Venturi-Mini Technical Description

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V 1.0

Overview

The Venturi Mini (VM) is an audio convergence device intended for automobile use. VM allows handsfree mobile phone calls to be made and received using a microphone within the VM for uplink audio, and the FM radio receiver and loudspeakers built into the automobile for the the downlink audio. VM also allows the playback of music through the automobile FM radio and loudspeakers, either from files stored within a Bluetooth enabled mobile phone or music player, or from an externally connected music player such as an iPod. If the vehicle is equipped with an audio input connector, the VM can be connected to this and the FM transmitter switched off.

Mechanical arrangement

The housing comprises two parts, the stem power module and the main user interface housing. The two are able to rotate relative to each other for ease of positioning in the vehicle. The stem power module is plugged into the cigar lighter socket which provides mechanical support and electrical power.

The connection to the vehicle ground is made through a nickel-plated steel spring which presses against a gold-plated contact area on the underside of the printed circuit board in the stem module and also presses against the inside wall of the cigar lighter socket. The connection to the 12V supply is made by a steel cap covering a coil spring which presses against the centre contact of the socket. The spring is soldered onto the top side of the stem printed circuit board.

The user interface housing contains two 6-layer printed circuit boards which are positioned at an angle to one another in order to give the product its distinctive shape which maximises the number of vehicles into which it can be fitted. The two pcbs are electrically linked by a 25-way flexible interconnection device.

The upper pcb which is the larger of the two, supports four push switches, a scroller wheel and encoder, two light emitting diodes, a light sensor and an organic light emitting diode (OLED) dot matrix display. It also contains most of the active circuits in the product and the antenna structures for both Bluetooth and VHF FM transmission. The antennae are completely enclosed within the insulating housing and there is no provision for any external connection to them.

The lower pcb supports audio input and output jacks (J1, J2), a USB connector (USB1) for charging the batteries of external devices such as mobile phones and music players, an acoustic sounder (Audio2), a linear voltage regulator (U3), two push switches and four LEDs.

The lower PCB is linked to the stem PCB by a 4-way flexible wiring harness which passes through the hinge between the stem and the user interface housing.

Each PCB has a ground plane covering all the board area except where there is a specific reason for it to be absent, such as around the Bluetooth antenna. Care has been taken to avoid slots or aggregates of large numbers of vias piercing the ground plane, so as to minimise the potential for inadvertent slot antennas to be created.

Programming of the flash eprom and Tiny13 processor are carried out in conjuction with test pads on the upper PCB which connect with test pins on a “bed of nails” fixture in the factory. It would therefore be extremely difficult for the user of the VM to alter the software or configuration data.

Functional blocks

Power management

The 12V supply from the vehicle is protected with a series-connected Polyswitch temperature and currrent limiter (VR91) and a shunt zener diode (ZD91) for transient, load dump, overvoltage, reverse polarity and short circuit protection. A switching regulator (on the same pcb as the Polyswitch and zener diode) based on an MC33063AD (U91) provides a 5V output rated at 0.5A for charging external accessories via a USB-style connector in the user interface housing. The switching regulator operates at approximately 50kHz, although this frequency drops due to cycle-skipping when the output is lightly loaded. The 5V regulator incorporates current limiting which limits the peak current in the switch transistor within the controller IC to approximately 1A, corresponding to an output current of at least 500mA but less than 1A (the exact value depending on the vehicle supply voltage). The switching regulator circuit is conventional, but incorporates the following features to minimize RF emissions: The 100µH energy storage inductor L92 is of a shielded type. The input capacitor C92 is a 220µF low-esr aluminum electrolytic type to minimize conducted 50kHz noise. The input is filtered by a 4.7µH series inductor L91 and a shunt 2.2µF capacitor C91 which attenuate harmonics of the switching frequency. The ferrite bead FB91 in series with the power schottky diode D92 damps sharp switching transitions which would otherwise cause ringing at about 30MHz.

The regulated 5V output is connected to the USB connector on the lower main board using two conductors of a 4-way interconnection harness made from UL1061 26AWG PVC insulated stranded wires. The data contacts of the USB connector are connected to passive resistor networks (R64, R65, R99, R100) to signal that the device is a charger and has no data transfer capabilities.

The protected 12V supply is connected to the lower main board by the remaining two conductors of the interconnection harness. It is regulated by an LM317LD linear voltage regulator (U3) which provides a current-limited and over-temperature protected 8.5V output.

The 8.5V supply is linked to the upper main board through a 1µH inductor. On the upper board, the 8.5V is dropped to 3.3V with a linear regulator for the logic level devices and the audio op-amp. It is also separately dropped to a nominal 3.8V by means of a series zener diode (ZD1) to power the regulator input of the BC5 Bluetooth processor. This provides an appropriate input voltage to the BC5 on-chip regulator while reducing the power dissipation in the 3.3V regulator and avoiding the ripple voltage on the 3.3V supply which might otherwise be caused by Bluetooth activity. A schottky diode (D1) helps to maintain the input voltage to the BC5 when the vehicle supply voltage drops severely during cold cranking in winter conditions. The BC5 chip has three internal linear regulators dropping the 3.8V supply first to 1.8V, then to a pair of 1.5V supplies – one for audio circuits and the other for RF and internal digital processing. All power supplies are appropriately decoupled with ceramic capacitors. The 8.5V supply is used directly by the organic light emitting diode (OLED) display and by the light emitting diodes (LEDs).

Bluetooth processor

The heart of the VM is the CSR BC5 multimedia processor (IC5). This device incorporates a Bluetooth transceiver, a microcontroller for BT protocol handling and system control code, a digital signal processor for handsfree processing and music decompression, stereo audio codecs and a set of digital input/output ports. Program code and configuration settings are stored in a 16 M-bit flash eprom (IC2) with a 16-bit parallel interface. All connections between the BC5 and the flash memory are kept as short as possible and well away from the edges of the PCB to reduce radiated emissions.

The BC5 is clocked using an on-chip oscillator in conjunction with an external quartz crystal resonator (XTAL1) at a frequency of 19.2MHz. The metal shield of the crystal resonator is grounded and there are no signal-carrying tracks close to the resonator connections. This ensures that excellent phase noise performance is maintained.

The oscillation frequency is trimmed during manufacture of the VM to ensure an accuracy of +/- 20ppm over the temperature range of -20 to +55 deg C. Trimming is by an array of switched capacitors on the BC5 chip. Trim parameters are stored in the flash memory and cannot be altered by the user. The 19.2MHz clock is used (in conjunction with an on-chip frequency synthesizer) to synchronise the two processors within the BC5 chip, running at 32MHz and at 64MHz respectively. It is also used as a reference source for the Bluetooth frequency synthesizer within the BC5 chip and externally as a frequency reference for the generation of FM broadcast band transmissions.

The RF performance of the Bluetooth transceiver is dependent on the PCB layout which provides excellent grounding of the BC5 chip to the ground plane below it, to the use of appropriate decoupling capacitors and to the use of an integrated complex-conjugate matching circuit, balun and bandpass filter (Balun1) between the BC5 and the printed antenna structure.

Bluetooth antenna
The Bluetooth antenna is a simple ¼ wavelength monopole element, printed onto the bottom layer of the PCB at one end and folded to fit into the available space. The ground plane is removed from this area. The antenna is designed to be as close to omnidirectional as possible.

FM modulator
The VM uses an Alps TSMZ1-603A modulator module (U10) to generate FM broadcast band signals. This device receives a 19.2MHz clock signal from the BC5 chip and synthesizes the broadcast band carrier signal using a local oscillator tuned to four times the required output frequency. The output frequency is locked to the 19.2MHz reference input from the BC5 using a frequency divider and a phase locked loop. This arrangement ensures that the radiated signal always has a carrier frequency within +/- 20ppm of the specified value. The modulator incorporates a digital signal processor which provides audio compression and limiting together with 75μs pre-emphasis and also pilot tone generation, stereo subcarrier generation and RBDS subcarrier generation. The composite modulation signal is applied to the balanced pair of varactor diodes in the local oscillator. The modulation amplitude is automatically adjusted according to the transmission frequency to maintain uniform frequency deviation across the FM band. The BC5 tunes the modulator and updates RBDS information by sending control data over an i^2c bus connection at 400kbit/s.

FM antenna
In order to save space, a conventional antenna has not been used. Instead, the ground plane of the upper main PCB is used as an FM antenna, with the lower main PCB and the stem power boards acting as ground reference. Because of mechanical and space constraints, most of the active circuits are placed on the antenna board. This in turn requires a mechanism for transmitting power and signals between the upper antenna board and the lower ground reference board. This is done with a mixture of inductors and resistors. Where possible, for example the audio inputs, switch inputs and LED control signal outputs, 22kΩ resistors (R9, R10, R18, R19, R32, R33, R47, R89, R90, R91, R92) electrically bridge the gap between the upper and lower boards. Their impedance is so much higher than the RF impedance of the antenna structure that they do not significantly influence its operation.

When a larger current must pass between the boards, inductors are used. A total of five inductors (L1, L2, L7, L8, L12) carry out the following functions: linking the ground planes at DC, transmitting power at 8.5V DC, linking the audio output ground to the upper PCB, transmitting the audio left and right channel outputs from the upper to the lower PCB.

Each inductor is 1μH, so the aggregate inductance of all five inductors is 0.2μH. This inductance is in parallel with the self capacitance of the upper ground plane resulting in a structure which resonates at approximately 100MHz with an impedance of about 300Ω.

The output from the FM modulator module is impressed between the upper and lower ground planes through a resistive attenuator (R36, R101, R35). The attenuator was adjusted during testing on a calibrated open air test site to give the correct radiated output power. The combination of resistor values was set so as to approximate a 50Ω load on the modulator output which ensures correct operation of the harmonic filter. The impedance seen from the antenna structure was also kept reasonably close to 50Ω so as to provide substantial damping of the antenna and thereby ensure a low quality factor and a very wide bandwidth.

OLED display
The main visual display for user interaction is an organic LED dot matrix device. The display is controlled by a chip mounted directly onto the glass display module. A short flexible interconnect links the display and controller module with the main upper PCB through connector CONN3. The display is clocked at a nominal frequency of 360kHz generated within the controller chip using an RC oscillator. This clock is not accessible outside the controller chip.

LEDs
There are six LEDs in the system, in red, green and white (LED1 to LED6). Each of these is driven by an NPN transistor (U4, U5, U6, U7, U8, U9) configured as a linear constant current sink in conjunction with the 8.5V regulated supply. The base of each transistor is connected through current limiting resistors to a separate output of a serial input shift register chip (U1). Whenever the state of the LEDs needs to be changed, the BC5 clocks data into the shift register using a pair of programmable output pins. The clock frequency depends on software timing, but never exceeds 12kHz. The bases of all the driver transistors are connected through diodes (DD1, DD7, DD8) to a common brightness control signal which is driven by the output of a digital to analog converter in the BC5 chip. The use of current sinks in this way allows the brightness of LEDs having different colors to track regardless of their varying voltage drops. Brightness control by duty cycle modulation was avoided in the VM to reduce the risk of audio interference from the pulsed power supply current which this would have entailed.

Light sensor
An “eye response” light sensor (PD1) consisting of a photodiode and darlington transistor pair is connected to an analog to digital converter in the BC5 chip. This allows the brightness of the OLED display and LEDs to be varied according to ambient lighting conditions.

Tiny13 microcontroller
The processor in the BC5 does not have sufficient resources to decode the switch signals from the scroller encoder when it is being moved quickly. A very simple microcontroller, the Atmel Tiny13 (U12) is used to support this task. It is clocked from an on-chip RC oscillator with a nominal frequency of 9.6MHz, with a tolerance of 15% over temperature and manufacturing tolerance. No clock or other high frequency signals appear on the pins of the Tiny13. The power supply pin is filtered and decoupled with a resistor/capacitor combination (R12, C63) to ensure negligible leakage of the processor clock signal onto the 3.3V power supply.

The Tiny13 is also used to monitor whether or not an external music source is active. The outputs of the left and right channel differential amplifiers described below are summed and connected to the analog to digital converter input of the Tiny13. The converter data are processed to determine the level of any audio input and this information is sent to the BC5.

All signalling to the BC5 is by width modulation of 100 to 200ms pulses sent on a pair of connections.

Phonebook memory
Electrically erasible memory (e^2prom) (IC8) is provided to allow phonebook information to be downloaded from the Bluetooth-linked phone and stored within the VM. Information is passed from the BC5 to and from the e^2prom memory over an i^2c bus at a rate of 400kbit/s.

Audio circuits
The analogue audio circuits consist mainly of a quad CMOS op-amp (IC7) and a pair of multiplexers (IC4, IC6). The op-amps are configured as differential amplifiers, two for each audio channel. One pair of differential

amplifiers (IC7a, IC7b) is used to bridge the external audio input across the gap between the lower and upper ground planes. The differential action reduces the effect of any voltage drop across the inductor L2 that links the two ground planes. The second pair of differential amplifiers (IC7c, IC7d) convert the differential outputs of the BC5 digital to analog converters into a single-ended format while minimizing unwanted noise. Each amplifier is configured as a low-pass filter to prevent ultrasonic electrical noise from being propagated through the audio channels. The outputs of the differential amplifiers are connected to the two-input multiplexers IC4 and IC6 which select which audio source is to be fed into the FM modulator module, under the control of the BC5. The multiplexer outputs are connected to the audio output jack (J2) through an RLC low-pass filter which includes the bridging inductors L7 and L8. A separate ground connection from the upper ground plane is brought to J2 by inductor L12 so as to avoid common mode noise that appears across the main ground linking inductor L2. The multiplexer outputs are also attenuated and low-pass filtered immediately before the modulator inputs. This ensures that the modulator inputs are not overloaded and that signals outside the audio band are attenuated and do not disturb the operation of the analog to digital converter in the modulator.

A clean reference voltage for the audio “virtual ground” is generated using a filtered voltage divider buffered by an NPN transistor (U11).

The electret microphone (MIC1) is connected to an analog to digital converter in the BC5 chip through a passive power filtering network of resistors and capacitors.

Components which affect radiated RF levels
For Bluetooth transmissions, only the BC5 chip (IC5) and the combined impedance match, balun and bandpass filter module (Balun1) affect the output power and harmonic emissions.

For FM transmissions, only the modulator module (U10) and the attenuator resistors (R35, R36, R101) affect the output power and harmonic emissions.

Spurious emissions from other sources are substantially below regulatory limits and depend on good general PCB layout practice in conjunction with the appropriate use of ground planes.