

# VLSI Based Design and Performance of LNA for Impedance Matched Network Realization

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**Abstract :** In this paper Low Noise Amplifier (LNA) design and performance of Impedance Matched Network has been studied and analyzed. Agilent Advance design system used to amplify the detected weak signal from transceiver device. Transistor level approach provides the performance metrics such as Stability (S-parameter), Gain Bandwidth, Noise figure, VSWR and Impedance matching. VLSI tools such as Tanner EDA and simulation software's like MATLAB, Microwind, HSPICE used for the proposed work. With the help of these tools the important factors like Noise, Gain, Linearity, Power consumption has been briefly analyzed. The frequency range of proposed LNA operates at 2.5-5.1 GHz, Transducer Gain is 10 dB and it is operated at 50-Ohms. Gain, S-parameters and Noise Figure are optimized based on particle swarm optimization. Widely used in application areas such as Wireless Application for effective communication with reduced Noise Margin for users, Satellite Communication, Global Positioning System (GPS), Cordless Phones, Automotive RKE (Remote Keyless Entry).

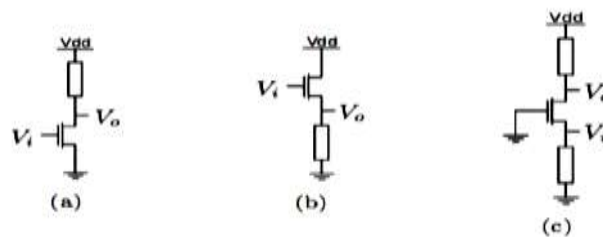
**IndexTerms -** Cascode amplifiers, Gain, HSPICE, Low Noise Amplifier (LNA), MATLAB, Microwind, Noise tradeoffs, Particle Swarm Optimization (PSO), Power, Signal-to-Noise Ratio (SNR).

## I. INTRODUCTION

For radio receiver communication systems, LNA is one of the main key component. The LNA design to satisfy the common requirements such as follows:

1. High gain and linearity
2. Matched input and output network
3. Low Noise level & power consumption of the device.

Common Source (CS), Common Gate (CG) and Common Drain (CD) are the three different topologies for impedance matched network as shown in below Fig.1.



**Fig.1.Different LNA topologies**

(a) Common Source (b) Common Gate (c) Common Drain

### 1.1 Cascode LNA

To operate in higher frequencies there is need of Cascode LNA structure that provides the quality and combined advantages of CS and CG topologies. The two ways for impedance matching LNA is either parallel resistance at input side or negative feedback resistance path. But both these methods are harmful to the amplifiers Noise figure factor. Hence Particle Swarm optimization technique used to optimize the impedance matched network.

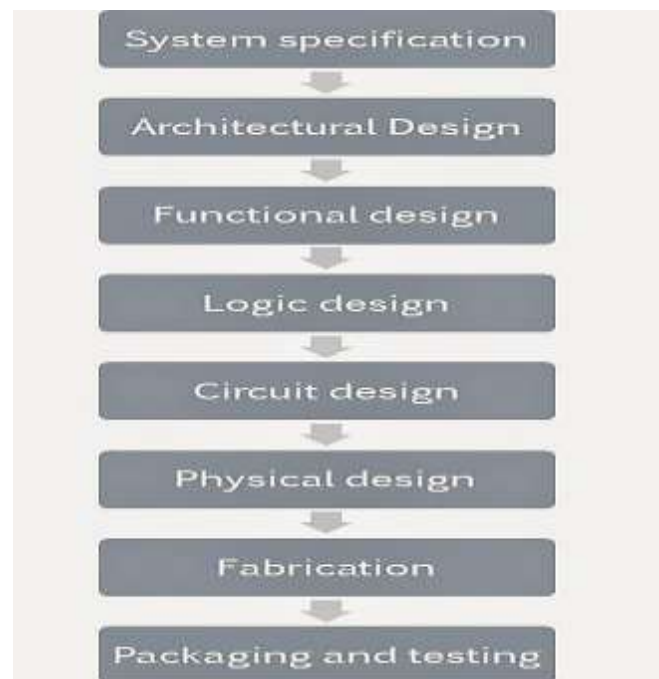
### 1.2 Particle Swarm Optimization (PSO) Technique

PSO computation process used as optimal and robust best location finder in a multidimensional search space. It has been used for solving LNA design biasing problem and to provide power optimization and better result. In this paper, PSO algorithm is linked with MATLAB electrical simulator, HSPICE.

### 1.3 VLSI DESIGN PROBLEMS

The below are the most important entities are:

- Area: Minimization of the chip area
- Speed: Operation speed should satisfy for faster circuit performance
- Power Dissipation: primary importance is low power consumption
- Design Time: should met the design specifications
- Testability: the chip needs easy testable by satisfying design time.



**Fig.2 VLSI design level flow chart**

The above Fig.2 shows that the standard VLSI design flow chart in various abstraction levels.

## II. LITERATURE SURVEY

### 2.1 RELATED WORKS ON LNA

CMOS Low Noise Amplifier design using inductive source degeneration network optimal procedure of PSO technique. Impedance matching connection achieved in two ways, (i) Connecting parallel resistance with  $1/g_{ms2}$  at the amplifier input, (ii) by building a negative parallel resistive feedback. Optimized design has better forward gain with considerable low noise figure. LNA design is working at 2.4 and implemented in 0.18  $\mu\text{m}$  technology. It has a forward gain of 32 dB and noise figure of 0.52 dB at 2.4GHz [1] [10]. The best performance of the designed circuit is achieved by continuous and repeated tune the designed circuit elements. To perform a circuit simulation using an electric computer-aided design (ECAD) software. To optimize active devices model parameters and sizes, passive devices parameters, biasing conditions, etc. it is in general a long time, high complexity and complicated work. A proper optimization method can be used to overcome this problem. In this work PSO algorithm in MATLAB which has been linked with an electrical simulator, HSPICE. The performance of LNA is considered in terms of NF, gain, s-parameters and power consumption [2] [13]. Genetic algorithm and simulation based optimization were combined to produce an accurate tool for LNA designing. Multi objective algorithms like NSGA-II are some of the best methods for designing of RF circuits where they can be even used for designing of other characteristics as distortion behavior and so on. This method used for designing of this circuit is a general method and it is usable for any other types of RF circuits [3]. Design of three stages cascode network [14] Prime challenge takes place to produce the appropriate value of gain while completing the design. By doing the number of experiment the design will meet the required gain value [4] [12]. Challenges encountered when designing ULP, ULV circuits, and introduce an extended ULP ULV biasing metric to optimize transistor performance. A combination of circuit techniques that are suitable for ULP ULV designs are presented, and a broadband resistive-feedback LNA in a 90-nm CMOS technology is designed using these techniques and its measured performance is compared with state-of-the-art works. The principles in the proposed low voltage and low-power design methodology presented here can be readily adapted and applied to other RF circuits. The power supply reduction is the important challenging issue while designing the LNA circuit [5] [11]. Higher gain would expand the coverage or communication distance. The goals in LNA design are to maximize its gain and minimize its noise figure with sufficient linearity and impedance matching. In order to achieved the key demands for Wi-MAX receiver characteristics, a LNA is designed should be met are the noise figure less than 3 dB and power gain should be more than 20 dB. Also good input and output impedance matching to achieved the S-parameter values [6] [8].

In implementation of CMOS, LNA design is one of the biggest challenges. This is because it is not just to optimize one target, but must meet several requirements such as sufficient gain which suppresses the noise, low noise figure (NF) to enhance receiver sensitivity, low power consumption to increase battery life and small die area to reduce the cost [7] [9]. Multiple tradeoffs between all targets should be considered in designing successful LNA. Based on the findings, self-biased inverter is the best design to be adopted in WSN for further research enhancement. This is because it gives the lowest power consumption which will be the main objective of the research.

## III. EXISTING SYSTEM

### A. MATCHING NETWORK DESIGN FOR AN HGA

In this type of LNA design, the matching circuit designed with the allocated gain values as shown in Fig.3.

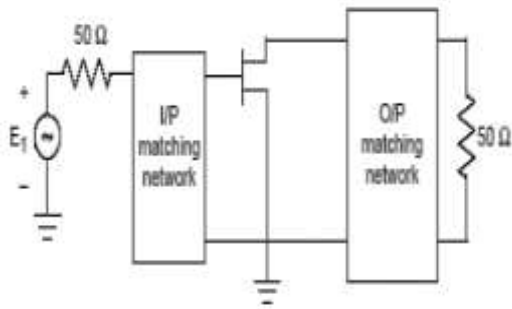


Fig.3 General Matching Networks

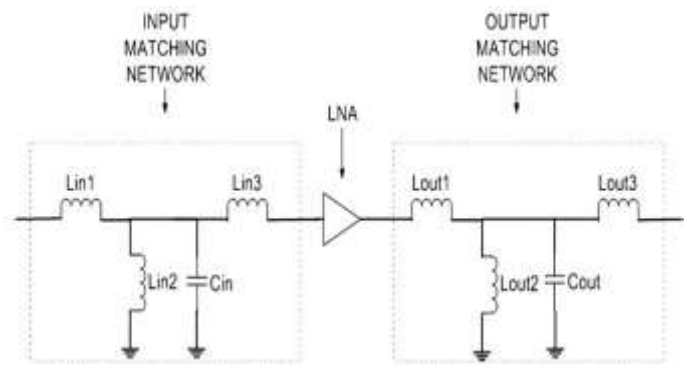


Fig.4 Matching network topology

High gain amplifier (HGA) has simple approach compared to LNA design. HGA chooses any arbitrary point on the constant gain circles in the stable region of operation and then input and the output matching networks can be designed. The below Fig.4 shows the matching network for HGA.

**B. DESIGNING MULTISTAGE AMPLIFIERS**

The need for using multistage amplifier designs is to provide greater gain and noise immunity by cascading LNA and HGA amplifiers while single stage amplifiers on the other side don't provide enough gain required for design. This Multiple Cascading structures with proper matching leads to have good stability and VSWR compared to individual stage designs. The implemented design as shown in Fig.5 will provide gain greater than 20 dB and a noise figure not more than 2 dB over a 10% bandwidth with center frequency at 16 GHz

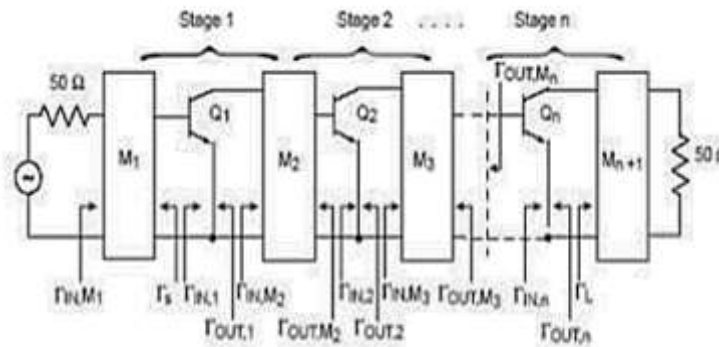


Fig.5 Multistage amplifier design input, output and inter-stage matching networks

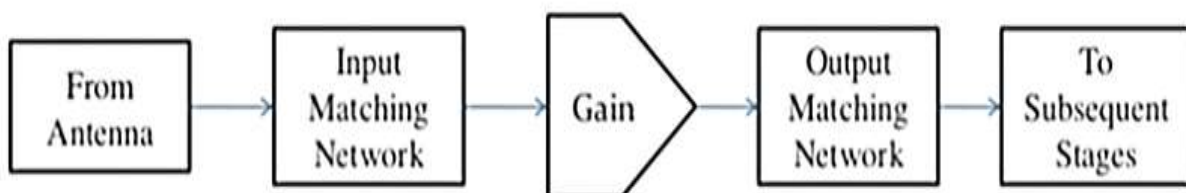
**IV. PROPOSED WORK**

*A. Design Procedure*

The proposed LNA design work with proper matching was carried out by the below sequence order:

1. To Set the Design parameters.
2. To Specify - Bandwidth, Impedance, Center Frequency, Noise Figure
3. Creation of an Amplifier Object and Perform Analysis
4. To Examine Stability, Power Gain and Noise Figure
5. Design the Input and Output Matching Networks
6. Complete Circuit Formation with the Matching Networks and the Amplifier
7. For Optimization of the Input & Output Matching Network

Several performance points such as Objective function, Choice of cost function, Optimization variables, Optimization method, Number of iterations/function evaluations, Tolerance value are considered. Fig.6 represents the fundamental block diagram of basic LNA is shown below



**Fig.6 Fundamental Block diagram of LNA**

By analyzing Friis Equation 4.1, LNA importance and its impact on SNR is analyzed.

$$F_{TOT} = F_1 + \frac{F_2}{1+G_1} + \frac{F_3}{1+G_2G_3} + \dots \quad (4.1)$$

Where  $F_i$  = noise factor of the  $i$ th component in the receiver chain,  
 $G_i$  = gain of the  $i$ th component.

By minimizing the noise Figure and maximizing the gain of the LNA, the total receiver noise Figure can be minimized. This relationship relates to receiver performance; the noise factor is defined as:

$$F = \frac{SNR_{OUT}}{SNR_{IN}} \quad (4.2)$$

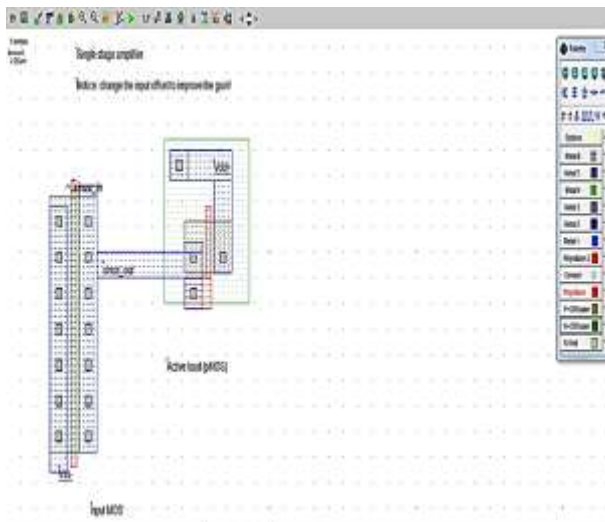
Therefore, a noiseless amplifier will have a noise factor of one. Noise factor can be related to the ratio of input SNR to the output SNR and commonly used by noise Figure (NF) = 10 log (F) which is expressed in dB. By re-arranging Equation (4.2), the following relationship is obtained:

$$SNR_{OUT} = \frac{SNR_{IN}}{NF_{TOT}} \quad (4.3)$$

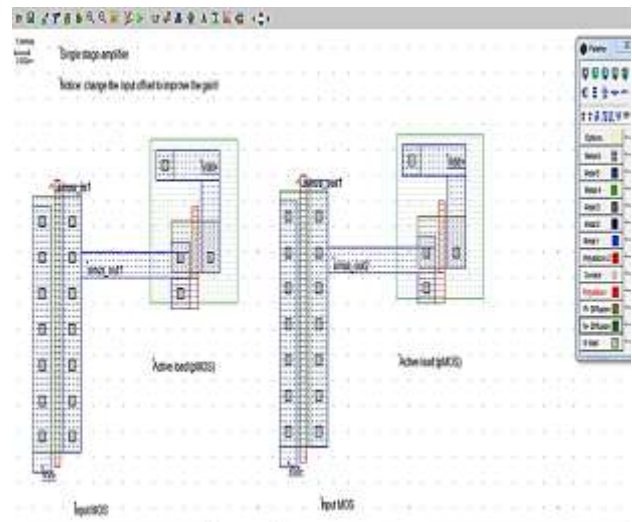
The above which shows that minimizing the total noise Figure will yield the highest output SNR. Designing very high-performance LNAs is an active research area and is of crucial importance for next-generation wireless technologies.

**A. LAYOUT LEVEL DESIGN**

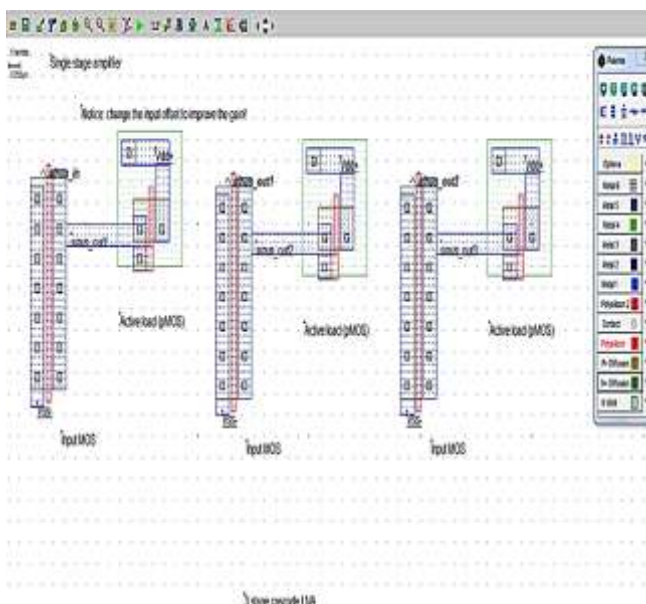
By Using Microwind tool the following Layout level design for Single stage, Two stage and Three stage Cascode amplifiers are designed and examined successfully. Single stage cascode amplifier layout design is shown in Fig.7. Similarly Two stage cascode layout is shown in Fig.8 and Three stage cascode layout is shown in Fig.9. respectively.



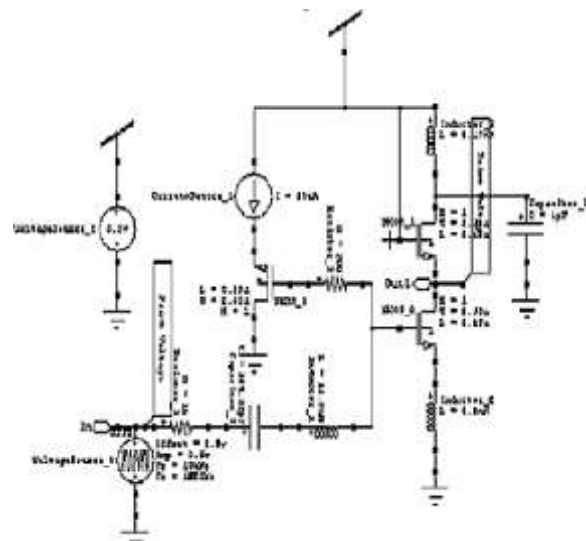
**Fig.7 Single stage cascode LNA**



**Fig.8 Two stage cascode LNA Layout Schematic**



**Fig.9 Three Stage Cascode LNA layout schematic**



**Fig.10 Single stage Cascode LNA network**

The above Fig.10 represents the Schematic diagram of Single stage cascode LNA network is designed by using Tanner EDA tool. As shown in Fig.11 each individual cascode stages will have amplifier inputs V1, V2 and V3, amplifier outputs V2, V3, V3 and gain G1, G2, G3 as labeled in above schematic design.

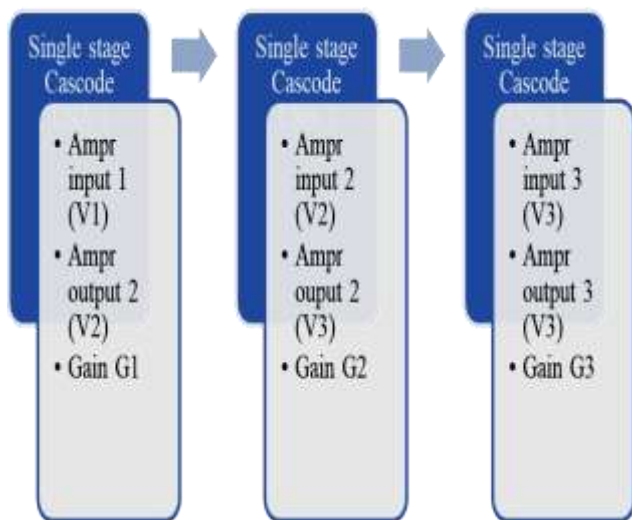


Fig.11 Three stage Cascode LNA block diagram

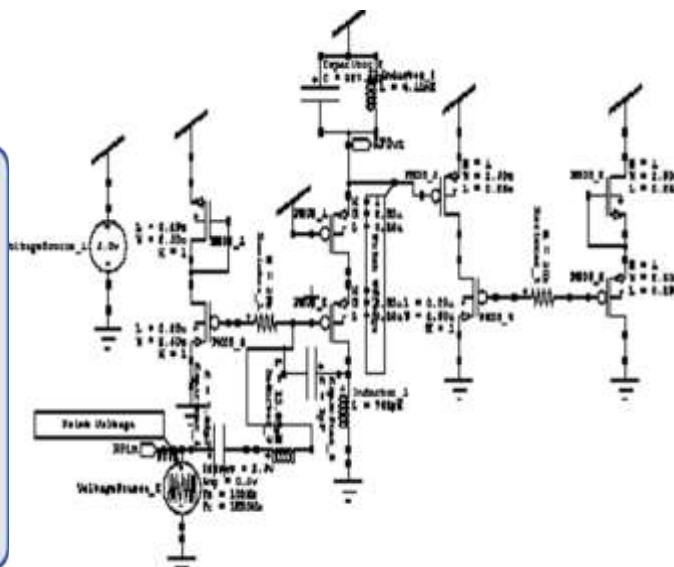


Fig.12 Cascode LNA using Buffer circuit

Cascode LNA using buffer circuit schematic is shown in the following representation Fig.12. Table.1 shows the design specifications and parameters used for LNA network. Existing LNA network simulation results is tabulated in the Table.2.

Table.1. The design parameters and specification

The position vector's elements	Design specifications
$I_{ref}$	NF
$W_{M1}$	IIP3
$W_{M2}$	Power dissipated
$W_{M3}$	$S_{11}$ (input return l)
$L_d$	$S_{22}$ (output return l)
$L_s$	$S_{21}$ (power gain)
$L_g$	$S_{12}$ (reverse power gain)

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### 3.1 Population and Sample

KSE-100 index is an index of 100 companies selected from 580 companies on the basis of sector leading and market capitalization. It represents almost 80% weight of the total market capitalization of KSE. It reflects different sector company's performance and productivity. It is the performance indicator or benchmark of all listed companies of KSE. So it can be regarded as universe of the study. Non-financial firms listed at KSE-100 Index (74 companies according to the page of KSE visited on 20.5.2015) are treated as universe of the study and the study have selected sample from these companies.

The study comprised of non-financial companies listed at KSE-100 Index and 30 actively traded companies are selected on the bases of market capitalization. And 2015 is taken as base year for KSE-100 index.

### 3.2 Data and Sources of Data

For this study secondary data has been collected. From the website of KSE the monthly stock prices for the sample firms are obtained from Jan 2010 to Dec 2014. And from the website of SBP the data for the macroeconomic variables are collected for the period of five years. The time series monthly data is collected on stock prices for sample firms and relative macroeconomic variables for the period of 5 years. The data collection period is ranging from January 2010 to Dec 2014. Monthly prices of KSE - 100 Index is taken from yahoo finance.

### 3.3 Theoretical framework

Variables of the study contains dependent and independent variable. The study used pre-specified method for the selection of variables. The study used the Stock returns are as dependent variable. From the share price of the firm the Stock returns are calculated. Rate of a stock salable at stock market is known as stock price.

Systematic risk is the only independent variable for the CAPM and inflation, interest rate, oil prices and exchange rate are the independent variables for APT model.

Consumer Price Index (CPI) is used as a proxy in this study for inflation rate. CPI is a wide basic measure to compute usual variation in prices of goods and services throughout a particular time period. It is assumed that rise in inflation is inversely associated to security prices because inflation is at last turned into nominal interest rate and change in nominal interest rates caused change in discount rate so discount rate increase due to increase in inflation rate and increase in discount rate leads to decrease the cash flow's present value (Jecheche, 2010). The purchasing power of money decreased due to inflation, and due to which the investors demand high rate of return, and the prices decreased with increase in required rate of return (Iqbal et al, 2010).

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## I. RESEARCH METHODOLOGY

The methodology section outline the plan and method that how the study is conducted. This includes Universe of the study, sample of the study, Data and Sources of Data, study's variables and analytical framework. The details are as follows;

### 3.1 Population and Sample

KSE-100 index is an index of 100 companies selected from 580 companies on the basis of sector leading and market capitalization. It represents almost 80% weight of the total market capitalization of KSE. It reflects different sector company's performance and productivity. It is the performance indicator or benchmark of all listed companies of KSE. So it can be regarded as universe of the study. Non-financial firms listed at KSE-100 Index (74 companies according to the page of KSE visited on 20.5.2015) are treated as universe of the study and the study have selected sample from these companies.

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Exchange rate is a rate at which one currency exchanged with another currency. Nominal effective exchange rate (Pak Rupee/U.S.D) is taken in this study. This is assumed that decrease in the home currency is inversely associated to share prices (Jecheche, 2010). Pan et al. (2007) studied exchange rate and its dynamic relationship with share prices in seven East Asian Countries and concluded that relationship of exchange rate and share prices varies across economies of different countries. So there may be both possibility of either exchange rate directly or inversely related with stock prices. Oil prices are positively related with share prices if oil prices increase stock prices also increase (Iqbal et al, 2012). Atallah (2001) suggested that oil prices cause positive change in the movement of stock prices. The oil price has no significant effect on stock prices (Dash & Rishika, 2011). Six month T-bills rate is used as proxy of interest rate. As investors are very sensitive about profit and where the signals turn into red they definitely sell the shares. And this sensitivity of the investors towards profit effects the relationship of the stock prices and interest rate, so the more volatility will be there in the market if the behaviors of the investors are more sensitive. Plethora (2002) has tested interest rate sensitivity to stock market returns, and concluded an inverse relationship between interest rate and stock returns. Nguyen (2010) studies Thailand market and found that Interest rate has an inverse relationship with stock prices.

KSE-100 index is used as proxy of market risk. KSE-100 index contains top 100 firms which are selected on the bases of their market capitalization. Beta is the measure of systematic risk and has a linear relationship with return (Horn, 1993). High risk is associated with high return (Basu, 1977, Reiganum, 1981 and Gibbons, 1982). Fama and MacBeth (1973) suggested the existence of a significant linear positive relation between realized return and systematic risk as measured by  $\beta$ . But on the other side some empirical results showed that high risk is not associated with high return (Michailidis et al. 2006, Hanif, 2009). Mollah and Jamil (2003) suggested that risk-return relationship is nonlinear perhaps due to high volatility.

### 3.4 Statistical tools and econometric models

This section elaborates the proper statistical/econometric/financial models which are being used to forward the study from data towards inferences. The detail of methodology is given as follows.

#### 3.4.1 Descriptive Statistics

Descriptive Statics has been used to find the maximum, minimum, standard deviation, mean and normally distribution of the data of all the variables of the study. Normal distribution of data shows the sensitivity of the variables towards the periodic changes and speculation. When the data is not normally distributed it means that the data is sensitive towards periodic changes and speculations which create the chances of arbitrage and the investors have the chance to earn above the normal profit. But the assumption of the APT is that there should not be arbitrage in the market and the investors can earn only normal profit. Jarque bera test is used to test the normality of data.

### 3.4.2 Fama-McBeth two pass regression

After the test statistics the methodology is following the next step in order to test the asset pricing models. When testing asset pricing models related to risk premium on asset to their betas, the primary question of interest is whether the beta risk of particular factor is priced. Fama and McBeth(1973)develop a two pass methodology in which the beta of each asset with respect to a factor is estimated in a first pass time series regression and estimated betas are then used in second pass cross sectional regression to estimate the risk premium of the factor. According to Blum (1968) testing two-parameter models immediately presents an unavoidable errors-in-the variables problem. It is important to note that portfolios (rather than individual assets) are used for the reason of making the analysis statistically feasible. Fama McBeth regression is used to attenuate the problem of errors-in-variables (EIV) for two parameter models (Campbell, Lo and MacKinlay, 1997). If the errors are in the  $\beta$  (beta) of individual security are not perfectly positively correlated, the  $\beta$  of portfolios can be much more precise estimates of the true  $\beta$  (Blum, 1968).

The study follow Fama and McBeth two pass regression to test these asset pricing models. The Durbin Watson is used to check serial correlation and measures the linear association between adjacent residuals from a regression model. If there is no serial correlation, the DW statistic will be around 2. The DW statistic will fall if there is positive serial correlation (in worst case, it will be near zero). If there is a negative correlation, the statistic will lie somewhere between 2 and 4. Usually the limit for non-serial correlation is considered to be DW is from 1.8 to 2.2. A very strong positive serial correlation is considered at DW lower than 1.5 (Richardson and smith, 1993).

According to Richardson and smith(1993) to make the model more effective and efficient the selection criteria for the shares in the period are: Shares with no missing values in the period, Shares with adjusted  $R^2 < 0$  or F significant (p-value)  $> 0.05$  of the first pass regression of the excess returns on the market risk premium are excluded. And Shares are grouped by alphabetic order into group of 30 individual securities (Roll and Ross, 1980).

#### 3.4.2.1 Model for CAPM

In first pass the linear regression is used to estimate beta which is the systematic risk.

$$R_i - R_f = (R_m - R_f)\beta \quad (3.1)$$

Where  $R_i$  is Monthly return of thesecurity,  $R_f$  is Monthly risk free rate,  $R_m$  is Monthly return of market and  $\beta$  is systematic risk (market risk).

The excess returns  $R_i - R_f$  of each security is estimated from a time series share prices of KSE-100 index listed shares for each period under consideration. And for the same period the market Premium  $R_m - R_f$  also estimated. After that regress the excess returns  $R_i - R_f$  on the market premium  $R_m - R_f$  to find the beta coefficient (systematic risk).

Then a cross sectional regression or second pass regression is used on average excess returns of the shares and estimated betas.

$$\hat{R}_i = \gamma_0 + \gamma_1\beta_i + \epsilon \quad (3.2)$$

Where  $\lambda_0 =$  intercept,  $\hat{R}_i$  is average excess returns of security  $i$ ,  $\beta_i$  is estimated be coefficient of security  $i$  and  $\epsilon$  is error term.

#### 3.4.2.2 Model for APT

In first pass the betas coefficients are computed by using regression.

$$R_i - R_f = \beta_{i1}f_1 + \beta_{i2}f_2 + \beta_{i3}f_3 + \beta_{i4}f_4 + \epsilon \quad (3.3)$$

Where  $R_i$  is the monthly return of stock  $i$ ,  $R_f$  is risk free rate,  $\beta_i$  is the sensitivity of stock  $i$  with factors and  $\epsilon$  is the error term.

Then a cross sectional regression or second pass regression is used on average excess returns of the shares on the factor scores.

$$\hat{R}_i = \gamma_0 + \gamma_1\beta_1 + \gamma_2\beta_2 + \gamma_3\beta_3 + \gamma_4\beta_4 + \epsilon_i \quad (3.4)$$

Where  $\hat{R}_i$  is average monthly excess return of stock  $i$ ,  $\lambda$  = risk premium,  $\beta_1$  to  $\beta_4$  are the factors scores and  $\epsilon_i$  is the error term.

### 3.4.3 Comparison of the Models

The next step of the study is to compare these competing models to evaluate that which one of these models is more supported by data. This study follows the methods used by Chen (1983), the Davidson and Mackinnon equation (1981) and the posterior odds ratio (Zellner, 1979) for comparison of these Models.

#### 3.4.3.1 Davidson and MacKinnon Equation

CAPM is considered the particular or strictly case of APT. These two models are non-nested because by imposing a set of linear restrictions on the parameters the APT cannot be reduced to CAPM. In other words the models do not have any common variable. Davidson and MacKinnon (1981) suggested the method to compare non-nested models. The study used the Davidson and MacKinnon equation (1981) to compare CAPM and APT.

This equation is as follows;

$$R_i = \alpha R_{APT} + (1 - \alpha) R_{CAPM} + e_i \quad (3.5)$$

Where  $R_i =$  the average monthly excess returns of the stock  $i$ ,  $R_{APT} =$  expected excess returns estimated by APT,  $R_{CAPM} =$  expected excess returns estimated by CAPM and  $\alpha$  measure the effectiveness of the models. The APT is the accurate model to forecast the returns of the stocks as compare to CAPM if  $\alpha$  is close to 1.

#### 3.4.3.2 Posterior Odds Ratio

A standard assumption in theoretical and empirical research in finance is that relevant variables (e.g stock returns) have multivariate normal distributions (Richardson and smith, 1993). Given the assumption that the residuals of the cross-sectional regression of the CAPM and the APT satisfy the IID (Independently and identically distribution) multivariate normal assumption



(Campbell, Lo and MacKinlay, 1997), it is possible to calculate the posterior odds ratio between the two models. In general the posterior odds ratio is a more formal technique as compare to DM equation and has sounder theoretical grounds (Aggelidis and Maditinos, 2006).

The second comparison is done using posterior odd ratio. The formula for posterior odds is given by Zellner (1979) in favor of model 0 over model 1.

The formula has the following form;

$$R = [ESS_0/ESS_1]^{N/2} N^{K_0-K_1/2} \quad (3.6)$$

Where  $ESS_0$  is error sum of squares of APT,  $ESS_1$  is error sum of squares of CAPM,  $N$  is number of observations,  $K_0$  is number of independent variables of the APT and  $K_1$  is number of independent variables of the CAPM. As according to the ratio when;  $R > 1$  means CAPM is more strongly supported by data under consideration than APT.  $R < 1$  means APT is more strongly supported by data under consideration than CAPM.

#### IV. RESULTS AND DISCUSSION

##### 4.1 Results of Descriptive Statics of Study Variables

Table 4.1: Descriptive Statics

Variable	Minimum	Maximum	Mean	Std. Deviation	Jarque-Bera test	Sig
KSE-100 Index	-0.11	0.14	0.020	0.047	5.558	0.062
Inflation	-0.01	0.02	0.007	0.008	1.345	0.510
Exchange rate	-0.07	0.04	0.003	0.013	1.517	0.467
Oil Prices	-0.24	0.11	0.041	0.060	2.474	0.290
Interest rate	-0.13	0.05	0.047	0.029	1.745	0.418

Table 4.1 displayed mean, standard deviation, maximum minimum and jarque-bera test and its p value of the macroeconomic variables of the study. The descriptive statistics indicated that the mean values of variables (index, INF, EX, OilP and INT) were 0.020, 0.007, 0.003, 0.041 and 0.047 respectively. The maximum values of the variables between the study periods were 0.14, 0.02, 0.04, 0.41, 0.11 and 0.05 for the KSE- 100 Index, inflation, exchange rate, oil prices and interest rate.

The standard deviations for each variable indicated that data were widely spread around their respective means.

Column 6 in table 4.1 shows jarque bera test which is used to check the normality of data. The hypotheses of the normal distribution are given;

$H_0$ : The data is normally distributed.

$H_1$ : The data is not normally distributed.

Table 4.1 shows that at 5 % level of confidence, the null hypothesis of normality cannot be rejected. KSE-100 index and macroeconomic variables inflation, exchange rate, oil prices and interest rate are normally distributed.

The descriptive statistics from Table 4.1 showed that the values were normally distributed about their mean and variance. This indicated that aggregate stock prices on the KSE and the macroeconomic factors, inflation rate, oil prices, exchange rate, and interest rate are all not too much sensitive to periodic changes and speculation. To interpret, this study found that an individual investor could not earn higher rate of profit from the KSE. Additionally, individual investors and corporations could not earn higher profits and interest rates from the economy and foreign companies could not earn considerably higher returns in terms of exchange rate. The investor could only earn a normal profit from KSE.

##### Figures and Tables

Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table captions should appear above the tables. Insert figures and tables after they are recited in the text. Use the abbreviation “**Fig.1**” in the text, and “**Figure 1**” at the beginning of a sentence.

Use **10 point Times New Roman** for figure labels. Use words rather than symbols or abbreviations when writing figure-axis labels to avoid confusing the reader. As an example, write the quantity “Magnetization”, or “Magnetization, M”, not just “M”.

Table 1 Table Type Styles

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#### IV. ACKNOWLEDGMENT

The preferred spelling of the word “acknowledgment” in America is without an “e” after the “g”. Avoid the stilted expression, “One of us (R.B.G.) thanks...”  
Instead, try “R.B.G. thanks”. Put applicable sponsor acknowledgments here; DONOT place them on the first page of your paper or as a footnote.

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