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### **Envelope Transient Analysis: Successful Wireless Systems and IC Designs**

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## Envelope Transient Analysis: Key to First- Pass Successful Wireless Systems and IC Designs

**Dr. Alex Passinsky and Dr. Vladimir Veremey**

Xpedion Design Systems, Inc.

4677 Old Ironsides Dr.

Santa Clara, CA 95054

alexp@xpedion.com, vladimirv@xpedion.com

408-987- 0603 x301

www.xpedion.com

### I. Introduction

3G (third generation) mobile phone networks are an (r)evolutionary step up from today's cellular and PCS digital mobile systems based on GSM, CDMA, TDMA, IS- 54 etc. standards. 3G smart phones and communicators, based on W-CDMA, UMTS, CDMA 2000 and other standards, will be able to transmit and receive a combination of digital information including speech, pictures, video and various kinds of information contents. This will require higher bit rates and increased RF bandwidth from the present RF channel bandwidth of 30 kHz to 200 kHz and even to 1.6 MHz.

Architectural design trade-offs for a typical dual-band or three- band transceiver RF section requires an understanding of various integration approaches, which has substantial impact on three critical design variables-cost, size and power consumption.

Main design trade-off in the receiver includes RF gain distribution, to achieve optimum dynamic range (IIP3/NF trade-off). However, a higher IIP3 leads to higher current consumption and hence shorter standby time. Strict linearity requirements in digital mode (ACPR) conflict with a power amplifier high-power-added- efficiency. Spectrally efficient modulation and demodulation schemes, such as  $\pi/4$ ,  $\pi/8$ , ...  $\pi/64$  PSK, MKS FQPSK, translate into new requirements in the areas of receiver static and faded sensitivity, inter-modulation, spurious responses, co-channel and delay interval BER and transmitter EVM requirements. PA linearity vs. efficiency trade- off is a function of the employed modulation schemes.

### II. Circuit Simulation

RF circuits have several unique characteristics that are barriers to the application of traditional circuit simulation, which represents a significant practical challenge to integrate RF and base-band sections of a transceiver onto a single chip.

Non-linearities are absolutely critical to the proper operation of wireless communication circuits. In some ap-

plications, such as highly linear amplifier design, the goal is to generate an amplified replica of the input signal, and minimize any nonlinear effects that lead to distortion of the waveform. In other designs, such as mixers or frequency-doublers, non- linearities are purposely used to introduce desired frequency-translated components into the output signal. In the latter case, undesired spurious products are minimized through careful design and the use of balancing and/or linear filtering techniques.

The presence of stiff bias elements (such as RF chokes and blocking capacitors) along with potentially narrow band high-Q filters introduces the long time constants, and thus necessitates simulation over a prohibitively large number of periods to reach steady state. In addition, many high-frequency linear elements accounting for dispersion, loss, and parasitic components are extremely difficult to model in the time domain.

### III. Time Domain

RF circuits process signals, which are high frequency carriers, modulated by lower frequency, narrow band signals using various schemes such as amplitude, phase and frequency modulation. For example a typical PCS wireless transmission has 1 carrier frequency of 1-2 GHz, modulated by a 10- 30 kHz narrow band signal. Transient analysis is inefficient when it is necessary to resolve relatively low modulating frequency in the presence of high carrier frequency and also when there are distributed transmission line elements present in the design.

The most notable shortcomings of conventional transient analysis are its inability to directly capture the steady state response of systems driven by quasi-periodic input signals, along with its poor performance in the presence of widely separated spectral components. For example, the IF frequency in a communication system may be 10 kHz, which corresponds to a period of 100 ms. The RF frequency, on the other hand, may be at 1.0 GHz, corresponding to a period of less than 1 ns. Furthermore, harmonics of the RF and LO must be accounted for, poten-

tially pushing the associated period to around 0.1 ns if, for example, 9 harmonics are needed to be taken into account. This wide disparity in the length of the periods means that transient simulators must integrate over a large number of time points to cover a full IF period. Furthermore, the simulator must cover many periods of the IF signal in order to reach steady state.

#### IV. Harmonic Balance

Where as, harmonic balance can handle mild non-linearity and lossy distributed transmission lines, but only performs steady state analysis by computing the Fourier coefficients of the output solution. Such assumption is not adequate to represent the continuous spectrum of a transient signal or a non-periodic digitally modulated signal, which is the case in all commercial wireless communication standards. However, a major setback of HB technique is the considerable increase in the number of state variables involved, as the circuit becomes more non-linear, or the number of non-linear devices in a circuit increase.

HB does not apply accurately and efficiently to analyze mixers, non-linear amplifiers, samplers, etc. because they contain the signals, which are far from sinusoidal.

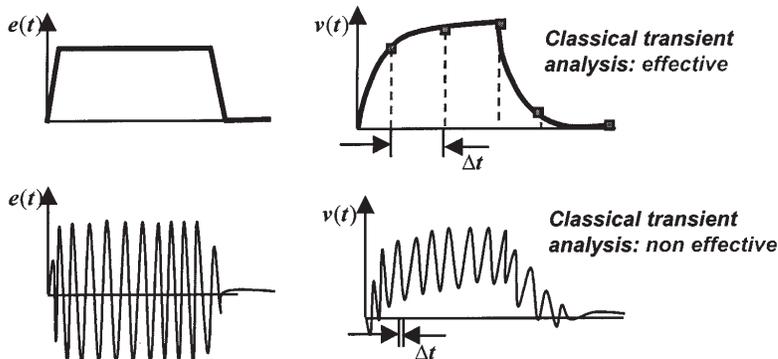
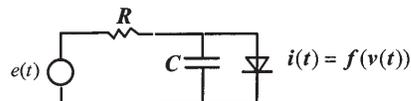
#### V. Envelope

HB techniques can carry out communication system analysis under modulated carrier excitation through the notion of Amplitude Modulation- Phase Modulation (AM-AM, AM-PM) conversion characteristics, which does not effectively take into account the non-linear envelope effects.

Envelope transient technique is the best suited and the only practical simulation technique, used in conjunction with harmonic balance and linear RF simulation, for all present and future wireless communication designs. Using envelope simulation one can analyze circuits with input stimulus as RF carriers with time-varying complex envelopes such as amplitude and phase modulations. Their spectrum may represent transient signals or pseudo-random digital modulation with their continuous spectrum, or may also include periodic signals with their discrete spectral lines, such as those representing the inter-modulation products from a mixer or amplifier under multi-tone sinusoidal excitation.

Envelope transient technique handles the transient and steady state analysis of RF and microwave circuits for arbitrary modulated carrier excitation, without excessive

computational overhead. This technique considers a modulated signal as a combination of low frequency dynamic- the envelope of the carrier or the modulation, and a high frequency dynamic- the carrier, which are analyzed separately and then merged together.

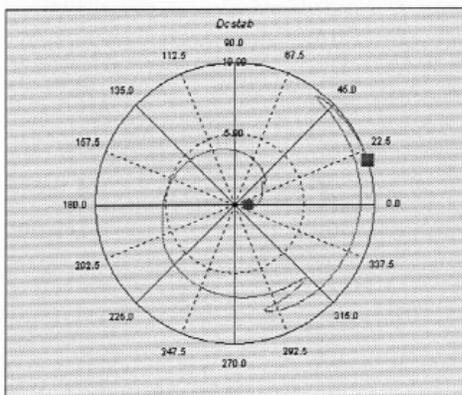


Envelope transient analysis predicts the response of a circuit when it is driven with a complex digital modulation signal. Inter-channel interference, resulting from inter-modulation distortion, is a critical analysis for digital wireless communication systems. Simple inter-modulation tests involving small number of sinusoids as can be performed with HB balance is not a good indicator of how the non-linearity of the circuit couples the digitally modulated signals between adjacent channels. Instead, one has to apply the digital modulation, simulate with envelope transient and then determine how the modulation spectrum spreads into the adjacent channels. Envelope transient technique is very useful in analyzing long term behavior of certain RF circuits, such as turn-on behavior of oscillators, power amplifiers, capture and lock behavior of PLL, turn-on and turn-off behavior of TDMA transmitters.

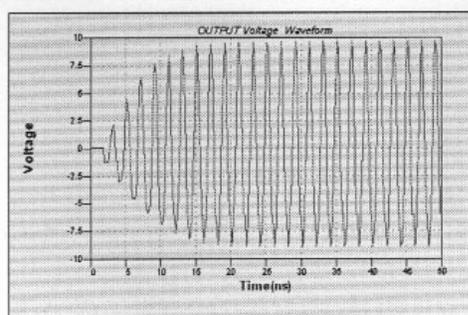
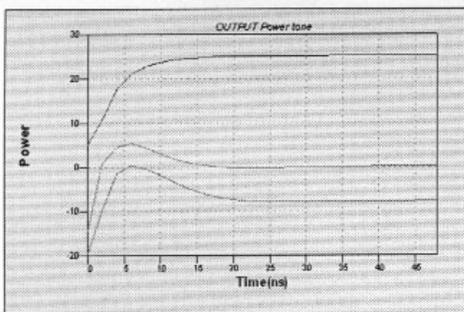
Xpedion Design Systems' GoldenGate suite of simulators offers a unified design environment, which enables designers to use linear RF, Harmonic Balance with efficient Krylov sub-space and an efficient pre-conditioner algorithms, which improve the HB performance by an order of magnitude or better, and envelope analyses based upon Xpedion's proprietary technology, all in the same design environment. All these simulators are usable without making any changes to a circuit and uses same set of active passive device models, so one can obtain consistent and reliable results, irrespective of the simulation technique used.

## VI. Power Amplifier Design Example

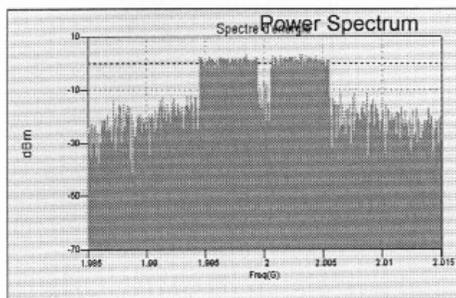
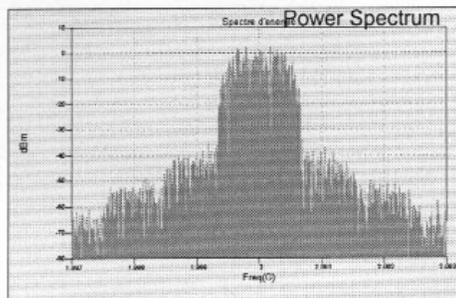
Nyquist stability analysis: GoldenGate provides a projection of the natural locus into the phase plane, called unwrapped locus where the user can easily check the encircling of the origin. The frequency step along the locus is also automatically monitored by the simulator to adapt with fast or slow variation of the locus. This is very important analysis for high Q circuits.



Startup Transient of Power Amplifier: Envelope transient needs only 80 envelope time points to cover the transient duration where classical transient will need 8000 times points, because it samples the carrier. Besides, Envelope provides amplitude and phase variation of harmonics during the transient, which cannot be obtained by both classical transient analysis and HB.



ACPR and NPR Analyses:



Envelope provides the ability of computing ACPR and NPR figures of merit, two of the most important design criterion for any power amplifier applied to any modern wireless system. It is also possible to directly visualize the impact of any amplifier design parameter on the ACPR or NPR. With Envelope one can quickly analyze the impact of complex modulations on each transistor's power dissipation and overall power consumption, which is not possible with classical system level tools. Design tools, applying HB technique to calculate ACPR analysis, use inaccurate simulation techniques by first computing first AM/AM/PM characteristic of the amplifier and applying a QPSK signal on it. This does not provide any visibility to the internal operation of power amplifier, apart from input and output characteristics, with no information about power efficiency and harmonics. Also, such analysis results-in very inaccurate results for non-linear amplifier, or when amplifier is driven into or close to its saturation point.

## References

- [1] M. S. Nakhla and J. Vlach, "A piecewise harmonic balance technique for determination of the periodic response of nonlinear systems," *IEEE Transactions on Circuits and Systems*, vol. 23, pp. 85-91, Feb. 1976.
- [2] Ngoya, E., Larcheveque, R., "Envelop transient analysis: a new method for the transient and steady state analysis of microwave communication circuits and systems," *IEEE MTT Symposium Digest*, 1996, pp. 1365-1368.
- [3] Xpedion Design Systems, *GoldenGate Users Manual*, Santa Clara, CA.
- [4] J. F. Sevic, M. B. Steer, and A. M. Pavio, "Nonlinear Analysis Methods for the Simulation of Digital Wireless Communication Systems," *International Journal of Microwave and Millimeter-Wave Computer-Aided Engineering*, vol. 6, pp. 197- 216, May 1996.
- [5] P. Feldmann and J. Roychowdhury, "Computation of waveform envelopes using an efficient, matrix-decomposed harmonic balance algorithm," *Proc. of the IEEE/ ACM Internation Conference on Computer-Aided Design*, pp. 295-300, Nov. 1996.
- [6] K. S. Kundert and A. Sangiovanni-Vincentelli, "Simulation of nonlinear circuits in the frequency domain," *IEEE Transactions on Microwave Theory and Techniques*, vol. 5, pp. 521-535, Oct. 1986.
- [7] D. Hente and R.H. Jansen, "Frequency domain continuation method for the analysis and stability investigation of nonlinear microwave circuits," *IEE Proceedings, part H*, vol. 133, no.5, pp. 351-362, Oct. 1986.
- [8] K. S. Kundert, J.K. White, and A. Sangiovanni-Vincentelli, "Steady-State Methods for Simulating Analog and Microwave Circuits," *Kluwer Academic Publishers*, 1990.
- [9] P. N. Brown, A. C. Hindmarsh, and L. R. Petzold, "Using Krylov subspace methods in the solution of large-scale differential-algebraic systems," *SIAM Journal on Scientific and Statistical Computing*, vol. 15, pp. 1467-1488, Nov. 1994.

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