National Taiwan University
Graduate Institute of Communication Engineering Newsletter

Vol. 3, No. 1 February 2012 http://www.comm.ntu.edu.tw gice_newsletter@cc.ee.ntu.edu.tw

In this issue

Upcoming Events:

March 5
Dr. Min-Hsiu Hsieh visit
Department of Pure Mathematics and Mathematical Statistics, University of Cambridge

March 19
Prof. Armand Makowski visit
Dept. of Electrical and Computer Engineering, University of Maryland

March 19
Prof. S.Y. Kung visit
Dept. of Electrical Engineering, Princeton University

April 9
Prof. Chee Wei Tan visit
Department of Computer Science, City University of Hong Kong

Technology Developed in GICE

A Novel Adaptive Continuous Wave Interference (CWI) Detecting Notch Filter for GPS Receivers

from Communication and Signal Processing Group

A Global Positioning System (GPS) inherently has the anti-jamming ability due to its characteristics of spreading spectrum. However, the performance of GPS receivers will severely degrade as the jamming signals exceeds the system's anti-jamming ability. The existing results [1] indicated that one of the most insidious jamming sources is the continuous wave interference (CWI), which can easily overwhelm a GPS receiver's analog-to-digital converter (ADC) and the analog front-end and paralyze the GPS.

We propose a low-complexity time-domain approach, using the adaptive notch filter (ANF) module, which is able to detect, estimate, and notch one single-tone CWI [2]. The ANF module is composed of a simple second-order IIR filter with the lattice structure. We show that if the −3 dB bandwidth of the IIR filter is less than about 30 KHz, the non-linear phase response of the IIR filter brings almost zero offset errors on both the acquisition and tracking loops. Therefore, as shown in Fig. 1, the proposed ANF does not require complicated Fast Fourier transform (FFT) blocks. Moreover, to adaptively adjust the notch frequency, we crosscorrelate the output and

(Continued on page 2)

GICE Honors

Professor Wanjiun Liao

2011 Best Journal Paper Award of IEEE Communications Society Technical Committee on Multimedia Communications(MMTC)

Professor Homer H. Chen

IEEE Circuits and Systems Society Distinguished Lecturer

Professor Kwang-Cheng Chen

IEEE Communications Society Wireless Communications Recognition Award

Student Winning IEEE GLOBECOM Best Paper Award

Sheng-Chieh Wang
Advisor: Professor Wanjiun Liao
Topic: Cooperative Multicasting for Scalable Video in Wireless Networks

Students Winning 2011 IEEE Signal Processing Society Young Author Best Paper Award

Yi-Hsuan Yang, Yu-Ching Lin, Ya-Fan Su
Advisor: Professor Homer H. Chen
Topic: A Regression Approach to Music Emotion Recognition

Technology (continued from page 1)

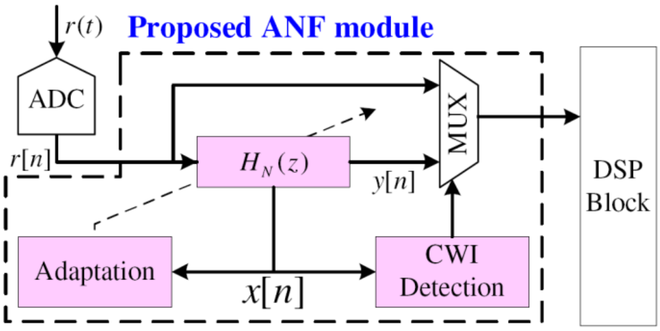

Fig. 1 A GPS anti-jamming system model.

internal adaptive signals of the ANF module. The power of the notched CWI can be simultaneously estimated by using the internal adaptive information embedded within the ANF module as well. Furthermore, we devise a novel jamming signal detection algorithm without using frequency-domain information. When there is no jamming signal, the received signal will bypass the ANF module so thatthe degradation of signal-to-noise ratio (SNR) caused by the ANF can be avoided. The proposed scheme can deal with multi-tone CWIs by cascading multiple ANF modules, as shown in Fig. 2, and we show that each stage can notch the strongest CWI appearing at its input. As shown in Fig. 3, we exploit the variance of β, a parameter to control the notch frequency, to detect whether the CWI appears. As shown in Fig. 4, we need to pre-define a threshold parameter and then periodically calculate var(β).

In [2], we have presented CWI detection and estimation algorithms operating in the time domain, which need no frequency domain information and therefore reduce the hardware cost, and employ the ANF modules to notch multiple CWIs. Our algorithms leveraged the variation and the embedded band-pass characteristics of the ANF module to detect and estimate the strongest CWI that has been conducted to the ith stage. The threshold of CWI detection, v, is determined according to C/No and the acceptable false alarm probability. In addition, we have examined the impact of the non-linearity associated with the phase responses of ANF module on the acquisition and tracking loops. Simulation results have shown that: 1) The non-linear phase response of the ANF module causes almost zero phase bias if the −3 dB bandwidth of the ANF is smaller than about 30 KHz; 2) the estimation error of jamming power decreases when the JSR increases; 3) the convergence time and resulting variation of for each ANF module decreases when the JSR increases; 4) the proposed ANF module will adaptively adjust its notch frequency to the jamming frequency of the strongest CWI appears at its input when multiple CWIs appear; 5) the resulting SINR improvement reaches 21 dB when the JSR is 50 dB.

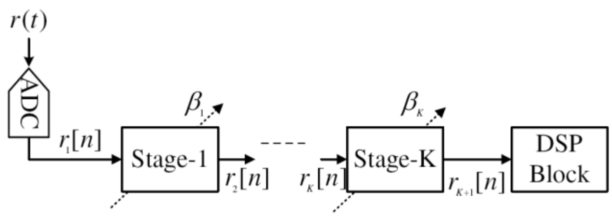

Fig. 2 The block diagram of an anti-jamming GPS receiver with multiple ANF modules.

(Continued on page 3)

Message from the Director

Kwang-Cheng Chen

Professor &
GICE Director

At the starting of 2012, we are glad to share some interesting research from our Institute with you, along with some IEEE honors for our faculty members. GICE is proud to keep delivering excellent technology and to attract attention from the community. We wish such serious efforts to blossom as those spring flowers on our beautiful campus.

Technology (continued from page 2)

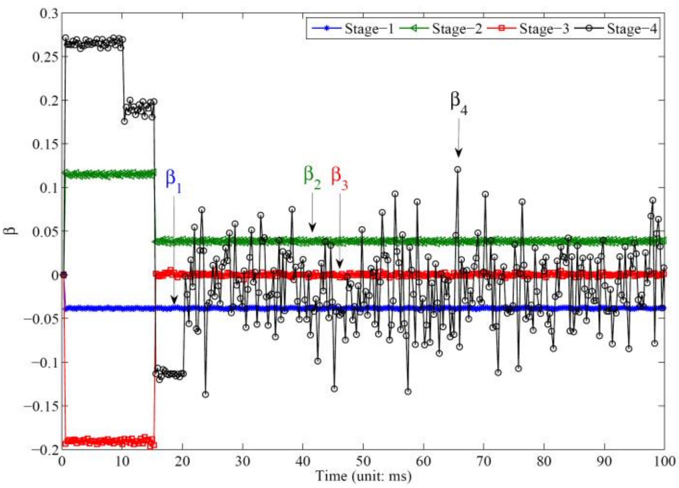

Fig. 3 The learning curve of β at each stage.

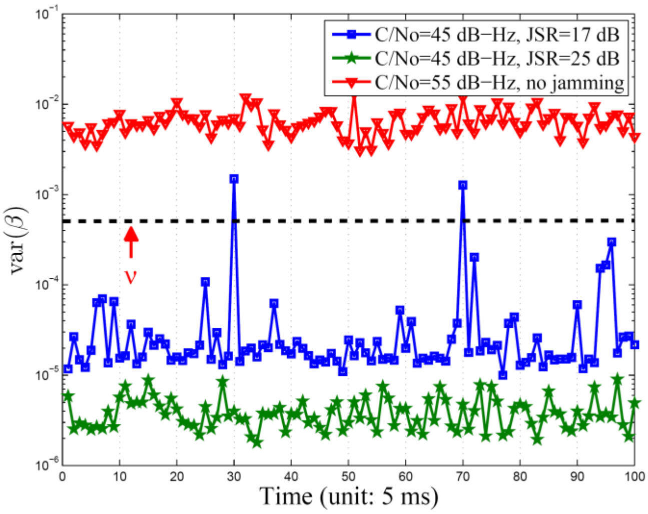

Fig. 4 Determination of the threshold v

Reference

[1] E. D. Kaplan, Understanding GPS: Principles and Applications, 2nd ed. Artech House, 2006.

[2] Ying-Ren Chien, Yi-Cheng Huang, De-Nian Yang, and Hen-Wai Tsao, "A Novel Continuous Wave Interference Detectable Adaptive Notch Filter for GPS Receivers", IEEE GLOBECOM, pp. 1-6, Miami, FL, USA, 6-10 Dec, 2010.

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Performance Analysis of Two Multi-channel Fast Retransmission Schemes for Delay-Sensitive Flows

from Communication and Signal Processing Group

For many broadband wireless systems and short range communications, there may be many communication channels available to use. Consequently, it is natural to arrange the link layer packets to be transmitted over multiple channels to boost bandwidth. Issues regarding how to design and analyze the multi-channel transmission schemes have recently become an important research direction. However, throughput formulas derived from many previous works (such as [1-3]) did not reflect the effective throughput which must satisfy the typical delay constraints of streaming-type or real-time multimedia flows. In other words, when we face the strict quality of service demands of delay-sensitive flows, it is necessary to re-examine and re-design multi-channel retransmission schemes.

The considered system model is conceptually shown in Fig. 1. For such a model, we propose a multi-radio multi-channel Fast Automatic-Repeat-reQuest (MF ARQ) scheme and an MF Hybrid ARQ (MF HARQ) scheme intended for transporting delay-sensitive flows in a multi-channel environment. The proposed schemes are designed to allow the retransmission for only one time using one or multiple channels simultaneously unlike other ones where the retransmission(s) of a link packet can only be in one channel and continue until it is successfully received. By using the application throughput as the objective, the optimal retransmission policy can be determined based on the estimated channel quality and the size of Application layer Protocol Data Unit (APDU).

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Technology (continued from page 3)

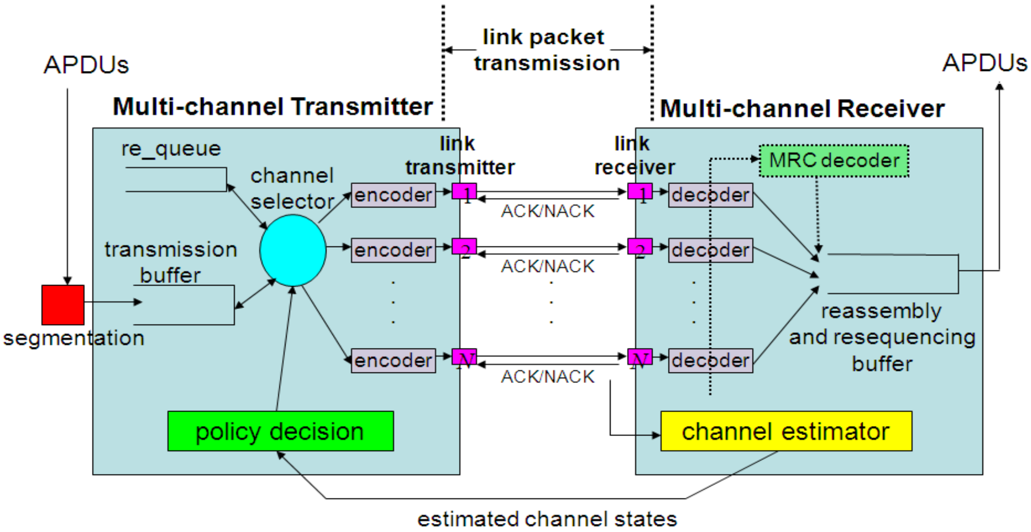

Fig. 1. The system model designed for the MF ARQ/HARQ schemes, with the maximal ratio combining (MRC) for the MF HARQ scheme.

Optimal throughputs of the MF ARQ and the MF HARQ schemes versus BERs in the Nakagami-3 environment are plotted in Fig. 2. From Fig. 2, it is found that the performance of the optimized MF HARQ scheme and the optimized MF ARQ scheme coincides at $\varepsilon = 0.21 \times 10^{-4}$. In other words, when delay-sensitive flows become the major traffic demand, and $\varepsilon \geq 0.21 \times 10^{-4}$, the optimized MF HARQ scheme can achieve optimal performance; otherwise, better performance is achieved by the optimized MF ARQ scheme. Therefore, both of the presented schemes can be adopted adaptively according to channel environments (such as mean SNR) to achieve optimal throughput performance. We thus conclude that both the MF ARQ scheme and the MF HARQ scheme are excellent ARQ candidates for the real-time multimedia transport in the multi-radio multi-channel environment.

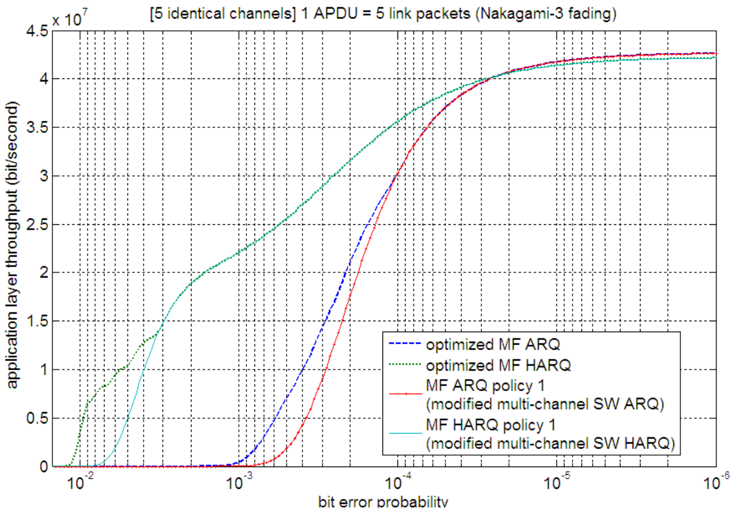

Fig. 2. Application layer throughput (in bit/sec.) comparison among the proposed optimized schemes, and the modified multi-channel SW ARQ/HARQ schemes in the independent Nakagami-3 slow-fading environment.

References

[1] N. Shacham and B. C. Shin, "A selective-repeat-ARQ protocol for parallel channels and its resequencing analysis," IEEE Trans. Commun., vol. COM-40, pp. 773-782, Apr. 1992.

[2] J. F. Chang and T. H. Yang, "Multichannel ARQ protocols," IEEE Trans. Commun., vol. COM-41, pp. 592-598, Apr. 1993.

[3] Z. Ding and M. Rice, "ARQ error control for parallel multichannel communications," IEEE Trans. Wireless Commun., vol. COM-5, no. 11, pp. 3039-3044, Nov. 2006.

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Co-author of the article: Yao-Liang Chung, PhD Candidate of NTU GICE

Technology

Blind channel estimation in MIMO-OFDM systems using small amount of received data

from Communication and Signal Processing Group

Communication systems with multiple antennas, commonly known as multiple-input-multiple-output (MIMO) systems, are well known to be capable of increasing data rates through multiplexing or improving performance through diversity. However, the advantages of MIMO systems in bandwidth efficiency often require accurate knowledge of the channel state information at the receiver. In practice, this must be realized by an adequate channel estimator.

In modern communication systems, including the orthogonal frequency division multiplexing (OFDM) systems, channel estimation is usually done by inserting some symbols in the transmitted signal that are known to the receiver, commonly known as pilot signals. Since these pilot signals do not carry any information, it essentially results in a decrease of bandwidth efficiency. When MIMO systems are considered, the decrease is even larger since the number of pilot symbols needed increases in order to obtain estimates of coefficients of multiple channels, counteracting the benefits of MIMO systems aforementioned. On the other hand, blind or semi-blind channel estimation uses few or no pilot samples known to the receiver, possesses better bandwidth efficiency, and therefore is of great research interest.

In this article, we consider an MIMO-OFDM system with K transmit antennas and J receive antennas using zero padding (ZP) as the guard intervals of length L. Figure 1 depicts part of the system block diagram, highlighting the channel between the kth transmit antenna to the jth receive antenna, characterized as a finite-impulse-response (FIR) system with a maximum order L, i.e.,

$$h_{jk}(z) = \sum_{l=0}^{L} h_{jk}(l) z^{-l}$$

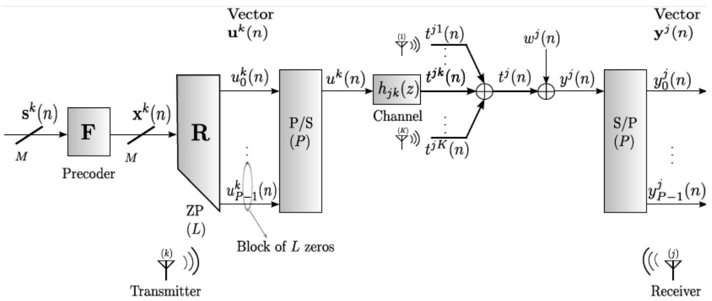

Figure 1: Blind channel estimation in MIMO block transmission systems with null guard intervals.

The discrete-time source vector from the kth transmit antenna is defined as

$$\mathbf{s}^k(n) \triangleq [s_0^k(n)^T \cdots s_{M-1}^k(n)^T]^T$$

of size M. The matrix $\mathbf{F}$ is the M x M inverse fast Fourier transform (IFFT) matrix. Assume the noise is complex additive white Gaussian noise (AWGN). It can be shown that each received block $\mathbf{y}(n)$ can be expressed as

$$\mathbf{y}(n) = \mathcal{H}(\mathbf{F} \otimes \mathbf{I}_K)\mathbf{s}(n) + \mathbf{w}(n) \tag{1}$$

where $\mathcal{H}$ is a JP x KM block Toeplitz channel matrix defined as

$$\mathcal{H} \triangleq \mathcal{T}_M^{(J,K)}\left(\begin{bmatrix} \mathbf{H}(0) \\ \mathbf{H}(1) \\ \vdots \\ \mathbf{H}(L) \end{bmatrix}\right) = \begin{bmatrix} \mathbf{H}(0) & \cdots & \mathbf{0}_{J\times K} & \cdots & \mathbf{0}_{J\times K} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathbf{H}(L) & \cdots & \mathbf{H}(0) & \cdots & \mathbf{0}_{J\times K} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathbf{0}_{J\times K} & \cdots & \mathbf{H}(L) & \cdots & \mathbf{H}(0) \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathbf{0}_{J\times K} & \cdots & \mathbf{0}_{J\times K} & \cdots & \mathbf{H}(L) \end{bmatrix} \tag{2}$$

and $\mathbf{H}(l)$ refers to the lth tap of the MIMO FIR channel, i.e., $[\mathbf{H}(l)]_{j,k} = h_{jk}(l)$.

After collecting N received blocks, we define a JP x N matrix $\mathbf{Y}^{(N)}$ concatenated from $\mathbf{y}(n)$ for $n = 0,\ldots,N-1$ as

$$\mathbf{Y}^{(N)} \triangleq [\mathbf{y}(0) \ \cdots \ \mathbf{y}(N-1)] \tag{3}$$

Then it is clear that

$$\mathbf{Y}^{(N)} = \mathcal{H}\mathbf{X}^{(N)} + \mathbf{W}^{(N)} \tag{4}$$

Where $\mathbf{X}^{(N)} \triangleq [\mathbf{x}(0) \ \cdots \ \mathbf{x}(N-1)]$ of size KM x N contains unknown transmitted blocks and $\mathbf{W}^{(N)} \triangleq [\mathbf{w}(0) \ \cdots \ \mathbf{w}(N-1)]$ of size JP x N contains the noise. Our goal here is to estimate channel coefficients $h_{ij}(l)$ using only received data $\mathbf{Y}^{(N)}$.

(Continued on page 6)

Technology (continued from page 5)

Subspace-based methods, compared to other blind techniques, possess many advantages including that it does not require knowledge on statistical information on transmitted signal. A conventional subspace-based algorithm for blind channel estimation in ZP-MIMO systems was presented in [1]. For simplicity, we consider the case in absence of noise first. As long as the matrix $\mathbf{X}^{(N)}$ has full row rank, the column space of $\mathbf{Y}^{(N)}$ will be equal to the columns space of $\mathcal{H}$, therefore enabling identification of channel coefficients contained in $\mathcal{H}$using $\mathbf{Y}^{(N)}$ without knowledge of $\mathbf{X}^{(N)}$.

However, a necessary condition for the matrix $\mathbf{X}^{(N)}$ to have full rank is $N \geq KM$, suggesting that the number of received blocks must be quite large comparing to the block size. In practice, this means the channel must remain constant during the time of accumulating such large amount of received data, decreasing its applicability of such methods in time-varying channels. In order to overcome this drawback, we propose to use received data "repeatedly" by reformulating the channel matrix so that the required number of received block is reduced. We first rearrange the contents of $\mathbf{Y}^{(N)}$ and form a $J(P + Q - 1) \times NQ$ matrix $\mathbf{Y}_Q^{(N)}$ defined as a composition of N block Toeplitz matrices:

$$\mathbf{Y}_Q^{(N)} \triangleq [\mathcal{T}_Q^{(J,1)}(\mathbf{y}(0)) \ \cdots \ \mathcal{T}_Q^{(J,1)}(\mathbf{y}(N-1)] \tag{5}$$

where Q is any positive integer. Since it can be readily shown that

$$\mathbf{Y}_Q^{(N)} = \mathcal{H}_Q \mathbf{X}_Q^{(N)} \tag{6}$$

Where $\mathbf{X}_Q^{(N)} \triangleq [\mathcal{T}_Q^{(J,1)}(\mathbf{x}(0)) \ \cdots \ \mathcal{T}_Q^{(J,1)}(\mathbf{x}(N-1))]$ contains transmitted signal and $\mathcal{H}_Q \triangleq \mathcal{T}_{M_Q}^{(J,K)}(\mathbf{H})$ contains channel information. Note that the Parameter Q can be chosen freely by the receiver as a parameter. Since each single received block contributes to Q columns in the newly formulated matrix, the parameter is called the "repetition index" first presented in [3]. The subspace-based method can also be applied on the matrix $\mathbf{Y}_Q^{(N)}$ only if the matrix $\mathbf{X}_Q^{(N)}$ has full row rank, implying

$$NQ \geq K(M+Q-1), \text{ or } \quad N \geq \frac{K(M+Q-1)}{Q}$$

It can be observed that when Q is chosen sufficiently large, the number of required received blocks can be reduced significantly. In the case with noise, techniques of eigenvalue decomposition will be needed to enable the subspace method.

We verify the applicability of the proposed method with a limited amount of received data using computer simulation. Figure 2 shows the simulation results of the channel estimation mean square error performance. Here the block size is set to $M = 12$ and the ZP length $L = 4$. Only $N = 10$ received blocks are available for blind channel estimation. The performances of proposed generalized blind channel estimation algorithm when Q = 3 and Q = 3 and their theoretical performances as well as the blind channel estimation algorithms in [1, 2] are compared. The CRB is plotted as the benchmark. The performane curve for the method in [1] is omitted here as the received blocks are too few for the method to work properly.

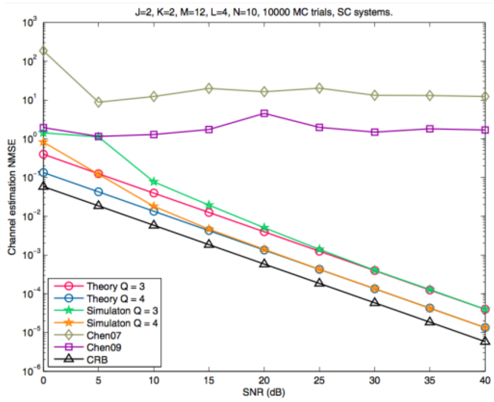

Figure 2: Simulation results of the blind channel estimation algorithms.

References
[1] Y. H. Zeng and T. S. Ng, "A semi-blind channel estimation method for multiuser multiantenna OFDM systems," IEEE Transactions on Signal Processing, vol. 52, no. 5, pp. 1419-1429, 2004.
[2] Y.-S. Chen and J.-Y. Wu, "Statistical covariance-matching based blind channel estimation for zero-padding MIMO-OFDM systems," in IEEE International Symposium on Circuits and Systems (IS-CAS), 2009, pp. 832-835.
[3] B. Su and P. P. Vaidyanathan, "Subspace-based blind channel identification for cyclic prefix systems using few received blocks," IEEE Transactions on Signal Processing, vol. 55, no. 10, pp. 4979-4993, 2007.

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Technology

Low-Phase-Noise CMOS Transformer VCOs

from Electromagnetics Group

Voltage controlled oscillator (VCO) is an important and power-hungry component for the LO signal source of wireless communication systems. The requirements of VCOs are low phase noise and low dc power consumption with enough output power or voltage swing. Due to the considerations of low cost and system integration, CMOS VCOs have attracted great attention. However, most of the high-frequency CMOS VCOs suffer from poor phase noise since the silicon substrate is lossy and MOSFETs have high flicker noise. Recently, several CMOS VCOs have been proposed using transformer feedback technique to improve the voltage swing and phase noise.

- Modified Colpitts VCOs using transformer technique

Figure 1 shows the schematic of conventional differential Colpitts oscillator. The bottom transistors act as current switches can reduce the noise perturbation and provide a larger small-signal loop gain. However the oscillation amplitude of the conventional Colpitts oscillator is limited due to the current switches. In order to achieve higher voltage swing, two *K*-band modified Colpitts oscillators using transformer technique are proposed [1]-[2].

In Fig. 2(a), the transformer is used to connect the main transistors and the current switch transistors of the Colpitts oscillator to improve the voltage swing [1]. This topology is used to design a VCO in 0.18-m CMOS technology as shown in Fig. 2(b), with a chip size of 0.35 mm^2. The tuning range of the proposed VCO is from 23.1 to 23.6 GHz, and the 1-MHz offset phase noise is -115 dBc/Hz at 23.5 GHz with core power consumption of 28 mW.

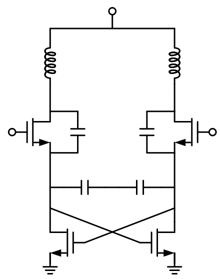
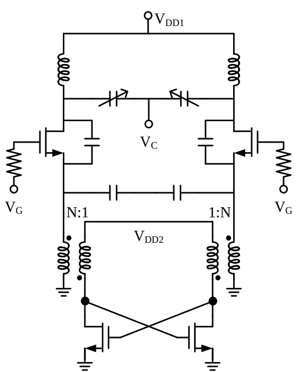


Fig. 1. Schematic of the conventional differential Colpitts oscillator.

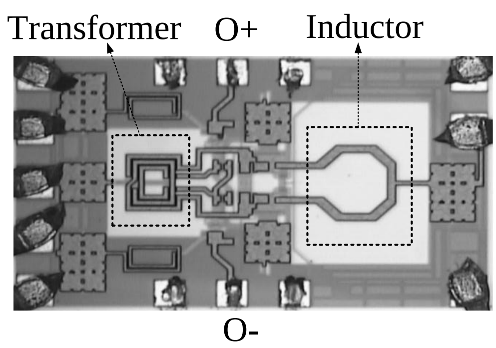
Fig. 3(a) shows the proposed modified Colpitts VCO using transformer to replace the current switch transistors which is implemented by 0.13-μm CMOS technology [2]. Fig. 3(b) shows the chip photo of the proposed modified Colpitts VCO with a chip size of 0.57 x 0.57 mm^2. The oscillation frequency is from 22.7 to 23 GHz. The measured 1 MHz offset phase noises at 23 GHz are -100 and -109.5 dBc/Hz for 4 and 10 mW dc power consumptions, respectively.

- Complementary VCO using three-coil transformer feedback [3]

NMOS-only and complementary cross-coupled topologies are widely used for CMOS VCO designs. The complementary topology offers higher transconductance for a given current,



(a)



(b)

Fig. 2. (a) Schematic, and (b) chip photo of the modified Colpitts oscillators with transformer between main transistors and the current switch transistors.

Technology (continued from page 7)

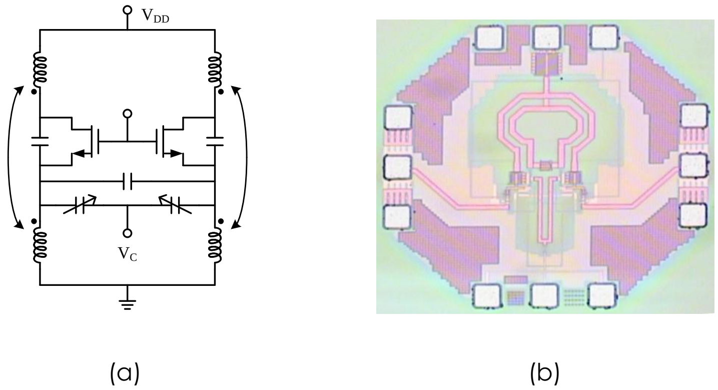


Fig. 3. (a) Schematic, and (b) chip photo of the modified Colpitts oscillators using transformer to replace the current switch transistors.

which results in faster switching of the cross-coupled differential pair and offers better rise-time and fall-time symmetry. However, the amplitudes of complementary topology is limited by a given supply voltage. To improve the oscillator performance for low supply voltage and low power, the complementary VCO using three-coil transfomer is proposed as shown in Fig. 4 and is realized in 0.18 μm CMOS technology. Fig. 5 shows the structure of the three-coil transformer and the chip photo of the proposed VCO with a chip size of 0.54 x 0.43 mm^2. The oscillating frequency is from 8.27 to 8.83 GHz when control voltage is from 0 to 1.1 V. The tuning range can be increased to 11.6% with a control voltage from -0.8 to 1.8 V. The phase noise at 1 MHz offset is better than -115 dBc/Hz between 8.09 and 8.42 GHz, and the best phase noise is -118.5 dBc/Hz at 8.2 GHz. The dc power consumption of the core circuit is 1.1 V with 0.6 mA.

Reference

[1] Chi-Kai Hsieh, Kun-Yao Kao, and Kun-You Lin, "A K-Band low phase noise transformer coupled Colpitts VCO in 0.18-μm CMOS technology," in 2011 Asia-Pacific Microwave Conference Technical Digest, Dec. 2011, pp. 1626-1629.

[2] Chi-Kai Hsieh, Kun-Yao Kao, Jeffrey Ronald Tseng, and Kun-You Lin, "A K-band CMOS low power modified Colpitts VCO using transformer feedback," in IEEE MTT-S Int. Microw. Symp. Dig., June 2009, pp. 1293-1296.

[3] Chi-Kai Hsieh, Kun-Yao Kao, and Kun-You Lin, "An ultra-low-power CMOS complementary VCO using three-coil transformer feedback," in IEEE RFIC Symp. Dig., June 2009, pp. 91-94.

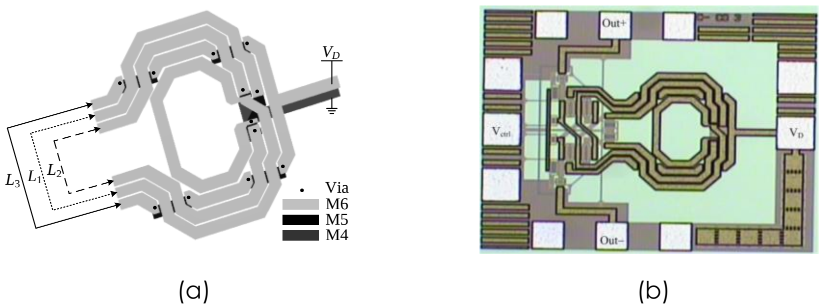


Fig. 5. (a) Structure of the three-coil transformer, and (b) chip photo of the proposed complementary oscillator with three-coil transformer feedback.

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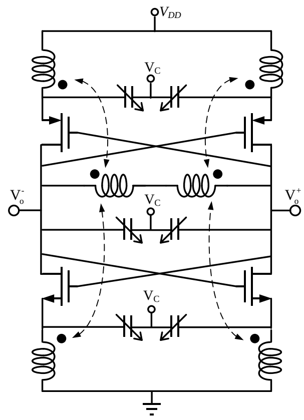

Fig. 4. Schematic of the proposed complementary oscillator with three-coil transformer feedback.

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