MaSSTOC method: From the third-order sum of squared cumulant objective function

$$\psi_3 := \kappa_{111}(\hat{\mathbf{x}})^2 + \kappa_{222}(\hat{\mathbf{x}})^2 \qquad (12)$$

the following estimator can be obtained to estimate the angle of the Givens rotation

$$\hat{\theta}_{MaSSTOC} = -\frac{1}{4} \times \arctan \frac{\langle \rho_\mu^3 \sin 3\phi_\mu \rangle \langle \rho_\mu^3 \cos \phi_\mu \rangle + \langle \rho_\mu^3 \cos 3\phi_\mu \rangle \langle \rho_\mu^3 \sin \phi_\mu \rangle}{\langle \rho_\mu^3 \cos 3\phi_\mu \rangle \langle \rho_\mu^3 \cos \phi_\mu \rangle - \langle \rho_\mu^3 \sin 3\phi_\mu \rangle \langle \rho_\mu^3 \sin \phi_\mu \rangle} \qquad (13)$$

MaSSTOC stands for maximisation of sum of squared third-order cumulants.

Simulations: Simulations have been carried out which employ the source kurtosis sum estimator (SKSE) [4, 7 – 9], a fourth order, and the novel MaSSTOC estimator. The source signals consists of superimposed realisations (**s**) of uniformly and exponentially independently distributed processes

$$\mathbf{x} = \nu\, \mathbf{s}_{uniform} + (1 - \nu)\, \mathbf{s}_{exponential} \qquad (14)$$

The parameter $\nu \in (0, 1)$ determines the shares of both distributions in the source signal. The rotation is a randomly generated angle uniformly distributed within the interval 0 to 2π. Each experiment provides a single angle estimate based on $N = 2000$ observations. The angle estimates are averaged over 300 independent experiments to determine the estimator variance about the true angle $\langle(\hat{\theta} - \theta)^2\rangle$ by sample estimates. The results are shown in Fig. 1, where the estimation variance is given as a function of both the source kurtosis (bottom axis) as well as source skewness (top axis). Additionally, the approximated CRB (eqn. 11) for sources with positive kurtosis values ($\kappa_{kkkk} > 0$), including third- and fourth-order and neglecting higher order cumulants, is displayed. The simulation outcomes confirm the anticipation, that the third- and fourth-order estimators show significantly different performances for a wide skewness/kurtosis range. The estimation variance increases where the respective cumulant becomes small. In this case the other estimator possesses the smallest distance to the CRB, and is the most efficient since 'all available' statistical information is used. For sources with mixed statistics the SKSE should be replaced by the well-behaved MaSSFOC estimator [7] to avoid performance losses.

Summary: In this Letter a novel third-order cumulant based Givens rotation estimator has been introduced. It is shown, that the estimation variance can be significantly reduced solely by choosing the right source statistics for optimisation. The authors do not aim to promote the performance improvements by simply replacing fourth- with third-order statistics. Instead, the necessity to exploit complete source statistics as much as possible is emphasised. Nonetheless this algorithm might be useful, where asymmetric distributions dominate, as in image processing applications. In addition, it appears to be feasible to switch between different order algorithms on demand.

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Power amplifier linearisation using post-distortion error canceller based on complex envelope transfer characteristics

Jae-Hee Han and Sangwook Nam

A new linearisation technique for an RF high-power amplifier (HPA) using a post-distortion error canceller (PDEC) is presented. The PDEC generates an error signal based on the complex envelope transfer characteristics of the HPA, which is combined at the output of the HPA. Therefore, the stability of the system is guaranteed.

Introduction: In digital mobile communication systems, linear modulation schemes such as QPSK and *M*-ary QAM are widely adopted to improve spectral efficiency and system capacity. However, their fluctuating envelopes cause spectral regrowth and intermodulation distortion when amplified by a nonlinear high power amplifier (HPA). Hence, many linearisation techniques for HPAs such as feedforward, feedback and predistortion have been developed to combat these problems [1].

In this Letter, a new linearisation technique using a post-distortion error canceller (PDEC) is presented. The PDEC generates an error signal based on the complex envelope transfer characteristics of the FIPA, which is combined at the output of the HPA. Therefore, the stability of the proposed system is guaranteed.

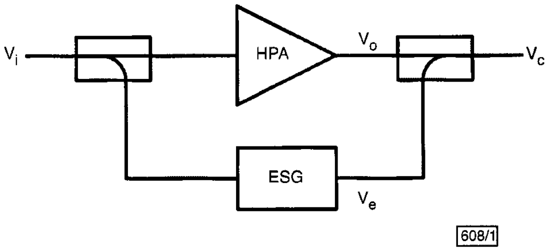

Fig. 1 *Simplified block diagram of proposed lineariser*

Description of system: A simplified block diagram of the proposed system is shown in Fig. 1. Through the upper path, the input signal V_i is amplified and distorted by the memoryless nonlinear HPA. Using the notation in Fig. 1, the relationship between input and output complex envelopes of the HPA can be expressed as [1]

$$V_o = C_1 V_i + C_3 r_i^2 V_i + C_5 r_i^4 V_i + \cdots + C_N r_i^{N-1} V_i \qquad (1)$$

where $r_i = |V_i| = \sqrt{[i_i^2 + q_i^2]}$ and the complex coefficients $C_k = a_k + jb_k$ account for the AM-AM and AM-PM nonlinearities of the HPA.

In the lower path, there is the *N*th order error signal generator (ESG_N) which produces the same amplitude but antiphase *N*th order intermodulation distortions produced by the HPA. The output signal from the ESG_N is given by

$$V_e = -C_3 r_i^2 V_i - C_5 r_i^4 - \cdots - C_N r_i^{N-1} V_i \qquad (2)$$

By combining V_o and V_e at the output of the HPA we obtain a linear replica of the input signal of the HPA, V_i:

$$V_c = V_o + V_e = C_1 V_i \qquad (3)$$

This lineariser is inherently stable, since the nonlinear distortion is cancelled at the output of the HPA. Moreover, the proposed system is easy to implement due to the simple circuit configuration.

Implementation: The third-order intermodulation product has dominant effect in the spectral regrowth. Therefore, we designed the PDEC with the third-order ESG (ESG_3) and the detailed block diagram is illustrated in Fig. 2. The magnitude square of the input signal envelope r_i^2 obtained from a square-law envelope detector is multiplied by $C_{e(3)}V_i$. This complex multiplication is performed using a quadrature modulator, of which the in-phase and quadrature component gains $a_{e(3)}$ and $b_{e(3)}$, respectively, are adjusted as

$$\begin{aligned} a_{e(3)} &= -a_3 \\ b_{e(3)} &= -b_3 \end{aligned} \qquad (4)$$

The real-time estimation for the complex envelope transfer characteristics of the HPA which have been reported in [2] can be used for the constant adaptation of $C_{e(3)}$ to $-C_3$. The real bandpass output signal from the ESG_3 then becomes [3]

$$\begin{aligned} v_{e(3)} &= a_{e(3)} r_i^2(t)\{i_i(t)\cos\omega_c t - q_i(t)\sin\omega_c t\} \\ &\quad - b_{e(3)} r_i^2(t)\{i_i(t)\sin\omega_c t + q_i(t)\cos\omega_c t\} \\ &= \{b_3 q_1(t) - a_3 i_i(t)\} r_i^2(t)\cos\omega_c t \\ &\quad + \{a_3 q_i(t) + b_3 i_i(t)\} r_i^2(t)\sin\omega_c t \end{aligned} \qquad (5)$$

and the real bandpass third-order intermodulation product of the HPA is

$$\begin{aligned} v_{o(3)} &= \mathrm{Re}\{r_i^2(t)\beta_3 V_i(t) e^{j\omega_c t}\} \\ &= \{a_3 i_i(t) - b_3 q_i(t)\} r_i^2(t)\cos\omega_c t \\ &\quad - \{a_3 q_i(t) + b_3 i_i(t)\} r_i^2(t)\sin\omega_c t \end{aligned} \qquad (6)$$

where ω_c is the carrier frequency of the bandpass signals. From eqns. 5 and 6, therefore, the third-order distortion can be completely cancelled by the ESG_3 at the output of the HPA.

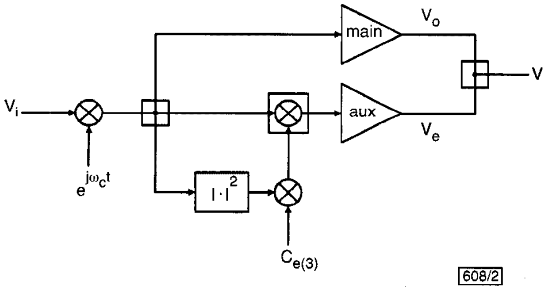

Fig. 2 *Detailed block diagram of implemented system*

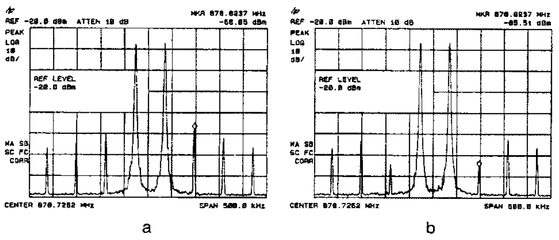

Fig. 3 *Measured output spectra of HPA*

a Nonlinear output spectrum
b Linearised output spectrum

Experimental results: The performance of the PDEC was measured using a 20W HPA and the complex gain $C_{e(3)}$ was tuned manually to minimise the third-order intermodulation component out of the system. The output spectra were measured after 60dB attenuation to protect the spectrum analyser. As shown in Fig. 3, the third-order intermodulation distortion was reduced by > 17dB at an output power of 36dBm. Furthermore, only the third-order intermodulation components were cancelled out since, as shown, higher-order components are not affected by the ESG_3. This is different to predistortion where application of ESG_3 components at the input tends to influence (and sometimes worsen) higher-order intermodulation components.

Conclusion: A new technique for linearising a high-power amplifier has been proposed. The implemented system generates the third-order intermodulation distortion signal based on the complex envelope transfer characteristics of the high-power amplifier, which is combined at the output of the amplifier. Hence, the stability of the proposed lineariser is guaranteed and the high-order intermodulation components are not affected by the third-order error signal generator. As an experimental result, we have obtained an improvement of 17.5dB in the IMD_3 using a 20W high-power amplifier.

Our future work will concentrate on the higher-order distortion cancellation and an adaptive system for tracking the variations in the envelope transfer characteristics.

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Tracking moving speech source using cyclic adaptive beamforming

B. Vo, N. Ma, P.C. Ching and K.M. Wong

A novel method for tracking the direction of arrival of a moving speech source is proposed. The technique involves extracting from the received speech signals certain cyclostationary parameters and application of the blind cyclic adaptive beamforming (CAB) algorithm to steer the beam towards the speech source. The fast convergence and computational simplicity of the CAB algorithms are exploited to track the spatially non-stationary and temporally cyclostationary source.

Introduction: Tracking the direction of arrival (DOA) of moving sources has received increased attention [1, 2], and many adaptive methods for estimating and tracking the subspace have been proposed [3 – 5]. However, these techniques, which are based on the assumption of stationary signal sources, are not applicable to speech signals because of their non-stationary nature.

The blind cyclic adaptive beamforming (CAB) algorithm [6], which exploits the cyclostationarity of signals, has fast convergence characteristics and computational efficiency, which are necessary for tracking. By using the cyclostationarity features of the speech signal, the CAB algorithm can be applied to steer the beam towards the speech source, thereby performing source tracking.

Speaker feature extraction using cyclostationarity: It is very difficult to model a particular speaker. Formant frequencies, which depend on the vocal tract shape and the pronunciation habits of the speaker, can be used as one feature to identifiy a particular speaker, but formant frequencies depend on pronunciation and