

# Asynchronously Coupled Resonant Junctions for Diplexers and Multi-port Filtering Networks

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**Abstract**— This paper proposes the use of asynchronously coupled resonator junctions in the design of diplexers. This is to ease the control and implementation of the external couplings at the common port of an all-resonator-based diplexer. A comparison study has been performed between a conventional diplexer and the proposed diplexer. To further explore the possibilities of the proposed junction technique, a four-port multi-port filtering networks was proposed and designed to function as a double diplexer. Good agreements have been achieved between the measurements of the prototype devices and the simulations.

## I. INTRODUCTION

Diplexers are three-port devices used in the communication systems for transmitting and receiving signals through a shared antenna. A diplexer is made up of two channel filters connected by a junction. In the case of conventional diplexers, the junction is usually formed of transmission lines in the form of T-junction [1] or Y-junction [2]. In addition to these, hybrid couplers [3], manifolds [4] or circulators [5] were also used. Recently, a new design approach which utilises resonant junctions was introduced into diplexer designs [6]-[8]. Circuit miniaturisation is achieved when the resonating junction not only serves to split/combine signals but also as a resonant pole contributing to the frequency selectivity. Such techniques were reported in [8], [9] using single-mode junction resonators and in [10]-[12] using dual-mode junction resonators such as T-shaped resonators [13], stepped-impedance resonators (SIRs) [14] and patches [6]. The need for the junction resonator to couple in three ways to the common port as well as to the two channels complicates the implementation. Single-mode junction resonators restrict the overall bandwidth of the signal that is allowed in a diplexer. For dual-mode junctions, the main challenge is the control of the external couplings to the two respective modes from a common port.

This work is built on from the design concept of resonant junctions but proposes the use of asynchronously coupled resonator junctions to ease the control and implementation of the external couplings at the common port. Two diplexers based on a conventional T-junction and the proposed resonant junction, as illustrated in Fig. 1(a) and (b), were first designed and compared. The proposed junction structure was then applied to demonstrate the realisation of a four-port filtering network as illustrated in Fig. 1(c).

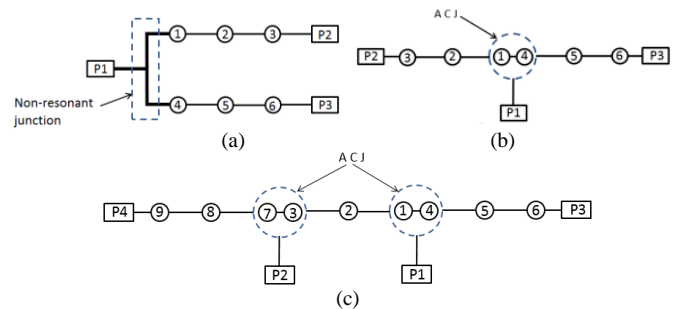


Fig. 1. Coupling topologies of (a) a conventional diplexer, (b) the proposed diplexer and (c) a 4-port filtering network, where ACJ stands for asynchronously coupled resonator junction.

## II. DIPLEXER DESIGN AND COMPARISON

### A. Layouts of Diplexers

Fig. 1(a) demonstrates the topology of a conventional T-junction diplexer. The non-resonant T-junction is designed using  $\lambda/4$  transmission lines. Fig. 1(b) demonstrates the proposed diplexer coupling topology where the dashed circle indicates the asynchronously coupled resonant junction (ACJ). The junction is essentially a pair of asynchronously tuned resonators of different resonating frequencies coupled together. The coupling topologies of Fig. 1(a) and (b) are translated into their circuit layouts using microstrip technology as presented in Fig. 2 and Fig. 3 respectively.

The conventional T-junction diplexer in Fig. 2 and the proposed asynchronous coupled resonant junction diplexer in Fig. 3 are both designed to operate at 1.8 GHz and 2.1 GHz with a 4% fractional bandwidth (FBW), and 20 dB return loss on each channel. Two channel filters operating at 1.8 GHz and 2.1 GHz were first separately designed to specifications using hairpin resonators. To join the channel filters, the T-junction transmission line was used for the conventional diplexer as shown in Fig. 2. In the case of the proposed coupled resonant junction diplexer, the first resonators of both channel filters were asynchronously coupled together. A single feed-line from the common port was sequentially coupled to these two resonators through edge coupling. The technique resulted in a compact circuit. More importantly the external couplings from the common port to the two resonators serving the two respective channels can be readily controlled.

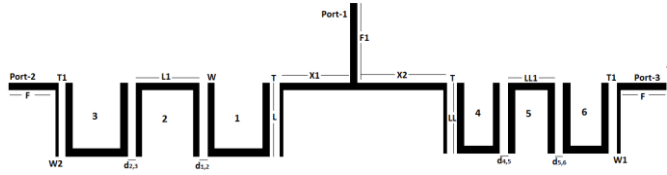


Fig. 2. Layout of the conventional diplexer.  $F = 10$ ,  $F1 = 13.7$ ,  $X1 = 13.8$ ,  $X2 = 17.6$ ,  $T = 0.3$ ,  $T1 = 0.4$ ,  $W = 1.2$ ,  $W1 = 0.6$ ,  $W2 = 0.6$ ,  $L = 11.5$ ,  $L1 = 9.95$ ,  $LL = 11$ ,  $LL1 = 6.59$ ,  $d_{1,2} = 1.77$ ,  $d_{2,3} = 1.77$ ,  $d_{4,5} = 1.75$ ,  $d_{5,6} = 1.75$ . Unit: mm.

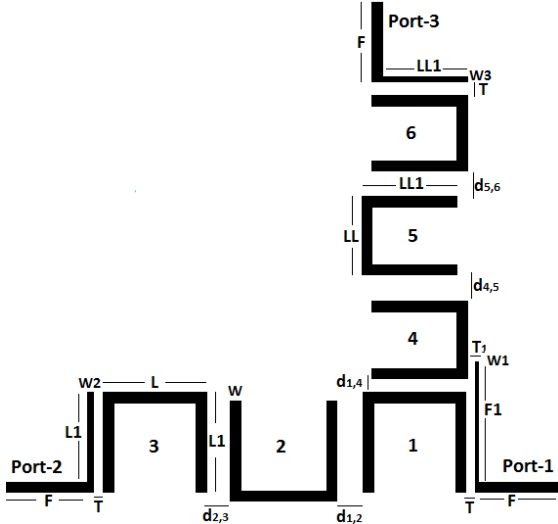


Fig. 3. Proposed diplexer.  $F = 10$ ,  $T = 0.4$ ,  $T1 = 0.2$ ,  $W = 1.2$ ,  $W1 = 0.4$ ,  $W2 = 0.6$ ,  $W3 = 0.6$ ,  $L = 9.6$ ,  $L1 = 11.5$ ,  $LL = 6.6$ ,  $LL1 = 11$ ,  $d_{1,2} = 1.7$ ,  $d_{1,4} = 0.2$ ,  $d_{2,3} = 1.7$ ,  $d_{4,5} = 1.65$ ,  $d_{5,6} = 1.7$ . Unit: mm.

### B. Asynchronous Coupling and $Q_{ext}$

The diplexers in Fig. 3 are made up of two filters of  $f_1 = 1.8$  GHz and  $f_2 = 2.1$  GHz with 4% FBW each. These filters are designed to meet the three-pole Chebyshev ripple factor of 0.043 dB with a lowpass prototype derived from [15]–[16] with  $g$ -values of  $g_0 = g_4 = 1.0$ ,  $g_1 = g_3 = 0.8516$ , and  $g_2 = 1.1032$ . The  $g$ -values are used in obtaining the coupling coefficients and external  $Q$ -factors used for the physical dimensioning of the resonators. Using the general filter synthesis method, the coupling coefficients and external quality factors were derived from (1) and (2).

$$M_{1,2} = M_{2,3} = M_{4,5} = M_{5,6} = \frac{FBW}{\sqrt{g_1 g_2}} = 0.041 \quad (1)$$

$$Q_{ex1(L)} = Q_{ex1(H)} = Q_{ex2} = Q_{ex3} = \frac{g_1 g_0}{FBW} = 21.29 \quad (2)$$

where  $Q_{ex1(L)}$  and  $Q_{ex1(H)}$  are the external  $Q$ -factors from the common port to the low and high channel respectively. After individually designing the channel filters to specification, the first resonators of the 1.8 GHz and 2.1 GHz filters were coupled together to define the two channel frequencies as shown in Fig. 4.

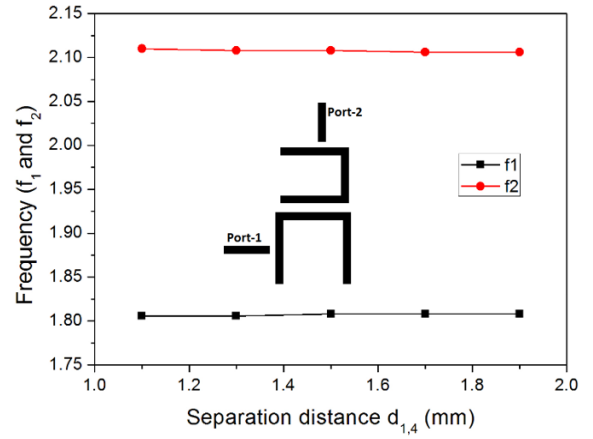


Fig. 4. Asynchronous coupling between resonator 1 and 4.

To achieve the external quality factors ( $Q_{ext}$ ) from the common port to the asynchronous coupled resonator junction, a coupled feed line was used as shown in Fig. 5. Port-2 and port-3 in Fig. 5 were weakly coupled to the resonators whereas the coupling gap, width and length of the feed line were adjusted to achieve the required  $Q_{ext}$  using (3).

$$Q_{ex1(L)/(H)} = \frac{f_{1(L)/(H)}}{\Delta f_{1(L)/(H)}} \quad (3)$$

where  $f_{1(L)/(H)}$  and  $\Delta f_{1(L)/(H)}$  are the centre frequencies and the 3dB bandwidths of the resonance curves corresponding to the low and high channel. Fig. 5(a) presents a graph of the typical responses. Fig. 5(b) shows the simulated current distribution at the resonator junction at 1.8 GHz and 2.1 GHz. It is evident that the ACJ acts as a signal splitter.

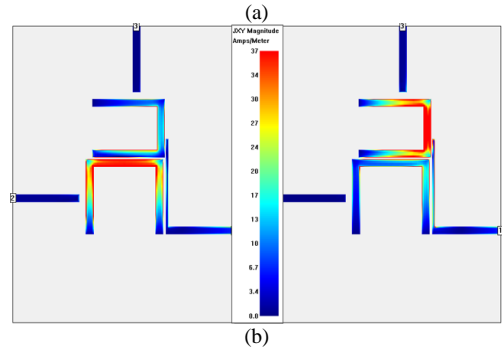
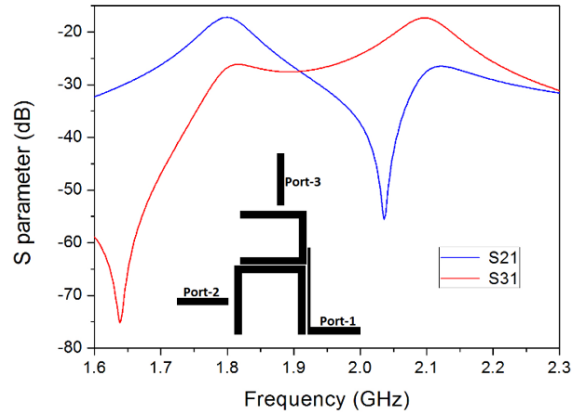


Fig. 5. (a) Simulated responses of the configuration used to extract  $Q_{ext}$ ; (b) Simulated current distribution at 1.8 GHz (left) and 2.1 GHz (right).

### C. Performance Comparison

The EM software Sonnet is used for the simulation. Fig. 2 and 3 present the achieved physical dimensions after optimization. Fig. 6 compares the achieved simulated responses of the proposed diplexer (solid lines) with the conventional T-junction diplexer (dash lines). While the two diplexers achieved similar rejection in the high band, the resonator junction provided less rejection in the low band. This is expected due to the lack of isolation between the two coupled resonators which is one shortcoming of resonator junctions. Rogers 3010 substrates with a thickness of 1.27mm, a relative permittivity of 10.8 and a loss tangent of 0.0022 were used. Measurements were taken using Agilent Network Analyser N5230A. The measured responses of the two diplexers are presented in Fig. 7. Good agreement between the simulations and measurements has been achieved.

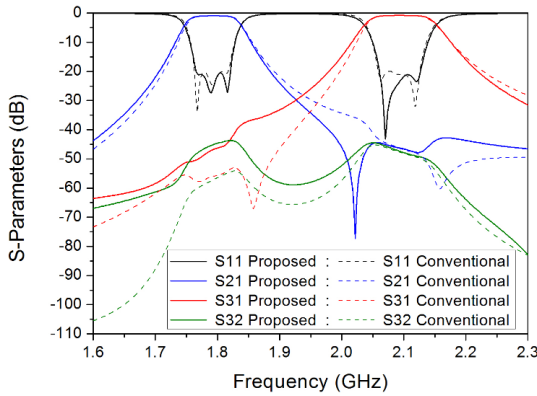


Fig. 6. Simulated responses of the proposed and the conventional diplexers.

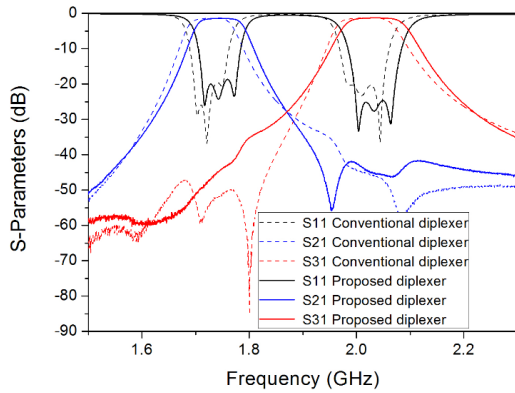


Fig. 7. Measured responses of the proposed and the conventional diplexer.

### III. 4-PORT FILTERING NETWORK

To further explore the potentials of the coupled resonator junctions, a four-port filtering network in the form of two back-to-back diplexers is designed as illustrated in Fig. 1(c). It is not targeting any specific application at this stage but to demonstrate the capability of realizing multi-port coupled-resonator networks. From the coupling topology, the network contains two asynchronous coupled resonator junctions, three filters (three bands) and four ports. Fig. 8 presents the design layout where resonators 1 and 4 as well as resonators 3 and 7 represent the asynchronous coupled resonator junctions. The

resonators 1-3 forms the channel of 1.8 GHz, resonators 4-6 and resonators 7-9 forms the channels of 2.1 GHz and 2.6 GHz respectively.

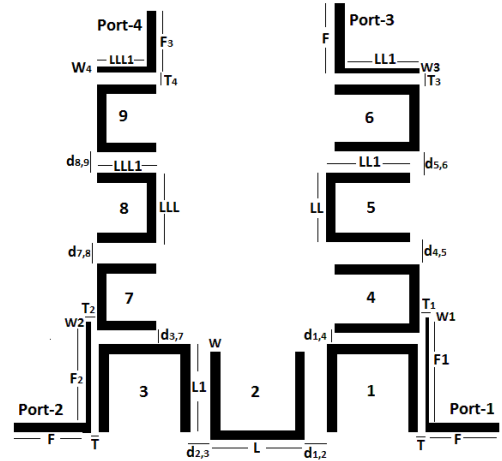
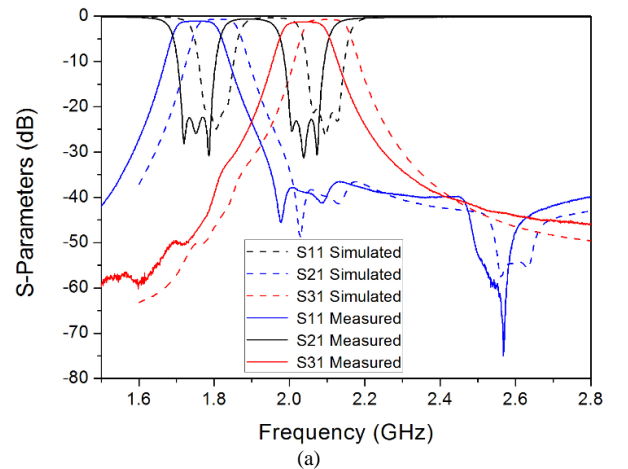


Fig. 8. Layout of the proposed double diplexer.  $F = 10$ ,  $F1 = 15$ ,  $F2 = 15$ ,  $T = 0.4$ ,  $T1 = 0.2$ ,  $T2 = 0.38$ ,  $W = 1.2$ ,  $W1 = 0.4$ ,  $W2 = 0.6$ ,  $W3 = 0.6$ ,  $L = 9.6$ ,  $L1 = 11.5$ ,  $LL = 6.6$ ,  $LL1 = 11$ ,  $d_{1,2} = 1.46$ ,  $d_{1,4} = 0.2$ ,  $d_{2,3} = 1.48$ ,  $d_{3,7} = 0.22$ ,  $d_{4,5} = 1.65$ ,  $d_{5,6} = 1.7$ ,  $d_{7,8} = 1.84$ ,  $d_{8,9} = 1.82$ . Unit: mm.

The design in Fig. 8 is built on from the diplexer in Fig. 3 by adding on a 2.6 GHz filter using another asynchronous coupled resonator junction. That is resonator 7 coupled to resonator 3. The coupling topology of this circuit offers this design an opportunity to function as switchable diplexers or even multi-input and multi-output filtering networks. Fig. 9 presents two possible choices of selected diplexer channels. Fig. 9(a) shows the frequency duplexing at 1.8 GHz and 2.1 GHz when the common port is Port-1. Fig. 9(b) shows the duplexing of 1.8 GHz and 2.6 GHz when the common port is Port-2. All the return losses are below 20 dB. Measurements and simulations show reasonably good agreement except for the frequency shift of 10 MHz. This is believed to be due to the thinning of the substrate from milling as well as the tolerance of the dielectric constant of this high permittivity anisotropic substrate material. Fig. 10 presents the isolation response between port-1 and port-4, port-2 and port-3 as well as port-3 and port-4. The solid lines represent the measured responses while the dashed lines represent the simulated responses.



(a)

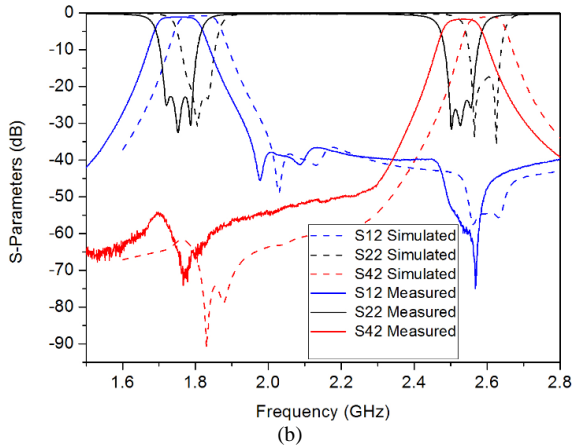


Fig. 9. Simulated and measured duplexing responses of the design in Fig. 8 when (a) Port-1 is the common port and (b) Port-2 is the common port.

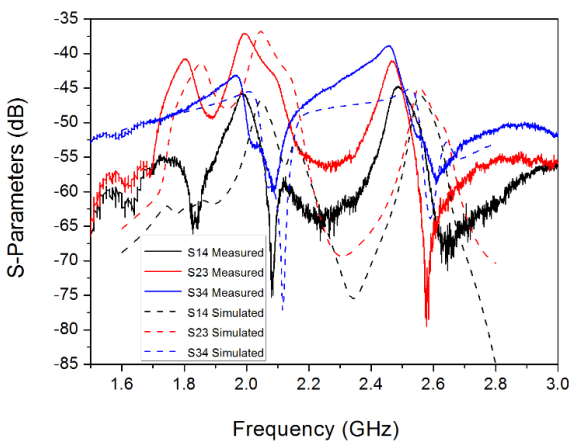


Fig. 10. Simulated and measured isolation responses of  $S_{14}$ ,  $S_{23}$  and  $S_{34}$  of the design in Fig. 8.

#### IV. CONCLUSIONS

In this work, asynchronously coupled resonant junctions are proposed and investigated for applications in resonator-based duplexers and multi-port filtering networks. The proposed resonant junction structure succeeded in easing the implementation of external couplings at the common ports as compared with previous reported single-mode or dual-mode junctions. The comparison between a conventional T-junction duplexer and the proposed resonant junction duplexer has concluded a more compact structure of the proposed duplexer but at the cost of channel rejection. Better isolation between the asynchronously coupled resonators is desired at the junction. It is also worth mentioning that the asynchronous coupled resonator junction technique can be used in designing duplexers or multiplexers with both narrowly or widely separated channels. To further demonstrate the capability of the coupled junction, a four-port filtering network in the form

of a double duplexer was presented. Depending on the choice of the common port, different duplexing schemes can be realized. Although this four-port device is not currently conceived for any specific application, the underlining concept of a generic multi-port resonator network could be explored for circuit functions such as switchable duplexers or multi-input and multi-output filtering networks.

#### REFERENCES

- [1] T. Yang, P. L. Chi and T. Itoh, "High Isolation and Compact Duplexer Using the Hybrid Resonators," in *IEEE Microwave and Wireless Components Letters*, vol. 20, no. 10, pp. 551-553, Oct. 2010.
- [2] K. L. Wu and W. Meng, "A Direct Synthesis Approach for Microwave Filters With a Complex Load and Its Application to Direct Duplexer Design," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 55, no. 5, pp. 1010-1017, May 2007.
- [3] Y. L. Cheng, H. W. Chen, P. D. Huang and C. Y. Chang, "A W-band quadrature hybrid coupled substrate integrated waveguide duplexer," *2015 Asia-Pacific Microwave Conference (APMC)*, Nanjing, 2015, pp. 1-3.
- [4] T. Skaik and M. Lancaster, "Coupled Resonator Duplexer without External Junctions," *Journal of Electromagnetic Analysis and Applications*, Vol. 3 No. 6, 2011, pp. 238-241.
- [5] C. E. Saavedra, "Duplexer using a circulator and interchangeable filters," *2008 7th International Caribbean Conference on Devices, Circuits and Systems*, Cancun, 2008, pp. 1-5.
- [6] E. A. Ogbodo, Y. Wu and Y. Wang, "Microstrip duplexers with dual-mode patch resonant junctions," *2016 46th European Microwave Conference (EuMC)*, London, United Kingdom, 2016, pp. 1155-1158.
- [7] X. Guan et al., "A novel microstrip duplexer with a common square ring resonator for WCDMA," *2016 IEEE International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM)*, Nanjing, 2016, pp. 1-3.
- [8] Y. Wu, Y. Wang and E. A. Ogbodo, "Microstrip wideband duplexer with narrow guard band based on all-resonator structures," *2016 46th European Microwave Conference (EuMC)*, London, United Kingdom, 2016, pp. 1163-1166.
- [9] G. Macchiarella, "Synthesis of Star-Junction Multiplexers," in *IEEE Microwave Magazine*, vol. 12, no. 6, pp. 101-109, Oct. 2011.
- [10] T. F. Skaik and D. A. Tubail, "Novel multiplexer topologies based on coupled resonator structures," *Microwave Symposium (MMS)*, 2015 IEEE 15th Mediterranean, Lecce, 2015, pp. 1-4.
- [11] X. Shang, Y. Wang, X. Wenlin, M. J. Lancaster, "Novel Multiplexer Topologies Based on All-Resonator Structures," *IEEE Trans. Microwave Theory and Techniques*, vol 61, no. 11, 2013, pp. 3838 – 3845.
- [12] M. L. Chuang and M. T. Wu, "Microstrip duplexer design using common T-shaped resonator," *IEEE Microwave. Wireless Components. Letter.*, vol. 21, no. 11, pp. 583-585, Nov. 2011.
- [13] X. Guan, F. Yang, H. Liu and L. Zhu, "Compact and High-Isolation Duplexer Using Dual-Mode Stub-Loaded Resonators," in *IEEE Microwave and Wireless Components Letters*, vol. 24, no. 6, pp. 385-387, June 2014.
- [14] C. F. Chen, T. Y. Huang, C. P. Chou and R. B. Wu, "Microstrip Duplexers With Common Resonator Sections for Compact Size, But High Isolation," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 5, May 2006.
- [15] J.-S. Hong "Microstrip Filters for RF/Microwave Applications," John Wiley & Sons, Inc. 2011.
- [16] D. M. Pozar, *Microwave Engineering*. 3rd ed. New York: Wiley, 2005.