ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
DOI: 10.17559/TV-20140330063721

# DESIGN OF A BAND-PASS FILTER IN 0,18 µm CMOS FOR 2,4 GHz READER-LESS RFID TRANSPONDER

*Mohammd Arif Sobhan Bhuiyan, Muhammad Tazarudin Bin Mohd. Taib, Mamun Bin Ibne Reaz, Fazida Hanim Hashim, Sawal Hamid Md. Ali*

Original scientific paper
Radio Frequency Identification (RFID) based systems are ubiquitous nowadays. Band pass filters always play an important role in overall performance of an RFID transponder. In this paper, a band pass filter with a transistor only active inductor is presented for compact high performance reader-less RFID transponder. Post layout simulation result reveals that the centre frequency of the filter can be set to 2,42 GHz frequency with a bandwidth of 38 MHz. The filter core occupies an area of 0,004 mm$^2$ and dissipates only 1,3 mW at 1,5 V supply voltage. CEDEC 0,18 µm CMOS technology in Mentor Graphics environment has been used for the design of the proposed filter.

**Keywords:** *active inductor; band-pass filter; CMOS (Complementary Metal-Oxide Semiconductor); RFID (Radio Frequency Identification)*

## Dizajn pojasnog filtra u 0,18 µm CMOS za 2,4 GHz RFID transponder bez čitača

Izvorni znanstveni članak
Sustavi temeljeni na Radio Frequency Identification (RFID) sada su široko rasprostranjeni. Pojasno fazni filtri igraju važnu ulogu u funkcioniranju RFID transpondera. U ovom radu, pojasno fazni filtar s induktorom aktivnim samo s tranzistorom prikazan je za kompaktni RFID transponder bez čitača visokih performansi. Rezultat simulacije rasporeda otkriva da središnja frekvencija filtra može biti postavljena na frekvenciju od 2,42 GHz sa širinom pojasa od 38 MHz. Jezgra filtra zauzima površinu od 0,004 mm$^2$ i gubi samo 1,3 mW kod napona napajanja od 1,5 V. Predloženi filtar dizajniran je pomoću CEDEC 0,18 µm CMOS tehnologije u Mentor Graphics okruženju.

**Ključne riječi:** *aktivni induktor; pojasno fazni filtar; CMOS (dopunski metalno oksidni poluvodič); RFID (radio frekvencijska identifikacija)*

## 1 Introduction

RFID is a lucrative automatic system for storing as well as remotely retrieving information through contact-free electromagnetic communication in a cost effective way [1]. It consists of three basic attributes; tags, readers and associated data-processing equipment [2]. The tags, attached to the objects from which information is to be retrieved, contain identification i.e. Electronic Product Code (EPC) and storage for keeping information which is read by a reader. Finally the information is processed by computers. Almost every country spends a considerable amount of money to develop RFID for different applications [3-6].

An RFID tag can be passive (draw power from the reader), active (battery powered) or semi- passive (require battery- but the tag lies inactive until a signal is received from the reader). A reader reads tag data by using wireless communication and typically, these transmissions occur in UHF band or High Frequency band [7]. Current technology lets the researchers to use microwave band for nowadays [8]. The frequency band of RFID is determined by the purpose of their usage. Such a communication system offers many advantages over other similar systems like magnetic strip, bar code etc. [9].

The IEEE 802.11 standard in the 2,4 GHz band has emerged as a popular technology for wireless access. The IEEE 802.11 protocol-based wireless communication is robust, resistant to interference and has more range and a lower bit error rate (BER) at data rates as high as several Mbps [10]. IPv6 protocol is going to replace the IPv4 in the near future, for global unique address structure [11]. In contrast to WLAN, an RFID network is less secure, but more expensive. Reader is the highest priced component in an RFID network [12]. To eliminate the vendor specific monopoly business and unnecessary establishment investment, a novel RFID using WiFi has been proposed where the integrated Wireless Network Interface Cards (WNIC) of laptops or PCs can be replaced for readers [13]. The Electronic Product Code (EPC) would be mapped in the IPv6 protocol that is only 128 bits. As a result the complete scenario of concurrent RFID system will be changed and the users will be able to use a common RFID tag for their applications and the readers will be no more required. So overall system cost will be less.

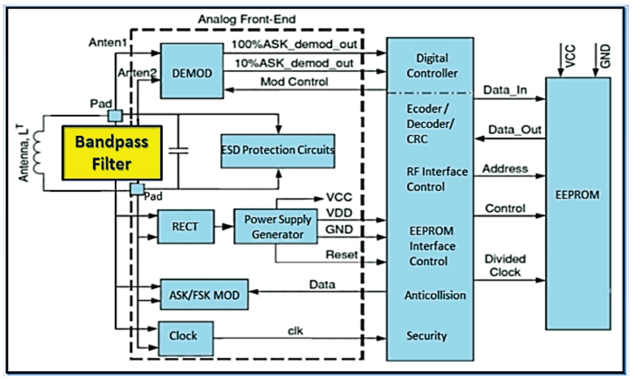

**Figure 1** Block diagram of RFID tag IC

Current trend of the IC design led the researchers to fabricate low cost, low power and compact wireless communication systems [14, 15]. An RF filter is an important block for RFID transceivers as shown in Fig. 1. The filter performance greatly influences the overall performance of the transceiver. On-chip spiral inductors are usually utilized to realize the RF bandpass filters. But such spiral inductors are not recommended due to resistive loss and the capacitive coupling to the substrate.

Moreover, they are not suitable for RF circuits where high Q factor and high inductance are required. Active inductor is one of the promising solutions to overcome these limitations [16, 17]. Therefore, in this study, an active inductor based bandpass filter design is proposed for 2.4 GHz ISM band RFID transponder.

## 2 Methodology

The idea of an active inductor is derived from a well-recognized gyrator concept as shown in Fig. 2 [18], which is a two-port circuit usually consisting of a couple of transconductors connected in negative feedback.

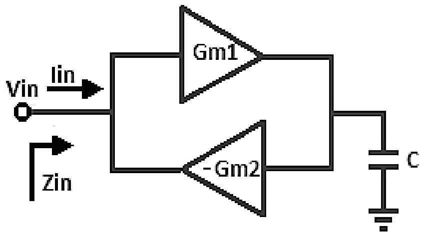


**Figure 2** Basic concept of a gyrator

where, $G_{mx}$s are the transconductances of the amplifiers.

An active inductor is a circuit which consists of a combination of CMOS transistors and works as an alternative to the spiral inductor. The active inductors are preferred because of their large inductance values, high quality factor, low chip area and tenability. But the usage of active inductors in RF bandpass filter encounters a few difficulties like poor noise performance, inadequate dynamic range and relatively higher power consumption [19].

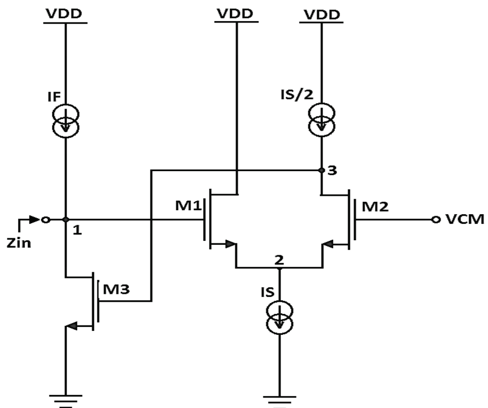


**Figure 3** An all NMOS active inductor circuit [20]

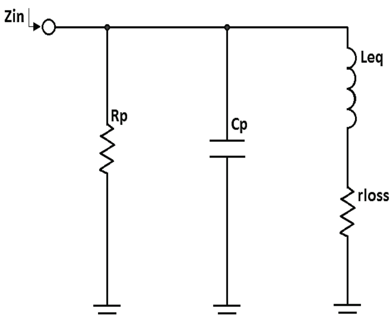


**Figure 4** Equivalent RLC circuit of active inductor

Fig. 3 and Fig. 4 show an active inductor circuit and its equivalent RLC circuit. Here, the current-mirror transistors are represented by ideal current sources.

In this circuit, $M_1$ and $M_2$ act as a non-inverting transconductor which is labeled as $G_{M1}$ whereas transistor $M_3$ works as an inverting transconductor which is labeled as $-G_{M2}$. Thus, $G_{m1}$ and $-G_{m2}$ build up a gyrator. This gyrator along with the parasitic capacitor $C_3$ at Node 3, works as an equivalent inductor, $L_{eq}= C_3/(G_{m1}G_{m2})$ at Node 1. To tune the center frequency and Q factor of the inductor, varactors, $M_I$ and $M_Q$ are added, respectively, to the proposed active inductor circuit as shown in Fig. 5.

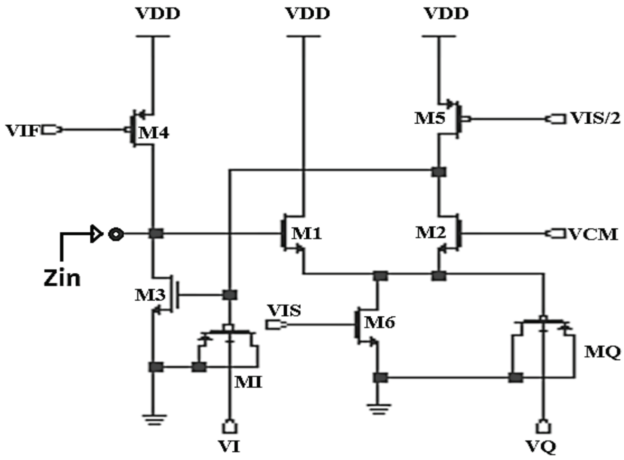


**Figure 5** Active inductor with tuning functionality

The proposed band pass filter is framed with three phases as shown in Fig. 6. The input buffer generates a current which is fed to the active inductor based tank circuit to produce the desired output voltage. To avoid the change in centre frequency and Q factor tuning of the inductor due to load, an output buffer is incorporated.


**Figure 6** Block diagram of the proposed inductor-less band-pass filter

The complete circuit schematic of the proposed band pass filter is shown in Fig. 7.

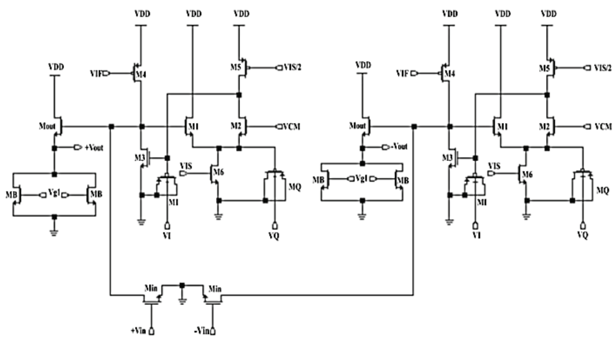

**Figure 7** Proposed Bandpass Filter Circuit with all Biasing and Tuning Components. Transistors Sizes (W/L in µm) and nominal bias values are $M_{1,2,3}$ 30/0,18, $M_4$ 16/0,18, $M_5$ 8/0,18, $M_{6,I,Q,in}$ 3/0,18, $M_{out}$ 2/0,18, $M_B$ 1/0,18, $V_{IF,\ IS/2,IS}$ = 0,85 V, $V_I$ = 0,65 V, $V_Q$ = 0,7 V, $V_{CM}$ = 0,7 V, $V_{DD}$ = 1,5 V

## 3 Results and Discussions

The bandpass filter is designed and simulated in CEDEC 0,18 μm CMOS process parameters with 1,5 V power supply. Design Architect (DA-IC) and IC station tools of Mentor graphics is used to measure the performance of the band pass filter. In this study, centre frequency, bandwidth, *Q* factor, power dissipation of the filter are evaluated from the post layout simulation result.

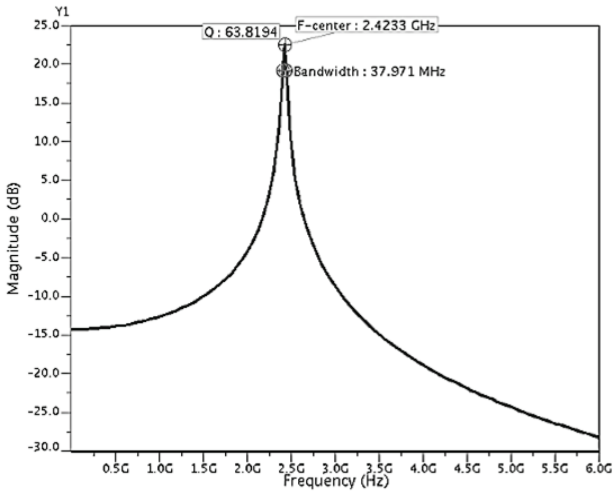


**Figure 8** AC analyses of the bandpass filter circuit

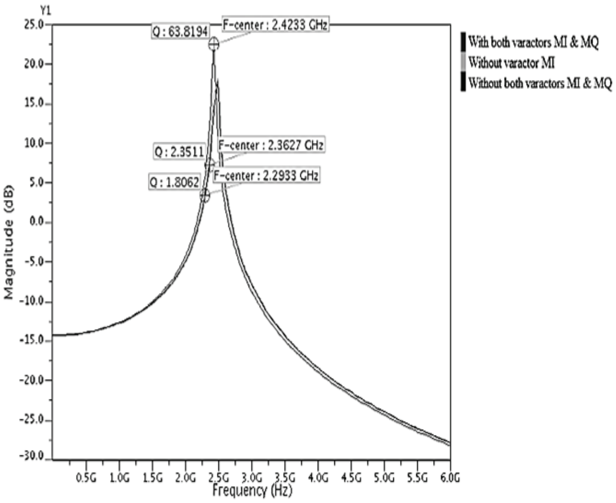


**Figure 9** AC analyses of the bandpass filter circuit with and without a varactor

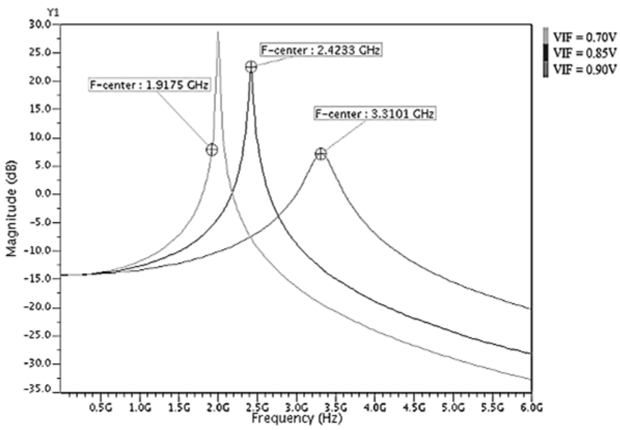


**Figure 10** Centre frequency tuning by $V_{IF}$

The AC analyses of the bandpass filter circuit are shown in Fig. 8, from which it is evident that the proposed band pass filter circuit can operate at the centre frequency of 2,42 GHz having a quality factor of 63,81 and bandwidth of 37,97 MHz. The comparison of centre frequency with and without varactors $M_I$ and $M_Q$ is shown in Fig. 9. Without a varactor $M_I$, it shows that the bandpass filter circuit operates at the centre frequency at 2,29 GHz. While without both varactor $M_I$ and $M_Q$, it shows that the bandpass filter circuit operates at the centre frequency at 2,36 GHz. It shows that two MOS varactors, $M_I$ and $M_Q$ are added for tuning the centre frequency and quality factor respectively.

Fig. 10 shows the centre frequency tuning of the proposed bandpass filter circuit by varying VIF. Gate voltage for transistor $M_4$ is varied from 0,70 V to 0,90 V. It shows that the chosen value for VIF equal to 0.85 V will result in 2,42 GHz centre frequency of the proposed bandpass filter circuit. The total power dissipated by the filter including all the associated circuitries is 1,3 mW. The power consumption of the filter will be less if it is used alone excluding the input and the output buffer. The layout design for the bandpass filter is shown in Fig. 11. It occupies a die area of 0,004 μm$^2$. The performance of the proposed bandpass filter is abridged in Tab. 1.

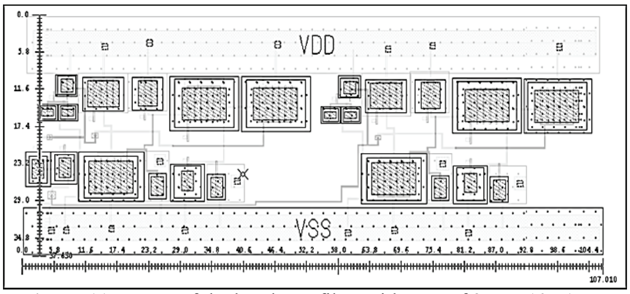


**Figure 11** Layout of the bandpass filter with area of 37,5× 107,1 μm

**Table 1** Summary of the proposed bandpass filter circuit

| Parameters | Value |
|---|---|
| Technology (μm) | 0,18 |
| Centre frequency (GHz) | 2,42 |
| Power supply (V) | 1,5 |
| Power dissipation (mW) | 1,3 |
| Quality factor | 63,81 |
| Bandwidth(MHz) | 37,97 |

**Table 2** Performance comparison of the proposed bandpass filter with previous works

| Specifications | [21] 2006 | [22] 2008 | [23] 2011 | This work |
|---|---|---|---|---|
| Technology (μm) | 0,18 | 0,18 | 0,18 | 0,18 |
| Centre frequency (GHz) | 2,4 | 2,44 | 2,35 | 2,42 |
| Power dissipation (mW) | 3,2 | 10,8 | 4,3 | 1,3 |
| Supply voltage (V) | 2,0 | 1,8 | 1,8 | 1,5 |
| Die area (mm$^2$) | NA | 0,03 | 0,40* | 0,004 |
| Quality factor | >38 | NA | NA | >63 |
| Bandwidth (MHz) | NA | 60 | NA | 37,97 |

* including pad

A comparison of this work with the previous works in literature is presented in Tab. 2. From the assessment it is obvious that the proposed filter, including the input and the output buffer, dissipated only 1,3 mW power at 1,5 V supply voltage. The die area is also very small which is only 0,004 $mm^2$ without pad and matching networks. The Q factor and bandwidth of the filter are also competitive with previous works. The filter also got the privilege of adjustable center frequency ranging from 1,91 to 3,31 GHz.

## 4 Conclusion

RFID technology, being a reliable wireless communication system, offers many advantages over other similar systems. As a result its utilization for different applications is increasing day by day. In this paper, a design of a fully integrated bandpass filter for 2,45 GHz RFID tag front-end in 0,18 µm CMOS process has been presented. The post layout simulation result demonstrates that the filter can operate at 2,42 GHz center frequency and achieve less power dissipation at low supply voltage of 1,5 V when compared with previous works. Such a filter is essential for high performance analog front-end of a readerless active RFID tag.

## 5 References


[1] Yasin, F. M.; Khaw, M. K.; Reaz, M. B. I. Radio frequency identification: Evolution of transponder circuit design. // Microwave journal. 49, 6(2006), pp. 56-70.

[2] Bhuiyan, M. A. S.; Reaz, M. B. I.; Jalil, J.; Rahman, L. F.; Chang, T. G. Design Trends in Fully Integrated 2.4 GHz CMOS SPDT Switches. // Current Nanoscience. 10, 3(2014), pp. 334-343. DOI: 10.2174/15734137113096660106

[3] Uddin, M. J.; Nordin, A. N.; Reaz, M.; Bhuiyan, M. A. S. A CMOS power splitter for 2,45 GHz ISM band RFID reader in 0,18 µm CMOS technology. // Tehnički vjesnik. 20, 1(2013), pp. 125-129.

[4] Uddin, J.; Reaz, M. B. I.; Hasan, M. A.; Nordin, A.N.; Ibrahimy, M. I.; Ali, M. A. M; Fu, K. UHF RFID antenna architectures and applications. // Scientific Research and Essays. 10, 5(2010), pp. 1033-1051.

[5] Aljarajreh, H.; Rifin, M. R.; Mamun, M.; Amin, S.; Zaki, W. M. D. W. Low Noise Amplifiers in RFID Systems. // Journal of Engineering and Applied Sciences. 8, (2013), pp. 21-28.

[6] Angerer, C.; Langwieser, R.; Rupp, M. Evaluation and exploration of RFID systems by rapid prototyping. // Personal and Ubiquitous Computing. 16, (2012), pp. 309-321. DOI: 10.1007/s00779-011-0391-3

[7] Wu, N. C.; Nystrom, M.; Lin, T. R.; Yu, H. C. Challenges to global RFID adoption. // Technovation, 26, (2006), pp. 1317-1323. DOI: 10.1016/j.technovation.2005.08.012

[8] Khaw, M. K.; Yasin, F. M.; Reaz, M. I. Recent advances in the integrated circuit design of RFID transponder. // Proceeding of the 2004 IEEE International Conference onSemiconductor Electronics. / Kuala Lumpur, 2004, pp. 326-330. DOI: 10.1109/SMELEC.2004.1620898

[9] Uddin, M. J.; Ibrahimy, M. I.; Reaz, M. B. I.; Nordin, A. N. Design and application of radio frequency identification systems. // European Journal of Scientific Research. 33, 3(2009), pp. 438-453.

[10] Amin, M.; Reaz, M.; Rahman, L.; Jalil, J. Digital Modulator and Demodulator IC for RFID Tag Employing DSSS and Barker Code. // Journal of Applied Research and Technology.10, (2012), pp. 819-825.

[11] Rahman, L. F.; Reaz, M.; Ali, M.; Kamada, M. Design of an EEPROM in RFID tag: Employing mapped EPC and IPv6 address. // Proceeding of the IEEE Asia Pacific Conf. on Circuits and Systems. / Kuala Lumpur, 2010, pp.168-171. DOI: 10.1109/apccas.2010.5774814

[12] Amin, M.; Reaz, M.; Jalil, J. Design of a novel adder-less Barker matched filter for RFID. // International Journal of Circuit Theory and Applications. 42, (2014), pp. 321-329. DOI: 10.1002/cta.1895. DOI: 10.1002/cta.1895

[13] Rahman, L. F.; Reaz, M.; Ali, M.; Marufuzzaman, M.; Alam, M. Beyond the WIFI: Introducing RFID system using IPv6. // Proceeding of the 2010 ITU-T Kaleidoscope: Beyond the Internet? - Innovations for Future Networks and Services. / Pune, 2010, pp. 1-4.

[14] Kader, W. M.; Rashid, H.; Mamun, M.; Bhuiyan, M. A. S. Advancement of CMOS Schmitt Trigger Circuits. // Modern Applied Science. 6, (2012), pp. 51-58. DOI: 10.5539/mas.v6n12p51

[15] Yasin, F. M.; Khaw, M.; Reaz, M. Techniques of RFID systems: Architectures and applications. // Microwave Journal. 49, (2006), pp. 62-74.

[16] Sato, T.; Ito, T. Design of low distortion active inductor and its applications. // Analog Integrated Circuits and Signal Processing. 75, (2013), pp. 245-255. DOI: 10.1007/s10470-012-9955-z

[17] Aljarajreh, H.; Reaz, M.; Amin, M.; Husain, H. An Active Inductor Based Low Noise Amplifier for RF Receiver. // Electronics and Electrical Engineering. 19, (2013), pp. 49-52. DOI: 10.5755/j01.eee.19.5.2158

[18] Thanachayanont, A. Low-voltage low-power high-Q CMOS RF bandpass filter. // Electronics letters. 38, (2002), pp. 615-616. DOI: 10.1049/el:20020440

[19] Bhuiyan, M. A. S.; Zijie, Y.; Yu, J. S.; Reaz, M. B. I.; Kamal, N.; Chang, T. G. Active inductor based fully integrated CMOS transmit/receive switch for 2.4 GHz RF transceiver. // Anais da Academia Brasileira de Ciências. 88, 2 (2016), pp. 1089-1098. DOI: 10.1590/0001-3765201620150123

[20] Karsilayan, A. I.; Schaumann, R. A high-frequency high-Q CMOS active inductor with DC bias control. // Proceeding of the IEEE Midwest Symposium on Circuits and Systems. / Lansing, 2000, pp. 486-489. DOI: 10.1109/mwscas.2000.951689

[21] Lin, K. Y.; Weng, R. M. A Low-power Tunable Bandpass Amplifier for RF Applications. // Proceeding of the IEEE Asia Pacific Conference on Circuits and Systems. / Singapore, 2006, pp. 1776-1778. DOI: 10.1109/apccas.2006.342162

[22] Gao, Z.; Ma, J.; Yu, M.; Ye, Y. A fully integrated CMOS active bandpass filter for multiband RF front-ends. // IEEE Transactions on Circuits and Systems II: Express Briefs. 55, (2008), pp.718-722. DOI: 10.1109/TCSII.2008.922392

[23] Chen, S. W.; Wu, J. W.; Wu, J. D.; Li, J. S. Tunable active bandpass filter design. // Electronics letters. 47, (2011), pp. 1019-1021. DOI: 10.1049/el.2011.1401



**Authors' addresses**

***Mohammd Arif Sobhan Bhuiyan,***
***Muhammad Tazarudin Bin Mohd. Taib,***
***Mamun Bin Ibne Reaz,***
***Fazida Hanim Hashim,***
***Sawal Hamid Md. Ali***
Universiti Kebangsaan Malaysia,
Department of Electrical, Electronic and Systems Engineering,
43600 Bangi, Selangor, Malaysia
Tel: +603-89216311
E-mail: mamun.reaz@gmail.com