.00	Acceptable	1.76	-1.46	Acceptable	1.87	-0.85	Acceptable
P6	1.74	-0.84	Acceptable	1.78	0.00	Acceptable	1.88	0.00	Acceptable
P7	1.74	-0.84	Acceptable	1.780	0.00	Acceptable	1.880	0.00	Acceptable
P8	1.75	0.00	Acceptable	1.77	-0.73	Acceptable	1.9	1.71	Acceptable
P9	1.75	0.00	Acceptable	1.77	-0.73	Acceptable	1.9	1.71	Acceptable
P10	1.74	-0.84	Acceptable	1.76	-1.46	Acceptable	1.9	1.71	Acceptable

1. Band 1 frequency 2100 MHz, 64QAM modulation, bandwidth 50 MHz with 100% acceptable results. As shown in Table 18.

Table 18. Z' score results 2100 MHz frequency, 64QAM modulation, 50 MHz bandwidth

Measure	SAR (W/Kg), Freq 2100 MHz BW 50 MHz								
	Freq Low	Z' Score	Result	Freq Mid	Z' Score	Result	Freq High	Z' Score	Result
P1	1.75	0.77	Acceptable	1.75	-1.12	Acceptable	1.81	-0.47	Acceptable
P2	1.75	0.77	Acceptable	1.75	-1.12	Acceptable	1.81	-0.47	Acceptable
P3	1.73	0.00	Acceptable	1.74	-1.44	Acceptable	1.81	-0.47	Acceptable
P4	1.75	0.77	Acceptable	1.74	-1.44	Acceptable	1.82	0.00	Acceptable
P5	1.73	0.00	Acceptable	1.79	0.16	Acceptable	1.83	0.47	Acceptable
P6	1.72	-0.39	Acceptable	1.78	-0.16	Acceptable	1.8	-0.93	Acceptable
P7	1.71	-0.77	Acceptable	1.790	0.16	Acceptable	1.820	0.00	Acceptable
P8	1.71	-0.77	Acceptable	1.79	0.16	Acceptable	1.84	0.93	Acceptable
P9	1.73	0.00	Acceptable	1.79	0.16	Acceptable	1.85	1.40	Acceptable
P10	1.71	-0.77	Acceptable	1.8	0.48	Acceptable	1.86	1.86	Acceptable

From the results of the Z 'score, all data is in the acceptable and warning categories, meaning that all data does not deviate and is valid for analysis.

4.3. Analysis of the Study Results

From the test results shown in Table 5 and Table 6, several things can be analyzed such as the effect of frequency on SAR value, the effect of bandwidth on SAR value, the effect of modulation on SAR value.

a. Effect of Frequency on SAR Value

From the test results, it is found that higher frequencies produce greater SAR values. The SAR value at 2100 MHz is always greater than the SAR value at 900 MHz. Likewise, for low frequency, center frequency, and high frequency in each frequency band (900 MHz and 2100 MHz), it is found that the SAR value at high frequency is always greater than the SAR value at low frequency and center frequency. Figure 1 shows a graph of the effect of frequency on SAR values, Figure 2 shows a graph of the effect of 900 MHz in band frequency on SAR values, and Figure 3 shows a graph of the effect of 2100 MHz in band frequency on SAR values.

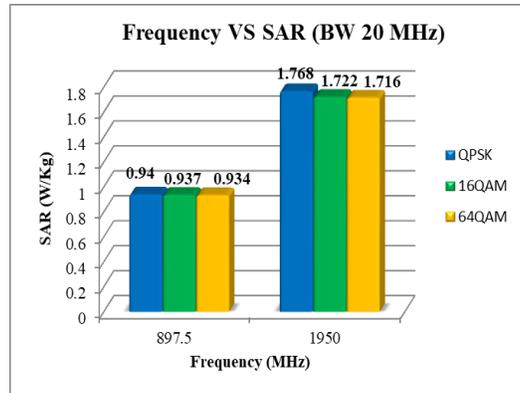


Figure 1. Graph of Frequency Effect on SAR

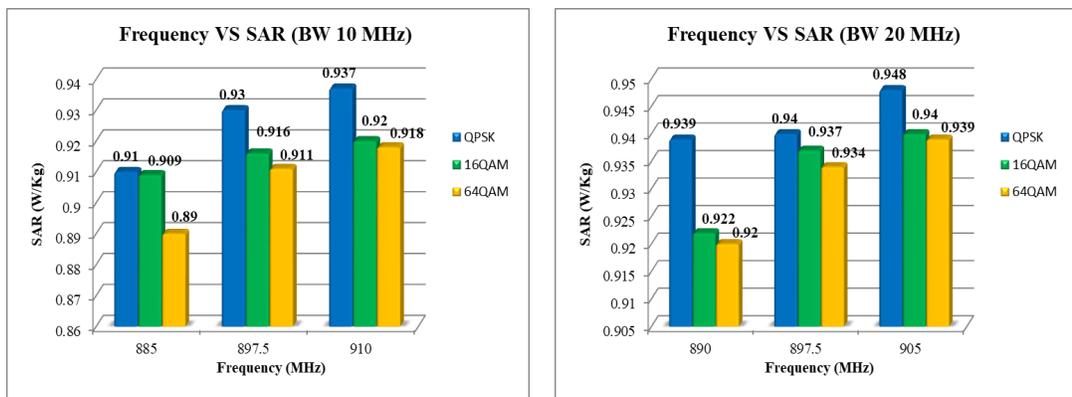


Figure 2. Graph of the Effect of 900 MHz in band Frequency on SAR

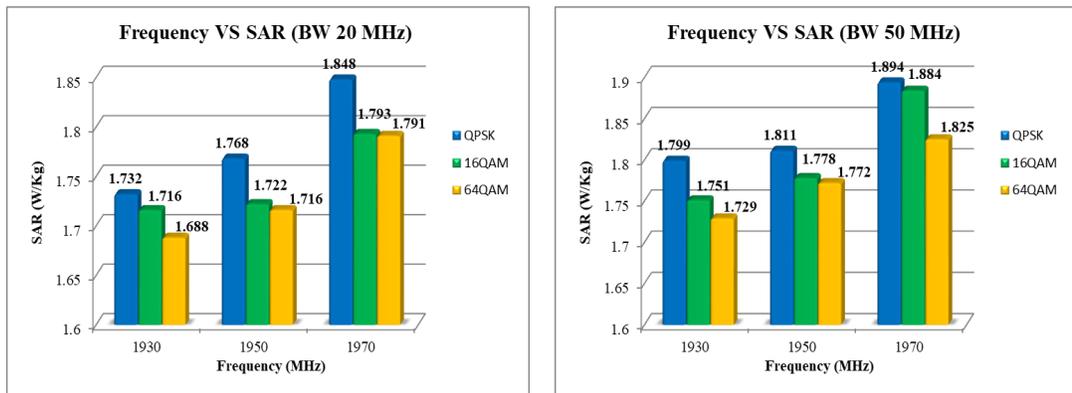


Figure 3. Graph of the Effect of 2100 MHz in band Frequency on SAR

b. Effect of Bandwidth on SAR Value

From the test results, it is found that the larger bandwidth will produce a higher SAR value. The SAR value at 50 MHz bandwidth is always greater than the SAR value at 20 MHz and 10 MHz bandwidth. The graph of the effect of bandwidth on SAR value is shown in Figure 4.

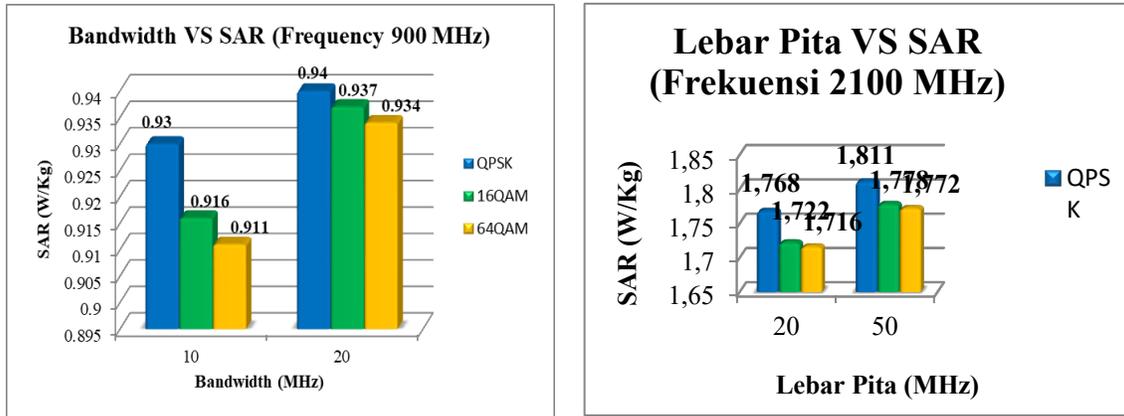


Figure 4. Graph of Effect of Bandwidth on SAR

c. Effect of Modulation on SAR Value

From the test results, it is found that QPSK modulation always produces a greater SAR value than 16QAM and 64QAM modulation both at 900 MHz and 2100 MHz frequencies. The graph of the effect of modulation on SAR value is shown in Figure 5.

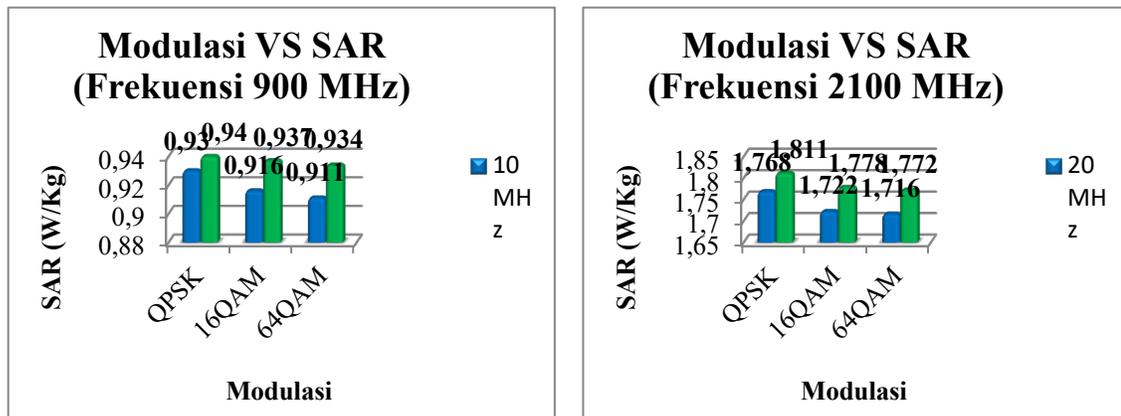


Figure 5. Graph of Effect of Modulation on SAR

4.4. Reduction of Testing Parameters

The large number of 5G SAR test parameters that reach 396 parameters[4] for one position makes the test duration very long. By referring to the analysis results above, we can reduce the frequency, bandwidth, and modulation parameters so that the number of 5G SAR testing parameters becomes 5 parameters. With a test time duration for one parameter about 20 minutes, before the reduction it takes 7920 minutes of test time for one position. after reduction it only takes 100 minutes for SAR testing at one position. So the percentage of time reduced by 98,74%.

This has increased the number of applications that can be resolved each year. Before the reduction can only complete 3 applications each year, by applying the reduction method the applications that can be resolved to 208, an increase that occurs by $208 / 3 = 69.33$ times from before. This means that the current process is 69.33 times more efficient than before. In terms of PNBPN revenue, it also increased by 69.33 times from before.

5. Conclusion

Based on the results of data analysis and discussion, the conclusions that can be drawn from research on Specific Absorption Rate (SAR) Testing Parameter Analysis for 5G Device Evaluation Optimization are as follows, the proposed alternative configurations that can be applied for SAR testing of 5G devices are settings at high frequencies, use QPSK modulation and the largest bandwidth.

By implementing the alternative configuration, the SAR measurement completion time of 5G devices has been reduced by 98.74% from before. In addition, the testing process is 69.33 times more efficient than before, as well as in terms of non-tax state revenue (PNBP) revenue increased by 69.33 times from before.

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