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A Study of the Effect of DC Conditions on a 5.8 GHz Power Amplifier's S-Parameters

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ABSTRACT: This study investigates changes of S-parameters (S_{21}, S_{11}, S_{22}, S_{12}) of a SBB5089Z power amplifier module in relation to changing DC conditions. Behaviour of those linear performance parameters (S_{21}, S_{11}, S_{22}, S_{12}) was examined graphically. S-parameters of SBB5089Z were analysed covering the 5.8 GHz WiMAX frequency from 5.7 GHz to 5.9 GHz with 200 MHz bandwidth. DC conditions were controlled using a microcontroller, an R/2R Digital Analogue Converter (DAC) ladder circuit and a voltage follower with LM324. The R/2R ladder circuit and voltage follower with LM324 have been integrated with the microcontroller. Also ACS712 current sensor and ADS1115 16-bit Analog Digital Convertor (ADC) are integrated to the microcontroller. PA's current was read with microcontroller.

Keywords: Power Amplifier, WiMAX, 5.8 GHz, DC conditions, microcontroller

Besleme Koşullarının 5.8 GHz Güç Yükselteci S-Parametreleri Etkisi Üzerine Bir Çalışma

ÖZET: Bu çalışma, değişen DC koşullara bağlı olarak SBB5089Z güç yükselteç modülü S-parametrelerindeki (S_{21}, S_{11}, S_{22}, S_{12}) değişimleri araştırmaktadır. Doğrusal performans parametrelerinin (S_{21}, S_{11}, S_{22}, S_{12}) davranışı grafiksel olarak incelenmiştir. SBB5089Z' nin S-parametreleri, 5.8 GHz WiMAX frekansını kapsayan, 5.7 GHz'den 5.9 GHz'e kadar 200MHz bant genişliği ile analiz edilmiştir. DC koşullar, bir mikrodenetleyici, bir R/2R sayısal analog dönüştürücü merdiven devresi ve LM324'lü bir gerilim izleyici kullanılarak kontrol edilmiştir. R/2R merdiven devresi ve LM324'lü gerilim izleyici devresi mikrodenetleyici ile entegre edilmiştir. Aynı zamanda, mikrodenetleyiciye ACS712 akım sensörü ve ADS1115 16-bit analog sayısal dönüştürücü de entegre edilmiştir. Güç yükselteci akımı mikrodenetleyici ile ölçülmüştür.

Anahtar Kelimeler: Güç Yükselteci, WiMAX, 5.8 GHz, DC koşullar, Mikrodenetleyici

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INTRODUCTION

Amplification of the signal is one of the most basic and important functions of a microwave amplifier circuit (Pozar, 2012). Radio frequency (RF) Power Amplifiers (PAs) are important elements of wireless communication systems and are expected to provide appropriate output power at a good gain value with high efficiency and linearity. The output power of RF PAs should be sufficient for real communication (Saad, 2006; Kaya et al., 2008). While efficiency in PAs is important in terms of battery life, the importance of linear performance for PAs can be summarized in three points:

- Modern wireless communication systems use wide bandwidths, and therefore efficient use of the spectrum is required. This increases the need for wide-band linear amplifiers for transceiver systems.
- Since many wireless communication standards use a non-constant envelope modulation method (with high PAPR values), signals must be amplified by highly linear amplifiers.
- Sinusoidal input power applied to the amplifiers used in wireless transmitter systems is transformed into heat or high intermodulation (IM) outputs, outside of the amplifier's linear operating range (in the regions above the 1 dB gain compression point) (Pedro, 2003).

Due to the reasons mentioned above, high linearity amplifier design has become an important research topic in recent years. Linearity needs to be achieved within the rapidly developing and growing mobile device market with minimum circuit complexity, power consumption and cost (Brinkhoff, 2003).

In practice, PAs are driven with modulated RF signals varying in amplitude over time, and the amplitude of these signals is increasing or decreasing according to various conditions. Due to the high PAPR value of the modulated signal, the PAs to be used in those systems should be operated in highly linear regions with high power back-off values. On the other hand, operating the amplifier in the back-off region causes a drop in its efficiency. This poses a great challenge to PA designers, as the design of PAs has to meet the linearity requirements but still have highly efficient performance (Gecan et al., 2017; Tripathi et al., 2017). Gain, reflection coefficient, and linearity parameters of the PA get worse at high levels of the RF input signal. Therefore, for linear performance of a PA, it is preferred to operate in the back-off region. However, in the back-off region the efficiency of PAs gets worse (Lee, 2010). There is a trade-off between linearity and efficiency according to changing RF input power levels (Senel et al., 2017).

The deterioration of PA's performance parameters caused by RF input power can be improved by changing DC conditions (Cripps, 2002; Wong et al., 2012). There are many studies in literature on this subject. Dynamic gate biasing (Gecan et al., 2016), dynamic biasing (Lee et al., 2017; Chen et al., 2016), adaptive biasing (Harzheim, 2016; Cohen et al., 2013; Akbarpour, 2017), and envelope tracking (Auer et al., 2017; Olavsbråten and Gecan, 2017) are some of the methods of changing DC conditions depending on the RF input power signal. In dynamic biasing, dynamic gate biasing and adaptive biasing DC conditions change according to the power of the RF input signal (Tafuri, 2013), whereas in envelope tracking method DC conditions change according to the envelope of the RF input signal (Jing and Bakkaloğlu, 2017).

Detailed technical literature review has shown that DC conditions have a significant influence on PA's performance parameters. In the literature especially changing of nonlinear performance parameters of PA like output power, according to DC conditions have been investigated. In this study, we investigate how the linear gain (S_{21}), input and output reflection coefficient (S_{11}&S_{22}) and back transmission coefficient (S_{12}) parameters of a SBB5089Z power amplifier module change with changing DC conditions from 5.7 GHz to 5.9 GHz, with 200 MHz bandwidths covering 5.8 GHz WiMAX frequency. In this study firstly, we chose proper a commercial power amplifier module. As mentioned earlier it is SBB5089Z operating at 5.8 GHz frequency and 5 V nominal V_{DC}. We began with measurement S-parameters of PA module whether PA module operates or not at 5.8 GHz frequency. After verifying that PA module operates at 5.8 GHz frequency with 200 MHz bandwidth, we changed DC conditions (V_D) of PA module from 0 V to 5 V and investigated how varied S-parameters of PA.

MATERIAL AND METHODS

In this study we have used a 50 MHz – 6 GHz broadband InGaP HBT MMIC SBB5089Z power amplifier module. Measured S-parameters (S_{21}, S_{11}, S_{22}, S_{12}) of the SBB5089Z module, from 5.7 GHz to 5.9 GHz, are shown in Figure 1. In measurements, the following equipment was used: a 6 GHz Rohde&Schwarz FSH6 spectrum analyzer, a DC power supply, and a broadband micro strip directional coupler – for dividing and monitoring the power levels. DC conditions were adjusted at V_D = 5 V and I_D = 69 mA.

S-parameters and DC power consumption are summarized in Table 1.

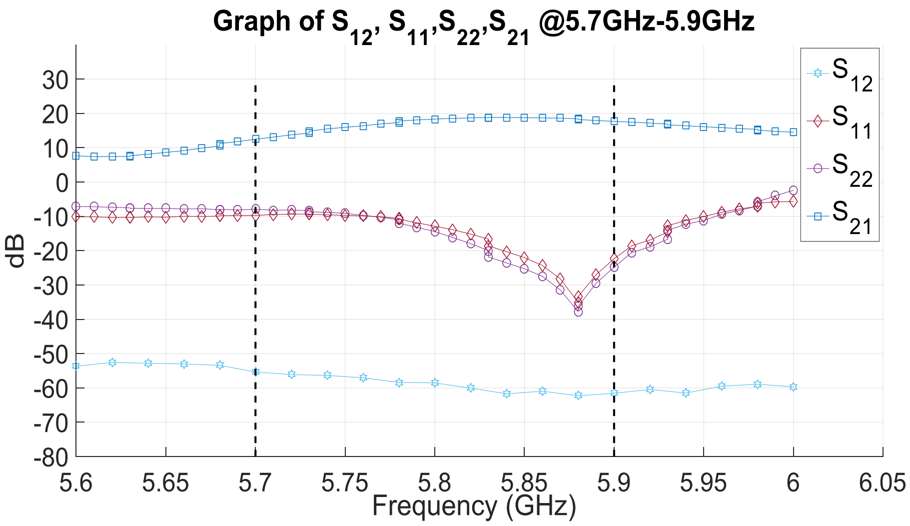


Figure 1. Measured s-parameters of SBB5089Z

Table 1. Performance parameters of SBB5089Z@5.8GHz

Performance Parameters	Value
S_{21} (dB)	18.35
S_{11} (dB)	-14.43
S_{22} (dB)	-12.87
S_{12} (dB)	-58.54
P_{diss} (Watt) (V_D*I_D)	0.3725

According to measurement results presented in Table 1, SBB5089Z has $S_{21} > 10dB$, S_{11} & $S_{22} < -10dB$, and $S_{12} < -20dB$, so they are sufficient for this work and meet the requirements.

Methodology of Changing the DC Voltages

In the system designed in the study, the DC voltage values (V_D) applied to the PA are automatically changed with the microcontroller in 5 second periods. Thus, PA is automatically biased with V_D voltage. The ACS712 current sensor and ADS 1115 16-bit Analog Digital Convertor (ADC) are integrated to the microcontroller. PA's current is also automatically read by the microcontroller with current sensor and ADC. S-parameters of PA were measured by the Rohde & Schwarz FSH6 spectrum analyzer. Since the spectrum analyzer connected to the output of the PA is not suitable to be triggered by the microcontroller, the values that the spectrum analyzer reads are recorded in the .CSV file by the spectrum analyzer every 5 seconds synchronously with the microcontroller. After examining the S-parameters of the SBB5089Z PA module, the DC requirements of the SBB5089Z were changed from 0 V to 5 V in approximately 75 mV steps (with 6-bit resolution, so $2^6 = 64$ steps) using the microcontroller. Because the maximum supply voltage (V_D) of SBB5089Z is 5.5V, in order not to burn out the PA module, DC voltage was changed only up to 5V. It has been studied graphically in detail how varying the DC conditions changes the linear performance parameters (S_{21}, S_{11}, S_{22}, S_{12}) of the SBB5089Z. Block diagram of S-parameter measurement set up is shown in Figure 2, as well as microcontroller program flow chart is shown in Figure 3.

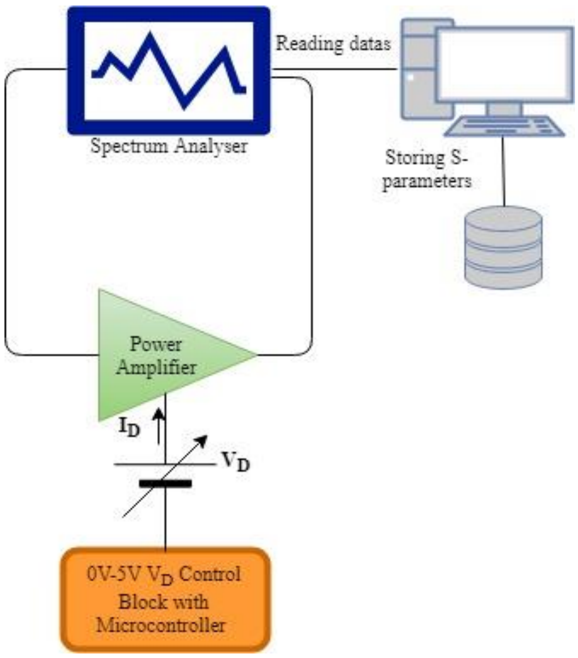


Figure 2. Block diagram of S-parameter measurement set up

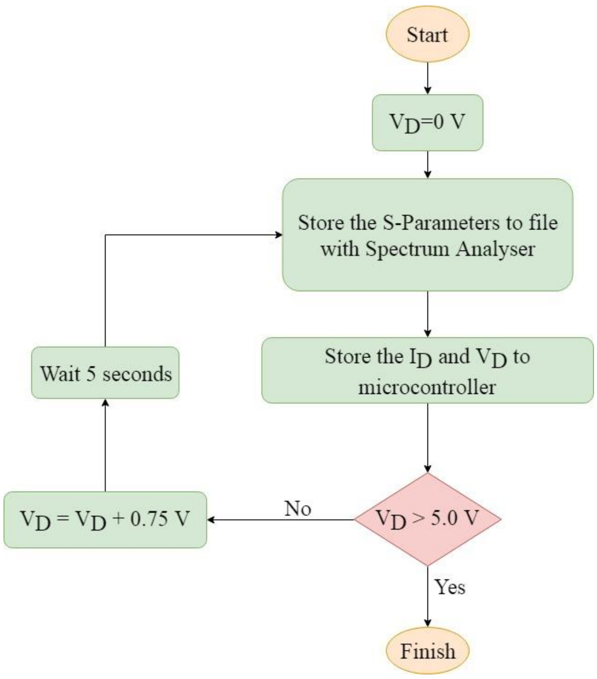


Figure 3. Microcontroller program flow chart

DC Biasing Control Unit with Microcontroller

In this study, a microcontroller was used to change DC conditions of the SBB5089Z. Microcontroller's digital output pins were integrated to an R/2R DAC ladder circuit to obtain more stable V_D. The LM324 voltage follower circuit was used after the R/2R circuit and the SBB5089Z was driven by that LM324 voltage follower circuit. As well as a current sensor named ACS712 and a 16 bit ADS1115 analog digital convertor are used to read current drawn by PA. The block diagram and implementation of the DC biasing control unit are shown in Figure 4 and 5, respectively.

Measurement set up is shown in Figure 6.

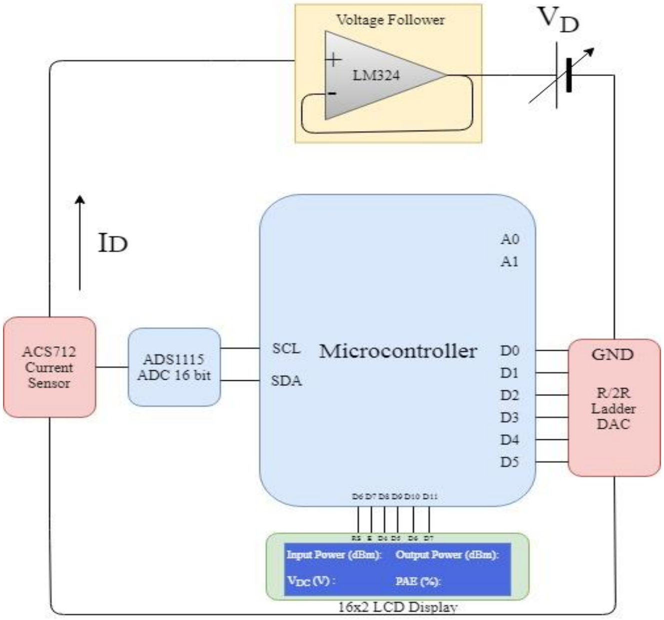


Figure 4. Schematics of the DC Biasing Control Unit

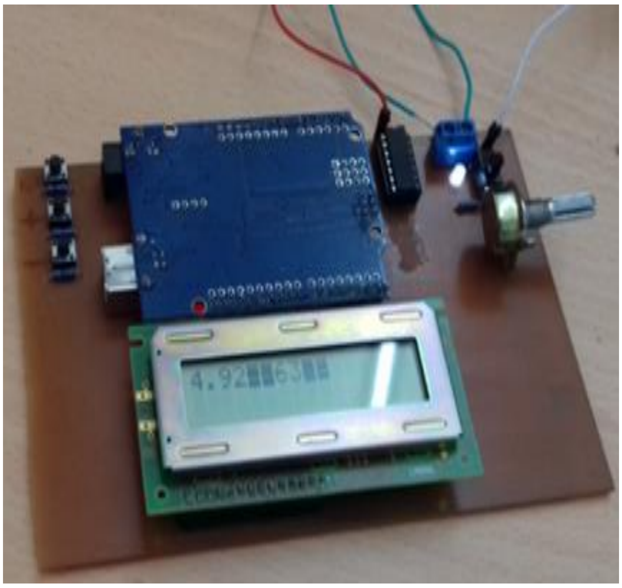


Figure 5. Implementation of the DC biasing control unit

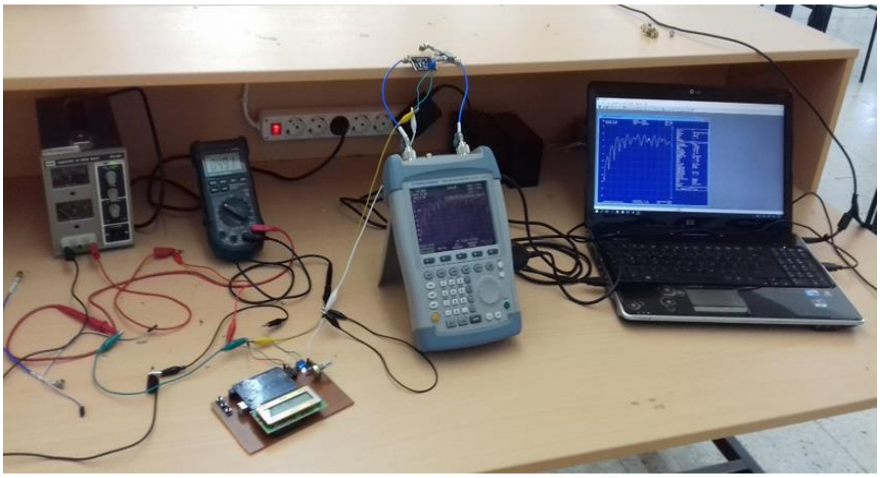


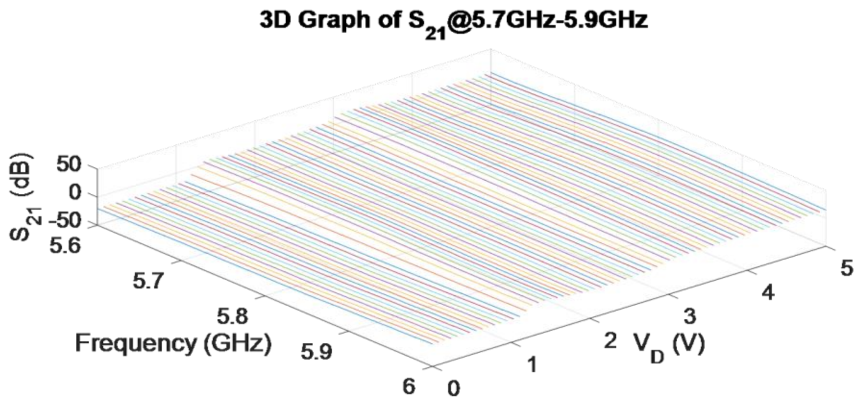
Figure 6. Measurement set up

RESULTS AND DISCUSSION

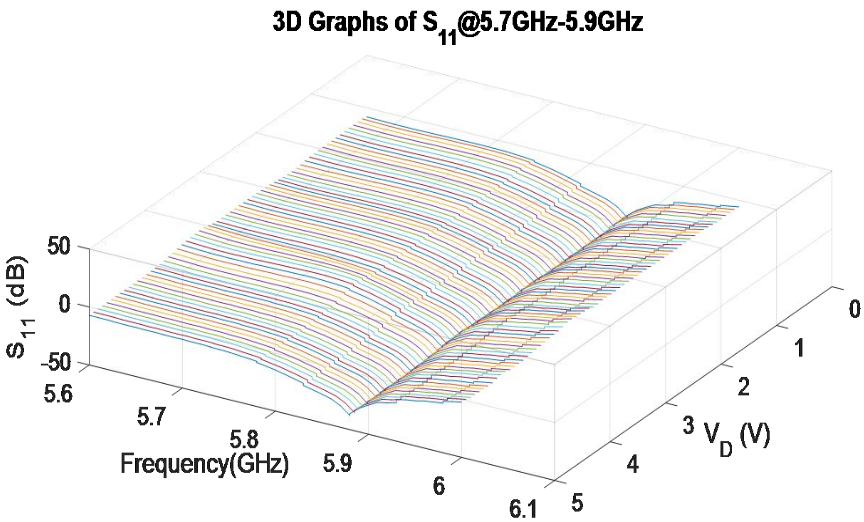
Changing S-Parameters with Modified DC Conditions

Figures 7 displays three-dimensional graphs of the S_{21}, S_{11}, S_{22}, and S_{12} parameters, respectively, in relation to V_D, which is increasing in 75 mV steps from 0 V to 5 V, for a 200 MHz bandwidth from 5.7 GHz to 5.9 GHz, covering the 5.8 GHz WiMAX band.

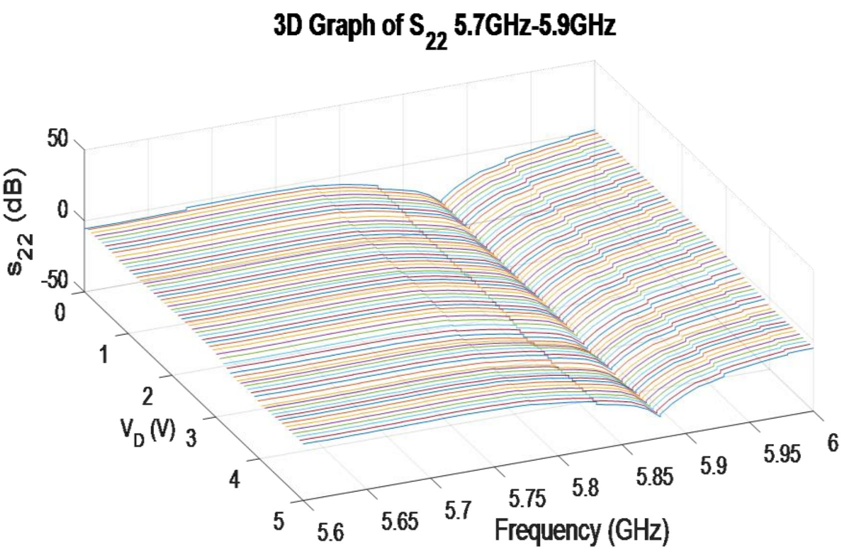
The increase/decrease of performance parameters of the SBB5089Z at 5.8 GHz, while DC conditions of the PA module were changed from V_D = 3.095V to 5V, is summarized in Table 2. The minimum value of approximately 3V was chosen for V_D, because S_{11} and S_{22} get much worse when V_D drops below 3V.


3D Graph of S21@5.7GHz-5.9GHz
S21 (dB)
50
0
-50
5.6
5.7
5.8
5.9
6
Frequency (GHz)
0
1
2
3
4
5
VD (V)

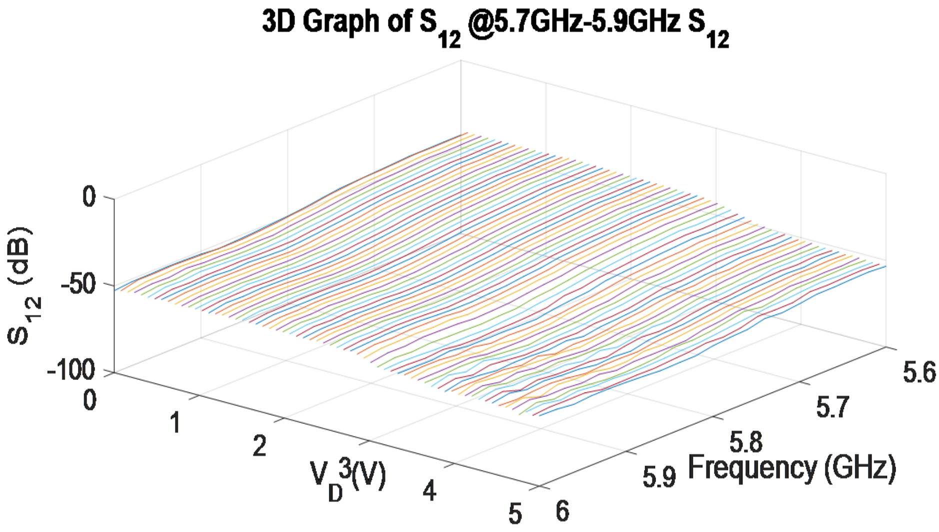
(a)


3D Graphs of S11@5.7GHz-5.9GHz
S11 (dB)
50
0
-50
5.6
5.7
5.8
5.9
6
6.1
Frequency(GHz)
0
1
2
3
4
5
VD (V)

(b)


3D Graph of S22 5.7GHz-5.9GHz
s22 (dB)
50
0
-50
0
1
2
3
4
5
VD (V)
5.6
5.65
5.7
5.75
5.8
5.85
5.9
5.95
6
Frequency (GHz)

(c)



(d)

Figure 7. 3D Graphs of S_{21}, S_{11}, S_{22}, S_{12} versus 5.7GHz-5.9GHz frequency interval and 0V-5V V_D voltage interval (a) 3D Graph of S_{21} versus frequency and V_D (b) 3D Graph of S_{11} versus frequency and V_D (c) 3D Graph of S_{22} versus frequency and V_D (d) 3D Graph of S_{12} versus frequency and V_D

Table 2. PA performance parameters comparison for V_D at 3.095V and 5V@5.8GHz

	V_D@3.095V	V_D@5V	increase / decrease
S_{21} (dB)	16.49	18.35	1.86
S_{11} (dB)	-7.943	-12.36	-4.417
S_{22} (dB)	-6.344	-12.87	-6.526
S_{12} (dB)	-36.02	-58.4	-22.38
$P_{dissipated}$	0.07025	0.346	0.27575

CONCLUSION

In the study, first, the S-parameters were measured at nominal V_D with 200 MHz bandwidths from 5.7 GHz to 5.9 GHz to show that the SBB5089Z is suitable for further analysis. Then, the variation of the linear performance parameters of the module was investigated with respect to changing DC biasing conditions. It has shown that increasing DC voltage levels increases gain (S_{21}), but decreases input and output reflection coefficients (S_{11} and S_{22}), and the reverse transmission coefficient (S_{12}). S_{21} increased by about 2 dB, S_{11} and S_{22} decreased by about 5 dB and S_{12} dropped by 22 dB, when V_D of the SBB5089Z were increased from 3.095 V to 5 V. Increasing V_D from 3V to 5V increased power dissipation by about 0.275W. In relation to the altered DC conditions, all S-parameters of the SBB5089Z improved. It is clear that linear performance of the PA got better with increased DC voltage levels. Only power dissipation degraded because of increased current and voltage levels.

According to the results obtained in this study and according to the results of the change of the different performance parameters of the PA according to changing DC conditions, an adaptive DC biasing circuit will be designed. Therefore, the data obtained in this study are essential for adaptive PA design. As well as S-parameters for PA is important, DC power consumption is also very important in terms of thermal effects which occur in PA. In the study, it is obtained that there is a trade-off between S-parameters and DC power consumption according to the increased DC conditions. It is also concluded that PA S-parameters can be used in supply voltage values less than 5V in case of satisfying the desired conditions, thus reducing PA DC power consumption.

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