Abstract

This document describes the procedure for generating an LRA configuration script for optimal performance with the DA7280 Haptic Driver I.C.
Generating an LRA Configuration Script for DA7280

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1 Terms and Definitions

359-02-B Performance Board PCB containing DUT, LRA and accelerometer circuitry
BEMF Back electromotive force is the voltage that opposes the change in current which is induced in it.
LOOP_CAP LOOP_FILT_CAP_TRIM register
LOOP_RES LOOP_FILT_RES_TRIM register
LRA Linear resonant actuator
Override value Used to set the output drive level in DRO mode.
POR Power on reset

2 References

[1] DA7280, Datasheet, Dialog Semiconductor

3 Introduction

This document describes the procedure for creating the configuration setup script for the Jahwa 1040 LRA (product number JHV-10L5-L000SB). This procedure is applicable to any LRA.

The configuration script created for the LRA on this Performance Board would be used as the basis for the customer's final product. A further tuning for the actual product with the LRA properly mounted inside its final housing would also need to be performed.

4 Attaching the LRA

The attaching of the LRA on the Performance Board or within a customer product can have dramatic performance differences if not secured correctly.

- Ideally, you want as little movement as possible when the LRA is vibrating.

For the Performance Board, use double sided sticky pads with high adhesion strength - it works adequately but would not represent the optimal way to hold the LRA. The LRA could also be glued down for better mechanical contact but removing and changing the LRA would be difficult without damaging both the LRA and the Performance Board.

For more information on mounting see - UM-AU-011 DA7280 - Performance Board User Manual.
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Please follow the LRA manufacturer's datasheet best practices for attaching the LRA securely without adversely affecting performance. For example, a custom housing gripping the LRA on each side is usually the preferred method in mobile phones, an example is shown below.

![LRA mounted in mobile phone](image)

**Figure 1: LRA mounted in mobile phone**

## 5 Procedure

This section describes the setup procedure in detail. It is important to follow this procedure sequentially. At the end of this procedure, a setup script will be saved that should be downloaded to DA7280 after power on reset (POR) to configure DA7280 for operation with the specific LRA being used.

Connect the Performance board to the computer and run the SmartCanvas GUI. Ensure the Performance Board is not directly in contact with a hard surface. The Performance Board should be placed on foam or sponge to improve damping from the hard surface.

The setup script can also contain Waveform Memory data; this document will not describe this feature in any detail. For detailed description on Performance Board, GUI and Waveform Memory please refer to the UM-AU-011 DA7280 - Performance Board User Manual document.
5.1 Tuning flow diagram

Shown here is the tuning flow diagram, each step is detailed in this document.

Figure 2: Tuning flow diagram
5.2 Examine the LRA’s Electrical Characteristics

From the LRA datasheet, note the LRA electrical characteristics. These parameters are used as the basis for driving the LRA correctly. See below for Jahwa 1040 parameters:

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated voltage</td>
<td></td>
<td>$2.5V_{rms}$ (Sinewave)</td>
</tr>
<tr>
<td>Resonant frequency</td>
<td></td>
<td>$170$ Hz $\pm$ 5</td>
</tr>
<tr>
<td>Rated current</td>
<td>$2.5V_{rms}$</td>
<td>Max. 170 mA</td>
</tr>
<tr>
<td>Terminal resistance</td>
<td>Between terminals</td>
<td>$12\pm2\Omega$</td>
</tr>
</tbody>
</table>
| Noise                 | $2.5V_{rms}$ | Touch : Max. 35 dB  
                        |                        | Band : Max. 35 dB    
                        |                        | THD : Max. 25%        |

*Figure 3: LRA’s Electrical Characteristics*

5.3 Measure the Impedance and Inductance of the LRA

Before connecting the LRA to the Performance Board, the impedance and inductance should be measured between the two terminals of the motor:

- Measured Impedance = 12.6 Ohms
- Measured Inductance = 354uH

5.4 ABS_MAX and NOM_MAX Setup

Set ABS_MAX and NOM_MAX to be the same value as per datasheet, in this case 2.5V. See 5.6.

- NOM_MAX is the nominal maximum RMS voltage.
- ABS_MAX is the absolute maximum RMS voltage.
- If ACCELERATION is disabled, unsigned full scale is set by ABS_MAX.
- If ACCELERATION is enabled, unsigned full scale is set by NOM_MAX and ABS_MAX is the level reached when overdriving by the automatic algorithm.

Setting ABS_MAX above NOM_MAX is recommended when the ACCELERATION_EN feature is used and the user wants to allow DA7280 to overdrive the LRA for short periods by the automatic algorithm inside DA7280.

5.5 Calculate I Max

Always allow for 10% extra I Max current as specified by the LRA manufacturer to compensate for the BEMF. If no I Max is specified in the datasheet, please use the ABS_MAX voltage divided by the Measured Impedance.

- $I_{Max} = 170$mA $\times 1.1 = 187$mA
5.6 Updating Settings in the GUI

Manually enter the following values or as closer as possible values into the GUI using the sliders and numerical entry boxes, always press ENTER after numerical data to boxes.

- Abs Max = 2.5
- Nom Max = 2.5
- I Max = 0.187
- Override Value = 0.6
- Resonant Frequency = 170, then press Enter
- Impedance = 13 then press Enter
- Inductance = 354 then press Enter (this automatically sets the LOOP_CAP and LOOP_RES trim values, see 4 for further explanation)

![GUI screenshot showing settings](image)

**Figure 4: Entering DC Parameters to the GUI**
5.7 Using DA7280 to Measure the Resonant Frequency and Impedance of the LRA

To accurately measure the resonant frequency and impedance using DA7280, set the operation mode to 'Direct register override' to drive the LRA. The GUI will then report to the user what are the actual LRA resonant frequency and impedance. At this point the DA7280 settings have been updated automatically and the next time a haptic effect is driven, DA7280 will use the newer and more accurate values as a starting point. Switch the operation mode back to INACTIVE to stop driving the LRA.

![GUI Showing Resonant Frequency and Impedance](image)

Figure 5: GUI Showing Resonant Frequency and Impedance
5.8 Kp & Ki tuning

The closed-loop frequency tracking on DA7280 is implemented via a proportional-integral (PI) controller. Good closed-loop frequency tracking ensures the resonant frequency tracking and rapid Stop features works as optimally as possible.

The proportional coefficient is stored in FRQ_PID_Kp_H/L and the integral coefficient in FRQ_PID_Ki_H/L. The default values of the coefficients are optimized to cover a wide range of LRA actuators with typical settling times of approximately 40ms from a 20 % frequency offset.

The Kp and Ki registers can be found on the SYSTEM tab.

![Figure 6: GUI the FRQ_PID_K* Registers](image)

5.8.1 LRA Tuning Tool overview

DA7280 GUI has an LRA Tuning Tool plugin to automate finding the best Kp and Ki values for any LRA.

In Tools select LRA Tuning Tool.

![Figure 7: Launching the LRA Tuning Tool](image)
Figure 8: LRA Tuning Tool

Sweep Defaults:
- These are the start and stop limits for the Kp and Ki coefficients.

Target Parameters:
- Settling Time: Time for Resonant Frequency to settle to within 0.5Hz of the initial Resonant Frequency level.
- Rise Time: Time for Resonant Frequency tracking to cross the initial Resonant Frequency level.
- Frequency Overshoot Target: Percentage overshoot of the Initial Resonant Frequency Target.

Sweep Mode Settings:
- Plot Target Parameters: When ON this means the Plot will only show when the actual Settling Time, Rise Time and Frequency Overshoot Targets are below the set Target Parameters. Switching this OFF means every plot will be shown regardless of Target Parameters.
- Stop Sweep when targets reached (ON by default), the sweep stops and cannot be continued from stop point.

RUN/STOP Sweep Analysis:
- Run the entire sweep analysis as defined by the Kp and Ki defaults from the initial settings.

Current Kp Ki Settings:
- Use to run the sweep analysis once as defined by current Kp and Ki settings.
5.8.2 Run default Kp and Ki settings

Deselect the Plot Target Parameters tick-box and press RUN SWEEP ON CURRENT KP AND KI SETTINGS to run 1 sweep showing the Kp and Ki plot.

Sweep results can be seen below; note the step change injected before the 1 second mark and the settling behavior. The user can then select better settling behavior by trading aggressiveness of the Kp/ki settings with regards to settling time, stability, and overshoot.

The blue trace is the average frequency been read back from DA7280. Ideally, we want this to settle to the resonant frequency as quickly as possible, for the overshoot (amount it overshoots the resonant frequency) to be low, and the settling time (time it settles to within 0.5Hz of resonant frequency) to be as short as possible. Depending on the LRA been tuned, the target parameters may need to be changed depending on how fast/slow the LRA response times are, this requires experimentation with Target Parameters and Kp and Ki values.

![Figure 9: Running default Kp and Ki sweep](image)

- Rise time: The rise time is 129.24ms and would be considered slow for this LRA.
- Overshoot: Very low overshoot of 0.84%, ideally looking for <2%.
- Settling time: The settling time is very long at 275ms and shows significant oscillation as it tries to sync to the resonant frequency.

The ringing/oscillation behavior in the settling period as it tries to sync to the resonant frequency suggests the Kp and Ki default settings are unstable, a full Sweep Analysis is required.
5.8.3 Example of stable Kp and Ki response

A full Sweep Analysis has been run and the Target Parameters set as shown below, note the Frequency Overshoot Target (%) has been set to 2%, the Plot Target Parameter and Stop Sweep when targets reached is ON this ensures that the as the sweep runs only when the targets have been met the sweep stops and the resulting plot is then shown, this is the fastest way to get results.

The following observations can be made:

- Rise time: The rise time is fast at 62ms.
- Overshoot: Very low overshoot of 0.64%.
- Settling time: Fast settling time at 69.94ms with good damping in the settling period.

The Kp and Ki values are producing stable performance.
5.8.4 Example of unstable Kp and Ki response

Figure 11: Poor Frequency Tracking Settling Behavior; Poor Loop Stability

The following observations can be made:

- **Rise time**: The rise time is 49.13 ms.
- **Overshoot**: Overshoot of 3.27% which is within the initial target specification of <5%.
- **Settling time**: The settling time is 245.02 ms with poor damping.

These parameters for Kp and Ki show unstable performance with long settling time around 2.4x the initial target parameter.
5.8.5 Procedure for tuning Kp and Ki for any LRA

1. Ensure Operation Mode is set to Inactive Mode in USER Tab of main GUI.
2. Ensure Performance Board is isolated from hard surface.
3. Keep the initial Sweep Defaults as per GUI.
4. Change Target Parameters Frequency Overshoot Target to 2%.
5. Keep Sweep Mode Settings as per GUI.
6. Press the ‘RUN SWEEP ON CURRENT KP AND KI SETTINGS’
   - Determine if the default settings are stable, see section: Run default Kp and Ki settings. If they are not stable, then continue to next step.
7. Press RUN/STOP Sweep Analysis Button, this now runs a full Sweep analysis and could take up to 20 minutes to run.
8. The tool will now begin to capture the data for the Frequency Tracking Response.
   - By deselecting the Plot Target Parameters; it will show each plot regardless of the response meeting the Target Parameters, this will slow down the overall run time of the sweep as each plot is now shown to the user.
   - With Stop Sweep box checked it will stop when target parameters are reached.
9. When a sweep response meets the Target Parameters, visually observe that the ringing within the settling period is stable, see section: Example of stable Kp and Ki response
10. The TOP_INT_CFG6 and TOP_INT_CFG7 registers now hold the correct Kp and Ki values for this LRA.
5.9 Connect the Oscilloscope for Debug

Ensure the Performance Board is not directly in contact with a hard surface. The Performance Board should be placed on foam or sponge to improve damping from the hard surface below.

- Channel 1 to OUTN_F (Connector J2)
  - This is the filtered OUTN signal from DA7280
- Channel 2 to OUTP_F (Connector J2)
  - This is the filtered OUTP signal from DA7280
- Channel 3 to Z-AXIS (Connector J1)
  - Measures the vibrations caused by the LRA's movement driven from DA7280 and outputs this as voltage

Note: On the existing accelerometer setup on the 359-02-B board the output capacitors at C13, C14, C16 are with 100nF value giving a cutoff of 50Hz. Should an absolute accuracy acceleration measurement be needed, please replace them with 10nF capacitors for 500Hz cutoff. The absolute scale of the output is 295mV for 1G of acceleration, but the above modification needs to be carried out before relating the output of the accelerometer into Gs.

![Figure 12: Connecting Oscilloscope to Performance Board](image-url)
5.10 When to use the Active Acceleration and Rapid Stop features

Active Acceleration and Rapid Stop only work with frequency tracking enabled.

Active Acceleration works best on actuators with slow start up times (> 40ms) it does not require any calibration; it requires the ABS_MAX setting to be set higher than the NOM_MAX.

- Rapid stop feature only works for sequences longer than 3 half periods and requires calibration, see section Tuning the Rapid Stop Performance.
- For very fast actuators (with start times <40ms) Rapid Stop may not function optimally and manual breaking to stop the LRA may be required as shown in UM-AU-011 DA7280 - Performance Board User Manual, section named JAHWA_1040_FREQ_TRACK_ON and Sequence 2.

5.11 Checking Active Acceleration Performance

The GUI settings are shown below, Frequency Tracking is On and Acceleration is Off. Note that ABS_MAX and NOM_MAX are now different from the previous settings.

- It is also possible to increase ABS_MAX to overdrive beyond the datasheet specification, however the start-up time does not improve significantly for this LRA.

![GUI settings for checking Acceleration feature](image)

Figure 13: GUI settings for checking Acceleration feature
With Acceleration Off, change the mode to Operation Mode to Direct Register Override and capture the startup output acceleration.

![Figure 14: Acceleration Off](image)

- This LRA reaches maximum output acceleration of 143.25mV in 20.3ms with Acceleration Off.

Change Operation Mode back to Inactive, switch Acceleration On, now change the mode to Direct Register Override and capture the startup output acceleration.

![Figure 15: Acceleration On](image)

- This LRA reaches maximum output acceleration of 152.25mV in 20.5ms with Acceleration On.
Conclusion: enabling the Acceleration feature has no real impact on the startup time of this LRA as both are almost identical ~20ms to maximum output acceleration or maximum drive signal level. The extra output acceleration ~6% with Acceleration On can be observed residing to the same nominal level in both cases within 2 to 3 full periods. Acceleration should be switched Off for this LRA.

For LRA's with slower start times, with Acceleration On it should improve the time to reach maximum output acceleration. Here is an example with Acceleration ON improving the startup time to maximum output acceleration.

![Graph showing comparison between Acceleration Off and Acceleration On]

**Figure 16: Example of when Acceleration ON improves start-up time**
5.12 Check Stopping Performance with Rapid Stop Disabled

In the GUI, set ABS_MAX and NOM_MAX as shown, set the Override Value close to 0.5 and set the Operation Mode to Direct Register Override (also shortened to DRO from this point). See Figure 17: Setting up DRO Mode.

Figure 17: Setting up DRO Mode
The signals on the oscilloscope should look like these; the LRA is oscillating at its resonant frequency of 161 Hz producing 157mv peak-to-peak acceleration (see red box in Figure 18)

- Channel 1 (yellow trace) is showing OUTN filtered signal.
- Channel 2 (green trace) is showing OUTP filtered signal.
- Channel 3 (blue trace) is showing the Z-AXIS acceleration signal from the accelerometer.

**Figure 18: Driving in DRO Mode**
With operation mode set to Direct Register Override, now change the Operation Mode to Inactive and capture on the oscilloscope the stopping performance. The OUTP and OUTN signals stop switching and the LRA slowly stops oscillating. This is the normal behavior without Rapid Stop enabled.

Figure 19: No Rapid Stop Performance
5.13 Tuning the Rapid Stop Performance

Rapid Stop is the automatic algorithm inside DA7280 used to quickly stop an actuator. Depending on the actuator chosen, it might require additional tuning to optimize performance. Please follow the procedure below for that:

Enable Rapid Stop in the GUI.

![Enabling Rapid Stop](image)

**Figure 20: Enabling Rapid Stop**

TST_AMP_RAPID_STOP_LIM in register TOP_INT_CFG8 sets the rapid Stop threshold at which DA7280 stops driving while braking. The mechanism itself is based on BEMF sensing; a higher register value corresponds to a higher BEMF voltage threshold.

![TOP_INT_CFG8](image)

**Figure 21: TOP_INT_CFG8**
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The following procedure is repeated with values 3 to 4 for TST_AMP_RAPID_STOP_LIM

1. Set TST_AMP_RAPID_STOP_LIM to start at value 3, increase value, and repeat points 2 and 3
2. Enable DRO mode
3. Switch to Inactive Mode
4. Capture the stopping performance on the oscilloscope

An ideal setup has the least amount of ringing after rapid stop is engaged and the quickest settling time within ~20ms window.

Note that TST_AMP_RAPID_STOP_LIM value should always be equal or greater than the value of TST_FREQ_TRACK_BEMF_LIM.

Looking at the OUTP and OUTN (the green and yellow) signals below in Figure 22, one can see that:

- The voltage level for the last two half periods of the drive signal has increased.
- The drive signal phase has reversed. Instead of another OUTN signal (yellow signal) following the OUTP (green signal) the device actually gets another OUTP (green signal).

Looking at the acceleration profile (blue trace), the period after the rapid stop has been engaged we are terming the ‘20ms stop window’. In this period we ideally want to see:

- Low ringing
- Fast settling to very low residual oscillations of the LRA

Setting TST_AMP_RAPID_STOP_LIM=3

As explained above, the stopping performance within the 20ms stop window is poor as the Rapid Stop threshold is too low and the stopping continues for too long.

![Image of oscilloscope showing OUTP and OUTN signals with excessive ringing and continual oscillations during the 20ms stop window.]

Figure 22: TST_AMP_RAPID_STOP_LIM=3
Setting TST_AMP_RAPID_STOP_LIM=4

Acceleration profile below shows a very good stop performance whereby the LRA has stopped in a short time, <10ms, and the amount of residual ringing within 20ms after the rapid stop has been engaged is very low.

![Image](image_url)

Figure 23: TST_AMP_RAPID_STOP_LIM=6

**5.14 Save All Registers**

Now save the register settings to file ensuring that the Kp and Ki settings are the same as noted down in 5.8, this is your setup script for the now tuned LRA.

The File Format can be Number or Name, whereby either the register number or register name is saved to the file.

![Image](image_url)

Figure 24: Save All Registers
Appendix A

A.1 Searching for Registers in the GUI

To easily find any register, simply enter the register name in the Search Widget in the GUI. Select All Text and press Find Button.

Figure 25: Search Widget in GUI
A.2 Notes on using the Acceleration feature

- If Acceleration is Enabled, then V2I_FACTOR_OFFSET_EN should also be enabled this applies a 50mV offset to the V2I factor calculation.
- If Acceleration is Disabled, then V2I_FACTOR_OFFSET_EN should be disabled and no offset is applied to the V2I factor calculation.

Figure 26: Setting V2I_FACTOR_OFFSET_EN

- MEM_DATA_SIGNED needs to be set according to the value of ACCELERATION_EN. The GUI automatically sets this.
  - 0: Unsigned (for ACCELERATION_EN = 1)
  - 1: Signed (for ACCELERATION_EN = 0)

Figure 27: MEM_DATA_SIGNED Bit
A.3 Overdriving the LRA

The ABS_MAX could be increased for overdriving the LRA, please consult with LRA manufacturer about reliability concerns regarding overdriving voltages.

A.3.1 Acceleration Enabled

If ACCELERATION_EN=1, then the automatic algorithm in DA7280 will overdrive for short periods of time to the ABS_MAX level when transitioning between drive levels to speed up the mechanical response of the actuator before dropping to NOM_MAX or below (based on the drive level being set via DRO/PWM/WM).

A.3.2 Acceleration Disabled

If ACCELERATION_EN=0, then the drive level sent via any input (DRO / PWM / WM) will scale directly to ABS_MAX. Should the user require to overdrive above the LRA datasheet parameters, the timing is fully controlled by the user.

A.3.3 Compensating for the BEMF

ABS_MAX and NOM_MAX are based on the I*R drop across the actuator and do not factor in the BEMF voltage amplitude (which is usually negligible). If the customer requires no overshoot above the specified datasheet value, the following procedure can be followed:

1. Do the initial setup as specified in this document
2. Drive at full scale DRO value of 1.0.
3. Observe the filtered down OUTP or OUTN voltage on the scope
4. Scale back ABS_MAX until the voltage is below the datasheet parameter
5. Update the saved script using the new ABS_MAX value

The process for setting up a 2V maximum voltage drive including the BEMF is shown graphically below:

![Figure 28: Scaling Back Drive for Nominal 2V Output](image)

A.3.4 Acceleration Disabled

If ACCELERATION_EN=0, then the drive level sent via any input (DRO/PWM/WM) will scale directly to ABS_MAX. Should the user require to overdrive above the LRA datasheet parameters, the timing is fully controlled by the user.
A.4 VDD Margin

VDD_MARGIN is a register that determines the space in the voltage domain between the output across the actuator and the supply. This is important because DA7280 is a current-loop controlled driver and if it runs out of voltage headroom, the system will stop regulating current, which in turn ruins all the closed loop algorithms. VDD_MARGIN is programmable in steps of 187.5mV where 0 is 0V margin, 1 is 187.5mV margin, etc. It needs to be greater than the combined values of the BEMF, IR drop across the power FETs, and the limit imposed by the maximum duty cycle.

Constants:
1. Usual maximum impedance of the H-bridge – 2 Ohm
2. Maximum duty cycle – 93%
3. BEMF rule-of-thumb – 100mV to 200mV (needs to be checked on the specific actuator at maximum nominal settings)

Example using an LRA actuator with 140mA I max, 160mV BEMF, and 24Ω impedance below:
1. IR drop is 140mA * 2Ohm = 280mV
2. At 3.8V, max duty cycle of 93% means DA7280 cannot drive at the top 0.07 * 3.8 = 266mV (3.8V selected as it is the realistic value where the device is expected to start infringing on the limit)
3. BEMF is about 160mV
4. From the above, the needed margin is 280mV + 266mV + 160mV = 706mV
5. Closest setting to that is VDD_MARGIN=4, which gives 4 * 187.5=750mV

Note: It is advisable to sweep VDD over its expected range with DRO set at 1 and observe the voltage across the LRA for instabilities. Should those be present, increase the VDD_MARGIN value.
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Revision History

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<thead>
<tr>
<th>Revision</th>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>June 2018</td>
<td>Released version</td>
</tr>
<tr>
<td>1.1</td>
<td>October 2018</td>
<td>LRA Tuning Tool updates.</td>
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Status Definitions

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<th>Status</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>DRAFT</td>
<td>The content of this document is under review and subject to formal approval, which may result in modifications or additions.</td>
</tr>
<tr>
<td>APPROVED or unmarked</td>
<td>The content of this document has been approved for publication.</td>
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</tbody>
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