

Low Frequency Multiple Divider Using Resonant Model

Chih Chin Yang, Chih Yu Lee, Jing Yi Wang, Mei Zhen Xue, Chia Yueh Wu

Abstract—A well-defined frequency multiple dividing (FMD) circuit using a resonant model is presented in this research. The basic component of a frequency multiple divider as used in a resonant model is established by compositing a well-defined resonant effect of negative differential resistance (NDR) characteristics which possesses a wider operational region and high operational current at a bias voltage of about 1.15 V. The resonant model is then applied in the frequency dividing circuit with the above division ratio (R_D) of 200 at the signal input of middle frequency. The division ratio also exists at the input of a low frequency signal.

Keywords—Divider, frequency, resonant model.

I. INTRODUCTION

RECENTLY, resonant tunneling devices have been researched from a solid state semiconductor device [1] to organic semiconductor devices [2], [3]. The advantages of solid state semiconductor devices in resonant tunneling devices are a long operational period, harmless structure and low working bias, but its high fabrication cost and complexity of device fabrication are not easily solved. The polymer resonant tunneling device does not have a long usage period, but its fabrication cost is extremely low. The realization of good resonant tunnel devices is studied in the characteristics of current-to-voltage to obtain a high peak-to-valley current ratio and high peak-current ratio because of the wider operational region of the device which is used in memory devices [4], [5], multi-value logic circuits [6], [7], dividing frequency circuits [8], [9] and sensor devices [10], [11]. A frequency divider must have the advantage of low power consumption and be of the variety of dividing frequency. In this paper, a frequency divider, with multiple frequencies from low to middle frequencies, is studied. FMD circuits are explored using a resonant model based on numerical simulation and calculation. The frequency dividing circuit, with a resonant circuit model, is simplified by discrete devices. The combined discrete devices should be able to fabricate in part of the integrated circuit by adoption of suitable fabrication technology. The well-defined frequency dividing characteristics will be used in more fields of wireless communication.

Chih Chin Yang*, Chih Yu Lee, Jing Yi Wang, Mei Zhen Xue, and Chia Yueh Wu are with the National Kaohsiung Marine University, Department of Microelectronics Engineering, Kaohsiung, Taiwan, 81157 Republic of China. (*corresponding author; phone: 886-7-361-7141; fax: 886-7-364-5589; e-mail: chchyang@mail.nkmu.edu.tw).

II. RESEARCH METHOD

In this research, PSPICE software is used for simulation of dividing frequency circuits with a resonant model combined by a discrete element. The multiple dividing frequency circuit, with a resonant model, can be drawn by using a choice of patterns for the analysis of circuit simulation. The results show that the circuits can be completely installed in the workstation by the simulation of PSPICE. The resonant model applied in FMD circuits will be introduced by the analog circuit following the experimental steps below. First, the PSPICE software with a resonant model is used in the drawing schematic. Second, mapping is accomplished by the click option in the capture mode analysis with direct current and time domain simulation. Third, the analog circuits in the PSPICE module are added and analyzed. Then, as the simulated results are not complete, the components of the circuit in dividing frequency must be corrected by using the component of time domain and then, redoing the circuit simulation. After revising the component of FMD circuits, the simulation results show the frequency dividing function which will produce the output of dividing frequency, as above. If the spectrum analysis is completed using the Fourier analysis, it will produce a spectrum with different frequencies while simulating the FMD circuits. Lastly, the X-axis and Y-axis will be adjusted in the simulated results if the X-axis and Y-axis of the calculated results are improper. In this study, the different divided frequencies verify that each frequency is varied with the resonant component.

III. RESULTS AND DISCUSSION

A FMD system using a resonant analog circuit is constructed with an adjusted precise resistance. The resonant analog circuit includes a third-order negative different resistance in sub-circuits which is composited with lumped elements and an amplifier. In order to realize the frequency divider, the exact value of the lumped element, such as resistances, must be arranged by the calculation and simulation of PSPICE. The frequency multiple divider using a resonant model is established, as shown in Fig. 1.

The output of NDR characteristics for the resonant model is shown in Fig. 2. The curve of voltage versus conductance has a maximum value for the conductance at a bias of about 1.15 V in this single resonant model. To cause a formed maximum conductance value it is suggested that NDR must occur because of the design of the resonant circuit. This resonant circuit has resistances, capacitances and three terminal devices, of which the resistance is the key element. The resistance value of a resonant model is important when deciding the frequency dividing value because the operational point is found by the

cross of NDR characteristics and the load line at a resonant region.

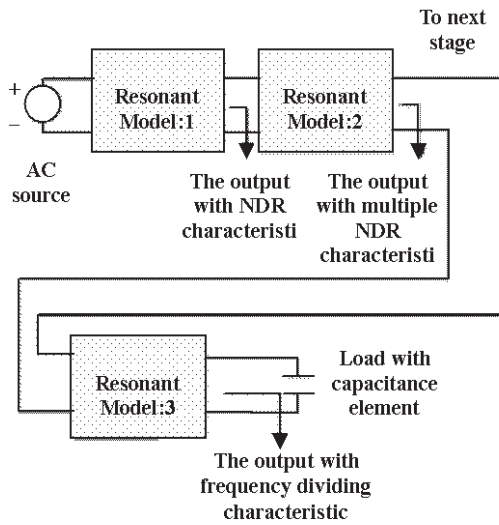


Fig. 1 Schematic of frequency divider using resonant analog circuit

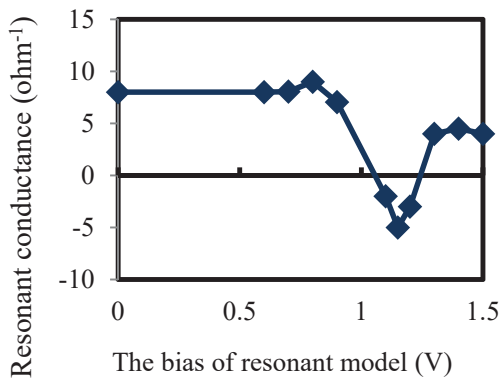


Fig. 2 The negative differential resistance characteristic for the resonant model

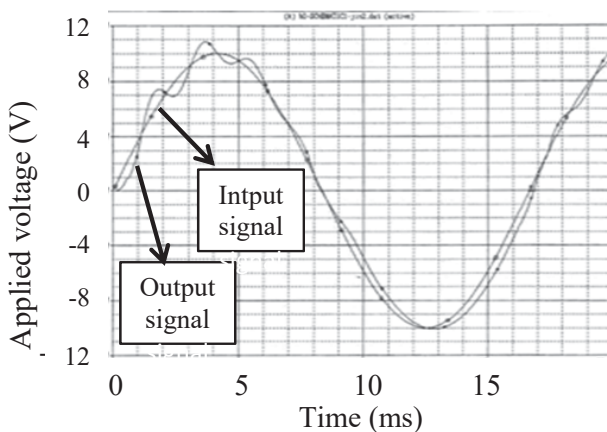


Fig. 3 The output of frequency divider at the input of low frequency

With the successful establishment of a well-defined resonant model, a frequency divider is constructed, as shown in Fig. 1, by using the above resonant model. In this frequency divider, a three-stage resonant model is utilized to complete the frequency division from a low frequency to a middle frequency. The researched results are shown in Fig. 3, which shows the output of the divided frequency.

In Fig. 3, the input frequency is divided in multiples of 0.9 at a slightly low frequency. The multiplication of divide is called the division ratio (R_D). The division ratio (R_D) is defined by input frequency (F_I) over output frequency (F_O), as shown in (1):

$$R_D = \frac{F_I}{F_O} \quad (1)$$

The frequency divider in this research is completely established and proven by the simulation. The signal input of various frequencies is arranged from the low frequency to the middle frequency. The frequency is inputted from about the base band to 100 KHz, as shown in Table I. From this result, the frequency divider possesses a dividing function at various frequencies from the low frequency to the middle frequency. The results show that the ratio of division (R_D) rises as the input frequency rises. This model can be adapted to the frequency division of higher frequencies by using these results.

As the input frequency rises, the division ratio (R_D) also rises, although a variety of ratios of division (R_D) has a nonlinear relation as a function of the frequency variable. This phenomenon agrees with the conclusion that the switching function of a resonant model is the speed of charge and discharge with the effect of inductance and capacitance.

The component of frequency dividing circuit, as above, is defined in a resonant model. The resonant model can be constructed and listed by two methods. The resonant model can first be defined in the resonant electronics circuit which includes the lumped elements and amplified devices. The fundamental of the resonant electronics circuit is a switching operation of the transistor with various resistance values. When one of the transistors is turned on at the first stage, the system current will be increased with the increased bias voltage. Before the first transistor turns off, the second stage turns on, and the current of the resonant model will fall to a lower value. In this situation, a negative differential effect of the current-voltage characteristics will occur. When the transistor of the second stage is turned on and the transistor of the first stage is turned off, the resonant model will produce a rising current with an increasing bias voltage. Therefore, the negative differential characteristic of a resonant model will be applied in the switching circuit which can construct the frequency dividing system. As the negative differential characteristic is well-defined, the operation of frequency dividing system will be able to be used at a higher frequency. In this study, the frequency dividing system normally worked at a frequency of 100 KHz.

TABLE I
THE OUTPUT FREQUENCY AS THE FUNCTION OF VARIOUS INPUT FREQUENCIES

Input (F_i)	60 Hz	500 Hz	100 KHz
Output			
Frequency output (F_o)	59 Hz	400 Hz	0.5 KHz
Division ratio	1.02	1.25	200

As the resonant model is added to the capacitance load in the resonant system, FMD system can be established because of the combination of both the capacitance and switching device in this structure, resulting in the division of input frequency, called the frequency dividing device. Another type of resonant model is constructed by using the growth of thin films in semiconductor fabrication. The resonant model of this semiconductor type also shows good negative differential characteristics because of the precise control of thin film growth for the quantum well or quantum dot. A resonant model of a semiconductor type possesses fixed inductance values due to the quantum well effect. Since the capacitance load is combined with a resonant model of an inductance type, a frequency multiple divider with a resonant effect will be established. The frequency divider of a semiconductor type will not have good control of the inductance value because the inductance effect in the quantum structure is still unknown. The advantage of a frequency dividing system for the semiconductor type is that the device can be grown with fabrication of integrated circuits *in situ* on a silicon base. The resonant model of a semiconductor type includes both a geometrical depletion capacitance and a quantum capacitance which is not easily declared. The phenomenon, as described above, is a disadvantage for the resonant model of a semiconductor type, although the dimension of a frequency dividing system can be minimized in this type.

Equations (2) and (3) exhibit the input signal (v_i) and output signal (v_o) of FMD circuits, respectively. In the equations, F_i and F_o are the input frequency and output frequency, respectively. θ_{pe} is the phase error between the input signal and output signal [12].

$$v_i = V_{m,in} \sin(F_i t) \quad (2)$$

$$v_o = V_{m,out} \sin(F_o t + \theta_{pe}) \quad (3)$$

The relationship between the frequency input (F_i) and frequency output (F_o) is shown in Fig. 4. The frequency input is a function of the frequency output. The curve shown in Fig. 4 reveals the nonlinear function. When the input frequency is more than 400 Hz, the output frequency is abruptly increased which results in a better division ratio. Therefore, the output frequencies of FMD devices proposed in this research are well-defined in high frequency reached as MHz.

The relationship between the division ratio (DR) and frequency output (F_o) is presented in Fig. 5. When the output frequency is more than 400 Hz, the division ratio is significantly increased from 1.25 to about 200. This suggests that the high division ratio in a high frequency is due to the resonant conductance effect including the external inductance

(L_Q), series resistance (R_s) and load impedance (Z_L) with capacitance effect (C) [13].

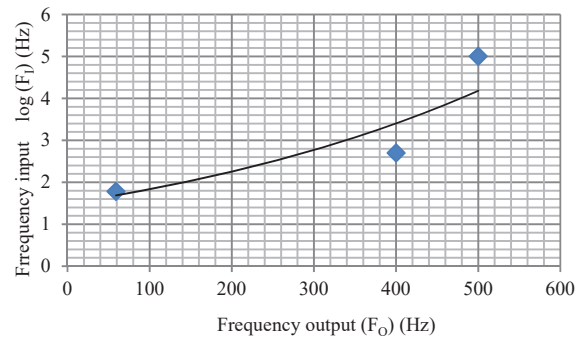


Fig. 4 The relationship between frequency input (F_i) and frequency output (F_o)

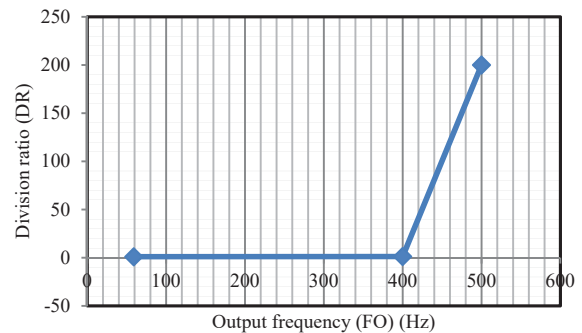


Fig. 5 The relationship between division ratio (DR) and frequency output (F_o)

The external inductance (L_Q), series resistance (R_s) and load impedance (Z_L) with capacitance effect (C) originate from the leakage current items, wire bonding effect and load effect of FMD devices, respectively. NDR (R_N) of FMD devices also plays a critical role in the division ratio (DR). A NDR (R_N) is generated at the output frequency (F_o) [14]. The NDR (R_N) is a function of the output frequency (F_o), as shown in (4) [14]. The n and C are the constant value of about 0.5 and device capacitance effect, respectively.

$$\frac{1}{R_N} = \frac{F_o}{2} \left(\frac{n}{n+1} \right) C \quad (4)$$

In this research, the C and output frequency (F_o) are defined as 440 pF and 0.5 KHz, respectively [13]. The R_N is about 121.2×10^6 ohm. In this situation, the optimum value of the division ratio (R_D) could reach 200 as NDR (R_N) and capacitance value (C) of FMD device are all fixed at the constant values. The research results are exhibited in Fig. 5. This frequency dividing function of a FMD device can be applied in wireless sensor systems, short-range communication and radio frequency identification systems.

IV. CONCLUSIONS

A frequency multiple divider using a resonant model is proposed in this paper, obtaining proof of dividing frequency from base frequency to middle frequency by calculating the frequency dividing circuit. The basic element of a dividing frequency circuit used in a resonant model has been exactly completed by composition of lumped elements and amplifier. A resonant model is developed with the characteristics of NDR which has been applied in the frequency dividing circuit in this study. This research proposes a frequency dividing circuit with a well-defined division ratio (R_D) from the signal input of low frequency to middle frequency of about 100 KHz.

ACKNOWLEDGMENT

This work was supported by the National Science Council (NSC), Taiwan, Republic of China.

REFERENCES

- [1] C. C. Yang and Y. K. Su, "Well-defined electrical properties of high-strain resonant interband tunneling structure," *Microelectronics Journal*, vol. 39 (1), pp.67-69, Jan. 2008.
- [2] J. A. Duraes, M. J. Araujo Sales, R. F. Souto, A. Romariz, J. C. da Costa, A. M. Ceschin, and S. G. C. Moreira, "Observation of negative differential resistance and hysteretic effect on buriti oil; polystyrene organic devices," *Applied Physics Letters*, vol. 89(13), pp.133502, Sept. 2006.
- [3] J. Chen, L. Xu, J. Lin, Y. Geng, L. Wang, and D. Ma, "Negative differential resistance effect in organic devices based on an anthracene derivative," *Applied Physics letters*, vol. 89(8), pp. 083514, Aug. 2006.
- [4] J. P. Wagt, H. Tang, T. E. Broekaert, A. Seabaugh, and Y. C. Kao, "Miltibit resonant tunneling diode SRAM cell based on slew-rate addressing," *IEEE Transactions on Electron Devices*, vol. 46(1), pp.55-62, Jan. 1999.
- [5] R. Lame and J. Yang, "A physics based model for the RTD quantum capacitance," *IEEE Transactions on Electron Devices*, vol. 50(3), pp.785-789, March 2003.
- [6] J. H. Tsai, "High-performance AlInAs/GaInAs -doped HEMT with negative differential resistance switch for logic application," *Solid State Electronics*, vol. 48(1), pp. 81-85, Jan. 2004.
- [7] K. J. Gan, C. S. Tsai, D. S. Liang, C. D. Tu, and Y. H. Chen, "Multi input NOR logic design using negative differential resistance circuits implemented by standard SiGe process," *Solid-State Electronics*, vol. 52(2), pp. 175-178, Feb. 2008.
- [8] Y. Kawano, Y. Ohno, S. Kishimoto, K. Maezawa, and T. Mizutani, "50 GHz frequency divider using resonant tunneling chaos circuit," *Electronics Letters*, vol. 38(7), pp. 305-306, Mar. 2002.
- [9] T. Kim, Y. Jeong, and K. Yang, "Low power static frequency divider using an InP-based monolithic RTD/HBT technology," *Electronics Letters*, vol. 42(1), pp. 27-29, Jan. 2006.
- [10] H. J. Pan, K. W. Lin, K. H. Yu, C. C. Cheng, K. B. Thei, W. C. Liu and H. I. Chen, "Highly hydrogen sensitive Pd/InP metal oxide semiconductor schottky diode hydrogen sensor," *Electrons Letters*, vol. 38(2), pp.92-94, Jan. 2002.
- [11] B. Zhang, J. Wang, C. Xue, W. Zhang, and J. Xiong, "A GaAs acoustic sensor with frequency output based on resonant tunneling diodes," *Sensors and Actuators A*, vol. 139(1-2), pp. 42-46, Sept. 2007.
- [12] B. Razavi, Design of Analog CMOS Integrated Circuits. New York: McGraw-Hill, 2001, ch. 15, pp. 540-541.
- [13] C. C. Yang, "Frequency computation of resonant signal in resonant tunneling circuit for communication," *Advances in Mathematical and Computational Methods (Adv Math Comput Meth)*, vol. 1, No.2, pp. 8-14, Dec. 2011.
- [14] M. M. Driscoll, "Phase noise performance of analog frequency dividers," *Proceedings of the 43rd IEEE Annual Symposium on Frequency Control*, pp. 342 - 348, 1989.

Chih Chin Yang received the Ph.D degree in Electrical Engineering from National Sun Yat-sen University, Kaohsiung, Taiwan. He has been engaged in research of gallium aluminum arsenic thin film growth and studies of microwave and resonant tunneling devices. After receiving his Ph. D degree, he was a Associate Professor in the Department of Electronic Communication Engineering at the National Peng-hu Institute of Technology, Peng-hu, Taiwan, from 1997 to 1999. In 1997, he was a Dean of office of Business Affairs in National Peng-hu Institute of Technology, Peng-Hu, Taiwan. He is currently an Associate Professor in the Department of Microelectronic Engineering at the National Kaohsiung Marine University, Kaohsiung, Taiwan, from 2002. He has been engaged in research of semiconductor devices and materials, bio-sensors, annealing in semiconductor material, optimize model of semiconductor manufacturing process, infrared light detector, divided frequency and multi-value circuits. He has published many papers in SCI Journal and international conference from 1994 to now. He had passed person qualified of the National Senior and Special Examination in civil service of electronic engineering in 1992.

Chih Yu Lee received the Master degree in Mathematics from California State University at Hayward, USA. She has been engaged in research of numerical analysis and mathematical physics. She is currently an Assistant Professor in the Department of Microelectronic Engineering at the National Kaohsiung Marine University, Kaohsiung, Taiwan, Republic of China.

Jing Yi Wang received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan, Republic of China. She has been engaged in research of negative differential resistance devices and system.

Mei Zhen Xue received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan, Republic of China. She has been engaged in research of resonant tunneling circuit and system.

Chia Yueh Wu received the B.S. degree in Microelectronics Engineering from National Kaohsiung Marine University, Kaohsiung, Taiwan, Republic of China. She has been engaged in research of divider and related circuits.