ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

Qualitative Analysis of a Small-Signal MOSFET Based Sziklai Pair Amplifier

Sachchida Nand Shukla

Professor, Department of Physics & Electronics, Dr. RamManohar Lohia Avadh University, Ayodhya, UP, India

ABSTRACT: New circuit models of MOSFET based RC coupled small-signal Sziklai pair amplifiers are proposed and qualitatively analyzed for the first time. Both the proposed circuits crop fairly high current gains, moderate range bandwidths, significantly low THDs and voltage gains considerably greater than unity at 10mV, 1KHz input AC signal. Qualitative features of the proposed amplifiers offer them a flexible application range as high voltage gain and high power gain amplifiers in audible frequency range. Variation of voltage gain with frequency and different biasing resistances, input and output noises at various operating frequencies, temperature dependency of performance parameters and total harmonic distortion of the amplifier are pursued for providing wide spectrum to the qualitative studies. Proposed circuits are also free from poor response problem of small-signal Darlington pair amplifiers at higher frequencies and narrow-bandwidth response of PNP and NPN driven small-signal Sziklai pair amplifiers.

KEYWORDS: Sziklai Pair, Small signal MOSFET Amplifiers, Circuit Simulation, Circuit Analysis.

I. INTRODUCTION

Common-Source-MOSFET acts as good amplifier for small-signals with high input impedance, low output impedance, high current gain and a voltage gain just greater than unity [1]-[4]. Various researches explored CS-MOSFET suitable for developing high speed switching circuits, memory segments, logic gates, buffer amplifiers, power amplifiers and trans-conductance amplifiers [1]-[6]. However, use of CS-MOSFET in Sziklai-pair topology [7]-[11] to develop a small-signal amplifier results a voltage gain below unity with poor frequency response and low order current gain. Consequently this configuration is yet to be established as fruitful system to design small-signal audio-range amplifier.

Unlike Darlington pair [1], [12]-[14] Sziklai-pair topology uses two similar active devices of opposite polarities (such as one NPN and other PNP transistor in CE-CE connection in case of BJT-Sziklai-pair, which is also known as Complementary-feedback-pair) [7]-[11]. Polarity of this compound configuration is always determined by the *driver* device. For example, in case of BJT- Sziklai-pair (Complementary-feedback-pair), the pair having PNP driver and NPN output transistor behaves like a PNP transistor and vice versa [7] -[11].

Author recently developed a series of RC coupled small-signal amplifiers using Sziklai pairs (BJT-complementary-feedback-pair topology) [8]-[11]. Present investigation is the extension of mentioned series of work with MOSFETs.

Present exploration focuses around MOSFET based Sziklai-pairs those uses one N-MOSFET and other P-MOSFET in respective composite units [7]-[11]. These Sziklai or Complementary-feedback pairs with MOSFETs are explored herein as new circuit models of small-signal RC coupled amplifiers suitable for scaling low order AC signals in audio frequency range.

II. DESCRIPTION OF CIRCUITS

Present work comprises a qualitative comparison between two small-signal RC coupled amplifiers using 'MOSFET-Sziklai-pair' in respective circuit configurations (Fig.1 and Fig.2).

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

Basic designs of both the proposed circuits are similar except positions of the MOSFETS in Sziklai pair [7]-[11]. The Sziklai pair in Fig.1 uses N-MOSFET at driver position which determines the nature of the paired unit. Similarly, proposed amplifier of Fig.2 uses P-MOSFET at driver position in the respective Sziklai pair. Both the proposed circuits are biased using voltage divider biasing methodology with properly selected passive biasing components and using an additional biasing resistance R_A in their design. Component details of respective circuits are summarized in TABLE I.

PSpice simulation (Student version 9.2) is performed to carry out present investigations [15]. Observations are procured by feeding the amplifier circuits with 1V AC input signal source, from which, a small-distortion-less AC signal of 10mV for both the amplifiers (Fig.1 and 2) at 1KHz frequency is drawn as input for the amplification purpose.

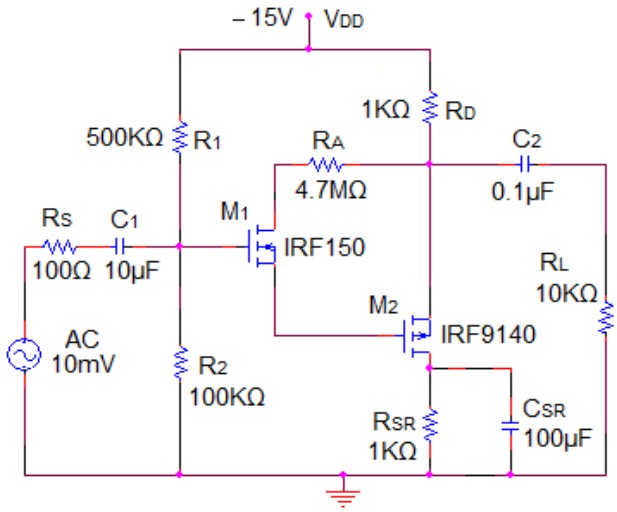

Fig.1. N-MOS Sziklai pair amplifier (Circuit-1)

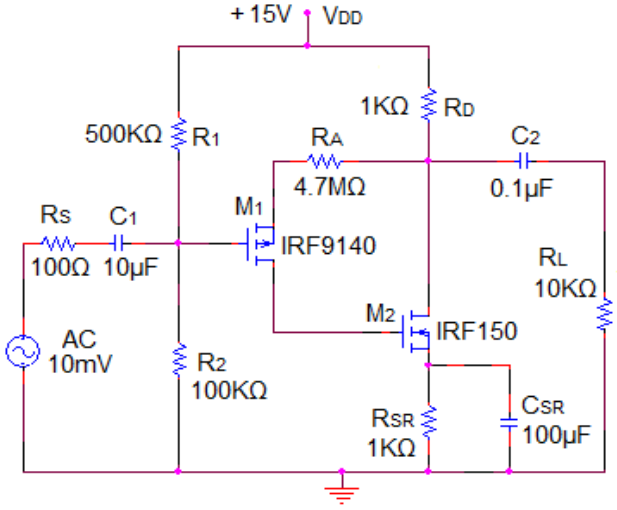

Fig.2. P-MOS Sziklai pair amplifier (Circuit-2)

TABLE-I: COMPONENT DETAILS OF THE CIRCUITS UNDER DISCUSSION

Components	Proposed Amplifier (Circuit-1)	Proposed Amplifier (Circuit-2)
M1 (MOSFET)	IRF150 (NMOS, V_{TO}= 2.831V)	IRF9140 (PMOS, V_{TO}=-3.67V)
M2 (MOSFET)	IRF9140 (PMOS)	IRF150 (NMOS)
R_S (Input Source biasing resistance)	100 Ω	100 Ω
R_1 (Biasing resistance)	500 KΩ	500 KΩ
R_2 (Biasing resistance)	100KΩ	100KΩ
R_D (Drain Biasing resistance)	1KΩ	1KΩ
R_{SR} (Source Biasing resistance)	1KΩ	1KΩ
R_{A1}(Additional Biasing resistance)	4.7MEG	4.7MEG
R_L (Load resistance)	1KΩ	1KΩ
C_1 (Input coupling capacitor)	10µF	10µF
C_2 (Output coupling capacitor)	0.1µF	0.1µF
C_{SR} (Source by-pass capacitor)	100µF	100µF
DC Biasing Supply	+15V DC	+15V DC
Input AC Signal range for fair output	10-700mV(1KHz)	10-400mV(1KHz)

Amplifiers of Fig.1 and Fig.2 provide fair and distortion-less results in 10-700mV and 10-400mV range of AC input signals respectively at 1KHz frequency. However the best results for both the amplifiers are received at 10mV AC inputs.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

III. RESULTS AND DISCUSSIONS

Fig.3 depicts the variation of voltage gain as a function of frequency. At biasing parameter values of TABLE I, the amplifier of Fig.1 produces 4.711 maximum voltage gain A_{VG} (with 47.702mV peak output voltage), 30.536 maximum current gain A_{IG} (with 4.763µA peak output current) and 388.028KHz bandwidth B_W (with f_L=177.709Hz and f_H=388.206KHz) whereas the amplifier of Fig.2 generates 6.753 maximum voltage gain A_{VG} (with 72.287mV peak output voltage), 42.868 maximum current gain A_{IG} (with 7.227µA peak output current) and 325.821KHz bandwidth B_W (with f_L=187.977Hz and f_H=326.009KHz).

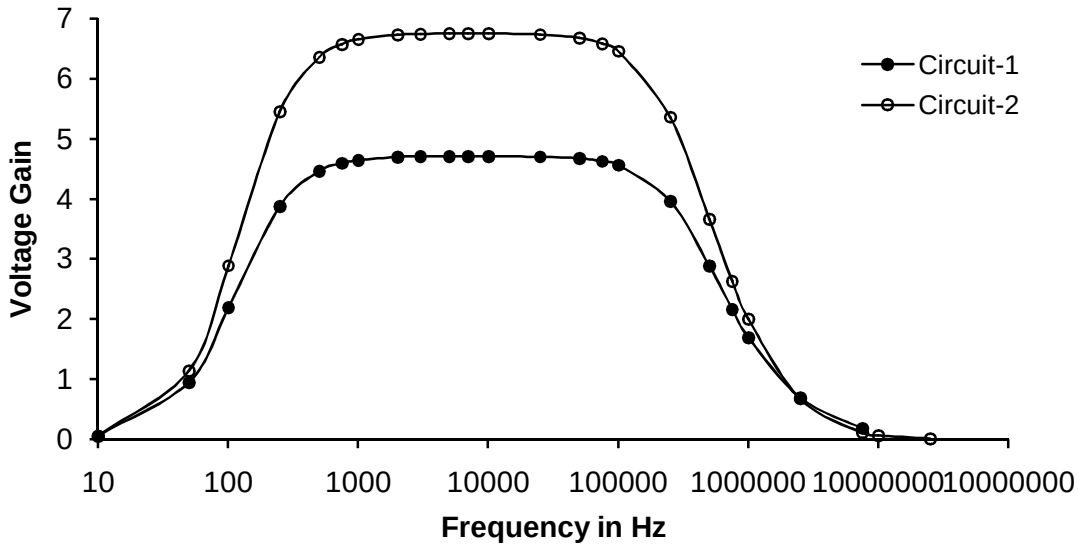

Fig.3. Voltage gain as a function of frequency

Usually CS-MOSFETs in RC coupled small-signal amplifier configuration are known for unity gain performance, and therefore popularly used as buffer amplifiers [1]-[4]. However, set of proposed amplifiers with CS-CS arrangement of MOSFETs in Sziklai-pair [7]-[11] are producing significantly higher voltage gain than unity. Similarly, the proposed circuits also produce better bandwidth than PNP Sziklai pair (B_W=4.80KHz) and NPN Sziklai pair (B_W=15.10KHz) amplifier circuits, recently designed by the author (Chapter-8 and Chapter-9). In addition, the proposed design is also free from the consequences with frequency response of Darlington pair small-signal amplifiers at higher frequencies and presented 180^o phase shifted output [12]-[14].

Total Harmonic Distortion percentage (THD%) for proposed amplifiers is calculated using following formula [8]-[11], [16]-[17].

$$\% \text{ nth harmonic distortion} = \%Dn = \frac{|An|}{|A1|} \times 100\%$$

In light of mentioned formula, THD for proposed amplifier of Fig.1 for 10 harmonics terms is observed to be 0.39% whereas it is recorded for amplifier of Fig.2 with a value 0.97% for similar number of harmonic terms. These values of THDs are considerably lower than the values of THDs for NPN-Sziklai pair (0.73%) and PNP-Sziklai pair amplifiers (1.72%) [8], [10].

Variation of A_{VG}, A_{IG} and bandwidth with temperature for both the amplifiers is also measured and respective outcomes are listed in TABLE II. Referring TABLE II, voltage gain, current gain and the bandwidth for amplifier of Fig.1

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

gradually decreases with temperature elevation but the gradient of decrement for voltage and current gains are lower than bandwidth. Almost similar situation exists with the amplifier of Fig.2. Perhaps due to the typical configuration of MOSFETs in Sziklai-pair the Drain-Source resistance of the composite unit for amplifier of Fig.1 nominally increases with temperature which causes effective voltage/current gains to reduce with a low gradient [16]-[17]. On the other hand, reduction in bandwidth with temperature elevation can be associated with the effective circuit capacitance at different temperatures. At increasing temperature, perhaps the series combination of the capacitance due to MOSFETs in composite unit and the output coupling capacitor C_2 causes improvement in the effective circuit capacitance which in turn reduces the bandwidth [16]-[17].

TABLE-II: VARIATION OF $\mathbf{A_{VG}}$, $\mathbf{A_{IG}}$ AND BANDWIDTH $\mathbf{B_W}$ WITH TEMPERATURE

Temperature (°C)	Circuit-1			Circuit-2		
	Voltage Gain	Current Gain	Bandwidth KHz	Voltage Gain	Current Gain	Bandwidth KHz
-30	4.7319	30.656	391.019	6.8264	43.272	333.658
-20	4.7281	30.634	390.494	6.8132	43.199	331.639
-10	4.7244	30.613	390.026	6.8002	43.127	330.007
0	4.7207	30.592	389.421	2873	43.055	328.070
10	4.7171	30.571	388.898	2747	42.985	327.243
27	4.7110	30.536	388.028	2535	42.868	325.821
50	4.7030	30.489	386.913	2257	42.713	320.297
80	4.6928	30.431	385.356	6.6905	42.518	317.508

Fig.4 shows the variation of maximum voltage gain (A_{VG}) with added resistance R_A [16]-[17]. The overall property is that A_{VG} is almost constant at higher incremental values of R_A greater than 15K Ω, for both the proposed circuit configurations. Additionally, the gain value falls below unity for R_A<160Ω for amplifier of Fig.1 and the similar situation exists for amplifier of Fig.2 for R_A<130Ω.

Analytical study shows that increasing R_A (for both the considered amplifiers) does not affect gate to source voltages of MOSFETs in the pair, rather it mildly increases drain to source voltage and the drain current. This comes out as gradual increase in load current and forces voltage gain to increase with low gradient.

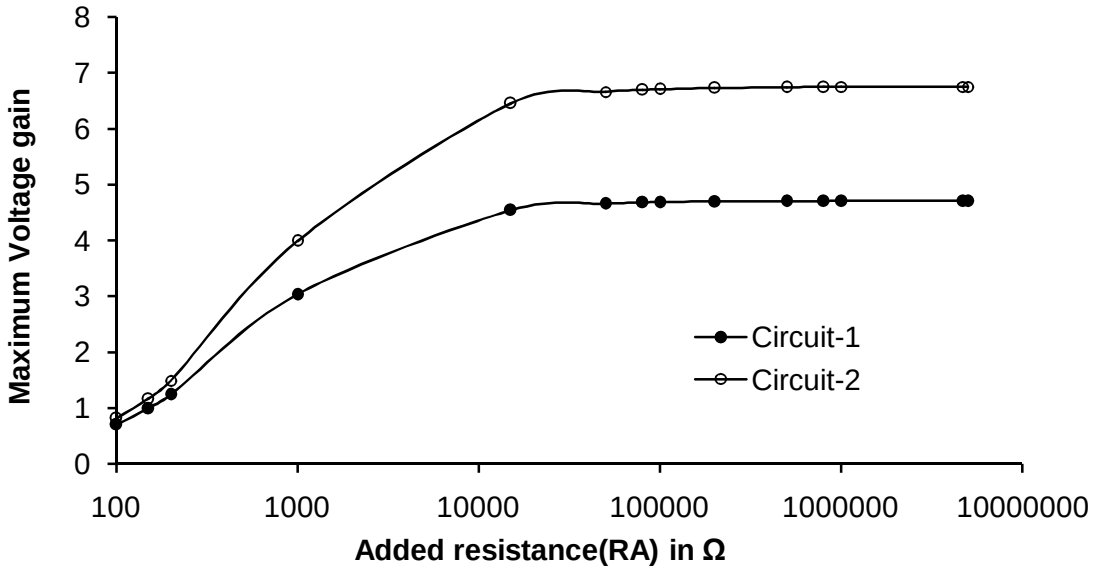

Fig.4. Variation of Maximum voltage with Added resistance R_A

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

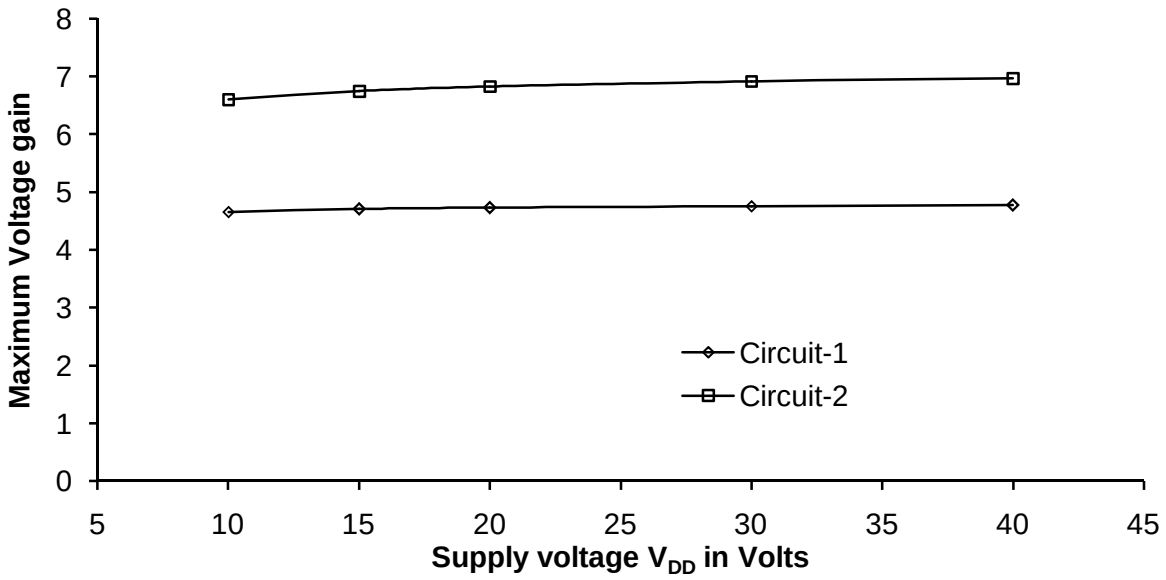

Fig.5. Variation of Maximum voltage gain with supply voltage

Effect of DC supply voltage V_{DD} on maximum voltage gain A_{VG} for both the amplifiers is depicted in Fig.5. Maximum voltage gain for both the amplifiers gradually increases with DC biasing supply voltage. Referring Fig.5; MOSFET-feedback-pairs of Fig.1 and Fig.2 switch-ON at 10V, show consistent and fair response between 10-40V and produce heavy distortion in output waveform beyond 40V of DC biasing. In fact, MOSFETs in the composite unit of proposed amplifiers hold threshold voltages V_{TO}= 2.831V (for N-MOSFET IRF150) and V_{TO}= -3.67V (for P-MOSFET IRF9140). Below 10V of V_{DD}, driving potential to gates of M1 and M2 MOSFETs are found less than respective threshold voltages [16]-[17]. This maintains respective composite units into OFF state. At 10V of V_{DD}, driving gate voltages of M1 and M2 cross the forbidden boundary of V_{TO}. This brings respective composite units into conducting state. In the range of 10-40V, gate voltage of both the MOSFETs in composite units crosses V_{TO}. This ensures the participation of each MOSFET in the amplification process and brings voltage gain to increase gradually with V_{DD}. However, as V_{DD} increases beyond 40V, the channel width broadens and causes sudden enhancement in I_D which in turn forces for an abrupt voltage drop across the load and distorts the frequency response curve [16]-[17].

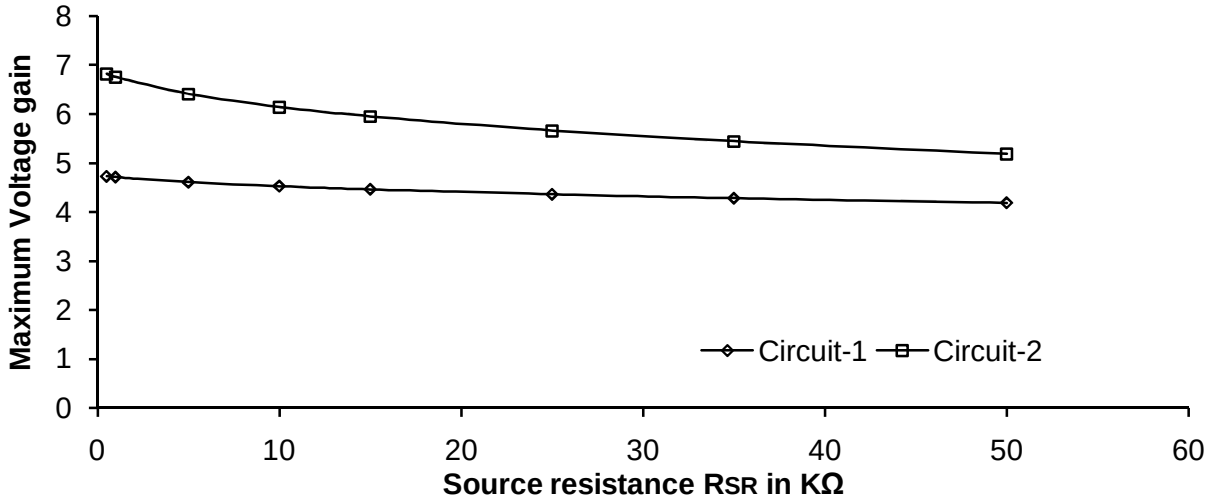

Fig.6. Variation of Maximum voltage gain with Source resistance

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

Fig.6. shows the variation of maximum voltage gain with R_{SR} for amplifiers of Fig.1 and Fig.2. Voltage gain curves for respective amplifiers gradually decrease at rising values of source resistances. These amplifiers fairly respond in 500Ω to 50 KΩ range of R_{SR} and beyond this range produce distortion-full outputs. The analytical findings suggest that increasing values of R_{SR} considerably increases gate to source voltages of respective MOSFETs with a significant decrease in drain to source voltages. This concurrently reduces the load current and hence the voltage gain of respective circuits.

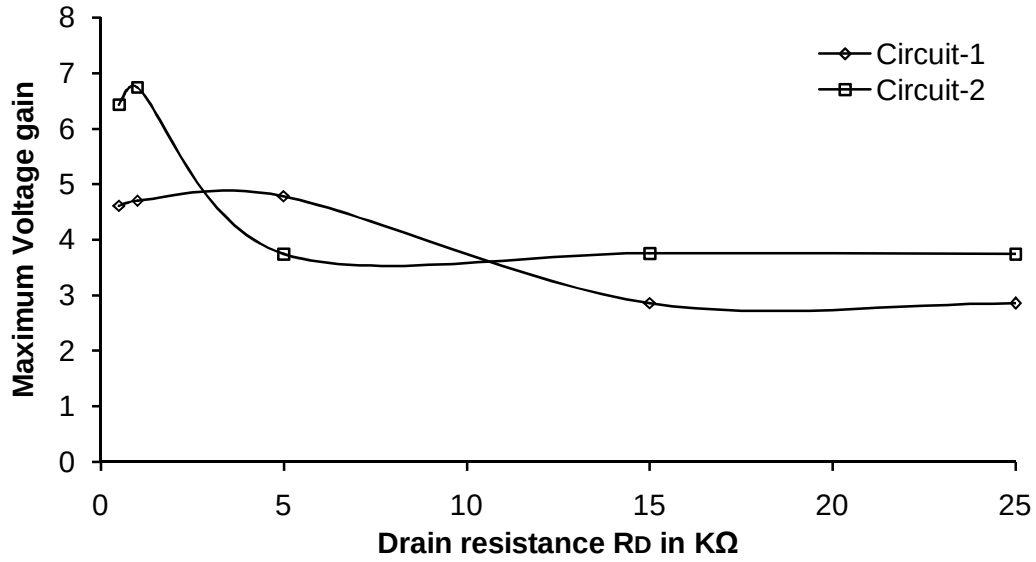

Fig.7. Variation of Maximum voltage gain with Drain resistance

Maximum voltage gain of respective amplifiers highly depends on the drain resistance R_D. Corresponding outcomes are depicted in Fig.7. Figure indicates that the gain first increases to a maximum, thereafter falls down to a critical point and finally settled with a tendency of saturation. The maxim of the voltage gain for Fig.1 amplifier appears at 5KΩ whereas for amplifier of Fig.2 it is obtained at 1KΩ of R_D.

The analytical findings suggest that primarily the increasing values of R_D mildly decreases gate to source voltages of respective MOSFETs with a significant decrease in source current and almost no change in drain to source voltages. This increases load current and therefore the respective voltage gain. However, further increase in R_D beyond critical point brings a significant decrease in gate to source voltages and improves drain to source voltages to a considerable extent. This reduces load current and respective voltage gain.

Variations of maximum voltage gain with load resistance R_L is also estimated but not shown in form of figure. it is observed that voltage gain rises up linearly in low resistance range up to 50KΩ and 100KΩ value of R_L for amplifiers of Fig.1 and Fig.2 respectively. However, for higher R_L values it gradually acquires a sustained level. The rising and saturation of the voltage gain with R_L is soundly found in accordance of the usual behaviour of small signal amplifiers [8]-[11], [13]-[14], [16]-[17].

The input and output noises for both the amplifiers at 100Hz, 1KHz and 1MHz frequencies are observed and respective values are listed in TABLE III. Usually, resistors and semiconductor devices in electronic circuits generate noises during amplification process [15]. TABLE clearly indicates that levels of input and output noises are significantly low for amplifiers and within the permissible limit. Both varieties of noises reduce with elevation of operating frequency. Moreover, it also increases with temperature which is an obvious feature due to generation of more carriers and their higher collision rate at elevated temperature.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

TABLE-III: VARIATION OF INPUT AND OUTPUT NOISES WITH TEMPERATURE FOR CIRCUIT-1 AND CIRCUIT-2

Temp (^{O}C)	Total Output Noise (Volts/√Hz)						Total Input Noise (Volts/√Hz)					
	Fig.1. amplifier			Fig.2 amplifier			Fig.1. amplifier			Fig.2 amplifier		
	100Hz x10^{-8}	1KHz x10^{-8}	1MHz x10^{-9}	100Hz x10^{-8}	1KHz x10^{-8}	1MHz x10^{-9}	100Hz x10^{-8}	1KHz x10^{-9}	1MHz x10^{-9}	100Hz x10^{-8}	1KHz x10^{-9}	1MHz x10^{-9}
-30	5.578	1.320	2.277	6.816	1.795	2.902	2.535	2.828	1.327	2.343	2.669	1.387
-20	5.688	1.346	2.323	6.947	1.829	2.947	2.587	2.886	1.357	2.391	2.724	1.419
-10	5.796	1.371	2.367	7.075	1.861	2.989	2.637	2.943	1.386	2.438	2.778	1.451
0	5.902	1.396	2.411	7.200	1.894	3.030	2.687	2.999	1.414	2.484	2.831	1.483
10	6.006	1.421	2.453	7.323	1.925	3.070	2.736	3.054	1.442	2.529	2.884	1.514
27	6.178	1.461	2.524	7.525	1.977	3.134	2.817	3.145	1.490	2.604	2.971	1.566
50	6.403	1.514	2.616	7.789	2.044	3.215	2.923	3.265	1.552	2.702	3.085	1.635
80	6.683	1.581	2.731	8.118	2.128	3.312	3.056	3.414	1.630	2.825	3.227	1.723

IV. CONCLUSION

As a novel approach, MOSFETs of different polarities are used in Sziklai pair topology to explore the proposed set of circuits as small-signal amplifiers. An additional biasing resistance R_A (ranging in 15KΩ to 5MΩ) is to be essentially included in both the circuits to maintain their voltage/current amplification property. Amplifier of Fig.1 can process small-signals ranging in 10-700mV in the frequency band extended from 177.709Hz to 388.206 KHz at 1 KHz input frequency. However these ranges for amplifier of Fig.2 are 10-400mV and 187.977 Hz to 326.009 KHz respectively. With moderate range bandwidths, high current gains and voltage gains noticeably greater than unity, the proposed amplifiers generate only 0.392% and 0.97% harmonic distortion respectively which is fairly adaptive for small-signal amplifiers. The proposed amplifiers show considerable response for V_{DD}, R_{SR}, R_D and R_L almost in the same way as is usually observed for small-signal RC coupled Common Source amplifiers. Observed values of voltage and current gains logically set the power gain of the proposed amplifiers considerably larger than unity. Collectively, these features provide a unique flavour to the proposed amplifiers in the respective class of MOSFET based small-signal audio amplifiers.

REFERENCES

[1] R. L. Boylestad and L. Nashelsky, *Electronic Devices and Circuit Theory*, Pearson Education Asia, 9th ed., p.633, 638, 2008
[2] David A. Bell, *Electronic devices and circuit*, Prentice Hall of India, 3rd ed., 687, 2002
[3] E. Vernon, D. Bryson, E.S. Orr and S.N. Mohammad, *Role of supply voltage and load capacitors in the experimental operations of small signal MOSFET amplifiers*, Solid State Electronics, Vol.45(12), p-2033, 2001
[4] E. Vernon, D. Bryson, E.S. Orr and S.N. Mohammad, *Experimental studies of frequency response of small signal MOSFET amplifiers*, Solid State Electronics, Vol. 46(2), p-287-294, 2002
[5] P. McGregor, J. Mena, C.A.T. Salama, *Small signal high frequency performance of power MOS transistors*, Solid State Electronics, Vol. 27(5) p-419, 1984
[6] P. M. Figueiredo and J. C. Vital, *The MOS capacitor amplifier*, IEEE Transactions on Circuits and Systems-II: Express Briefs, Vol. 51, No.3, 2004
[7] G. C. Sziklai, *Push-pull complementary type transistor amplifier.*, U.S. Patent 2,762,870, September 11, 1956
[8] B. Pandey, S. Srivastava, S. N. Tiwari, J. Singh and S. N. Shukla, *Qualitative Analysis of Small-Signal Modified Sziklai Pair Amplifier*, Indian Journal of Pure and Applied Physics, Vol.50 (4), p-272, 2012
[9] S.N. Shukla, B. Pandey and S. Srivastava, *Qualitative Study of a New Circuit Model of Small-signal Amplifier using Sziklai pair in Compound Configuration*, Procd. IEEE-ICSE2012 (Proceedings of 10th IEEE International Conference on Semiconductor Electronics, September 19-21, 2012, Kuala Lumpur), , IEEE-Xplore, p-563-569, 2012
[10] S.N. Shukla and S. Srivastava, *A New Circuit Model of Small-signal Sziklai pair amplifier*, International Journal of Applied Physics and Mathematics, Vol.3, No.4, p-231-236, 2013
[11] S.N. Shukla and S. Srivastava, *Development and Qualitative Analysis of a New Circuit Model of Two-stage Small-signal Sziklai pair Amplifier*, International Journal of Computer Theory and Engineering, Vol.5, No. 4, p-668-672, 2013
[12] A.M.H. Sayed ElAhl, M.M.E. Fahmi and S. N. Mohammad, *Qualitative analysis of high frequency performance of modified Darlington pair*, Solid State Electronics, 46, p-593, 2002

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

[13] S. N. Tiwari and S. N. Shukla, *Qualitative Analysis of Small Signal Modified Darlington Pair and Triple Darlington Amplifiers*, Bulletin of Pure and Applied Science, 28D No.1, p-01, 2009
[14] S. N. Tiwari, A.K. Dwivedi and S. N. Shukla, *Qualitative Analysis of Modified Darlington Amplifier*, Journal of Ultra Scientist of Physical Sciences, 20 No.3, p-625, 2008
[15] M. H. Rashid, *Introduction to PSpice Using OrCAD for Circuits and Electronics*, Pearson Education, 3rd Ed., p-255, 2004
[16] S. N. Shukla and S. Srivastava, *A New Circuit Model of Small-Signal Amplifier Using MOSFETs in Triple Darlington Topology*, International Journal of Modeling and Optimization Vol. 3, No. 5, pp. 394-398, 2013
[17] S.N.Shukla and S.Srivastrava, *Qualitative and Tuning Performance of MOSFET Based Small-Signal Darlington pair Amplifiers*, International Journal of Enhanced Research in Science Technology & Engineering, Vol.1, Issue 2, p-1-6, 2013

BIOGRAPHY

Sachchida Nand Shukla received his M.Sc. and Ph.D. Degrees in Physics (Electronics) from Dr. RamManohar Lohia Avadh University, Ayodhya (India) in 1988 and 1991 respectively. Presently he is serving the Department of Physics and Electronics, Dr. Ram Manohar Lohia Avadh University, Ayodhya, U.P., India as Professor. The Fellow of IACSIT and Associate Fellow of IAPS Dr. Shukla is presently working in the field of 'Circuit Designing and Simulation'. He supervised 6 Ph.D. scholars and published 2 books and more than 50 research papers in International/National journals and Conference Proceedings during last 8 years.