Theory of Operation and Circuit Description for T36 Transmitter

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General Description:

The T36 transmitter has been designed for use in language interpretation and hearing assistance applications. The transmitter operates in the 72-76 MHz frequency band under part 15 of the FCC and Industry Canada regulations. The T36 is a belt-worn type transmitter made for use with one of four microphones using the microphone cord as the transmitting antenna (all T36 microphones use the ground wire on the microphone cord as a monopole RF antenna). The unit comes with an auxiliary input cable which may be connected to any line level (or headphone level) audio source. The unit can also be operated with audio input from a microphone. The T36 will be sold without a microphone but the MIC 044, MIC 054, MIC 090, and MIC 096 microphones may be used with the unit (The T36 has been designed such that the MIC 096 is the most efficient antenna). The enclosure for the unit is made completely from plastic in a three piece structure, with four screws holding the unit together. The transmitter is powered from two AA batteries located inside the unit behind the battery door on the back of the unit.

Reference Documents:

Schematic P/N: SCH202*
Printed Circuit Board P/N: PCB202*
Printed Circuit Assembly Drawing P/N: PCA202*
User Manual: MAN142*
Microphones (also used as the RF antenna): MIC044*, MIC054*, MIC090*, MIC096*
Battery Information: BAT001*, BAT026*
Cable Information: WCA087*
FCC label P/N: IDL425*
FCC label location: IDL425 location*
Internal Controls label P/N: IDL424*
T36 Block Diagram*
Industry Canada REL letter: IC REL signed*
T36 changes from Timco units to production*

* = Revision, date, or other information may be present in file name

Basic Unit Characteristics:

User controls, indicators, and connectors inside the battery door of the unit

1. The power for the unit is provided by two AA alkaline or NiMH rechargeable batteries inside the door on the back of the unit. The battery selection switch (also inside the battery compartment) is to be set for the type of battery used Alkaline or NiMH.
2. Master audio level adjustment potentiometer – Used to adjust the volume level of the microphone and the auxiliary input (if used). The master audio level adjustment is located inside the battery door at the farthest left location.
3. Auxiliary input level adjustment potentiometer – Used to adjust the volume level of the auxiliary input only. The aux. level adjustment is located inside the battery door at the location second from the left side.
4. Compression selector switch – Used to set the audio compression level to 2:1 (switch positioned up) or 1:1 (switch positioned down). This feature (2:1 setting) is generally used for people that have more severe hearing loss and is typically not used in normal applications. The compression selector switch is located inside the battery door at the location second from the right side.

5. Channel lock switch – Used to lock the frequency from changing (when the switch is in the up position) even if the rotary channel selector switch on the front of the unit is changed. This feature is used to prevent a user from intentionally or unintentionally changing the channel when the system is set up for a one specific channel.

User controls, indicators, and connectors on the top bezel of the unit

6. Channel selection switch – A 16 position rotary switch is used to change the transmitted frequency, pending that the lock switch inside the battery door is set to the unlocked state.
7. Power/Mute button – Used to power on or off the unit if the button is held for three seconds. Also used to toggle on/off the microphone mute if the button is pressed momentarily and released.
8. Mute LED – Red LED located behind the mute button (power/mute button is transparent). The LED blinks to indicate that the microphone is muted, and is off when the microphone is not muted.
9. Power LED – Green LED that indicates that the unit is powered on and transmitting if the LED is steady on. Also used to indicate that the batteries are low if the LED is blinking.
10. Microphone Jack – Gold plated 3.5mm jack used to connect the microphone. The microphone cable also operates as the transmitter's antenna; and thus must be present even if the microphone use is not desired (to use in this mode, attach the microphone to this jack and press and release the power/mute button to mute the microphone). This is one of two types of audio inputs that can be transmitted with the T36.
11. Auxiliary (AUX) jack – For use when line level or headphone level audio input is desired. This is the second of two types of audio inputs that can be transmitted using the T36. Both the microphone audio and the auxiliary audio inputs can be used simultaneously.

Circuit Functionality:

The circuit functionality is described in blocks of circuitry which are essential to meeting the requirements of the PPA T36 transmitter. Some smaller circuit blocks with functions such as preventative measures, noise immunity/suppression, or other stability/reliability issues, may be referenced on schematic SCH 202.

1. Audio Circuit – This circuit accepts audio signals from the microphone jack or auxiliary line/headphone level input jack and amplifies them to the level needed for modulation of the transmitter. Potentiometer R54 is the master audio gain adjustment to accommodate different levels of input amplitudes and microphone sensitivity. Potentiometer R75 adjusts the input amplitude of the auxiliary input separately, to limit overloading on that specific input. A 75 micro-second pre-emphasis is added by a second amplifier. Audio limiting to prevent over-modulation is done in two stages. The first stage senses the audio level and clamps it to a preset level, while the second stage is a hard diode limiter or clamp circuit. The final modulation level is preset by adjusting the internal trimmer potentiometer R46 while the audio amplitude is at the limiter level. This will ensure that the transmitter will not over-modulate the transmitting frequency from an input signal at this level or higher.

2. Modulator circuit – This circuit combines the output of the audio circuit with the Phase-Locked Loop (PLL) filter output and applies it to the Voltage Controlled Oscillator (VCO) section of the circuitry to create a clear, low distortion, FM transmission.

3. VCO circuit – This circuit creates the RF output signal. The VCO is controlled by the PLL chip and modulator circuits through a feedback network.

4. RF power amplifier circuit – This circuit provides a controlled amplification of the RF from the VCO. The output stage of this circuit also provides necessary harmonic filtering and matching network to the RF antenna (the ground of the microphone cable is used as the RF antenna in this transmitter).

5. PLL circuit – This circuit is facilitated by an IC designed for this application which keeps the VCO locked on frequency via a feedback network.

6. Microcontroller circuit – This circuit is programmed to respond to user controls affecting the power on/off, frequency selection, mic mute control, and lock/unlock functionality, by outputting the appropriate data to LED's and loading PLL chip registers. The microcontroller's oscillator driver circuitry is also used to run the 5.5Mhz crystal X1, which provides the reference frequency to the PLL chip.

7. Voltage boost and regulation circuitry – The voltage boosting is done by IC6, which takes a battery voltage of 1.8 to 3.2 volts and converts it to 5.0vdc. This voltage is then regulated to a low-noise 4.5vdc by IC1, which provides the power for nearly all of the components on the T36.

8. Noise and transient suppression circuitry – many spots on the board have components or PCB traces which minimize noise, the goal of these parts/traces being to not create interference to external entities, and/or not accept interference from external entities. These components and traces are not described in the detailed portion of this document, but may be referred to in SCH 202 and PCB 202.

Detailed Circuit Section Descriptions:

This segment describes operation of each circuit section, the inputs required, and outputs generated. Please refer to SCH 202 and PCA 202 for any part reference designators or testpad names (TPx) listed. For the entire circuit, combining all sections, please refer to SCH 202.

Power Section

The power section of the unit which is described below will combine the input power handling, and the outputs necessary to power each board section. The purpose of this section is to provide a clean reliable DC voltage so that all portions of the circuitry work properly.

Inputs: 3.2 to 1.8vdc (55mA to 165mA respectively) from two AA battery cells
Outputs: Low noise 4.5vdc (TP10) used as the power for most of the sections.

The block diagram for the battery section is shown below in *Diagram 1*:

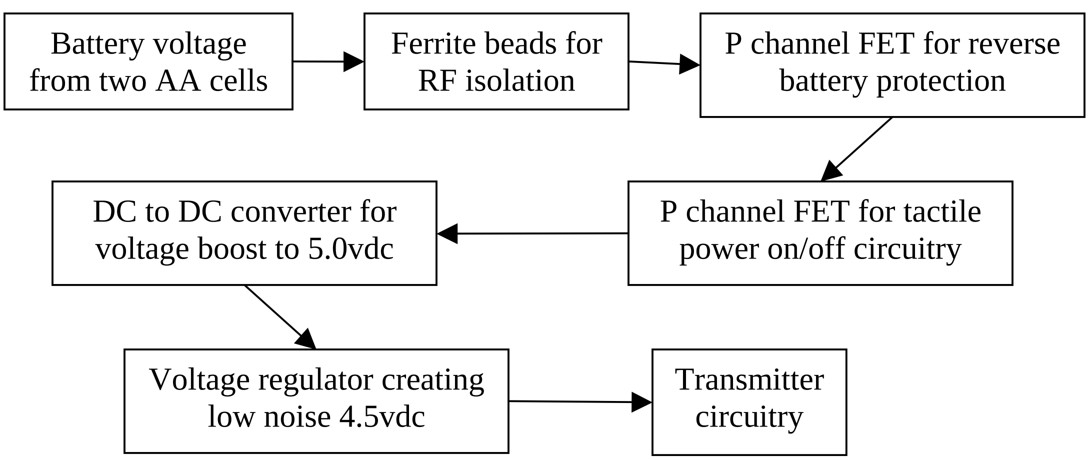

Diagram 1
Power Configuration

As illustrated by the above diagram, the battery power goes through a number of stages before reaching its final destination of powering the necessary portions of the transmitter. Most of the stages of this section are fairly straightforward and the application and/or supporting components are described in the device data sheets. The one stage that is custom designed is the tactile power on/off FET operation. This FET is supported by the surrounding components to do the following:

- Power up the unit while the tactile power/mute button is held down.
- Allow the microcontroller to hold the FET (Q1) on, once the button has been held for approximately three seconds.
- Allow the microcontroller (once powered) to take an analog to digital conversion on the switched line to see if the switch is pressed or released.
- Also allow the microcontroller to use the switch line as the drive line for the microcontroller to hold the power for the unit on. The ADC reading on this line is performed at a very low duty cycle while C6 holds the unit on. Once the ADC is complete, IC8 pin 7 switches back to an output and drives Q1 again to keep the unit powered on (when the button is not pressed).

---ADJUSTMENTS---

If the power section of the board is working properly, the following should be true with new batteries in the unit:

1. **When the switch is held down, the voltage across C60 should be slightly less than the battery voltage.**
2. **The DC to DC converter voltage from IC6 should be approximately 5vdc at TP9.**
3. **The voltage regulator output from IC1 should be approximately 4.5vdc at TP10.**

VCO

The Voltage Controlled Oscillator (VCO) section of the circuit is operated with the following parameters:

Inputs: +4.5vdc from voltage regulator IC1, steering voltage from the PLL loop filter, and audio from the modulator circuit

Outputs: 72-76MHz RF to the PLL chip IC7 pin 6, 72-76 MHz to the Radio Frequency Power Amplifier (RFPA) via capacitor C24 (NOTE: this point must be measured with a FET probe or equivalent. Standard probes have too low of an impedance at radio frequencies and will give false measurements.)

The VCO is created by a modified Colpitts circuit. The capacitive divider of C91 and C92, added with the parallel capacitances from D7 and D8, added to the load capacitances and stray capacitances created by the board and other items; resonate against L11 to form the tuning network of the oscillator. The oscillator is tuned via the voltage applied to the variable capacitance diode (D7 through R90). The VCO is modulated via D8 with the audio input. When the frequency is above approximately 300Hz, D8 is the dominant device in the modulation operation. When the frequency is below approximately 300Hz, D7 becomes the dominant device.The resistor R96 sets the drive level of the oscillator, the current through R96 should measure around 2-3mA.

---ADJUSTMENTS---

The oscillator is tuned by setting the channel to the lowest frequency possible (72.1 MHz) by setting the rotary channel switch to "1". At this point L1 should be adjusted with a non-metallic tuning tool until a voltage of 1.2vdc (+ or -0.1vdc) is obtained between the VCO control line (TP1) and GND. The lower end of the tuning range should now be set. To verify the upper end of the tuning frequencies are in proper range, set the channel to the highest frequency possible (75.9 MHz) by setting the rotary channel switch to "16". At this point the VCO voltage on TP1 should be no more than 4.1vdc. (Setting the VCO above 0.8vdc will ensure that diode D7 has enough voltage to maintain a high Q value. Keeping the VCO below 4.1vdc will ensure that the VCO voltage stays well below the rail of 4.5vdc when considering tolerances and temperature changes.). If the frequency locks near the desired channel, but is not quite on the exact frequency, see the "PLL" section of this document under "---ADJUSTMENTS---" for proper frequency trimming. If this section of the circuit is operating properly, the PLL chip should lock onto the frequency indicated on the rotary switch, and the RF outputs should be as specified above.

PLL

The Phase Locked Loop (PLL) section of the transmitter is controlled via a PLL chip, National Semiconductor PN: LMX2306TM (IC7). This chip works in conjunction with the VCO and the modulator circuit to provide a consistent and clean RF signal, locked on the correct frequency.

Inputs: +4.5vdc from voltage regulator IC1, data bus signals – inputs only when a change in RF frequency is initiated (clock, enable, and data) from IC8, 5.5 MHz crystal oscillator (X1) output from IC8 which is used as a reference frequency.
Outputs: Locked RF signal from the VCO on the specified frequency.

The PLL circuit allows the system to stay locked on a desired frequency. This frequency is based off of the reference crystal (X1) which gives a stable 5.5 MHz frequency to the microcontroller. The microcontroller buffers and drives the signal for its internal clock frequency, and then also provides the PLL chip with that signal for a reference frequency. Due to variations in tolerance of different lots of parts (and other variables), the resonating capacitors (C3 and C2 plus C18) are setup so that C18 can be adjusted to trim the frequency to exactly 5.5000 MHz. Below in *Diagram 2* is a simplified operation of the PLL section of the circuit.

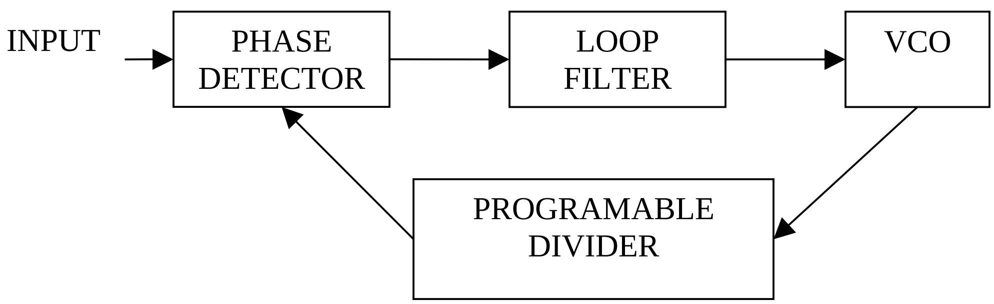

Diagram 2

The phase detector and programmable divider are built into the PLL chip. The VCO operation is described above in the "VCO" section of this document. The loop filter is primarily controlled by R79, C78, C82, R85, C83, R32, and R68. The loop filter is designed to roll off all noise and modulation below approximately 300 Hz.

---ADJUSTMENTS---

If this section is working properly, each channel selected should generate the correct RF output with a stable and locked frequency. If the frequency is off slightly, but the RF output still locks on frequency, C18 may need to be adjusted to trim the frequency to the exact desired output. If the frequency does not lock, see the "VCO" section of this document under "---ADJUSTMENTS---" for proper tuning.

Modulator Section

The modulator section of the circuit is operated with the following parameters:

Inputs: +4.5vdc from voltage regulator IC1, Audio from the audio processor circuit, and level setting from the modulation adjustment potentiometer R46.
Outputs: Audio to modulate D8, Integrated audio scaled and summed with the PLL error voltage at IC9 pin 2.

This circuit has two outputs which when summed together in the VCO, enable the loop filter to be set to a very wide range (several hundred hertz). This occurs while passing audio down to less than 200 hertz to inhibit noise, microphonics, and human body movements. This circuit is fairly simple in complexity when compared to the other sections of the transmitter. Audio is received from the audio processor at the input of the modulation potentiometer R46. This audio is routed in two directions: One direction goes to the audio modulation varicap, D8, in the VCO. The other direction is integrated by R83 and C80, buffered by IC9 and scaled by R79, then it is summed with the PLL error voltage at IC9 pin 2 (part of the loop filter). The second signal has the effect of canceling the error voltage resulting from the modulation, permitting the PLL to be modulated at frequencies below the loop roll off.

---ADJUSTMENTS---

There is one adjustment in the modulator section of the circuit needed to make the transmitter operate within the guidelines of the FCC and IC. **The modulation on the transmitting frequency must be limited to the bandwidth requirements dictated by the FCC and IC. To do this, set up an audio input level that hits the hard limiter D5 (this is accomplished when an increasing audio level no longer increases the modulation on the output frequency), then adjust R46 until the modulation on the carrier frequency is 65KHz +-2Khz. If the modulator section of the board is working properly, the audio as seen by an RF receiver on the corresponding radio frequency should be nearly flat in response from 200 Hz to 16 KHz**. If the audio response rolls off too soon or contains a distinct hump somewhere in the frequency band, the modulator portion of the circuit should be inspected for errors.

RFPA

The Radio Frequency Power Amplifier (RFPA) section of the circuit is operated with the following parameters:

Inputs: +5.0vdc from DC to DC converter IC6, +4.5vdc from voltage regulator IC1, RF input (72-76MHz) at gate 1 of Q2 from the VCO.
Outputs: RF transmission via the microphone cord ground (used as the antenna).

This circuit section uses a dual gate MOSFET device (Q2) as a gain controlled amplifier. RF is applied at gate 1 of Q2. The RF output power is adjusted by trimming the bias potentiometer, R18,of Q2 gate 2 to the desired output level. Gate 1 of Q2 acts as a very light load to the VCO circuit, helping to maintain a high Q value in the circuit, thus keeping a low noise system. Another important feature of the MOSFET is that it provides a high isolation between the VCO and the antenna. This reduces undesirable frequency pulling due to body-motion-induced impedance changes (it is not desirable to have changes to the external antenna affect the VCO or audio waveform). The RF match and filter network (created by L1, C15, C12, C14, C10, L4, L5, and C21) make up the circuit that matches Q2 to the antenna (made up of the microphone cable and PCB ground plane), while filtering out undesired harmonics.

---ADJUSTMENTS---

The power output on the transmitting frequency must be limited to power requirements dictated by the FCC and IC for the frequencies used. To set the power to a point below the FCC and IC limit, adjust R18 until a passing field strength less than or equal to the measurements and distance set by the Timco FCC/IC testing results (The unit’s field strength may also be compared to and set below the maximum level of an existing Williams Sound Corp. transmitter that has passed the FCC/IC requirements). Aside from the RF power output, the circuit is designed to require no adjustment if the specified component types, values, and tolerances are inserted in this section. If this section is not operating properly, the range and field strength may fluctuate beyond that of a correctly operating transmitter. Incorrect values, component types and/or tolerances may be a possible cause (the use of wire wound inductors is a crucial part of the match network operating correctly).

Microcontroller

The microcontroller section of the circuit is created around a PIC16F676 Microchip part. This integrated circuit (IC8) is the control center for all power on/off, frequency selection, locking, and mute commands given by the transmitter operator. The microcontroller has certain other special features during testing and programming; however, the inputs and outputs specified below will be as used during normal operation.

Inputs: +4.5vdc from voltage regulator IC1, Crystal oscillator X1 for clock frequency input, tactile power on/off switch, rotary channel selector switch, lock switch, and battery voltage (for low battery detection).

Outputs: PLL chip programming data (clock, data, and enable – only active when frequency is changed), power on holding circuit (to keep the unit powered up after the power/mute button is released), mute control to mute the microphone, modulation attenuator control for attenuation on the upper frequencies, power and mute LED outputs.

The microcontroller is setup with a clock frequency of 5.5 MHz. The code used in this part is written in assembly language in a continuous loop format (no events are time sensitive enough to need software or hardware interrupts). The frequency selection is setup in software tables, allowing for quick and easy access to data values. When an operator has changed the frequency of the unit, the transmitter will immediately be updated to reflect the new desired frequency, unless the lock switch is in the locked position. In this case the frequency will remain unchanged until the lock switch is moved to the unlocked state. The microcontroller uses many I/O's multiplexed for both input and output functionality on this transmitter. For example the rotary switch inputs SW1 bits 4 and 8 also double as the PLL serial data loading lines PLL_CLK and PLL_DATA respectively. This is accomplished by setting the port pin as an input to watch the switch, but any time the frequency is changed, these inputs change to outputs and drive the data and clock lines to the PLL chip to program in the new frequency. Once the new frequency is programmed, the port pins change back to inputs to watch the SW1 bit lines once again.

Another complex feature of the microcontroller is the tactile power on/off control, and the detection of the mute/power switch on the same line. This multi-purpose task was accomplished by periodically switching the power on drive line (keeping Q1 on via Q14) to an input and than an analog to digital conversion line. At this point the ADC takes a reading to detect whether the line is being driven by the micro itself (a reading of just less than 4.5volts) or being over-ridden by SW2 (connecting the PWR_ON/OFF line to battery voltage, 1.8 to 3.2 volts) the microcontroller then switches the I/O back to an output to keep Q1 (the transmitters power) on when SW2 is released. The microcontroller can now deal with the information accordingly as it now has the information indicating the power/mute button is pressed or released.

---ADJUSTMENTS---

Once the microcontroller has been properly programmed, no adjustments to this section are necessary. **If the microcontroller section is working properly, the green LED should be on and the transmitter transmitting, when the unit is powered. If switches are changed or buttons pressed, the microcontroller should make the appropriate changes corresponding to each specific control change.**

LED Indicators

There are two LED indicators on the T36 unit. The green LED, D2, is used to indicate power on/off and low battery conditions. The Red LED (located behind the SW2 clear actuator button) is used to indicate microphone mute on/off.

Inputs: +5.0vdc from DC to DC converter IC6, two microcontroller driving lines.
Outputs: Illumination of green LED D2 and red LED D9.

The LEDs are used to indicate to the user when the transmitter is in certain states. Both LEDs have a constant 5.0vdc supplied by the DC to DC converter, and then are driven low by the microcontroller when the states dictate that the LED should be on. The purpose of this configuration is to keep the LED current from drawing additional current through regulator IC1, thus keeping the IC1 output voltage cleaner (less ripple).

Originally in early versions of the circuit, the LEDs were driven directly by the battery voltage. This proved to be a problem for two reasons. The first reason is that the transmitter needs to operate down to at least a battery voltage of 2.0vdc, and the Vdrop of the LEDs is around 2.0vdc. This means that there is no room for a required current limiting resistor (adding additional Vdrop) in the circuit. The second reason is that the LEDs would dim as the battery voltage decreased, an undesirable side affect when the intensity level is important.

---ADJUSTMENTS---

No adjustments are needed in this section. If the unit is operating properly the green LED should always be on (or blinking if the battery is low) when the unit is transmitting. The red LED

should remain off until the microphone mute is activated. Once the mute is activated, the red LED should blink at a duty cycle of 1/8 every 1 second.

REVISION HISTORY:

Date:	Rev:	By:	Changes:
05/12/08	A	KWW	Initial Revision