App Note 3551: Conditioning A/V Signals for RF Modulation

Even as display devices move toward digital video, they retain the legacy of an RF-modulated analog TV output. That output is specified in the US by the National Television Standards Committee (NTSC), and utilized in security applications and in the Digital Video Broadcasting (DVB) Project as specified by the European TV standard phase alternation line (PAL). All modulators, whether simple analog types or single-chip synthesizers, require properly conditioned audio and video input signals.

Despite the need for an integrated circuit, the ubiquitous interface between the modulator and audio/video (A/V) signals has not yet been reduced to an IC. The main reasons for that deficiency are the difficulty of such a design, the variations required for different standards, and the variable levels required by the modulator itself. The alternative to an IC interface is a discrete design.

The signal-conditioning requirements include lowpass and notch filtering of the video, group-delay compensation for the video, preemphasis for the audio, and (to adjust the modulation level) level controls for both audio and video. Because many cable and satellite receivers, VCRs, DVDs, and TVs do not fully comply with these signal-conditioning requirements, the modulated signals of channels 3 and 4 have poorer quality than that of the baseband composite (Cvbs). The following discussion explains the interface requirements and how to meet them using standard op amps and discrete components. The resulting low-cost circuitry can also provide rear-panel outputs for most A/V appliances.

Requirements and Concerns

For driving RF modulators in NTSC and PAL systems, the allowable video group-delay variation and required audio preemphasis are clearly specified by Recommendation ITU-R BT.470-6. Most of the other indistinct specifications are summarized and extrapolated to include other, unstated design specifications in **Tables 1 and 2**. Table content is based on typical back-panel outputs for a TV, DVD, or set-top box having both baseband and RF-modulated A/V outputs (**Figure 1**).
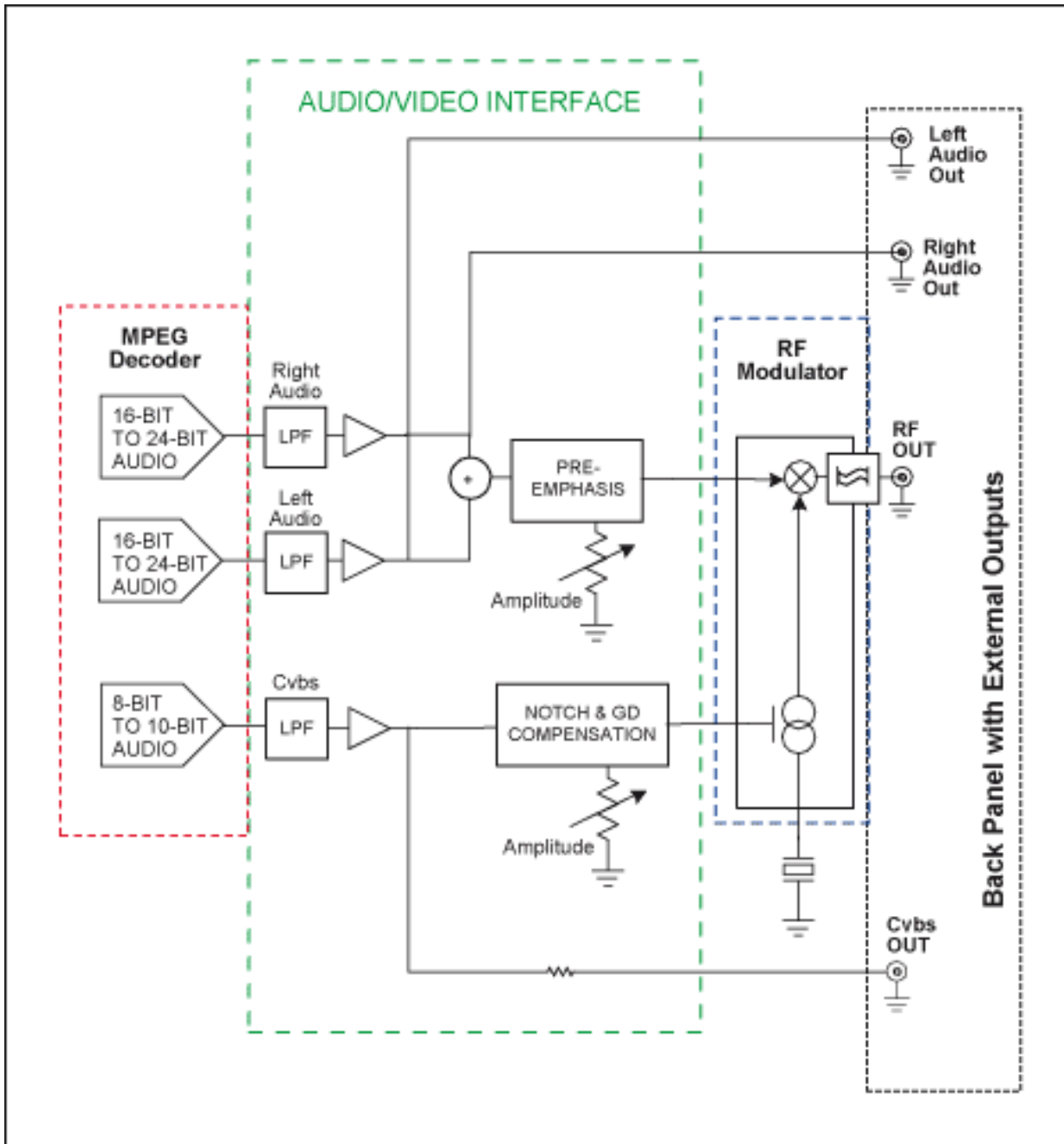
Figure 1. Block Diagram of A/V Signal Conditioning to Drive an RF Modulator.

Table 1. Audio Requirements from ITU-R BT.470-6

Audio	NTSC	PAL
Level at Rear Panel	$2V_{RMS}$	$2V_{RMS}$
LP Bandwidth	20kHz	20kHz
Preemphasis	75µs	50µs
FM Bandwidth	F_{ac} ±25kHz	F_{ac} ±50kHz

Table 2. Video Requirements from ITU-R BT.470-6

Video	NTSC	PAL

Level at Rear Panel	$1V_{P-P}$	$1V_{P-P}$
Color Subcarrier (F_{sc})	3.58MHz	4.43MHz
Color Subcarrier Bandwidth	F_{sc} +620kHz F_{sc} -1300kHz	F_{sc} +600kHz F_{sc} -1300kHz
Audio Subcarrier (F_{ac})	4.5MHz	5.5MHz
LP Bandwidth, -3dB	4.2MHz	5.0MHz
Notch Bandwidth, -3dB	600kHz	600kHz
Notch Bandwidth, -15dB	50kHz	50kHz
Notch Depth at F_{ac} ±25kHz	-15dB (min)	-15dB (min)
Group Delay at F_{sc}	170ns (typ)	170ns (typ)
Group Delay Variation	Note 1	Note 1

Note 1: See Figure 3 of ITU-R BT.470-6.

Some of these requirements depend on the source. If the signals to the modulator come from a DAC, for example, they obviously need reconstruction filtering to prevent out-of-band modulation, and to remove artifacts, noise, and aliased signals. Generally, they must also be amplified to compensate for back-terminated loads and variation in the DAC outputs.

The requirement to notch-filter the video around the audio subcarrier is not stated, but implied by the group-delay adjustment described in Figure 3 of ITU-R BT.470-6. Such notch filtering is usually recommended for modulator chips. Also requiring attenuation are the rear-panel signals, whose output levels are typically higher than required for the modulator inputs. These conditions lead to requirements for the A/V interface of Figure 1:

- A lowpass reconstruction filter for A/V outputs generated by DACs

- A sound-subcarrier bandstop or notch filter, centered on the sound subcarrier; this filtering causes a large variation in group delay near the notch frequency[1]

- Group-delay compensation to meet the profile in Figure 3 of ITU-R BT.470-6, as determined by that standard

- Summing of right and left channels to form monaural audio (necessary only when putting stereo outputs into a monaural modulator)

- Audio preemphasis, as determined by the ITU-R BT.470-6 standard (Table 1)

- Adjustable A/V amplitude to set the modulation index as determined by the ITU-R BT.470-6 standard and the modulator chip used

Start by Filtering

The first thing to be done is lowpass-reconstruction filtering to suppress aliased outputs and out-of-band noise in the modulator's audio and video inputs. Active filters for that purpose allow the increase of the DAC output to standard levels, while driving the rear panel and the RF modulator.

Audio adjustment requires a lowpass filter (LPF) with a -3dB point of 22kHz to 24kHz, and enough gain to produce $2V_{RMS}$ at the rear panel. We assume a gain of two and, because audio is highly oversampled, the requirement can be met with a single passive RC filter. As explained later, the second RC filter is for the audio modulator, not

reconstruction. The **Figure 2** circuit drives the rear-panel outputs and the input to the audio portion of the RF modulator.
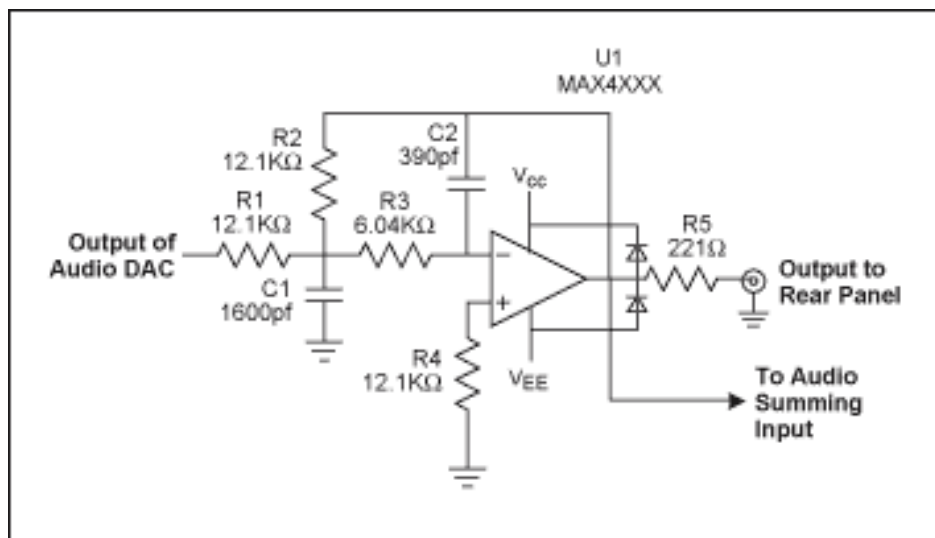

Figure 2. Pole Reconstruction and Noise Filter with Gain of 2V/V for Audio Outputs.

Video adjustment is more difficult. It is not highly oversampled and, therefore, requires at least a three-pole reconstruction filter. If this filter causes excessive group-delay variation, you must compensate for it and add gain to make up for variations in the video DAC output and back-termination loss. Again, the best solution is an active filter. A suggested design for NTSC or PAL[2] applications is shown in **Figure 3**. Benefits of this design are adjustable group delay (using R8), and the ability to drive the rear panel as well as the input to the video portion of the RF modulator. You can address multiple outputs such as composite video and S-video by combining the active filter with a triple or quad op amp (like the MAX4382 or MAX4383).
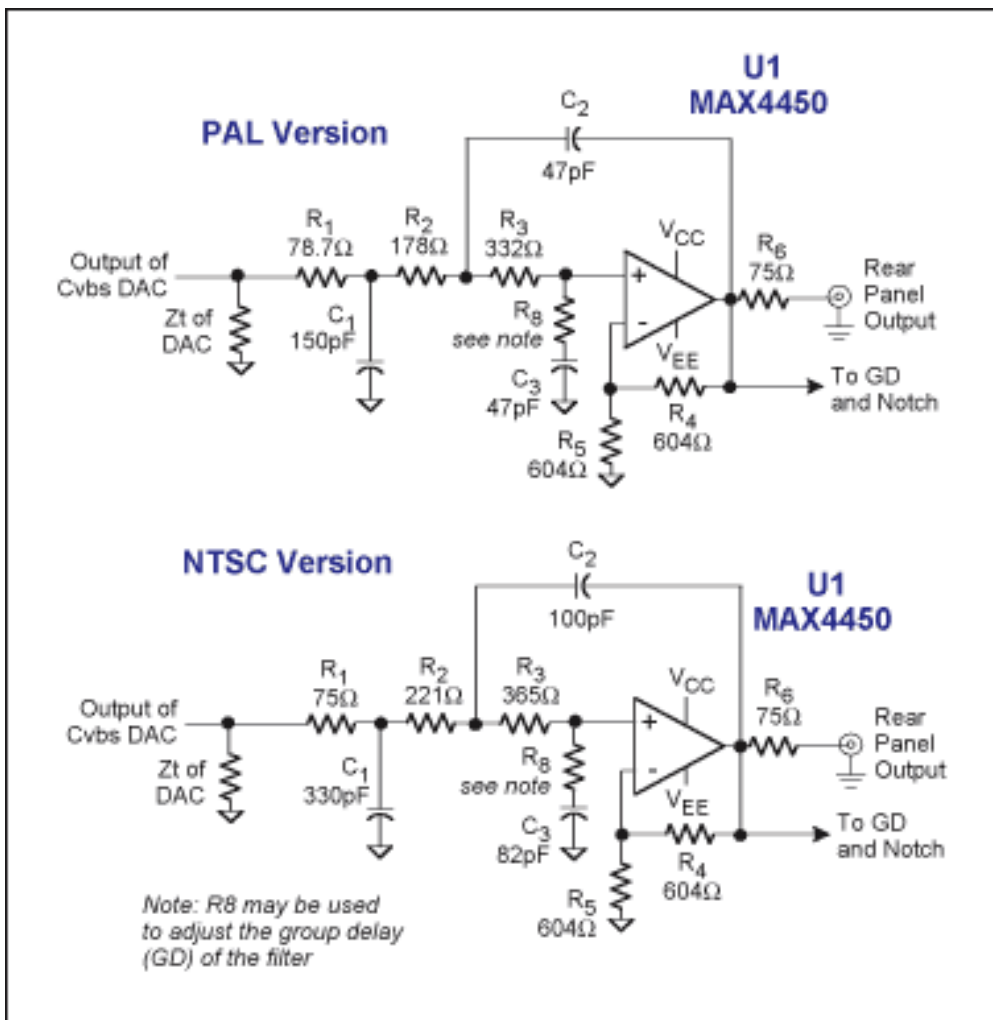
Figure 3. NTSC and PAL Reconstruction Filters.

Audio-Modulator Signal Conditioning

The first step in signal conditioning for the audio modulator is to sum the left and right stereo channels into a single channel and reduce their amplitudes[3]. Next, add a buffer with preemphasis network[4] to boost the high frequencies. A low-cost method for boosting high frequencies (**Figure 4**) employs a resistive-tee network with variable resistance to ground. Thus, the left and right audio signals are summed by R1 and R2 into the sum of R3 and R4. R3 adjusts the level, and R4 sets the maximum attenuation.
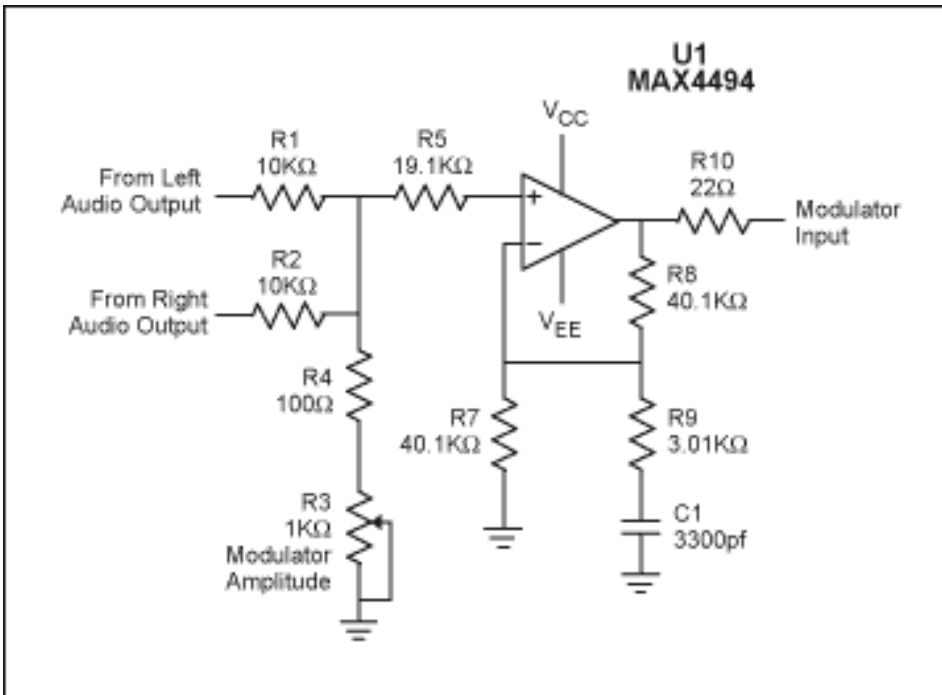
Figure 4. Summing Network with Attenuation and Preemphasis for Audio-Modulator Drive.

The preemphasis network is a lead-lag network formed around the op amp by R7, R8, R9 and C1. This network's time constant is t = 2π(R7R8/R7 + R8) + R9C1, or 75µs (~2100Hz) for NTSC. To modify the circuit for PAL systems, change the value of R7/R8/R9 and/or C1 to achieve a 50µs time constant. R5 balances the offset voltage caused by the input and bias currents, and R10 isolates the output from excessive capacitive loads.

Note that, to prevent overmodulation by the boosted frequencies, the Figure 4 preemphasis is essentially removed by the second pole in the audio-reconstruction filter. This action is called "roofed" preemphasis. As a note of caution, increasing the LPF bandwidth can cause overmodulation if the audio DAC signal includes significant out-of-band noise. The tradeoff is a separate audio-reconstruction filter for the modulator and the rear-panel outputs.

Video-Modulator Signal Conditioning

The next step is conditioning the video. We must apply a notch or bandstop filter to the composite video near the FM-sound subcarrier to prevent interference when that subcarrier is combined with the video. The sound subcarrier is just above the color subcarrier, and the group-delay variation caused by notch filtering is several hundred nanoseconds. Notch filtering causes color to change by altering the color-subcarrier phase. To correct it, several first-order delay stages must be added. To reduce the number of stages in this case, we use second-order LC circuits, rather than RC circuits, for the notch filter and group-delay compensation (**Figure 5**). This example is for NTSC applications, but is also suitable for PAL systems after some adjustment in component values.
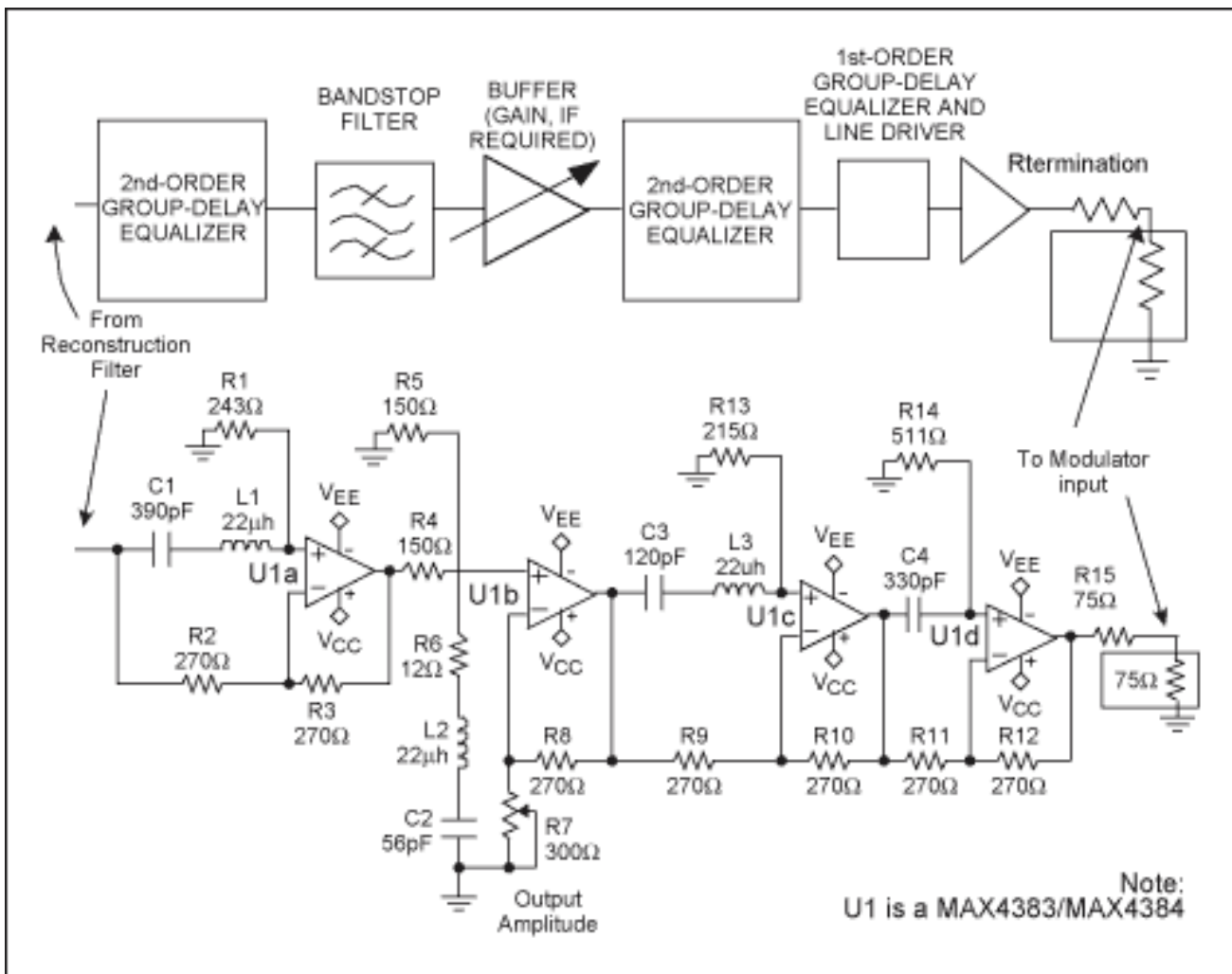
Figure 5. Block Diagram and Schematic of NTSC Bandstop Filter and Delay Equalizer.

The second-order equalizer stage uses R2 and R3 to set the gain, L1 and C1 to set the frequency, and R1 to set the Q of a second-order allpass network. L1 is a standard 22µH inductor from SMD. C1 is adjusted to set the frequency, and R1 is adjusted to set the Q and group delay. This stage sets the GD at slightly less than the peak value of GD produced by the notch filter.

The center frequency of the LC bandstop filter is set by:

$$F_{AC} = 1/\sqrt{L2\,C2}$$

Bandwidth (BW) or loaded Q is set by the equivalent resistance (R_{eq}) and inductive reactance (XI):

$Q = R_{eq}/Xl = (R4R5/R4+R5) + R6/2\pi L2 = F_{ac}/BW$

We know L2 and F_{ac}, and the BW we need is 3.58MHz + 620kHz = 4.2MHz. F_{ac} is 4.5MHz, so the BW is ±300kHz, or 600kHz from Table 2. Therefore,

$Q = 4.5MHz/600kHz = 7.5$

Choosing L2 and solving for R_{eq}, we get 622Ω/7.5 = 83Ω. Using 150Ω for R4 and R5, and R6 as a trimmer, the R4-

R5 divider attenuates the input by -6dB. The tolerance of L2 is compensated by adjusting C2 only.

U1b forms a buffer with adjustable gain set by R7 and R8, which prevents loading the prior stage. If no gain is required, you can prevent oscillation[5] by removing R7 and lowering the R8 value to 22Ω. This modification and the attenuator in the prior stage allow the output level to be adjusted to match the modulator and set the modulation index.

The next second-order equalizer stage is similar to the first, only higher in frequency and lower in Q. The frequency is adjusted with C3, and Q with R13. The gain is set to 1V/V by R9 and R10 around U1c.

The final stage is a first-order equalizer and line driver, in which R14 and C4 set the delay, and R11 and R12 set unity gain. R15 back-terminates the output into a 75Ω load. The group delay and notch characteristics are shown in **Figure 6**, though not the reconstruction filter.
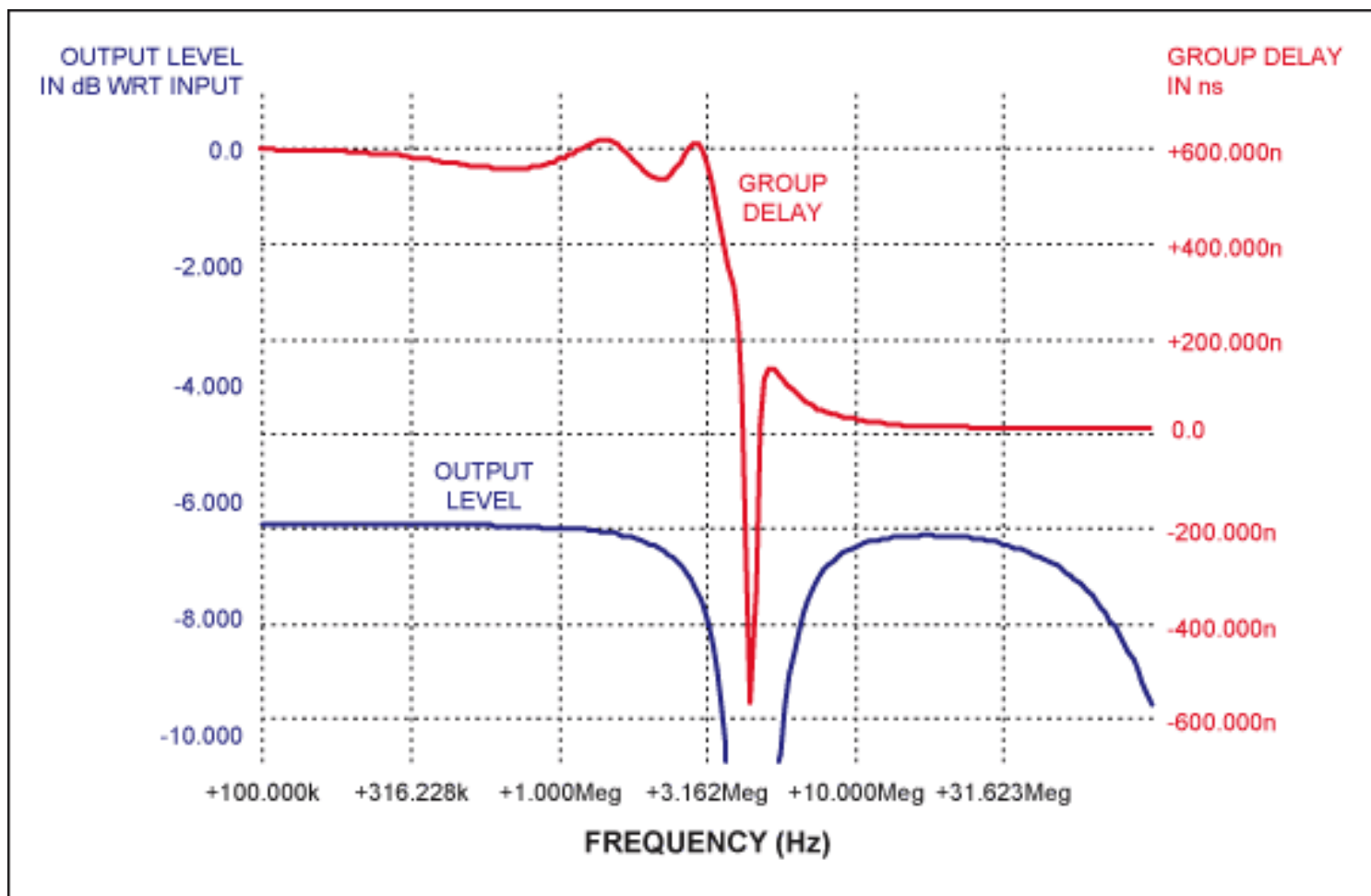

Figure 6. Gain and Group Delay of the Notch Filter and GD Compensation.

Once you've selected the audio and video DACs, or the MPEG decoder and modulator IC, many of the adjustments can be implemented with fixed-value components in the final design. Some values may need adjustment due to layout and parasitic effects. Despite the difficulties in such a design, you can design an A/V interface using op amps and discrete components that will drive baseband outputs on the rear panel as well as on the RF modulator. The benefits are:

- Low-cost, flexible design using standard components

- Minimum number of adjustments

- Meets the requirements of Recommendation ITU-R BT.470-6

- Can be used with any combination of MPEG decoder and RF modulator

- Can be used for NTSC or PAL applications

Notes

[1]To make this compensation possible, both NTSC and PAL place the sound subcarrier above the video's minimum -3dB bandwidth.

[2] See Maxim application note "5MHz, 3-Pole, Low-Pass Filter plus Video Line Driver for Consumer Video Applications"

[3]Some stereo modulators with separate left and right inputs don't require summing the audio. Those require two stages for left and right, as in Figure 4.

[4] http://perso.wanadoo.fr/jf.fourcadier/television/preaccentuation/preaccentuation_e.htm

[5]MAX4380 - MAX4383 datasheet