OSCILLATOR PHASE NOISE AND ITS EFFECTS IN A CATV SYSTEM

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ABSTRACT

Phase noise of oscillators such as local oscillators in modulators, receivers, set-top converters, etc., can introduce noise in TV pictures in a CATV system. Acceptable characteristics and the effects of phase noise are not recognized as readily as other more familiar and routinely measured distortions. The qualitative measure of phase noise is the perceptibility of phase noise in a TV picture. A quantitative measure is the baseband signal-to-noise ratio (SNR) and noise spectral density. This paper presents the theory relating the RF noise spectrum of an oscillator and the resulting video noise spectrum and SNR. Some representative data for oscillator noise in video modulators and set-top converters is given along with results of perceptibility tests.

INTRODUCTION

In recent years, experienced CATV engineers spoke of an effect they had begun to observe in which television pictures appeared to the trained eye to have more noise than standard traditional measurements indicated. In mid-1987 an ad-hoc group consisting of representatives of the NCTA, cable operators, and equipment manufacturers organized to examine the issue. A short time later this group was incorporated by the NCTA Engineering Committee into its HDTV Subcommittee, called Group 1, and charged with the investigation and documentation of signal transfer characteristics in cable systems with particular emphasis on parameters useful in forecasting the transparency of a cable system to various HDTV proposals. Improved quality of present CATV service is also an expected result. This paper, together with the companion paper by Gerald Robinson [1], form the first published results of the Group 1 investigations.

It was determined that the first efforts of the group should be devoted to rigorous investigation of phase noise effects throughout the entire network, including satellite links and through final detection.

In this paper both RF and baseband theoretical and measured results are presented. This paper is concerned with high frequency phase noise and its effect in vestigial sideband television. The perceptually dominant effects of phase noise over thermal noise after detection are isolated and presented.

BACKGROUND THEORY

A general expression for oscillator phase noise as derived by Leesson [2] is

$$L(fm) = \frac{1}{2}\left[1 + \frac{fo^2}{fm^2}\frac{1}{4Q^2}\right]\frac{KTF}{P} \qquad (1)$$

where L(fm) is the ratio of single-sideband noise power in a 1 Hz bandwidth (centered fm Hertz from the carrier) to the carrier power, and

fm = frequency offset from the carrier (modulating frequency),
fo = carrier frequency,
Q = loaded Q of oscillator resonator,
F = noise factor of active drive,
K = Boltzmann's constant,
T = temperature in degrees Kelvin, and
P = available carrier power in watts.

Equation (1) predicts the spectral distribution due to intrinsic noise in the active device, and assumes the AM contribution is negligible, as it is in a well designed oscillator. Low-frequency phase noise, which is usually predominately power-supply related, is not included, nor is low-frequency flicker noise. Furthermore, in CATV equipment, oscillators of concern are often incorporated in a synthesizer phaselock loop which modifies the close-in spectrum. As a result, the close-in spectrum is determined by the particular circuit design and can not be predicted in a general way. Low frequency phase modulation is often caused primarily by insufficient filtering or isolation of the oscillator power supply. The result is frequency modulation at 60 Hz and harmonics of 60 Hz. The clamping action of TV sets tends to suppress the effects of this low frequency FM, and TV sets may respond quite differently to this low frequency disturbance. The effect of high-frequency noise is quite different, and the analysis here will be limited to high-frequency noise, that is, noise modulation approximately 10 kHz or higher in frequency.

From Eqn. (1), the spectral density (noise power/Hertz) is proportional to $1/fm^2$ up to the point at which it "breaks flat" (fm = fo/2Q). In this paper we will consider oscillator phase noise to be that which has a noise power spectrum proportional to $1/fm^2$; i.e., a 6 dB per octave decrease with offset frequency. Eventually the oscillator phase noise falls below the "noise floor" of the system. The "noise floor" of the system is limited by the carrier-to-noise (C/N) ratio of the distribution system, but the earth station, head-end equipment, set-top converters, etc. are also contributors. The system "noise floor" is caused by amplified thermal noise, and is referred to as thermal noise . It contains equal amounts of AM and PM noise, and upper and lower sidebands are correlated. Here we will consider system noise to be comprised of (1) oscillator phase noise, plus (2) thermal noise. From Eqn. (1), that part we call oscillator phase noise is:

$$L(fm) = 1/(fmQe)^2 \qquad (2)$$

where Qe is a constant ("effective Q") which defines the spectral purity of the oscillator. The equations that follow give phase noise, frequency noise, and video SNR as a function of the parameter Qe.

The term L(fm) is the reciprocal of the more commonly used term C/No, where C is carrier power and No is noise power in a 1 Hertz bandwidth. In this paper we will use the notation C/N_p for the ratio of carrier to phase noise, and C/N_t for the carrier to thermal noise ratio. For noise given in a 1 Hertz bandwidth, the notation is

$$C/No_p = \text{Carrier/phase noise/Hz} \qquad (3)$$

$$C/No_t = \text{Carrier/thermal noise/Hz} \qquad (4)$$

Qe expressed in dB is 20log(Qe). Qe can be obtained directly from the oscillator spectrum measured with a spectrum analyzer by

$$Qe = C/N_p - 1.7 - 20\log(fm) + 10\log(B) \text{ dB} \qquad (5)$$

where C/N is the carrier/phase-noise sideband ratio in dB, B is the analyzer bandwidth, and 1.7 is the usual analyzer correction factor applied to noise measurements [3]. For example, if an oscillator spectrum measures 56 dB below carrier in a 1 kHz bandwidth 20 kHz from the carrier, then Qe = -1.7 dB.

In analyzing the effects of oscillator phase noise in an NTSC system, it is helpful to convert phase noise to frequency noise since it is FM noise that is directly converted to AM noise by the Nyquist filter in the TV receiver. For the analysis, it is convenient to make use of the principal that random noise can be approximated by a large number of sinusoidal components all approximately equally spaced and of arbitrary phase [4]. Thus, the oscillator spectrum can be considered to consist of a carrier plus sinusoidal components 1 Hz apart. The ratio of the <u>power</u> of each component to the carrier <u>power</u> is, therefore, L(fm); (refer to the definition of L(fm)). The ratio of the RMS voltage of each component to the RMS voltage of the carrier is $\sqrt{L(fm)}$. The <u>peak</u> phase deviation of the oscillator at a frequency fm is equal to the sum of the upper and lower sideband phasors, or $2\sqrt{L(fm)}$. The RMS phase deviation θn for a 1 Hertz bandwidth is:

$$\theta n(fm) = \sqrt{2L(fm)} \quad \text{RMS Rad/Hz} \qquad (6)$$

Instantaneous frequency in radians/sec. is the time derivative of phase ($w=d\theta/dt$). Thus, for the above sinusoidal peak phase deviation of $2\sqrt{L(fm)}$, the <u>peak</u> frequency deviation is $2fm\sqrt{L(fm)}$. The RMS frequency deviation due to phase noise in a 1 Hz bandwidth fm Hertz from the carrier is:

$$\Delta f(fm) = fm\sqrt{2L(fm)} \quad \text{RMS Hz} \qquad (7)$$

$$= \sqrt{2}/Qe \qquad (7a)$$

Thus, the spectral density of frequency noise is constant (white) for $1/fm^2$ spectral phase noise.

The slope of a TV Nyquist filter extends over a nominal range of ± 750 kHz centered around the picture carrier. First assume the Nyquist slope is linear over that bandwidth. A deviation of

750 kHz in this case would theoretically produce 100% amplitude modulation at the output of the Nyquist filter. As a result, the AM depth of modulation is equal to $1/750*10^3$ times the frequency deviation which, from Eqn. (7), is:

$$An(fm) = \frac{fm\sqrt{2L(fm)}}{750 \cdot 10^3} \qquad fm < 750 \text{ kHz} \qquad (8)$$

$$= \sqrt{2}/750 \cdot 10^3 \cdot Qe \qquad (8a)$$

An(fm) is specifically the ratio of the RMS noise component that is in phase with the carrier to the RMS carrier voltage. Likewise, $\theta n(fm)$, (Eqn. 6), is the ratio of the quadrature RMS component to the RMS carrier.

Now consider the effects of phase noise for frequencies where the response of the Nyquist filter is flat; i.e, the single-sideband region. The amplitude response of a the Nyquist filter should be down 6 dB at the carrier frequency relative to the response at single-sideband frequencies. As a result, the relative single-sideband noise power is four times greater than at the input to the Nyquist filter; the noise power ratio at the output is 4L(fm). For single-sideband noise, the AM and PM spectral components are equal in power: each is 1/2 the total spectral power. The AM component of noise power is 2L(fm); the RMS noise voltage ratio is

$$An(fm) = \sqrt{2L(fm)} \qquad fm > 750 \text{ kHz} \qquad (9)$$

$$= \frac{\sqrt{2}}{C/No_p} \qquad (9a)$$

In this region the noise spectrum at the filter output has the same shape as the input noise spectrum, and the ratio of carrier to noise power density is degraded 3 dB.

Now consider the effects of the Nyquist filter on white thermal noise. For thermal noise, sidebands are uncorrelated, and, as for single-sideband phase noise, half the power is in the AM component and half in the PM component. The effect of the Nyquist filter can be calculated by power addition of AM sideband components at the output of the filter. With the assumption of a linear Nyquist filter, sidebands add to produce a baseband noise spectra that increases quadratically 3 dB to 750 kHz [5]. Above 750 kHz, the output of the receiver filter is single sideband, and the result is the same as above for phase noise.

APPLICATION OF THEORY

The assumption of a simple linear characteristic for the receiver Nyquist filter is useful, but, of course, real receiver filters are not linear. To more accurately calculate noise resulting from slope detection in the Nyquist filter and to better correlate the theory with measured data, this analysis is based on the response of the Nyquist filter in the Teletronix 1450-1 Television Demodulator used in the video SNR and baseband spectra measurements. A plot of the Nyquist filter response is given in Figure 1. Also superimposed is 1/2 cycle of a sine function, and as seen, it is a very good approximation of the actual filter function. With this characteristic and the equations above, good accuracy has been achieved in relating baseband measurements - video noise spectra and weighted and unweighted SNR - to the carrier phase noise spectra and thermal noise.

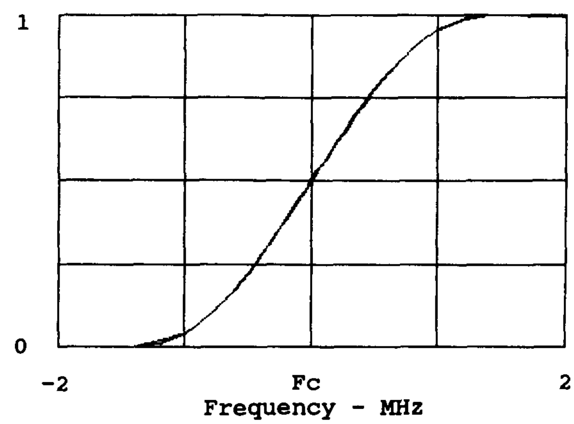

FIGURE 1. Nyquist Filter Response

(a) Measured data
(b) Approximation

Figure 2 is a plot of the AM noise spectra at the output of the Nyquist filter caused by thermal and phase noise. Thermal noise produces a video noise spectrum that increases from DC to the upper limit of the Nyquist filter and is constant above that. For frequencies near carrier frequency, the AM (in phase) component is the same at the output of the filter as at the input since upper and lower sidebands are nearly equal. The thermal noise plot shows, simply, the effect of the Nyquist filter on AM noise.

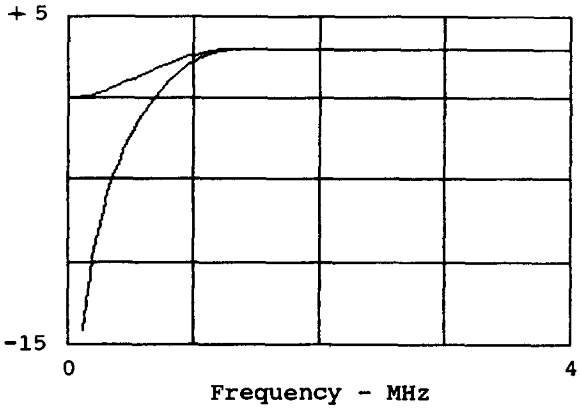

FIGURE 2. AM Demodulation of RF Noise.

Ordinate is C/No : S/No in dB for
(a) Thermal noise
(b) Phase noise

Figure 3 shows the PM to AM conversion of oscillator phase noise. In the frequency range of the Nyquist filter there is some noise roll off; for a linear Nyquist filter the response would be flat. Above the cut off of the Nyquist filter the baseband noise roll off is the same as at RF. Oscillator phase noise contributes primarily to low frequency video noise in the frequency range of perhaps a few hundred kilohertz to a megahertz or more.

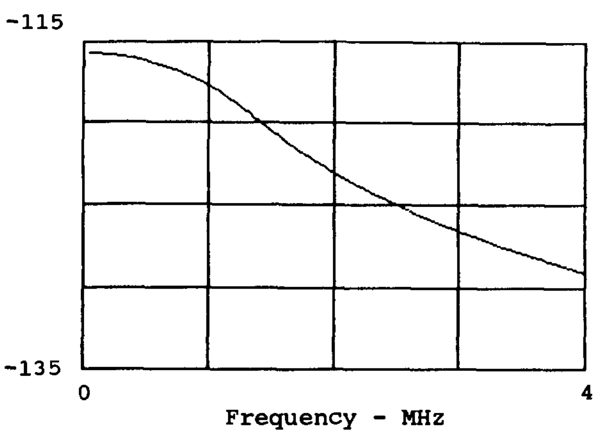

FIGURE 3. Baseband Noise Spectra for Phase Noise = $1/(fmQe)^2$.

Ordinate is No/S in dB for Qe = 1

Oscillator phase noise can be recognized and distinguished from video noise in an examination of the video baseband spectra. For high oscillator phase noise, the noise seen when viewing a TV set in recognizable as low frequency noise and appears different from broadband nose. Data is given in a later section that illustrates these points.

The objective of this paper is to relate RF C/N measurements to video SNR and baseband noise spectra. Weighted SNR is the ratio of the total luminance signal (100 IRE Units) to the weighted RMS noise level expressed in dB. Note, however, that noise due to phase noise is different from thermal noise in that it is directly proportional to the carrier level. If the carrier were to drop to zero percent modulation, there would be no phase noise contribution, of course. Thermal noise is the same (for constant receiver gain) regardless of carrier level. Furthermore, note that noise is more noticeable in dark TV scenes of perhaps 10 to 20 IRE. In our experiments, SNR is determined by measuring weighted baseband noise with the carrier unmodulated in accordance with EIA Standard RS-250-B. The amount of noise caused by phase noise is determined by turning the phase modulation on and off. Phase SNR is the ratio of the signal for 100% modulation (1.143V for 1V/100IRE) divided by the RMS phase noise voltage.

Phase noise can be measured also on a waveform monitor using the Tektronix 147 Test Signal Generator or by the NTC Report No.7 Approximation Technique. With these procedures the amount of phase noise measured will depend on the level of the waveform pedestal at which noise is measured. If noise is measured at a level of 20 IRE, these procedures theoretically give the same results and agree with the above measurement and definition of phase SNR.

For the Nyquist filter data the theoretical AM baseband spectral density is plotted in Figure 3 for Qe = 1. Video SNR can be obtained by a noise power integration of Figure 3. The weighted SNR is obtained by multiplying the spectral density in Figure 2 by the noïse weighting function. For this data and in our tests, the weighting filter given in Report 637-1, Equation 4, "for system M (prior to the introduction of the unified network" was used. This network is in general use for NTSC system measurements. Performing the noise power integration to 4.2 MHz gives

SNR due to phase noise:
SNR unweighted = 54.2 + Qe dB (10)

SNR weighted = 57.7 + Qe dB (11)

In a similar manner, the unweighted and weighted video SNR due to thermal noise is obtained.

SNR due to thermal noise:

$$\text{SNR unweighted} = C/N - 6.9 \text{ dB} \quad (12)$$

$$\text{SNR weighted} = C/N - .5 \text{ dB} \quad (13)$$

From Eqns. (5) and (11) one obtains a fortuitous and very neat identity. By measuring phase noise at 20 kHz offset from the carrier in a 1 kHz bandwidth,

$$\text{SNR weighted} \approx C/Np \text{ dB} \quad (14)$$

where C/N_p is the carrier to noise ratio. This is a simple and possibly very useful measurement for predicting degradation caused by phase noise.

The amount of phase noise relative to that produced by thermal noise in the system can be calculated from Eqn. (11) and (13) and the definitions of Qe and C/N. Given that the phase noise spectrum crosses the thermal noise spectrum (measured in the same resolution bandwidth) at a frequency F, then, for equal contribution of each to the weighted SNR, F is equal to 1.53 MHz. Thus, if the phase noise spectrum crosses the thermal noise spectrum below 1.53 MHz, thermal noise predominates; if it crosses above 1.53 MHz, phase noise predominates.

These equations assume the oscillator spectrum decreases 6dB/octave, and one should observe the spectrum on a narrow and wide span to see if that is the case. Also, the spectrum in the range of 10 to 20 kHz can indicate higher phase modulation in that range than actually is present. Low-frequency high-deviation PM can cause high order Bessel sidebands to extend above 10 kHz and cause phase noise to appear high.

VIDEO DEMODULATOR TYPES & RESPONSE TO PHASE NOISE

The effect of phase noise on NTSC video depends on the type demodulator employed in the TV receiver or TV demodulator. Demodulators may be classified as envelope detectors, such as diode rectifiers, or product demodulators [6][7][8]. Envelope detectors respond to large quadrature modulation and distortion of the amplitude modulated signal can occur. However, the envelope detector is immune to the relative small amount of phase noise considered here. This can clearly be seen when one considers that oscillator phase noise produces low deviation FM which, in this case, may be a deviation of perhaps a few hundred Hertz or even a few kilohertz. Deviation that low would not be detected by a broadband envelope detector except for detection by FM to AM conversion in the Nyquist filter.

Product demodulators or coherent demodulators in principle detect an AM signal by recovering the carrier from the modulated signal and multiplying the RF signal by the recovered carrier (hence the name "product" demodulator.) A mixer (ring diode type or integrated circuit mixer) is effectively a multiplier for this purpose. Product demodulators are realized in different implementations and respond differently to the presence of PM on the desired AM signal. In TV applications, product demodulators are known also as synchronous demodulators and quasi-synchronous demodulators. Furthermore, envelope detectors, as in the Tektronix 1450 TV Demodulator, can be realized as product demodulators. Generally, the synchronous detector recovers the carrier by phase locking a local oscillator to the carrier of the TV signal. The bandwidth of the phase lock loop is low, approximately 50 Hz for the Tektronix 1450 Demodulator and Scientific-Atlanta 6250 Demodulator, and the oscillator may be a crystal oscillator. Certainly, this type of synchronous detector can not handle a large amount of phase noise, particularly 60 Hz power supply noise and low frequency jitter. The advantage of the synchronous demodulator is its good linearity and immunity to quadrature distortion provided incidental phase modulation is low.

Quasi-synchronous demodulators, and envelope detectors realized as quasi-synchronous demodulators, recover a carrier by filtering and limiting the TV IF signal and applying it as the reference (local oscillator) for the IF signal mixer. Since the filtering occurs at IF, the filter bandwidth is relatively wide: 50 kHz for the Tektronix demodulator and about 200-300 kHz or more currently for TV receivers. Within this frequency range, the recovered carrier tracks the signal carrier and the system behaves as an envelope detector. However, in recovering the carrier, if the filter bandwidth is too small and phase noise is high, the detector itself will convert phase noise to AM noise. Theoretically, the output of a product demodulator is proportional to the cosine of the angle between the recovered carrier and the carrier of the input signal. For a small tracking error (small phase error), the cosine of the angle is approximately 1 and negligible error is caused by the detector. If the tracking error is large, the detected signal is modulated by the cosine of the tracking error. Thus, inability of the recovered carrier to track phase noise results in additional PM to AM conversion in the detector itself. This should not be a problem except for very narrow band tracking loops and excessive low frequency phase noise. By integrating the mean square phase noise spectra from frequency f_1 to infinity, the total RMS phase noise is obtained:

$$\delta = \frac{1}{f_1}\sqrt{\frac{2}{Qe}} \qquad \text{Rad RMS}$$

For example, for phase noise that would result in weighted SNR of 46 dB, from Eqn. (12), Qe is -11.7 dB, or a factor of 0.26. The total phase noise in the spectrum above f_1 = 10 kHz is only .016 deg RMS. This small amount of high frequency phase noise should not be detrimental to the quasi-synchronous demodulator.

PERCEPTIBILITY TESTS

Tests have been conducted to investigate the effects of phase noise on TV reception and determine the threshold of perceptibility. In tests reported by Giorgio Allora-Abbondi [9] and Robb Balsdon [10], a Hewlett Packard 8660B Synthesized Signal Generator was frequency modulated by the broadband noise source of a Tektronix 147 Test Signal Generator and the Synthesizer output was substituted for the output convertor LO in a Scientific-Atlanta 6530 TV Modulator. The bandwidth for noise modulation was limited by the synthesizer to about 250-500 kHz. In these and other tests, phase noise was measured by measuring carrier sideband noise level in dBc at 20 kHz offset from the carrier and in a 1 kHz bandwidth. Balsdon reported that phase noise became perceptible at a noise level of about -53 dBc on three TV sets, and at -54 dBc when using a Scientific-Atlanta 6250 TV Demodulator in the envelope detector mode. When operating in the synchronous detector mode, phase noise became perceptible at a much lower level, -67 dBc, due to the narrow bandwidth of the synchronous demodulator (approximately 50 Hz) and its inability to track the low frequency noise.

In a similar test, Allora-Abbondi found the perceptibility threshold to be -52 dBc to -56.5 dBc with -53 dBc to be typical for envelope detectors. With Tektronix and Scientific-Atlanta synchronous demodulators, susceptibility to phase noise was much greater: -57 dBc to less than -64 dBc. Performance in the synchronous mode was best with the fast detector time constant due to better tracking between the reference oscillator and the incoming signal. With no phase noise added, weighted SNR of the system was 54dB.

The tests that follow were conducted at Scientific Atlanta with participation by members of the Group 1 committee. In tests similar to those above and using an HP 8640 Signal Generator as the noise modulated source, the perceptibility threshold was found to be at a phase noise level of -56 dBc. Levels were set for optimum performance; without phase noise weighted SNR measured 66 dB. At the phase noise threshold, weighted phase SNR measured 60 dB.

In another test, an oscillator with 4 MHz modulation bandwidth capability was frequency modulated by the Tektronix 147 noise source and substituted for the Scientific Atlanta 6350 video modulator output converter LO. With this oscillator the background SNR was 64 dB. Phase noise and weighted SNR measured -62 dBc and 60 dB respectively at the perceptibility threshold. Phase noise at 20 kHz offset from the carrier was 6 dB lower than with the HP8640 source due to the narrower modulation bandwidth of the HP8640, approximately 250 kHz, but the resulting SNR's were the same.

Thermal noise was added from a broadband RF source and the perceptibility test repeated for thermal noise only. Weighted SNR measured 58 dB for the same degree of perceptibility. This is within 2 dB of the above SNR's measured for wideband and band limited phase noise. We believe that weighted SNR gives a good quantification of system performance regardless of whether noise is thermal or phase in origin.

Thermal noise was increased to give a weighted SNR of 46 dB. Under this condition, phase noise measured -50 dBc at threshold. Weighted SNR due to phase noise (measured with thermal noise off) measured 50.7 dB.

For the above Scientific-Atlanta tests, test patterns were very closely scrutinized to see any noise effects. Tests were also made with program video obtained from a satellite feed. The HP 8640 Signal Generator was noise modulated and used for these tests. Video SNR from the satellite feed measured approximately 53 dB. For moving program video phase noise became visible generally in highly saturated areas at a phase noise level of -47.6 dBc (at 20 kHz offset from the carrier and in a 1 kHz bandwidth, as before).

Phase noise appears a little different from thermal noise in test patterns and video. Thermal noise appears as fine grain noise; phase noise has more of a streaked, low frequency characteristic which is to be expected from general knowledge of the baseband spectrum. In the Scientific Atlanta tests, plots were made of the baseband video spectra (with the Tektronix 1450 Demodulator operated in manual gain mode to insure that the gain is the same with unmodulated carrier as for normal video). Phase noise was easily distinguished from thermal noise by its shape. Phase noise showed a roll-off with frequency, whereas thermal noise showed a slight rise from dc to approximately 1 MHz and was flat from there to 4 MHz.

REPRESENTATIVE DATA

Figure 4 is data for a fixed-frequency (CH. 5) video modulator. Oscillators in this modulator are crystal oscillators, and, of course, phase noise is very low. The baseband plot is characteristic of a system white noise limited: no phase noise is evident. Spurious responses in the baseband plot are evident, but these are low enough so as not to materially effect the results. Calculated unweighted phase noise is more than 10 dB below measured noise.

Figure 5 is data for an agile modulator. This modulator shows results of oscillator phase noise that is somewhat high. The oscillator spectrum has the classical 6dB/octave roll off up to approximately 2 MHz where it approaches the noise floor of the modulator. Above that frequency, baseband noise is determined by thermal noise; below approximately 2 MHz baseband noise is predominately phase noise in origin.

Figure 6 is data for a set-top converter. The input level was set relatively high - 16dBmV - but not excessive for a single channel in order to achieve maximum dynamic range for the spectrum plots and SNR. Also, the converter output was amplified ahead of the spectrum analyzer for the same reason. Notice that for the 100 kHz RF span, the carrier is several dB below the reference line. The carrier was actually set to the reference line in a wide IF bandwidth (30 kHz), and because of low frequency FM, the carrier appears low when plotted with an IF bandwidth of 1 kHz. At baseband, there is a definite contribution from phase noise below 1 MHz. For no phase noise, there should be a dip in the baseband spectrum below 1 MHz. As shown in the 1 MHz RF span, the oscillator spectrum falls off more rapidly than 6dB/octave, and apparently is below the noise floor of the converter by 500 kHz. This causes a sharper roll-off in the baseband spectrum to 500 kHz as compared with that shown in Figure 3.

CONCLUSIONS

Phase noise is another source of system noise in a CATV system which could result in a discernible amount of noise in the final TV display but should not be noticeable in systems with SNR 45 dB or worse. A general discussion of oscillator phase noise was presented and equations given for the case in which the noise spectrum decreases at a 6dB/octave rate from the carrier. Simple equations enable one to calculate the video SNR from measurements of the phase noise spectrum. Actually, the RF carrier spectrum may vary to a large extent from the assumed 6dB/octave roll off, but an understanding of the principles discussed will help in evaluating and determining the effects of phase noise.

Phase noise in distinguished from thermal noise by its low frequency character. Generally, demodulated phase noise decreases slowly to approximately 1 MHz and follows the roll off in the RF spectrum above that. An examination of the video spectrum will show if the noise caused by phase modulation of the carrier is significant.

Phase noise, if excessive, appears in a TV display generally in low luminance and highly color saturated areas. Phase noise appears different from thermal noise due to its higher low frequency content. Phase noise does not appear as granular as thermal noise and shows some low frequency streaking.

A baseline for phase noise measurement is the sideband level of the unmodulated carrier at 20 kHz offset and in a 1 kHz bandwidth. For an RF carrier with sidebands that generally decrease 6dB/octave, the weighted SNR due to phase noise sidebands is approximately equal to the sideband level thus measured. Also, if the phase noise spectrum intercepts the thermal noise floor (measured in the same IF bandwidth) below approximately 1.5 MHz, thermal noise is likely to predominate. If it intercepts above approximately 1.5 MHz, phase noise is likely to predominate. These are simple tests that should help the operator realize whether phase noise is likely a problem.

Perceptibility tests are reported in which a video carrier is noise modulated with modulation bandwidth approximately 250-500 kHz. In these tests, phase noise became perceptible at a level of about -52 dBc to -56.5 dBc (measured 20 kHz from the carrier in a 1 kHz bandwidth). Video SNR without added phase noise was 54 dB or better. In a similar test with an oscillator with 4 MHz modulation bandwidth, phase noise became perceptible at -62 dBc. With thermal noise increased to make weighted SNR equal to 46 dB, phase noise became perceptible at a sideband level of -50 dBc.

Synchronous detectors respond the same as envelope detectors or quasi-synchronous detectors to low levels of phase noise. Above a threshold narrow band synchronous detectors are much more sensitive to phase modulation and are particularly sensitive to low frequency noise. High frequency phase noise (above 10 kHz) is not expected to be a problem for tracking bandwidths 10 kHz or greater, but low frequency, high deviation noise can cause PM to AM conversion in the detector.

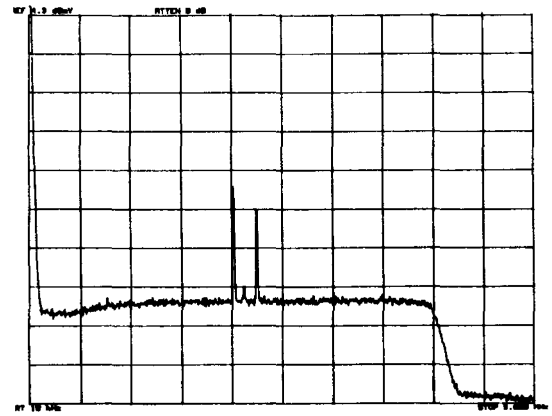

FIGURE 4. Fixed Frequency Modulator Baseband Noise Spectrum.
Start: 10kHz Stop: 5MHz BW: 10kHz
Ref: 4.3 dBmv 5dB/div

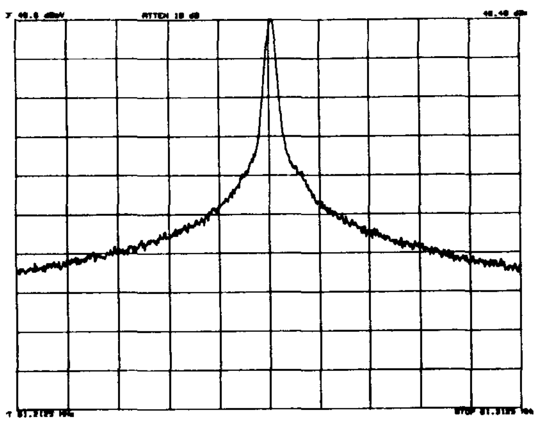

FIGURE 5a. Agile Frequency Modulator RF Noise Spectrum.
Center Freq: 61.25MHz Span:100kHz
BW: 1kHz 10dB/div
Ref: 4.3 dBmv 5dB/div

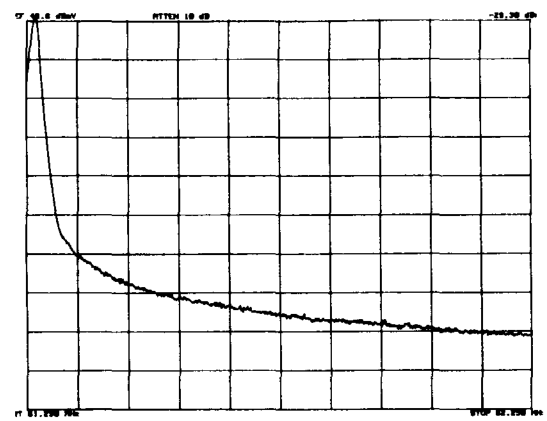

FIGURE 5b.
Span: 100kHz BW: 10kHz 10dB/div

FIGURE 5c. Baseband Noise Spectrum
Start: 10kHz Stop: 5MHz BW: 10kHz
Ref: 4.3dBmv 5dB/div

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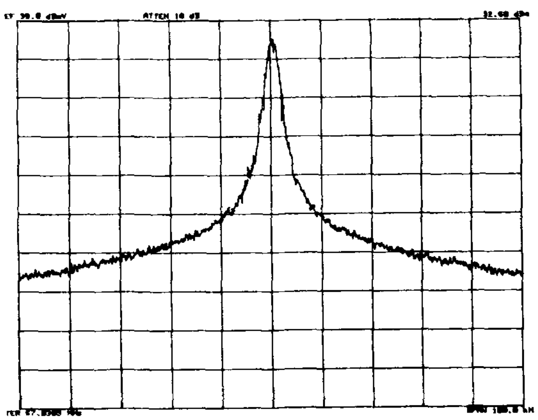

FIGURE 6a. Set-Top Converter.
Center Freq: 67.0MHz Span: 100kHz
BW: 1kHz 10dB/div

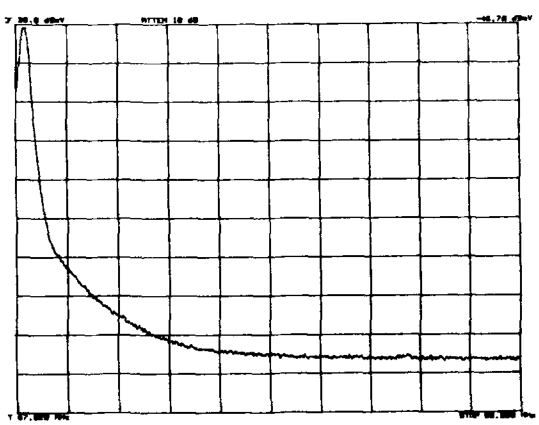

FIGURE 6b. RF Spectrum.
Span: 1MHz BW: 10kHz 10dB/div

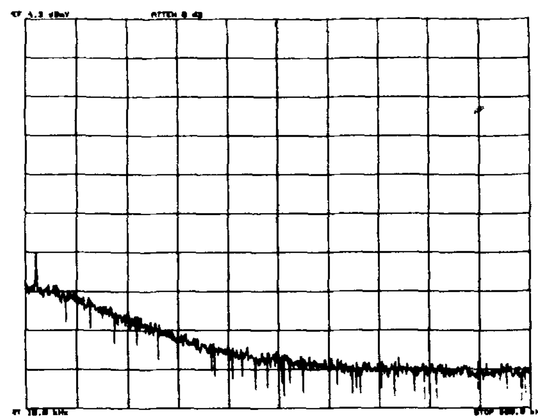

FIGURE 6c. Baseband Noise Spectrum.
Start: 10kHz Stop: 500kHz BW: 10kHz
Ref: 4.3dBmv 5dB/div

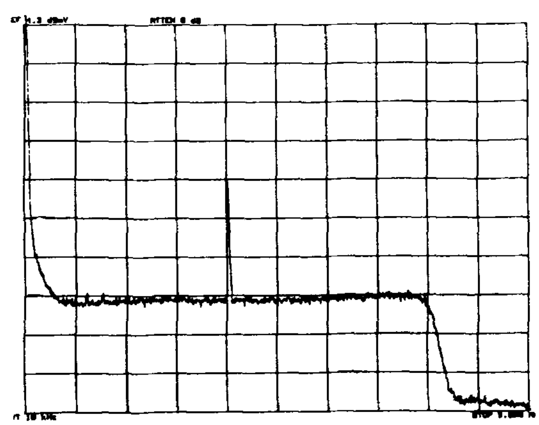

FIGURE 6d. Baseband Noise Spectrum.
Start: 10kHz Stop: 5MHz BW: 10kHz
Ref:4.3dBmv 5dB/div