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GSM Transceiver Design Optimization

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ABSTRACT—*Transceiver design is a tradeoff between several parameters that impact on the transceiver specifications. These parameters are also interrelated such that an increase in one parameter impacts on the possible values of the second parameter and these determine the specifications achievable. This work presents the design of a GSM transceiver system and presents that achieved results in comparison to the ETSI GSM specifications. The parameters were all subjected to the same percentage variation and Matlab software was used to develop algorithms for determining the variations and interrelationships between the parameters .One key criteria in transceiver design is the Noise figure and the results show that the frontend comprising of the Duplexer, LNA, the Mixer has the greatest impact on the transceiver design while the power amplifier noise figures have very minimal effect of the overall system noise figure. It also shows the power amplifier as the unit that consumes the most power. From the results, several power saving techniques such as sleep modes targeted at the Power amplifiers can be implemented without having any significant effect on the transceiver speed, The results also show an inverse relationship between the overall system gain and the dynamic range of the transceiver such that to achieve a higher dynamic range, the system gain would have to be reduced. . This work enables an understanding of the relationships between the different parameters of the GSM transceiver design*

Keywords—GSM, transceiver, Noise figure, Gain

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1. INTRODUCTION

Radio receiver design requires a compromise between the various specifications of the system. The parameters involved are interrelated together both in direct and indirect proportions. This linkages and interdependence coupled with the availability of different types of the same components with different specifications, makes the design of radio receivers and transceivers a process of compromise between the different specifications.

The low noise amplifier is desired to have a very high gain so as to reduce the effect of the noise figure of the filters and mixer stages. A high gain however affects the mixers linearity limiting its performance [1] The system gain is desired to be high so that the transceivers can cover longer distances but the dynamic range of the receiver is reduced by a high system gain. This entire interrelationship between the different blocks of the transceiver makes it necessary to perform optimization on the system design to determine the parameter changes required so as to achieve system specifications as close as possible to the target specification.

1.1 Transceivers

Transceivers can be described as a system comprising of a direct coupled receiver and transmitter systems. Figs 1(a) and (b) is a combination of a receiver and a transmitter to produce a single down/up conversion transceiver based in the super heterodyne topology. Figure 1(a) is a transceiver used for the uplink direction from the GSM mobile to the base station or a satellite uplink while 1 (b) is for transmission from the satellite down to the mobile. This is known as Downlink. Both configurations can be combined in a single transceiver block to create a bidirectional transceiver system

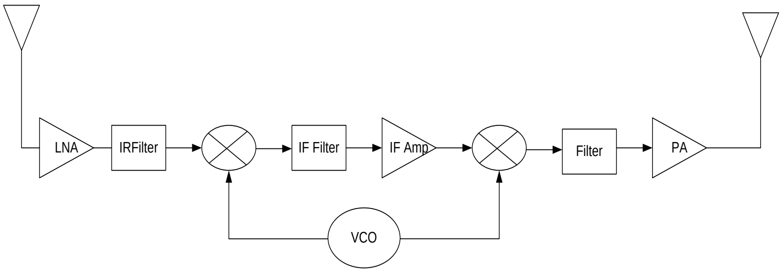


Figure 1(a): Transceiver block diagram (Uplink)

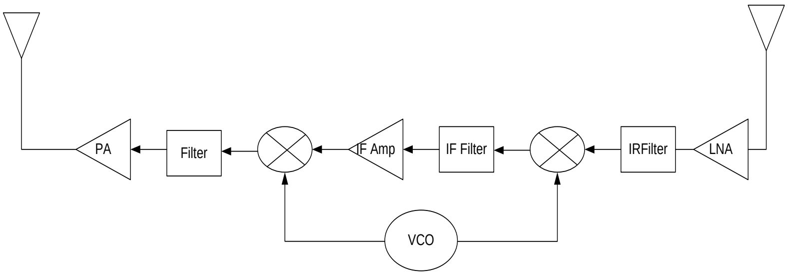


Figure 1(b): Transceiver block diagram (Downlink)

1.2 Noise figure

Noise is a vital factor in digital communication system as it gives rise to bit error due to the fact that the information which is being transmitted and received may be incorrect or lost [2].In addition Signal to Noise Ratio (SNR) at the output of receiving system is another very significant criterion. It is a function of the transmit output power, Gain of transmit and receive antennas, receiver noise and pathloss [3].The overall noise figure of the cascaded system can be calculated using the Friis equation and the noise figure and gain values of each block in the system.

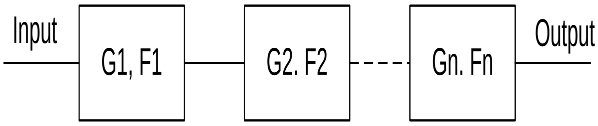


Figure 2: Noise Figure, F for cascaded network

In general, cascade of n devices is given by friss equation

$$F_{1-n} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots\dots\dots + \frac{F_n - 1}{G_1 G_2 \dots\dots\dots G_n}$$

Where

F = Noise figure of the Receiver

S_I = Signal power at the input

G = Gain of the receiver

1.3 Sensitivity

Sensitivity is the ability of the receiver to reliably detect the minimum signals in a system by specifying the strength of the minimum signal at the input. Minimum Detectable Signal (MDS) determines the sensitivity of the receiver and is given as [4]:

$$MDS = FK_B T_S B(SNR_{\min})$$

$$MDS(dBm) = -174 + F(dB) + SNR_{\min}(dB) + 10\log_{10} B$$

Where

SNR min =Minimum signal to noise ratio

F= Noise figure

Ts =Absolute temperature of the receivers input (^{0} K)

B= Receiver Bandwidth

Ks = Boltzmann's constant $1.38*10^{-23}$Joules/K

2. TRANSCEIVER DESIGN PROCESS

The design of the transceiver involves selection of the various application specific integrated circuits (ASICs) such that the overall system specification achieved will be within acceptable limits of the target specifications. The target specifications for the GSM standard are as described by the ETSI and shown in Table 1

Table 1: ETSI 05.05 specifications

Parameters	Specification(DCS in brackets)
Sensitivity	-102 dBm (-100dBm)
Maximum receive signal strength	-15dBm
Noise figure	9.98dB(11.8dB)
C/N for BER performance	9dB
IIP_3	-19.5 dBm
P1dB	-29.5dBm
Dynamic range	87dB
Up link	1710-1785MHz
Downlink	1805- 1880MHz
Channel band width	200KHz

2.1 Chip Selection

The various ASIC chips for the implementation of each of the blocks of the system to meet the ETSI specification are identified and used in the system design.

Table 2: Selected Chips for the Transceiver UPLINK (1710-1785MHz)

Block	CHIP	G (dB)	N.F (dB)	Freq Range	OIP_3
LNA	HMC375LP3	17.5	0.9	1.7-2.2GHz	34
SAW Image reject filter	SAFCC1G74KA0 T00	-4.2	4.5	1710 – 1785MHz	100
Down conversion Mixer	HMC380QS16G	11	9	RF=1.7 - 2.2GHz IF= 50 - 300MHz	19 (IIP_3)
IF Filter	855625	-4.2	4.2	190MHz (B/W 200KHz)	100
Gain Block	ADL5530	16	2.5	0 – 1GHz (B/W 1GHz)	37dBm
Up conversion Mixer	MAX 2039	-7.1	7.3	RF = 1.7 -2.2GHz LO = 1.5 – 2.0GHz IF = 0 – 350MHz	33.5dBm(IIP_3)
SAW Image reject filter	SAFCC1G74KA0 T00	-4.2	4.5	1710 – 1785MHz	100
The Power Amplifier	HMC457Q16G	27dB	6dB	1.7 – 2.2GHz	46dBm (IIP_3)

DOWNLINK (1805 – 1880MHz)

From the frequency distribution of the system, the same IF frequency value is used for the uplink and downlink, the chips that differentiate both links are the image reject filters.

2.2 The SAW IR

The chip selected for Implementing the Image reject frequency for the uplink is the SAWEP1G84CQ0F00

2.3 The Voltage Controlled Oscillator (VCO)

With the choice of 190MHz (0.19GHz) for IF, the VCO is required to have the following frequency range.

RF – LO = IF

$LO_{min} = RF_{min} – IF$

$LO_{max} = RF_{max} – IF$

Uplink

LO_{min} = 1.710GHz – 0.19GHz = 1.520GHz

LO_{max} = 1.785GHz – 0.19GHz = 1.595GHz

Downlink

LO_{min} = 1.805GHz – 0.19GHz = 1.615GHz

LO_{max} = 1.880GHz – 0.19GHz = 1.690GHz

From the chip specifications for the VCO, the required LO frequencies for an IF of 190MHz is from 1.52GHz to a maximum of 1.69GHz. A chip that will give this frequency value at low voltage is desired. The T0M9211 is the optimum choice.

2.4 The Duplexer

The transceiver will utilize the same antenna for both receive and transmit so a duplexer would be required to separate both channels. The duplexer chosen for the system is the ADF1800.

The transceiver designed based on these chips achieved the following specifications.

Table 3: Design specifications achieved and target specifications

Parameters	Design values (Achieved)	Target Specification (DCS in brackets)
Sensitivity	-107.93 dBm	-102dBm(-100dBm)
Maximum receive signal strength	-69.93 dBm	-15dBm
Noise figure	4.07dB	9.98dB(11.8dB)
C/N for BER performance	9dB	9dB
IIP_3	-59.88dBm	-19.5 dBm
P1dB	-69.88dBm	-29.5dBm
Dynamic range	38dB	87dB
Uplink	1710-1785MHz	1710-1785MHz
Downlink	1805-1880MHz	1805- 1880MHz
Channel band width	200KHz	200KHz

From the results obtained, the transceiver designed achieved a better noise figure value than the target specification but the IIP_3, P1dB and dynamic range were below the target specification values.

3. DESIGN OPTIMIZATION USING MATLAB

Optimization in transceiver design involves a means of identifying the optimum value of the various components. The optimization is done to determine the specification of components that can be used to achieve or approach the target specification of the GSM receiver specifications [5].

There are three basic approaches used for circuit optimization and these are simulation based approach, equation based approach and geometric programming [6,7,8,9]. The equation based approach is utilized using the Matlab software to generate new specification based on the variation of the parameter values of each block.

The optimization procedure is as listed below.

(1) Determine the system specifications

(2) Apply the same percentage variation to a particular specification (gain, noise factor) of each block sequentially.

(3) Determine which component and which specification had the greatest impact on the transceiver's overall specifications.

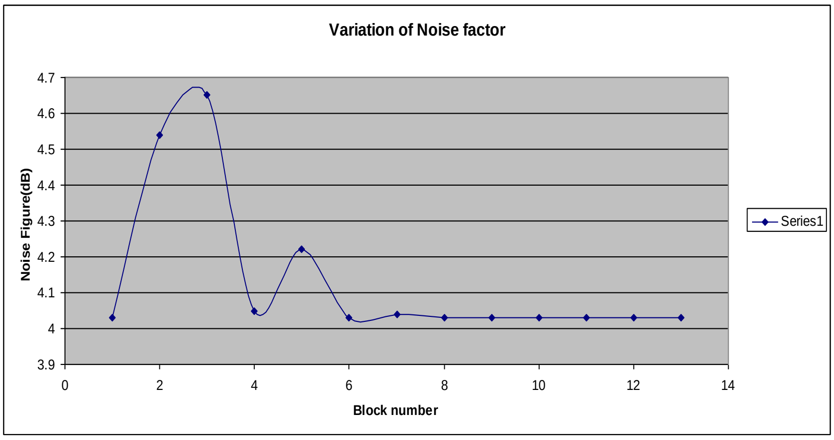
(4) Based on steps 2 and 3 determine the component and parameter to alter and the amount of alteration required to achieve the desired transceiver results.

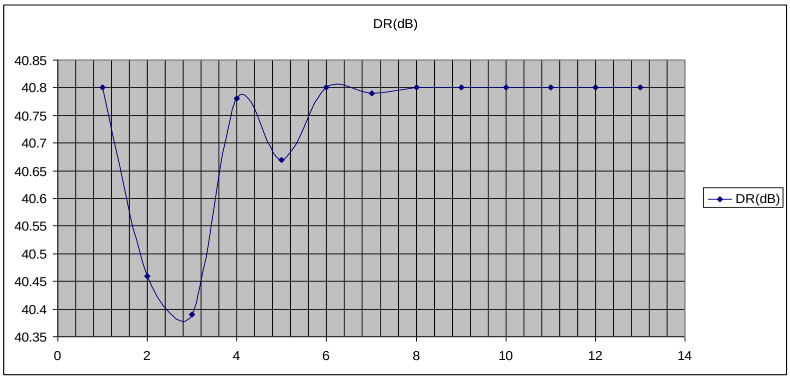
From the optimization procedure listed above a variation value of 20% was selected to show the trend of the effect of each component parameter on the overall system specifications. Using the Matlab software, the noise factor and the gain values of each component were varied and their results are plotted to show their effect on the system specifications.

4. RESULTS AND DISCUSSION

The following results were obtained when the noise figure of each block was varied by a 20% change in value.

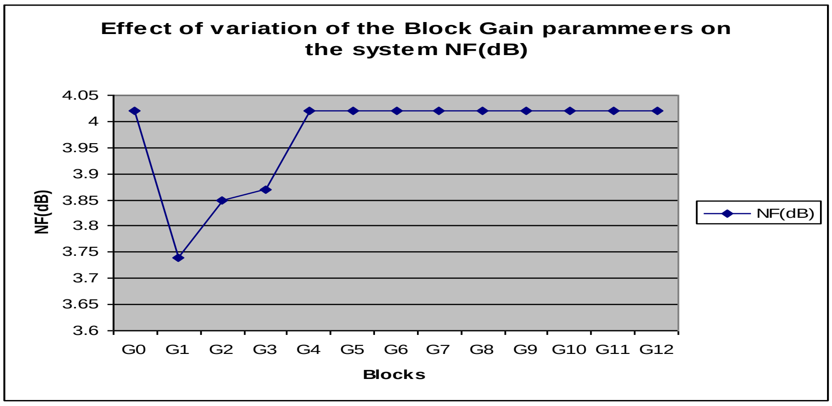
Plotting the graph to determine which component noise figure had the greatest effect on the overall system noise figure yields the following results.





From the graph, the first three blocks are the most critical as they have the greatest effect on the system noise figure with a percentage variation of up to 15.38% for the LNA.

The effect of the variation of the gain of each component on both the dynamic range and the noise figure yields the following results:



The graph also shows that the gains of the first three blocks of the transceiver are the most critical and an increase in the gain value leads to a reduction in the noise figure. From the graphs, an increase in the gain of blocks 4 to 12 had no impact on the system noise figure.

From the formula, the dynamic range is given by:

$$\text{Dynamic range} = (2/3)*(11P_3 – MDS)$$

4.1 Dynamic range optimization.

From the equation of the dynamic range, it is evident that the transceiver gain is related to the system dynamic range. Variation of the system gain from 40dB to 100dB shows the following variation of the system gain from 40dB to 100Db

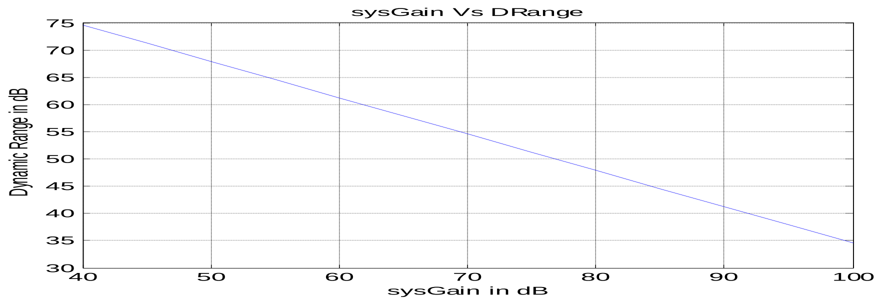


Figure 3: system gain Vs Dynamic range

From graph shown above in figure 3, the desired dynamic range and the corresponding system gain can be determined. The result from the graph shows that a reduction in the gain leads to an increase in the dynamic range while the results in table 1 shows that the gain of components after the IF stage have little effect on the system noise figure, P1dB and sensitivity.

Eliminating one of the Power amplifiers and rerunning the program yielded the following

Gain	NF	MDS	Sensitivity	Dynamic range
63.66	4.03	-113.96	-107.96	57.42

The results show an increase of the dynamic range to 57.42dB with the gain reduced to 63.66dB, the system NF remained unaffected by the change in system gain. Table 4 shows the parameters achieved after the optimization

Table 4: Parameters achieved after optimization of the Transceiver

Parameters	Optimized values achieved	Target Specification (DCS in brackets)
Sensitivity	-107.96 dBm	-102 dBm (-100dBm)
Maximum receive signal strength	-50.54 dBm	-15dBm
Noise figure	4.03dB	9.98dB(11.8dB)
C/N for BER performance	9dB	9dB
IIP_3	-27.82dBm	-19.5 dBm
P1dB	-37.82dBm	-29.5dBm
Dynamic range	57.42dB	87dB
Uplink	1710-1785MHz	1710-1785MHz
Downlink	1805-1880MHz	1805- 1880MHz
Channel band width	200KHz	200KHz

5. CONCLUSION

From the results in Table 4. the values of the components (gain and noise figure) have significant effects on the overall system parameters. Components placed after the mixers have little effect on the system parameters. The result also shows that the dynamic range is inversely related to the system gain. The dynamic gain can thus be increased by reducing the power amplifier gain value. This reduction in gain can be made up for by the use of highly directional antennas.

6. REFERENCES

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