THE IDEAL MODULATOR/DEMODULATOR

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The first step in evaluating the baseband performance of a head-end modulator is to obtain an "ideal" demodulator. Otherwise, shortcomings of the test equipment and those of the device under test will be difficult to separate. A similar requirement plagues the evaluation of the head-end demodulator. In this case the "perfect" modulator is needed. But what is "perfect"? How are the "perfect" instruments tested? This paper answers these questions.

Introduction

Cable television today is an exact science. Providing quality signals to the customer requires not only reliable and sophisticated plant equipment but also the best instruments available for testing and maintaining that equipment. The job of quality assurance is made easier by modern test equipment. However, in some cases the equipment under test is of higher quality than the test equipment. This is not a problem for the system operator. He does not need a precise characterization of his plant equipment. But for the design engineer the situation is different.

For the sake of illustration, assume that an engineer is developing a new head-end modulator. Consider some of the questions that he must face.

Does a demodulator exist which is good enough for testing this modulator? If so, what kind of detector does it have? Does it have a differential gain less than one percent? If it has excessive differential gain, how does it vary with luminance level? Will it cost more than $8000? Can I find a substitute? If so, can I get away with $100 in materials?

It is true; the best philosophy for testing a modulator is to find the perfect demodulator. Conversely, the perfect modulator is needed to test a demodulator. However, it is more practical to search for the virtual perfect demodulator and modulator. That is, make it appear as though the perfect test instruments were used. A simple example is to subtract the distortion of a test device alone from the composite distortion of the piece under test and the test device operating together. This assumes, of course, that the distortion of the test device is accurately known.

Therefore, the question now is not how or where to find the perfect modulator or demodulator, but, rather how to simulate them. As a first step in answering this question, it is important to realize that the technique or device which brings about the simulation does not come in a single clearly defined embodiment. Rather, for each test performed, the technique, the lash-up, indeed the entire concept may be different.

The Perfect Demodulator

Returning now to the head-end modulator, which is to be tested for differential gain, one's first reaction is to look for the best demodulator available, a vectorscope and a video waveform generator. However, a careful analysis of this test will result in less expensive equipment. Furthermore, accuracy will be as good or better.

What is differential gain? It is a measure of the change in color subcarrier amplitude over the luminance dynamic range. Luminance and color are supposed to be independent. If they are not, then differential gain is present. A common method of measuring it is to add a steady subcarrier to the normal video portion of a stair-step waveform, apply the result to the modulator under test, recover the video in a precision demodulator, discard the luminance by passing the recovered video through a filter, rectify the remaining 3.58 MHz subcarrier, and display the resulting D.C. as a function of luminance on an oscilloscope.

As a matter of fact, the chief advantage of this test approach is convenience. Accuracy is excellent when synchronous detection is used in the demodulator but commercially available units using this technique are expensive.

There is another method which yields high accuracy and low cost. The RF produced by the modulator contains the color subcarrier in the form of a sideband component 3.58 MHz above the picture carrier. If the modulator exhibits differential gain, it will not be confined to this component only. However, since differential gain pertains to color only, it is customary to measure it at the color subcarrier frequency. Nevertheless, the frequency does not have to be precise. The only item of interest is amplitude variations, not frequency variations. For the sake of illustration, assume the subcarrier sideband component to be in TV channel 2. It falls, therfore, at about 58.83 MHz. Any amplitude variations of this component will cause a corresponding variation in the 3.58 MHz output of the video detector. But most video detectors will create additional differential gain which is difficult to separate. However, since this additional distortion is caused by the luminance portion of the signal, why not remove it? Doing so results in the added advantage of not needing a third detector to convert the 3.58 MHz to D.C. The desired D.C. can be obtained directly from the 58.83 MHz component. In this illustration, the entire test set-up requires a video waveform, a narrow bandpass filter tuned to 58.83 MHz, a diode detector, and an oscilloscope. A very convenient form of tunable bandpass filter and diode detector is available in the signal level meter. They are are available with adequate selectivity and with a video output port.

The companion test, differential phase, is more difficult because it requires comparing two signals of practically identical frequency. Again, the frequency need not be precise, but the frequency of the first must be precisely equal to that of the second. This test is similar to differential gain; only phase change rather than amplitude change is under scrutiny. Differential phase is the change in phase of the color subcarrier over the dynamic range of luminance. There should be complete independence between luminance and color subcarrier phase. If there is not, then differential phase is present.

The customary test set-up requires a video waveform generator which delivers a ramp or stairstep with steady subcarrier during the luminance interval. This generator drives the modulator under test, which then feeds a precision demodulator. The color subcarrier is separated from the the demodulator output and is applied to a phase detector, the output of which is displayed versus luminance level on an oscilloscope.

The measurement of differential phase is further complicated because of the relationship between baseband subcarrier and picture carrier. Furthermore, this relationship is strongly affected by the type of detector used to recover the subcarrier. If an envelope detector is used, the phase of the baseband subcarrier is determined by the instantaneous phase difference between the picture carrier and the RF color subcarrier. If a synchronous detector is used, the phase of the baseband subcarrier is determined by the instantaneous phase difference between the RF subcarrier and the local oscillator signal, which drives the synchronous detector.

If the modulator generates an RF subcarrier phase jitter, then the picture carrier most likely has a similar phase jitter. Because the phase difference between the two signals is unchanged, the phase of the baseband subcarrier output of an envelope detector will remain unchanged. In certain practical applications, this can be a distinct advantage. However, more often the inherent distortion of the envelope detector will offset this advantage. However, in a synchronous detector, the local oscillator signal does not change phase in exactly the same manner as the picture carrier; therefore, the subcarrier output of a synchronous detector will show a phase distortion.

The proper characterization of a modulator should be independent of the demodulator with which it is used and conversely, of course. Therefore, determining the behavior of a modulator as it pertains to differential phase requires that all parameters be measured which might affect differential phase. Those parameters are RF (or IF) color subcarrier phase and picture carrier phase. The former can be readily measured by making use of a sample of both the modulator IF local oscillator signal and the baseband color subcarrier. The local oscillator sample will be independent of the modulated version. Therefore, if it is mixed with the IF color subcarrier after it has been extracted from the composite signal by means of a narrow bandpass filter, the resultant 3.58 MHz signal will exhibit a phase variation which is dependent only on the phase of the IF subcarrier. This signal can be applied to a phase detector which is driven by the baseband subcarrier sample from the video generator. The output of the phase detector can then be displayed versus luminance on an oscilloscope.

Measuring the phase variation of the picture carrier is difficult because of the interfering luminance components. They are too close in frequency to be filtered out. One method is to detect the luminance quadrature component of the picture carrier. That component is the part of the modulated picture carrier which is ninety degrees out of phase with the unmodulated picture carrier. Wherever the output of the quadrature phase detector is different from zero, the angle of phase change is equal to the change in the setting of a calibrated phase shifter required to restore zero output from the phase detector. If the video luminance waveform is applied to the horizontal input of an oscilloscope, and the quadrature output to the vertical terminals, the phase shifter can be used as a comparator scale and the oscilloscope as a null indicator.

Another example of simulating the ideal demodulator can be found in the measurement of modulator flatness. Before examining this in detail, it is important to interpret the meaning of flatness as it pertains to modulators. Naturally, any demodulator should produce a video output which is an exact replica of the video at the input of the modulator. This ideal condition can be called one of zero flatness, that is, zero amplitude variation versus baseband frequency from video input to video output. Any deviation from the ideal would be called a flatness of some percentage of full amplitude, or more commonly, a flatness of some dB.

It is desirable to express this quantity as if the ideal demodulator were used. This admits that any deviation from the ideal is caused by the modulator. An alternative is to give flatness in terms of the RF output only. Regardless of whether the demodulator is ideal or practical, the video obtained from it can be predicted only by knowing the RF characteristics of the modulator.

One method of obtaining this is to apply the output of the modulator to a broadband diode detector. The modulator input is a sinewave of adjustable video frequency. Depth of modulation should be light so that the nonlinear properties of the diode are not evident. This is permissible since frequency response is not affected by modulation depth.

The output of most head-end modulators is vestigial sideband. Over part of the video frequency range, a double sideband is produced, but over the remainder, only a single sideband is produced. When a broadband envelope detector is used for this signal, the output for a given modulation depth is twice as large for video components producing a double sideband as it is for those producing a single sideband. Consequently, the output of a wideband envelope detector is intentionally non-flat. A good method of determining the "flatness" of a modulator is to measure deviation from this intentional non-flat characteristic.

More examples of measurements on a modulator could be given. They all will have one quality in common. They all will be designed to simulate the perfect demodulator, that is, they will produce data which allows the determination of the nature of the signal which would be delivered by a perfect demodulator if it were driven by the modulator being measured.

Similar techniques are used when evaluating a demodulator. The test data which characterize a demodulator should presuppose the use of a perfect modulator in making the tests. Attention is now directed to the question of how to bring about this simulation.

The Perfect Modulator

Although the philosophy is the same, corresponding tests will show surprising differences. For the sake of comparison, consider the requirements for measuring the flatness of a demodulator.

As for the practical modulator, the RF characteristics of the practical demodulator must be known before one can predict how it behaves with any modulator, perfect or otherwise. Also, the demodulator RF characteristic is purposely non-flat in order to compensate for the vestigial sideband non-flatness. Therefore, as with the modulator, the best way to measure the "flatness" of a demodulator is to measure the deviation from its ideal non-flat RF characteristic.

One common approach is to take advantage of the Nyquist slope, which has two virtues. First, it compensates for the double sideband portion of the input signal thus causing it to appear as a single sideband signal. Secondly, it rejects components in that part of the lower sideband which are supposed to be rejected by the modulator. Therefore, if the input signal is double sideband, the demodulator response will be the same as for a vestigial sideband signal. The double sideband signal is easy to produce, hence the desirability of this test. However, it has the disadvantage of not revealing the true shape of the Nyquist region. A second test, namely to sweep the Nyquist filter, can remove any doubt, and should always accompany the double sideband test.

Another approach to the measurement of demodulator flatness is to provide two input signals, both unmodulated sinewaves. The first signal is set to the picture carrier frequency. The second signal has an adjustable amplitude and frequency, which is variable between 4.5 MHz above and 1.25 MHz below the picture carrier. As the second signal is moved across the band, a calibrated attenuator is adjusted to maintain constant detector output. The attenuator readings versus frequency give a plot of the RF characteristic including, of course, the Nyquist region.

Assuming an instrument is linear, its behavior can be fully described by specifying both amplitude response and phase response. A plot of phase versus frequency provides the necessary information. However, that data will be translated into the more common form known as group delay, which is the slope of the phase versus frequency curve. This quantity is a more sensitive measure of system performance. The following example will show how group delay is measured.

In keeping with the previous philosophy concerning the measurement of amplitude response, the measurement of demodulator group delay is performed in a manner which simulates the use of a perfect modulator. Also it is desirable once again to characterize the demodulator in terms of RF response. Furthermore, because of difficulties in measuring group delay at very low video frequencies, say from 200 KHz down, RF measurements are necessary. By making use of both RF group-delay and RF amplitude data, the baseband group delay can be calculated all the way to zero frequency. This technique accomplishes more than the simulation of an ideal modulator, it also simulates an ideal group-delay measuring device, in the sense that it is practically impossible to make the measurement at baseband.

How is this test implemented? A double-sideband modulator can be the source, but precautions the same as those for amplitude response must be taken. The Nyquist filter response must assure that no contribution is made to group delay from the region below the Nyquist slope. The method is valid over the entire video band except for the lower end from about 200 KHz down. The wideband modulator is driven by a video group delay source and the group delay detector is driven by the video from the demodulator under test.

For the region from 200 KHz down, a single-signal technique must be used. One approach is to apply to the RF input of the demodulator a signal directly from the group-delay source having a carrier frequency covering the range from 200 KHz above to 200 KHz below the picture carrier frequency. The resulting group delay data along with amplitude response will allow the calculating of the equivalent baseband delay from 200 KHz down to zero frequency.

What is Perfect?

Several examples have been cited of methods of simulating a perfect test instrument. Unfortunately even the simulation is not perfect. But whenever this approach is taken, the notion of specialization is suggested. That is, there is not any single instrument which can perform or aid in performing a plurality of functions in an optimum manner. When video enters a modulator, it is only natural to consider that a process has begun, the end of which is the delivery of that same video at the output of a demodulator. However, within that process are many sub-processes which can give greater insight into the final product than the final product itself. When it comes to testing a mod-demod system or any part of it, the notion of perfection is ever present. But somehow the desire for perfection is accompanied by an equal desire for simplicity. An attempt at simplicity was made in formulating each of the tests described. Furthermore, each test is designed to be the most accurate and straightforward for the parameter being examined.

Conclusion

It should be obvious that no attempt has been made to convey much detail about precision testing of head-end modulators and demodulators. One objective was to expose an engineering dilemma concerning accuracy both in the laboratory and on published product specifications. The dilemma was an obstacle to precision testing, namely the ideal modulator/demodulator. A second objective was to show that this dilemma was removed by recognizing that another course had to be taken. There is an ideal modulator/demodulator but not in the form normally expected. And if they ever do take the more familiar form, it will only be because the virtual instruments were used so skillfully.

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