A CORRECTION SCHEME FOR MEASUREMENT ACCURACY IMPROVEMENT IN MULTICHANNEL CATV SYSTEMS

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Abstract

Many commercially-available oscilloscopes offer the FFT-based spectral analysis capability and it is one of the most economical ways to perform spectral measurement. However, the measurement accuracy is always degraded by the incomplete-cycle sampling present in FFT. Such degradation in the FFT-based measurement of multichannel CATV systems is investigated. It severely degrades the spectral amplitude accuracy as well as the frequency resolution, both of which are important in deriving the system parameters such as CTB, CSO, and CNR. The undesirable effect is formulated mathematically for multichannel systems and the result is useful to obtain more accurate spectral values. Windowing and a proposed correction method are used to alleviate such detrimental effects, and an improvement of 3-5 dB in CTB measurement is achieved with the proposed correction scheme. A procedure to achieve better spectrum analysis for multichannel CATV systems is also presented. The analysis and the proposed schemes can improve the accuracy in the FFT-based measurements of multichannel CATV systems than the traditional windowing method.

I. Introduction

Multichannel analog community antenna television (CATV) distribution system is still widely used in many areas nowadays due to its low cost and compatibility with current TV sets. In such analog CATV systems, the video signals transmitted are susceptible to noises and nonlinear distortions present in the transmission link [1]. In order to obtain the distortion characteristics of a component or system, it is necessary to acquire the spectral information, from which the carrier levels and distortion levels are obtained to calculate the composite-second-order (CSO), composite-triple-beat (CTB), and carrier-to-noise ratio (CNR). Conventional methods of analyzing the distortion of cable-TV components, such as laser diodes, optical amplifiers, or Mach-Zehnder modulators, are achieved by either direct measurement or computer-aided analysis. For the former method, a set of frequency carriers (tones) generated from a matrix generator is fed into the component-under-test. The distortion level is then measured using a spectrum analyser from which the readings are taken manually or through some data acquisition interfaces such as IEEE 488 and GPIB. Such method requires much expensive equipments and experimental errors often arise in manual reading or data acquisition. For the latter method, two approaches are usually used. The first is using the components' transfer characteristics, such as the power-current (P-I) curve of a laser diode, to find the nonlinear coefficients in the transfer function expressed in power series, $y = c_o + c_1x + c_2x^2 + c_3x^3 + \cdots$ [2]. The obtained nonlinear coefficients c_1, c_2 and c_3 then can be used to calculate the distortion level. The second is using the numerical method to solve the governing equations, like the laser rate equations [3] [4], of the component and thus distortion level can be obtained. When performing characterization of system components using computer-aided measurement, the obtained system raw data can be analysed in a more simple and economical way by using some digital signal processing techniques, such as the discrete Fourier transform (DFT). Therefore, the practice of using computer-aided distortion measurement in multichannel systems is very advantageous. However, in fast-Fourier transform (FFT), due to the finite sampling frequency and sampling interval, the simulation results may be unreliable and lead to inaccurate distortion calculation. This is also a great problem in some FFT-based spectrum analysers and digital sampling oscilloscopes with FFT-based spectrum analysis capability.

Several algorithms, such as non-parametric schemes [5], windowing [6] [7] and interpolation [8], have been proposed to improve the frequency resolution and to reduce the spectral variance for signal corrupted by random noise. However, with the prior knowledge of carrier frequencies in CATV systems, it is possible to achieve even more accurate spectral power estimation at particular frequencies of interest, such as the frequencies of carriers and different distortion components, by properly choosing the sampling parameters.

In characterizing multichannel CATV distribution systems, only the channel carriers, without video signal modulated, are input to the system for characterization. This complies with the standard CATV characterization procedure in analyzing the carrier-to-noise ratios and distortions of cable TV components and systems. All channel carriers are supposed to have equal power levels. However, using computer-aided FFT-based measurement with incomplete-cycle sampling, which will be discussed in section II, all sampled frequency carriers will have unequal power levels and the frequency resolution will be drastically degraded. This will certainly lead to inaccuracy in obtaining some system performance parameters such as the CNR, CSO and CTB, in which a precise power estimation of the frequency components is very crucial. In short, we have to find some ways to ensure both good spectral amplitude accuracy and adequate frequency resolution in order to obtain reliable FFT-based measurement in multichannel CATV systems.

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In this paper, the effects of sampling frequency and sampling interval on the distortion calculation are presented and a simple correction scheme to improve the accuracy of spectral amplitudes is proposed. The incomplete-cycle sampling issue and possible methods to alleviate the problem will be discussed in section II and III respectively. In section IV, the accuracy of the nonlinear distortion measurements of multichannel CATV systems will be discussed. The proposed scheme is shown to be superior to the window methods. Finally, a procedure to assure the spectral accuracy will be presented in section V. The procedure can facilitate the components circuit design for the CATV systems using subcarrier-multiplexing (SCM), and can be applied to more general multichannel transmission systems. It can be implemented on oscilloscopes with FFT-based spectrum analysis capability and FFT-based spectrum analysers to improve the accuracy for CATV system or other multichannel system characterization.

II. Effects of Incomplete-cycle Sampling

In FFT-based measurement, the input waveform is first sampled, digitized and then the FFT is performed. The FFT operates on a finite time interval and replicates that time interval over all time. If the finite time interval is chosen such that the period of the resultant waveform is the common multiple of the periods of all frequency components (i.e. complete-cycle sampling; see Figure 1 (a)), then the FFT results will approximate the actual spectrum with high fidelity. Otherwise, there will be great transition or discontinuity at the joints between two replicas and will give rise to a great problem (see Figure 1 (b)) known as the spectral leakage effect [5] [6], which is denoted as the incomplete-cycle sampling effect in this paper. Such effect deteriorates the frequency resolution drastically. The spectral lines are much broadened and spread out over a wide frequency range. Moreover, the power level of each spectral line is lowered and fluctuates since the energy of each frequency component is spreaded to other frequencies. It is shown that the spectral amplitude fluctuation greatly depends on the *incomplete-cycle sampling ratio*, L, which is defined as the ratio of the number of sampled points to the number of sampled points in one complete period of the frequency components considered. Note that when L is an integer, this corresponds to the complete-cycle sampling case. Practically, this incomplete-cycle sampling effect appears very often in spectrum estimation since in general the input waveform is random or is corrupted by random noise. It is quite infeasible to find a finite time interval that can achieve complete-cycle sampling for all frequency components. Thus, the discontinuities among replicas of the chosen time interval often exist. Even for deterministic signal input such as the multi-carrier case, it is still be difficult to find the common multiple of the periods of all frequency components. As a result, the accuracy of the analysis results is often degraded.

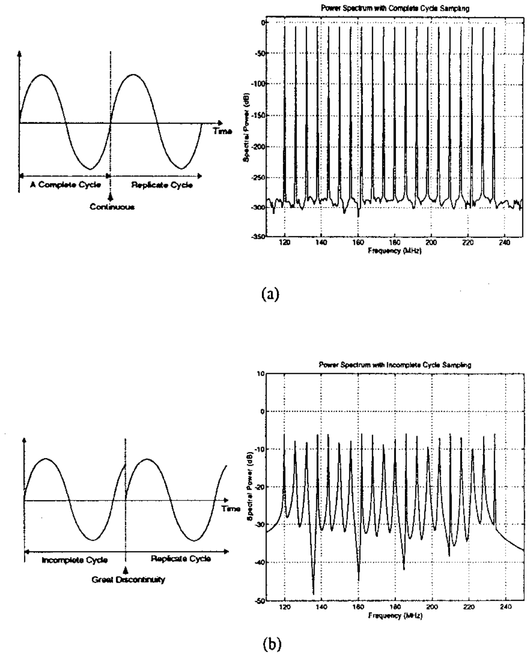

Fig. 1. Incomplete-cycle sampling in 20-channel system (a) Complete-cycle (b) Incomplete-cycle sampling, spectral amplitude inaccuracy=4.28dB. Channel frequencies: From 120 MHz to 234 MHz with 6 MHz channel spacing; amplitude of each channel carrier=1; sampling frequency = 2340 MHz; number of sample points used in FFT is 3900 for complete-cycle sampling, and 4000 for incomplete-cycle sampling

For instance, we consider a 20-channel CATV system (carrier frequency from 120 MHz to 234 MHz with 6 MHz separation) in which each carrier has equal power level. The carrier frequencies used are harmonically-related carriers (HRC) [9] for CATV transmission just for simplicity in the analysis. After performing the FFT, the obtained power spectra with complete-cycle sampling and with incomplete-cycle sampling are shown in Figure 1 (a) & (b) respectively. The sampling frequency is 2340 MHz, and the number of sample points is 3900 for complete-cycle sampling and 4000 for incomplete-cycle sampling. Notice the severe spectral line broadening, the degraded frequency resolution and the fluctuating power level of each frequency carrier due to the incomplete-cycle sampling in Figure 1 (b). The noise floor is raised by about 260 dB and the value of CNR obtained is unreliable in the incomplete-cycle sampling case. When analysing nonlinear systems, the distortion terms which have power levels below this 'raised noise floor' can no longer be identified. Furthermore, the closely-spaced spectral components are smeared and become indistinguishable. The lowered and fluctuating power levels of the distortion terms also lead to inaccurate distortion level estimation.

In order to study the effect of incomplete-cycle sampling on the power spectrum, first we attempt to model the effect on the channel carriers in which the resultant variations in their power levels are quite significant in affecting the measurement accuracy. When there are N frequency carriers in the system, the resultant signal in time domain is periodic, in which the period is equal to the least common multiple of the periods of all N individual channel carriers. The resultant composite signal is : $x(t) = \sum_{i=1}^{N} a_i \sin(2\pi f_i t + \phi_i)$ where a_i, f_i and ϕ_i are the amplitude, frequency and phase of the ith channel carrier respectively in time domain. In DFT, a finite time interval of the input signal is chosen for transformation and the spectrum of the original input signal can be estimated. When M sample points are used with sampling frequency f_s, the spectral power of the carrier f_r is derived and simplified as in expression (1).

$$P_r = \frac{1}{M^2}\left|\sum_{i=1}^{N} \frac{a_i}{2j}\left[\frac{\sin(\pi(L_i-L_r+\Delta))}{\sin(\frac{\pi}{M}(L_i-L_r+\Delta))}e^{j\pi(L_i-L_r+\Delta)(\frac{M-1}{M})+j\phi_i} - \frac{\sin(\pi(L_i+L_r-\Delta))}{\sin(\frac{\pi}{M}(L_i+L_r-\Delta))}e^{-j\pi(L_i+L_r-\Delta)(\frac{M-1}{M})-j\phi_i}\right]\right|^2 \quad (1)$$

where $\Delta = \left[\frac{Mf_r}{f_s} - \Phi(\frac{Mf_r}{f_s})\right]$, $\Phi(\cdot)$ is a round-off operator and L_i is the incomplete-cycle sampling ratio of f_r. For the case of incomplete-cycle sampling (i.e. $\Delta \neq 0$ and $\frac{Mf_i}{f_s} \neq integer$), the variation in power levels of all carriers seems to have a regular 'ripple' pattern which can be attributed to those sine terms in the numerators and denumerators in expression (1). This power fluctuation severely degrades the spectral estimation accuracy. Therefore, methods to alleviate the incomplete-cycle sampling effects need to be sought.

III. Methods to Alleviate the Incomplete-cycle Sampling Effect

In this section, we will present a new scheme to alleviate the incomplete-cycle sampling effects. For comparison, the common windowing scheme will be presented first and followed by the proposed scheme.

A. Windowing

A possible method to solve the problem of incomplete-cycle sampling is to force the both ends of the waveform used in the finite time interval of the DFT to zero in a graceful manner such that the transition or the discontinuity is greatly reduced. This can be attained by multiplying the finite waveform by a window function. There are several kinds of window functions [5] used in the design of the finite-impulse-response (FIR) filters. Different kinds of window function have different shapes and frequency responses and thus produce different frequency resolutions and spectral amplitude accuracies. In order to have good frequency resolution, the mainlobe of the frequency spectrum of the window function should be narrow while the sidelobes should be kept as low as possible to reduce the power leakage to other frequencies which raises the noise floor. On the other hand, for good spectral amplitude accuracy, the window passband should be flat but the frequency resolution will be sacrificed. The spectral lines will be broadened and the closely packed spectral components cannot be differentiated. Thus, it seems that the frequency resolution and the spectral amplitude accuracy cannot be optimized simultaneously.

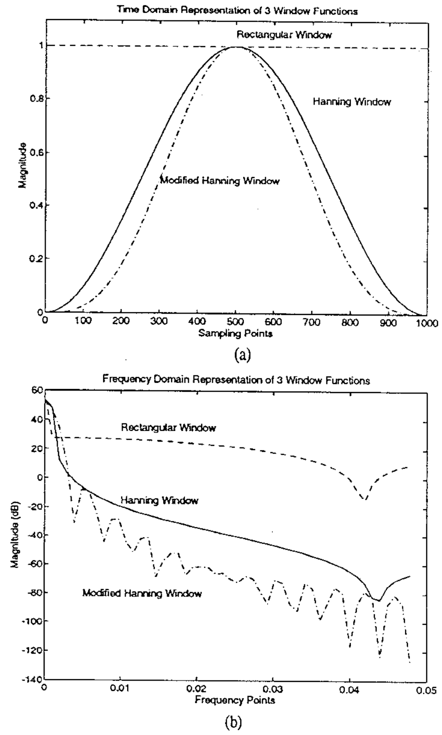

Fig. 2. Rectangular window, hanning window and modified-hanning window (a) Time domain representation; (b) Frequency response.

Here, we will consider three types of window functions and the results of using the three windows will be discussed. The three windows are (i) rectangular window, (ii) hanning window, and (iii) modified-hanning window.

For $n = 0, \cdots, (M-1)$
Rectangular Window :

$$w(n) = 1 \qquad [rect(M)]$$

Hanning Window :

$$w(n) = \frac{1}{2}[1 - \cos(\frac{2\pi n}{M-1})] \qquad [hanning(M)]$$

Modified-hanning Window :

$$\tilde{w}(n) = hanning(\tfrac{3}{4}M + 1) \otimes rect(\tfrac{1}{4})$$
$$w(n) = \tilde{w}(n)/|\tilde{w}(n)| \qquad [modified - hanning(M)]$$

The first two are standard window functions while the third one is proposed and obtained by convolving a rectangular window with a hanning window. The time domain and frequency domain representations of these three window functions are shown in Figure 2 (a) & (b) respectively. Figure 2 (b) is shown that the rectangular window has the narrowest passband but it gives the greatest discontinuity at the end of the chosen finite time interval in the case of incomplete-cycle sampling. Therefore in terms of frequency resolution, rectangular window has the best performance in complete-cycle sampling case but the worst in incomplete-cycle sampling. For the second and the third windows, the discontinuity problem is greatly alleviated due to their graceful rolloff at both ends. The hanning window has relatively higher sidelobe level and thus higher noise floor than the modified hanning window, but its passband is narrower than the latter. So there exists a tradeoff, the wider the spectral lines, the lower the noise floor or vice versa.

The use of window functions imposes a power penalty to the system. All carrier power levels will be lowered. However, since the power penalty can be determined according to the window function used, the final spectrum obtained can be corrected to compensate for such power penalty, with the advantage of improved frequency resolution. For any number of channels, the power penalty of using hanning window and modified-hanning window is about 6 dB and 7.7 dB, respectively. The effects of the use of hanning window and modified-hanning window functions to alleviate the incomplete-cycle sampling effect are shown in the Figures 3 and 4. Note the reduced carrier power level variations when windows are used as compared with Figure 1(b) and the lower noise floor of the modified-hanning window case over the hanning window case.

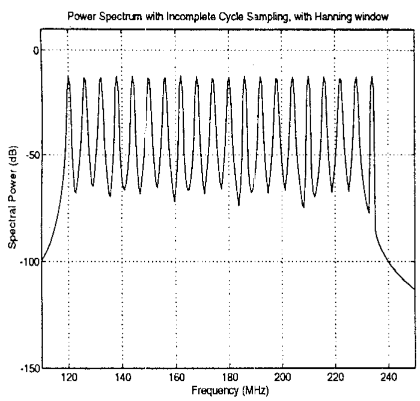

Fig. 3. Incomplete-cycle sampling in 20-channel system using hanning window; spectral amplitude inaccuracy = 1.35 dB. (Same parameters as in Figure 1).

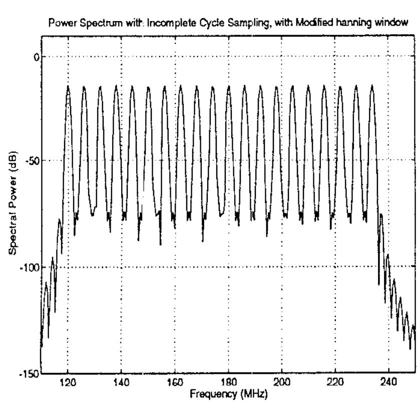

Fig. 4. Incomplete-cycle sampling in 20-channel system using modified-hanning window; spectral amplitude inaccuracy = 0.97 dB. (Same parameters as in Figure 1).

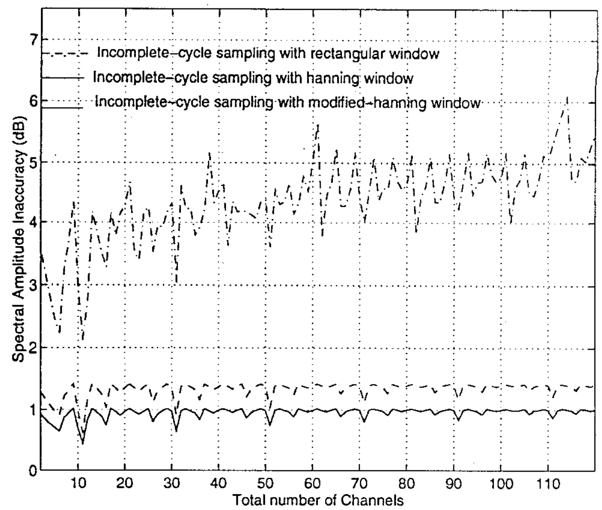

Fig. 5. Spectral amplitude inaccuracy versus total number of channels using the three kinds of window functions. (Same parameters as in Figure 1).

B. Correction Scheme for Carrier Power

A correction method is proposed to correct the carrier amplitude inaccuracy of a given spectrum. A parameter, the incomplete-cycle sampling ratio L_i of the frequency component f_i, is defined as the ratio of the number of sample points (M) to the number of sample points in one complete period of the frequency component f_i (i.e. $\frac{f_i}{f_s}$). Such parameter is the measure of the degree of incomplete-cycle sampling effect on the particular frequency component f_i. A correction factor C, which is based on the mathematical formulation of the spectral amplitude fluctuation due to incomplete-cycle sampling effect, is derived in terms of the $L's$. The correction factor for channel r is given by:

$$C_r = \left| \sum_{i=1}^{N} \left[\frac{\sin(\pi(L_i - L_r + \Delta))}{\sin(\frac{\pi}{M}(L_i - L_r + \Delta))} e^{j\pi(L_i - L_r + \Delta)(\frac{M-1}{M})} - \frac{\sin(\pi(L_i + L_r - \Delta))}{\sin(\frac{\pi}{M}(L_i + L_r - \Delta))} e^{-j\pi(L_i + L_r - \Delta)(\frac{M-1}{M})} \right] \right|^2 \tag{2}$$

Given a spectrum of N channels after performing FFT, the correction factor C for each channel can be derived in terms of the corresponding values of $L's$. By applying such correction factor, the actual spectral power of the carriers can be restored. For instance, for channel r, the obtained spectral power after FFT is P_r. The corrected spectral power will be $\tilde{P}_{r(dB)} = P_{r(dB)} - C_{r(dB)}$. Numerical simulation shows that the spectral power of the channel carriers in a multichannel case can be corrected to nearly 100% accuracy.

In the next section, we will consider the distortion issue in CATV systems and the correction method will be extended to the correction of spectral power of distortion components.

IV. Nonlinear Distortion in Multichannel CATV Systems

Due to the nonlinearities of transmitters, receivers, amplifiers and other operating devices, many unwanted spurious frequency components (distortions) are generated in multichannel analog CATV transmission systems. These distortion terms severely degrade the video signal quality when they fall on the video channels. The nonlinear distortion performance can be assessed by examining the frequency spectrum and finding the relative power levels of the distortion components with respect to the channel carrier power. For HRC frequency assignment, the channel frequencies are integers and thus it is quite easy to achieve complete-cycle sampling. However, in the standard CATV channel frequency assignment, the channel frequencies are not integers and thus it seems that the incomplete-cycle sampling always exists in FFT-based spectrum measurement. The power levels of channel carriers and the distortion terms are no longer accurate and the obtained system parameters such as CNR, CTB and CSO are unreliable. The correction method for the carrier power has been proposed in the previous section. For the inaccuracy of a distortion term's power, it is contributed by the incomplete-cycle sampling effect of the channel carriers, the distortion term itself and all other distortion terms. The following two examples illustrate the FFT-based two-tone third-order distortion estimation and the triple-beat distortion estimation. It is shown that the measurement accuracy is improved by using the proposed correction scheme as well as the traditional windowing method.

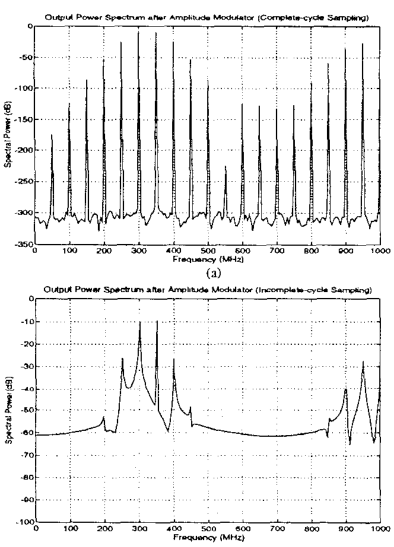

Fig. 6. Incomplete-cycle sampling on nonlinear distortion performance in a 2-channel input (a) Complete-cycle sampling; (b) Incomplete-cycle sampling. Channel frequencies: 300MHz and 350MHz; amplitude of each channel carrier=1; sampling frequency=3500MHz; number of sample points used in FFT is 700 for complete-cycle sampling and 710 for incomplete-cycle sampling.

A. Two-tone Third Order Distortion Estimation

Consider the input composite signal: $x(t) = a_1 \sin(2\pi f_1 t) + a_2 \sin(2\pi f_2 t)$. Assume this two-tone composite signal is fed into a Mach-Zehnder modulator, which has a sinusoidal transfer characteristic and is biased at the half-transmission point. The even-order distortions are negligible [10] since the transfer function is an odd function. The output signal is

$$\begin{aligned} y(t) &= \sin(x(t)) \\ &= \sin(a_1 sin(2\pi f_1 t) + a_2 \sin(2\pi f_2 t)) \end{aligned} \quad (3)$$

Figure 6 (a) & (b) show the spectrum of the output signal in the cases of complete-cycle and incomplete-cycle sampling respectively for $f_1 = 300$MHz and $f_2 = 350$MHz. For these two carriers, different types of distortion terms, such as $(f_1 \pm f_2)$, $(2f_1 \pm f_2)$, $\cdots$, do not fall on the two input carriers. In the case of complete-cycle sampling, all second-order and third-order distortion terms present are also in the case of complete-cycle sampling and so the spectral amplitudes are accurate. However, as depicted in Figure 6 (b), the peak power levels of the carriers and distortion terms show deviations from the complete-cycle sampling case (Figure 6 (a)). Moreover, the 'noise floor' is raised by 240dB, and all the distortion terms that are buried under the 'noise floor' can no longer be identified. The power levels of those buried distortion terms are assumed to be the noise floor level. Thus the obtained values of the second- and third-order distortions will be higher than the actual values while the CNR will be much smaller. The inaccuracy of the nonlinear distortion level in the case of incomplete-cycle sampling can also be alleviated using the windowing and the proposed correction methods.

(a) *Windowing*

The spectral amplitude accuracy obtained can be improved by using the window functions mentioned in section III. Although there will be a power penalty of all frequency components' peak power levels when using the window functions, the power levels can be corrected using a correction factor (the value of the power penalty of the corresponding window function). In this way, the power levels will still be reliable with improvements in the frequency resolution. The spectral power of the two-tone third-order distortion terms $f_d = (2f_2 - f_1)$ (400MHz) before and after windowing versus different incomplete-cycle sampling ratio L_d of this distortion term are shown in Figures 7 and 8 respectively, where f_1=300MHz, f_2=350MHz, sampling frequency f_s=3500MHz and the number of sample points varies from 2000 to 2100. The window correction factor has been added to compensate for the power penalty of the window function used. It is shown that the variation of the spectral power of f_d is -1.34 dB for using hanning window and -0.97 dB for using modified-hanning window. The obtained spectral power of the distortion term is always lowered than the actual value.

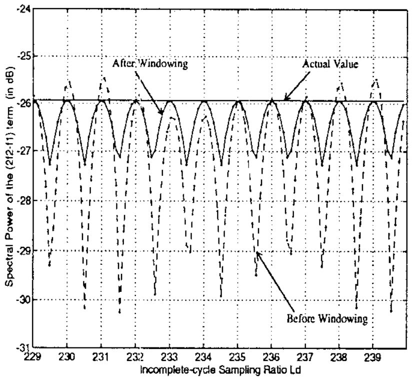

Fig. 7. Spectral power of $(2f_2 - f_1)$ (at 400MHz) distortion term of two-channel input (f_1=300MHz, f_2=350MHz), sampled at 3500MHz with 2000 to 2100 sample points, using hanning window

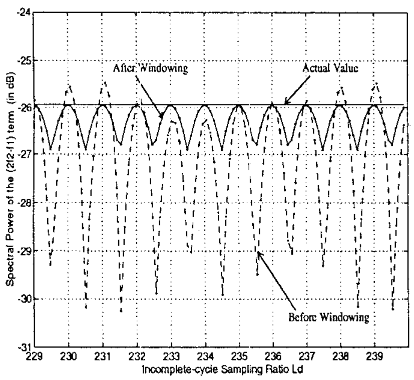

Fig. 8. Spectral power of $(2f_2 - f_1)$ (at 400MHz) distortion term of two-channel input (f_1=300MHz, f_2=350MHz) using modified-hanning window, sampled at 3500MHz with 2000 to 2100 sample points

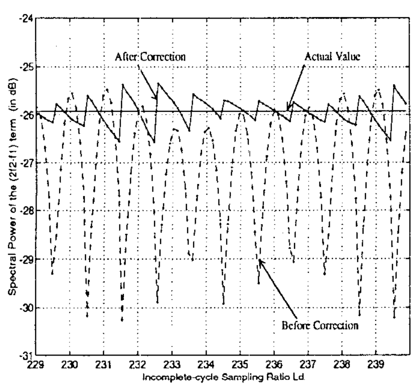

Fig. 9. Spectral power of $(2f_2 - f_1)$ (at 400MHz) distortion term of two-channel input (f_1=300MHz, f_2=350MHz) using correction scheme, sampled at 3500MHz with 2000 to 2100 sample points

(b) *Correction Scheme for Distortion Power*

The correction method used in section III-b can be extended to correct the spectral power of the distortions present. Since the carrier amplitudes are much greater than that of the distortions, we can assume that the incomplete-cycle sampling effect from other distortion terms that affect the specified distortion term are insignificant as compared with the contribution from the channel carriers. A correction scheme is proposed to give better estimation of the spectral power of the distortion components. Consider the distortion component f_d, the corrected spectral power is derived and is given by:

$$\tilde{P}_d = \frac{1}{M^2}\left|[\frac{1}{B}X\text{-}f_d - D_1]/D_2\right|^2 \qquad (4)$$

where $X\text{-}f_d$ is the obtained spectral amplitude at f_d after performing FFT and

$$\begin{aligned} D_1 &= \sum_{i=1}^{N}\frac{a_i}{2j}\left[\frac{\sin(\pi(L_i - L_d + \Delta))}{\sin(\frac{\pi}{M}(L_i - L_d + \Delta))}e^{j\pi(L_i - L_d)}\right. \\ &\quad \left. -\frac{\sin(\pi(L_i + L_d - \Delta))}{\sin(\frac{\pi}{M}(L_i + L_d - \Delta))}e^{-j\pi(L_i + L_d)}\right] \\ D_2 &= \frac{\sin(\pi\Delta)}{\sin(\frac{\pi}{M}\Delta)} - \frac{\sin(\pi(2L_d - \Delta))}{\sin(\frac{\pi}{M}(2L_d - \Delta))}e^{-j2\pi L_d} \\ B &= e^{j\pi\Delta(\frac{M-1}{M})} \end{aligned}$$

The spectral power of the two-tone third-order distortion terms $f_d = (2f_2 - f_1)$ (400MHz) before and after correction versus different incomplete-cycle sampling ratios L_d of this distortion term is shown in Figure 9 where f_1=300MHz , f_2=350MHz, sampling frequency f_s=3500MHz and the number of sample points varies from 2000 to 2100. After the correction, the spectral power variation at f_d is greatly reduced to about ± 0.5dB. Compared with the result using hanning window (-1.35dB) and modified-hanning window functions (-0.97dB), it gives smaller spectral power variation. Moreover, the variation of the spectral power at f_d exhibits a periodic pattern. The variation range reduces gradually with greater number of sample points (i.e. greater incomplete-cycle sampling ratio L_d). Note that at integer values of the incomplete-cycle sampling ratio L_d, the spectral power at 400MHz is the closest to the actual value since at these points, complete-cycle sampling of the distortion term at 400MHz occurs. The small spectral power variation after the correction is due to the incomplete-cycle sampling effects from other distortion terms. For instance, as depicted in Figure 9, when L_d equals 230.5, error reduction after correction is about 3.95 dB. Using the scheme, the spectral power error of 3-4dB in the distortion term can be corrected. Thus the proposed correction scheme is quite effective in improving the spectral power accuracy.

B. Composite Triple Beat Estimation

Consider a 10-channel CATV system with channels carrier frequencies start from 121.25MHz to 175.25MHz with 6MHz spacing. For such standard CATV frequency assignment, the distortion components present at the carrier frequencies are the triple beat terms while the second-order and two-tone third-order distortion components will not fall on the carrier frequencies. The whole composite signal is passed through a Mach-Zehnder modulator biased at half-transmission point. The output signal is sampled at 1752.5MHz and then FFT is performed. Incomplete-cycle sampling occurs and thus the spectral power estimation using FFT is inaccurate. Three approaches, the hanning window, the proposed modified-hanning windows and the proposed correction scheme have been applied to alleviate the incomplete-cycle sampling effects. The numerical simulation for CTB estimation is done in two steps. First, the spectral power P_{i-C} of the chosen channel, say channel i at frequency f_i, is determined when only channel i is present in the system. Then, the channel i is disabled and all other 9 channel carriers are enabled. The distortion falling at frequency f_i will be the triple beat components and its spectral power P_{i-CTB} is also obtained. The ratio of P_{i-CTB} to P_{i-C} will be the value of CTB at channel i. In this example, the values of obtained CTB at channel frequency 139.25MHz, using the above spectral estimation approaches, are shown in Figure 10. Notice that the proposed correction scheme gives the most accurate values in CTB estimation, among the three approaches, for different incomplete-cycle sampling ratios. The proposed correction scheme gives about 3 to 5 dB accuracy improvement over the windowing methods.

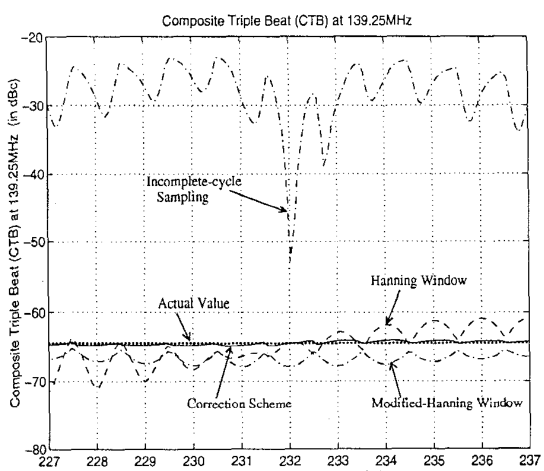

Fig. 10. CTB at 139.25MHz in a 10-channel CATV system, sampled at 1752.5MHz

V. A Procedure of Spectrum Analysis for Multichannel CATV Systems

Incomplete-cycle sampling which leads to spectral power variation is quite common in FFT-based spectrum analysis. Therefore, we propose a procedure as a guideline to attain better spectral estimation accuracy in multichannel CATV systems and thus the system parameters, such as CSO, CTB and CNR, obtained will be more reliable. The procedure is summarized in the flowchart as shown in Figure 11. When the channel frequencies are HRC, complete-cycle sampling can easily be achieved. The obtained spectral amplitudes at the channel carriers are thus quite accurate but incomplete-cycle sampling may still occur at the distortion components. Incomplete-cycle sampling often occurs when standard CATV frequencies are used. Therefore, windowing or the correction method may be used to obtain better results. Either choose a window function with low sidelobe level for lower spectral leakage effect or use the proposed correction scheme to obtain more accurate and reliable results. When the proposed correction scheme is used, the incomplete-cycle sampling ratio should be obtained first for the frequency component concerned. Then, the correction methods for channel carriers and distortion components are used to correct the FFT's results. It provides an alternative to achieve better accuracy in FFT-based measurement in multichannel CATV systems.

By following the above as a general guideline, the FFT-based multichannel CATV system measurement is done in two steps. First, the spectral power of each channel carrier should be estimated first, considering only that channel is present in the system, by using either the windowing or correction methods. These obtained channel carrier spectral powers will be used to calculate the CSO, CTB and CNR later. Also, this information is useful in the proposed correction scheme for distortion estimation. After that, all channels should be enabled and the second-order and two-tone third order distortions can be similarly estimated. For composite triple beat distortion measurement, the chosen channel should be disabled since the triple beat distortion will fall on the carrier frequency. After these two steps, the values of CSO, CTB and CNR can be more accurately estimated.

In general, by using this procedure, the spectral power variation of different frequency components concerned is minimized and the frequency resolution can be improved. Moreover, this procedure can be implemented easily in oscilloscopes with FFT-based spectrum analysis capability and FFT-based spectrum analysers to achieve better spectral power accuracy and frequency resolution.

VI. Conclusion

FFT-based measurement is simple and economical but it always suffers from the undesirable incomplete-cycle sampling effect which severely degrades the spectral amplitude accuracy as well as the frequency resolution. In this paper, we have studied such deteriorous effect on FFT-based multichannel CATV system measurements. This is formulated mathematically for multichannel systems and the result is useful in giving more accurate spectral values. Windowing and a proposed correction method have been used to alleviate such detrimental effect on both carrier and distortion power measurements, and the comparison results are given. It is shown that the proposed correction scheme has 3-5dB improvement to achieve more accurate CTB measurement over the windowing method. A procedure to achieve better spectrum analysis for multichannel CATV systems is also presented. The proposed schemes can be implemented in the oscilloscopes with FFT capability and also the FFT-based spectrum analysers to improve the measurement accuracy in multichannel CATV systems.

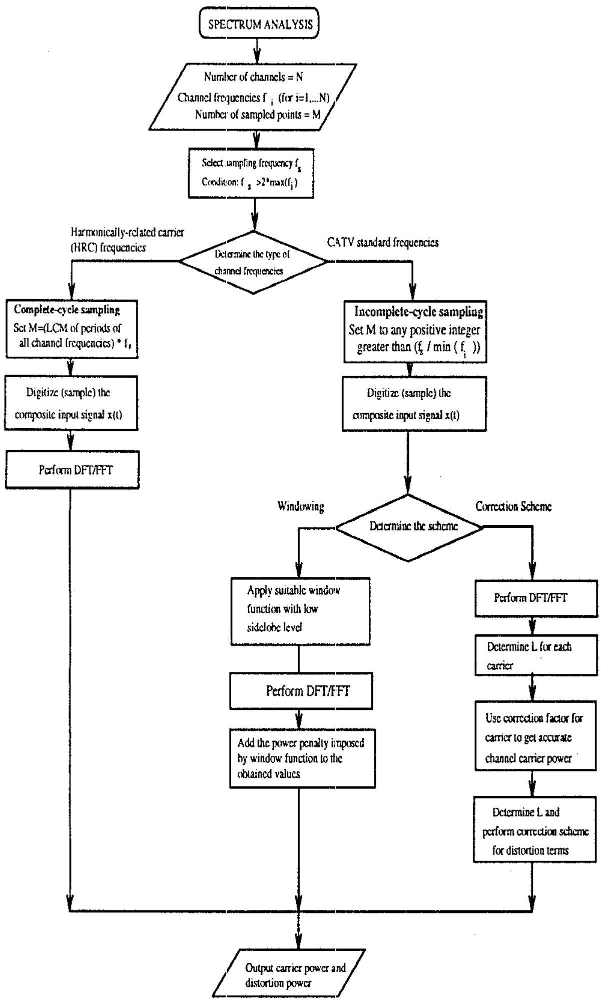

Fig. 11. Flowchart of the proposed procedure of spectrum analysis for multichannel CATV systems.

References

[1] W. I. Way, "Subcarrier Multiplexed Lightwave System Design Considerations For Subscriber Loop Applications," *IEEE J. Lightwave Technol.*, vol. 7, pp. 1806–1818, Nov. 1989.

[2] J. C. Daly, "Fiber Optic Intermodulation Distortion," *IEEE Trans. Commun.*, vol. 30, pp. 1954–1958, Aug. 1982.

[3] K. Y. Lau and A. Yariv, "Intermodulation Distortion in a Directly Modulated Semiconductor Injection Laser," *Appl. Phys. Lett.*, vol. 45, pp. 1034–1036, Nov. 1984.

[4] C. Su and L. K. Chen, "Analysis of Fundamental Nonlinear Distortions in Optical Source and the Effect on SCM Optical Networks," *ICCT'94, Shanghai*, 1994.

[5] J. G. Proakis, *Digital Signal Processing: Principles, Algorithms and Applications*, ch. 12. Macmillan, 1992.

[6] F. J. Harris, "On the Use of Windows for Harmonic Analysis with the Discrete Fourier Transform," *Proc. IEEE*, pp. 51–83, Jan. 1978.

[7] G. Andria, M. Savino, and A. Trotta, "Windows and Interpolation Algorithms to Improve Electrical Measurement Accuracy," *IEEE Trans. Instrum. Meas.*, vol. 38, pp. 856–863, Aug. 1989.

[8] V. K. Jain, W. L. Collins, and D. C. Davis, "High-Accuracy Analog Measurements via Interpolated FFT," *IEEE Trans. Instrum. Meas.*, vol. 28, pp. 113–122, June 1979.

[9] I. Switzer, "A Harmonically Related Carrier System for Cable Television," *IEEE Trans. Commun.*, vol. 23, pp. 155–197, Jan. 1975.

[10] Y. Trisno, L. K. Chen, and D. R. Huber, "A Linearized External Modulator for Analog Distribution," *SPIE OE/Fiber'90, San Jose, U.S.A.*, 1990.

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