ENVELOPE DETECTION OF VESTIGIAL SIDEBAND TV SIGNALS WITH CARRIER REINSERTION

Lizhong Sun and Jens Bornemann, Senior Member IEEE
Laboratory for Lightwave Electronics, Microwaves and Communications (LLiMiC)
Department of Electrical and Computer Engineering
University of Victoria, P.O. Box 3055,
Victoria, B.C. Canada V8W 3P6

ABSTRACT

A model to investigate the envelope detection of vestigial sideband TV signals with nonideal carrier reinsertion is presented. For a typical television test waveform, the amplitude and phase distortions at the output of the envelope detector are calculated as a function of the reinserted carrier amplitude and phase. For given specifications in terms of differential gain and differential phase, the relation between minimum permitted carrier amplitude and maximum permitted carrier phase error is established. This technique permits circuit design without the need for large scale testing.

I. INTRODUCTION

Modern cable television (CATV) systems are wideband analog systems which currently transport up to 83 vestigial sideband (VSB) modulated signals [1]. While bandwidth efficiency and cost-effective envelope demodulation are considered to be advantages of VSB transmission, a disadvantage lies in the amplitude level that the carrier requires with respect to the information (sideband) level. As the number of channels increases, the wider bandwidth, the carrier-to-sideband level as well as linearity specifications result in considerable requirements for the signal amplification. For acceptable channel signal-to-noise ratios the amplifier power has to be increased while low distortion levels should be maintained. However, high power and low distortion are specifications which are difficult to meet simultaneously for wideband amplifiers. As a result, amplitude and phase imperfections of the individual components contribute to the overall noise and distortion, hence limiting the number of amplifying devices which can be cascaded.

A proposed solution to this problem is the complete or partial suppression of the carrier in order to reduce the power loading of the amplifiers. Any carrier suppression technique on the transmitter side, however, would require its synchronized reinsertion at the receiver end.

Therefore, this paper focuses on the envelope detection of VSB signals with nonideal carrier reinsertion. The presented model calculates the amplitude and phase distortions at the output of the envelope detector as a function of the reinserted carrier amplitude and phase. For a typical television test waveform, the minimum required amplitude and the maximum acceptable phase error of the reinserted carrier are computed to satisfy common color TV specifications.

This work has been financially supported by Rogers Canadian Cable Labs Fund, Burnaby, British Columbia, Canada.

II. THEORY

Vestigial sideband filtering in commercial TV broadcast systems is carried out in two steps. At the transmitter, the filter spectrum is shaped without rigidly controlling the transition region. The input filter at the receiver further shapes the incoming signal so that the overall performance is comparable with ideal VSB transmission. Fig.1 shows the idealized frequency response for a combined vestigial sideband filter [2].

Consider a TV signal f(t) with corresponding spectrum $F(\omega)$, and let f(t) modulate a carrier with angular frequency ω_0 and phase α. If a product modulator is used followed by a VSB filter, the resulting signal is identified as VSB-SC which can be written as

$$S_{VSB}(t) = f(t)\cos(\omega_0 t + \alpha) - \tilde{f}(t)\sin(\omega_0 t + \alpha) \tag{1}$$

where $\tilde{f}(t)$ is specified by the transfer function $H_Q(\omega)$ of the ideal quadrature filter (Fig. 2) [3].

$$\tilde{f}(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(\omega)\, H_Q(\omega)\, e^{j\omega t}\, d\omega \tag{2}$$

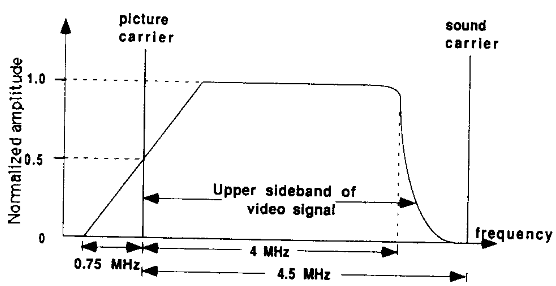


Fig. 1 Idealized frequency response of a combined vestigial sideband filter.

Contributed Paper
Revised manuscript received October 1, 1991

Before the modulated video signal (1) reaches the subscriber, the picture carrier is reinserted with amplitude A and phase β. Therefore, at the input of the receiver, we have

$$\begin{aligned} S_{REC}(t) &= S_{VSB}(t) + A_C \cos(\omega_0 t + \beta) \\ &= f(t)\cos(\omega_0 t + \alpha) - \tilde{f}(t)\sin(\omega_0 t + \alpha) + \\ &\quad + A_C \cos(\omega_0 t + \beta) \\ &= A(t)\cos(\omega_0 t + \psi(t)) \end{aligned} \tag{3}$$

where $A_C = A/2$,

$$\begin{aligned} A(t) &= [A_C^2 + f^2(t) + \tilde{f}^2(t) + \\ &\quad + 2A_C\{f(t)\cos(\alpha-\beta) - \tilde{f}(t)\sin(\alpha-\beta)\}]^{1/2} \end{aligned} \tag{4}$$

and

$$\psi(t) = \tan^{-1}\left[\frac{A_C\sin\beta + f(t)\sin\alpha + \tilde{f}(t)\cos\alpha}{A_C\cos\beta + f(t)\cos\alpha - \tilde{f}(t)\sin\alpha}\right] \tag{5}$$

As long as both conditions

$$A_C >> \sqrt{f^2(t) + \tilde{f}^2(t)} \tag{6}$$

and $\alpha = \beta$ are satisfied, the TV signal f(t) can be recovered. Otherwise, a significant amount of distortion is introduced.

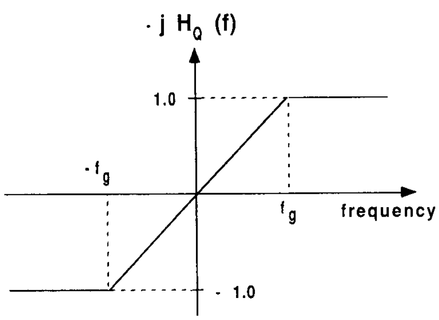


Fig.2 Frequency response of ideal quadrature filter.

Staircase signals provide a convenient dynamic check for transfer distortion [4]. Therefore, the modulated 5 riser stairstep function (Fig. 3.) is used as a test signal f(t) to calculate the distortion due to nonideal carrier reinsertion. (The ripple in the individual steps in Fig. 3 are not part of the signal but are caused by the plotting routine.) A sample of the 3.58-MHz color subcarrier with a fixed amplitude of 40 IRE units peak-to-peak and a phase, which is identical to that of the color burst, is added to the conventional staircase function. After carrier reinsertion, the differential amplitude is used to specify the amplitude distortion. This quantity is defined as the difference between the subcarrier amplitude of the fifth step to that of the first step. The phase accuracy is specified in terms of the diffential phase, which is defined as the phase difference between the fifth and the first burst (c.f. Fig. 3).

In order to calculate these quantities, each step of the staircase signal can be expressed by $a_i + b\sin(\omega_0 t)$, and from (2) we know that $\tilde{f}(t) = -b\cos(\omega_0 t)$. Therefore, (4) can be approximated by

$$A_i(t) = C_{0i} + Q_i \sin(\omega_0 t + \Theta_i) \tag{7}$$

where i = 1 to 5 identifies the number of the step and

$$Q_i = \frac{1}{2}\sqrt{\frac{C_{1i}^2 + C_2^2}{C_{0i}}} \tag{8}$$

$$\Theta_i = \tan^{-1}\frac{C_2}{C_{1i}} \tag{9}$$

$$\begin{aligned} C_{0i} &= A_C^2 + a_i^2 + b^2 + 2A_C a_i \cos(\alpha-\beta) \\ C_{1i} &= 2\,a_i b + 2A_C b\cos(\alpha-\beta) \\ C_2 &= 2A_C b\sin(\alpha-\beta) \end{aligned} \tag{10}$$

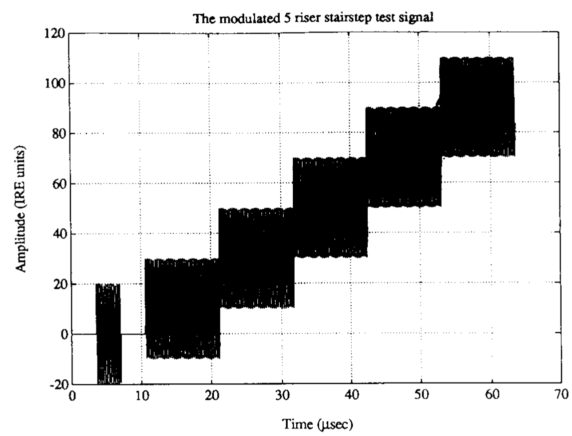


Fig. 3 Modulated five riser stairstep test signal. (Note that the ripple is caused by the plot routine.)

In (7) - (10), b and Q_i are the amplitudes for the 3.58 MHz color subcarrier in the test and the output signal, respectively. a_i is the step height in the test signal (e.g. 10 IRE units at the first step and 90 IRE units at the last one). Θ_i is the phase of the ith 3.58MHz color subcarrier in the output signal. Using (7) - (10), the differential amplitude ΔQ and the phase difference $\Delta\Theta$ can be calculated as a function of the amplitude and phase of the reinserted carrier.

III. RESULTS

A composite video signal including synchronization impulses spans 160 IRE units in amplitude [4]. In order to avoid overmodulation, the theoretical minimum carrier amplitude is 80 units in DSB operation and 160 units in VSB operation to account for the VSB filter of Fig. 1.

Fig. 4 shows the differential amplitude as a function of the phase and amplitude of the reinserted carrier. As expected, the differential amplitude decreases with increasing carrier amplitude while the influence of the carrier phase error on the differential amplitude is only marginal. It should be noted, however, that the commonly accepted amplitude error is 2 IRE units which is obviously achieved as long as the amplitude of the reinserted carrier, even with a considerable phase error, is high enough (Fig.4).

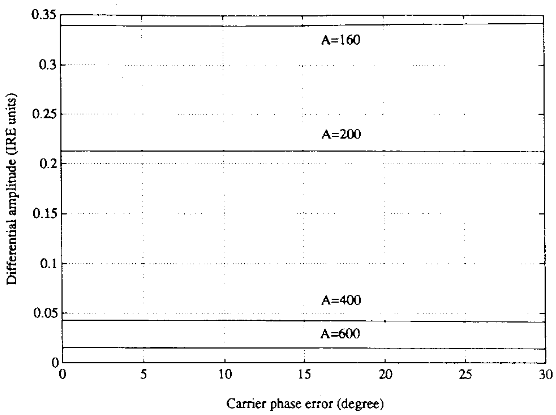


Fig. 4 Differential amplitude in IRE units versus phase error of reinserted carrier with the carrier amplitude as parameter.

The differential phase (Fig. 5) increases monotonously with the phase error of the reinserted carrier. Higher amplitudes can only slightly reduce the effect of the phase error and, therefore, the differential phase is the more critical quantity to be monitored in systems with carrier reinsertion. Fig. 5 also indicates that the differential phase vanishes if the carrier is reinserted with the correct phase (0^o deviation).

In practical applications, it is more convenient to specify the acceptable distortion and calculate the minimum required amplitude and maximum permitted phase error of the reinserted carrier accordingly. In general, the performance objectives of a

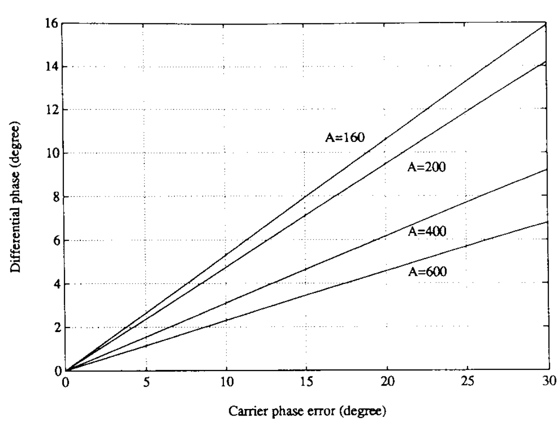


Fig. 5 Differential phase versus phase error of reinserted carrier in degrees with the carrier amplitude as parameter.

TV receiver are that the differential amplitude shall not exceed 2 IRE units and the phase distortion shall not exceed 2 degrees. Using these two criteria together with (8) and (9), Fig. 6 shows the calculated results which define the required carrier accuracy for a maximum differential phase of two degrees. It is obvious that for a certain carrier phase error, a larger carrier amplitude is needed to satisfy the phase accuracy requirement. If the carrier is reinserted with a moderate amplitude of 170 IRE units before the VSB filter, then a phase accuracy of better than five degrees should be maintained (Fig.6).

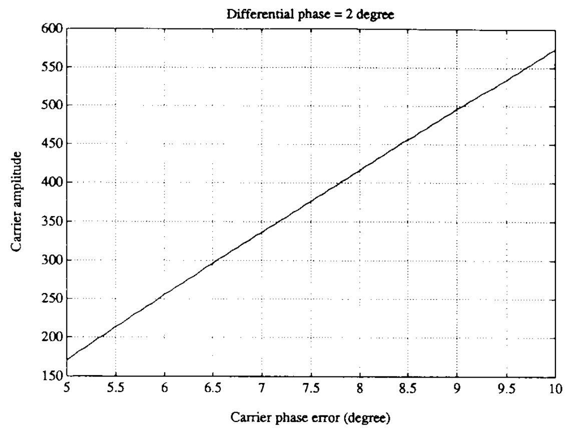


Fig. 6 Required amplitude (in IRE units) and permitted phase error of reinserted carrier for commonly accepted distortion levels.

IV. CONCLUSIONS

The envelope detection of vestigial sideband TV signals with nonideal carrier reinsertion is investigated. For given picture quality specifications in terms of differential amplitude and phase, the theoretical model predicts the accuracy requirements for the reinserted carrier. It is found that the critical parameter is the carrier phase which has to be kept within a five degree margin in order to comply with commonly applied regulations. The model presented allows the corresponding circuits to be designed without the need for large scale testing.

Acknowledgement: The authors would like to thank Drs. P.F. Driessen and R. Vahldieck for helpful discussions and suggestions, and Rogers Canadian Cable Labs Fund for financial support.

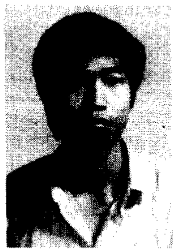
REFERENCES

[1] P.B. Lathi, *Modern Digital and Analog Communication Systems*, Holt, Rinehart and Winston, New York, 1983.

[2] S. Haykin, *Communication Systems*, John Wiley & Sons, New York, 1983

[3] L. I. Bluestein, "Envelope detection of vestigial sideband signals with application to television reception", IEEE Trans. Consum. Electron., vol. CE-21, pp. 369-379, Nov. 1975.

[4] K.B. Benson, *Television Engineering Handbook*, McGraw-Hill, New York, 1986.



Lizhong Sun was born in Fujian, China on March 5, 1964. He received the B. Sc. degree in Radio Engineering from Fuzhou University, China, in 1983 and the M. Sc. degree in Radio Enginering from Beijing University of Posts and Telecommunications, China, in 1988.

From 1983 to 1985 he was an assistant engineer in the Automation Research Institute of Changzhou, China. In 1991, he joined the Department of Electrical and Computer Engineering of the University of Victoria, Canada, to pursue work toward the Ph.D. degree in the area of communication components and systems.

Jens Bornemann (M'87 - SM'90) was born in Hamburg, West Germany, on May 26, 1952. He received the Dipl.-Ing. and the Dr.-Ing. degrees, both in electrical engineering, from the University of Bremen, West Germany, in 1980 and 1984, respectively.

From 1980 to 1983, he was a Research and Teaching Assistant in the Microwave Department at the University of Bremen, working on quasi-planar waveguide configurations and computer-aided E-plane filter design. After a two year period as a consulting engineer, he joined the University of Bremen again, in 1985, where he was employed at the level of Assistant Professor. Since April 1988, he has been an Associate Professor at the University of Victoria, Victoria, B.C., Canada. His current research activities include microwave and communications system design.

Dr. Bornemann was one of the recipients of the A.F. Bulgin Premium of the Institution of Electronic and Radio Engineers in 1983. He is a Senior Member of IEEE, serves on the editorial board of the IEEE Transactions on Microwave Theory and Techniques, and has authored and coauthored more than 50 technical papers.