I3C Application Note:
Hot-Join

For MIPI I3C® v1.1+ & MIPI I3C Basic℠ v1.1.1+

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This document is subject to further editorial and technical development.

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Release History

Date	App Note Version	Description
04-Sep-2021	v1.0	Initial Board approved release.

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1 Introduction

The MIPI I3C Bus interface ***[MIPI01]*** is an evolutionary specification that improves upon the features of the I^2C specification. I3C offers a flexible multi-drop interface between a host processor and peripheral devices, reducing the number of physical pins, and supporting low-power, high-speed digital communication.

I3C's main features include:

- Multi-Controller and Multi-drop capabilities
- Only two physical lines: SDA and SCL
- Dynamic Addressing
- In-Band Interrupts
- Timing synchronization
- Hot-Join support
- Backward compatibility with I^2C

The I3C interface is expected to play a fundamental role in streamlining sensor integration in smartphones, wearables, and Internet-of-Things (IoT) devices. This Application Note is intended to help users understand how the I3C interface's Hot-Join feature works.

1.1 Scope

This Hot-Join Application Note is intended:

- To help those developing MIPI I3C Target Devices with Hot-Join capabilities understand how these Devices can make use of this feature.
- To help those developing MIPI I3C Controller Devices (both Primary Controllers and Secondary Controllers) understand how to handle Hot-Join Requests.
- To guide System Designers in deciding how to adopt I3C Hot-Join features in their Devices, based both on Hot-Join's possible uses and on its restrictions.
- To guide electrical requirements and safe insertion precautions for Hot-Joining Devices

2 Terminology

Also see Section 2 in the MIPI I3C Specification ***[MIPI01]*** or the MIPI I3C Basic Specification ***[MIPI02]***.

2.1 Definitions

Active Controller: The I3C Device that presently has control of the I3C Bus.

Bus: The physical and logical implementation of the SCL and SDA lines.

Bus Idle Condition: A period during which the Bus Free Condition, after a STOP and before a START, is sustained continuously for a duration of at least t_{IDLE}.

Controller: An I3C Device (or Role embodied by such a Device) that is capable of controlling the I3C Bus. I3C and I3C Basic versions prior to v1.1.1 used the term Master, which MIPI Alliance has deprecated.

Master: Deprecated term, see Controller.

Slave: Deprecated term, see Target.

START: The I3C Bus condition of a High-to-Low transition on the SDA line while the SCL line remains High. In this Application Note, a START is abbreviated as ‘S’.

STOP: The I3C Bus condition of a Low to High transition on the SDA line while the SCL line remains High. In this Application Note, a STOP is abbreviated as ‘P’.

System Designer: Engineer designing a system that includes an I3C Bus.

Target: An I3C Device (or a Role embodied by such a Device) that can only respond to either Common or individual commands from a Controller. Some Targets can initiate In-Band Interrupt requests on the I3C Bus. I3C and I3C Basic versions prior to v1.1.1 used the term Slave, which MIPI Alliance has deprecated.

2.2 Abbreviations

e.g.	For example (Latin: exempli gratia)
i.e.	That is (Latin: id est)

2.3 Acronyms

BCR	Bus Configuration Register
CCC	Common Command Code
DCR	Device Configuration Register
DAA	Dynamic Address Assignment
I3C	MIPI Improved Inter Integrated Circuit interface or its Specification document ***[MIPI01]***
IBI	In Band Interrupt

3 References

[MIPI01] *MIPI Alliance Specification for I3C® (Improved Inter Integrated Circuit)*, version 1.1.1, MIPI Alliance, Inc., 11 June 2021 (MIPI Board Adopted 11 June 2021).

[MIPI02] *MIPI Alliance Specification for I3C Basic℠ (Improved Inter Integrated Circuit)*, version 1.1.1, MIPI Alliance, Inc., 9 June 2021 (MIPI Board Adopted 23 June 2021).

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4 Overview

This Application Note illustrates the Hot-Join feature in I3C system designs.

It details:

- Requirements deriving from the I3C Specification ***[MIPI01]***
- Different types of Hot-Join
- Requirements to send a Hot-Join Request
- How Targets should initiate a Hot-Join Request
- How Controllers should handle received Hot-Join Requests
- How Target designers may provide a way to enable or disable the Hot-Join feature

For each Hot-Join feature, the relevant parts of the I3C Specification are identified. Implementation advice is also provided for the most complex Hot-Join features, in order to help avoid system design errors.

4.1 Supported Capabilities

Readers developing aspects of I3C-based systems should consult the relevant Application Note sections for guidance not found in the I3C Specification itself. This information is intended to help avoid implementation mistakes.

4.2 Using Added Functionality

The I3C Specification includes optional extended functionality, and the flexibility to allow for different use cases. Some of these use cases have implications for the System Designer and for software on the Controller.

The I3C Specification is focused on how each feature works from a protocol perspective; by contrast, this Application Note provides additional information on how each feature can be incorporated into a system. This additional information is intended to guide both assessments of whether it will be possible to accomplish what is wanted, and assessments of how to accomplish it.

4.3 Use Cases for a Target Sending Hot-Join Requests

The I3C Bus protocol supports a mechanism for Devices to join the I3C Bus after it has already been powered and configured. A Target issuing a Hot-Join Request exploits the In-Band-Interrupt procedure to ask the Active Controller to assign the Target a Dynamic Address. Getting a Dynamic Address will allow the Target to then fully participate in I3C Bus activity, including gaining the role of a Secondary Controller.

Use cases for a Target issuing a Hot-Join Request include:

- A Target Device that is physically inserted into the I3C Bus not at Bus initialization time, but later, after the Bus has already been configured.
- A Target that is mounted on the same board as the Controller, but is kept powered-down until it is needed. Such a Target may send the Hot-Join Request when it is powered-up.
- A Target that was previously assigned a Dynamic Address, but has now lost it. For example, after being powered off, or after a hard reset.
- A Target Device that is behaving as an I^2C Device but detects an I3C Frame on the Bus, indicating that the Bus is also capable of I3C communication.
- A Target that is powered-on only when needed on the Bus, and kept powered-off otherwise.

5 The Hot-Join Concept

I3C's Hot-Join mechanism allows an I3C Device to inform the Active Controller that a newly-joined Target is present on the I3C Bus and is ready to receive a Dynamic Address, in order to become fully functional on the Bus. The I3C Specification ***[MIPI01]*** defines the conditions under which a Target may issue the Hot-Join Request, and the expected behaviors. A Device that is issuing a Hot-Join Request, for any reason, should do so only after the I3C Bus has already been powered and configured.

An I3C Device always joins the I3C Bus as a Target. Only after the Device has been properly initialized may it become a Secondary Controller.

The Hot-Join mechanism requires the joining Target to send a special In-Band-Interrupt (IBI) Request to trigger the Hot-Join procedure. The Target must wait for a Bus Idle condition before sending the Hot-Join Request. The Bus Idle condition is defined as a period during which the Bus Available status is maintained for a duration of at least t_{IDLE} (which is ~200 µs), meaning that the SCL and SDA lines are both held High for the t_{IDLE} period. The Bus Idle condition duration was chosen specifically to help ensure Bus stability during Hot-Join events.

Note:

> *In I3C v1.0, the Bus Idle time t_{IDLE} was defined 1 ms, not ~200 µs as used in I3C v1.1 and higher. Be aware that if any I3C v1.0 Devices are present on a Bus, they could use the original 1 ms Bus Idle time.*

Once a joining Target has determined that the Bus is in the Bus Idle condition, it may initiate a Hot-Join Request by performing the following sequence:

1. The joining Target pulls SDA Low, then waits for the Active Controller to act
2. The Active Controller, detecting the condition, pulls SCL Low, thus generating a START
3. The Active Controller then clocks the SCL line, to get the Reserved Target Address (i.e., 7'h02).
4. The joining Target issues the Reserved Target Address 7'b000 0010 with the 8^{th} bit set to 0 (write) to notify the Active Controller that a Target Device on the Bus needs a Dynamic Address to become fully operational.
   - Typically, the joining Target is the only Device on the Bus with no Dynamic Address assigned, so if the Active Controller initiates the Dynamic Address procedure, then the joining Target will be the only Device to participate in the Dynamic Address Arbitration (DAA) and receive a Dynamic Address.
   - However, it is also possible for multiple Devices to send their Hot-Join Requests simultaneously. In this case, the DAA procedure will iterate and assign Dynamic Addresses to all Targets requesting an Address.
5. Once the joining Target has been assigned its new Dynamic Address, it is fully operational on the I3C Bus.

A Hot-Join Request is a special form of then In-Band Interrupt (IBI), in which the joining Device uses the Hot-Join reserved Address 7'h02 for the Target Address and sets the R/W bit to 0 (Write). With the Hot-Join reserved Address, no Mandatory Data Byte follows the request; this allows the Active Controller to take control of the Bus after the 9th clock as shown in ***Figure 1***.

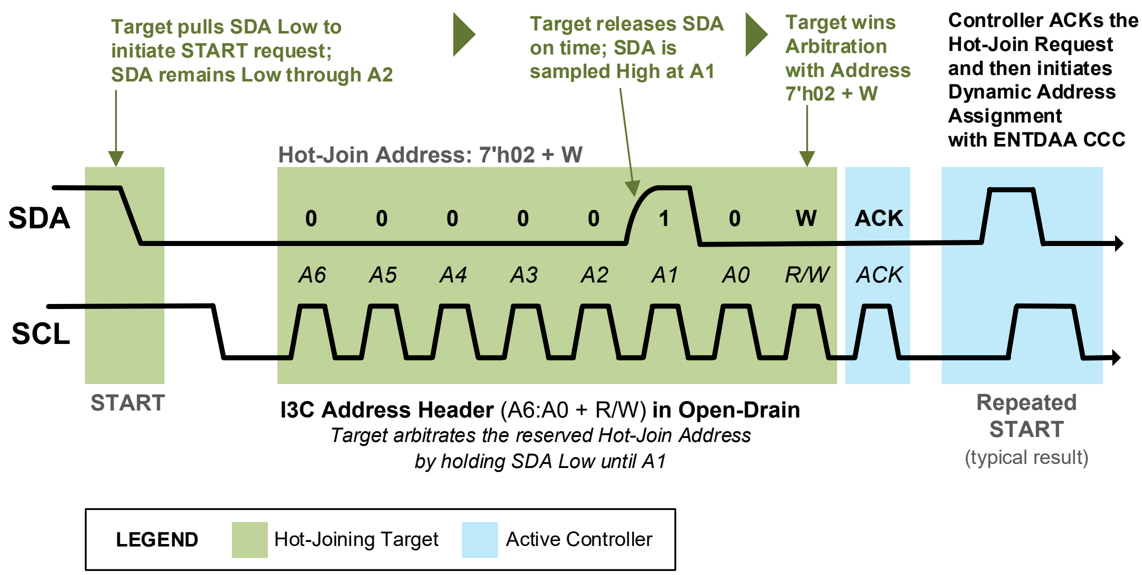

Figure 1 Hot-Join Request with In-Band Interrupt (IBI)

There are several potential situations where a Target Device might be unable to send the Hot-Join Request, or where the Active Controller cannot immediately start the DAA procedure after receiving the Hot-Join Request, for example:

1. If the Hot-Join Request occurs either before the Active Controller has initialized the Bus, or during Bus initialization. In such cases the Active Controller can hold the SCL line, thereby preventing the Bus Idle Condition from being met (and in turn preventing the Hot-Joining Target from detecting that the Bus Idle Condition has been).
2. If the Target drops off the Bus during the Hot-Join sequence, either by becoming physically detached or because it loses power.

If the Active Controller is unable to initiate the DAA procedure for any reason, then it always has the option to simply NACK the IBI request.

5.1 Controller Handling of Hot-Join Request

The Current Controller can perform one of three actions after receiving a Hot-Join Request:

1. NACK the request. The Target attempting to Hot-Join will try again, following the I3C Target Interrupt Request procedure.

Or

2. ACK the request, but disable Hot-Join. To do this, issue a Broadcast ENEC/DISEC CCC (ENable/DISable Target Events Command) with the DISHJ (DISable Hot-Join event) bit set.

Or

3. ACK the request and then issue a Broadcast ENTDAA (Enter Dynamic Address Assignment) CCC to start the Dynamic Address Assignment process.

When an Active Controller that is capable of handling Hot-Join Requests from I3C Target Devices receives one, it should perform the following procedure (also illustrated in ***Figure 2***):

1. The Hot-Joining Target detects an idle, issues an IBI Request, and the Active Controller ACKs the request.
2. The Active Controller issues a Repeated START followed by the Broadcast Address (7'h7E + W)
3. The Active Controller issues the ENTDAA CCC (ENTter Dynamic Address Assignment) as described in ***Section 5.1.4.2*** of the I3C Specification ***[MIPI01]***.
4. The Target responds to the ENTDAA CCC by sending its 48-bit Provisional ID, followed by its BCR and DCR values.
5. The Active Controller sends the Target its 7-bit Dynamic Address + parity to the Target. Thus, the Target acquires a Dynamic Address.
6. It’s possible for more than one Target to require servicing with the DAA process. In this case, the Active Controller will continue to assign Dynamic Addresses until it receives a NACK for the Reserved byte transfer. This NACK indicates that all Targets that required DAA servicing have been initialized, and so the DAA process is concluded.
7. The Active Controller terminates the sequence by issuing a STOP.
8. If the Active Controller knows that any Secondary Controllers are on the I3C Bus, then it sends a DEFTGTS CCC (DEFine list of TarGeTS) to inform all Controller-capable Devices on the I3C Bus about the newly-configured Device(s).

At this point the I3C Bus is fully configured, and one or more newly-joined Targets are active on the Bus.

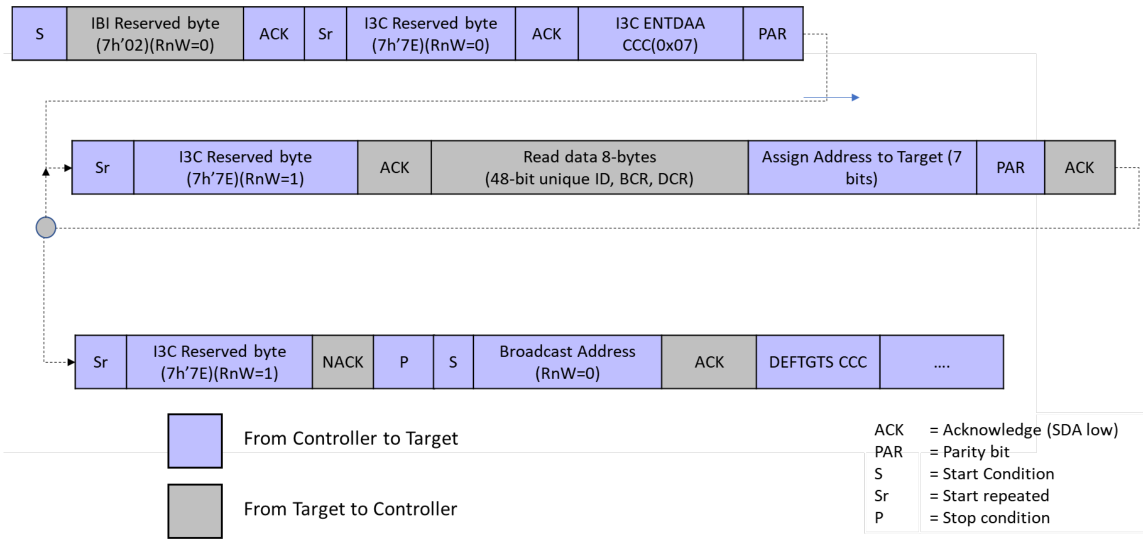

Figure 2 Typical Hot-Join & Dynamic Address Assignment Data Flow

5.1.1 Alternate Method

The Active Controller also has another option for handling the Hot-Join Request.

After the ACK following the 7h'02 IBI, the Active Controller emits a Broadcast DISEC CCC (DISable Events Command) with the DISHJ bit set (DISable Hot-Join event). This will prevent other Hot-Join Requests from being issued. If another Target then attaches to the Bus (or powers-up) and tries a Hot-Join Request, then it will not have seen this DISEC CCC with DISHJ bit, so the Active Controller may repeat the DISEC CCC with DISHJ bit.

The Active Controller can NACK the Hot-Join Request after the 7h'02 IBI for any of the following reasons:

- The system was not designed to accommodate the Hot-Join
- The Active Controller is not capable of handling Dynamic Address Assignment
- The Active Controller is busy with other tasks. (In this case, the Controller should send a DISEC CCC with the DISHJ bit set to prevent repeated Hot-Join Requests.)

5.2 Device Detach

The Active Controller should monitor the status of the Device(s) attached to the Bus so it can detect any disconnection. Devices that are observed to exchange data vis the Bus are clearly attached, but for Devices with no data exchange the Active Controller can monitor presence via a polling technique, i.e., by periodically issuing a GETSTATUS CCC (GET Device STATUS). If there is no response to the GETSTATUS CCC, then the Active Controller can assume that the Device has detached from the Bus, either physically or being powered down.

If a Device is capable of going offline (which will be indicated in BCR Bit[4]), then the Active Controller should try to wake the Device up using the GETSTATUS CCC with a few retries. If there is still no response to the GETSTATUS CCC, then the Active Controller should remove the Device from the list of configured Devices.

If any Secondary Controller Devices are on the I3C Bus, then the Active Controller should immediately notify them about the new Bus configuration whenever the Active Controller detects the detachment of any Device(s). This is done by issuing a DEFTGTS CCC (DEFine list of TarGeTS) with the updated configuration of the Bus.

5.3 Target I3C Protocol Requirements

For an I3C Target Device to be capable of performing Hot-Joins, it must implement the following I3C protocol requirements:

- Support the ENEC and DISEC CCCs (ENable Events Command and DISable Events Command). This allows the Controller to enable and disable Hot-Join Requests.
- Support the Dynamic Address Assignment (DAA) process of the ENTDAA CCC (ENTer Dynamic Address Assignment). This allows the Target to receive its I3C Dynamic Address from the Controller, which is a key prerequisite before the Target can become active on the I3C Bus.
- Possess an internal oscillator allowing measurement of the Bus Idle Condition time period.
- Ignore all ENTDAA CCCs (ENTer Dynamic Address Assignment) that the Active Controller might send before the Target sends its Hot-Join Request.

5.4 Target Hot-Join Eligibility Requirements

As described in the following sub-sections there are two different types of Hot-Joining Devices. Each type has its own eligibility requirements that must be met before the joining Device can send a Hot-Join Request.

5.4.1 Bus Idle Time Requirements

All Devices that join the Bus should:

1. Follow the Bus electrical and safety requirements. This ensures that the Devices will not cause any electrical communication issues on the Bus.
2. Wait for the minimum Bus Idle time before sending a START or arbitrating to send their Hot-Join Request.

5.4.2 Passive Hot-Join Requirement

The following requirement applies for all I3C Devices that work as I^2C Devices, but which can also send a Hot-Join Request after determining that the Bus is an I3C Bus. (A Bus can be considered an I3C Bus if the Device detects the following pattern: START followed by the I^2C Reserved Address 7'h7E; this is the I3C Broadcast Address.)

Once the Device detects this pattern ending with a STOP, the Device can enable its Hot-Join feature. However, the Device cannot then send any Hot-Join Request until after the Bus Idle Time condition is met (see ***Section 5.4.1***).

5.5 Target Electrical Requirements

For safe insertion on the I3C Bus without disrupting Bus operation, Target Devices designed to perform Hot-Joins should adopt the following safety features:

- The physical design of the Hot-Joining Target's connector should ensure connection of each signal separately, per the system designer's intentions.
- The I/O PIN capacitance should not exceed the maximum specified by the specification: 5 pF for VDD < 1.8V, and 10 pF for VDD ≥ 1.8V.
- SDA and SCL should be in High-Z after Hot-Joining until the SDA-Low request is sent.
- Keep the internal (active or resistive) Pull-Up and Pull-Down disconnected from the from the SDA and SCL lines.

6 Hot-Join Types

There are four types of Hot-Join, as described in the following sub-sections:

- **Hot Plug Hot-Join**
- **Hot Swap Hot-Join**
- **Offline Hot-Join**
- **Passive Hot-Join**

6.1 Hot Plug Hot-Join

The I3C Specification does not define physical connectors for Hot Plug, focusing instead on the logical effect of a Hot-Join onto the I3C Bus. However the specification does provide basic guidance and some rules for the designer of the physical connector.

The most critical requirement for the Hot-Plug or Hot-Unplug operation is to not disturb the I3C Bus SCL or SDA lines in any way that is perceptible to the Targets and Controllers on the Bus.

This requirement leads to three guidelines for Hot-Plug connector design:

1. **Ground should be connected first, to stabilize the ground plane.**
    - Make the ground connector 'finger' longer than the other fingers, so that ground is always connected first. This can also be handled via a connector jacket that connects first.
    - To avoid ground plane bouncing on the mother/base board, consider impedance issues.
2. **If possible, design the connector so that the Power pin is connected before any of the I/O pins.**
    - See ***Section 6.1.1*** below for Failsafe considerations.
    - The operating voltage of the I3C Devices on the plug-in module should be reasonably matched to the mother/base board.
    - Current inrush management might be needed to avoid a voltage drop to the I3C Bus sufficient to cause erratic behavior. Generally this is set by the ramp rate if a PoL Regulator is used on the plug-in module. It is also advisable to have an adequate decoupling capacitance on the base board near the connector.
    - Consider using a ferrite bead (or similar) to control high-frequency noise that can feed through the base board; this could cause noise amplification on the newly plugged-in board.
3. **The I/Os for SCL and SDA should not cause unwanted current draw or impedance changes during the connection.**

    In addition to that, there are few restrictions:

- In addition to Fail-Safe (if power is not pre-applied and is long enough to avoid this concern), it is critical to consider any pre-power-up anti-float measures that the Device might have (e.g., weak Pull-Up or Pull-Down resistances in the pads) and do a careful general pad design in terms of effective capacitance, especially in this newly powered-up (or not yet powered-up) state.
- The I3C Bus might not be able to tolerate the capacitance changes or ringing that such a connection could potentially cause. Therefore, care is required in the design of the connection and/or the connector-related characteristics of the Bus topology.
- The System Designer should consider the different topologies with the connection and without, including the effective stub from the plug-in module, as well as any inductance from the connector itself.
- The I/Os should be in High-Z until the Hot-Join mechanism drives SDA.

Note:

As a guideline for Hot-Plugging Devices, the System Designer should provide information regarding Bus capacitance.

6.1.1 Failsafe Pads Requirement

As explained in ***Section 5.1.5.1*** of the I3C Specification ***[MIPI01]***, any I/O on the I3C Bus while unpowered must use Failsafe pads, i.e., there must be no parasitic current draw from the SCL or SDA lines. Parasitic draw can be due to the current trying to power the V_{DD} rail in the Device through the PMOS (where it acts like a diode), or excess ground leakage through the NMOS, or through the ESD protection structure (when it uses an active/powered mechanism vs. fixed voltage such as snapback). The input (Schmitt) can also cause leakage beyond the allowed leakage, and capacitance, depending on the design. It is also important to look at such parasitic leakage over the temperature range at which the Bus will be operating: some Devices can perform well at room temperature, but have excessive current at higher temperatures, including due to self-heating (e.g., the Device may have been unplugged and re-plugged before cooling down).

Each Device manufacturer should document what types of pads they are using; if this is not documented, then the System Designer cannot assume that the pads are Failsafe. If the pads are not Failsafe, then separate methods can be used to isolate the Device from the Bus when using Offline, and power should be pre-connected when using Hot-Plug. For Offline, this can be isolation transistors on SCL and SDA, as long as they are capable of managing I3C switching speeds (i.e., 12.5 MHz) without excess delay (i.e., under 1 ns lag). It's also possible to disconnect from ground and power when offline, as long as reconnection can be accomplished without violating the above considerations.

6.2 Hot Swap Hot-Join

Hot Swapping is a special type of Hot-Plugging intended to address use cases where the joining Device is replacing a malfunctioning one. In a Hot Swap, the joining Device must have the same *characteristics* as the Device being replaced. Note that this is different from Hot Plugging where the joining Device is expected to have the same *features* as the Device being removed from the Bus.

Hot Swapping Devices should follow the same guidelines as Hot-Plugging Devices (see ***Section 6.1***) when plugging and removing Devices on the Bus.

Hot Swapping for identical Devices follows the same flow of operations as a Device that lost its dynamic Address when it went offline and powered up to request a Hot-Join.

6.3 Offline Hot-Join

Offline is a form of Hot-Join in which a Device is dynamically powered down and up while the I3C Bus remains continuously active. The offline Device might already be powered-up when the I3C Bus is first started (and then de-powered later), or it might be unpowered when the I3C Bus is first started and then powered up later. This situation has the potential for the Device to retain a previously-assigned Dynamic Address, which could have the advantage of speeding up and simplifying the process of re-joining the Bus.

In order not to disturb the I3C Bus when the Offline Device powers up or loses power, the Offline Device must be Failsafe on the SCL and SDA lines while unpowered. (See definition of "disturbance" in the Hot-Join section of the I3C Specification at ***Section 5.1.5***.)

There are two ways that an Offline Device can rejoin the I3C Bus:

1. By using the Hot-Join Request to get a new Dynamic Address via the DAA process
2. If the Device still retains a Dynamic Address that it was assigned in an earlier Hot-Join operation, and the Dynamic Address is still valid, then the Device can use an In-Band Interrupt (IBI), or else simply wait for a message.

   Note that any given Dynamic Address is only valid for a given session of the I3C Bus. As a result, if the previously assigned Dynamic Address is retained (e.g., standby with power supplied only to a special retention memory and pin set), then it is critical to determine whether the I3C Bus is vs. is not still in the same session as it was at the time the retained Dynamic Address was received from a DAA operation.

   If there is any doubt about whether the I3C Bus session has changed, then it is safer to use the full Hot-Join approach, because a new, valid Dynamic Address is obtained.

Offline Hot-Join resembles ordinary Hot-Join, in that the Device must first monitor the Bus and wait for a t_{IDLE} period of inactivity to verify that the Bus is free and it is therefore safe to emit the Hot-Join IBI.

In general, it is advisable for Devices with Hot-Join capabilities to be configurable to either Hot-Join the I3C Bus, or not Hot-Join the I3C Bus. As a general rule, a Device that is powered-up at the same time as the I3C Bus (i.e., when the Bus first starts) should not try to Hot-Join.

Because of the above considerations, it is advisable to make Device Hot-Join behavior configurable (i.e., whether the Device will Hot-Join the I3C Bus or not Hot-Join it), typically via some mechanism such as NVMEM or pin-strap.

6.4 Passive Hot-Join

Passive Hot-Join provides a way for I3C Target Devices to behave as I^2C Targets until and unless they detect an I3C Frame on the Bus. The I3C Hot-Join feature is not supported by I^2C Controllers; any Devices that behave as I^2C Targets before being assigned a Dynamic Address should have some separate mechanism (i.e., a method outside of the I3C protocol) to disable the I3C Hot-Join feature. (This could be via pin-strap or NVMEM.)

(See the I3C Specification discussion of Open Drain Pull-Up and High-Keeper at ***Section 5.1.3.1***)

Passive Hot-Join gives Target Devices the option of not needing a non-I3C-protocol method to disable Hot-Join and allows Targets to operate as I^2C Devices until they verify that the Active Controller is capable of I3C protocol communication.

Passive Hot-Join Devices will monitor the Bus to detect any I3C protocol SDR Frame, to verify that the Bus is capable of I3C communications. An SDR Frame starts with a START followed by a Broadcast Address (7'h7E + W) and ends with a STOP. After this STOP, the Passive Hot-Joining Target can enable the I3C Hot-Join feature and then wait for Bus Idle time to send a Hot-Join Request.

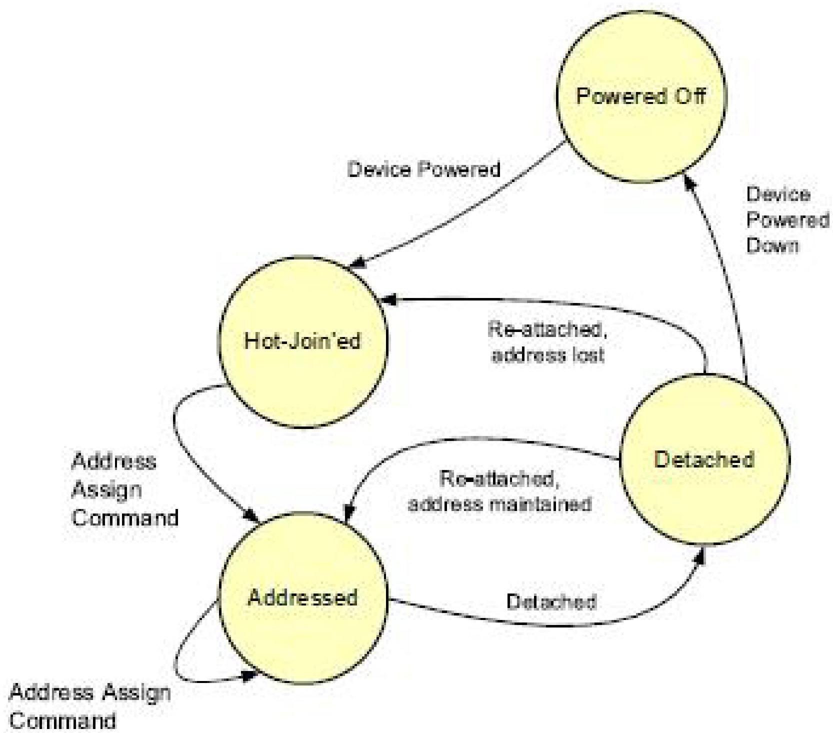

Figure 3 I3C Device State FSM

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Annex A FSM Diagrams

A.1 I3C Hot-Join FSM

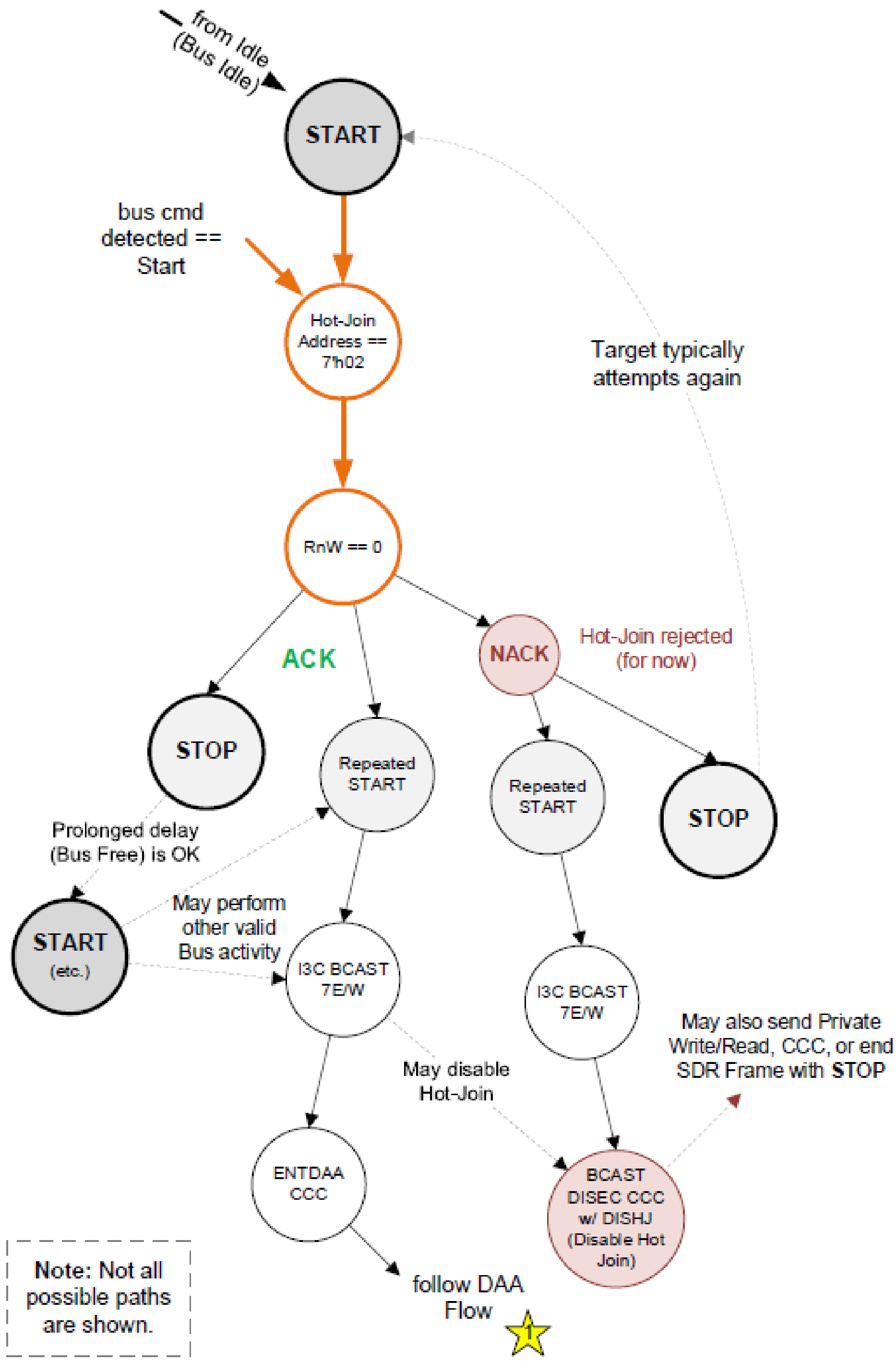

Figure 261 Hot-Join FSM

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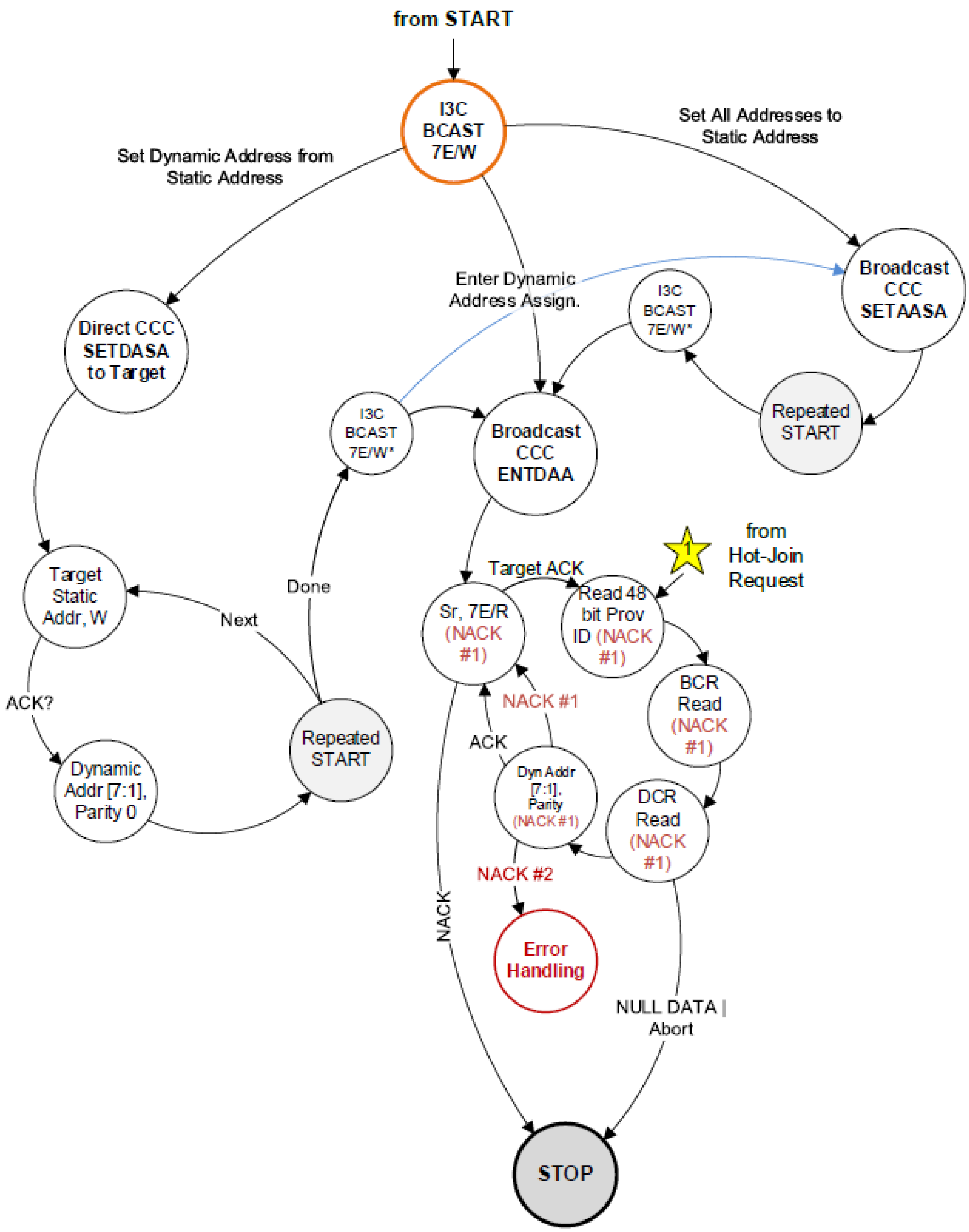
A.2 I3C Dynamic Address Assignment FSM



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