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High Frequency Controlled Universal Current Mode Filter using second generation conveyor CCII

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Abstract: *A new universal current mode filter circuit composed by three multi-output second generation current conveyor circuits (MOCCII), two controlled active resistances and two passive capacitors is presented. This filter can realize all the five standard filter functions, namely low pass, band pass, high pass, notch and all pass, without changing the circuit topology. TSPICE simulation using 0.18 µm process BISIM3V3 level 49 and ± 0.8 V power supply voltage confirm the theoretical analysis. Simulated frequency response of gain confirms the theoretical prediction of low sensitivity for passive and active components.*

Keyword: *Second generation current conveyor (CCII); Controlled active resistance; Universal filter; Current mode.*

1. INTRODUCTION

Analogue filters are considered as a basic building block of signal processing. It can be found in almost every telecommunication systems, measurement, instrumentation and control systems. These types of circuits can be used to separate audio signals before applying to loudspeakers, to combine or to separate several telephone conversations or to select a particular radio station from the radio receiver by rejecting all other channels.

Since 1970, many universal filter configurations using second generation current conveyor (CCII) have been reported in the literature. There are those who have multiple inputs single output (MISO) [1-3], others who have a single input multiple output (SIMO) [4-6] and others who have multiple-input multiple-output (MIMO) [7,8] operating in current mode, voltage mode or mixed mode.

In 2007, Worapong Tangsrirat and al. [7] have proposed a controlled current-mode universal biquadratic filter with two inputs and three outputs. The proposed circuit employs only three DOCCCIIs and two grounded capacitors, which provides the advantage of an electronic tuning capability. In 2010, Hua-Pin Chen [9] has proposed a voltage mode universal filter with three inputs and two outputs employing one second generation current conveyor CCII, three resistors and two capacitors. In 2008, P. KUMAR has proposed a high input impedance voltage-mode second order universal filter composed by three second generation current conveyors (CCIIs), three resistors and two capacitors [10]. This circuit can realized all the standard filter functions, namely low pass, high pass, band pass, notch and all-pass filter from the same configuration. In 2013, Neeta Pandey [11] has proposed an electronically tunable mixed mode universal filter based on multiple output current controlled current conveyor (MOCCCII) and two grounded capacitors. The proposed topology can be used to realize all four modes without any alteration i.e., voltage (VM), current (CM), transimpedance (TIM) and transadmittance (TAM).

In this paper, a new current mode universal filter constructed by three multi-output second generation current conveyor circuits, two grounded resistances and two capacitors is presented. In order to minimize surface and temperature of filter, the passive resistances are replaced by controlled active resistances, through the use of input stage of standard controlled second generation current conveyor circuit (CCCII). The proposed filter can realized all the five standard function filters without changing the circuit topology. The simulation results are performed by TSPICE with TSMC 0.18 µm CMOS process parameters and ± 0.8 V supply voltage.

2. PROPOSED CURRENT MODE UNIVERSAL FILTER

2.1 Circuit Description

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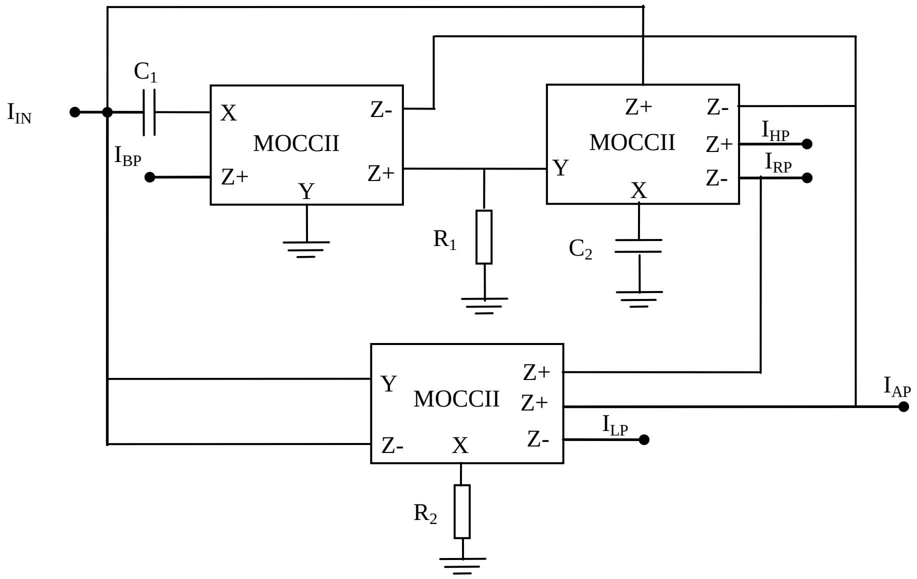

Figure 1 Universal current mode filter circuit based on MOCCII

The proposed single input five outputs current mode universal filter is shown in Fig 1. This filter is com- posed by three multi- output second generation current conveyor circuits, two grounded resistances and two capacitors. It can realize all the five standard filter functions without changing the topology.

Using standard notation, the relationship between input and output terminals of second generation cur- rent conveyor circuit can be characterized by:

$$I_Y = 0 \qquad V_Y = V_X \qquad I_X = I_{Z+} = -I_{Z-}$$

After routine analysis of this filter, its transfer functions can be described as:

– Low pass filter (LP):

$$I_{LP} = \frac{1}{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1} Iin \qquad (1)$$

– High pass filter (HP):

$$I_{HP} = \frac{s^2 R_1 R_2 C_1 C_2}{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1} Iin \qquad (2)$$

– Band pass filter (BP):

$$I_{BP} = \frac{sR_1 C_1}{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1} Iin \qquad (3)$$

– Reject pass filter (RP):

$$I_{RP} = \frac{s^2 R_1 R_2 C_1 C_2 + 1}{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1} Iin \qquad (4)$$

– All pass filter (AP):

$$I_{AP} = \frac{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1}{s^2 R_1 R_2 C_1 C_2 + sR_1 C_1 + 1} Iin \qquad (5)$$

The natural angular frequency and the quality factor expressions can be given as:

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$Q_0 = \sqrt{\frac{R_2 C_2}{R_1 C_1}}$$

Both ω_0 and Q_0 passive sensitivities are given by:

$$S_{R_1}^{\omega_0} = S_{R_2}^{\omega_0} = S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -\frac{1}{2}$$

$$S_{R_2}^{Q_0} = S_{C_2}^{Q_0} = \frac{1}{2}$$

$$S_{R_1}^{Q_0} = S_{C_1}^{Q_0} = -\frac{1}{2}$$

Taking the non-idealities of CCII into account, the relationships between terminal devices are become as follows:

$$I_Y = 0 \qquad V_X = \beta V_Y \qquad I_{Z+} = -I_{Z-} = \alpha\, I_X$$

Where $\alpha = 1 - \varepsilon_i$ and ε_i denotes the current tracking error, also $\beta = 1 - \varepsilon_v$ and ε_v denotes the voltage tracking error.

The transfer functions have become:

– Low pass filter (LP):

$$I_{LP} = \frac{1}{s^2 \frac{\alpha_1 \alpha_2 \beta_2}{\alpha_3 \beta_3} R_1 R_2 C_1 C_2 + s \frac{\alpha_1}{\alpha_3 \beta_3} R_1 C_1 + 1} Iin \qquad (6)$$

– High pass filter (HP):

$$I_{HP} = \frac{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2}{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + s\frac{\alpha_1}{\alpha_3\beta_3} R_1C_1 + 1} Iin \quad (7)$$

– Band pass filter (BP):

$$I_{BP} = \frac{s \frac{\alpha_1}{\alpha_3\beta_3} R_1C_1}{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + s\frac{\alpha_1}{\alpha_3\beta_3} R_1C_1 + 1} Iin \quad (8)$$

– Reject pass filter (RP):

$$I_{RP} = \frac{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + 1}{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + s\frac{\alpha_1}{\alpha_3\beta_3} R_1C_1 + 1} Iin \quad (9)$$

– All pass filter (AP):

$$I_{AP} = \frac{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + s\frac{\alpha_1}{\alpha_3\beta_3} R_1C_1 + 1}{s^2 \frac{\alpha_1\alpha_2\beta_2}{\alpha_3\beta_3} R_1R_2C_1C_2 + s\frac{\alpha_1}{\alpha_3\beta_3} R_1C_1 + 1} Iin \quad (10)$$

The natural angular frequency and the quality factor expressions have become as:

$$\omega_0 = \sqrt{\frac{\alpha_3\beta_3}{\alpha_1\alpha_2\beta_2 R_1R_2C_1C_2}}$$

$$Q_0 = \sqrt{\frac{\alpha_2\alpha_3\beta_2\beta_3 R_2C_2}{\alpha_1 R_1C_1}}$$

Both ω_0 and Q_0 active sensitivities are given by:

$$S_{\alpha_3}^{\omega_0} = S_{\beta_3}^{\omega_0} = \frac{1}{2}$$

$$S_{\alpha_1}^{\omega_0} = S_{\alpha_2}^{\omega_0} = S_{\beta_2}^{\omega_0} = -\frac{1}{2}$$

$$S_{\alpha_2}^{Q_0} = S_{\alpha_3}^{Q_0} = S_{\beta_2}^{Q_0} = S_{\beta_3}^{Q_0} = \frac{1}{2}$$

$$S_{\alpha_1}^{Q_0} = -\frac{1}{2}$$

From the above calculations, it can be seen that all sensitivities are smaller than 0.5 in magnitude.

To minimize the temperature effect, passive resistances are replaced by active resistances controlled by current source, through the use of input stage of standard controlled second generation current conveyor circuit (CCCII) [12, 13].

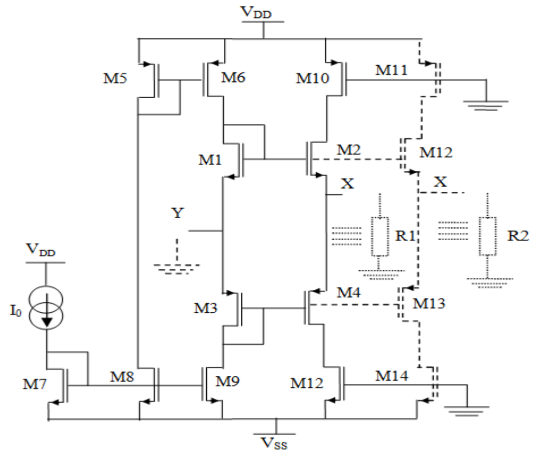

Figure 2 Two active resistances controlled by bias current I_0

Fig. 2 presents the input stage of standard controlled second generation current conveyor circuit. This circuit is composed by a mixed trans-linear loop (M1, M2, M3, M4), two current mirrors (M5, M6 and M7, M8, M9) and two current sources M10, M12.

The relationship between terminals X and Y is given by:

$$V_{XY} = V_{gs_{M1}} - V_{gs_{M2}} = V_{sg_{M4}} - V_{sg_{M3}} \quad (11)$$

Since the drain currents of transistors M1 and M3 are equal to I_0, the expression of potential difference V_{XY} has become as:

$$V_{XY} = \sqrt{\frac{2I_0}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{M1}}} - \sqrt{\frac{2I_{M2}}{\mu_n C_{ox}\left(\frac{W}{L}\right)_{M2}}} \quad (12)$$

$$V_{XY} = \sqrt{\frac{2I_{M4}}{\mu_p C_{ox}\left(\frac{W}{L}\right)_{M4}}} - \sqrt{\frac{2I_0}{\mu_p C_{ox}\left(\frac{W}{L}\right)_{M3}}} \quad (13)$$

The current at terminal X is equal to the different drain currents of transistors M2 and M4. For that, the voltage expression at terminal X is given by:

$$V_X \approx V_Y + \frac{I_X}{\sqrt{2I_0C_{ox}}\left(\sqrt{\mu_p C_{ox}\left(\frac{W}{L}\right)_{M4}} + \sqrt{\mu_n C_{ox}\left(\frac{W}{L}\right)_{M2}}\right)} \quad (14)$$

By connecting the Y terminal to ground, the voltage at X terminal is as the form of ground resistance traversed by current I_X and variable by a bias current I_0.

The active resistance expression is given by:

$$R = \frac{1}{\sqrt{2I_0C_{ox}}\left(\sqrt{\mu_p\left(\frac{W}{L}\right)_{M4}} + \sqrt{\mu_n\left(\frac{W}{L}\right)_{M2}}\right)} \quad (15)$$

In case of need more than a resistance, it's enough to duplicate the output stage as shown in Fig. 2.

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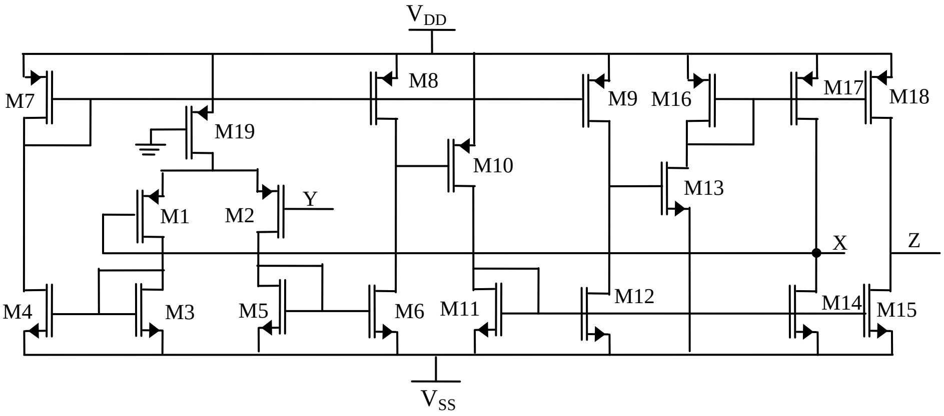

Figure 3 Second generation current conveyor circuit

2.2 Simulation Results

To verify the theoretical results obtained of proposed current mode universal filter, the simulations are perform by using TSPICE simulation program based on BSIM3v3 transistor model (level 49) for TSMC 0.18 µm CMOS process available from MOSIS at 25ºC and CMOS implementation of second generation current conveyor circuit [14] as shown in Fig.3 with the dimensions transistors are taken as specified in Table I.

The CCII circuit is powered at supply voltage ± 0.8V. It has a rail to rail dynamic range, good accuracy, low resistor at borne X (14.79 Ω), low power consumption (0.29 mW) and wide bandwidth current mode (3.9 GHz) and voltage mode (4.23 GHz).

The simulation results of current-mode universal filter are in good agreement with the theoretical results. The variation of bias current causes variation of active resistance and center frequency. The simulation result presented in Fig 4 is obtained by fixing two capacitors C_1 and C_2 to 3pF and varied each time the current polarization I_0.

TABLE I ASPECT RATIOS OF THE TRANSISTORS

Transistor	W(µm)/L (µm)
M1, M2, M19	5/0.18
M3, M4, M5, M6, M11, M12, M13, M14, M15	1/0.18
M7, M8, M9, M10, M16, M17, M18, M1a, M1b	2/0.18

Fig. 5 presents respectively the simulation results of high-pass, band-pass, reject-pass, low-pass, all-pass current mode filter with a bias current equal to 100 µA. The simulated frequency responses and phase responses agree well with the theoretical ones as expected, where as the difference between them arises from non-idealities such as non-ideal gain and parasitic impedance effects of the MOCCII.

It is possible to vary the center frequency of current mode universal filter to keeping the quality factor set to unity by varying only bias current I_0 (Fig 6).

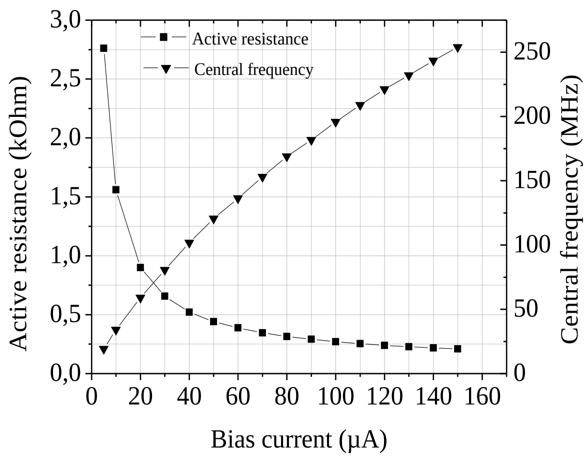

Figure 4 Variation of value active resistor and center frequency according by bias current I_0

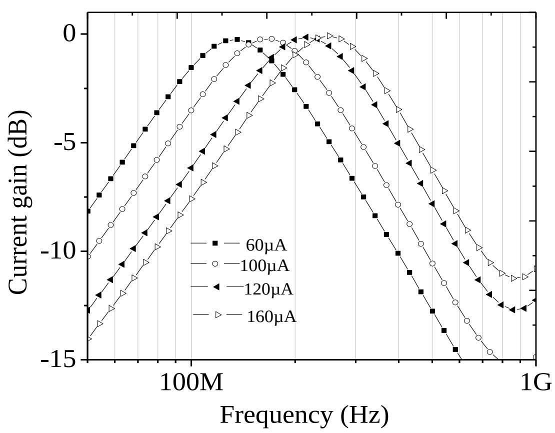

Figure 6 Center frequency variation of current mode universal filter

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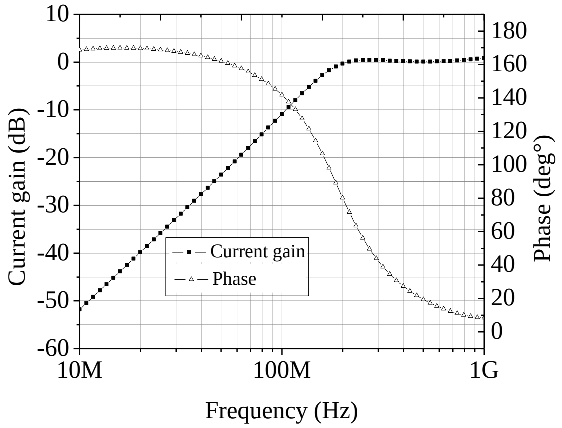
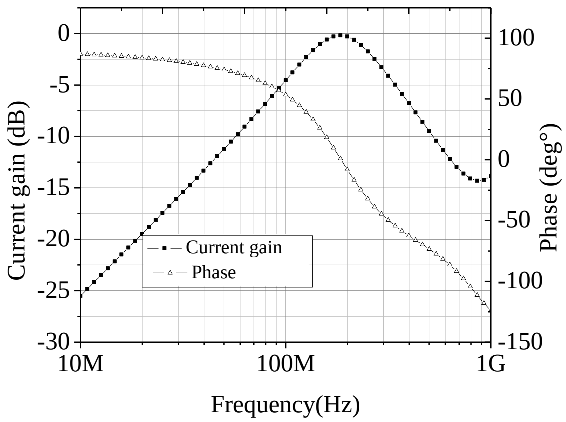
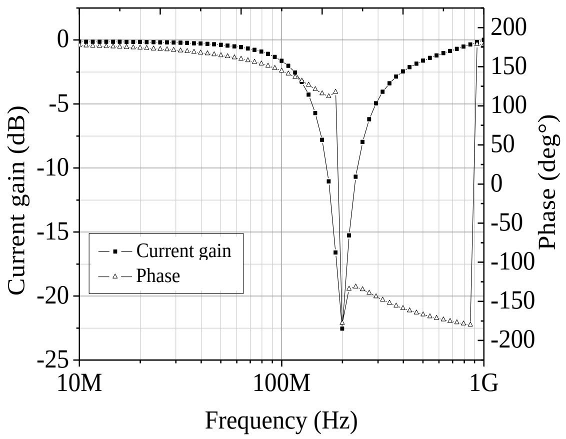


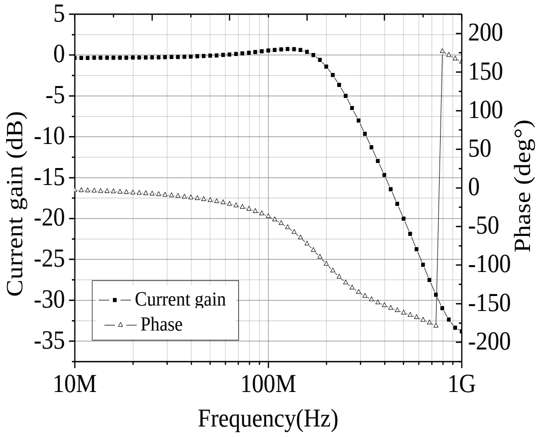
(a)



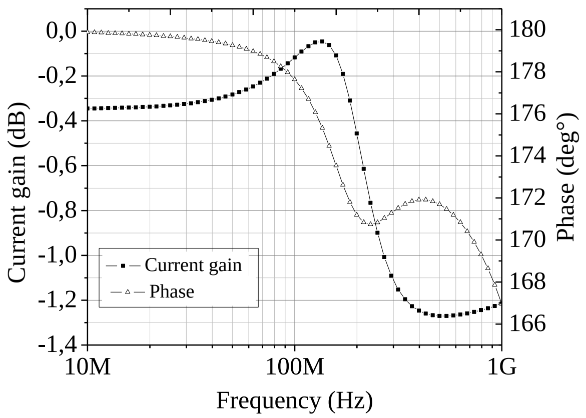
(b)



(c)



(d)



(e)

Figure 5 Current mode simulation results of mixed mode universal filter: (a): High pass, (b): Band pass, (c): Reject pass, (d): Low pass, (e): All pass

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3. CONCLUSION

In this paper, a new current mode universal filter composed by three multi output second generation current conveyor (MOCCII) circuits, two active resistances and two passive capacitors is presented. It can realize all the standard filter functions, namely low-pass, band-pass, high-pass, notch and all-pass, without changing the circuit topology. This filter is characterized by high output impedances good for cascadability to another circuits, a power consumption about 0.73mW, a maximal frequency of 1.40 GHz and low active and passive sensitivities. The simulation results with TSPICE using 0.18μm TSMC CMOS technology have a good accurate with the theoretical results.

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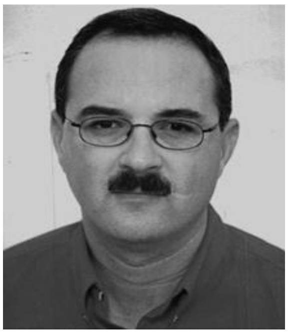
Authors Biography

Thouraya Ettaghzouti was born in Tozeur in 1983, Tunisia. She received the M.S. degree from the Faculty of Sciences of Monastir in 2008, the Ph.D. degree from at the same University at the Microelectronic and Instrumentation Laboratory in 2016. She is interested to the implementation of low voltage low power integrated circuit design.

Dr. Néjib HASSEN was born in 1961 in Moknine, Tunisia. He received the B.S. degree in EEA from the University of Aix-Marseille I, France in1990, the M.S. degree in Electronics in 1991 and the Ph.D. degree in 1995 from the University Louis Pasteur of Strasbourg, France. From 1991 to 1996, he has worked as a researcher in CCD digital camera design. He implemented IRDS new technique radiuses CCD noise at CRN of GOA in Strasbourg. In 1995, he joined the Faculty of Sciences of Monastir as an In 1995, he joined the Faculty of Sciences of Monastir as an Assistant Professor of physics and electronics Since 1997, he has worked as researcher in mixed-signals neural networks. Currently, he is professor of microelectronics and electronics to ISIMM University of Monastir. He is focusing on the implementation low voltage - low power mixed and analog circuits.



Dr. Kamel BESBES was born in Monastir, Tunisia, in 1960. He received the B.S. degree from the Faculty of Sciences of Monastir in 1985, the M.S. degree from the Ecole Centrale de Lyon, Lyon, France, in 1986, the Ph.D. degree from the Institut National des Sciences Appliquées de Lyon (INSA), Lyon, in 1989, and the Doctorat d'Etat degree from the Faculty of Sciences of Tunis, Tunisia, in 1995. In 1989, he joined the Faculty of Sciences of Monastir as an Assistant Professor of physics and electronics. He is now Director of Centre for Research on Microelectronics and Nanotechnology of Sousse (CRMN), Director of Microelectronic and Instrumentation Laboratory and Professor at University of Monastir. His research work and interest are focused on microelectronics, modeling, and instrumentation.