The hardware design of Type B residual current device

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Abstract

Conduct the analysis of available type B residual current device in the market, compare their functions and technical characteristics, research their operation principle and feature, then purpose the corresponding solution. Finally, develop a prototype and conduct the test. There are three samples. They are ABB RC223 residual current release, which can be combined with the Tmax T4 four-pole circuit-breaker in the fixed or plug-in version, Socomec earth leakage relay RESYS B 475 and Bender residual current monitor RCMA470LY

Keywords: residual current device (RCD), ABB RC223, circuit-breaker

1 Introduction

The Residual Current Device (RCD) plays an important role in the protection against earth leakage current and electric shock. According to the characteristic and residual current, the RCD is classified into type AC, type A and type B. Most of current RCD products are type AC or type A model, and there are few type B RCD products. Available products in the market include ABB RC223 residual current release, which can be combined with the Tmax T4 four-pole circuit-breaker in the fixed or plug-in version, Socomec earth leakage relay RESYS B 470 series and Bender residual current monitor RCMA470 series [1].

Conduct the analysis of available type B residual current device in the market, compare their functions and technical characteristics, research their operation principle and feature, then purpose the corresponding solution. Finally, develop a prototype and conduct the test.

2 Sample overview

There are three samples. They are ABB RC223 residual current release, which can be combined with the Tmax T4 four-pole circuit-breaker in the fixed or plug-in version[3], Socomec earth leakage relay RESYS B 475 and Bender residual current monitor RCMA470LY.

ABB RC223 can boast conformity with type B operation, which guarantees sensitivity to residual fault currents with alternating, alternating pulsating and direct current components. The reference Standards are: IEC 60947-1, IEC 60947-2 Appendix B and IEC 60755. Apart from the signals and settings typical of the "basic" residual current release, the RC223 also allows selection of the maximum threshold of sensitivity to the residual fault frequency (3 steps: 400 – 700 – 1000 Hz). It is therefore possible to adapt the residual current device to the different requirements of the industrial plant according to the prospective fault frequencies generated on the load side of the release. Typical installations which may require frequency thresholds different from the standard ones (50-60 Hz) are the welding plants for the automobile industry (1000 Hz), the textile industry (700 Hz), airports and three-phase drives (400 Hz). All the functions of the apparatus – even the most advanced ones can be checked by the user by means of a careful watchdog test which is carried out by a series of simple successive steps [4]. Detailed technical parameters are shown in Table 1.

TABLE 1 ABB RC223 technical parameters

Technology	Microprocessor-based
Primary service voltage(V)	110 … 500
Rated ultimate Residual short-circuit breaking capacity, $I_{\Delta m}$ (A)	100% I_{cu}
Operating frequency	0-1000 Hz
Operating frequency threshold	400-700-1000 Hz
Test operation range（V）	110 … 500
Rated service current (A)	up to 250
Rated residual current trip (A)	0.03-0.05-0.1-0.3-0.5-1
Time limit for non-trip (s)	0-0.1-0.2-0.3-0.5-1-2-3; 30 mA (instantaneous)
Tolerance over time trip	±20%

Cased with 18mm diameter built-in detection toroid, RESYS B 475 can monitoring all types of differential current in the TT, TNS and IT networks. It is particularly suitable for circuits with converters, with sensitivity of 0.03 to 3A, time delay of 0 to 10s and frequency of 0-700 Hz. Its technical parameters are shown in Table 2.

TABLE 2 Socomec Resys B 475 technical parameters

Supply voltage (Us)	9.6…84VDC
Operating rang of Us	0.85…1.1 Us
Power consumption	≤3.5 VA
Rated residual operating current (IΔn)	0.03…0.5A
Rated frequency	0…700 Hz
Response delay, adjustable	0…10 s
Internal measuring current transformer	Φ 18mm

RCMA 470LY is designed for monitoring earthed power supply systems where DC fault current or residual currents continuously greater than zero may occur. These are in particular loads containing six-pulse rectifiers or one way rectifiers with smoothing, such as converters, battery

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chargers [5], construction site equipment with frequency-controlled drives. The pre-warning stage (50% of the set response value) allow to distinguish between pre-warning and alarm. Since the values are measured with measuring current transformers, the device is nearly independent of the load current and the nominal voltage of the system. The device can also be used for busbar systems [6].

Bender RCMA470LY technical parameters are shown in Table 3.

TABLE 3 Bender RCMA 470LY technical parameters

Supply voltage	AC230V 50/60 Hz
Operating range of us	0.85…1.1V
Power consumption	≤3.5 VA
Rated residual operating current	AC/DC 30 mA…3A
Relative percentage error	0…-25%
Hysteresis	Approx.25% of the response value
Response time	<70 ms
Rated frequency	0…150 Hz
Response delay, adjustable	0…10 s
Rated contact voltage	AC 250 V/DC 300 V

Function comparison of samples is shown in Table 4.

TABLE 4 Display function

Sample name	RC223	RESYS B475	RCMA 470LY
Photo			
Manufacturer	ABB	Socomec	Bender
Technology	Microprocessor-based	Microprocessor-based	Microprocessor-based
Power supply	Self-supply	Auxillary power supply	Auxillary power supply
Rated residual current (A)	0.03-0.05-0.1-0.3-0.5-1	0.03A…0.05 A	0.03A…3A
Delay time (s)	0-.1-0.2-0.3-0.5-1-2-3	0…10	0…10
Frequency (Hz)	400-700-1000	0-700	0-150
Current sensor	Internal	Internal	Selectable diameter

3 Technical analysis and comparison

Circuit of ABB RC223 consists of a current transformer, a release and two PCBs. In the following analysis, it is divided into two parts: power supply and leakage current detection& control [7].

Power supply circuit consists of two parts: AC-DC and DC-DC, which is shown in Figures 1 and 2.

The AC-DC part is constant frequency current control switching power supply based on Si9114. The output is DC 27.2V, the switching frequency is 18KHz. Si9114 is a Bic/DMOS current-mode pulse width modulation controller IC for high-frequency dc/dc converters. The input range is 15 to 200V [8]. Therefore, the operation voltage range of RC223 is wide (line voltage 110-500V). The output inverter of Si9114 can typically source 500mA and sink 700 mA. The high-voltage DMOS transistor allows the IC to interface directly to bus voltage up to 200V. Other features include a 1.5% accurate voltage reference, 1.8MHz (min) bandwidth error amplifier, shutdown logic control [9], soft-start and undervoltage lockout circuits. In this circuit, SI9114 controls the conductions of MOSFET at constant frequency. Thus, pulse voltage is generated in the primary windings of transformer. After rectification and filtering, DC voltage can be obtained [10].

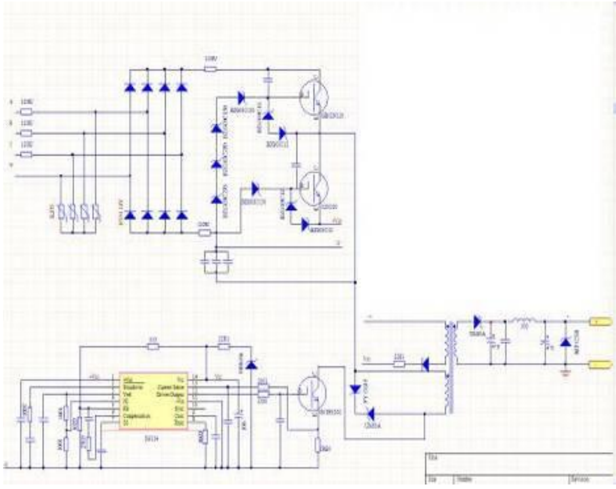

FIGURE 1 AC-DC circuit

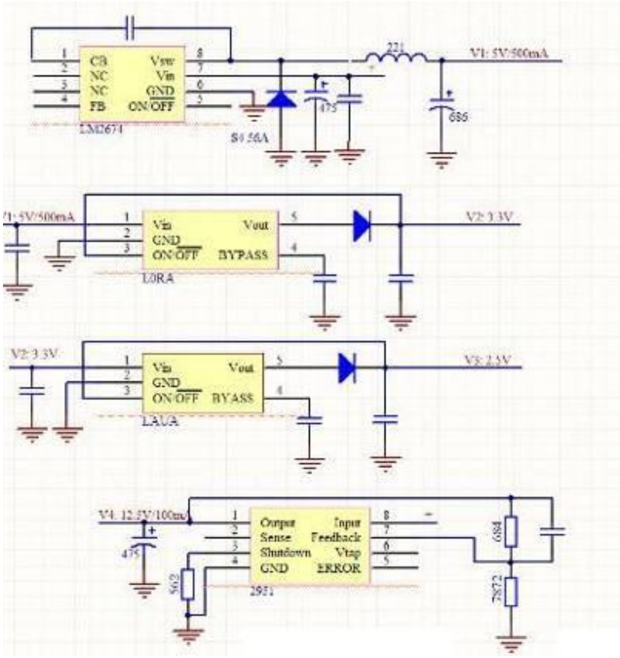

FIGURE 2 DC-DC circuit

In DC-DC conversion, the 27.2V DC is stepped down into three different voltages: +12.5V, +5V and +3.3V.Four ICs are applied for the conversion. They are LM2674, L0RA, LAUA and LP2951.

Due to the high efficiency switching power and low cost LDO, the total power consumption of RC223 is less than 10W.

4 Detection and control circuit analysis

DSP56F827FG80E is the brain of RC223. It is responsible for parameters (residual current, time delay) setting, pre-alarm, release tripping, protection display and residual current detection. The detailed introduction to each part is as follows [11].

4.1 DSP56F827FG80E

As shown in Figure 3, the DSP56F827 is a member of the DSP56800 core-based family of Digital Signal Processors (DSPs). It combines, on a single chip, the processing power of a DSP and the functionality of a microcontroller with a flexible set of peripherals to create an extremely cost-effective solution for general purpose applications. Because of its low cost, configuration flexibility, and compact program code, the DSP56F827 is well suited for many applications. The DSP56F827 includes many peripherals that are especially useful for applications [12].

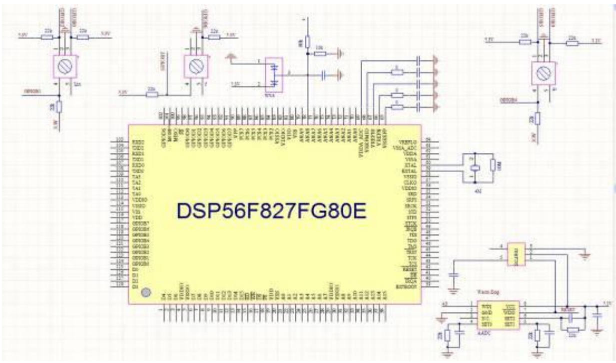

FIGURE 3 DSP and function setting circuit

4.2 RESIDUAL CURRENT DETECTION CIRCUIT

The oscillating circuit is shown in Figure 4. As to comparator 3702I, its circuit is shown in Figure 5. The relationship of 3702I input voltage (V5 and V6) can be figured out by the following calculation. From the testing results, output of PIN7 is square wave with high level of 12.5V and low level of 0V [13]. When the output of PIN7 is low, suppose voltage of PIN5 is Uo, the circuit is shown in Figure 6. The Uo is 4.65V.

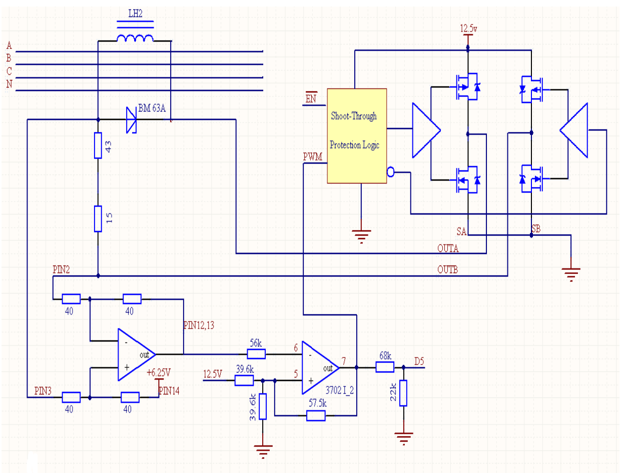

FIGURE 4 Oscillating circuit

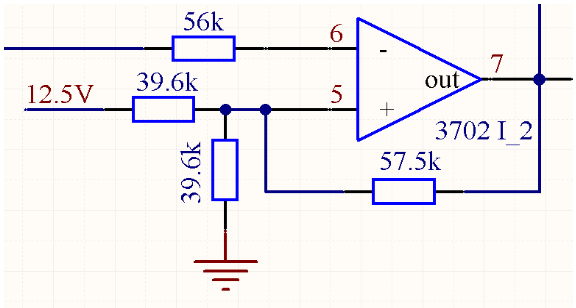

FIGURE 5 Circuit of 3702I comparator

When the output of PIN7 is high, the circuit is shown in Figure 7. The Uo is 7.85V.

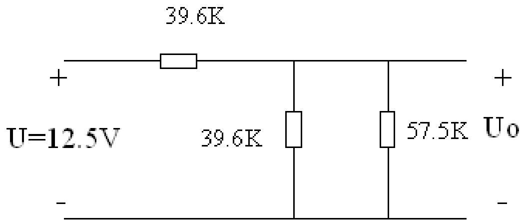

FIGURE 6 Circuit of 3702I when PIN7 is low

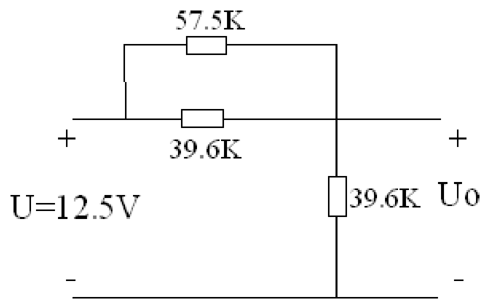

FIGURE 7 Circuit of 3702I when PIN7 is 12.5V

Therefore, the window voltage of 3702I is 4.65V and 7.85V respectively.

When power up, voltage of PIN5 is 6.25V, voltage of PIN6 is 0V; output of PIN7 is high level. So PIN3 of SI9988 is high level, PIN5 (OUTA) is high level, PIN8 (OUTB) is low level. PIN5 and PIN8 are connected with LH2 and resistor of 60ohm. IO relationship of IC INA2132 is$V0=V3-V2+Vref$, Where: V0, V2, V3 is the voltage of PIN13,PIN2 and PIN3. Voltage of PIN14 is the reference voltage Vref=6.25V. That is, $V0=V3-V2+6.25$. Due to the induction effect, V3 increases gradually. Here, for IC 3702I, voltage of PIN6 $V6=V3-V2+6.25$. When V6 is greater than 7.85V, output of PIN7 changes into low level. Consequently, for Si9988, PIN3 is low level, PIN5 is low level. PIN8 is high level [14].

For INA2132, $V0=V3-V2+6.25$ begins to decrease. When V6 of 3702I is less than 4.64V, output of PIN7 changes into high level. Thus, square wave is generated. The above mentioned waveform relationship is shown in Figure 8. The oscillating frequency is 2KHz and keeps constant due to feedback. According to Shannon sampling theory, the frequency can detect leakage current up to 1 KHz.

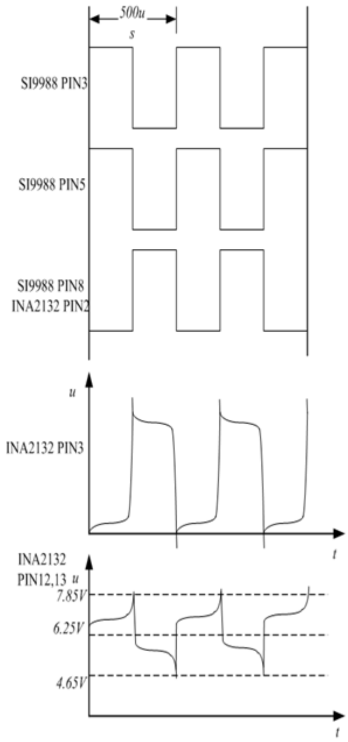

FIGURE 8 Waveform relationship

The iron core of Permalloy used to detect residual current has an excellent property of rectangular magnetic hysteresis and a small coercive force. The iron core is excited with a high-frequency electric source so that its magnetic field is greater than its coercive force. The B-H curve is shown in Figure 9.

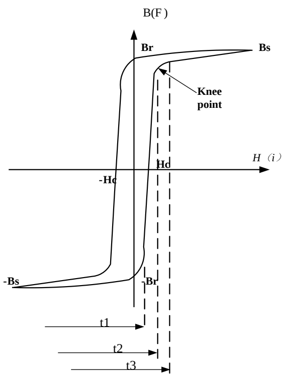

FIGURE 9 B-H curve

As to RC223, when PIN3 of SI9988 is high, PIN5 is 12.5V, PIN8 is 0V. When PIN3 of SI9988 is low level, PIN5 is 0V, PIN8 is 12.5V [15]. Therefore, voltage across the resistor and detection winding (LH2) is the square wave. The simplified circuit is shown in Figure 10. We define the direction of current positive when PIN5 is high level and PIN8 is low level.

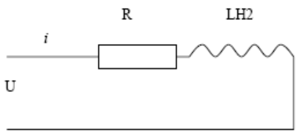

FIGURE 10 Excitation circuit

For RL circuit, the time constant is $\tau = L / R$.The greater the time constant τ, the slower the transient process. The curve is relatively smooth. As shown in Figure 11 $\tau_A < \tau_B$, that is $L_A < L_B$.

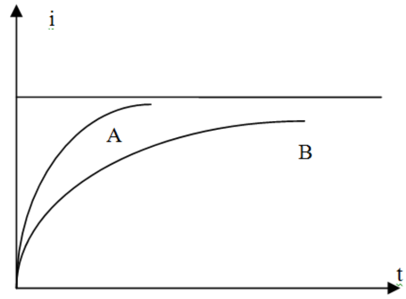

FIGURE 11 Relationship of transient process and time constant

Due to negative voltage effect, LH2 is in the negative saturated zone. The current is negative as well. Suppose when t =0, the negative square wave ends. Voltage changes from negative to positive [16]. In the B-H curve of Figure 9, t_1 is the time from the start to linear section. $t_1 < t < t_2$ is the time of linear section. $t_2 < t < t_3$ is the time of knee point. $t > t_3$ is the time of saturation. To simplify the process, suppose B-H curve changes from linear section to saturation direction. The corresponding equations are as follows:

$$\begin{cases} U = iR + L_1 \dfrac{di}{dt} (0 < t < t_1) \\ U = iR + L_2 \dfrac{di}{dt} (0 < t < t_2) \\ U = iR + L_3 \dfrac{di}{dt} (0 < t < t_\infty) \end{cases} . \tag{1}$$

Solve differential Equation (1):

$$\begin{cases} i = I_\infty + A_1 e^{-\frac{t}{\tau_1}} (0 < t < t1) \\ i = I_\infty + A_2 e^{-\frac{t-t1}{\tau_2}} (t1 < t < t2) \\ i = I_\infty + A_3 e^{-\frac{t-t2}{\tau_3}} (t2 < t < t_\infty) \end{cases} , \tag{2}$$

where $\tau_1 = L_1 / \mathrm{R}$, $\tau_2 = L_2 / \mathrm{R}$, $\tau_3 = L_3 / \mathrm{R}$. In addition, according to circuit theory, I_{s1} and I_{s2} is the transient value of I at time t_1 and t_2.

Then:

$$i = I_\infty + (1 - e^{\frac{t}{\tau_1}}) - I_{s0} e^{-\frac{t}{\tau_1}} (0 < t < t1) , \tag{3}$$

$$i = I_\infty + (I_{s1} - I_\infty) e^{\frac{t-t1}{\tau_2}} (t1 < t < t2) , \tag{4}$$

$$i = I_\infty + (I_{s2} i - I_\infty + (I_{s1} - I_\infty) \\ e^{\frac{t-t1}{\tau_2}} (t1 < t < t2) I_\infty) e^{\frac{t-t2}{\tau_3}} (t2 < t < t_\infty). \tag{5}$$

When $0 < t < t_1$, L_1 is small due to slowly changing of B. Consequently, time constant $\tau_1 = L_1 / \mathrm{R}$ is small as well. The current rises rapidly.

When $t_1<t<t_2$, L_2 is greater due to rapid changing of B. as a result, time constant $\tau_2 = L_2 / R$ is greater as well. The current rises slowly.

When $t > t_2$, the magnetic field reaches positive saturation, B reduces to saturation, L_3 reduces as well. So time constant $\tau_3 = L_3 / R$ reduces. Here, the rising speed of current increases to the saturation current [17].

Similar process can be analyzed when voltage is negative. Waveform of u-i in RL circuit is shown in Figure 12.

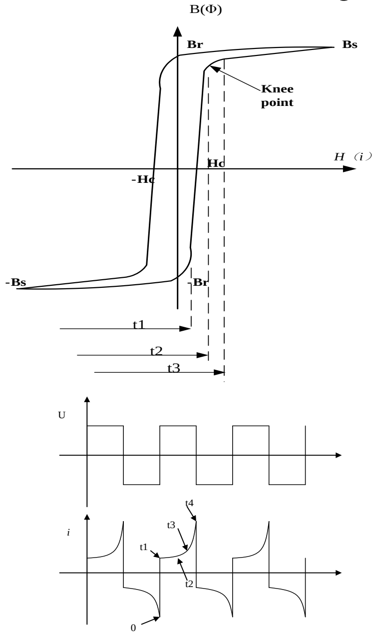

FIGURE 12 Principle of magnetic modulation

When $0 < t < t_1$ the current changes with exponential law In Figure 12. The current rises rapidly due to smaller time constant. It is shown in Equation (3). When $t_1<t<t_2$, current changes with exponential law as well.

5 Conclusion

By the above analysis, three kinds sample can resembled for two categories, which ABB RC223 and SOCOMEC RESYS B475 (include RCMA 470), their operating principle adopts magnetism to modulate principle, whose oscillating wave way diversity. In the side of signal processing, RC223 adopts DSP to carry out digital wave filtering, taking sample, judging and so on, especially that the outside circuit is simple, the software programming is complicated. Yet RESYS B475 adopts imitate circuit to carry out wave filtering and rectify current, at last sends in the monolithic machine carrying out processing, characteristic is that the outside circuit is complicated, imitate circuit that designed demand is highly, the software programming is relatively simple. Concerning we design, surplus electric current detecting asks for adopt magnetism modulation, but creation of oscillating wave way is different from the sample. Besides, in the side of signal processing, draw on the sample circuit, considering the hardware design and the software programming, thereby take form resolve a scheme.

References

[1] Lin X, Li Y, Ma Y 2009 Dynamic characteristics analysis on novel motor actuator of high voltage circuit breaker *Electric Machines and Control* **13**(2) 216-21

[2] Dennis S S L, Lithgow B J, Morrison R E 2003 *IEEE Transactions on Power Delivery* **18**(2) 454-9

[3] Hoidalen H K, Runde M 2005 *IEEE Transactions on Power Delivery* **20**(4) 2458-65

[4] Landry M, Lonard F, Beauchemin R 2008 *IEEE Transactions on Power delivery* **23**(4) 1986-94

[5] Huang J, Hu X G GENG X 2011 An intelligent fault diagnosis method of high voltage circuit breaker base on improved EMD energy entropy and multi-class support vector machine *Electrical Power System Research* **81**(2) 400-7

[6] Cheng J S, Yu D J, Tang J S 2008 Application of frequency family separation method based upon EMD and local Hilbert energy spectrum method to gear fault diagnosis *Mechanism and Machine Theory* **43**(6) 712-23

[7] Wang Z, Liu Q, Jia J 2000 The algorithm and error analysis that the practical electric current in the electrical endurance prediction of hight voltage circuit breaker *High Voltage Apparatus* (2) 22-4

[8] Nilsson J 1998 Real-time control systems with delays *Lund Institute of Technology* 36-47

[9] Huang Q, Shuang K, Xu P 2014 Prediction-based Dynamic Resource Scheduling for Virtualized Cloud Systems *Journal of Networks* **9**(2) 375-83

[10] Hu X, Sun L 2006 Study on the method of circuit breaker on-line insulation monitoring *Electric power automation Equipment* **26**(4) 253-8

[11] Wang Y, Pu X, Wang X 2005 Several calculation methods of circuit breaker life on-line monitoring *Journal of Shenyang Agricultural Uinversity* **36**(1) 78-83

[12] Li B 2005 Value and its online monitoring technology conversion, the electrical life of circuit breakers limit *High Voltage Electrical Apparatus* **41**(6) 43-9

[13] Ni Y, Chen H 2013 Detection of Underwater Carrier-Free Pulse based on Time-Frequency Analysis *Journal of Networks* 8(1) 205-12.

[14] Jing Z H, Hua J, Yang X N 2007 A new method for detecting negative SNR UWB Signal *Communication Countermeasures* **4** 17-21

[15] Li X, Yao H 2013 Improved Signal Processing Algorithm Based on Wavelet Transform *Journal of Multimedia* **8**(3) 226-32

[16] Hollot C V, Misra V, Towsley D, Gong W Analysis and design of controllers for AQM routers supporting TCP flows *IEEE Transactions on Automatic Control* 2002 47 945-59

[17] Min Y, Park H, Jang J, Kim K, Choi H 2011 The Enhanced Decoding Method for QO-SFBC System in Frequency Selective Fading Channel Environment *Journal of Networks* **6**(3) 378-86

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