T35 Theory of Operation
Preliminary Revision PA

Introduction: This document describes the theory of operation for the T35 transmitter. It provides basic operating concepts and criteria for successful understanding of the properties of the transmitter.

Overview: The T35 is a RF transmitter designed to support Voice, Music, and Hearing Assistance transmissions over short distances (up to 500 feet). The T35 provides both wide and narrow band FM signals at frequencies from 72.025 to 75.975 MHz. A variety of selectable audio processes are included, and typical audio connectors are supported. This product is intended for sale in the United States and is subject to US rules and specifications (Part 15.237). There are 17 possible wide band frequencies and 77 narrow band frequencies as shown below.

RF Channels: The T35 will transmit on any one of the channels specified in the tables below.

Wide Band Channels (MHz)		Narrow Band Channels (MHz)							
72.1	72.2	72.025	72.275	72.525	72.775	74.650	75.325	75.575	75.825
72.3	72.4	72.050	72.300	72.550	72.800	74.675	75.350	75.600	75.850
72.5	72.6	72.075	72.325	72.575	72.825	74.700	75.375	75.625	75.875
72.7	72.8	72.100	72.350	72.600	72.850	74.725	75.400	75.650	75.900
72.9	75.4	72.125	72.375	72.625	72.875	74.750	75.425	75.675	75.925
74.7	75.6	72.150	72.400	72.650	72.900	74.775	75.450	75.700	75.950
75.3	75.8	72.175	72.425	72.675	72.925	75.225	75.475	75.725	75.975
75.5		72.200	72.450	72.700	72.950	75.250	75.500	75.750	
75.7		72.225	72.475	72.725	72.975	75.275	75.525	75.775	
75.9		72.250	72.500	72.750	74.625	75.300	75.550	75.800	

Table 1. List of all wide band and narrow band frequencies possible with the T35.

Physical Configuration: The T35 is enclosed in a half rack case, and may be operated in either a fixed mode or a portable mode. In either case, the unit operates from standard 110 VAC, 60 Hz electrical power. The unit may be rack mounted with an available kit. Four antennas are available, depending on the application. The ANT 005 is a coaxial half wave dipole. The ANT 24 is a short dipole. The ANT 021 is a short rubber duck antenna which mounts through a hole in the top of the case, and the ANT 025 is a collapsible whip which also mounts through a hole in the top of the case. The antenna type may be selected depending on the application.

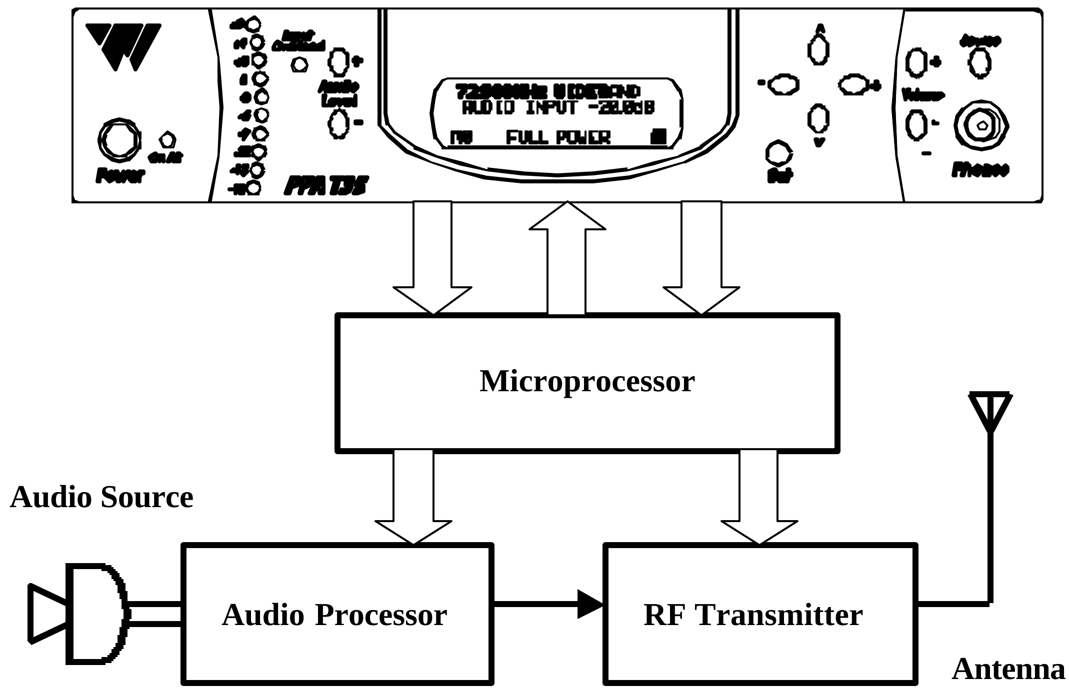

Figure 1. T35 System Block Diagram.

T35 System Level Description: See Figure 1 above.

Audio Processor: The audio processor takes an input audio signal and processes it to provide for a variety of applications, with microprocessor control to inhibit conflicting selections. It accepts an audio signal from a variety of sources. For Convenience the source is shown above as a microphone, but it might be one of several types of microphones, or any line level source as well. The audio processor, under the control of the microprocessor, will adapt to any of these sources (**NOT a 70 volt input signal!**). Both low pass and high pass audio filters are selectable for a number of configurations. A variety of compressor slopes and gains are also available.

RF Transmitter: The RF transmitter circuits, under microprocessor control, will generate any of the RF frequencies listed in Table 1. It accepts the processed audio from the Audio processor, and generates a high quality FM signal. This signal is amplified and controlled by transmitter circuitry, and routed to one of several antennas.

Microprocessor: The microprocessor is the controller for all functions of the T35. It interprets front panel switch presses, executes the selected commands, and displays relevant information on the front panel LCD, LED bar graph, and "on air" LED.

Front Panel Display: The front panel has all the controls for operating the T35, and displays all operating information.

Chassis: The chassis provides all mechanical support and shielding for the T35 transmitter.

RF Circuit Description: See Figure 2 below. The RF circuits of the T35 generate a controlled Frequency Modulated RF output controlled by the transmitter's microprocessor. The modulating signal is supplied by the audio processor circuit. The microprocessor controls both the frequency and amplitude of the RF output signal. The RF circuits operate from a single +15 Volt supply.

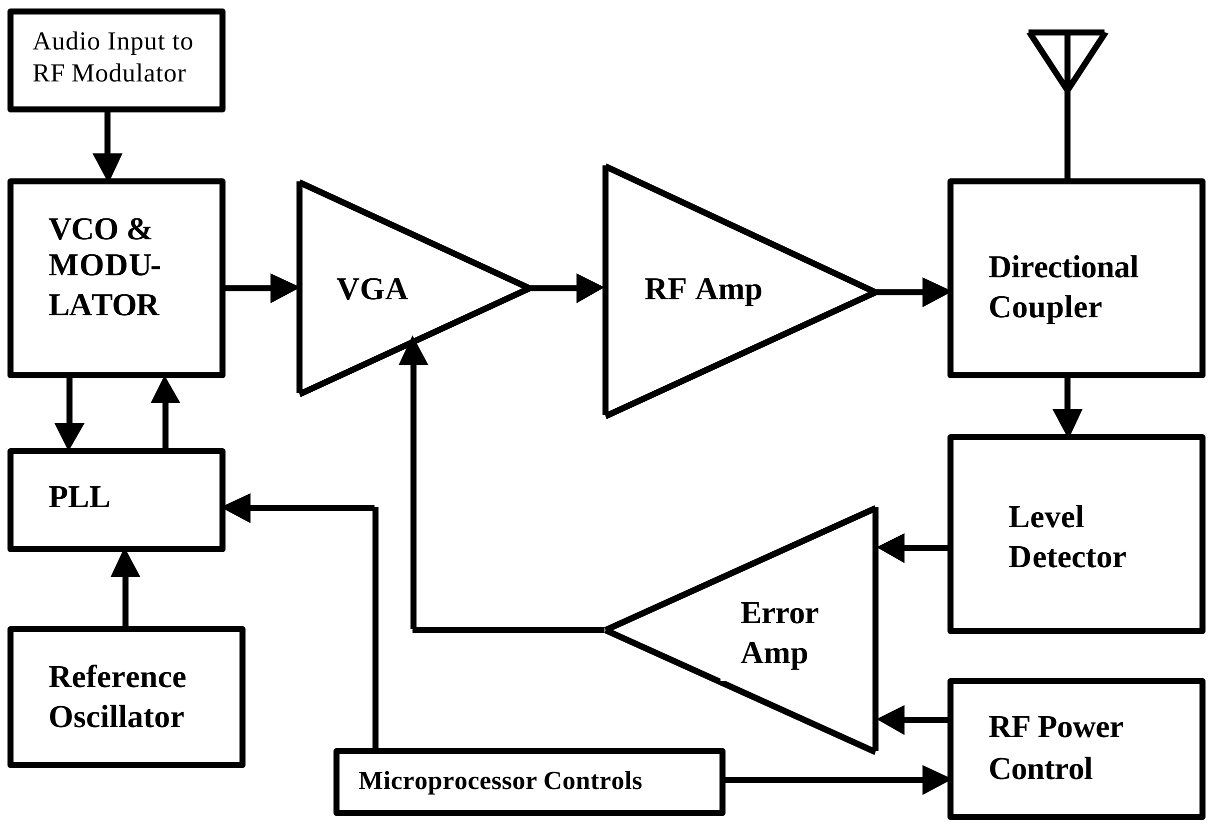

Figure 2. RF Subsystem Block Diagram

Circuit Description: The following paragraphs describe the RF circuits of the T35. Please reference SCH 180. Also, see the block diagram in Figure 2 above.

Reference Oscillator: The reference oscillator is a low cost 4 MHz oscillator which provides clock signals to both the PLL chip and the Microprocessor. Separate buffer circuits keep the microprocessor's noise and signals from influencing the RF, contributing to the overall low noise of the transmitter. The oscillator is locked to the 4 MHz crystal, and is trimmed by adjusting C507.

VCO/FM Modulator: The VCO (Voltage Controlled Oscillator) is a low noise, low distortion tuned oscillator that generates the transmitter's RF signal in the 72 to 76 MHz bands. Because the signal output is a nearly perfect sine wave, less filtering is required later. Power supply noise is decoupled by R603 and C602. The oscillator is a modified Colpitts circuit, having two varactors, one for tuning (D601) and the other for modulation (D602). T601 provides the necessary oscillator trim function, plus the secondary winding conveys the RF output to the VCA (Voltage Controlled Amplifier), matching impedance and helping eliminate possible ground loops.

Phase Locked Loop: The phase locked loop is based around the National Semiconductor LMX2306. This chip operates at 5 volts. It is programmed via a serial port controlled by the microprocessor. It compares the frequency of the reference oscillator to the frequency of the VCO, and sends an error signal from the charge pump to steer the VCO. The charge pump acts as a current source. Its output is filtered by the loop filter.

Loop Filter/Modulation integrator/summer: This circuit is constructed around IC503, which is a low noise, dual OP-AMP. The functions performed by this circuit include the following: The filter function removes reference frequency sidebands from the phase detector and helps to stabilize the loop response to noise and channel changes. The integrator/summer function integrates the incoming audio and sums it with the error signal from the phase detector. The net result of this is to modify the response of the loop filter to permit modulation down to 20 Hz or less. This permits the loop filter cutoff frequency to be set at about 100 Hz, which greatly enhances the unit's resistance to antenna impedance changes due to human body interactions.

Voltage Controlled Amplifier: The FCC specifies the maximum RF signal strength permitted this class of transmitters. The VCA provides about 50 dB of gain control to this transmitter. In this case Q201 is a dual gate MOSFET. The voltage applied to gate 2 controls the gain of the circuit, with max gain at 5 Volts and min gain at 0 volts. Gate 1 is high impedance, which does not load the VCO circuits.

RF Power amplifier: Q202 is a class A RF amplifier. The base is biased at 5 volts. The emitter resistors are calculated to set the collector current to 15 mA, keeping the gain constant across the RF bandwidth. Because the amplifier is class A, it does not generate much in the way of harmonics. The output match network matches the impedance of the collector to 75 ohms, and removes some of the residue of the harmonic radiation.

RF Power Sampler: C210, L207, L208, R208, R227, C211, and C218 are a Wilkinson hybrid power splitter, which splits the signal output from Q202 into two parts and further reduces the harmonic radiation of Q202, keeping it within FCC limits. One part of the signal is routed to the antenna, and the other is routed to the power sampler diode, D201. D201 is a biased rectifier/voltage doubler, which rectifies the sampled RF level. The DC output of the rectifier is applied to the ALC circuit to control the amplitude of the RF output.

ALC Circuit: IC201 This circuit keeps the RF output constant. It compares the output of the RF power sampler against the voltage from a voltage divider (R215, R216, R217, and R223). The voltage divider has 4 selectable voltages controlled by the microprocessor. IC201 is configured as an integrator and error amplifier. It amplifies the difference between the sampled RF output and the voltage divider, filters that difference, and applies it to gate 2 of the VCA to keep the amplitude of the RF output constant. Typical units should be constant, channel to channel, to within 0.15 dB or less.

Low Noise Power Supply: Power supply noise can contribute greatly to the overall noise of a transmitter. This circuit, based around Q501, is a classic beta multiplier circuit. It produces a low noise, controlled 5 volts to operate key 5 volt circuits in the RF portion of the transmitter, particularly the reference oscillator, PLL chip, Loop filter, VCA, and ALC.

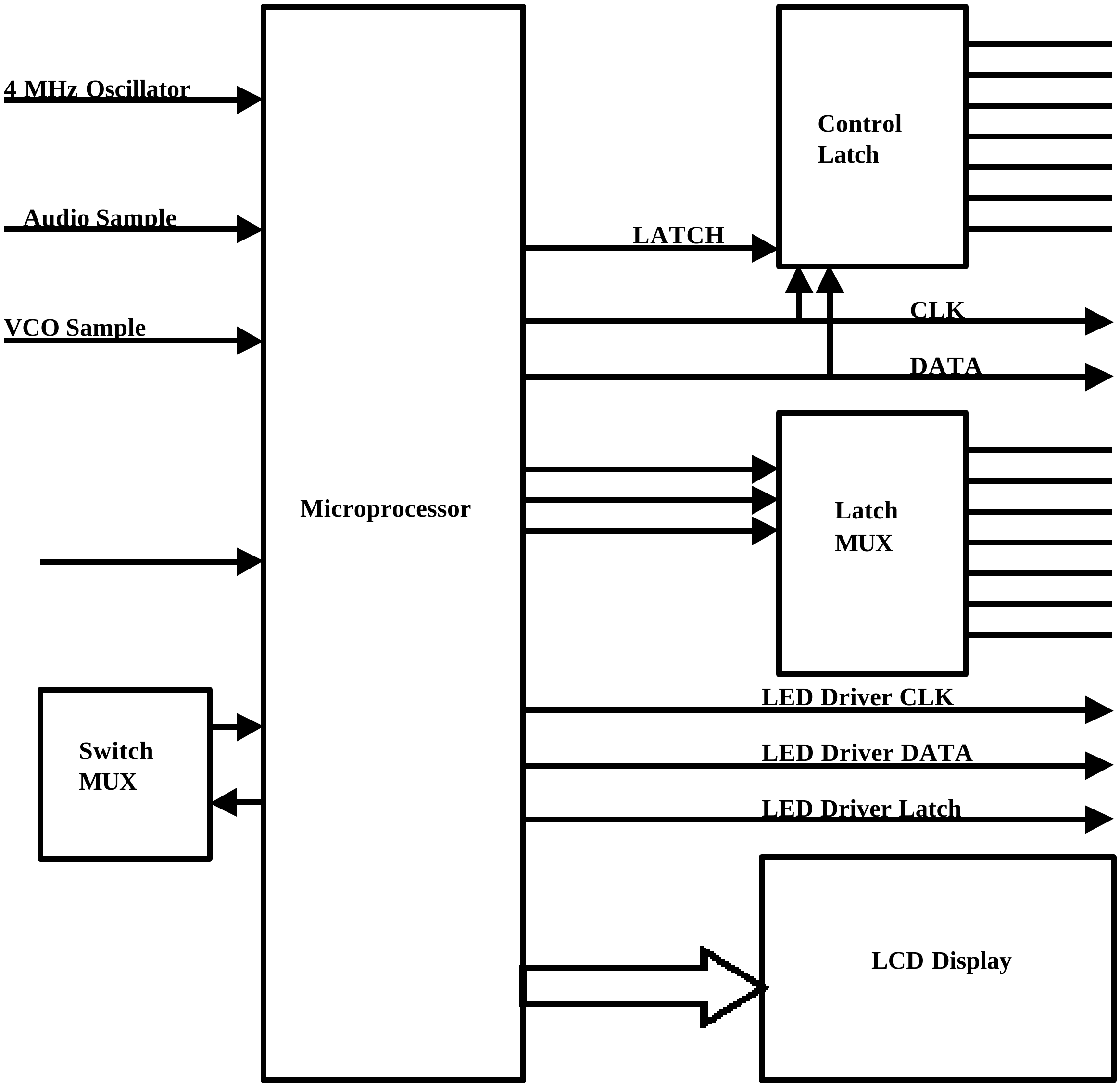

Figure 3. Digital Control Subsystem Block Diagram

Digital Control Circuit Description: See Figure 3. The T35 uses a microprocessor based digital control system. This system controls and regulates almost every aspect of the T35's performance. The digital control system operates the user interface, and, from that selection, sets up the RF and audio subsystems.

Microprocessor: The microprocessor (IC701) is a flash-based microprocessor. It is programmed after the board assembly is completed. A microprocessor of this type can be reprogrammed as needed to update the software. Program space includes 4 each 2K pages for instructions and data. The code version is indicated on the LCD at boot. The main clock signal is a 4 MHz clock provided by the reference oscillator. The clock is therefor synchronized to the RF system; prohibiting audio beat frequency signals (birdies) from contaminating the output. The microprocessor interprets switch presses on the control panel, and executes the function selected by the operator.

Switch MUX: The switch MUX is the interface between the front panel control switches and the microprocessor. The Switch MUX is made up of IC801, IC804, and IC805. The microprocessor continuously scans the switch MUX, checking for switch presses. When a switch press is detected, the microprocessor then executes the relevant program instructions.

Control Latch: The control latch (IC704) sets various control bits to control various transmitter functions. These functions control the SIMPLEX, MIC GAIN, Phones Source, Compression Gain, Narrowband/Wide Band, and RF power. A serial word from the microprocessor sets up the latch.

Clock, Data, and Select lines: These lines control various audio functions. The select lines choose the chip addressed, and the clock and data lines carry the data to set up the selected chip. One key item with regard to these lines is that they only have signals when actually changing one of the settings. Therefore they can only cause crosstalk, etc. at those times. Therefore, under normal operation they cannot be detected in the audio.

Latch MUX: The Latch MUX (IC703) selects which chip is written to by the CLK and DATA lines. 3 address lines from the microprocessor control which line is selected.

LED Driver Bus: The LED driver bus is a direct connection between the microprocessor (IC701) and the LED driver (IC803). Nothing else is connected to this bus because this signal is continuously updated. Therefore the signals present have less likelihood of contaminating the audio and RF functions of the transmitter.

Display: The LCD (MOD1) is a liquid crystal display that operates in graphic mode. It displays all the operator selections and prompts that permit the T35 to be easy to operate. The display is arranged in two halves, each of which is updated independently. The unit is backlit, with an operating current set to about 85 mA. The display contrast is set with the use of R704. All signals to operate the LCD are generated by the microprocessor.

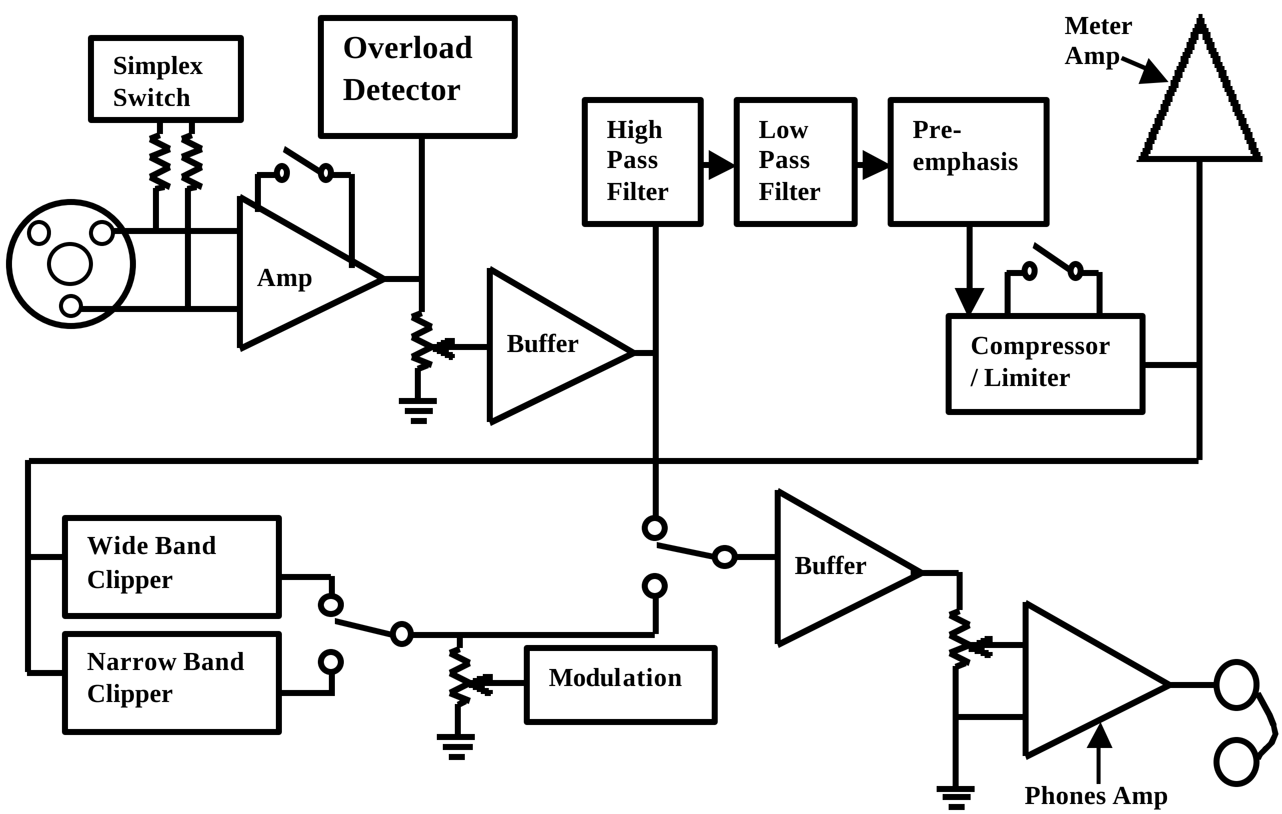

Figure 4. Audio Sub-system Block Diagram.

<u>Audio Processor Circuit Description:</u> See Figure 4. The T35 uses a sophisticated audio processor subsystem. This system will adapt the T35 to a wide variety of applications. Three basic applications are particularly addressed: voice, music, and hearing assistance. All audio functions are controlled and monitored by the microprocessor. All settings are made through the use of front panel controls. The following paragraphs describe the various audio circuits. Please see figure 4.

<u>Audio Input Connector</u>: The combination connector will allow either a standard XLR or a ¼ inch standard microphone plug, thus saving board space and reducing cost. Pin out is connected with industry standard pin 2 in phase, pin 3 out of phase and pin 1 circuit common.

<u>Simplex Power Circuit</u>: Approximately 13 volts DC simplex power is supplied at TP162 via transistor Q102 and in turn to J101 connector pins 2 and 3. A signal from the micro-controller turns the simplex power on or off, depending on the front panel selection. Simplex power is "on" when a low voltage (0 volts) is applied at TP149 and the base of Q101which causes a high voltage at its collector and also the base of Q102. This turns Q102 on and supplies simplex current through resistors R101 and R102 to the connector. Capacitors C104 and beta multiplied capacitor C109 ensure that the simplex voltage doesn't contain 60 Hz hum and is low noise. Simplex power is off when there is a high voltage (+5 volts) at TP149.

<u>Differential Input Amplifier:</u> The input amplifier IC101 is a low noise, instrumentation amplifier that takes the audio applied at the input connector, amplifies it by either 35 dB (mic mode) or 0 dB (line mode) and routes it to the input level digital potentiometer and input overload detector. The gain of IC101 is determined by the formula (6000/R119 + RS) +1 where RS is the drain to source resistance of the p-channel FET (Q105). In the microphone mode, FET Q105 is "on" and RS is approximately 85 ohms making the overall gain about 35 dB. In the line mode, FET Q105 is "off", RS is very high and the overall gain is 0 dB. The FET is turned on or off by the micro-controller signal at TP148. In the microphone mode, a high voltage (+5 volts) is applied to TP148 and the base of Q103, which in turn switches the collector low. Since the collector is connected to the gate of the FET, the gate to source voltage (VGS) is small and consequently the drain to source resistance low. The opposite occurs in the line mode where the micro-controller switches a low voltage at TP148, gate to source voltage is high and the FET is pinched off causing the drain to source resistance to be high.

A large level audio signal exists across the FET drain and source. On the positive potion of the signal, the drain conduction increases due to a higher drain voltage. On the negative signal portion, drain conduction decreases since the channel is driven more toward pinch-off. This causes distortion, which may be reduced by applying positive feedback from the drain back to the gate causing the gate to move with the drain. Feedback is accomplished by components R116 and C118.

<u>Input Overload Detector:</u> The input overload detector causes the front panel overload light to turn on when the analog input signal peak exceeds a limit. The detector consists of steering diodes in D105, IC102 comparator amplifiers at pins 12/13/14, 6/5/7 and rectifier diode D106. Normally, both steering diodes are conducting since they are connected to zero volts at pin 8 of IC101 and to the voltage divider R120/121 or R122/123. The first comparator is low until the voltage peak at pin 8 exceeds either divider voltage (+-8.02V). The corresponding diode will turn off causing the first comparator output to switch high. The diode D106 conducts and capacitor C114 holds the voltage high for a period of time determined by the time constant C114, R165 and R125. This turns the output of the second comparator low causing the overload LED to turn on since it is connected to a high voltage. The switching action of the second comparator is stabilized by the hysterisis action provided by R128.

<u>Input Level Potentiometer:</u> The input level potentiometer IC192 adjusts the input signal level to provide an optimum deviation level for the transmitter. The level of this pot is set by the microprocessor, as controlled by the Audio Level buttons on the front panel.

High Pass Filter: This filter *passes* high frequency components and rolls off (reduces) low frequency components of the audio signal at a 6dB/octave rate. It can reduce hum and some mechanical noise components if present. The filter's cutoff frequency is selected by the microprocessor with possible values varying from 22 Hz to 700 Hz. In hearing assistance mode, this reduction can assist those with a high frequency hearing loss. The filter is comprised of component C134, R145 and digital potentiometer IC132 pins 5, 6, and 7. The resistance of the digital potentiometer is controlled by the micro-controller, which in turn adjusts the cutoff frequency. The user selects the cutoff frequency on the front panel.

Low Pass Filter: This filter *passes* low frequency components and rolls off (reduces) high frequency components of the audio signal at a 12dB/octave rate. It can reduce hiss and other high frequency audio components. The filter's cutoff frequency is selected by the microprocessor, with possible values varying from 3.2 KHz to 16 KHz. The filter has two sections and is comprised of components R134, IC133, R135, C136 and C135. IC133 is a dual section digital potentiometer. The resistance of each section controlled by the micro-controller, which in turn adjusts the cutoff frequency. The user selects the cutoff frequency on the front panel. (Reference file: K:\T35\simulations\…lowpass#13.sxsch)

Wide/narrow band Clipper Circuit and switch: The wide and narrow band clipper circuits provide "hard" limiting to ensure that the large, short duration audio peaks that make it through the compressor's limit circuit cannot overdrive the FM modulator thus causing deviation beyond the FCC imposed +/- 75 KHz limits.

The clipper circuit is comprised of components IC191 (pins 2,3,1 and 13, 12,14) along with C181, R181, C182, R183, Q181, Q182, Q183 and Q184. The resistors and capacitors combinations provide a 6dB/octave pre-emphasis to signals above 10.2 k Hz for wideband and 5.7 k Hz for narrow band (-3 dB points). The gain of the amplifier, attenuator R177/178 and the parallel connected (diode-configured) transistors Q181, 182, 183, 184 are sized such that any short duration, high amp litude signals above 5.7k or 10.2 k Hz are clipped by the transistors. This signal is then routed through the de-emphasis components R187, C187, R188 and C188 to make the overall frequency response flat but void of any short duration high frequency components that may overdrive the successive FM modulation stage. Depending on the mode selected on the front panel, wide or narrow band clipper sections are selected by IC143 pins3, 5 and 4 via the control signal provided by the micro-controller at pin 9.
(Reference file: K:\T35\simulations\…narrowcutnew#6.sxsch, widecutnew#6.sxsch)

Wide band/Narrow Band De/Pre-emphasis and Switch: The T35's pre-emphasis circuit increases the amplitude of the high frequency components of the signal. This signal is transmitted by the T35. The corresponding de-emphasis in the associated receiver will then provide a flat overall system response. These functions improve the overall signal to noise ratio of the RF system. In wide band mode the de/pre-emphasis is 75 microseconds (2123 Hz, +-3 dB crossover point). In narrow band mode the de/pre-emphasis is 300 microseconds (530 Hz, +-3 dB crossover point).

Switch IC131 (pins 3,4,5) connects the correct wide or narrow band pre-emphasis circuit depending on the voltage supplied by the micro-controller on pin 9 and determined by the user selection on the front panel. In the wideband mode, resistor R136 is switched in parallel with R138 to provide a total resistance of 7.5 k ohms. This in conjunction with the buffer amplifier IC141 (pins 5,6, 7) and C137 gives a RC time constant of 75 u seconds to provide wideband pre-emphasis. In the narrow band mode, resistor R138 resistance of 30 k ohms in conjunction with C137 give a RC time constant of 300 u seconds to provide narrow band pre-emphasis. This signal is routed through the compressor and eventually to the deviation control potentiometer R192 that controls modulation level of the T35 transmitter.

Also, headphone and RCA jack needs to have a flat frequency response. Therefore, IC143 (pins 1,2,15) switches components R191 and C189 via the micro-controller signal at pin 10 to provide wideband de-emphasis or narrow band de-emphasis with components R190 and C192. This now flat frequency response signal is routed to the buffer amplifier (IC191 pins 5,6, and 7) and eventually to the headphone output and RCA jack.

Deviation control: Potentiometer R192 is used to adjust the audio level sent to the FM modulator. A voltage divider is used in narrow band to adjust the correct level at wide or narrow band with one switch. The micro-controller selects narrow or wideband deviation at IC143 pin 9, which switches pins 3, 4 and 5.

Compressor/ Limit Circuit: IC141 is a specialized IC that provides both compression and limit functions. The compressor function dynamically controls the amplified gain where low amplitude signals causes the gain to rise and a high amplitude signals cause the gain to maintain a predetermined level. The limit function doesn't allow high amplitude peaks to pass through to the output. These functions enhance the system by increasing the average deviation of the transmitter while limiting the peak deviation to keeping it within the FCC limit.

The user selects compression ratio on the front panel. A 6.0:1 ratio is the maximum compression while a 1.0:1 ratio is no compression. Compression ratio is defined as "an "r" dB change in input level causes a 1 dB change in output level. Here, "r" is defined as compression ratio. Depending on the compression ratio setting, the micro-controller changes the resistance of digital potentiometer IC132 at pins 8, 9 and 10. This resistance determines the DC voltage at Pin 10 of IC141and provides the control signal inside the IC to change the magnitude of the VCA (voltage controlled amplifier) and compression.

The compressor release time, determined by the formula t (m sec) = C153 (uF)*10, is the time the system reacts when a large input is followed by a small signal. Release time is determined by capacitor C153, connected to IC133 pin 8, which is another control signal to the VCA amplifier. Compressor attack time, the time it takes for the VCA gain to be reduced when a small signal is followed by a large signal, is mainly controlled by internal circuitry that also speeds up the attack for large level changes. This limits overload time to under 1 ms in most cases.

Additional peak detector components connected to pin 8 are used to dynamically reduce the VCA gain at very high audio input levels. This provides a very quick limiting function beyond that supplied by the slower 1 ms limit function internal to the IC. This ensures FM modulation levels to the transmitter are not exceeded. These components are C157, Q151, Q152 and Q153. Operation is a high positive peak level turns Q151 on, while high a high negative peak level turns Q152 on. If either transistor is on, Q153 turns on which charges C153, increases the control voltage and consequently reduces VCA gain.

The compressor rotation point is the transition point on the input/output transfer graph where compression and limiting occur. It effectively sets the maximum output signal. The T35 rotation point is 1.0 volt RMS. Resistor R151, connected to pin 11, determines the rotation point.

On the front panel, the user may select between *normal* or *reduced* compressor gain. The reduced choice causes the micro-controller to switch IC 131 pin 11 high. This switches pins 12 and 14 to cause R154 to be connected in parallel with R152, which reduces the gain of the VCA amplifier by approximately 6dB. In the reduced mode, the compression ratio will be reduced approximately one half. The rotation point remains the same.

Audio Sample VU Amplifier: Buffer amplifier IC191 (pins 9,10 and 8), connected to the output of the compressor, supplies the analog input signal to the A/D converter in the microprocessor which drives the 10 VU LEDs on the front panel. The amplifier gain is 20 dB with a flat frequency response. Since the amplifiers output is capable of +-15 volt swing, Schottky diodes (D192) are needed to clamp the output signal to ensure the 5volt maximum allowable input voltage to the micro-controller A/D is not exceeded. Resistor R175 is needed to buffer the amplifier output from the low impedance of a forward biased Schottky diode. R163 and R164 provide DC bias voltage for the amplifier. Resistor R163 is connected to the micro-controller's 5.7 volt B+ to ensure the meter amplifier bias point corresponds to the A/D reference voltage.

Source/Input Phone Select: On the front panel, the user may select between "transmitted" and "source" for the headphone output. "Transmitted" choice is the signal that goes through the T35 and is processed. "Source" choice is unprocessed by the T35 and is similar in level to the input signal at the J101 connector (only at 0dB input attenuator). Buffer amplifier IC102 pins 8, 9 and 10 is needed to adjust the level of the "source" signal. The micro-controller controls the headphone output via the voltage present at IC 143 pin 11. A high level at pin 11 is "transmitted" while a low level is "source".

Headphone Buffer Amplifier: The headphone buffer amplifier (IC191 pins 5, 6, 7) provides a high input impedance so the de-emphasis components R191/C189, and R190/C192 are not loaded down. These components de-emphasis the previously pre-emphasis signal to provide a flat frequency response. The buffer amplifier provides a low impedance output to the headphone volume control digital potentiometer.

Headphone Volume Control: Headphone volume level is controlled by the digital potentiometer (IC192 pins 19, 17 and 20) which is controlled by the microprocessor via a serial port. Approximately 40 dB of level change is permitted in 1dB steps. The user selects the level on the front panel with the headphone volume buttons.

Headphone Power Amplifier Circuit: The audio headphone amplifier (IC193) uses an LM386M or BM to amplify audio for the headphones. The M suffix part has a maximum supply voltage of 15 volts. Therefore, dual diode D193 is used to drop approximately 1.4 volts to ensure supply voltage is less than the maximum allowed. Capacitor C175 is needed to increase power supply rejection due to the added signal drop across D193. The amplifier has a fixed gain of 26 dB and provides 65 mW of power into 50 ohms. Load isolation is provided by two 51ohm resistors. Ferrite beads B191, 192 and 193 along with capacitors C196 and 197 are used to protect from unwanted RF radiation.

Voltage Regulators: Some IC's in the audio circuits are supplied by + 5V (IC171) and –5V regulators (IC172). These regulators are necessary to the drop supply voltage below the maximum allowable and to isolate sensitive audio circuits from the hum and noise inevitably present on the +15V and –15V supply lines.

Power Supply Circuits: The T35 uses a distributed regulator approach to spread heat dissipation, reduce noise and spurs, and eliminate expensive custom heat sinks. Five major regulators are used, and several additional lower power regulators are used for these purposes.

+15 Volt Supply. This fixed regulator (IC001) provides 15 volts to the RF and Audio circuits.

+15 Volt B Supply. This fixed regulator (IC004) provides 15 volts to the front panel LEDs and the headphone amplifier.

-15 Volt Supply. This fixed regulator (IC002) provides –15 volts to the RF and audio circuits.

+5.7 Volt Supply. This adjustable regulator (IC003) provides +5.7 volts to the digital circuits. The 5.7 volts are applied to a pair of steering diodes (D702A and D702B) which are configured to permit the microprocessor to be programmed only in an unpowered board. The steering diodes drop the voltage supply for the digital circuits to about +5.1 volts.

85 mA Current Source. This is a –15 volt regulator (IC005) configures as a current source. This circuit supplies current to drive the LCD backlight and bias only.