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TECHNICAL SESSIONS (Interactive Forum)

Friday, November 9 *10:00 - 11:30*

Session FR1-IF Room A

Chairs: Rozenn Allanic (Lab-STICC - UBO Brest, France), Hidehisa Shiomi (Osaka University, Japan)

FR1-IF-1
Parallel-coupled-line quasi-elliptic single-ended and balanced bandpass filters
Chih-Jung Chen (National Taiwan Ocean University & National Taiwan Ocean University, Taiwan); Chun-Lung Chen (National Taiwan Ocean University, Taiwan)

FR1-IF-2
Bandpass Filter with Capacitively Loaded Coupled Lines for Wideband Spurious Rejection
Peng Chen (University of Electronic Science and Technology of China, P.R. China); Luping Li (University of Electronic Science and Technology of China, P.R. China); Kai Yang (University of Electronic Science and Technology of China, P.R. China); Qiang Chen (Tohoku University, Japan)

FR1-IF-3
Matrix Synthesis of Cascaded K-Tuplets Filters with Frequency-Variant Couplings
Yuxing He (Yokohama National University, Japan); Nobuyuki Yoshikawa (Yokohama National University, Japan)

FR1-IF-4
A Design of Balun Bandpass Filter for Wide Stopband Attenuation Base on Stepped Impedance Resonators
Phirun Kim (Chonbuk National University, Korea); Wang Qi (Chonbuk National University, Korea); Girdhari Chaudhary (Chonbuk National University, Korea); Yongchae Jeong (Chonbuk National University, Korea)

FR1-IF-5
A Novel 3.5 GHz Low-Loss Bandpass Filter Using I.H.P. SAW
Yuichi Takamine (Murata Manufacturing Co., Ltd., Japan); Tsutomu Takai (Murata Manufacturing Co., Ltd., Japan); Hideki Iwamoto (Murata Manufacturing Co., Ltd., Japan); Takeshi Nakao (Murata MFG., Japan); Masayoshi Koshino (Murata Manufacturing Co., Ltd., Japan)

FR1-IF-6
Novel Length Independent Beltrami Resonators Using Corrugated Reflectors
Ryo Mochizuki (Kyoto University, Japan); Yuma Takano (Osaka University, Japan); Naoki Shinohara (Kyoto University, Japan); Atsushi Sanada (Osaka University, Japan)

FR1-IF-7
Compact Ultra-Narrowband Superconducting Filter using Asymmetric Twin-Spiral Resonators
Lin Tao (Tsinghua University, P.R. China); Bin Wei (Tsinghua University, P.R. China); Xubo Guo (Tsinghua University, P.R. China); Bisong Cao (Tsinghua University, P.R. China)

FR1-IF-8
Compact Microstrip Lowpass Filter with Ultra-wide Stopband
Thulaseedharan Kodiyattuvila Rekha (Cochin University of Science and Technology, India); Parambil Abdulla (Cochin University of Science and Technology, India); Thevaruparambil Abdulnazer Nisamol (Cochin University of Science and Technology, India)

FR1-IF-9
Compact Quasi-elliptic Bandpass Filter Using Magnetically Coupled LC Resonator Pair
Ting-Yi Lin (National Taiwan University & GICE, Taiwan); Tzong-Lin Wu (National Taiwan University, Taiwan)

FR1-IF-10
Miniaturized EMSIW Filter with High out of Band Rejection
Xing-He Nie (Southeast University & State Key Laboratory of Millimeter Waves, P.R. China); Wei Hong (Southeast University, P.R. China)

FR1-IF-11
Analysis and Determination of Microwave Filter Order
Eng Leong Tan (Nanyang Technological University, Singapore); Ding Yu Heh (Nanyang Technological University, Singapore)

FR1-IF-12
Design and fabrication of 3-pole BPF configured by hairpin resonators and different types of coupling and feed types at 20 GHz
Satoshi Ono (The University of Electro-Communications, Japan)

FR1-IF-13
A Compact Power Divider Using Dual Composite Right-/Left-Handed Resonators (D-CRLH) with Filtering Response
I-Ju Chen (National University of Kaohsiung, Taiwan); Wen-Chen Lee (National University of Kaohsiung, Taiwan); Yi-Hsin Pang (National University of Kaohsiung, Taiwan)

FR1-IF-14
A Notch Filter Design Using Quarter-mode SIW Cavities with High Mode Suppression
Xiaolong Huang (Shanghai Jiao Tong University, P.R. China); Liang Zhou (Shanghai Jiao Tong University, P.R. China); Junfa Mao (Shanghai Jiao Tong University, P.R. China)

FR1-IF-15
Design of Holographic Metasurface for Antenna Beam Steering Based on Liquid Crystal Technology
Xiang Zhang (University of Science and Technology of China, P.R. China); Qingyuan Zhang (University of Science and Technology of China, P.R. China); Chang Chen (University of Science and Technology of China, P.R. China); Weidong Chen (University of Science & Technology of China, P.R. China); Bin Liu (University of Science and Technology of China, P.R. China); Jian Cai (Institute of Microelectronics of the Chinese Academy of Sciences, P.R. China)

FR1-IF-16
Reconfigurable Metasurface as Microwave Reflectors and Polarization Converters
Badreddine Ratni (Univ Paris Nanterre, France); André de Lustrac (Institut d'Electronique Fondamentale Université Paris-Sud, France); Gérard-Pascal Piau (Airbus, France); Shah Nawaz Burokur (LEME, France)

FR1-IF-17
A Reconfigurable 4G MIMO Liquid Metal Mobile Handset Antenna
Haiqiang Gao (Beihang University, P.R. China); Zhengpeng Wang (Beihang University, P.R. China); Chang Xu (BeiHang University, P.R. China)

FR1-IF-18
Dual-band Conformal Antenna for Wireless Capsule Endoscopy Applications
Lijie Xu (Nanjing University of Posts and Telecommunications, P.R. China); Zhu Duan (Nanjing University of Information Science and Technology, P.R. China); Ming Zhang (Nanjing University of Posts and Telecommunications, P.R. China); Yaming Bo (Nanjing University of Posts and Telecommunications, P.R. China)

FR1-IF-19
Flexible Broadband achromatic microwave metalens design using polynomial fitting method
Ling Wang (Beijing University of Posts and Telecommunications, P.R. China); Weijun Hong (Beijing University of Posts and Telecommunications, P.R. China); Li Deng (Beijing University of Posts and Telecommunications, P.R. China); Shufang Li (Beijing University of Posts and Telecommunications, P.R. China); Shahab Uddin (Beijing University of Posts and Telecommunications, Pakistan); Haomin Tian (Beijing University of Posts and Telecommunications, P.R. China); Deken Chen (Beijing University of Posts and Telecommunications, P.R. China)

FR1-IF-20
High-Gain Low-Profile Substrate-Integrated Fabry-Pérot Cavity Antenna
Zhiming Liu (Nanjing University of Aeronautics and Astronautics, P.R. China); Xiangkun Kong (Nanjing University of Aeronautics and Astronautics, P.R. China)

FR1-IF-21
Circularly Polarized Antenna with Asymmetric-Metasurface
Jils Sheersha (Nanyang Technological University, Singapore); N Nasimuddin (Institute for Infocomm Research, Singapore); Arokiaswami Alphones (Nanyang Technological University, Singapore)

FR1-IF-22
Novel Compact High-Gain Wideband Filtering Metasurface Antenna
Si Chen (Nanjing University of Science and Technology, P.R. China); Wanchen Yang (Nanjing University of Science and Technology, P.R. China); Wenquan Che (Nanjing University of Science and Technology, P.R. China); Quan Xue (South China University of Technology, P.R. China); Wenjie Feng (Nanjing University of Science and Technology, P.R. China)

FR1-IF-23
Unambiguous Determination of Oscillation Frequency for Multiple Objects using Quadrature Doppler Radar
Avon Whitworth (University of Hawaii at Manoa, USA); Khaldoon Ishmael (University of Hawaii at Manoa, USA); Ehsan Yavari (University of Hawaii at Manoa, USA); Olga Boric-Lubecke (University of Hawaii at Manoa, USA)

FR1-IF-24
14.5GHz Circular Waveguide Applicator for the Treatment of Skin Cancer
Shaun Preston (Bangor University, United Kingdom (Great Britain)); Christopher Paul Hancock (Bangor University and Creo Medical, United Kingdom (Great Britain))

FR1-IF-25
A Miniature Flexible Microwave Applicator for the Ablation of Pancreatic Tumours at 5.8GHz
William Taplin (Bangor University, United Kingdom (Great Britain)); Shaun Preston (Bangor University, United Kingdom (Great Britain)); Christopher Paul Hancock (Bangor University and Creo Medical, United Kingdom (Great Britain))

FR1-IF-26
The Effect of Data Acquisition Configuration on Simultaneous Algebraic Reconstruction Technique Algorithm for Microwave Imaging System
Basari Basari (Universitas Indonesia, Indonesia); Ria Aprilliyani (Universitas Indonesia, Indonesia)

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A Design of Balun Bandpass Filter for Wide Stopband Attenuation Base on Stepped Impedance Resonators

Phirun Kim #1, Wang Qi#, Girdhari Chaudhary #, and Yongchae Jeong #2

#Division of Electronics Engineering, Chonbuk National University
Jeonju-si, Repuplic of Korea
1fmphirun@jbnu.ac.kr, 2ycjeong@jbnu.ac.kr

***Abstract* — This paper presents a design of microstrip balun bandpass filter (BPF). Since the quarter-wavelength (λ/4) stepped impedance resonators (SIRs) in the proposed balun BPF are oppositely coupled to the main line of open-circuited half-wavelength (λ/2) microstrip transmission line, the same magnitude and out-of-phased signals can be obtained at two output ports of the balun BPF. The balun BPF is designed with two stage SIRs to achieve wide stopband attenuation. The balun BPF operated at 2 GHz with fractional bandwidth of 5% Chebyshev response was designed, fabricated, and measured. The measured magnitude and phase imbalances within the passband of 1.95 to 2.05 GHz are obtained ± 0.3 dB and 180 ± 3.5°, respectively. The measured input return loss is higher than 17 dB within the same passband. Indeed, the stopband attenuation is higher than 25 dB from DC to 1.72 GHz of the lower stopband and from 2.48 GHz to 6.58 GHz of the higher stopband.**

Index Terms — Balun bandpass filter, coupled line, stepped impedance resonator, transmission zero.

I. INTRODUCTION

The balun bandpass filter (BPF) is an essential component to divide input signal into two output signals with equal power, filtering response, and out-of-phased. The marchand balun and branch line baluns can provide a good passband response. However, the stopband characteristics are poor [1]-[2]. Thus, the BPF was needed to improve stopband characteristics. This technique causes a large circuit size, high cost, and high insertion loss.

Accordingly, the balun BPFs have been studied with many significant features such as size and cost reductions, and good performances [3]-[8]. In [3], a wideband marchand balun with filtering response was proposed using additional slotlines in the ground plane with a limited stopband suppression. The slotlines required an extra gap from the ground to avoid electrical coupling effect. Meanwhile, a dual-mode ring resonator was used to design balun BPF with a high loss and limited stopband suppression [4]. To improve stopband suppression, a single open-circuited stub connected at the corner of the ring resonator was needed to produce a transmission zero in the stopband [5]. In [6], planar type balun BPFs for single and dual bands operations were proposed using dual-mode resonators. To improve selectivity and stopband characteristics, the same resonators of [6] were used to couple with microstrip-to-slotline transition in the ground plane [7].

In this paper, a balun BPF is proposed using quarter-wavelength (λ/4) stepped impedance resonator (SIR). Two λ/4 SIRs are coupled oppositely with the open-circuited stub half wavelength (λ/2) transmission line (TL). The proposed balun can provide a bandpass filtering response with identical magnitude and out-of-phase. To verify the design network, the proposed balun BPF is designed, simulated, and fabricated in a single layer microstrip line. Moreover, the measured results show a good passband performance and high stopband attenuation with wide spurious frequency.

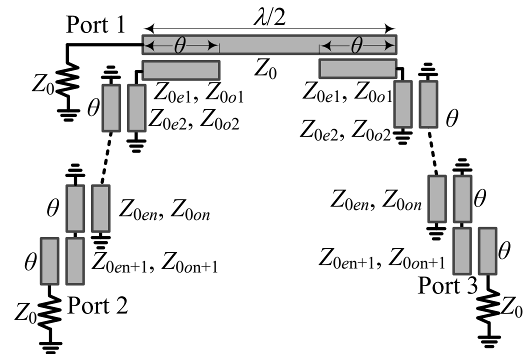

Fig. 1. Proposed balun BPF structure.

II. DESIGN EQUATIONS

Fig. 1 shows the proposed structure of microstrip balun BPF. The proposed circuit consists of two λ/4 SIRs coupled to the main line of open-ended λ/2 TL at end arms. The SIR is used to enhance the spurious frequency of the balun. Two route paths of balun can provide filtering responses of identical magnitude and out-of-phase in the passband. The coupling lengths of the SIRs are set to be θ. The balun is divided into two parts, namely, types A and B as shown in Fig. 2. The type A is composed of an antiparallel coupled line with its coupled port terminated by an open-circuited stub, whereas type B is composed of a TL cascaded with the parallel coupled line sections. For type A, the antiparallel coupled line and the open-circuited stub with a total length of λ/2 TL can produce transmission zeros in the stopband.

A. Design variables

The balun is designed to divide equally power at two output ports. Thus, the source impedances of two type networks (types A and B) are two times of the source impedance of balun. For the proposed balun, the designed variables can be derived easily from type B prototype. The

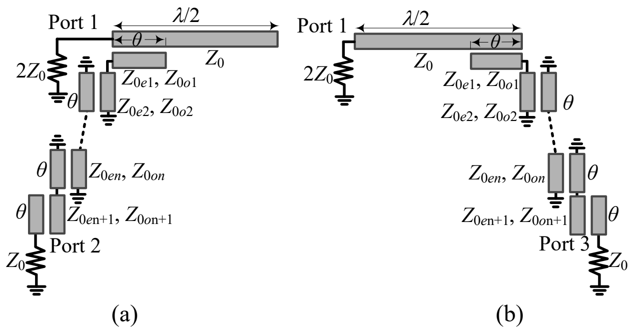

Fig. 2. Two types of balun filter: (a) type A and (b) type B networks.

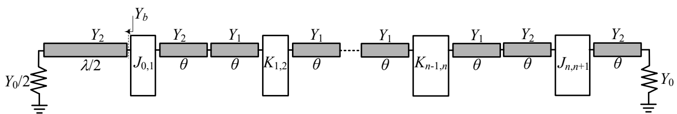

Fig. 3. Equivalent circuit of type B network.

equivalent circuit is shown in Fig. 3 by assuming $Y_0 = Y_2$. The type B prototype cannot produce transmission zero in the stopband. The $\lambda/2$ TL is terminated with the source admittance of $Y_0/2$. Thus, the input admittance of Y_b is the same as the source admittance and can be found as (1).

$$Y_b = \frac{Y_0}{2} \tag{1}$$

The J- and K-inverters of parallel coupled lines can be derived as (2).

$$J_{0,1} = Y_0\sqrt{\frac{\mathrm{FBW}\,\theta_0}{2g_0g_1}} \tag{2a}$$

$$K_{i,i+1} = \mathrm{FBW}\,\theta_0 Y_1\sqrt{\frac{1}{g_ig_i}} \tag{2b}$$

$$J_{j,j+1} = \mathrm{FBW}\,\theta_0 Y_0\sqrt{\frac{1}{g_jg_{j+1}}} \tag{2c}$$

$$J_{n,n+1} = Y_0\sqrt{\frac{\mathrm{FBW}\,\theta_0}{g_ng_{n+1}}}, \tag{2d}$$

where

$$\theta_0 = \tan^{-1}\sqrt{\frac{Y_1}{Y_2}} = \tan^{-1}\sqrt{R_Z}\,. \tag{3}$$

i and j are the odd and even numbers between 1 and n-1, respectively. The g_0, g_1, g_2, and g_3 are the prototype low-pass element values, and FBW is a fractional bandwidth of the passband. R_Z is a ratio of two characteristic admittances of SIR. The spurious frequency can be controlled by R_Z and it had been studied.

The relative formulas of even- and odd-mode impedances of parallel coupled lines are derived as (4) for open-circuited stub and (5) for short-circuited stub [8].

$$Z_{0ei} = Z_0\frac{1+JZ_0\csc\theta_0+J^2Z_0^2}{1-J^2Z_0^2\cot^2\theta_0} \tag{4a}$$

$$Z_{0oi} = Z_0\frac{1-JZ_0\csc\theta_0+J^2Z_0^2}{1-J^2Z_0^2\cot^2\theta_0} \tag{4b}$$

TABLE I

CALCULATED VALUES OF PROPOSED BALUN BPF

FBW = 5%, Z_1 = 90 Ω, Z_0 = Z_2 = 50 Ω, ripple = 0.043 dB						θ [degree]
n	Z_{0e1}, Z_{0o1} [Ω]	Z_{0e2}, Z_{0o2} [Ω]	Z_{0e3}, Z_{0o3} [Ω]	Z_{0e4}, Z_{0o4} [Ω]	Z_{0e5}, Z_{0o5} [Ω]	
2	67.07, 39.96	97.97, 82.02	77.43, 37.29			36.69
4	63.79, 41.17	94.39, 85.61	51.95, 48.19	94.39, 85.61	71.64, 38.6	

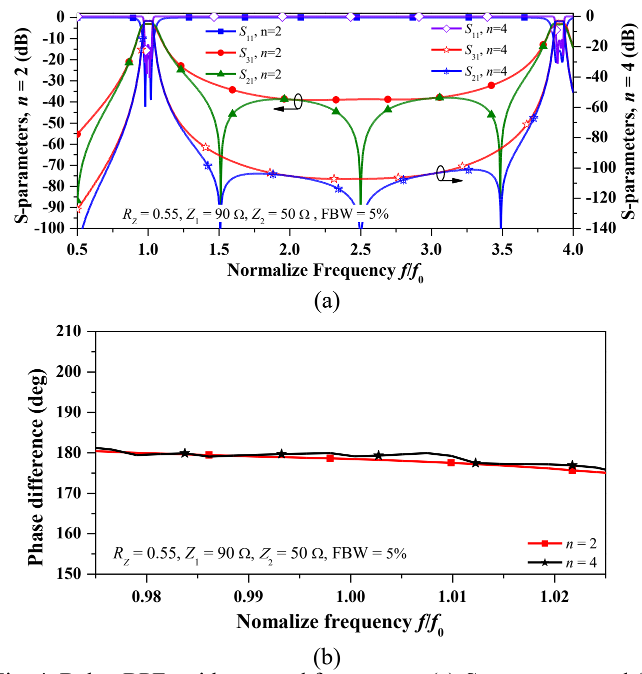

Fig. 4. Balun BPFs with two and four stages: (a) S-parameters and (b) phase difference between output ports.

$$Y_{0ej} = Y_0\frac{1-KY_0\csc\theta_0+K^2Y_0^2}{1-K^2Y_0^2\cot^2\theta_0} \tag{5a}$$

$$Y_{0oj} = Y_0\frac{1+KY_0\csc\theta_0+K_{12}^2Y_0^2}{1-K^2Y_0^2\cot^2\theta_0}, \tag{5b}$$

where $Y_{0ej} = 1 / Z_{0ej}$ and $Y_{0oj} = 1 / Z_{0oj}$.

B. Design Example

From the above analysis, the balun BPF with two stage SIRs, FBW = 5% of Chebyshev response, Z_1 = 90 Ω, n = 2 and 4, and Z_0 = Z_2 = 50 Ω are designed. From (2) and (4), the even- and odd-mode impedances of parallel coupled lines are calculated and listed in Table I. Fig. 4 (a) shows the simulation results of balun BPFs with two and four stages resonators. As shown in the figure, the characteristics of insertion loss near to the passband are almost the same at the both outputs ports. However, the transmission zeros are produced only at the output port 2. These transmission zeros are produced by $\lambda/2$ open-circuited TL of the type B prototype. For output port 3, the network is operated by the type A prototype and it cannot produce transmission zero in the stopband. Two and four transmission poles inside the passband can be obtained by two and four stages SIRs, respectively. The selectivity and stopband attenuation are improved by increase number of stages. Fig. 4(b) shows the

TABLE II

PHYSICAL DIMENSIONS OF THE PROPOSED BALUN BPF (UNIT: mm)

$W_{c1} = 1.7$	$W_{c2} = 1.05$	$W_{c3} = 1.5$	$L_1 = 13.2$
$S_{c1} = 0.25$	$S_{c2} = 1.6$	$S_{c3} = 0.15$	$W_1 = 2.4$
$L_{c1} = 11.8$	$L_{c2} = 12$	$L_{c3} = 12$	$L_2 = 5$

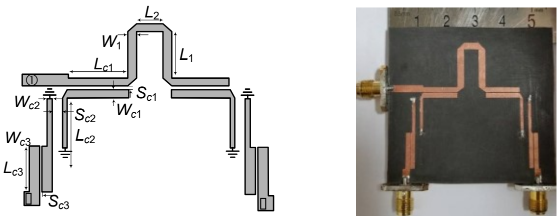

Fig. 5. Two stage balun BPF: (a) layout and (b) photograph of the fabricated circuit.

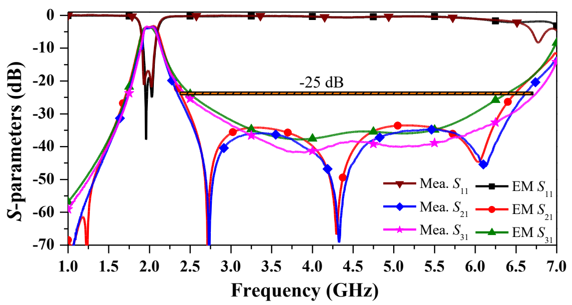

Fig. 6. Simulated and measured magnitude responses of balune BPF.

phase difference between output ports in the passband of proposed balun with n = 2 and 4. The phase differences are around 180° within the passband.

III. SIMULATION AND MEASUREMENT

To validate the proposed circuit, two stages balun BPF was designed and fabricated on the microstrip line of RT/Duriod 5880 substrate with a dielectric constant of 2.2 and thickness of 0.787 mm.

Fig. 5 shows the layout and photograph of the fabricated balun BPF. The physical dimensions of the balun BPF are shown in Table II. The total size of proposed circuit is 48.25 mm × 46.93 mm. The balun BPF is designed to operate at the center frequency (f_0) of 2 GHz with a FBW of 5%. The simulated and measured S-parameter are shown in Fig. 6. The measured input return loss is 17.5 dB at f_0. The measured S_{21} and S_{31} at the f_0 are 3.7 dB and 3.75 dB, respectively, showing a good agreement with the simulation results. Within frequency range of 1.95 GHz to 2.05 GHz, the measured power dividings and return loss are better than 3.9 dB and 17 dB, respectively. The transmission zeros of S_{21} are located at 1 GHz, 2.73 GHz, 4.33 GHz, and 6.13 GHz which provide a high selectivity and wide stopband characteristics. The stopband attenuations are more than 25 dB from DC to 1.72 GHz at lower side of operating band and from 2.37 GHz to 6.58 GHz at higher side of the operating band. The spurious frequency is occurred higher than 7 GHz (< $3.5f_0$). Fig. 7 show the simulated and measured magnitude imbalance and phase differences of the proposed balun. As seen in this figure, the

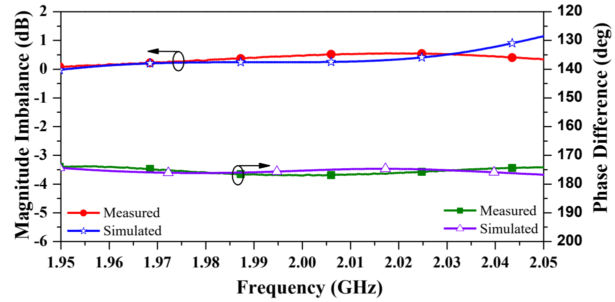

Fig. 7. Simulated and measured magnitude imbalance and phase difference in the passband of the proposed balun.

magnitude imbalance and phase differences between the output ports are better than ± 0.3 dB and 180 ± 3.5° in the passband of 1.95 GHz to 2.05 GHz, respectively.

IV. CONCLUSION

In this paper, a design of balun BPF with high attenuation and wide stopband characteristics is presented. The $\lambda/4$ SIRs are used to design the proposed balun BPF and it can improve the spurious frequency characteristics. To show the validity of the proposed circuit, a balun BPF is designed, fabricated, and measured in the single layer microstrip line. Both the simulation and measurement results agree well with the analysis. The proposed circuits are simple to design and fabricate in the single layer microstrip technology.

ACKNOWLEDGMENT

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