The Vestigial Sideband and Other Tribulations

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Abstract

In 1941, NTSC recommended standards to FCC that specified vestigial sideband amplitude modulation in order to squeeze a 4 MHz video signal into a 6 MHz channel. In 1954, NTSC recommended color TV standards that specified pre-correction at the transmitter for the group delay characteristics of what they believed to be an "average receiver". These two NTSC RF standards create enough mischief in modern TV reception largely to mask the improvement in baseband NTSC performance being pursued so diligently by ATSC and the FCC advisory committee on Advanced TV. FM transmission on cable, with Y/C delivery to the subscriber TV set would by-pass the VSB problem. Low-cost ($25) VLSI chips in the form of FM modulators and demodulators will be needed to achieve this economically. Correction of envelope delay distortions due to the IF sound trap should be made the sole responsibility of receiver designers, by eliminating the NTSC pre-correction standard for transmitters, cable TV processors and modulators, and establishing tight tolerances.

Historical

As early as 1936, five years before the first NTSC developed its monochrome television standards, the 6 MHz channel width had already been set in concrete by the Radio Manufacturers Association (RMA) television standards committees.[1] At that time, 100 MHz was at the frontier of the electromagnetic spectrum considered useful for public purposes. You may laugh, but references even to 75 megacycles as "ultra-high frequency" were commonplace. Frequencies (wavelengths) were measured with Lecher wires (ask some old-timers about those); Barkhausen transit-time tubes and magnetrons were used for power oscillators. The RMA recommendation that seven 6 MHz channels be established between 42 and 90 MHz was considered at the time to be both farsighted, and a little greedy. In hindsight, it is unfortunate they did not opt for 8 MHz channels, like the British did some 25-30 years later. Maybe this is the price of technological leadership.

In the 1936-37 RMA deliberations, there was general agreement on 441-line, 2.5 MHz video bandwidth, using double sideband amplitude modulation (Figure 1). By 1938, however, the RMA committees recommended the recently developed vestigial sideband technology in order to increase the video bandwidth to 4 MHz without expanding the 6 MHz channel width. It was only at the last meeting of the first NTSC, in March 1941, actually two months after its recommendation had been submitted to FCC, and after stormy debate, that

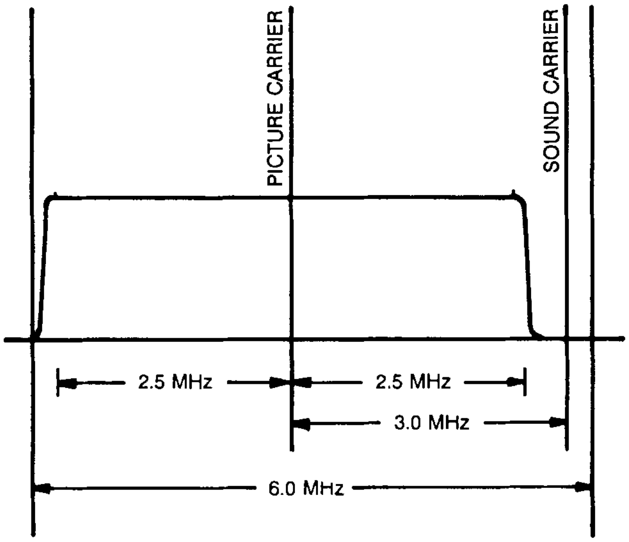


Figure 1

the number of scan lines was changed from 441 to 525, where it stands today.

In January, 1950, after the wartime freeze, the NTSC was reconvened to develop compatible color TV standards. By this time, it was politically impossible to expand the 6 MHz channel bandwidth. Therefore, the vestigial sideband, 525 line structure became literally immutable, and this standard was carried forward for NTSC color.

The Vestigial Sideband

What is the *vestigial sideband*? Simply stated, it is what is left after filtering out most of the lower sidebands generated in normal double sideband (DSB) amplitude modulation (see Figure 2).

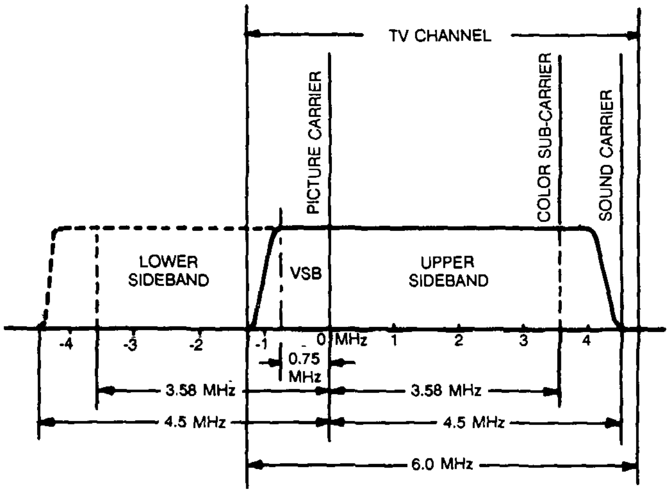


Figure 2

It is often useful to represent amplitude modulation as the sum of three vectors (see Figure 3). The large vector represents the visual carrier, and rotates at the rate of 54 to 550 million revolutions per second, the carrier frequency. The two shorter vectors represent the sidebands, rotating in opposite directions at a much slower rate, less than about 4 million revolutions per second, the video baseband frequency.

When both sidebands exist, with equal amplitudes and opposite phase, the resultant always coincides with the carrier vector. But when one of the sidebands is missing (shown as a dashed line in Figure 3) the resultant swings back and forth, depending on the relative position of the carrier and modulation vectors, causing quadrature distortion. The smaller the modulating amplitude, however, the smaller is the resultant swing back and forth.

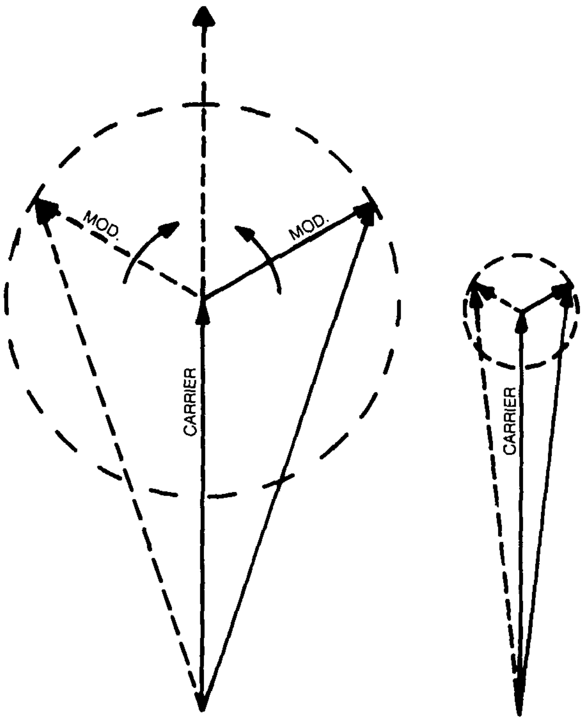


Figure 3

The RMA committee realized, correctly, that the sidebands at more than about 0.75 MHz from the visual carrier would normally be so small that most of the lower sidebands could safely be eliminated. It was a good tradeoff at that time. With VSB, the RMA committees were able to squeeze 4 MHz video bandwidth into the 6 MHz straitjacket.

The Nyquist Slope

Both sidebands do exist in VSB television, up to about 0.75 or 1.0 MHz. In this region, therefore, the resultant signal voltage is twice as great as it would be with only one sideband. An ideal detector would yield the response shown in Figure 4. To overcome this discrepancy, and to provide smooth transition from DSB to SSB, the receiver IF filter should have the shape shown in Figure 5. The so-called "Nyquist slope" at ± 0.75 MHz around the picture carrier, enables the combined amplitude of the upper and lower sidebands in the vestigial region to be the same as a single

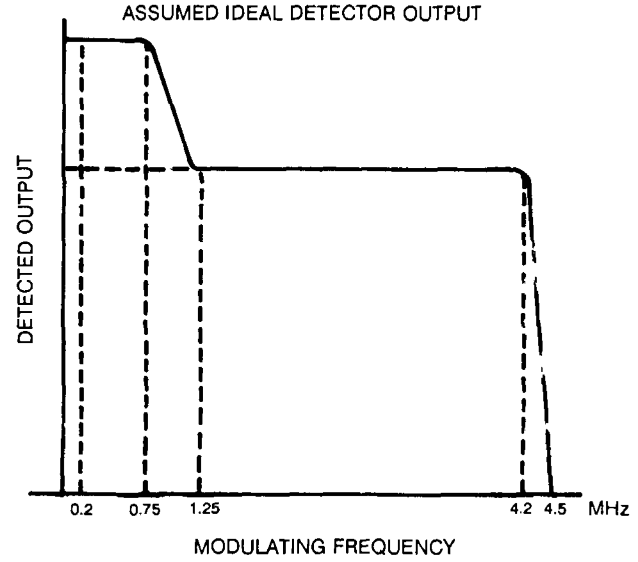


Figure 4

upper sideband in the single sideband region.[2] Ideally, the components of each sideband pair in the Nyquist region should have equal and opposite phase, like the DSB pair in Figure 3.

That is where the trouble arises. It is not easy to build a simple filter without phase shifts near the cut off frequency. Moreover, IF shaping filters designed to produce the Nyquist slope are likely to produce phase shifts above and below the picture carrier. The sharp corners at ± 0.75 MHz in Figure 5 do not exist. The real world looks more like the dashed lines.

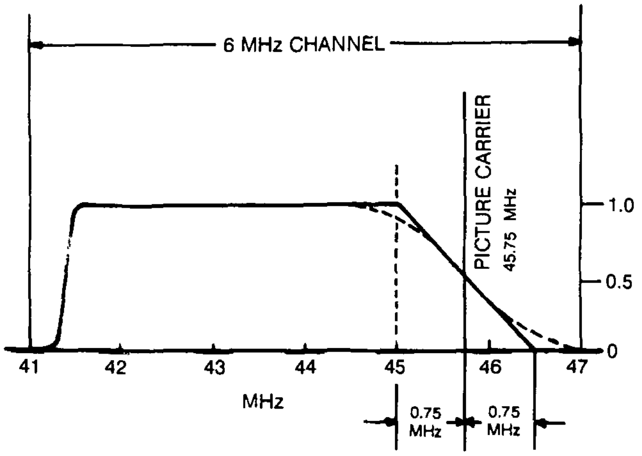


Figure 5

Group Delay

Now look at Figure 6 which shows what can happen because of phase errors in the residual lower sidebands at more than 0.75 MHz below the picture carrier. This represents the situation where the lower (vestigial) sideband is delayed substantially. At the instant when the upper sideband is in phase with the carrier, the lower sideband (dashed) has not yet arrived. A little later, the two sidebands will come in phase, as indicated by the solid arrows. However, the resultant envelope reaches its maximum substantially later than it should.

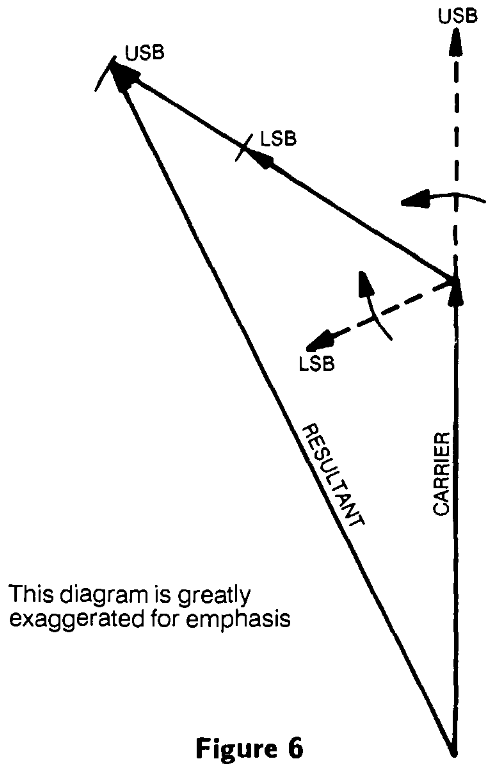
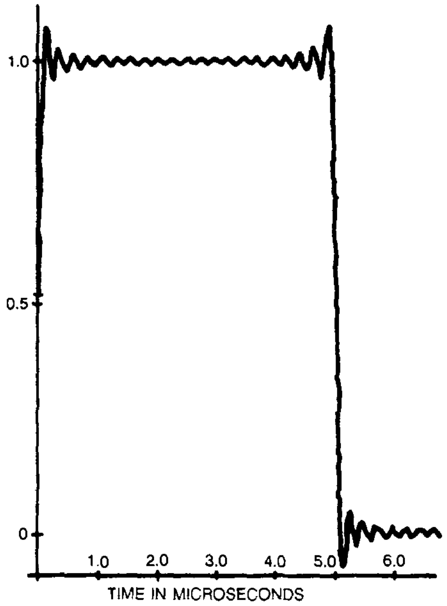


Figure 6

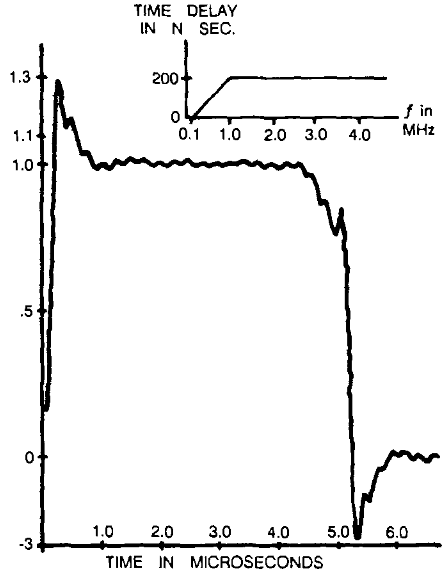
The lower sidebands, between roughly 0.5 and 1.0 MHz below the visual carrier, are susceptible to phase errors at both the VSB filter in the transmitter (or modulator) and at the IF shaping filter in the receiver (or demodulator). Upper sidebands between 0.5 and 1.0 MHz above the visual carrier also are generally susceptible to phase errors, but only at the receiver (or demodulator).

Figure 7 is a computer plot of the Fourier series for a 100 kHz square wave, with linear (i.e. correct) phase and 4.1



Computer plot. 100 kHz square wave.
Linear phase. 4.1 MHz bandwidth.
Source: Wilfred L. Hand 1970 (Ref. 3)

Figure 7



Computer plot. 100 kHz square wave.
Time delay as above. 4.1 MHz bandwidth.
Source: Wilfred L. Hand 1970 (Ref. 3)

Figure 8

MHz bandwidth The square wave, used for the calculation has zero risetime, with considerable energy remaining beyond the 4.1 MHz cutoff.[3] Had the sides of the square wave been 2T sine-squared, there would have been no ripple or ringing (this is why some character generators with steep risetimes, produce considerable ringing).

The time delay (related to the phase) of the Fourier terms below 1 MHz was then altered, as shown at the top of Figure 8, and the Fourier series recalculated. The result of the non-linear delay is a pre-shoot at the leading edge, and an overshoot at the trailing edge. Real world non-linear delays are more complex than was assumed for the computer plots. Nevertheless, Figure 8 shows how deviations in sideband delay cause the signal to come out of the second detector as a delayed low-level replica of the desired luminance pattern (picture).[4,5,6] That is a euphemism for a "ghost", and because the delay is relatively short, the effect is seen as a "close ghost" (not really "ringing", which is a different phenomenon).

It is possible for phase errors to produce "negative delay"; that is to produce a leading effect rather than trailing. This is sometimes seen as a leading undershoot outlining the left edge of a dark image in white, or a light image in black.

What Can Be Done About It?

The cures for this problem seem to require too much spectrum, are considered too expensive, are not operationally feasible, or simply have not been considered to be important. Full double sideband would clear it up; but we cannot afford the extra bandwidth, at least not for over-the-air broadcasting. Receivers can be designed with negligible phase error; the Tektronix Model 1450 Demodulator is such a receiver but it costs $15,000. Many years ago, we considered time domain equalizers; but because the errors are likely to be different for different combinations of transmitter, modulator and receivers, such a cure is impractical, although it could be effective in individual cases. Figure 9 shows how widely the group delay varies from receiver to receiver in the VSB region below picture carrier.[3]

The situation appears to be improving. Television transmitters are available with low-level intermediate frequency exciters. SAW technology provides much improved phase control in the vestigial sideband region compared with the older type filters operating at high-power. To the extent that SAW technology is also utilized in recent receiver design, another major source of phase error may be brought under control.

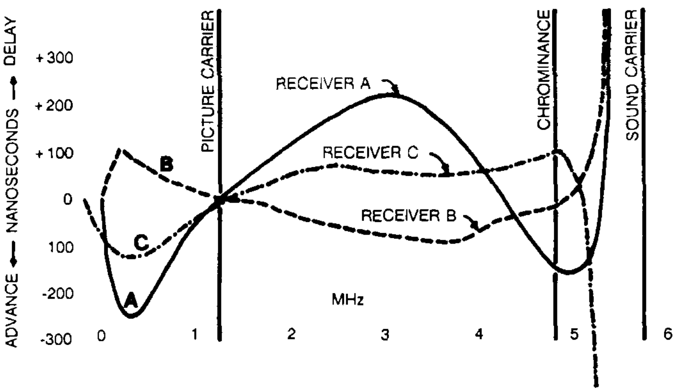


Figure 9

Lack of Awareness

The "close ghost" is still with us, directly off-the-air as well as on cable, although perhaps not quite as often as in the past. I am dismayed by the almost total lack of concern by television broadcast engineers, receiver engineers, and cable TV engineers for this type of picture defect. In 1969, I participated, along with others from NCTA, in the investigation of transmission (and reception) by a subcommittee of well known broadcast television engineers, sponsored by the JCIC (Joint Committee for Intersociety Coordination). We had a fairly elaborate receiving facility with waveform monitor and Polaroid camera set up in a motel room near Ottawa, Illinois. Full field test signals were transmitted after 1 a.m. from the Chicago network stations on channels 2, 5, and 7.

It was illuminating, and yet alarming, to realize that these experienced television broadcast engineers insisted on using a T-pulse instead of a 2T pulse for testing band-limited transmissions. It was discouraging to spend the time and effort (between 1 and 6 a.m.) only to read in the Final Report that the VSB problems we had hoped to quantify had been swept under a rug with "other multi-path effects".

But broadcasters are not the only technicians with tunnel vision on this point. I find that many cable TV personnel, both technical and otherwise, are not even aware of the "halo" effect until I point it out. Fortunately, it seems that the public is also unaware of this defect, and not bothered by it.

Advanced TV and the VSB

How likely is the public to become excited about 500 or 1000 line resolution when they are not even disturbed by the "close ghost"? How can we pump a Super VHS type picture through TV sets that put halos on the pictures? Remember that Super video cassettes can be played to Y and C monitor inputs without encountering the VSB problem. But in cable TV, we cannot get away from the IF shaping in the TV receiver, ahead of the second detector. We cannot correct the group delay ghost created in the subscriber's TV sets. However, we can and should make sure that our modulators and processors, provide as nearly flat group delay characteristics in the VSB region as is technologically and economically feasible. We need to make sure that any filters or traps or other frequency sensitive equipment do not distort the group delay in the sensitive vestigial sideband region.

But, how can we tell our customers that their TV sets are to blame for the edge effect, or halo, on our cable delivered pictures when they can see Super VHS (with Y/C input) on the same TV sets without such defects?

A Suggestion

We would be far better off if we were to transmit programs on coaxial cable (or optical fiber) with frequency modulation. We have the bandwidth to do it. The demodulated composite video signal could then be separated into Y and C components, just like Super VHS. Then the improved NTSC baseband techniques would really become effective. We would have totally by-passed the VSB problem.

What we need however, is a $25 frequency modulator, and a $35 FM demodulator. Don't laugh. For many years, a $5 AM modulator chip has been available for use with games, computers and VCRs. Why not FM?

Envelope Delay Pre-Correction

With the excellent hindsight afforded by 35 years of experience with NTSC, it seems clear (at least to me) that NTSC made a significant mistake in assuming that: "Past experience indicates that the envelope delays of color receivers will be sufficiently similar for the concept of the average receiver to be useful".[7] Based on this assumption, NTSC recommended the envelope delay pre-correction standard set forth in FCC RR 73.687(a)(3) (Figure 10).

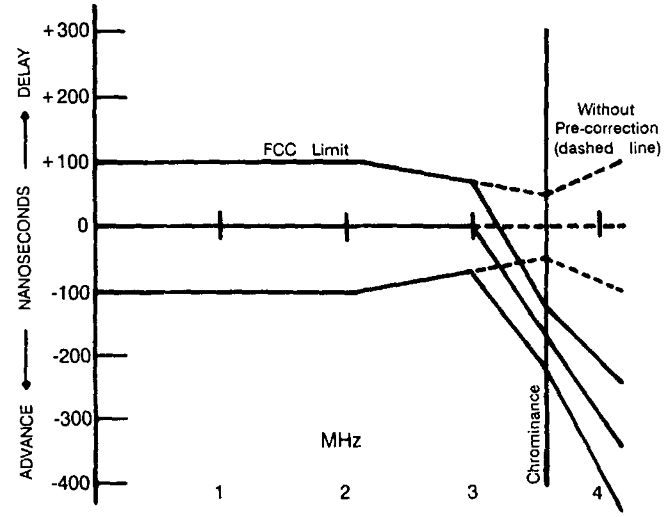


Figure 10

Unfortunately, there is no such "average receiver" group delay characteristic. Figure 9 shows the group delay measured on several 1970 vintage TV receivers (manufacturer not identified).[3] At that time, these receiver characteristics bore no resemblance to the FCC pre-correction curve. Today, SAW technology provides considerably tighter phase control, but even modern receivers probably do not conform with the 1954 NTSC idea of the "average receiver". Actually, pre-correction makes the large negative delay in receiver A even worse; and receivers B and C are reasonably close without any pre-correction.

Group delay errors at the chrominance sub-carrier frequency are most obviously the cause of color misregistration, sometimes called the "comic book effect". However, non-linear delays may also cause chroma crosstalk that cannot be corrected by such post-detection circuitry as comb-filters.

Further Suggestions

It is therefore, quite clear that group delay errors, in the vestigial sidebands and the chroma sidebands, will present serious obstacles to improving or enhancing NTSC video performance. I suggested above that the vestigial sideband problem could be by-passed by using frequency modulation for TV signals on our cables, providing someone finds out how to produce low enough cost FM modulators and demodulators to be included in the set-top interface at customer outlets. This would also greatly alleviate the chroma group delay problem.

There is no way broadcasting can shift its present terrestrial operation to FM. Therefore, in my opinion, it would be most desirable to delete the pre-correction requirement from the NTSC/FCC standards. With reasonably flat transmitted delay between 200 kHz and 4.0 MHz, receivers could be adjusted empirically to display pictures without serious chroma delay or crosstalk. As matters now stand, receiver designers really do not know what kind of signal consumers will receive. The receiver is often adjusted to match whatever signal is available, frequently improperly.

For improved NTSC, cable operators may have to devise sound notch phase equalizers, not only for processors and modulators, but for the bi-directional filters as well, so that we can maintain reasonably flat group delay, perhaps within 25, or at most 50 nanoseconds.

Conclusion

Extensive activity currently directed toward improving the NTSC color standard has been largely confined to the video baseband. These efforts will almost certainly be frustrated unless the NTSC radio frequency specifications are either more tightly controlled or appropriately modified, at both the transmitter and receiver. Otherwise, baseband improvements will surely be masked by:

(a) "close ghosts" and other luminance edge effects caused by group delay errors in the vestigial sideband region above and below the visual carrier; and

(b) chroma delay or cross-talk caused by improperly corrected group delay errors in the chrominance region. ■

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About The Author

Archer S. Taylor is a principal and co-founder of Malarkey-Taylor Associates, Inc. and its Senior Vice President, Engineering. He is a founder and pioneer in the field of cable television, having shared in building the first cable television system in the State of Montana in 1953. Mr. Taylor has maintained a professional practice as a consulting engineer for the broadcast and cable industries since 1944.

He was on the Board of Directors of The National Cable Television Association (NCTA) for six years. He served as National Vice Chairman, former Chairman NCTA Educational TV Policy Committee, and former Chairman of the NCTA Engineering Committee which developed many of the procedures adopted in the FCC rules and regulations.

He was Alternate Chairman of the Cable Television Advisory Committee (CTAC) which made engineering recommendations to the Federal Communications Commission concerning regulatory standards of good engineering practice. He was Chairman of the CTAC Panel on Picture Quality.

He is a Past President, Board of Governors of the Broadcast, Cable, and Consumer Electronics Society of the Institute of Electrical and Electronics Engineers (IEEE), a Fellow and Life Member of IEEE, Fellow Member, SCTE (UK), and Senior Member, SCTE (USA).

He also writes a monthly column entitled "My Turn" for CED magazine, on a variety of mostly technical issues.