# A phase locked fiber optic system using FM modulation AN1434

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## SYSTEM OPERATION SUMMARY

The purpose of the fiber link is to transmit broadband video and sound over moderate distances (2.5km) with existing low cost components and minimal complexity.

Figure 1 depicts a complete system implementation. The application makes use of a very wideband VCO to generate an FM modulated carrier at 28.6MHz followed by a fast TTL LED driver to emit saturated 850nm light signals for entry in to the glass fiber. A PIN diode receiver is coupled to a 140MHz bandwidth transimpedance preamplifier for increasing the detected signal amplitude and then fed to a phase-locked loop demodulator for recovering the original modulation signals.

The wideband FM sound subcarrier (150kHz deviation) is summed with baseband video at 10.7MHz and transmitted at a reduced level relative to the 3.58MHz color reference signal. Cross modulation between sound and picture information is minimized in this way. FM demodulation of the sound subcarrier is accomplished after passing through an IF gain block by a quadrature-type phase discriminator. The present sound circuit does not automatically frequency-lock to the transmitted subcarrier, but is fixed-tuned to 10.7MHz. A tracking PLL sound demodulator could be used to eliminate drift problems between transmitted sound subcarrier and the receiver in future designs.

## SYSTEM DESCRIPTION AND OPERATION

### Transmitter Unit: Video Channel

The transmitter circuit consists of a wideband differential amplifier (NE592), a VCO (NE564) and an LED driver, the NE522 high speed comparator (see Figure 2) The video signal is AC coupled into the modulator preamplifier and followed by a sync tip clamp to provide DC restoration of the composite video signal and to prevent variation of modulation deviation with varying picture content. (A complete video clamp and sync processor may be designed using the TDA9045 and TDA2595 combination. This particular application was not tested at the time of this publication.)

A video signal level of 250 to 300mV peak is required to maintain optimum picture modulation. Since there is no AGC circuit in this particular design, this is a critical parameter and must be con- trolled to prevent over-modulation and picture degradation. Addition of an AGC using the above-mentioned parts would be a definite improvement for varying input level video. Using the present limited design, however, -10dB of attenuation was used with a 1V peak NTSC signal source at 75$\Omega$. This is the common level available from most standard video signal systems.

Frequency compensation (pre-emphasis) is inserted in the form of a passive RC lead network at the Pin 14 input to the NE592 differential amplifier. This compensates for degenerative frequency distortion and provides better color balance in transmission.

The main FM modulator consists of an NE564 used only as a linear wideband VCO. The other sections of the device are not used. Differential DC coupling to the VCO terminals is attained via the loop filter terminals, Pins 4 and 5. The NE564 VCO is designed as a differential current controlled balanced multivibrator. It possesses an extremely linear transfer function as illustrated in Figure 3. The graph shows how the VCO frequency varies with applied DC voltage across Pins 4 and 5. The VCO center frequency is determined by value of the capacitance across Pins 12 and 13. In this particular example, the transmitter operates at 14.3MHz with the VCO set to 26.6MHz.

The slope of the VCO transfer function is termed $K_O$ and is measured in radians per second per volt or simply Herz per volt. Thus, to obtain the magnitude of the differential voltage for a given frequency deviation the relationship below is used:

$$V_{D(voltsDC)} = \frac{\Delta f}{k_O} \frac{MHz}{MHz/V}$$
$$I_{B2} = \text{Constant}$$

$K_O$ is dependent upon the control bias generator current at Pin 2 as is noted from the graph. Higher current into Pin 2 results in a higher conversion gain, $K_O$. For a center frequency of 1MHz and an 800$\mu$A bias current into Pin 2, $K_O$ is 1.7MHz/V across Pins 4 and 5 ($V_O$).

The value of $K_O$ also increases linearity with center frequency so that at 30MHz $K_O$ becomes 30X 1.7 or 51MHz/V. Note that in this application the bias current is set at 320$\mu$A; that is the device is sinking current into Pin 2. This lowers $K_O$ below the given value for 800$\mu$A shown on the graph in Figure 3 and requires a higher number of V/MHz to modulate the VCO. The signal to the VCO is DC coupled from the differential output of the NE592 in order to preserve bandwidth and to maintain proper biasing relative to the NE564.

### Setting FM Deviation

In order to calculate the approximate frequency deviation, a linear relationship between $\Delta K_O$ and $\Delta I_{B2}$ is assumed. The value of $K_O$ for a Pin 2 bias of 320$\mu$A is determined by the following relationship:

$$k_O = \left[\frac{(1.7 - 0.95) \cdot 320}{2 \cdot 800} + 0.95\right] \text{MHz/Volt}$$

= 1.1MHz/V@1MHz

= 33MHz/V@30MHz

The measured differential voltage between Pins 4 and 5 for normal operating signal levels and standard NTSC color bars transmitted is 80mV$_{P-P}$. The estimated total deviation is then 1.3MHz. This results in a Video channel bandwidth for the 3.58MHz color signal of approximately:

= 2(1.3 + 3.58)MHz

= 9.8MHz

This is rather a small deviation for wideband video transmission and the decision was made to use the 2nd harmonic of the fundamental VCO frequency to obtain twice the deviation. The VCO modulator is then set at an $I_B$ of 320$\mu$A which provides sufficient 2nd harmonic content for this to operate successfully. This is shown in Figure 5 with the fundamental at 14.3MHz with the middle spectral plot showing required 28.6MHz carrier harmonic with improved deviation ratio.

#### Total FM Signal Bandwidth

For a total video bandwidth of 4.2MHz the transmission bandwidth is:
BW = 2x2(1.3 + 4.2) = 22MHz

Note that a bandpass filter could be installed in the signal path between the NE592 preamp/buffer to reduce noise bandwidth, but this improvement was not tried. Adequate signal space for the baseband video and the 10.7MHz subcarrier would be 11MHz. (Filter characteristics must provide good differential gain and phase response.)

A second bandpass filter could be added in the path between the modulator and the LED driver stage (22MHz bandwidth). This would improve the overall video signal-to-noise ratio.

The NE592 is biased with +5V and -1.8V to achieve the critical dynamic swing to properly slew the VCO over the required range without sacrificing faithful waveform reproduction in the transformation to linear FM modulation. Video signals contain both very low and high frequencies which are transient and phase sensitive. The unused input pins to the phase detector, Pins 6 and 7 bypassed to ground. Pin 3 is grounded.

The 28.6MHz FM signal from the NE564 is taken from the Pin 9 open collector VCO output port which requires a 470Ω pull-up resistor to 5V. A100Ω resistor is added to Pin 11 to improve the fall time of the output waveform. The signal is then fed into the NE522 (74F3040) high speed comparator where a threshold level is set up on the inverting terminal to provide duty cycle adjustment and noise threshold. The NE522 has an open collector output which lends itself easily to driving the LED transmitter diode (CQF24); the 74F3040 has a source-sink output stage which requires that the LED be connected as shown in Figure 2a.

The CQF24 generates 100μW of 850nm optical energy with a typical rise and fall time of 10ns. It is rated at 250mW dissipation and 100mA continuous current.

Spectral frequency plots taken under normal operating conditions with NTSC color bar signal input for the sections of the transmitter described above appear in Figures 4 through 6.

### The Sound Channel

As shown in the block diagram in Figure 2, audio input is fed through a 2:1 compressor which consist of the NE575 low voltage compandor. This device compresses all audio signals according to the transfer function shown in Figure 7. It is required to limit the peak FM deviation for the10.7MHz VCO to ±75kHz for 0dBV input ($1V_{IN}$ 600Ω RMS). Audio compression also improves intelligibility in systems with limited signal-to-noise ratio. This device, NE575, operates at unity gain for an input level of $100mV_{RMS}$ audio input which is 0dB for the NE575. The 2:1 compression factor refers to the AC signal level in dB above or below $100mV_{RMS}$.[2] Output from the NE575 is fed to the second NE564 modulator with a VCO center frequency set at 10.7MHz. Refer to Figure 8 for typical circuit diagram. The 10.7MHz subcarrier is fed to the NE592 for summing with the main baseband video signal. The level of the sound subcarrier is adjusted to a level 20dB below the 3.58MHz color video sideband (28.6MHz signal) by adjustment of the output level potentiometer at the emitter follower, Q1 (see Figure 9). This can be accomplished most easily by monitoring the combined 28.6MHz signal from the main modulator (Pin 9 NE564) using a spectrum analyzer. The 10.7MHz carrier deviation is adjusted using 0dBm ($775mV_{RMS}$ into 600Ω) input to the compressor at 1kHz and adjusting the deviation with the input potentiometer, R7, which feeds the NE564 (see Figure 9 for the 10.7MHz schematic). Figure 10 displays the proper frequency deviation spectrum as set by the R7 adjustment. A 0dBm (775mV) input to the compressor is 16dB above the compandor 100mV reference level and the compressor will reduce this +18dB input level to approximately $260mV_{RMS}$ at the NE5750 output on Pin14. The pot. R7, provides the calibration adjustment for maximum 10.7MHz deviation.

The actual 10.7MHz level to the 30MHz modulator is set by pot R6 and is adjusted by monitoring the spectral level at the output, Pin 9, of the NE564 with a spectrum analyzer. The relative sound carrier (lower 28.6MHz sideband) is set approximately 20dB below the 3.58MHz color reference signal. This is accomplished by first noting the sideband level of the video information (Figure 5), removing the video modulation and setting the 10.7MHz level with R8 on the sound modulator board.

## The Receiver Unit

Light energy from the fiber optic cable is fed to the BPF24 PIN diode and transformed to a small current typically in the 1 to 5μA range. This photodiode current carries all of the FM carrier information in the signal bandwidth of approximately 22MHz centered at 28.6MHz. The photo- current is now amplified and transformed into a differential signal voltage by the NE5212 transimpedance amplifier (Pin 1 input). In this particular application, however, the output is not used differentially, but a single-ended signal is taken from Pin 5 of the NE5212 and AC coupled to Pin 6 of the NE564.

The NE5212 has a differential transresistance of 14k. This translates to 14μV/mA of input current, yielding 35mV of differential output voltage for 2.5μA input current. Since the device is used single ended, only half, or 17.5mV, output is available to drive the phase detector of the NE564. (See Figure 12 for actual output signal from NE5212). The low signal level input to the PLL makes it necessary to run the gain setting bias at a higher level than usual; this, in addition to the wide bandwidth, requires a bias current of 2.2mA sinking into Pin 2 of the NE564. Another modification to the nominal NE564 operating conditions is the choice of a higher supply voltage on the phase detector portion of the device (+8V on Pin 1) to increase the linearity and dynamic range for fast video signals. The VCO section is supplied from +8V through a 200Ω dropping resistor and operates on 4.5V at Pin 10. (Note that the absolute maximum voltages for the phase detector and VCO are 14 and 6V, respectively).

## VCO Frequency Adjustment

The NE564 receiver PLL is operated at the same frequency as the 2nd harmonic of the transmitter fundamental 28.6MHz. Prior to making any adjustments, the bias current to Pi n 2 is set to 2.2mA. The spectrum of the receiver VCO without a fiber link signal, fiber disconnected, is shown in Figure 13. When making the initial center frequency adjustment to the VCO trimmer cap (NE564 Pin 12, 13, 2-20pF) the fiber cable is disconnected. (Note that a thermal stabilization time of 1 hour is recommended prior to any transmitter or receiver calibration adjustments.)

With the link connected and a proper signal present at the input to the NE554 Pin 5, the PLL will lock onto and track the incoming wideband FM signal. (See Figure 14 for VCO spectrum.) Note that the unwanted harmonic signals number one and three have not been filtered out in this application example.

The demodulated baseband video plus 10.7MHz signal then appears on the analog output port, Pin14. A wideband amplifier with low differential gain and phase error (NE5539) is used to boost the combined signal with the composite video level raised to 1V peak into 7Ω. The actual measured value of the video using an NTSC color bar signal is $1V_{P-P}$ on the output port. The NE554 output to the NE564 from Pin14 is $250mV_{P-P}$.

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Figure 15 shows the composite baseband video plus 10.7MHz subcarrier spectrum.

The final stage of the video channel is the NE5539 which drives directly into the video monitor. Biasing the DC offset of the postamplifier is necessary to prevent sync distortion and optimum video response. This is accomplished by adjusting R2 (1MΩ pot on Pin 1 of NE5539) for 0V average at the output. Note that a lead-lag network is connected across Pins 1 and 14 to stabilize the op amp which has a closed loop bandwidth of approximately100MHz for a closed loop gain of 4. This excessive bandwidth creates noise in the picture information and is reduced by the 20pF capacitor from Pin 12 to 14. (See Figure 11.)

## Sound Channel Operation and Adjustment

A portion of the output signal from the NE5539 is also sent to the NE604A to be amplified and demodulated (see Figure 5).
The composite signal contains both the video and the 10.7MHz subcarrier. A ceramic 10.7MHz bandpass filter is used before the NE604A to remove all but the subcarrier. The NE604A contains a high gain IF amplifier and an LC quadrature detector for demodulating the FM sound Information.

Adjustment of the sound channel Is carried out after the system has been on for one hour to allow thermal stabilization. A 1kHz test signal is injected into the audio input port of the NE575 compressor board and set to 775mV$_{RMS}$ terminated in 600Ω. Using a spectrum analyzer adjust R7 while observing the 10.7MHz output on a spectrum analyzer and set the deviation for 150kHZ maximum. At this point make sure that the 10.7MHz VCO (NE564) is on frequency, and make any trim adjustments to the VCO trim capacitor. Finally adjust R8 for a carrier amplitude by monitoring the output of the transmitter VCO lower sideband, and set the10.7MHz signal 20dB below the 3.58MHz sideband relative to 28.6MHz. The last adjustment is the setting of the quadrature coil on the NE604A demodulator for maximum sound with the best signal-to-noise. (Refer to Figure 17 for the input signal spectrum to the NE604A.)

## CONCLUSION

The system example described Is capable of transmitting single channel color video and sound transmission at 850nm with glass or plastic fiber optic cable of $\geq$2.5km. Signal transmission is of adequate quality for Industrial inspection, security and other applications of this limited nature. The most notable feature is its minimal cost. It Is not meant to be used in broadcast quality environments. The user Is invited to make improvements and alterations to the system to attain greater stability and higher quality.

The audio amplifier and control section shown in Figure 1 is not included in this application note. For further detail on the audio portion and applications examples, please refer to Section 7 of the Philips Semiconductors IC-11: General-Purpose Linear ICs.

Suggested areas of improvement are: 1. The addition of bandpass filters to improve transmitter and receiver signal-to-noise; 2. Video sync tip or black level clamp with AGC at transmitter modulation input; 3. Addition of an AGC stage after the receiver transimpedance amplifier to improve optical path dynamic range.

## Power Supply Requirements

The regulated voltages required to operate the system are as follows:

+5.00V

-5.00V

+8.00V

-8.00V

## Test Equipment

1. HP8568B Spectrum Analyzer
2. Tektronix PC6202 FET Probe 10X
3. Philips 5510 Color Generator

## Footnotes

1. Philips Semiconductors Linear Data Manual, Volume 1, Communications, 1987
2. *Ibid.*

## REFERENCES


Roden, Martin S., *Analog and Digital Communications Systems*, 2nd Edition; Prentice Hall, 1985.
Philips Semiconductors, *Linear Data Manual, Volume 1, Communications*, 1987.

1. AN140: Compensation Techniques for Use with the NE/SE5539
2. AN175: Automatic Level Control: NE572
3. AN176: Compandor Cookbook
4. AN179: Circuit Description of the NE564
5. AN1991: Audio Decibel Level Detector with Meter Drive (NE604)

Philips Semiconductors, Linear Data Manual, Volume 3, Communications, 1987.

AN146; Wideband FM Composite Video Fiber Optic Link, Philips Semiconductors 1985

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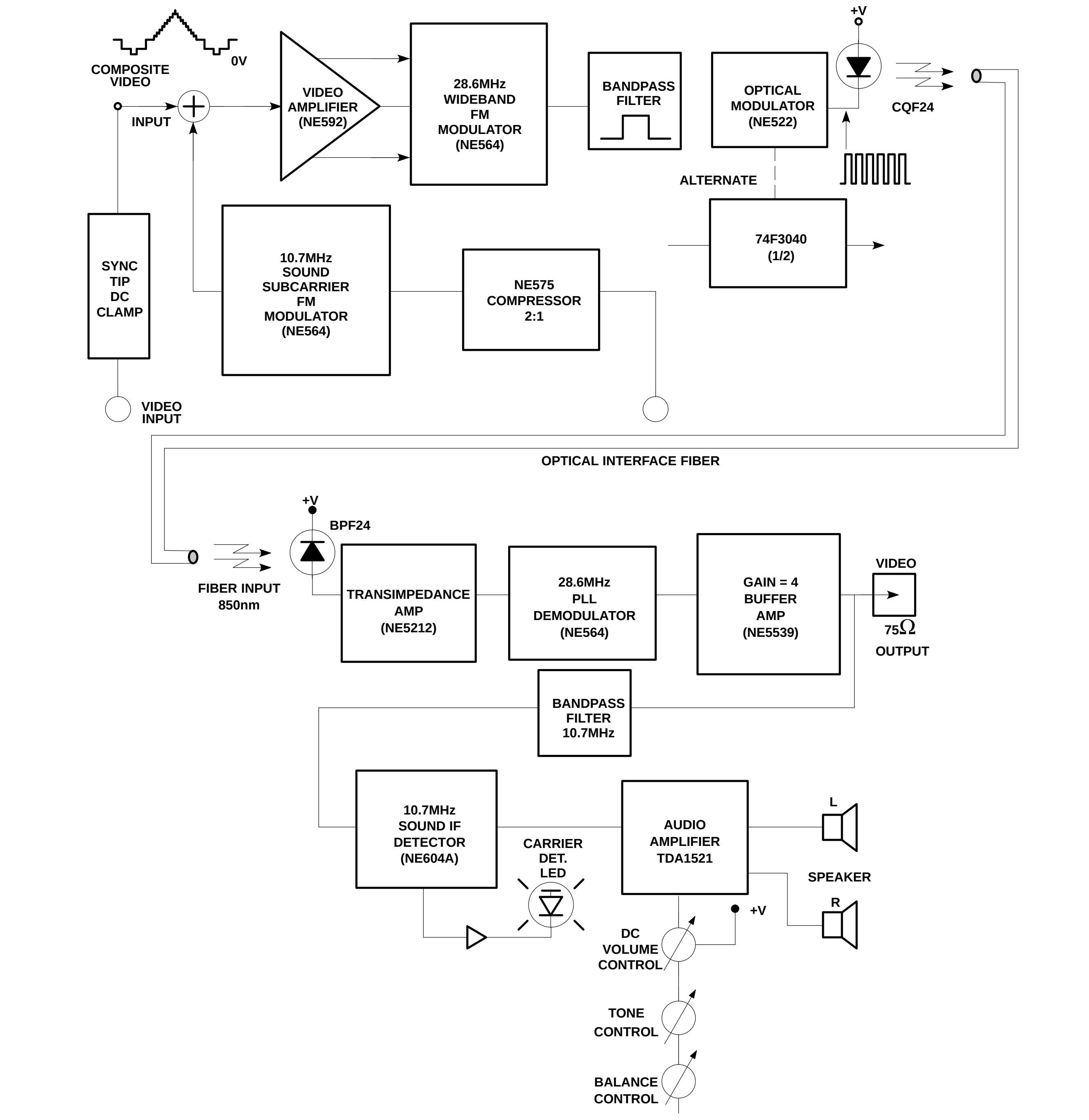


**Figure 1. Video Fiber Transmission System**

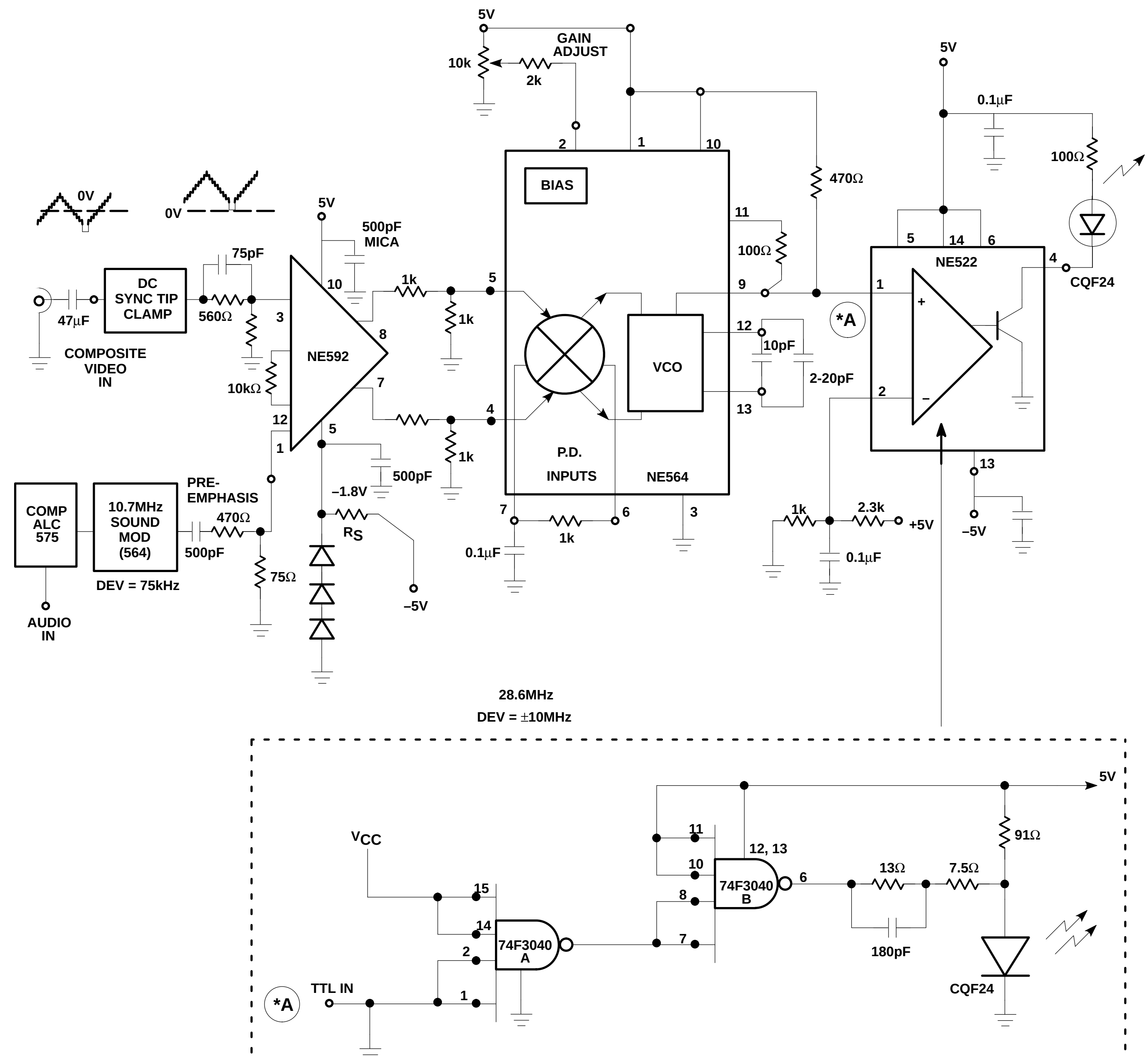


Figure 2a. LED Driver

*NOTE: An alternate LED driver which uses the 74F3040 line driver was incorporated in this particular application example. The 74F3040 has a higher current rating, but not the variable threshold capabilities of the NE522. The LED diode is operated in the saturated on-off mode for best signal-to-noise.

Figure 2. Fiber Optic Transmitter Block Diagram

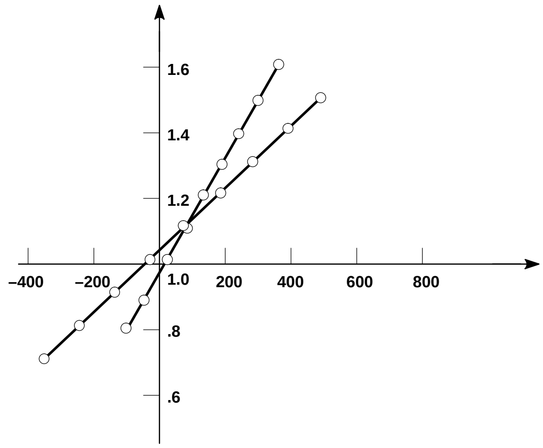


Figure 3. NE564 VCO Transfer Function, $K_O$

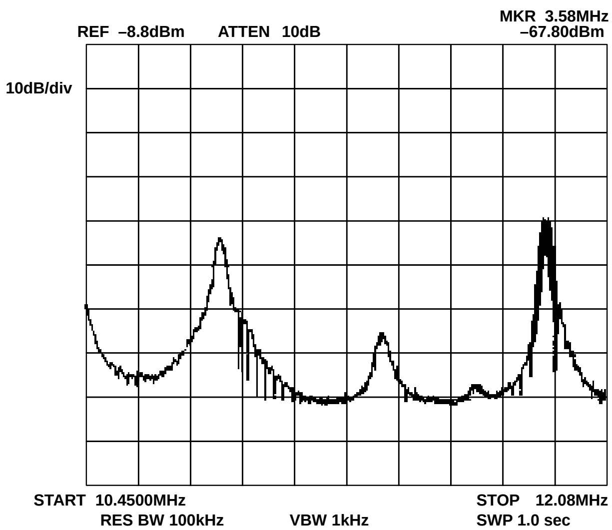


Figure 4. NE592 Output Signal NTSC Video Plus 10.7MHz Subcarrier (Probe 10X ATTN)

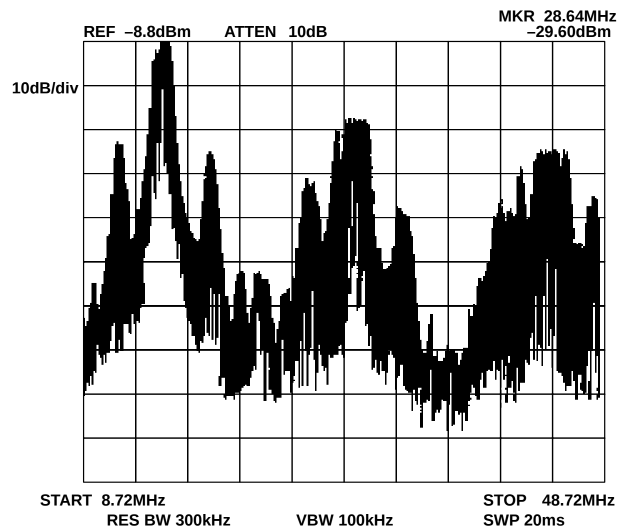


Figure 5. Transmitter PLL Output with NTSC Color Bar Test Pattern Input (Input Video –10dB Attenuation Below 1V Peak) (10X FET Probe at Pin 9 NE564)

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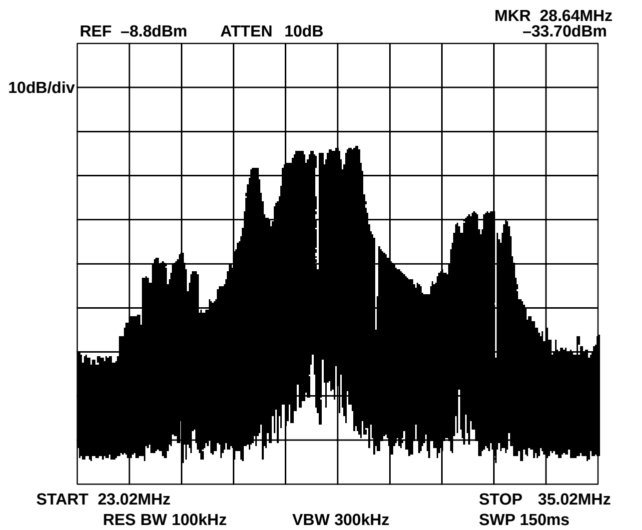


**Figure 6. Transmitter LED Drive Spectrum with 10.7MHz Sound Subcarrier and NTSC Video Test Signal Input (10x ATTN)**

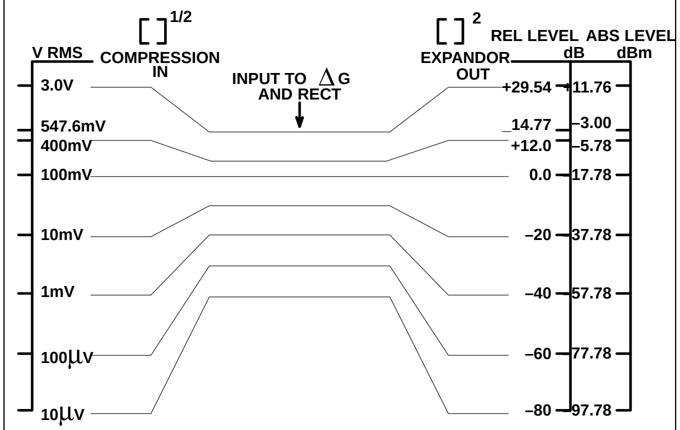


**Figure 7. NE575 Compressor Transfer Function**

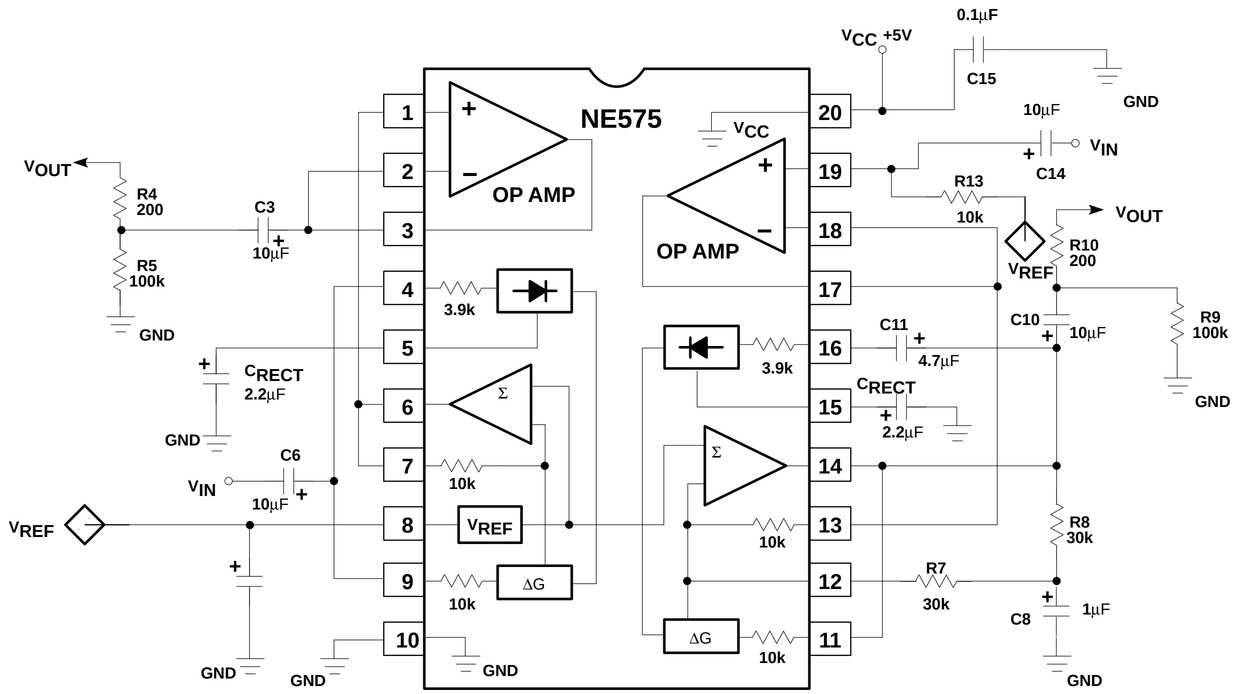


**Figure 8. Block Diagram**

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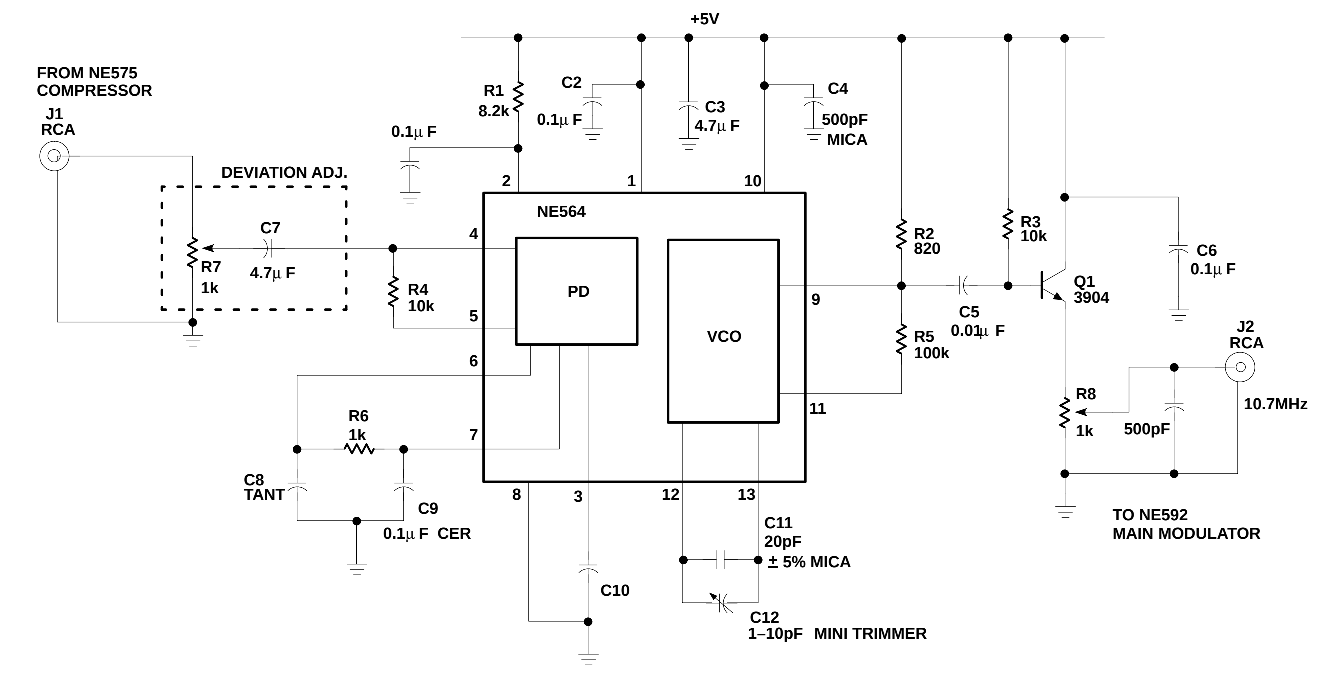


Figure 9. 10.7MHz Modulator

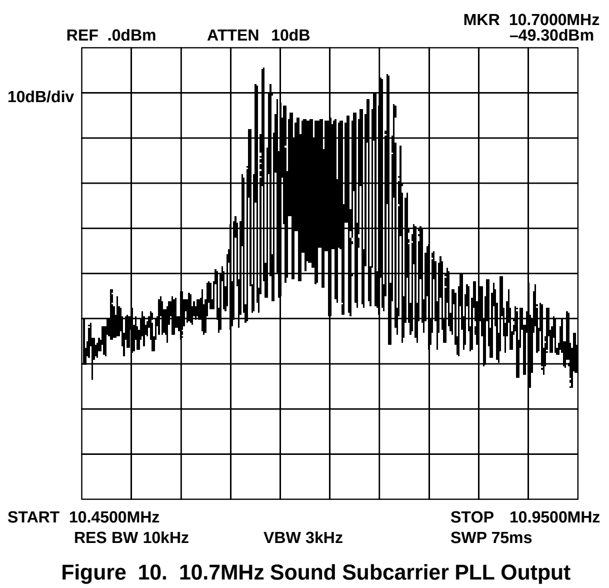


Figure 10. 10.7MHz Sound Subcarrier PLL Output with 1kHz Input After Compression (Probe 10x ATTN)

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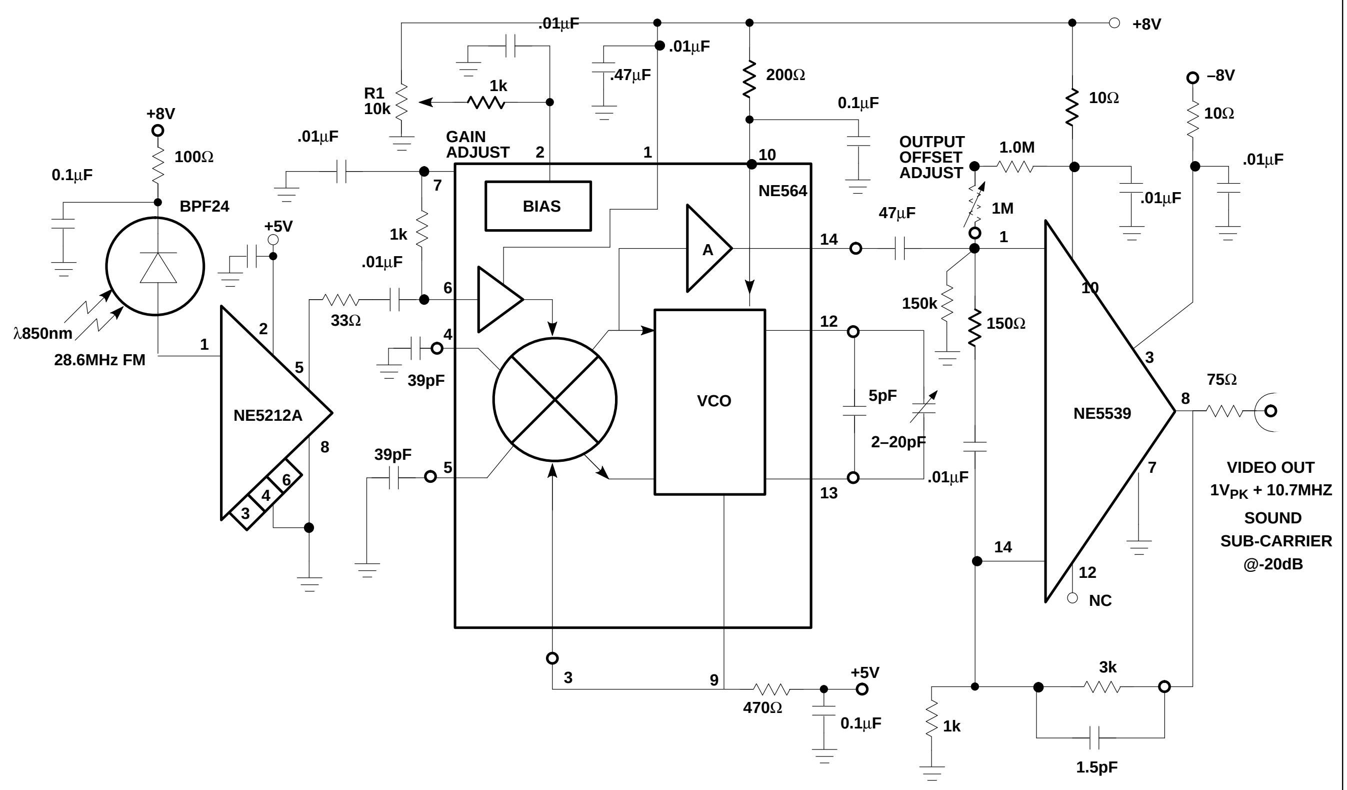


Figure 11. 28.6MHz Receiver Block Diagram

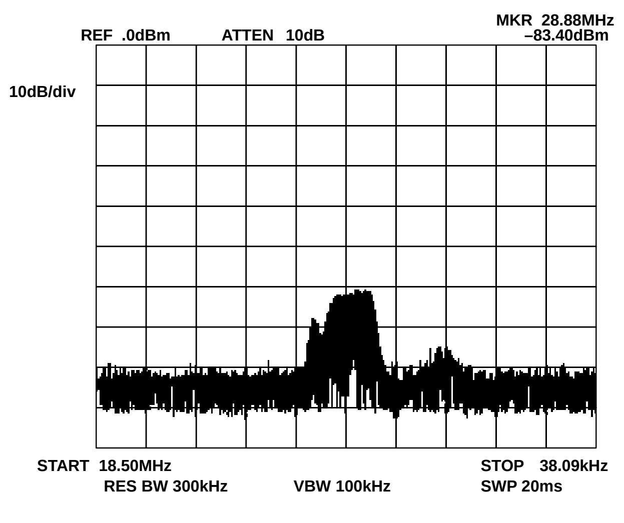


Figure 12. Receiver NE5212 Output at 28.6MHz with NTSC Color Bars and 5km Optical Attenuation (Probe 10x ATTN)

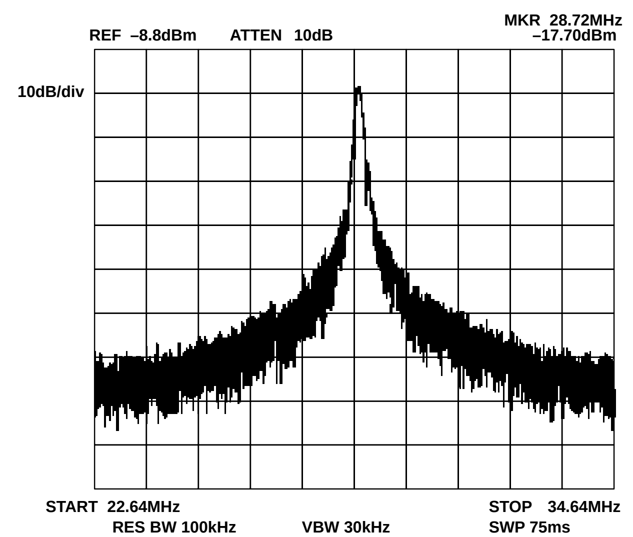


Figure 13. Receiver PLL Spectrum Frequency with No Signal from Fiber (Probe 10x ATTN)

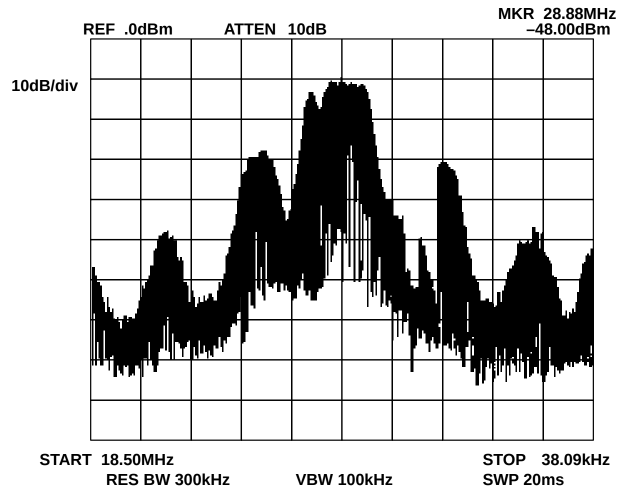


**Figure 14. 28.6MHz Receiver PLL VCO Spectrum with Link Phase-Locked and 5km Optical Attenuation (Probe 10x ATTN)**

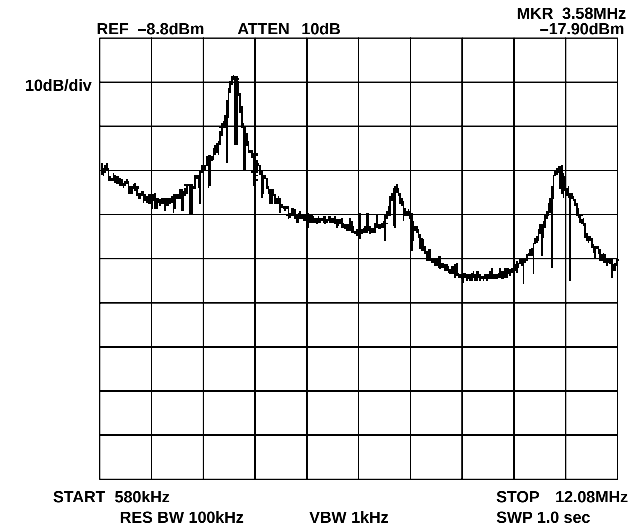


**Figure 15. NE5539 Postamplifier Spectrum Baseband Video and 10.7MHz Subcarrier (Probe 10x ATTN)**

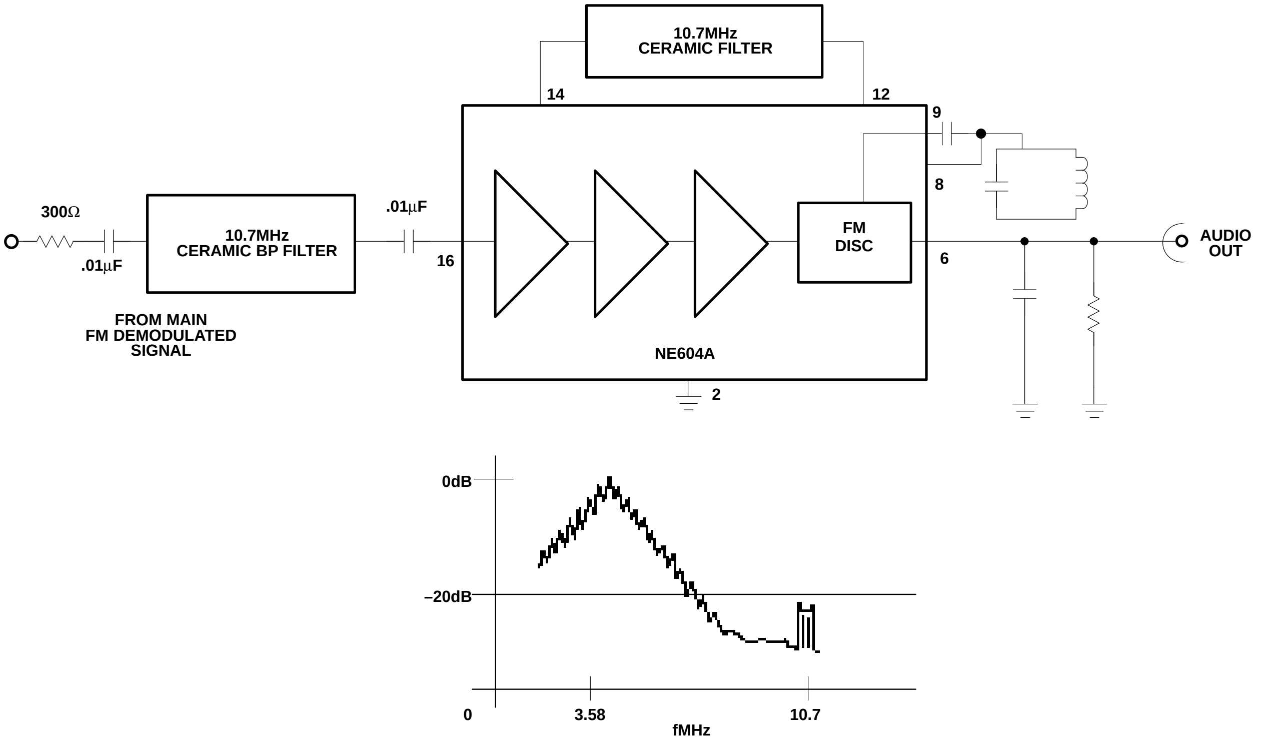


**Figure 16. FM Demodulator**

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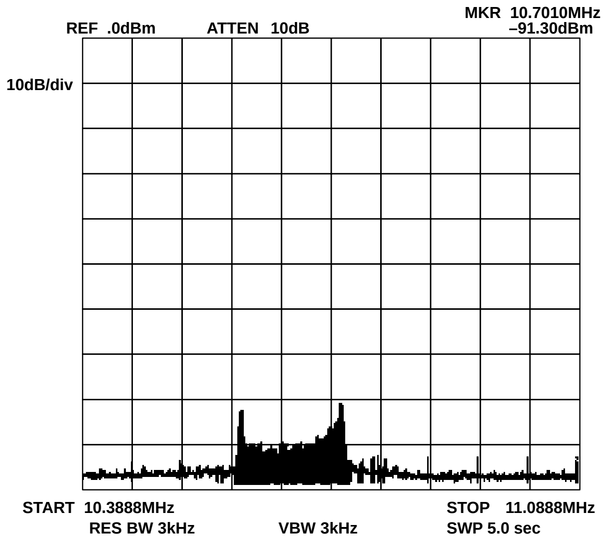


**Figure 17. 10.7MHz Recovered Signal Input to FM IF Amplifier/Discriminator NE604A (Probe 10x ATTN)**