Document History

Release Date	Purpose
8 May 2006	Initial version

finepitch™ EXPRESSION

FPE100 Datasheet
Integrated Circuit for Musical Instrument Tuners with Real-Time Pitch-to-MIDI

1 Overview

The *finepitch*™ **FPE100** integrated circuit provides a single-chip digital solution for electronic or acoustic instrument tuning applications with built-in monophonic pitch-to-MIDI functionality. Features such as the onboard analogue-to-digital converter and dedicated connections for a 7-LED tuning meter and 7-segment display facilitate the creation of high-quality tuning products with minimal external circuitry requirements. The low power consumption of the **FPE100** makes it suitable for use in portable, battery-powered products.

Incorporating scalable *finepitch*™ digital tuning technology, the **FPE100** has been optimised for low-cost, high-volume applications to achieve groundbreaking accuracy and performance at entry-level pricing—"sub-cent" measurement accuracy is achieved internally and sub-cent resolution is externally observable by an end-user.

By scaling *finepitch*™ technology, it is possible to significantly reduce the pitch-measurement time. This makes possible real-time pitch tracking of monophonic musical instruments; a technology dubbed *finepitch*™EXPRESSION.

1.1 Summary of features

The *finepitch*™ **FPE100** includes all the tuning features of *finepitch*™ **GTC100** NORMAL mode, with the BASS mode replaced by EXPRESSION mode (real-time pitch-to-MIDI). *finepitch*™ **FPE100** and *finepitch*™ **GTC100** are pin-compatible allowing the same platform to be used to build different products simply by changing the tuner chip. Refer to the *finepitch*™ **GTC100** datasheet for its full specification.

- **Tuning range C1 to C6***
- **Real-time MIDI range C2 to E6**
- **Pitch-to-MIDI conversion time of 35 ms**
- **Velocity-sensitive MIDI note output**
- **Accurate MIDI pitch-bend scaled for ±2 semitones**
- **Minimum tuning accuracy of 0·8 cents; better than 0·5 cents over most of the tuning range**
- **Sub-cent visual tuning capability**
- **Extremely fast tuning response**
- **Automatic note detection**
- **Reference frequency A_{440} adjustable from 437 Hz to 443 Hz in 1 Hz steps**
- **Accurate reference tone output—square wave**
- **Instrument temperaments—Equal tempered, Pythagorean (string), Just Major (wind)**
- **High noise rejection—useful when tuning acoustic instruments**
- **7-segment LED interface for note display**
- **7 LED tuning meter display via direct connection to chip—no glue logic required. Unique display allows visual tuning to better than 1·0 cent accuracy**
- **Clip indication via "note sharp" LED**
- **MIDI output enable line simplifies integration of multiple FPE100 in polyphonic applications. This can also be used as a "MIDI latch" function**
- **On-board ADC reduces component count and simplifies design**
- **Low current consumption makes the chip ideal for use in portable applications—typically <6 mA @3·3 V operation**
- **EXPRESSION mode consumes <8 mA for ultra-long battery life (including external LEDs)**
- **Small footprint (9 mm × 9 mm)† simplifies embedded applications**
- **Pin-compatible with the *finepitch*™ GTC100**

*. Middle C = C4.

†. Low-profile quad flat pack (LQFP32) package.

Typical applications include:

- Add real-time solo MIDI capability to instrument tuners.
- Products based on the *finepitch*™EXPRESSION Soloist concept design.
- MIDI guitar: multiple *finepitch*™ **FPE100** devices can be connected in parallel, one per string.

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1.2 Block Diagram

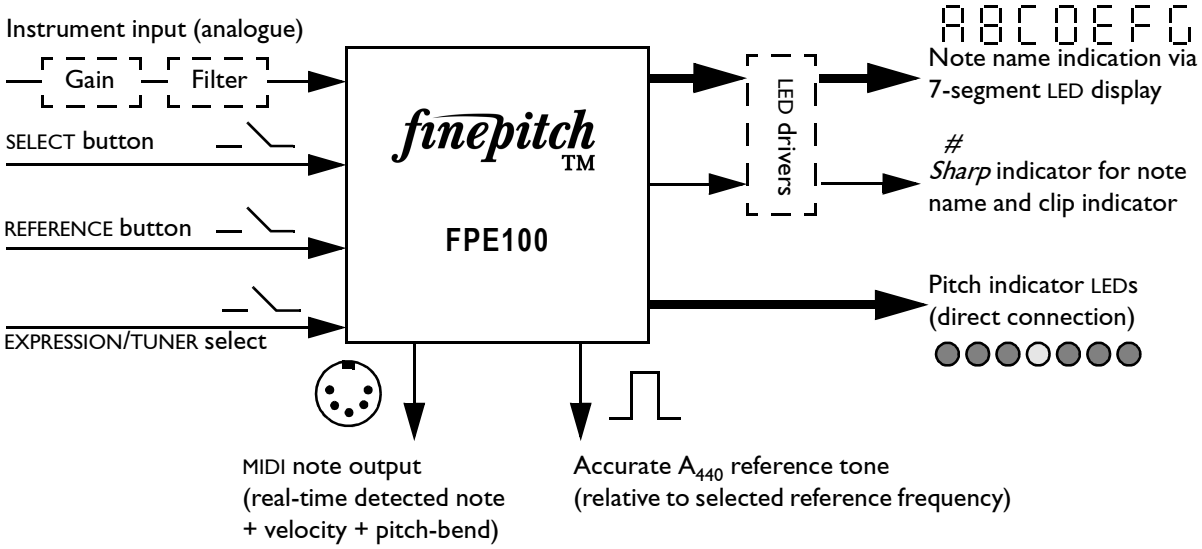


Figure 1: Block diagram of the *finepitch*™ FPE100.

2 Electrical Interface

2.1 Pin assignments and descriptions

The pin assignments for the **FPE100** are shown in Figure 2 and described in more detail in Table 1.

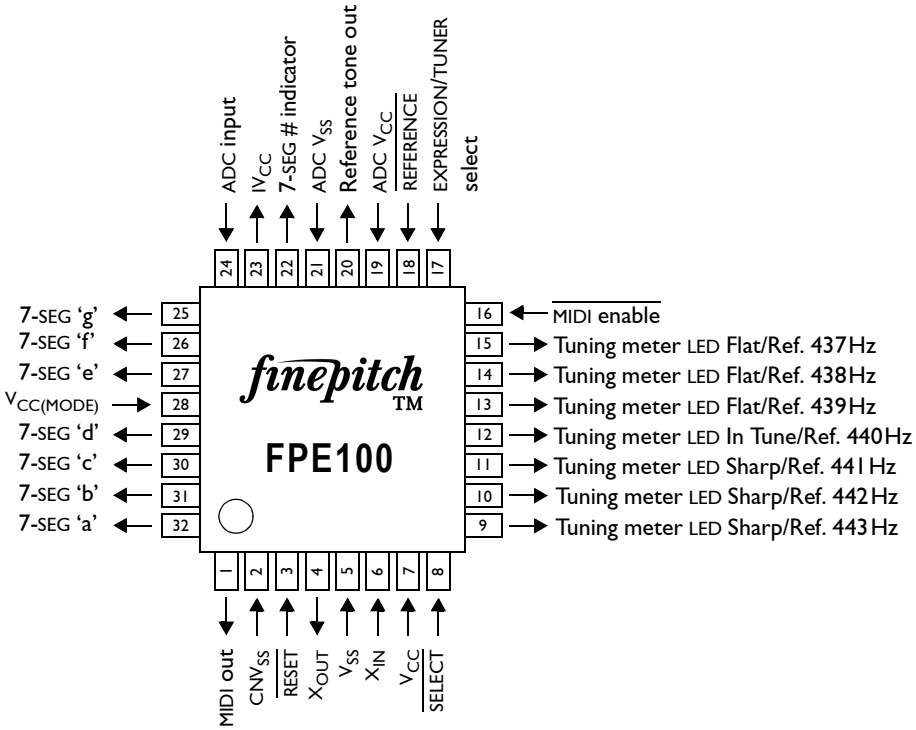


Figure 2: Pin assignments for the FPE100 (top view). Arrows indicate input or output pin.

Table 1: Pin descriptions

Pin name	Pin number	Input/Output	Description
V_{CC}	7	I	Power supply: apply 3.0V–5.5V to V_{CC} and apply 0V to V_{SS}. Connect V_{CC} to V_{SS} via a 100nF capacitor.
V_{SS}	5	I	
IV_{CC}	23	O	This pin stabilises the internal power supply. Connect this pin to V_{SS} (not V_{CC}) via a 100nF capacitor.
ADC V_{CC}	19	I	These are the power supply pins for the analogue-to-digital converter (ADC). ADC V_{CC} is also used as the reference voltage for conversion. Connect ADC V_{CC} to V_{CC} and ADC V_{SS} to V_{SS} and a 100nF capacitor between ADC V_{CC} and ADC V_{SS}.
ADC V_{SS}	21	I	
CNV_{SS}	2	I	Connect this pin to V_{SS} via a 5k resistor. The resistor should be as close to CNV_{SS} and V_{SS} as possible.
$V_{CC(MODE)}$	28	I	Connect this pin to V_{CC} via a 10k resistor.
$\overline{\text{RESET}}$	3	I	Low on this pin will reset the device.
X_{IN}	6	I	These pins provide the main clock generation circuit I/O. Connect a crystal oscillator between X_{IN} and X_{OUT}.
X_{OUT}	4	O	
ADC input	24	I	The audio input to be tuned is connected here. The input signal should be in the range ADC V_{SS} – ADC V_{CC}.
$\overline{\text{SELECT}}$	8	I	See user-interface section for more information. Normally connected to V_{CC}, and pulled to V_{SS} by a momentary switch.
$\overline{\text{REFERENCE}}$	18	I	See user-interface section for more information. Normally connected to V_{CC}, and pulled to V_{SS} by a momentary switch.
EXPRESSION/ TUNER select	17	I	Switches between EXPRESSION and TUNER measurement. Connect to 0V for EXPRESSION, V_{CC} for TUNER. This can be changed at run-time by a user-adjustable switch, or can be fixed.
Reference tone out	20	O	A square-wave tone is output at the chosen reference frequency (437Hz–443Hz).
MIDI out	1	O	MIDI note-on is output for the measured note, and MIDI note-off is output when this note changes, or stops being detected.
Tuning meter LEDs	9–15	O	These are connected to the tuning-meter LEDs which indicate real-time cents variation of the measured pitch. They also indicate the selected reference (A_{440}) frequency. These outputs can directly drive 2mA LEDs.
7-SEG #	22	O	The "sharp" LED. Used with the note name output to show sharp or natural note names of the note being measured. Typically, this is connected to the decimal-point of the 7-segment display, or to another dedicated LED.
7-SEG	25–27, 29–32	O	The measured note name and selected temperament number are shown on the 7-segment display. These are connected (using the standard lettering of 7-segment displays) as 32(a), 31(b), 30(c), 29(d), 27(e), 26(f), 25(g).
$\overline{\text{MIDI enable}}$	16	I	Low on this pin will enable MIDI output.

2.2 Crystal Oscillator

The **FPE100** requires an external oscillator connected to X_{IN}/X_{OUT}. A typical connection is shown in Figure 3. Since the frequency of this oscillator determines the accuracy of tuning measurements, an accurate crystal oscillator with an accuracy of at least 100ppm is recommended. The values of the capacitors C_{IN} and C_{OUT} should be chosen according to the specifications of the crystal—incorrect values of these capacitors can cause significant errors in the resonant frequency, and thus in the instrument tuning.

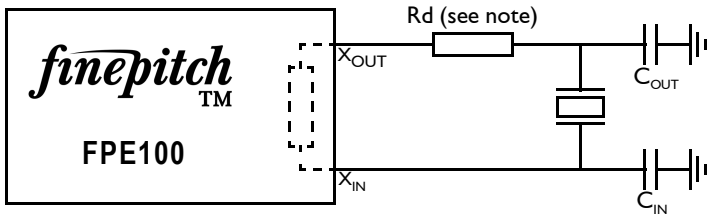


Figure 3: Connection of an external crystal oscillator. Insert a damping resistor (R_d) if required. Use the value recommended by the maker of the oscillator. FPE100 includes an internal feedback resistor in the oscillator drive circuit.

2.3 Anti-alias filter

The analogue input (ADC input) requires an external low-pass anti-alias filter. It is recommended that this filter is constructed to provide at least 15dB of attenuation at a frequency of 1250Hz in TUNER mode and 1550Hz in EXPRESSION mode. To compensate for the typically lower amplitude of an instrument's higher frequencies, this filter can be designed with an increased Q-factor to boost the higher frequencies slightly.

Ideally, different anti-alias filters should be used in TUNER and EXPRESSION modes, but where this is not possible it is usually acceptable to choose either specification and limit the EXPRESSION mode high-frequency capability by attenuating at 1250Hz, or allow some aliasing in tuning mode by attenuating at 1550Hz.

2.4 MIDI velocity

The velocity given to MIDI notes depends on the peak amplitude of the signal as shown in Figure 4, where V_{ADC} = ADC V_{CC} – ADC V_{SS}. The relationship is linear up to an amplitude of $V_{ADC}/8$, beyond which maximum MIDI velocity is assigned. Typically, the input gain of the external circuitry is user-adjustable to optimise the "feel" of the instrument. The clip indication is then used to ensure the input gain is not too high.

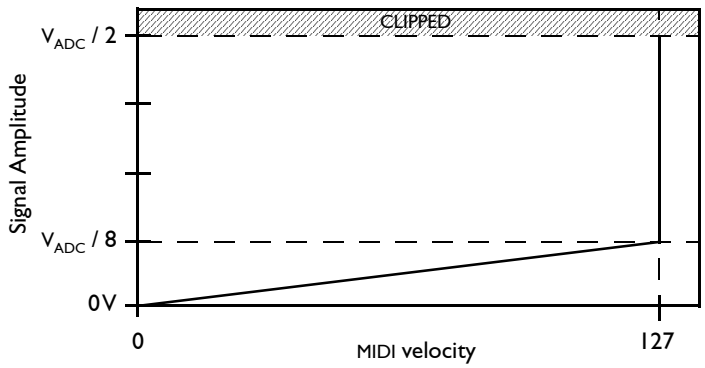


Figure 4: The relationship between the input signal amplitude and the velocity of a MIDI note generated by this signal. The maximum signal amplitude is $V_{ADC}/2$ since the signal is biassed at $V_{ADC}/2$.

3 User Interface

3.1 Button and switch inputs

Three inputs are provided to control various aspects of the *finepitch*™ **FPE100**. These can be connected to user-accessible switches or they can be hard-wired depending on the application. $\overline{\text{REFERENCE}}$ (pin 18) and $\overline{\text{SELECT}}$ (pin 8) should be connected to momentary switches which pull the signal low when actuated, EXPRESSION/TUNER (pin 15) should be connected to a latching or slide switch.

3.1.1 EXPRESSION/TUNER mode select input

A single input ('EXPRESSION/TUNER' pin 15) is provided for connection to a mode select switch. This selects the operational mode of the device.

TUNER mode is used for instrument tuning and is optimised for pitch detection over range 70Hz to 1100Hz. Frequencies as low as 40Hz can be measured in TUNER mode, but sub-cent accuracy may not be achieved at these ranges; typically the measurement accuracy is around 1 cent at these frequencies. Figure 5 illustrates the measurement performance. Note that no MIDI is output in this mode.

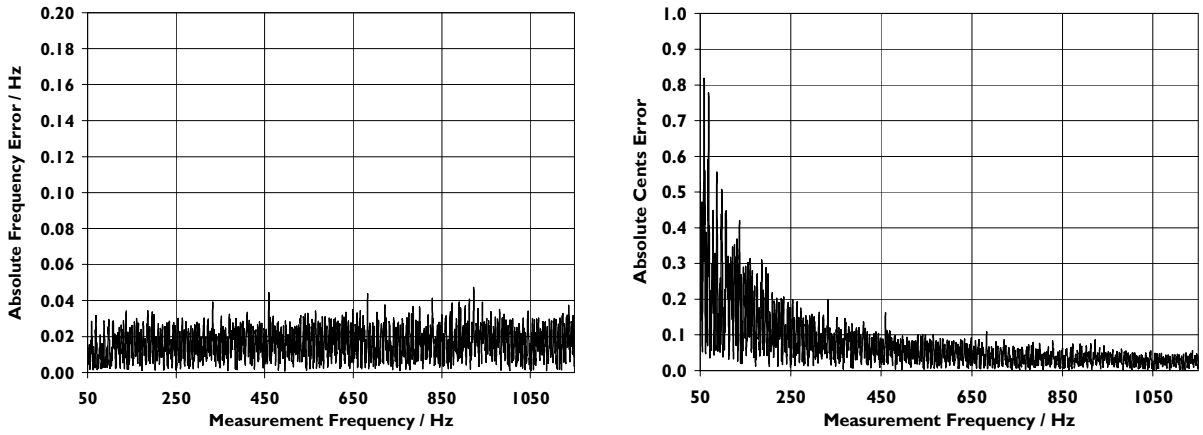


Figure 5: Maximum measurement errors for a sinusoidal input signal, in TUNER mode.

EXPRESSION mode is used for real-time pitch-to-MIDI operation and is optimised for the range of a standard guitar: C2–E6. In this mode, MIDI notes with velocity information (see Section 2.4) and pitch-bend scaled to ±2 semitones is output. When desired, pitch-bend output can be turned off (see Section 3.1.4). The conversion time from the reception of a new pitch to the output of a MIDI note is typically 35ms. This time may vary depending on the content of the input signal.

Only a monophonic input signal will be accurately converted to MIDI data. Thus only "solo" performances can be converted to MIDI. However, the *finepitch*™ **FPE100** has been designed to operate in parallel with other *finepitch*™ **FPE100** devices to facilitate multi-channel, polyphonic operation (*e.g.,* one **FPE100** per guitar string). To simplify this operation, the $\overline{\text{MIDI enable}}$ line (see Section 3.6) allows gating of the MIDI output to ease merging of multi-channel MIDI data in an external microcontroller.

3.1.2 Reference select input (TUNER mode)

A single input ($\overline{\text{REFERENCE}}$ pin 18) is provided for connection to a 'reference select' key. This allows the tuning reference frequency to be set within the range 437Hz to 443Hz, at 1Hz intervals; the default being 440Hz. If the reference select function is not required, pin 18 should be connected to V_{CC}.

The $\overline{\text{REFERENCE}}$ input has two modes of operation:

(a) Asserting the $\overline{\text{REFERENCE}}$ input low for a short period (< 1s) then de-asserting it, will cause the square wave reference tone output on pin 20 to be toggled between on and off.

(b) Asserting the $\overline{\text{REFERENCE}}$ input low for greater than 1s will cause the reference frequency to switch to the next available frequency (+1Hz). On reaching the maximum 443Hz, the next frequency selected will be 437Hz. If the $\overline{\text{REFERENCE}}$

input continues to be held low, the reference frequency will cycle through the available range, switching every 1s. Once the desired frequency is reached, the REFERENCE input should be de-asserted.

The selected reference frequency is indicated via the 7-LED tuning meter. Once the reference frequency has been changed, the appropriate LED will flash briefly to confirm the change (see section 3.2 for more detail).

3.1.3 Instrument (temperament) select input (TUNER mode)

A single input (SELECT pin 8) is provided for connection to an 'instrument (or temperament) select' key. This provides selection between three tuning temperaments: (1) Equal-tempered ("normal"), (2) Just Major ("wind") and (3) Pythagorean ("string"), the default being equal-tempered. If the instrument select function is not required, pin 8 should be connected to V_{CC}.

The instrument selection method is similar to that described in section 3.1.2(b), *i.e.,* asserting the SELECT input low for greater than 1s will cause the next temperament to be selected. If the input continues to be held low, the temperament will cycle through those available. Once the desired temperament is reached, the SELECT input should be de-asserted.

The selected temperament is indicated on the temperament select LED display and the root note (key) for the temperament is also displayed on the 7-segment display (see section 3.2 for more detail). When a new temperament is selected, the root note and selected temperament will flash briefly to confirm the change.

3.1.4 Pitch-bend control (EXPRESSION mode)

By default, pitch-bend MIDI messages are always sent in EXPRESSION mode. However, often it is desirable to send note information without pitch-bend. This can be achieved in two ways using the SELECT (pin 8) and REFERENCE (pin 18) inputs.

The first method is designed to be used by an end-user. Asserting the REFERENCE input low for greater than 1s then de-asserting it will cause the pitch-bend output mode to be toggled. The current state of this mode is indicated on the tuning LEDs: 440Hz illuminated means pitch-bend will be output, 441Hz illuminated means pitch-bend will not be output. While the REFERENCE input is asserted low, the current mode will be indicated.

The second method is designed to be used within an integrated system. When both the REFERENCE and SELECT inputs are asserted low at the same time, pitch-bend will not be output. When either or both of these inputs are high (the default) pitch-bend will be output. This method overrides, but does not modify the state of, the first method.

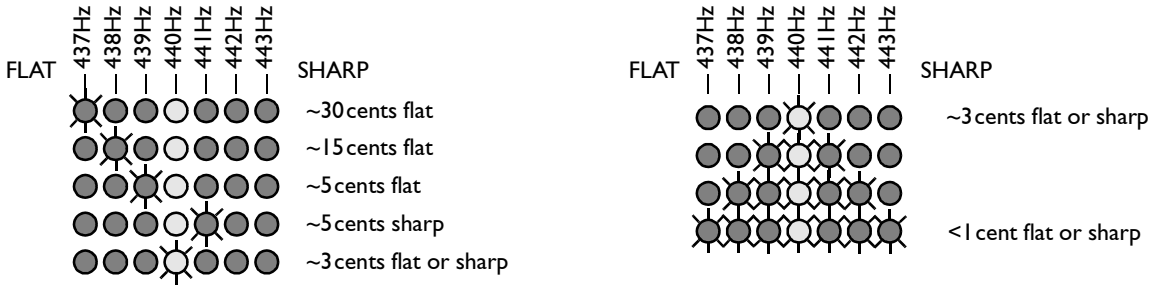
3.2 LED tuning meter

The **FPE100** provides connection to 7 LEDs which form a visual tuning meter. Three LEDs indicate flat tuning, a central LED indicates in-tune and three LEDs indicate sharp tuning relative to the note shown on the 7-segment display (see section 2.1 for LED meter connection information).

Figure 6 shows how the 7-LED meter indicates the cents deviation from the target note. Variations in the intensity of the LEDs allow finer graduations in the pitch to be visualised than would otherwise be possible with 7 LEDs. Tuning precision is obtained by virtue of the fine-tune indication where several LEDs illuminate as the detected pitch becomes closer to the target pitch. When the deviation is less than 1 cent, all LEDs are illuminated. Typically, the central LED is coloured differently to provide additional feedback to users.

The tuning meter provides a secondary function in conjunction with the reference select input. As described in section 3.1.2, when the REFERENCE input is asserted low and held, an individual LED will light to indicate the selected tuning reference frequency. The range of frequencies indicated is 437Hz to 443Hz, with the 'in-tune' output representing a frequency of 440Hz. Once the REFERENCE input is de-asserted, the 7 LEDs return to the tuning meter function. These reference frequencies are also indicated in Figure 6.

In EXPRESSION mode, the tuning meter flashes the central 440Hz LED briefly every 2s. This indicates that the unit is switched on, and is in EXPRESSION mode while consuming minimal power. The LEDs are also used to indicate the state of MIDI pitch-bend output (see Section 3.1.4).



Single LED illumination with variable intensity modulation of neighbouring LEDs shows coarse tuning and clearly indicates small variations in pitch.

Multiple LED illumination shows fine tuning with high clarity and accuracy.

Figure 6: Indication of cents deviation on 7-LED meter.

3.3 Instrument temperaments

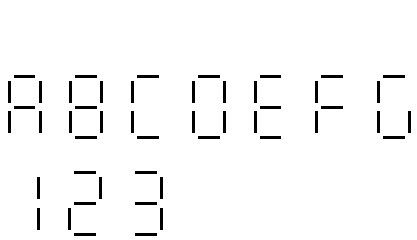
The selected temperament is indicated on the 7-segment display as a number as shown in Table 2 when the SELECT key is activated (see section 3.1.3 for more details). The temperament can only be selected in TUNER mode, but is applied in both TUNER and EXPRESSION modes.

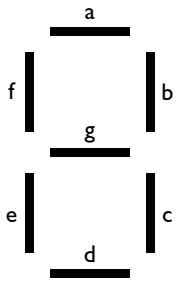
Table 2: Available temperaments

Temperament Number	Temperament Name	Application
1	Equal Tempered	General purpose
2	Just Major	Wind instruments
3	Pythagorean	Stringed instruments

3.4 7-segment display and # LED

The **FPE100** provides a connection for a 7-segment display. A separate pin is also provided to drive a sharp (#) LED indicator (typically the decimal point of the 7-segment display would connected to this). The **FPE100** cannot directly drive a 7-segment display. Instead, a simple transistor array must be used to drive this display. To reduce total current requirements of the design, the 7-segment display is driven so that only one segment is active at any time.





Segment	Pin
a	32
b	31
c	30
d	29
e	27
f	26
g	25
decimal point	22

Figure 7: The standard lettering of the segments of a 7-segment display (top-view). This shows which pins are connected to which segments (via additional driver circuitry). The segments used to indicate letter (for notes) and numbers (for temperaments) are also shown.

3.5 Clip indication (on # LED)

When a maximum amplitude (*i.e.,* possibly-clipped) signal is detected, the sharp(#) LED indicator is illuminated briefly. While this is active, all the other LEDs are extinguished to ensure the clipped state is observed by the user. The user should decrease the input level to avoid clipping. The optimal performance is obtained with large-amplitude signals that are not clipped.

3.6 MIDI output

MIDI note-on and note-off messages are output from pin 1 whenever a note is detected. This note matches the note displayed on the 7-segment display and includes both the note and the octave of the note. Pitch-bend information is also output (unless this feature is disabled, see Section 3.1.4). If MIDI output is not required, this pin can be left disconnected.

MIDI output can be enabled and disabled at any time by using the $\overline{\text{MIDI enable}}$ line. This simplifies merging of MIDI data in multi-channel systems (*e.g.,* polyphonic MIDI guitar) and it can also be used as a note-latch function in EXPRESSION mode (*e.g.,* controlled by a footswitch).

Note that MIDI data is only output in EXPRESSION mode. No MIDI data is output in TUNER mode.

4 Electrical Characteristics

Table 3: Absolute maximum ratings

Symbol	Parameter	Rated Value	Unit
V_{CC}	Supply voltage	–0·3 to 6·5	V
ADC V_{CC}	ADC supply voltage	–0·3 to 6·5	V
V_I	Input voltage	–0·3 to V_{CC}+0·3	V
V_O	Output voltage	–0·3 to V_{CC}+0·3	V
T_{opr}	Operating temperature	–20 to 85	°C
T_{store}	Storage temperature	–65 to 125	°C

Table 4: Recommended operating conditions

Symbol	Parameter	Min	Typical	Max	Unit
V_{CC}	Supply voltage	3·0	3·3	5·5	V
—	Supply current (at 3·3 V)[a]	2·5	4·5	6·5	mA
ADC V_{CC}	ADC supply voltage	—	V_{CC}	—	V
V_{SS}	Supply voltage	—	0	—	V
ADC V_{SS}	ADC supply voltage	—	V_{SS}	—	V
$f(X_{IN})$	Operating frequency	—	20·000[b]	—	MHz
LED_{OUT}	Tuning meter LED output current (per LED)	—	2	2·5	mA
7-SEG_{OUT}	7-segment LED output current (per segment)	—	0·1	1	mA

a. The supply current does not include any current required by directly-driven LEDs.
b. The main clock frequency determines the accuracy of all measurements. It is recommended that a crystal of the specified frequency is used with a tolerance of <= 100ppm.

Table 5: Audio and MIDI

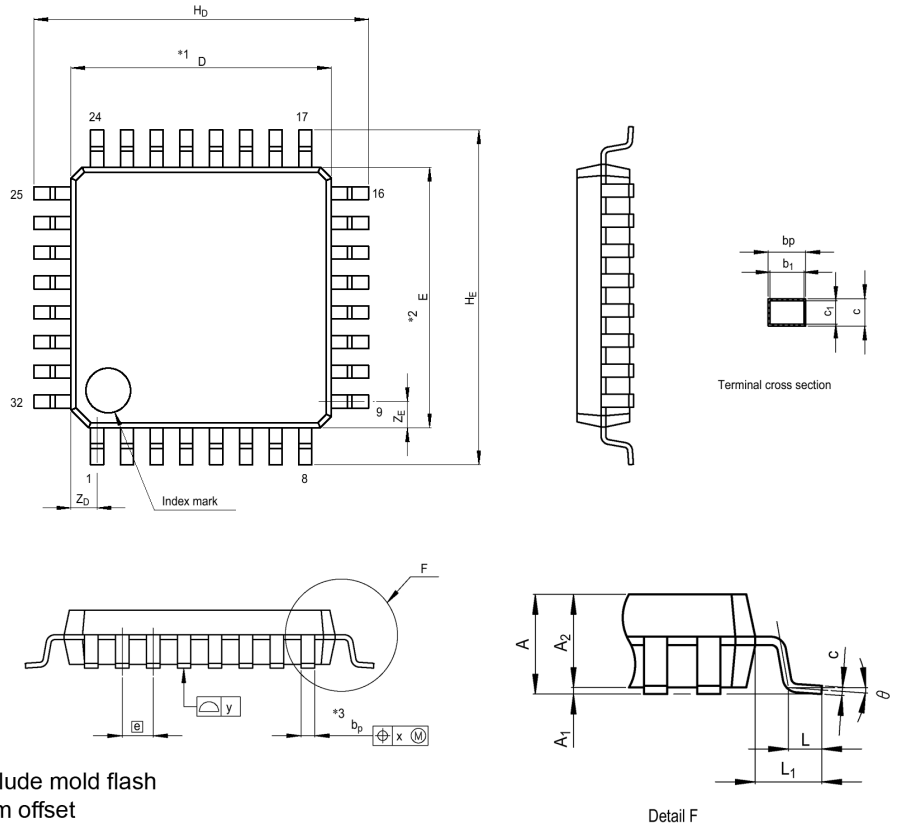
Parameter	Rated Value	Unit
Audio input level	V_{SS}–V_{CC}[a]	V
Reference tone output level	Square wave V_{SS}–V_{CC}	V
Reference tone frequency	437, 438, 439, 440, 441, 442, 443	Hz
MIDI baud rate	31250	baud
Pitch-to-MIDI conversion time	35 (typical)	ms

a. A bipolar audio input should be biased to set the zero-level to (V_{CC} – V_{SS}) / 2. The measurement system is tolerant of DC offsets, so the exact bias point is not critical.

5 Physical Characteristics

The **FPE100** is packaged in a low-profile quad flat pack with 32 pins (LQFP32). The dimensions of this package are shown in Figure 8.

Reference Symbol	Dimension in Millimeters		
	Min	Nom	Max
D	6.9	7.0	7.1
E	6.9	7.0	7.1
A_2	——	1.4	——
H_D	8.8	9.0	9.2
H_E	8.8	9.0	9.2
A	——	——	1.7
A_1	0	0.1	0.2
b_p	0.32	0.37	0.42
b_1	——	0.35	——
c	0.09	0.145	0.20
c_1	——	0.125	——
θ	0°	——	8°
e	——	0.8	——
x	——	——	0.20
y	——	——	0.10
Z_D	——	0.7	——
Z_E	——	0.7	——
L	0.3	0.5	0.7
L_1	——	1.0	——



NOTE:
1. Dimensions "*1" and "*2" do not include mold flash
2. Dimension "*3" does not include trim offset

Figure 8: Package Dimensions (JEITA Package Code P-LQFP32-7x7-0.80).

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