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SFP-RF: Interface Specifications for an RF-Modulated Small Form Factor Pluggable Optical Module

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1.0 SCOPE

The standardization and deployment of optical interfaces for headend equipment offer cost and power savings to MSOs. However, implementing optical interfaces in these devices presents significant technical challenges, since the lack of standardization may result in too many combinations of interfaces to support effectively in a headend device (power, wavelengths, cards, etc.).

Because of this challenge, the following specification proposes a standard for the interfaces between a downstream laser transmitter module and its host. The module is based on the [SFF-8431], but the input will consist of RF-modulated signals that will be amplitude modulated onto an optical carrier. For the purpose of this specification, this module is referred to as SFP-RF. This SFP-RF optical transmitter module could be integrated into headend equipment, such as a Converged Cable Access Platform (CCAP), a Cable Modem Termination System (CMTS), an Edge QAM, or a forward optical transmitter shelf, reducing the need for devices dedicated to forward lasers. The SFP-RF optical transmitter module will function as a downstream laser for the output of cable edge devices. The primary difference between the SFP-RF optical transmitter module and the XFP-RF optical transmitter module is the size of the module and the link lengths supported.

This standard will focus on the communications, electrical, and mechanical interfaces for the SFP-RF optical transmitter module. Unless otherwise noted, requirements held within this standard apply both to the transmitter module and its host.

2.0 NORMATIVE REFERENCES

The following documents contain provisions, which, through reference in this text, constitute provisions of the standard. At the time of Subcommittee approval, the editions indicated were valid. All standards are subject to revision; and while parties to any agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents may not be compatible with the referenced version.

Reference	Description
[IEC 61755-3-1]	IEC 61755-3-1:2006, ed. 1.0, July 1, 2006, Fibre optic connector optical interfaces – Part 3-1: Optical interface, 2,5 mm and 1,25 mm diameter cylindrical full zirconia PC ferrule, single mode fibre. IEC Sub-committee 86B
[IEC 61755-3-2]	IEC 61755-3-2, ed. 1.0, July 12, 2006, Fibre optic connector optical interfaces - Part 3-2: Optical interface, 2,5 mm and 1,25 mm diameter cylindrical full zirconia ferrules for 8 degrees

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	angled-PC single mode fibres, IEC Sub-committee 86B
[FINISH]	IEC 61300-3-35, ed. 1.0, November 20, 2009, Fibre optic interconnecting devices and passive components - Basic test and measurement procedures - Part 3-35: Examinations and measurements - Fibre optic connector endface visual and automated inspection, IEC Sub-committee 86B
[INF-8074]	INF-8074i, Revision 1.0, May 12, 2001, Specification for SFP (Small Formfactor Pluggable) Transceiver, SFF Committee, http://www.sffcommittee.com/
[XFP MSA]	INF-8077i, Revision 4.5, August 31, 2005, 10 Gigabit Small Form Factor Pluggable Module, SFF Committee, http://www.sffcommittee.com/
[SFF-8083]	SFF-8083, Revision 2.5, January 19, 2010, 0.8mm Card Edge Connector for 8/10 Gb/s Applications, SFF Committee, http://www.sffcommittee.com/
[SFF-8431]	SFF-8431, Revision 4.1, July 6, 2009, Enhanced Small Form Pluggable Module SFP+, SFF Committee, http://www.sffcommittee.com/
[SFF-8432]	SFF-8432, Revision 5.0, July 16, 2007, Improved Pluggable Formfactor, SFF Committee, http://www.sffcommittee.com/
[SFF-8433]	SFF-8433, Revision 0.7, June 5, 2009, Improved Pluggable Formfactor (IPF) for SFP+ Ganged Cages, SFF Committee, http://www.sffcommittee.com/
[SFF-8477]	SFF-8477, Revision 1.4, December 4, 2009, Tunable XFP for ITU Frequency Grid Applications, SFF Committee, http://www.sffcommittee.com/

3.0 INFORMATIVE REFERENCES

The following documents may provide valuable information to the reader but are not required when complying with this specification.

3.1 SCTE Standards and Specifications

Reference	Description
[DRFI]	ANSI/SCTE 133 2010 Downstream RF Interface for Cable Modem Termination Systems
[SCTE 55-1]	ANSI/SCTE 55-1 2009 Digital Broadband Delivery System: Out of Band Transport Part 1: Mode A
[SCTE 55-2]	ANSI/SCTE 55-2 2008 Digital Broadband Delivery System: Out of Band Transport Part 2: Mode B

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3.2 Standards and Specifications from other Organizations

Reference	Description
[UM10204]	UM10204, Version 4.0, February 13 2012, The I2C-Bus specification and user manual, NXP Semiconductors

4.0 COMPLIANCE NOTATION

"SHALL"	This word or the adjective "REQUIRED" means that the item is an absolute requirement of this specification.
"SHALL NOT"	This phrase means that the item is an absolute prohibition of this specification.
"SHOULD"	This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
"SHOULD NOT"	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
"MAY"	This word or the adjective "OPTIONAL" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

5.0 DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

Term	Definition
ADC	Analog-to-Digital Converter
AGC	Automatic Gain Control
APC	Angled Physical Contact
APD	Avalanche Photodiode
balun	A device or component that provides a transition between a balanced transmission line, circuit, source, or load, and an unbalanced transmission line, circuit, source, or load.
CLEI	Common Language Equipment Identification
EEPROM	Electrically Erasable Programmable Read-Only Memory
host	The device into which the optical module is integrated.
I/O	Input/Output
I^2C	Inter-Integrated Circuit, a 2-wire communication interface
ITU	International Telecommunication Union
NVRAM	Non-Volatile Random-Access Memory
Pmax	Maximum Composite Power
Pref	Reference composite power level that produces the optimal performance of the SFP-RF module
R/W	Read/Write
RF	Radio Frequency

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Term	Definition
RX	Receive
SCL	Serial Clock
SDA	Serial Data
SFP	Small Formfactor Pluggable
SFP-RF	Downstream optical transmitter module, based on the SFP and SFP-Plus MSAs, that transmits RF-modulated signals.
SNR	Signal-to-Noise Ratio
TEC	Thermo-Electric Cooler
TX	Transmit
UPC	Ultra Physical Contact
XFP	10 Gigabit Small Form Factor Pluggable; a standard for an optical transceiver. See [XFP MSA].
XFP-RF	Downstream optical transmitter module, based on the XFP MSA, that transmits RF-modulated signals.

6.0 MANAGEMENT INTERFACE

2-Wire Communications (I^2C) for the SFP-RF module are based upon [XFP MSA]. I^2C is an implementation of the NXP (formerly Philips) I^2C [UM10204] specification with mapped memory address locations (also known as "well-known addresses") for diagnostics and operations. The SFF Committee specifies the I^2C common memory mapping in [XFP MSA] and [SFF-8477] for SFP and XFP, as well as additional physical layer requirements. This specification uses the same well-known memory map locations (addresses) for functions that are the same or substantially similar. Because the SFP-RF is a RF transmitter (and not a digital transceiver), some memory map fields from [XFP MSA] and [SFF-8477] are re-allocated or not used; in addition, some memory map fields have been added.

The SFP-RF module shall implement the I^2C requirements specified in [XFP MSA], except where specified differently in the following sections.

6.1 Summary of 2-Wire Communications Requirements

In [XFP MSA] 2-wire communication requirements are spread across several sections, including Section 4.2 and Table 26, Section 2.6 and Table 3. The following bullets summarize these requirements; refer to [XFP MSA] for complete details.

- I^2C communications may not be available for up to 300 ms after power up or reset
- The Mod_DeSel Pin functions as defined in section 4.2 of [XFP MSA]. Note, if the I^2C interface bus is not shared, the Mod_DeSel Pin

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may be pulled *low* permanently. Note that such a "chip select" pin is new to the SFP-RF and was not included in the [SFF-8431].

- There must be at least 20 µs between the STOP signal and the next START signal for a particular module.
- The clock rate can be as high as 400 kHz (I^2C fast mode).
- Up to two START signals per command are allowed (the second START is also known as a RESTART signal).
- Only one STOP signal is allowed per command.
- Multiple master systems are not supported.
- Host boards shall accommodate SFP-RF modules which hold the SCL line low (clock stretching) for up to a maximum of 500 µs during an I^2C read or write operation.
- After a write from the host to the module, the module may not respond to further I^2C commands for up to 40 ms (typically this would be for writing non-volatile values). The phrase "not respond" means that the device address given immediately after the START signal from the host is not acknowledged by the module.
- I^2C packet error checking protocol is optional as defined in the [XFP MSA].

6.2 Theory of Operation

The operations of the SFP-RF module are based on Chapter 5: Management Interface of [XFP MSA]. The following sections define the operation of the SFP-RF module I^2C interface that is used for serial ID, digital diagnostics and other control/monitoring functions.

6.2.1 SFP-RF Module Boot-Up Sequence

When a SFP-RF module is plugged in, the host needs to perform a number of initialization steps in a particular order with a particular timing. Some of these involve the SFP-RF module pins, including the RF input, and some involve I^2C communications. As most of these are documented in the [XFP MSA] or are implied by stated dependencies, a reference to the location(s) in that document will accompany each step in the following sequence descriptions.

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Before the boot-up sequence can be discussed, communications and host requirements need to be understood.

6.2.1.1 I²C Communications Requirements

Once I²C is operational, the host shall adhere to the following timing and pin requirements (see [XFP MSA] Section 4.2, Table 26):

- The host shall pull Mod_DeSel *low* for a minimum of 2 ms before issuing the START signal (Host_select_setup).
- While Mod_DeSel is *low*, the host shall wait at least 20 µs after the previous STOP signal before issuing a new START signal (t_{BUF}).

If the SFP-RF module is not sharing the I²C interface bus with other SFP-RF modules, the Mod_DeSel pin may be left *low* indefinitely. Otherwise, it shall be pulled *high* for at least 2 ms before another command is executed on the shared bus (presumably to a different SFP-RF module).

Write operations may cause the SFP-RF module to not respond to further I²C signals or messages for up to 40 ms (t_{WR} in Section 4.3, Table 27, and Section 4.5.7 of [XFP MSA]). The specification does not restrict this to EEPROM writes. This applies for writes from one to four bytes (the limit for a write is four bytes).

The SFP-RF module may perform a clock stretch of up to 500 µs during read or write operations (T_clock_hold, [XFP MSA] Section 4.3, Table 27). This is distinct from unresponsiveness after a write operation (t_{WR}).

6.2.1.2 Pin State Prior to SFP-RF Module Boot Up

Before a SFP-RF module can begin boot up, the host shall meet the following pin requirements.

The voltages listed for pins 12 (VEE5), 15 (VCC3_DIGITAL), and 16 (VCC3_ANALOG) in Table 5 – SFP Module Electrical Pin Definition shall be available.

The value of pin 7 (P_Down/RST) should be set to *low* to allow the SFP-RF module to run in full power (power level 2), although a setting of *high* may be used to limit the SFP-RF module to low power consumption (≤ 1.0 watts).

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Refer to section 2.4.7.3, Module Behavior During Power Down and Reset of [XFP MSA] for further details.

Pin 8 ($\overline{\text{Interrupt}}$) shall be pulled *high* by the host. If an unmasked error, alarm or warning condition is encountered during operation, the SFP-RF module shall pull this value *low*.

6.2.1.3 Initial SFP-RF Module Boot Sequence

Once the SFP-RF module is inserted, it goes through its initialization sequence, as shown in the following flow chart.

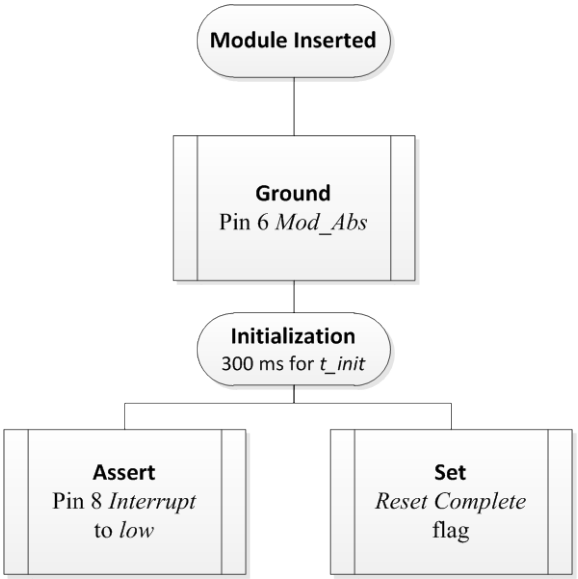

Figure 1 – SFP-RF Module Boot Sequence

This series of actions is described here.

1. The SFP-RF module shall indicate its presence to the host by grounding pin 6 (Mod_Abs) upon insertion.

2. After 300 ms, SFP-RF module initialization (aka *Reset Complete*, described in Section 2.4.7.3, Table 39 of [XFP MSA]) shall be finished (t_init, [XFP MSA] Section 2.6, Table 3).

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3. The SFP-RF module shall assert pin 8 ($\overline{\text{Interrupt}}$) to *low* and set corresponding *Reset Complete* flag ([XFP MSA] Section 2.4.7.3, Table 39). *Reset Complete* can be detected by the host via an $\overline{\text{Interrupt}}$ signal (pin 8 pulled *low*) with a corresponding *Reset Complete* flag being set.

Note that until the boot sequence is complete, pin signals may not be valid and the SFP-RF module shall not assert the $\overline{\text{Interrupt}}$ pin spuriously, as detailed in Section 2.4.7.3 of [XFP MSA].

Note that completing these steps does not imply that the SFP-RF transmitter module is ready—the Mod_NR pin is a better indicator of that condition. The *Reset Complete* flag also does not imply that registers are valid; the module sets the *Data_Not_Ready* flag (from Table 42 in [XFP MSA]) to *low* to indicate that register contents are valid and can be read.

6.2.2 Host Initialization of the SFP-RF Module

After completion of the SFP-RF module boot sequence, the host shall initialize the module, including interrupt masks, RF control, and miscellaneous parameters, as detailed in the following flow chart.

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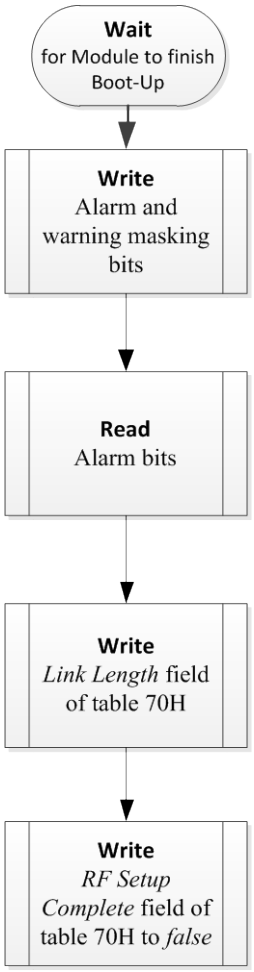

Figure 2 – Host SFP-RF Module Initialization

This series of actions is described here.

1. The host can set alarm and warning masks for any events of interest. These can be found in Table 40 in Section 5.11.1 of [XFP MSA] with the exception of those alarms and warnings listed in section 7.4.2, Lower Memory Map (Common Table). By default none of these is masked. In particular, the *Reset Complete* status bit (and its corresponding $\overline{\text{Interrupt}}$) is not masked. At a minimum, the host should set the masking bits for:

   - Receiver values (RX Power, RX_NR Status, RX_LOS, RX CDR Loss of Lock)

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- APD Supply (which is not supported)
- Wavelength Unlocked

2. The host can clear any existing latched alarms by reading those alarm bits (the alarm bits are listed in Table 39 in Section 5.11.1 of [XFP MSA]). As these flags are latched, their initial presence does not necessarily indicate a continuing fault. For example, the presence of the *Reset Complete* flag upon insertion of the module is not a fault. During initialization the SFP-RF module may not have set the TX Bias and TX Power before testing for errors. Among those that can be reasonably expected are:

   - TX_NR Status
   - Receiver values as listed above
   - Reset Complete
   - Wavelength Unlocked
   - TX Bias Low
   - TX Power Low

3. In Table 70h in upper memory, the host should update the *Link Length* field. This is a non-volatile field.

4. In Table 70h in upper memory, the host shall set the *RF Input Initialization Complete* flag to *false*. Once all RF input level tweaking is done, this flag shall be set to *true* by the host, whereupon the SFP-RF module can make any further internal adjustments that may have interfered with the host or taken a long time.

Table 70h is a new table described in section 7.4.3.3 of this document.

6.2.3 SFP-RF Module Control Sequence

Once the boot-up sequence is complete and the module has indicated that it is ready, or when the host needs to change the RF input level (e.g. to add channels), the host and module exchange information through a series of read and write actions to the module's non-volatile and volatile memory, as shown in Figure 3. These actions are written from the host's point of view.

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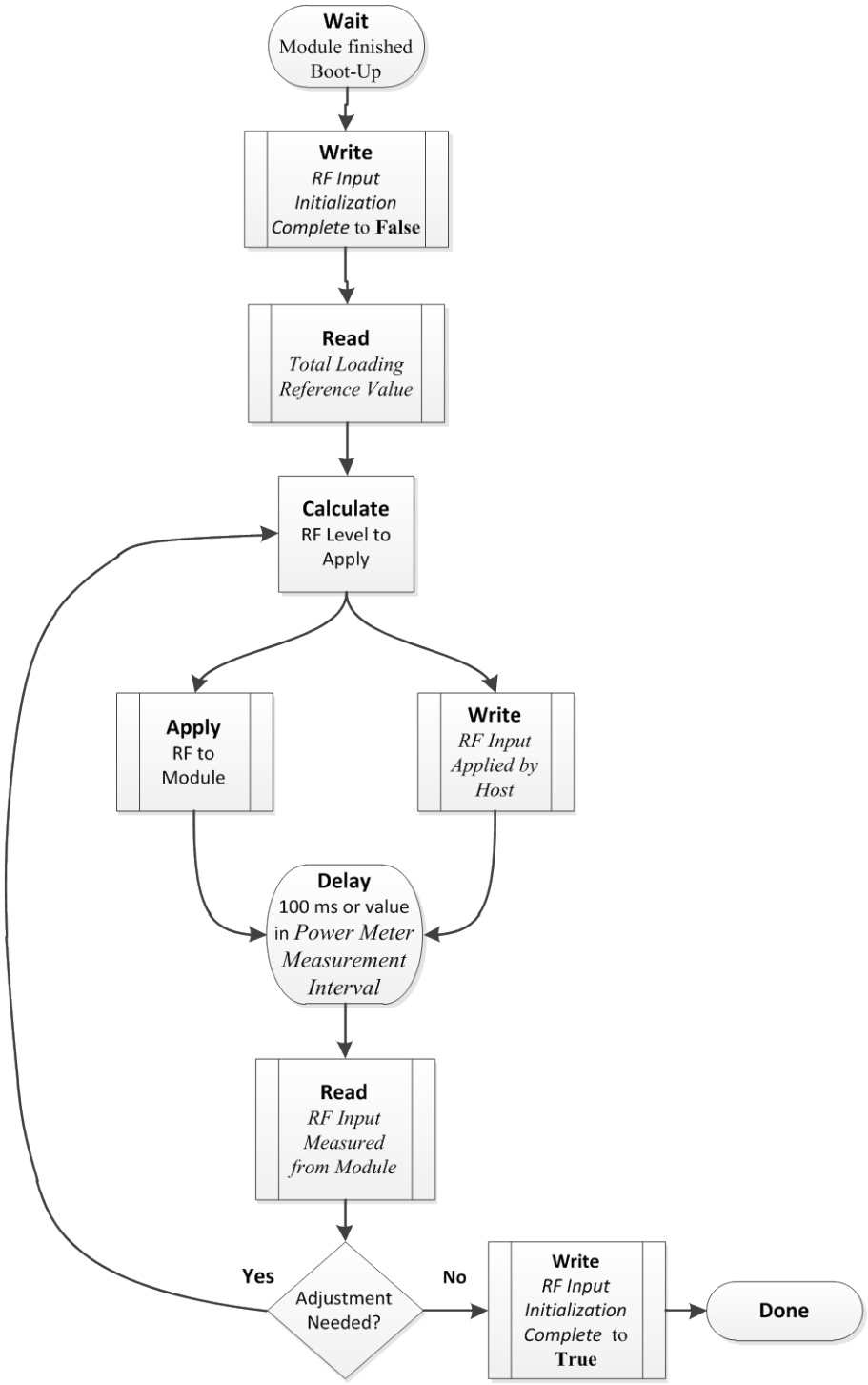

Figure 3 - Module Control Sequence

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This series of actions by the host is described here. Note that if the RF level is being changed while the module is in operation, the flow begins at step 2.

1. After boot up, the host shall wait for the SFP-RF module power-up or reset initialization (at least 300 ms).

2. The host shall read the *Pref* value from the SFP-RF module. This value reflects the RF power level required for optimal performance.

3. The host shall write false to *RF Input Initialization Complete* in the SFP-RF module.

4. Using the *Pref* value, as well as other values known to the host (such as channel plan, RF offset, etc.), the host calculates RF level to apply. The resulting RF level could be lower than the reference value if the host is not providing the full range of channels to the SFP-RF module.

5. The host shall write the RF level to the *RF Input Applied from Host* field. At the same time, the host shall apply RF at the module input.

At this point, there is the potential for tighter control in a loop. This makes sense only if the SFP-RF module has a power meter as indicated by the *Power Meter Measurement Interval* being a value other than 0 (zero). However running the loop is harmless even without a power meter; this can simplify control logic in the host.

6. Host shall pause to allow time for the SFP-RF module to update the *RF Input Measured from Module* field. This pause shall be at least the duration in the *Power Meter Measurement Interval* field or 100 ms, whichever is greater. Additional delay may be inserted to reduce dithering or network traffic.

7. Host shall read the *RF Input Measured from Module* field and decide if an adjustment is required. If there is a power meter in the SFP-RF module, its calibration may differ from the host and hysteresis should enter into the decision.

8. If an adjustment is required, the host shall go to step 4 and re-calculate the RF needed, write that value to *RF Input Applied from Host* and apply RF to the SFP-RF module. Otherwise, the host shall write *true* to *RF Input Initialization Complete* and exit the loop.

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