

Resistor-less Current-mode Universal Biquad Filter Using CCTAs and Grounded Capacitors

T. Thosdeekoraphat, S. Summart, C. Saetiaw, S. Santalunai and C. Thongsopa

Abstract—This article presents a current-mode universal biquadratic filter. The proposed circuit can apparently provide standard functions of the biquad filter: low-pass, high-pass, band-pass, band-reject and all-pass functions. The circuit uses 4 current controlled transconductance amplifiers (CCTAs) and 2 grounded capacitors. In addition, the pole frequency and quality factor can be adjusted by electronic method by adjusting the bias currents of the CCTA. The proposed circuit uses only grounded capacitors without additional external resistors, the proposed circuit is considerably appropriate to further developing into an integrated circuit. The results of PSPICE simulation program are corresponding to the theoretical analysis.

Keywords—Resistor-less, Current-mode, Biquad filter, CCTA.

I. INTRODUCTION

THE active building block (ABB) presented in active devices for electrical and electronics engineering is suitable for a class of analog signal processing for voltage-mode and current-mode technique, for example, current conveyor second generation (CCII) [1], second generation current controlled current conveyor (CCCII) [2], current differencing transconductance amplifier (CDTA) [3] and current conveyor transconductance amplifier (CCTA) [4], etc. Additionally, to help design a circuit and reduce passive devices used in a design process, ABB development has been required to be more qualified, such as, increasing parasitic resistances at input terminal, extending numbers of input and output terminals, etc.

Universal biquadratic filter is one of most popular analog filter circuit which provides several functions (low-pass filter, high-pass filter, band-pass filter, band-reject filter and all-pass filter). In the last decade, a lot of papers in universal filter circuit design have been presented in current-mode technique using the current-mode building block. It is recommended that the circuit designed by current-mode technique can provide advantages such as larger dynamic range, inherently wide bandwidth, higher slew-rate, greater linearity and low power consumption [5-6].

According to the recent research reviews on designing current-mode universal biquadratic filter circuit using active building block, it is found that the most recommended qualifications for an appropriate circuit design: without

additional external resistor, using grounded capacitors, reducing active and using passive devices in a design process, and the pole frequency and quality factor can be controlled by electronic method, and etc.

From literature survey, several implementations of biquadratic filter circuits using active building block devices in [13-25], have been evidently reported. Unfortunately, weakness of these reported circuits has been noticed as well. Many of these applications are the pole frequency and quality factor cannot be electronically controlled by adjusting the bias current [21-25]. The proposed circuits in [18, 22-25] use floating capacitor, which is not convenient for future fabrication in integrated circuits [7]. Excessively used as passive elements, especially external resistors [13-14, 16, 18, 20-21, 23, 25] and the proposed circuit in Refs. [13-15, 19, 22-25] consists of a large number (more than two components) of active components, which are not convenient for future fabrication in integrated circuits. Furthermore, the most of presented works cannot completely provide standard function [14-17, 19, 21-25]. The proposed circuit in Ref. [17-18] used of the parasitic resistances at the input terminal. Unfortunately, the parasitic resistances depend on integrated circuits manufacturing deviations, supply voltage and also obviously on temperature [8-9].

The purpose of this paper is to present the current-mode universal biquadratic filter, based on current conveyor transconductance amplifiers (CCTAs). The proposed universal filter circuit can completely provide standard function. In addition, the pole frequency is a quality factor can be adjusted by electronic method. The proposed circuit consists of two CCTAs and two grounded capacitors and without additional external resistances, which is convenient for future fabrication in integrated circuits [10-11]. The PSPICE simulation program results are also shown which are corresponding to the theoretical analysis.

II. THEORY AND PRINCIPLE

A. Basic Concept of CCTA

In 2005, a new active building block namely current conveyor transconductance amplifier (CCTA) is presented for analog signal processing [4], which suitable for a class of analog signal processing for voltage-mode and current-mode techniques. CCTA has been widely applied in current-mode circuit, for example, filter and oscillator circuits. The characteristics of the ideal current conveyor transconductance amplifier are represented by the following hybrid.

T. Thosdeekoraphat, S. Summart, C. Saetiaw, S. Santalunai, C. Thongsopa, School of Telecommunication Engineering, Suranaree University of Technology, Nakhonratchasima 30000, Thailand (e-mail: thanaset@sut.ac.th, ton_3555@hotmail.com, charinsak_s@yahoo.co.th, ja_s_tce@hotmail.com, chan@sut.ac.th).

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix} \quad (1)$$

where g_m is the transconductance of the CCTA. This g_m can be adjusted by external input bias current I_B . For bipolar junction transistor CCTA, the transconductance can be shown in Eq. (2). An ideal CCTA has high input impedances at the y input terminal, consists of voltage buffer circuit in the y input terminal. The symbol and the equivalent circuit of the CCTA are illustrated in Fig. 1 and Fig. 2, respectively.

$$g_m = \frac{I_B}{2V_T} \quad (2)$$

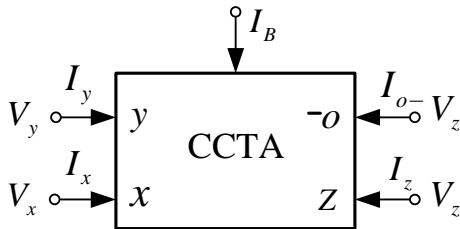


Fig. 1 Symbol of the CCTA

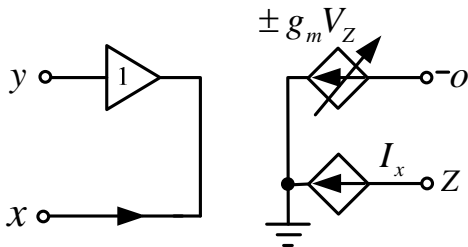


Fig. 2 Equivalent circuit of the CCTA

where V_T is the thermal voltage of the transistor. The bipolar junction transistor implementation of the internal construction of CCTA can be shown in Fig. 3.

B. Proposed current-mode universal biquad filter

The proposed current-mode universal biquadratic filter circuit can be shown in Fig. 4. It consists of 2 CCTAs and 2 grounded capacitors. The circuit does not use external resistors and parasitic resistances, only one grounded capacitor is ideal for integrated circuit. The transferring function of the circuit can be written as

$$I_{out} = \frac{\left(s^2 + \frac{g_{m1}}{C_1} s + \frac{g_{m1}g_{m2}}{C_1C_2} \right) I_{in3} - \frac{g_{m1}g_{m2}}{C_1C_2} I_{in2} - \frac{g_{m1}}{C_1} I_{in1}}{s^2 + \frac{g_{m1}}{C_1} s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (3)$$

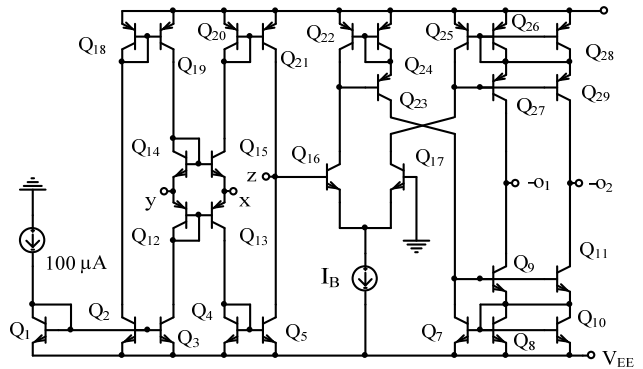


Fig. 3 Internal construction of the CCTA

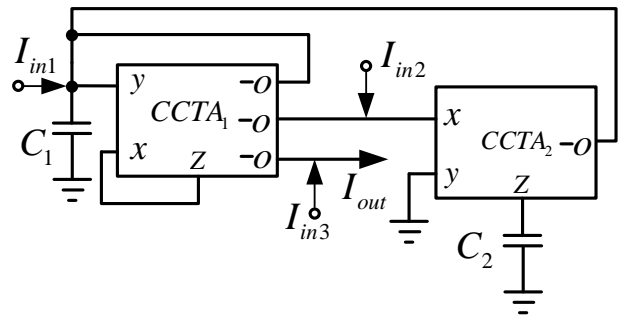


Fig. 4 The proposed current-mode universal biquad filter

From (3), the magnitude of input currents I_{in1} , I_{in2} and I_{in3} is chosen as Table I, digitally choosing by adding digitally selective circuit [12] of the input terminal to achieve standard function of second order networks. From (3), the transferring function of the low-pass (LP), high-pass (HP), band-pass (BP), band-reject (BR) and all-pass (AL) can be written as

$$LP: T_{LP}(s) = \frac{-\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m1}}{C_1} s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (4)$$

$$HP: T_{HP}(s) = \frac{s^2}{s^2 + \frac{g_{m1}}{C_1} s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (5)$$

$$BP : T_{BP}(s) = \frac{-\frac{g_{m1}}{C_1}}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (6)$$

$$BR : T_{BR}(s) = \frac{s^2 + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (7)$$

and

$$AP : T_{AP}(s) = \frac{s^2 - \frac{g_{m1}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (8)$$

TABLE I
 THE I_{in1} , I_{in2} AND I_{in3} VALUES FOR EACH FILTER FUNCTION

Function Type	I_{in1}	I_{in2}	I_{in3}
LP	0	1	0
HP	1	1	1
BP	1	0	0
BR	1	0	1
AP	2	0	1

From (3), the quality factor (Q_0) and cut off frequency (ω_0) can be written as

$$Q_0 = \sqrt{\frac{g_{m2}C_1}{g_{m1}C_2}} \quad (9)$$

and

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (10)$$

From (9) and (10), then substitute $g_{m1} = \frac{I_{B1}}{2V_T}$ and

$g_{m2} = \frac{I_{B2}}{2V_T}$, V_T is thermal voltage of the BJTs is approximately 26 mV at 27°C.

$$Q_0 = \sqrt{\frac{I_{B2}C_1}{I_{B1}C_2}} \quad (11)$$

and

$$\omega_0 = \frac{1}{2V_T} \sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}} \quad (12)$$

It can be seen that the Q_0 and ω_0 can be adjusted by varying I_{B1} and I_{B2} . In addition, bandwidth (BW) of the system can be expressed by

$$BW = \frac{\omega_0}{Q_0} = \frac{I_{B1}}{2V_T C_1} \quad (13)$$

From (9), the bandwidth can be controlled by I_{B1} . Sensitivities of the current-mode universal biquadratic filter are shown in Eqs. (14) and (15), respectively.

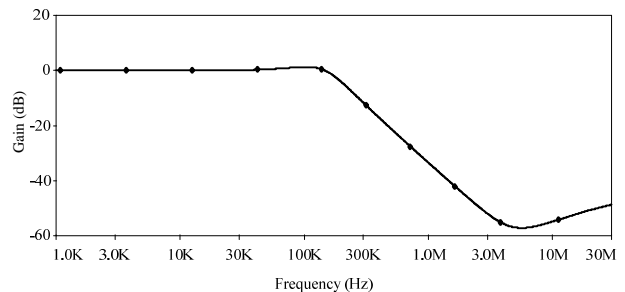
$$S_{I_{B2}, C_1}^{Q_0} = \frac{1}{2}, S_{I_{B1}, C_2}^{Q_0} = -\frac{1}{2} \quad (14)$$

and

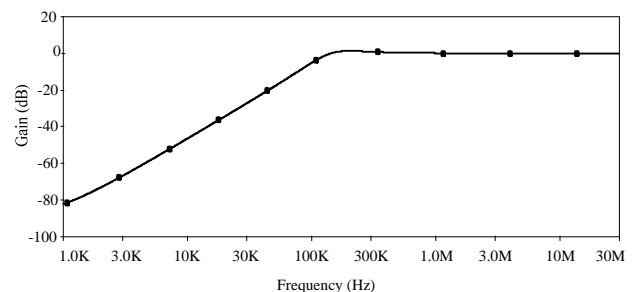
$$S_{I_{B1}, I_{B2}}^{\omega_0} = \frac{1}{2}, S_{C_1, C_2}^{\omega_0} = -\frac{1}{2}, S_{V_T}^{\omega_0} = -1 \quad (15)$$

III. SIMULATION RESULTS

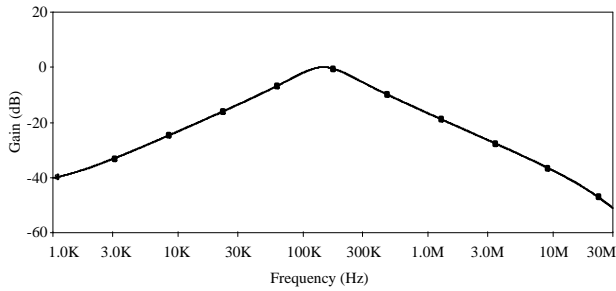
To verify the theoretical prediction of the proposed current-mode universal filter in Fig. 4, the PSPICE simulation was built with $C_1 = C_2 = 1nF$ and $I_{B1} = I_{B2} = 50\mu A$. The BJT implementation of the internal construction of CCTA used in simulation is shown in Fig. 3. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor arrayed from AT&T [26]. The circuit was biased with $\pm 2V$ supply voltages. The power consumption of the circuit is about $6.46mW$. Fig. 5 shows the gain responses of the proposed biquad filter obtained from Fig. 4. The proposed biquad filter circuit is able to provide standard functions: low-pass, high-pass, band-pass, band-reject and all-pass depending on digital selection as shown in Table I.



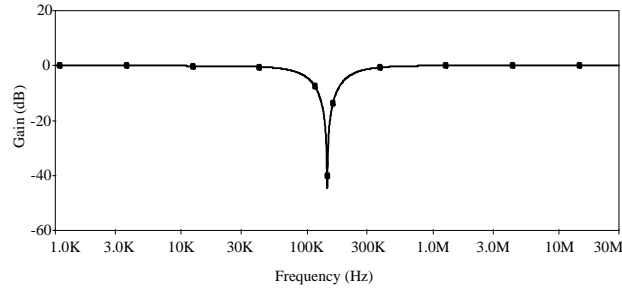
(a) Low-pass filter



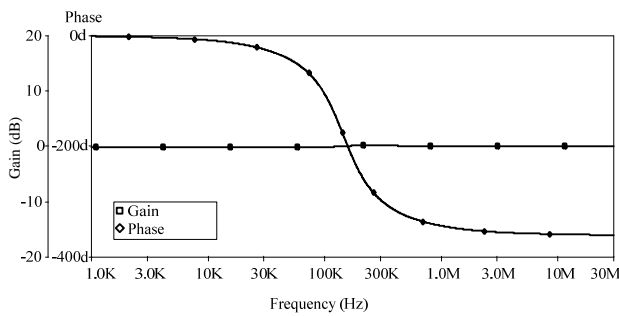
(b) High-pass filter



(c) Band-pass filter



(d) Band-reject filter



(e) All-pass filter

Fig. 5 Gain responses of the proposed biquad filter

Fig. 6 and Fig. 7 shows the gain responses of the band-pass and band-reject functions, where I_{B1} is set to $25\mu A$, $50\mu A$, $75\mu A$ and $100\mu A$, respectively. This shows that the bandwidths of the responses can be adjusted by the input bias current I_{B1} as depicted in (13). Fig. 8 shows simulated gain responses of the band-pass functions with the bias current $I_{B1} = I_{B2}$.

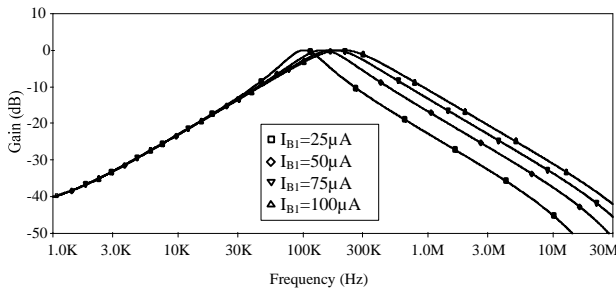


Fig. 6 Band-pass responses at different value of I_{B1}

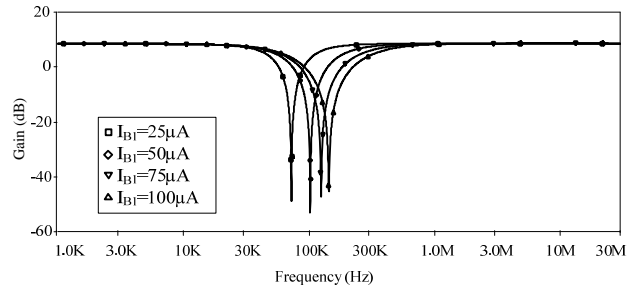


Fig. 7 Band-reject responses at different value of I_{B1}

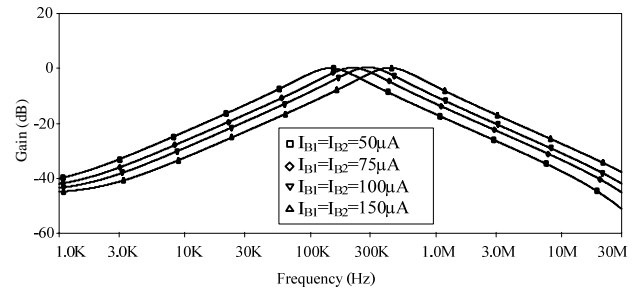


Fig. 8 band-pass responses at different value of $I_{B1} = I_{B2}$

IV. CONCLUSION

The current-mode universal biquadratic filter has been presented. The proposed universal filter circuit is apparently qualified with the standard functions: low-pass, high-pass, band-pass, band-reject and all-pass dependent on digital selection as shown in Table I. Moreover, the pole frequency and quality factor can be adjusted by electronic method by adjusting the bias currents of the CCTA. The proposed biquad filter circuit consists of CCTAs and grounded capacitors without additional external resistors. This circuit is extremely appropriate to further developing into an integrated circuit. The PSPICE simulations are included to verify the theoretical analysis. The simulation and theoretical results are in close.

ACKNOWLEDGMENT

This work was supported by Suranaree University of Technology (SUT) and by the Office of the Higher Education under NRU project of Thailand.

REFERENCES

- [1] K. C. Smith, and A. Sedra, "The current conveyor-a new circuit building block," *IEEE Proc.*, vol. 56, pp. 1368-1369.
- [2] A. Fabre, O. Saaid, F. Wiest, and C. Boucheron, "Current controllable bandpass filter based on translinear conveyors," *Electron. Lett.*, vol. 31, pp. 1727-1728, 1995.
- [3] D. Birolek, "CDTA-building block for current-mode analog signal processing," in *Proc. European Conference on Circuit Theory and Design*, 2003, pp. 397-400.
- [4] R. Prokop, and V. Musil, "New modern circuit block CCTA and some its application," in *Conf. The Fourteen International Scientific and Applied Science Conference Electronics ET 2005*, pp. 93-98.
- [5] C. Toumazou, and F. J. Lidgley, "Universal active filter using current conveyors," *Electron. Lett.*, vol. 22, pp. 662-664, 1986.

- [6] D. R. Bhaskar, V. K. Sharma, M. Monis, and S. M. I. Rizvi, "New current-mode universal biquad filter," *Microelectronics Journal*, vol. 30, pp. 837-839, 1999.
- [7] E. Yuce, and S. A. Minael, "A modified CFOA and its applications to simulated inductors, capacitance multipliers, and analog filters," *IEEE Trans. On Circuit and Syst. I*, vol. 55, pp. 266-275, 2008.
- [8] R. Sotner, Z. Hrubos, J. Slezak, and T. Dostal, "Simply adjustable sinusoidal oscillator based on negative three-port current conveyors," *Radioengineering*, vol. 19, pp. 446-454, 2010.
- [9] Y. Li, "A new single MCCCDDTA based wien-bridge oscillator with AGC," *International Journal of Electronics and Communications (AEU)*, vol. 66, pp. 153-156, 2012.
- [10] M. Bhusan, and R. W. Newcomb, "Grounding of capacitors in integrated circuits," *Electronics Letters*, vol. 3, pp. 148-149, 1969.
- [11] A. M. Soliman, "New grounded capacitor current mode band-pass low-pass filters using two balanced output ICCII," *Journal of Active and Passive Electronic Devices*, vol. 3, pp. 175-184, 2008.
- [12] Y. Maruyama, A. Hyogo, and K. Sekine, "A digitally programmable CMOS biquad filter using current-mode integrators," *IEICE Trans. On Fundamentals*, vol. E85-A, pp. 316-323, 2002.
- [13] R. Sotner, J. Slezak, T. Dostal, and J. Petrzela, "Universal tunable current-mode biquad employing distributed feedback structure with MO-CCII," *Journal of Electrical Engineering*, vol. 61, pp. 52-56, 2010.
- [14] R. Senani, V. K. Singh, A. K. Singh, and D. R. Bhaskar, "Novel electronically controllable current-mode universal biquad filter," *IEICE Electronics Express*, vol. 1, pp. 410-415, 2004.
- [15] M. T. Abuelma'atti, and N. A. Tasadduq, "A novel single-input multiple-output current-mode current-controlled universal filter," *Microelectronics Journal*, vol. 29, pp. 901-905, 1998.
- [16] D. Prasada, D. R. Bhaskara, and A. K. Singh, "Universal current-mode biquad filter using dual output current differencing transconductance amplifier," *Int. J. Electron. Commun. (AEU)*, vol. 63, pp. 497-501, 2009.
- [17] S. V. Singh, S. Maheshwari, and D. S. Chauhan, "Electronically tunable current/voltage-mode universal biquad filter using CCCCTA," *International J. of Recent Trends in Engineering and Technology*, Vol. 3, pp. 71-76, 2010.
- [18] S. V. Singh, S. Maheshwari, and D. S. Chauhan, "Single cccta-based miso voltage-mode universal biquad filter," *International J. of Recent Trends in Engineering and Technology*, Vol. 3, pp. 71-76, 2010.
- [19] S. Minaei, and S. Türköz, "Current-mode electronically tunable universal filter using only plus-type current controlled conveyors and grounded capacitors," *ETRI Journal*, vol. 26, pp. 292-296, 2004.
- [20] N. Herencsar, J. Koton, and K. Vrba, "Single CCTA-based universal biquadratic filters employing minimum components," *International Journal of Computer and Electrical Engineering*, vol. 1, pp. 1793-8163, 2009.
- [21] B. Chaturvedi, and S. Maheshwari, "Current mode biquad filter with minimum component count," *Active and Passive Electronic Components*, vol. 2011, pp. 1-7, 2011.
- [22] S. V. Singh, S. Maheshwari, J. Mohan, and D. S. Chauhan, "Electronically tunable current-mode universal biquad filter based on the CCCCTA," in *Conf. 2009 International Conference on Advances in Recent Technologies in Communication and Computing*, pp. 424-429.
- [23] N. A. Shah and M. A. Malink, "High impedance voltage and current-mode multifunction filter," *Int. J. Electron. Commun. (AEU)*, vol. 59, pp. 262-266, 2005.
- [24] J. Wu and E. I. El-masry, "Universal voltage and current-mode OTAs based biquads," *Int. J. Electronics*, vol. 85, pp. 553-560, 1998.
- [25] H. A. Alzahr, "A CMOS digitally programmable universal current-mode filter," *IEEE Transactions on Circuits and Systems II: Express Briefs*, vol. 55, pp. 758-762, 2008.
- [26] D. Frey, "Log-domain filtering: an approach to current-mode filtering," *IEE Proceedings-Circuits, Devices and Systems*, vol. 140, pp. 406-416, 1993.



T. Thosdeekoraphat received the B.Eng and M.Eng. degrees in telecommunication engineering from Suranaree University of Technology in 2006 and 2008, respectively. At present, I'm Studying doctoral's degree in telecommunication engineering at Suranaree University of Technology. Research interests include hyperthermia inductive heating, induction heating, RF circuit design, antenna, active antenna and UWB transmitter-receiver design and analysis of impulse

signal for UWB communication system.



S. Sumart received the B. Tech. Ed. degree in Telecommunication Engineering from Rajamangala Institute of Technology Khon Kaen Campus (RITKK) in 2002 and Master of Tech. Ed. in electrical technology from King Mongkut's University of Technology North Bangkok (KMUTNB) in 2008. Now, he is working toward Ph.D. in Telecommunication Engineering at Suranaree University of Technology (SUT). He has been with Electronic Program, Electronic Division, Northeastern Technology College, Khon Kaen, Thailand since 2007. His research interests include electronic communications, analog signal processing and analog integrated circuit.



C. Saetiauw received the B.Eng. degrees in Telecommunication Engineering from Suranaree University of Technology and M.Eng. degrees in Telecommunication Engineering from Suranaree University of Technology in 1997 and 2007, respectively. He is currently working toward the Ph.D. degree in Telecommunication Engineering of Suranaree University of Technology. His research focuses on antennas systems for several applications.



S. Santalunai received the B.Eng and M.Eng. degrees in Telecommunication Engineering from Suranaree University of Technology in 2007 and 2009, respectively. At present, Studying doctoral's degree in Telecommunication Engineering at Suranaree University of Technology, Thailand. Research interests include wireless power transfer, induction heating and RF circuit design.



C. Thongsopa B.Eng (1'Hons) Electronics Engineering, King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand, M.Eng. (Electrical and Communications Engineering), Kasetsart University, Thailand and D.Eng.(Electrical Engineering), King Mongkut's Institute of Technology Ladkrabang (KMITL), Thailand in 1992, 1996 and 2002, respectively. Experiences & Expert are RF circuit design, active antenna, Microwave heating application in 1992-1997 Researcher at Aeronautical Radio of Thailand Company Design Systems Air Traffic control: Design transmitters VHF-UHF (AM) 25W (on 24 Hour) and Design Transmitters HF (AM) 1KW (on 24 Hour). Furthermore, Researcher at National Electronics and Computer Technology Center (NECTEC) and consultant of SDH project at Telephone Organization of Thailand (TOT) design RF circuit in 1997-2000.