Electrical Isolation Requirements In Power-Over-Ethernet (PoE) Power Sourcing Equipment (PSE)

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***Abstract*—Power-Over-Ethernet (PoE) is becoming a popular way to deliver power to all types of end-point networking and peripheral equipment. Examples of equipment receiving power through Ethernet cable include wireless access points, surveillance cameras and Voice-Over-Internet (VOIP) telephones. There has been a lot written about the intricacies of the designing the 48 V power control circuits in the power sourcing equipment (PSE) and in the powered devices (PD). However, little has been said about how properly power both the 48 V sent from the PSE to the PD and the internal circuits of the PSE. The PoE standard, IEEE 802.af3, requires a high degree of electrical isolation between anything attached to the Ethernet cable and any circuitry sending and receiving transmissions over that cable. This paper starts by exploring the electrical isolation requirements of the PoE standard. It explains them in straightforward terms familiar to power supply and power system engineers. The paper then describes several power architectures for the equipment in the PSE that meet the PoE requirements. The conclusion is that there in no one right way to power PSE equipment and each equipment designer must understand the requirements and tradeoffs of their equipment in order to make the best choice.**

I. Introduction

The idea of sending power to a remote device over the same wires that carry signals is not new. Indeed, the telephone system has worked this way for more than 100 years. Since the introduction of Ethernet, people have made use of the spare pairs for many purposes, including sending power [1]. There were improvised, and generally incompatible, solutions for sending power over Ethernet cables for some time. The company PowerDSine started an effort to standardize the delivery of power over Ethernet in 1998 and recruited companies like 3Com, Intel, Mitel, National Semiconductor and Nortel Networks as promoters [2]. By the year 2000 the standards effort was well underway with many competing proposals [3]-[8]. The IEEE finally ratified the power-over-Ethernet (PoE) standard [9] on 12 June 2003.

The ideas for using power sent over Ethernet cable seem endless, including an electric shaver [10]. While a PoE powered shaver may be silly, there are many good applications for devices to be powered via Ethernet cable: voice-over-Internet-protocol (VOIP) telephones, wireless access devices, badge readers and access control devices, and surveillance cameras [10]-[12].

Since before the official adoption of the IEEE 802.af3 standard, much has been written about PoE. A small sample of articles includes general discussion articles [13]-[15], articles from PoE equipment suppliers [16][17], how-to-design articles [18][19], and literature from IC companies touting their solutions to PoE powering [20]-[27].

It is interesting that out of all that has been written about PoE, very little has been written about the power architecture that injects the power into the Ethernet cable. Reference [28] is about the only reference this author could find. Most of the information available, such as [18]-[27] are focused on the mechanics of the power detection and power up protocol of the PoE standard.

In particular, there is little or no discussion in the references listed about the electrical isolation requirements the Power-Sourcing-Equipment (PSE) used to send power out on the Ethernet cable. Reference [28] makes a small mention of the isolation requirements, but only in a sidebar.

This is an important requirement. If the proper isolation is not included in the design from the beginning, then the product will fail product safety testing, resulting in expensive re-design and re-testing.

The goal of this paper is to describe, in terms familiar to power supply and power system engineers, the electrical isolation requirements in PoE PSE and to describe several power architectures for PSE that meet the electrical isolation requirements.

II. Ethernet Electrical Isolation Requirements

Ethernet is often transmitted using unshielded twisted pair (UTP) cable with four pairs. For 10 Mb/s and 100 MB/s Ethernet, only two of the pairs are used. The basic Ethernet standard [29] talks about electrical isolation in many places. In general, the requirement is:

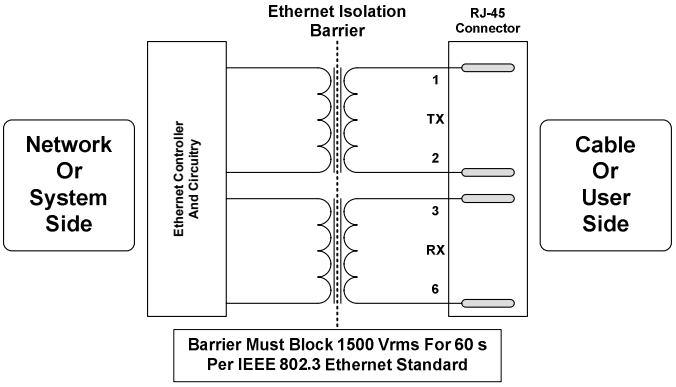

Figure 1. Electrical isolation by transformer in Ethernet

III. A Bit About Ethernet and Its Isolation Requirements

"This electrical isolation shall withstand at least one of the following electrical strength tests:

1. 1500 V rms at 50 Hz to 60 Hz for 60 s, applied as specified in subclause 5.3.2 of IEC 60950: 1991.
2. 2250 Vdc for 60 s, applied as specified in subclause 5.3.2 of IEC 60950: 1991.
3. A sequence of ten 2400 V impulses of alternating polarity, applied at intervals of not less than 1 s. The shape of the impulses shall be 1.2/50 µs (1.2 µs virtual front time, 50 µs virtual time or half value), as defined in IEC 60060.

There shall be no insulation breakdown, as defined in subclause 6.2.2.3 of IEC 60950-1:2001."

Transformers are used to create the needed isolation, as illustrated in Figure 1.

The PoE standard [9], however, has a slightly different, and more updated statement of electrical isolation:

"This electrical isolation shall withstand at least one of the following electrical strength tests:

a) 1500 V rms steady-state at 50-60 Hz for 60 seconds, applied as specified in subclause 6.2 of IEC 60950-1:2001.
b) An impulse test consisting of a 1500 V, 10/700 µs waveform, applied 10 times, with a 60 second interval between pulses, applied as specified in subclause 6.2 of IEC 60950-1:2001.

There shall be no insulation breakdown, as defined in subclause 6.2.2.3 of IEC 60950-1:2001."

The differences between these two requirements are a source of confusion. Many specifications for power supplies and dc-dc converters for PoE applications require the 2250 Vdc isolation, based on the older Ethernet requirements. The newer PoE standard requires the 1500 V rms test, which corresponds to a peak, or equivalent dc voltage of 2121 V. Those that say PoE does not require 2250 Vdc isolation are strictly correct. In practice however, there is no real difference in designing to meet 2250 Vdc isolation and designing to meet 1500 V rms isolation.

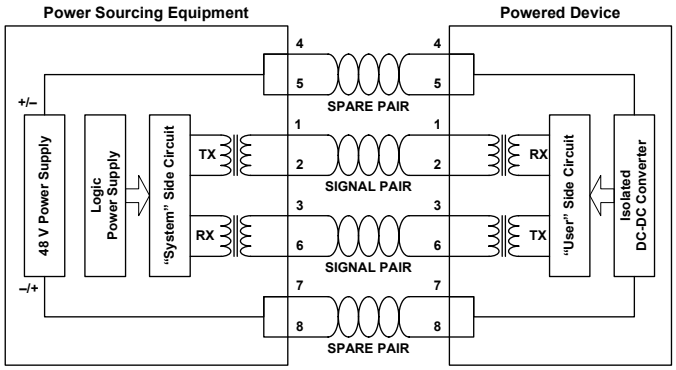

Figure 2. Alternative A, Transmitting power over spare pairs

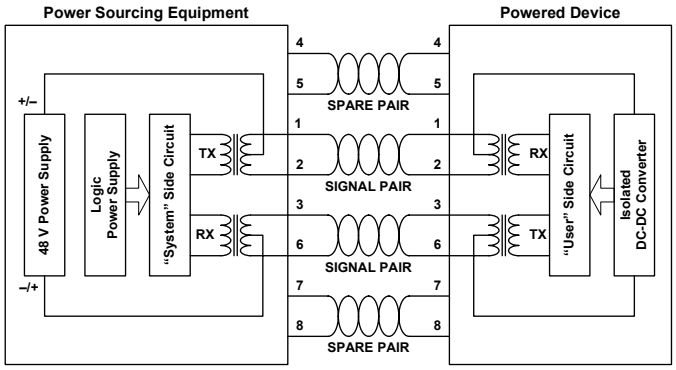

Figure 3. Alternative B, Transmitting power over pairs used for signaling

IV. What Is Power-Over-Ethernet?

The next step is understand how electrical power is transmitted over the Ethernet cable. There are two ways. One, Alternative A, uses the two spare pairs of conductors. The other, Alternative B, transmits the power over the pairs used for signaling. These are illustrated in Figure 2 and Figure 3.

Note that in both means of transmitting power, the current from the PSE to the powered device (PD) flows in a common mode manner over one pair and that the return current also flows in a common mode manner over another pair.

In most cases, equipment configured to be powered over the Ethernet cable is wired to accept power both Alternative A and Alternative B, as illustrated in Figure 4.

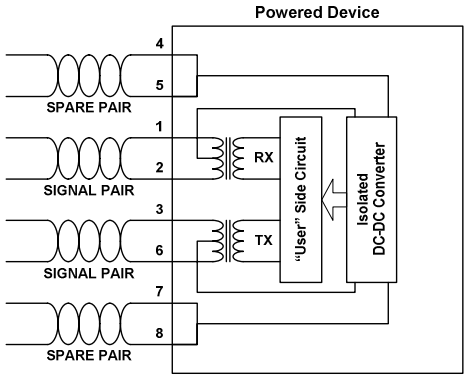

Figure 4. Power Device (PD) Configured to receive power from Alternative A and Alternative B

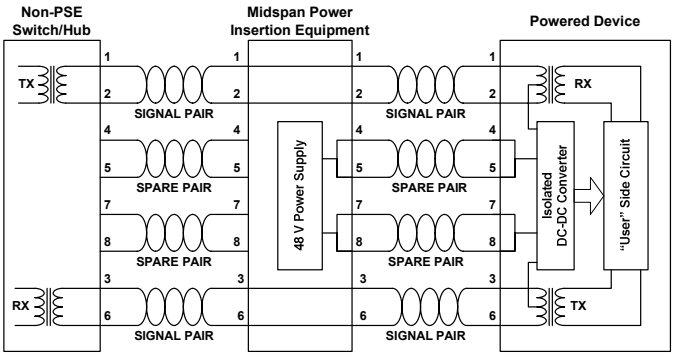

Figure 5. Midspan power injection

There are also two ways that power can be injected into the Ethernet cable. One is for the power source to be built into the Ethernet equipment that is connecting to the powered device. This is known as Endpoint PSE. This technique is illustrated in Figure 2 and Figure 3.

The other uses a power source that connects between the Ethernet source and the powered device. This is known as Midspan PSE. Midspan power injection, shown in Figure 5, may only use Alternative B, transmitting power on the spare pairs.

Endpoint power injection, as shown in Figure 2 and Figure 3 may use Alternative A, Alternative B, or both.

V. Applying The Ethernet Isolation Requirements To Power Sourcing Equipment

The fundamental rule, illustrated in Figure 6, and which for some reason does not seem to be well understood, is that 1500 V rms isolation is needed between the 48 V supply (and anything attached to it) and the power supply for the logic circuits in the PSE. Once this is understood, powering architectures that support this electrical isolation requirement can be developed.

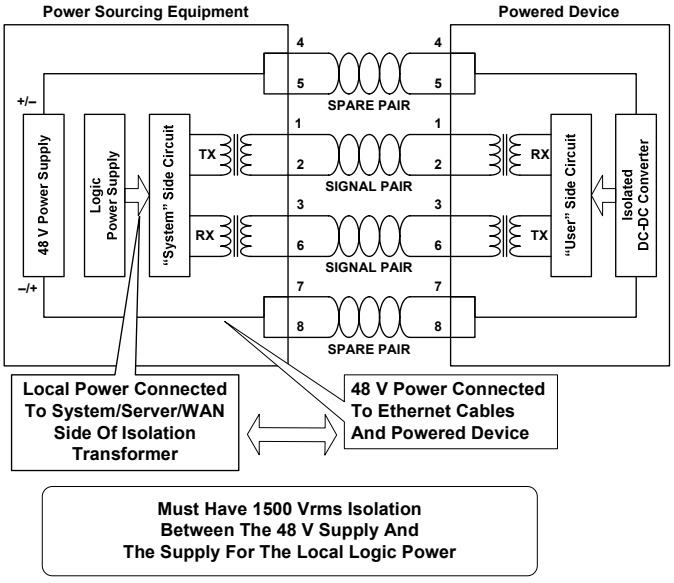

Figure 6. Electrical isolation requirements in PoE PSE

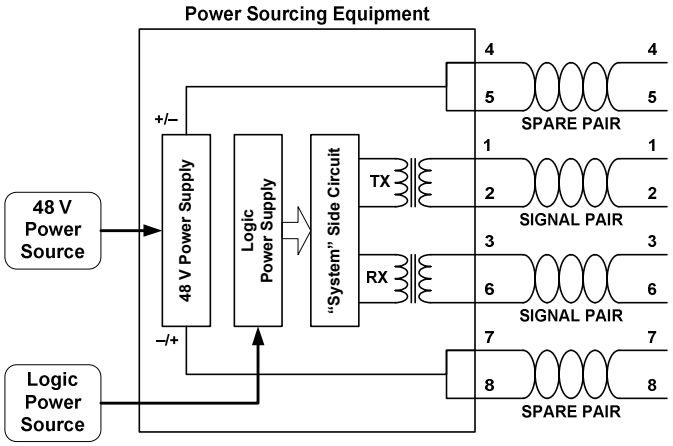

Figure 7. Using independent 48 V and local logic power supplies in PSE

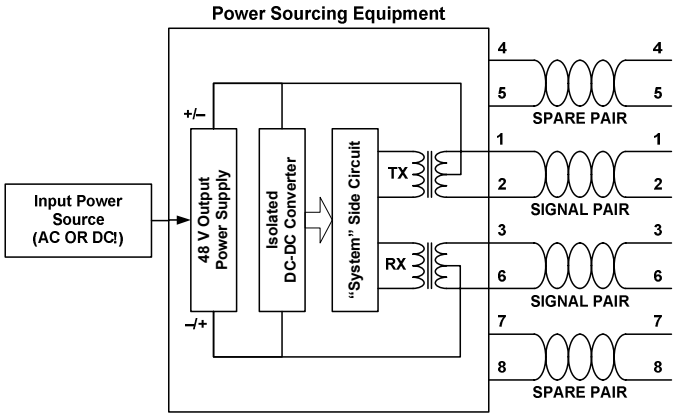

Figure 8. Cascaded power architecture for PSE

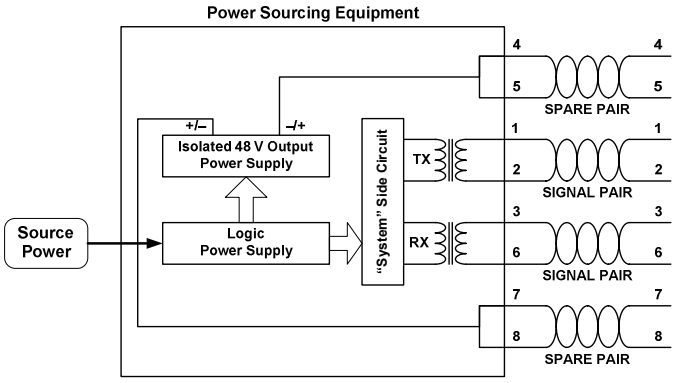

Figure 9. Another way of cascading the power in a PoE PSE

VI. Power Architectures For PSE Equipment

With this understanding of the isolation requirements between the 48 V PoE power and the local logic power, the four basic ways of architecting the power in the PSE can be identified.

The first is to use independent power supplies for the PoE and local logic power. This is illustrated in Figure 7. Due to the high cost of two individual power supplies operating from the same source, this approach is rarely, if ever, used.

The second and third methods use a cascade arrangement of two power supplies. In one case the first stage power supply powers the 48 V Ethernet power. Then a dc-dc converter with

1500 V rms of isolation is used to take power from the 48 V and supply it to the local logic power. This is a very popular method of powering PSE. This is illustrated in Figure 8.

The variation to the method shown in Figure 8 is to create the power for the local logic and then generate the 48 V power from that, as shown in Figure 9. This is less popular as the PoE power can be much larger than the local logic power. Processing the PoE power twice leads to a generally unnecessary increase in cost, increase in complexity and decrease in efficiency.

The fourth possibility is to use a two output power supply with independent secondary circuits that have the required 1500 V rms isolation between them as shown in Figure 10. Figure 10 shows a power architecture with an intermediate bus approach for the local logic power. This could, of course, be one or more outputs at the voltages needed by the local logic.

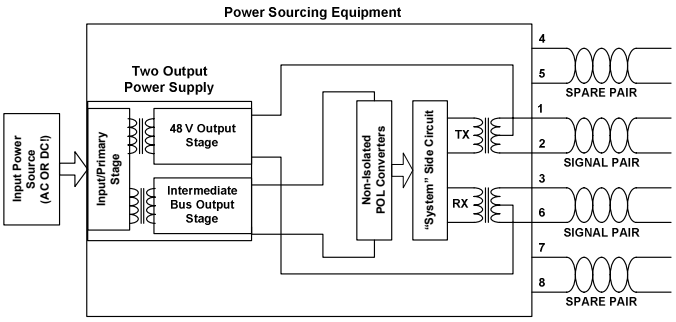

Figure 10. Using a two output power supply for PoE PSE

VII. SUMMARY

The Ethernet isolation requirements are critical in providing power in PoE Power Sourcing Equipment. This paper explains those requirements and how they apply. Four possible power architectures that meet the isolation requirements are also presented. Of these four methods, there is not one that is best for all applications. System engineers must understand these methods and the requirements of their systems in order to make the best choice for their applications.

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APEC 2006

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23 March 2006

Presentation Overview

- Ethernet Electrical Isolation Requirements
- Sending Power Over Ethernet Cable
- Power Architectures For Power Sourcing Equipment (PSE)

Presentation Overview

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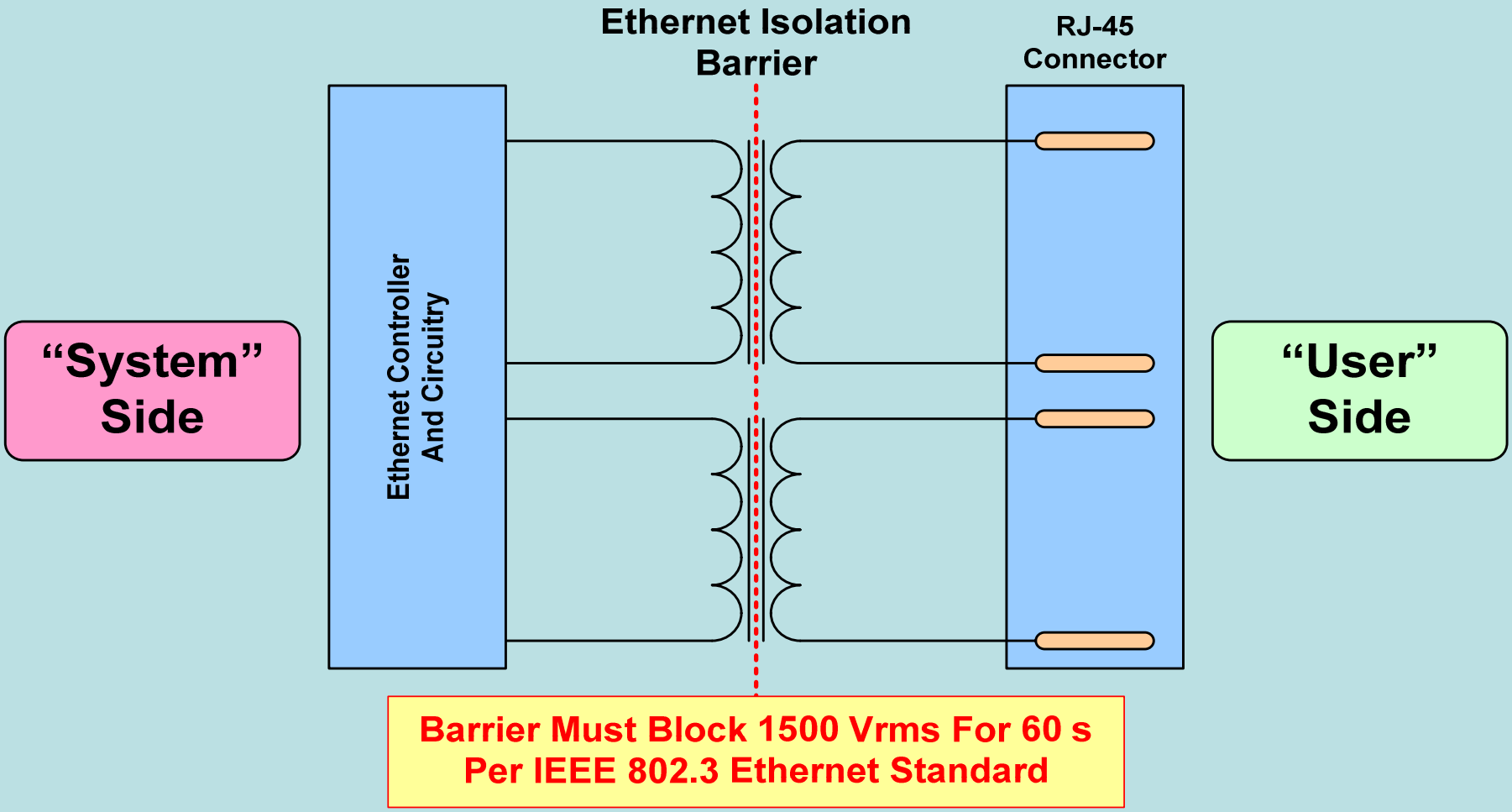
This Version Of The Presentation Is Improved Over The Version Presented At The Conference. Slides And Explanations Added To Make It Easier To Understand Without The Verbal Presentation. Also, New Info On Testing Requirements Added

This Presentation Focuses On Power Sourcing Equipment Electrical Isolation Requirements And Powering Architectures

It Does Not Address Powered Devices, Power/Current Limits/Limiting, Device Detection, Device Connect And Disconnect, Etc. See IEEE 802.3af3 And www.poweroverethernet.com For That Information

Ethernet Electrical Isolation Requirements

Ethernet Isolation Requirement



IEEE802.3 Says:

- **This isolation shall withstand** at least one of the following electrical strength tests:
  a) **1500 V rms at 50 to 60 Hz for 60 s**, applied as specified in 5.3.2 of IEC 60950: 1991.
  b) **2250 Vdc for 60 s**, applied as specified in 5.3.2 of IEC 60950:1991.
  c) **A sequence of ten 2400 V impulses** of alternating polarity, applied at intervals of not less than 1 s. The shape of the impulses shall be 1.2/50 μs (1.2 μs virtual front time, 50 μs virtual time of half value), as defined in IEC 60060.

IEEE802.3 Says:

- **There shall be no isolation breakdown**, as defined in 5.3.2 of IEC 60950: 1991, during the test. The resistance after the test shall be at least 2 Mohms, measured at 500 Vdc. In addition, the isolation impedance between the DTE and the coaxial cable shield shall be less than 15 ohms between 3 MHz and 30 MHz.

IEEE 802.3af3 (PoE Standard) Says:

- **The Power Sourcing Equipment (PSE) shall provide electrical isolation** between the Power Interface (PI) device circuits, including frame ground (if any), and all PI leads.
- This electrical isolation shall be in accordance with the **isolation requirements between SELV circuits** and telecommunication network connections in subclause 6.2 of IEC 60950-1:2001.

IEEE 802.3af3 (PoE Standard) Says:

- This electrical isolation shall withstand at least one of the following electrical strength tests:
  a) **1500 Vrms steady-state at 50-60 Hz for 60 seconds**, applied as specified in subclause 6.2 of IEC 60950-1:2001.
  b) **An impulse test** consisting of a 1500 V, 10/700 µs waveform, applied 10 times, with a 60 second interval between pulses, applied as specified in subclause 6.2 of IEC 60950-1:2001.

IEEE 802.3af3 (PoE Standard) Says:

- **There shall be no insulation breakdown**, as defined in subclause 6.2.2.3 of IEC 60950-1:2001.

IEEE 802.3af3 (PoE Standard) Says:

Note That The PoE Standard Does Not Mention 2250 Vdc Like The Regular Ethernet Standard!

Trick Question!

- How Is Compliance To The PoE Electrical Isolation Requirements Verified?

  A. Type Test During Design
  B. Production Test On Every Unit

Trick Question!

- How Is Compliance To The PoE Electrical Isolation Requirements Verified?

  A. Type Test During Design
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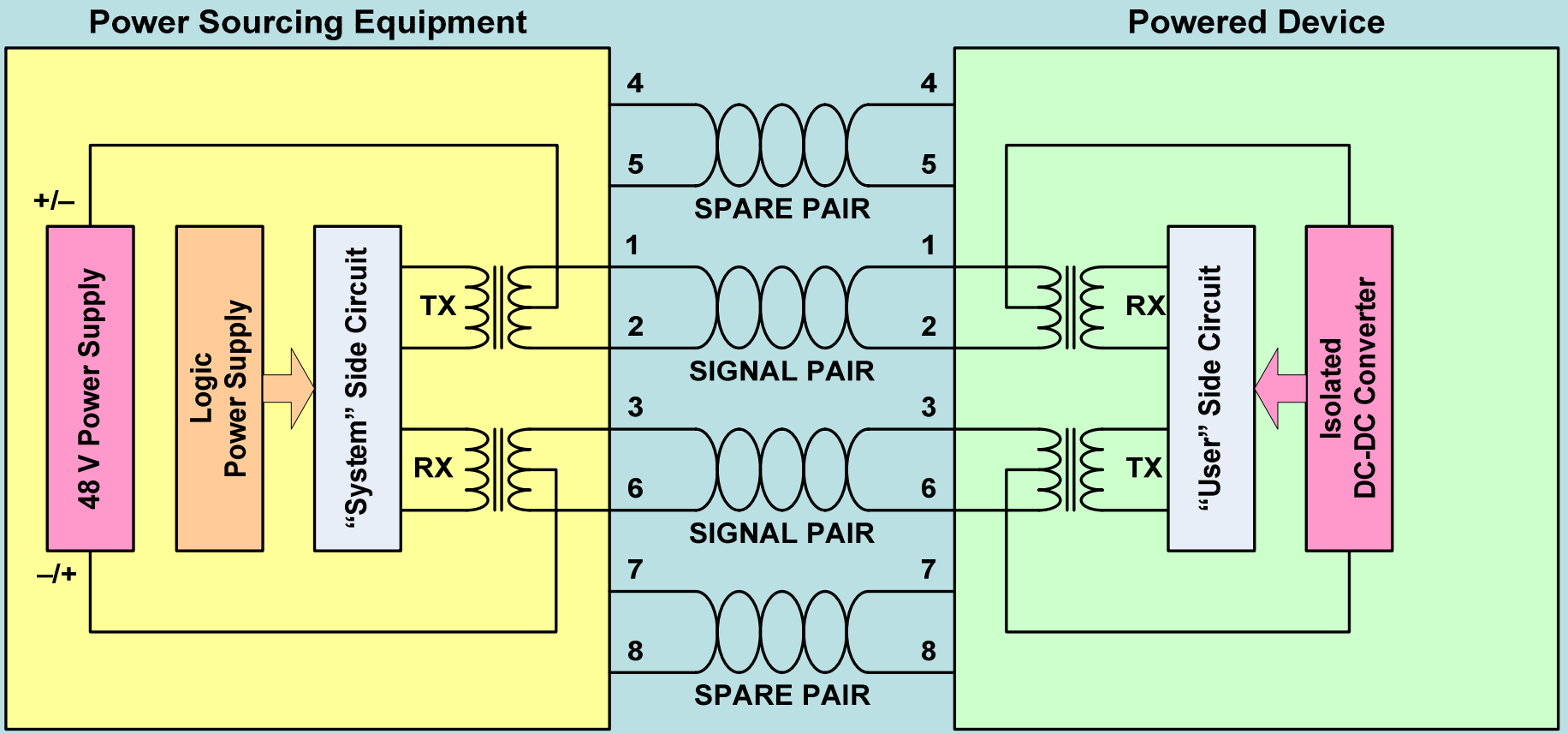
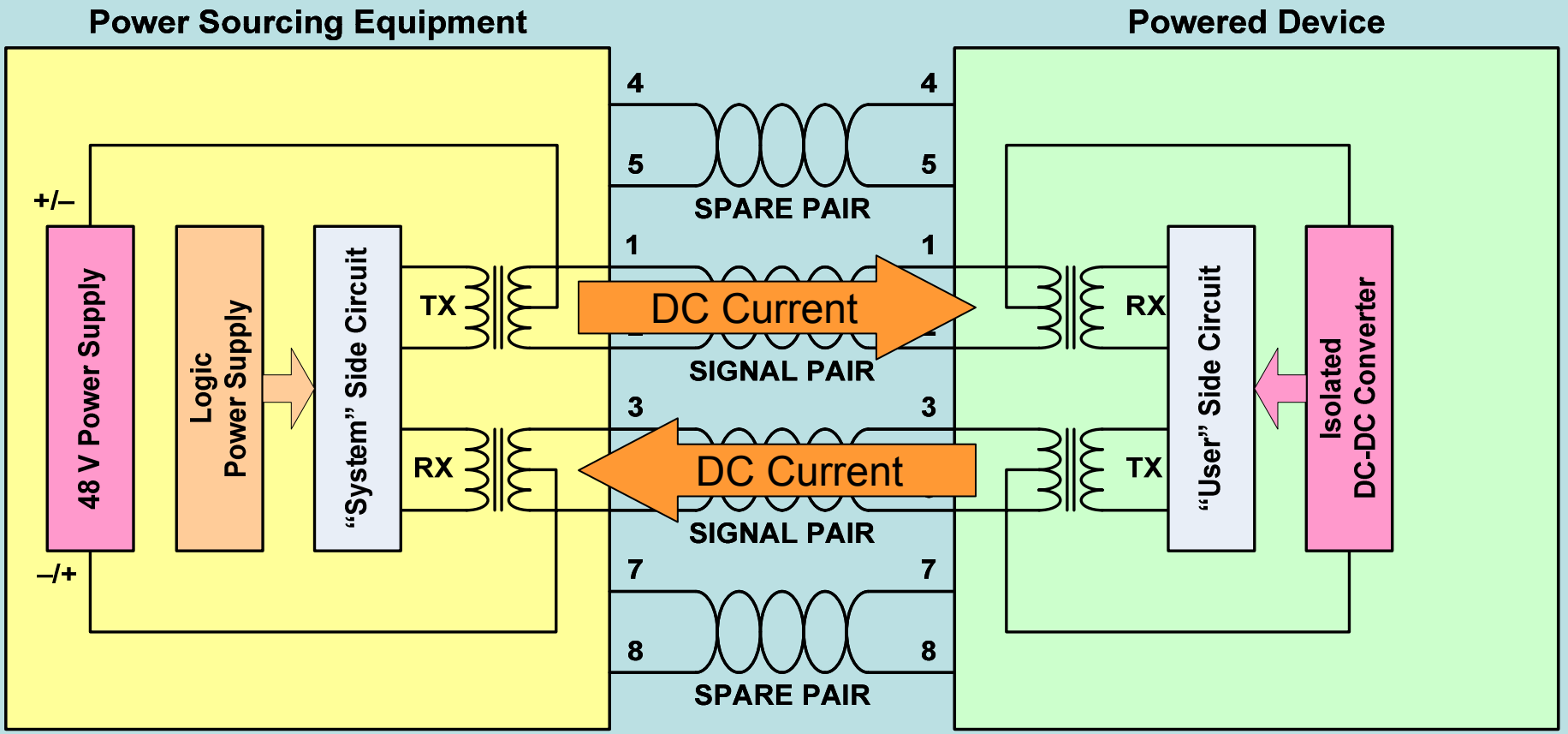
The PoE Standard Does Not Say!

Sending Power Over Ethernet Cable

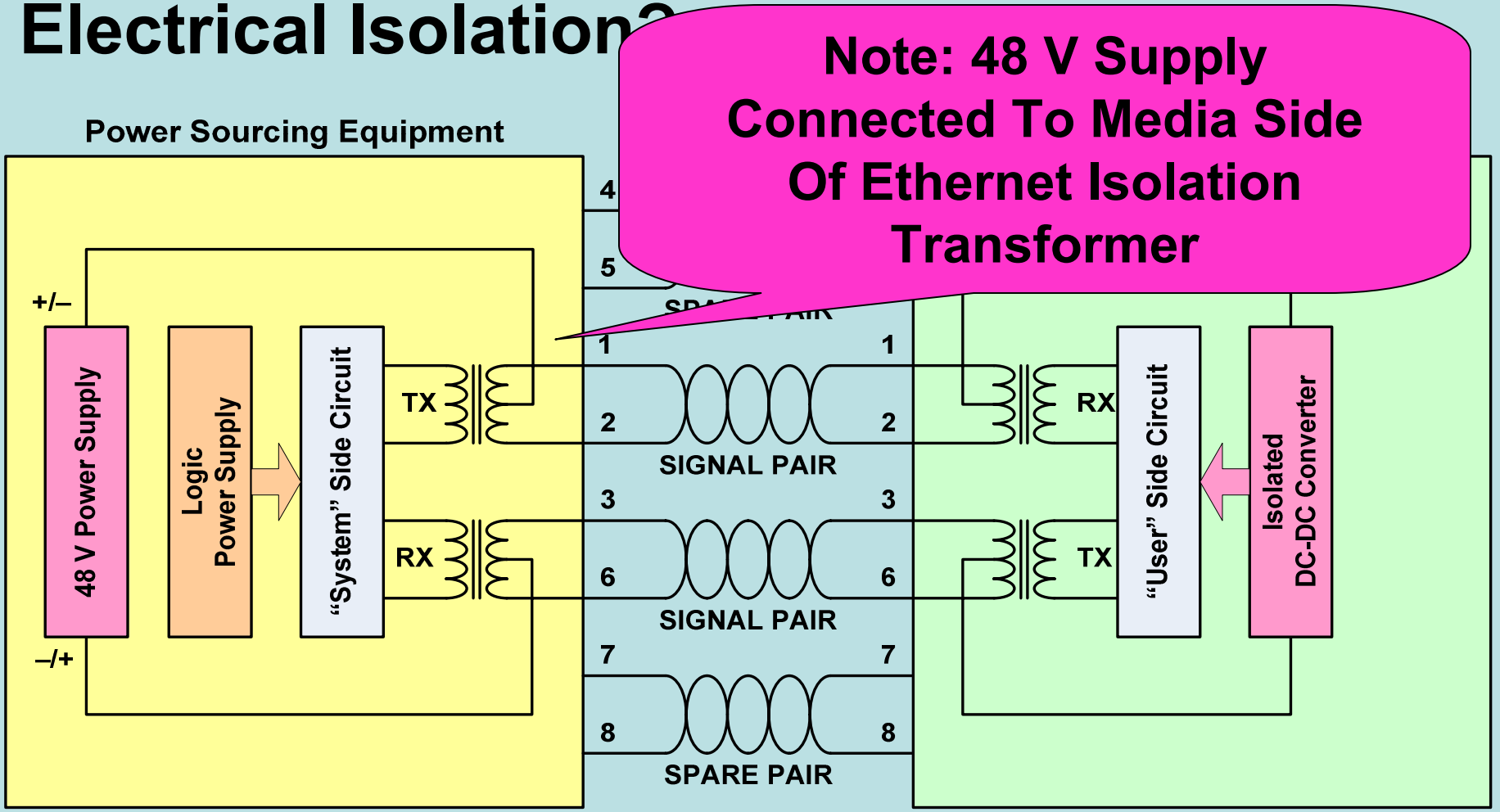
Injecting 48 V Into The Data Pairs (Alternative A)



Injecting 48 V Into The Data Pairs (Alternative A)



What Does This Mean For Electrical Isolation?



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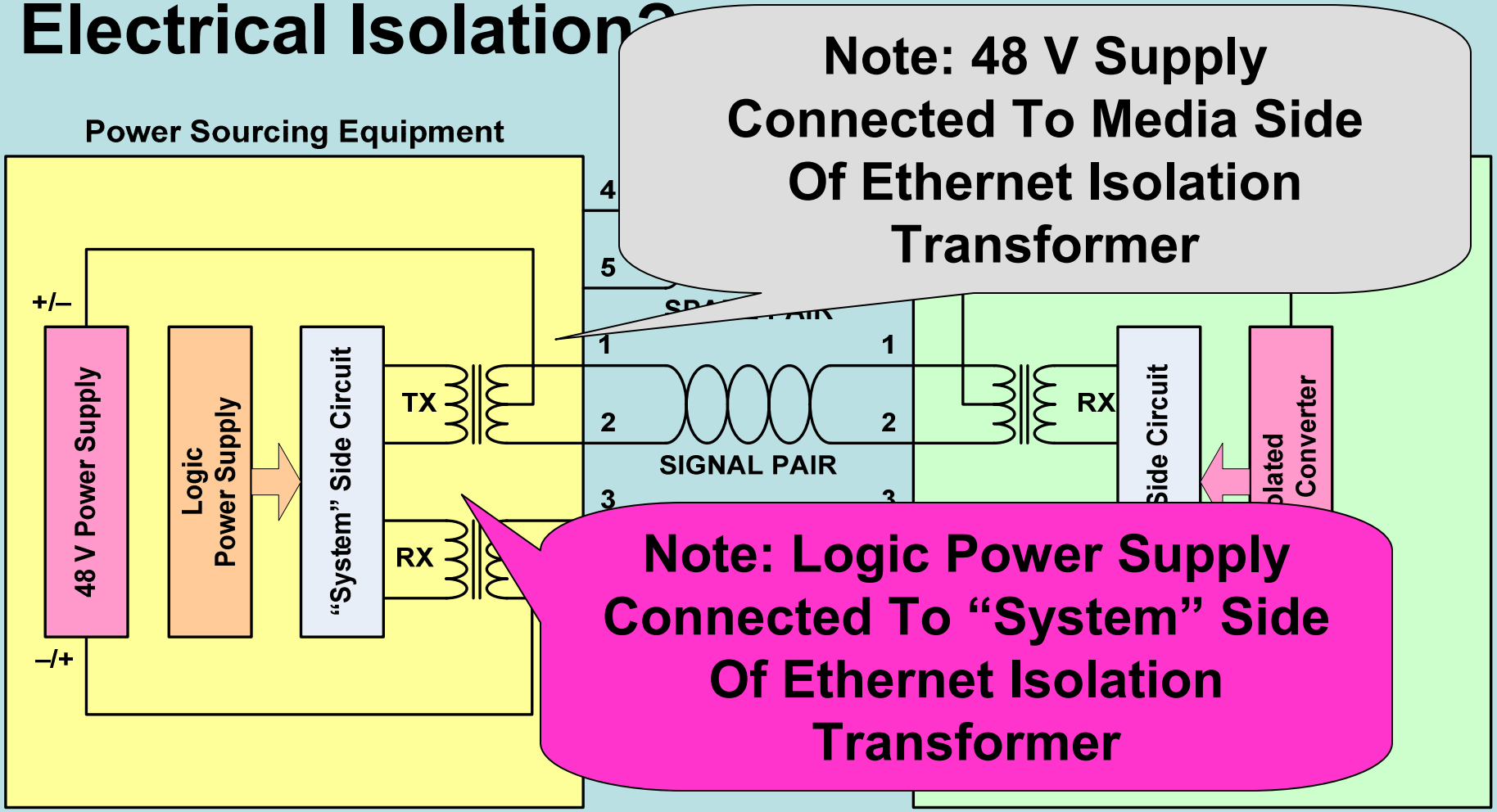

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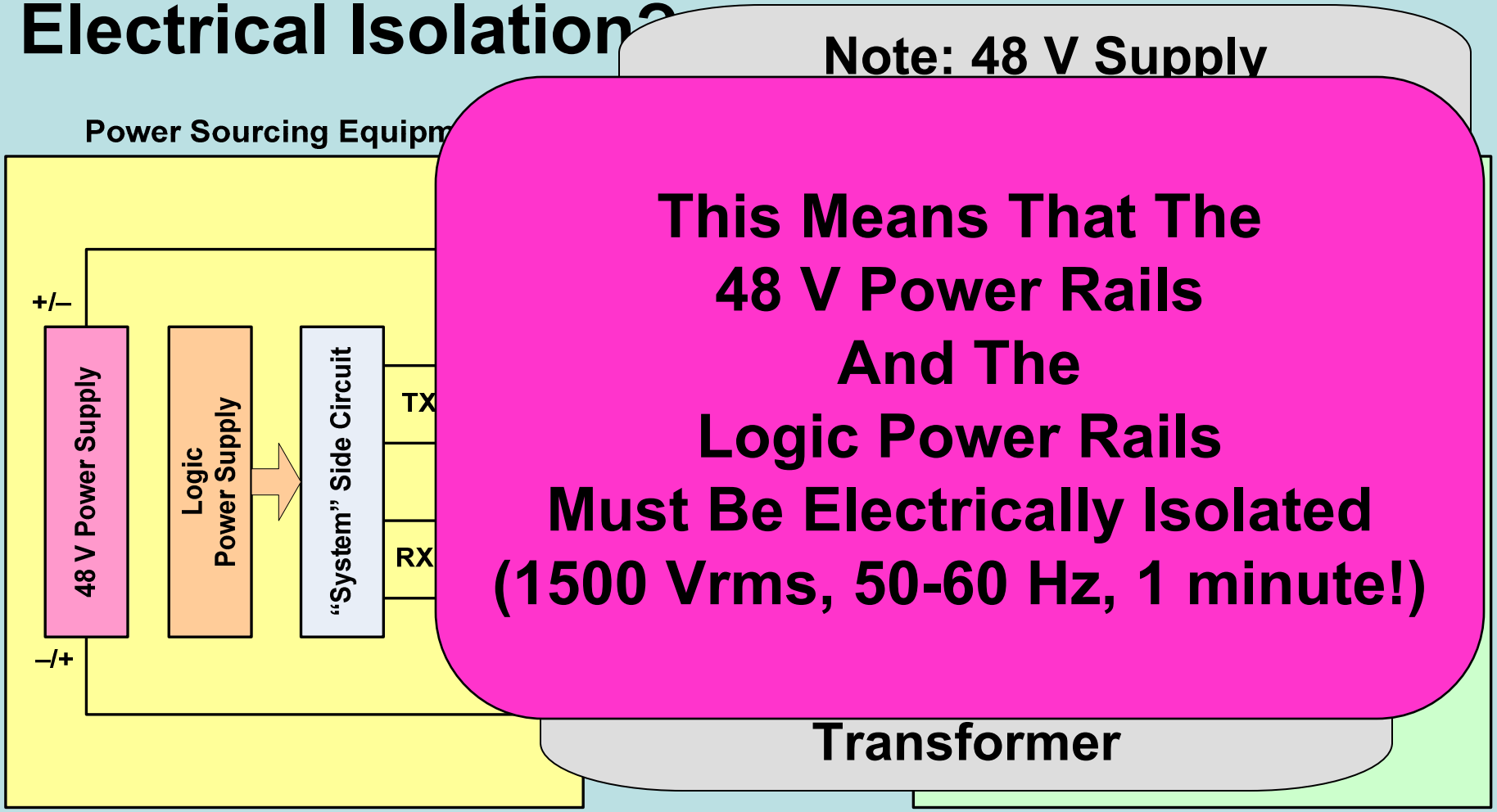
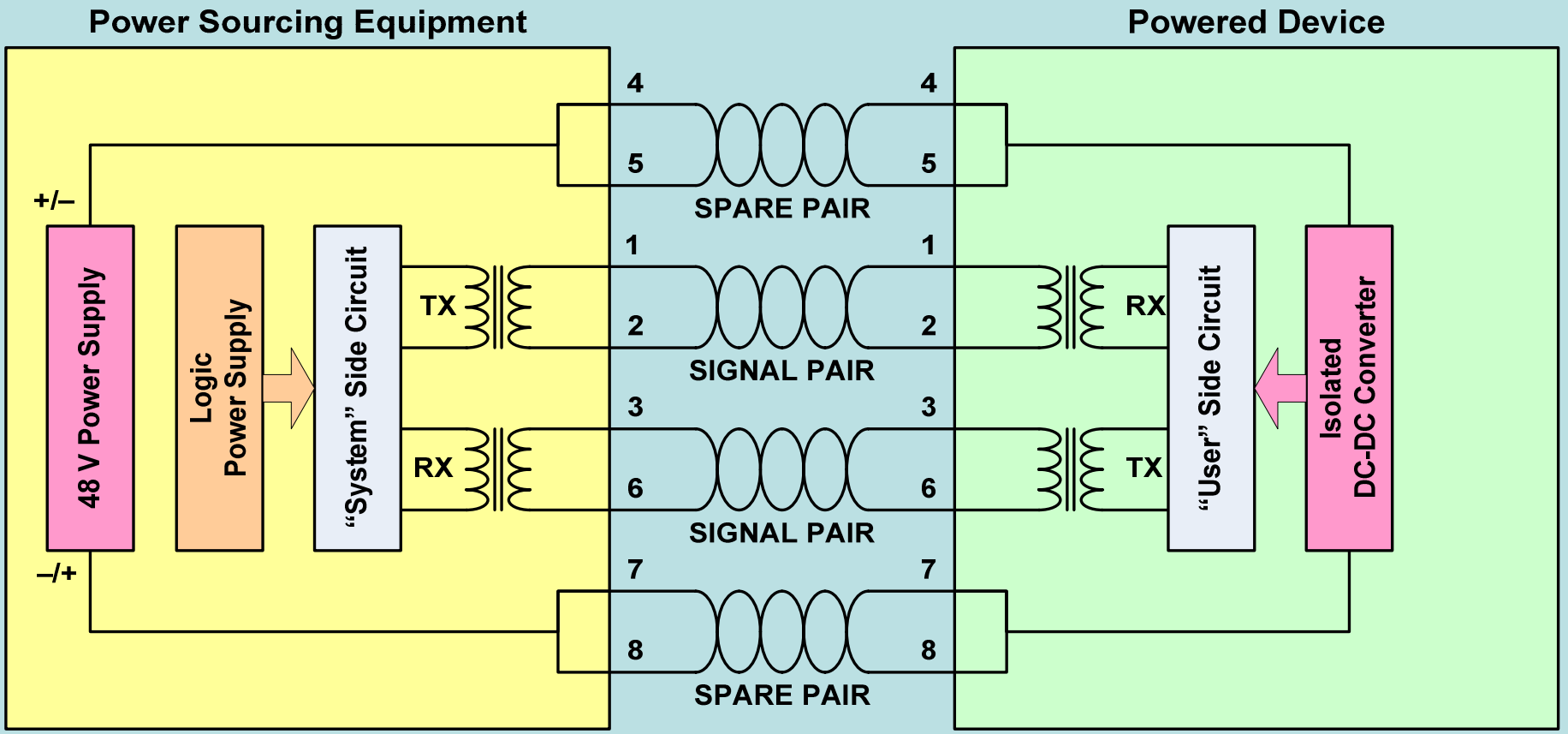


This Means That The 48 V Power Rails And The Logic Power Rails Must Be Electrically Isolated (1500 Vrms, 50-60 Hz, 1 minute!)

Injecting 48 V Power Into Spare Pairs (Alternative B)



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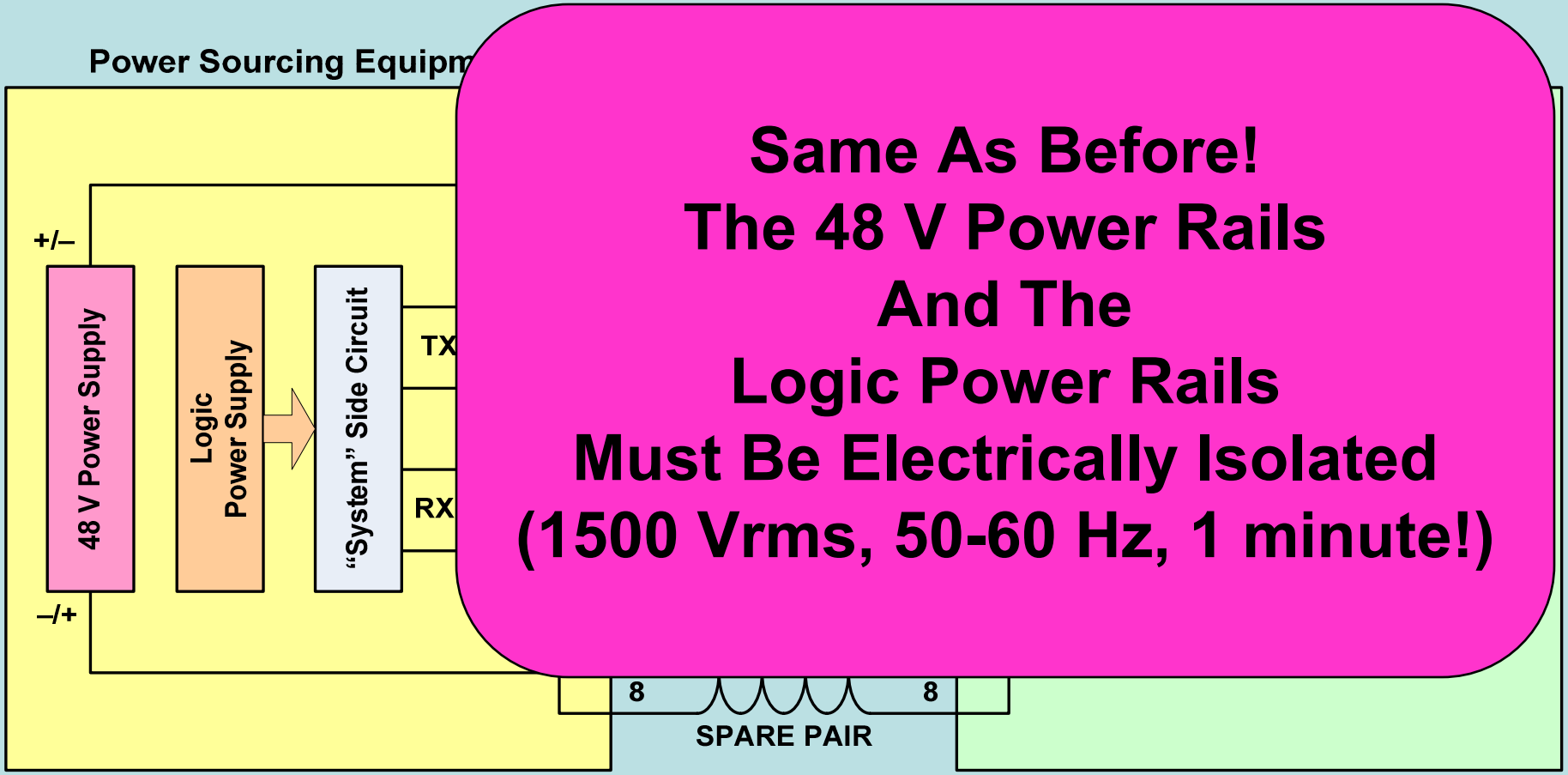
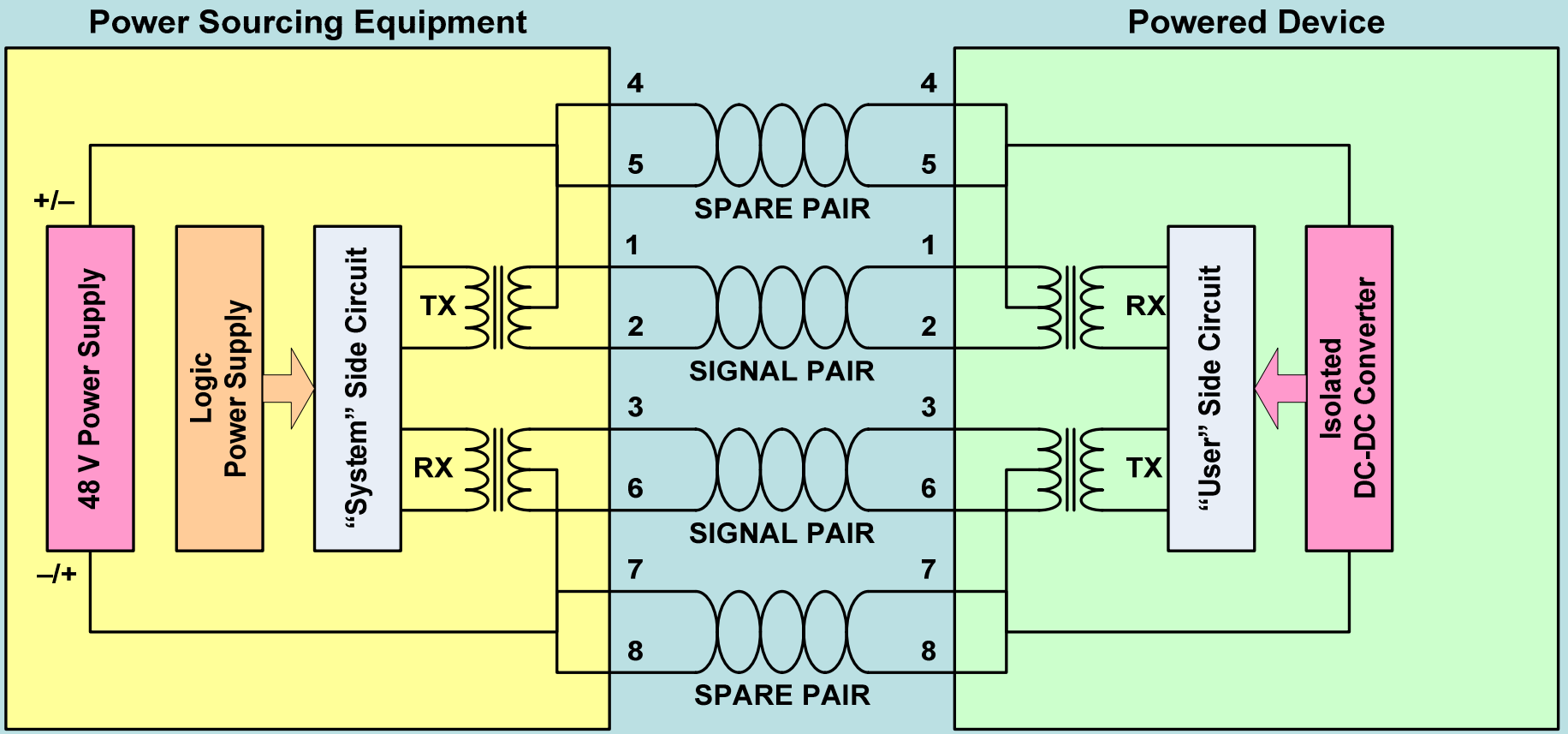
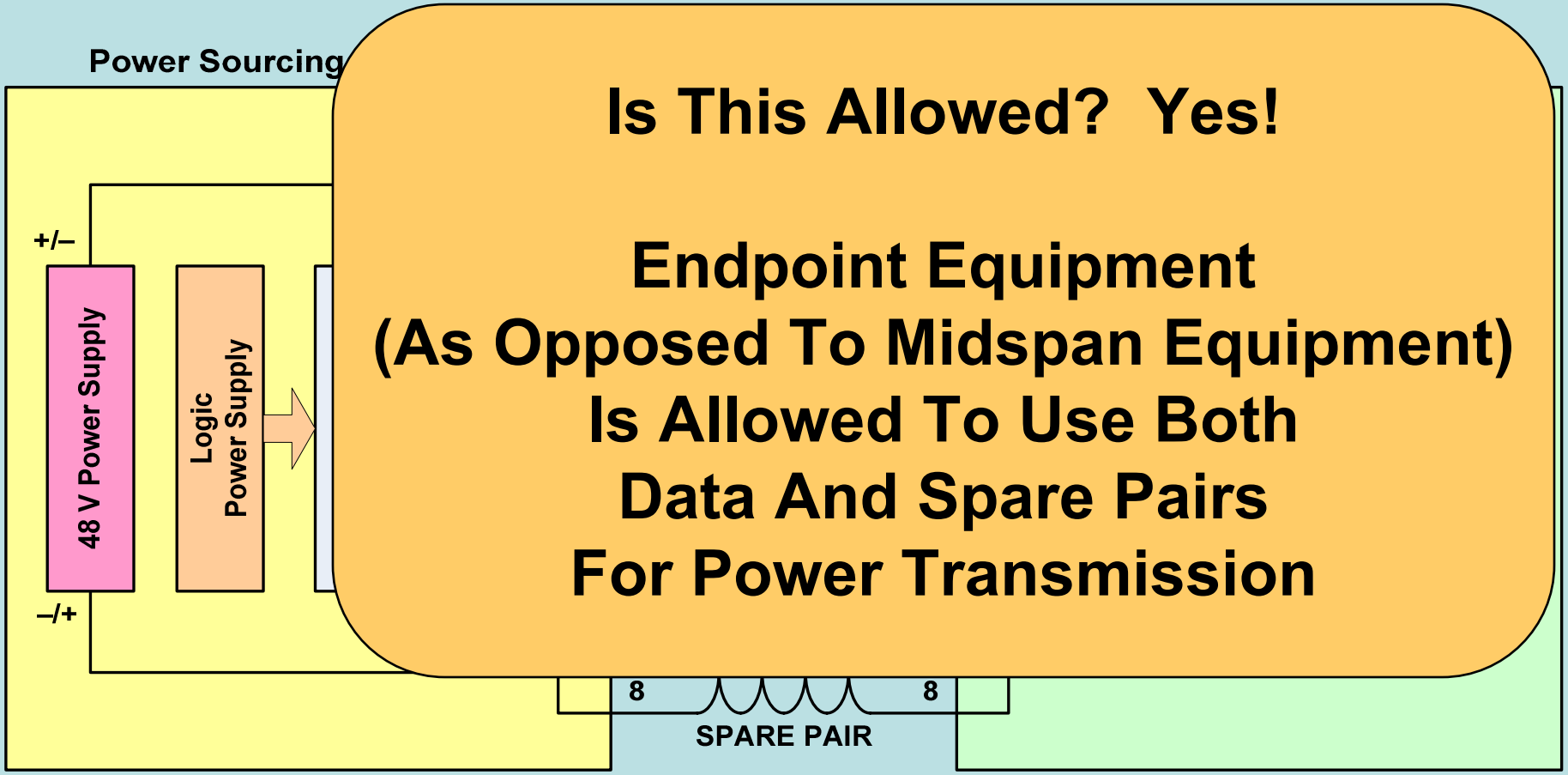


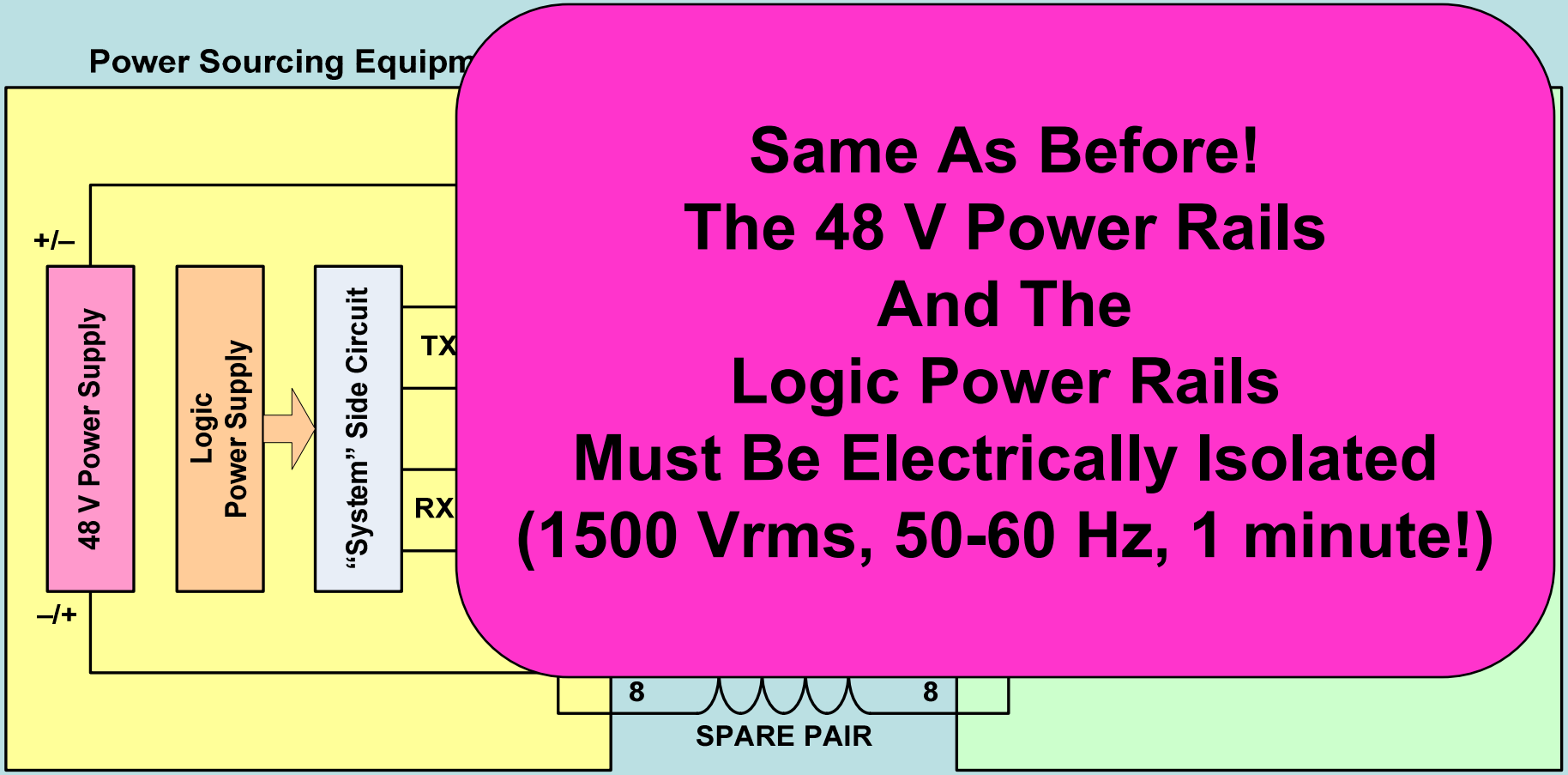
Using Both Data Pairs And Spare Pairs



Using Both Data Pairs And Spare Pairs



Electrical Isolation When Using Both Data Pairs And Spare Pairs

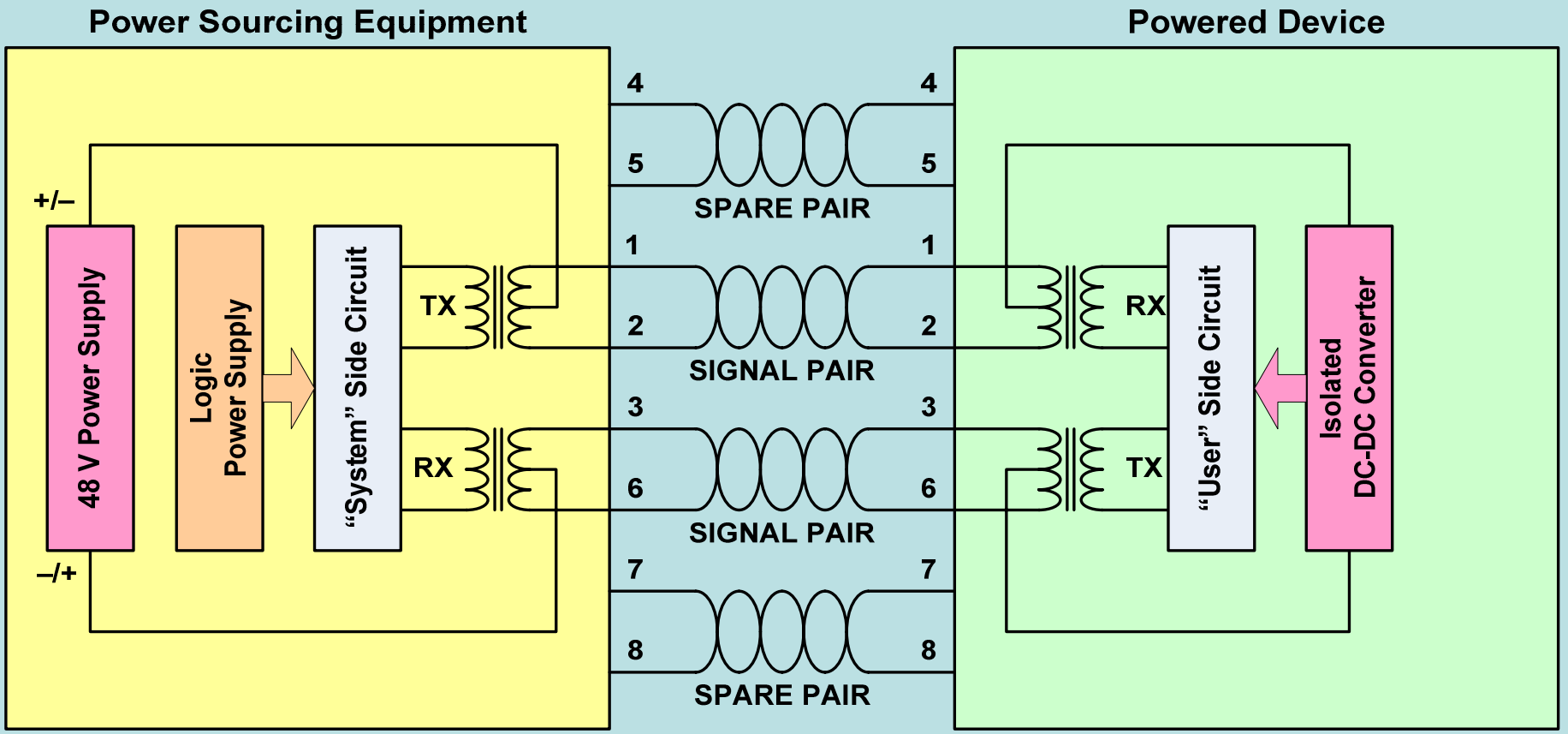


Power Architectures For Power Sourcing Equipment

PSE Input Power Architecture

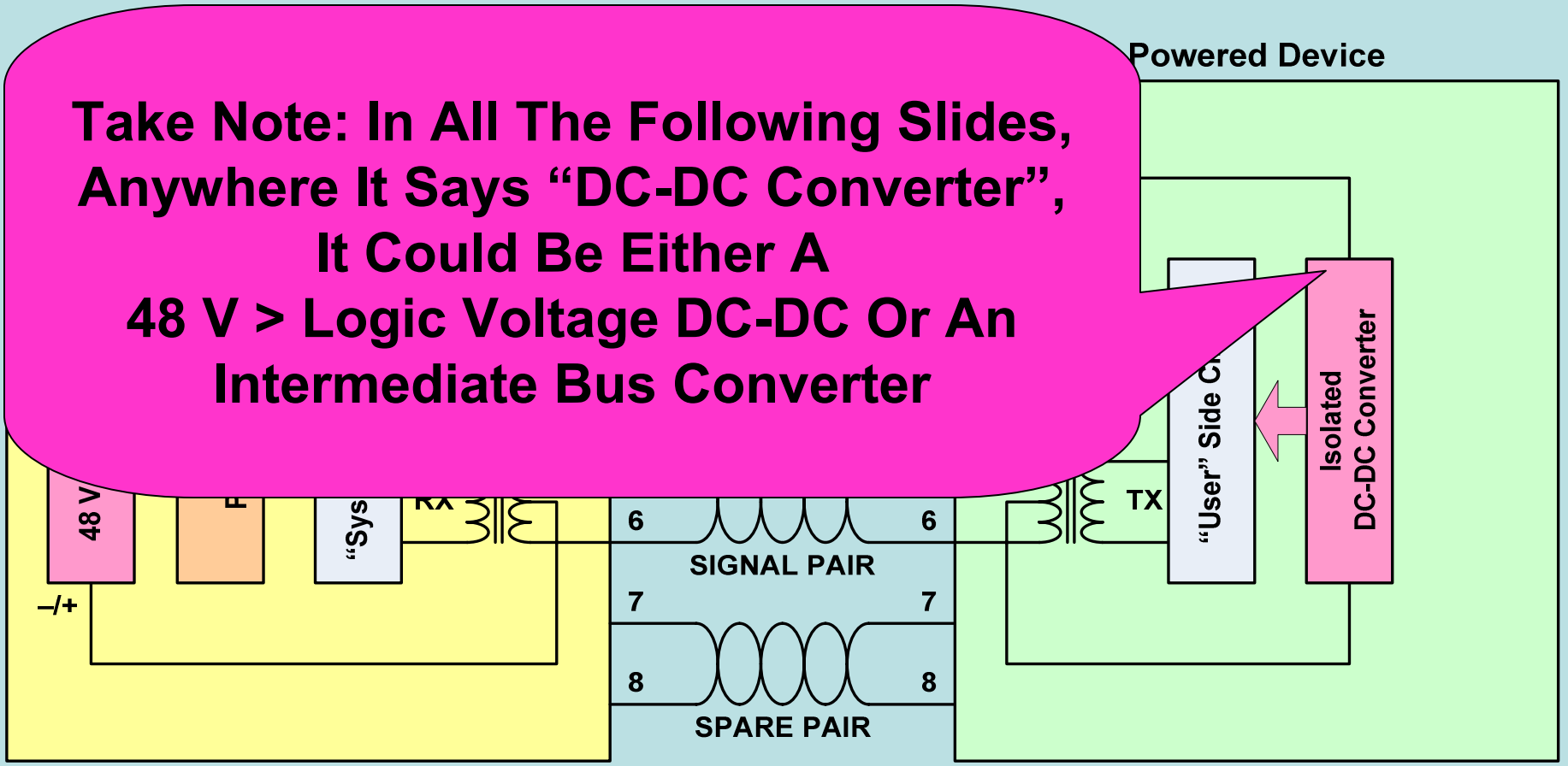
- There Are Many Options For The Power Architecture Of Power Sourcing Equipment (PSE)
- The Following Slides Illustrate Many Possibilities
- These Slides Only Show Power Over Data Pairs
- But Apply Equally To Power Over Spare Pairs

PSE Input Power Architecture

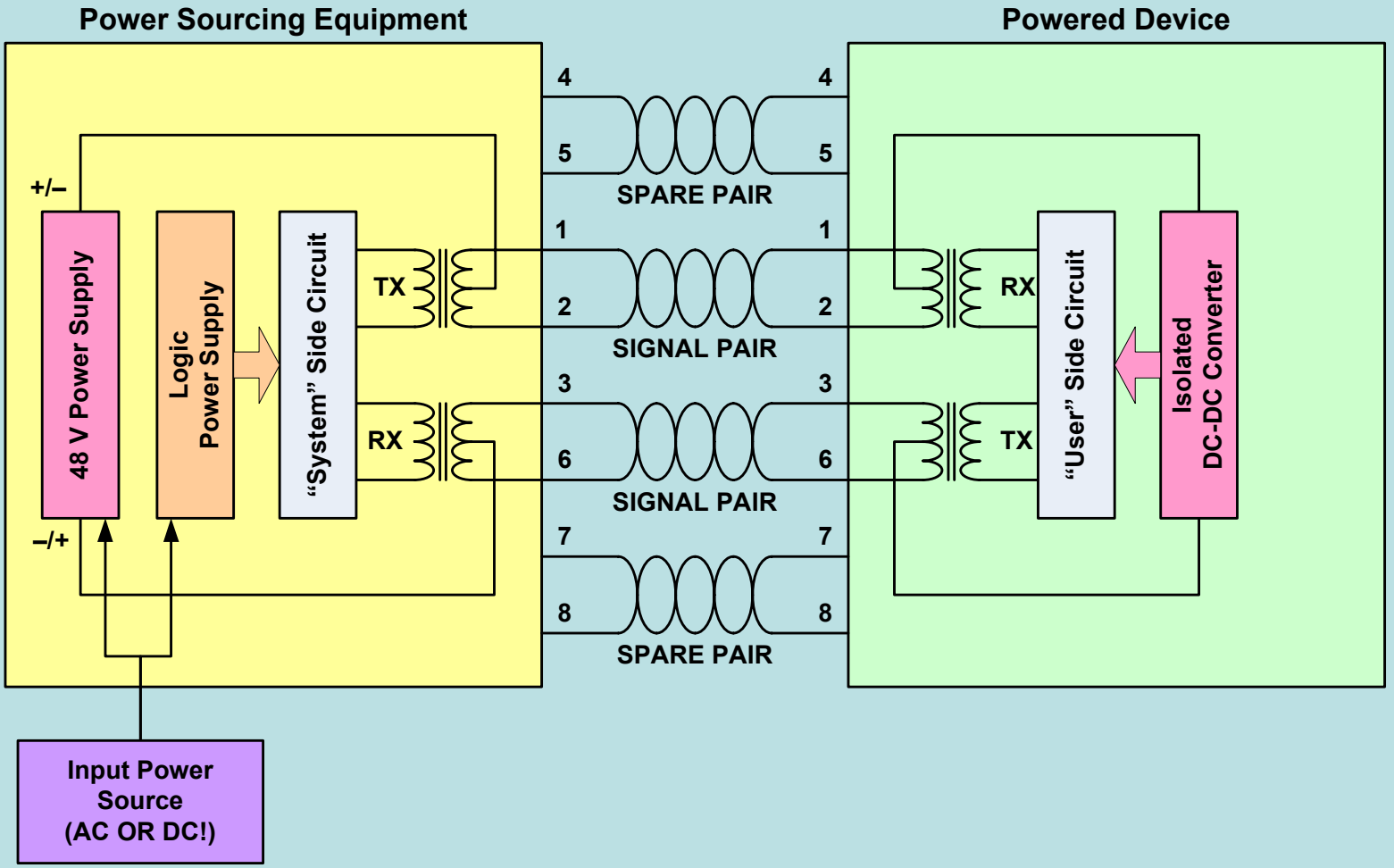


PSE Input Power Architecture

Take Note: In All The Following Slides, Anywhere It Says "DC-DC Converter", It Could Be Either A 48 V > Logic Voltage DC-DC Or An Intermediate Bus Converter



Architecture 1: Two Independent Power Supplies



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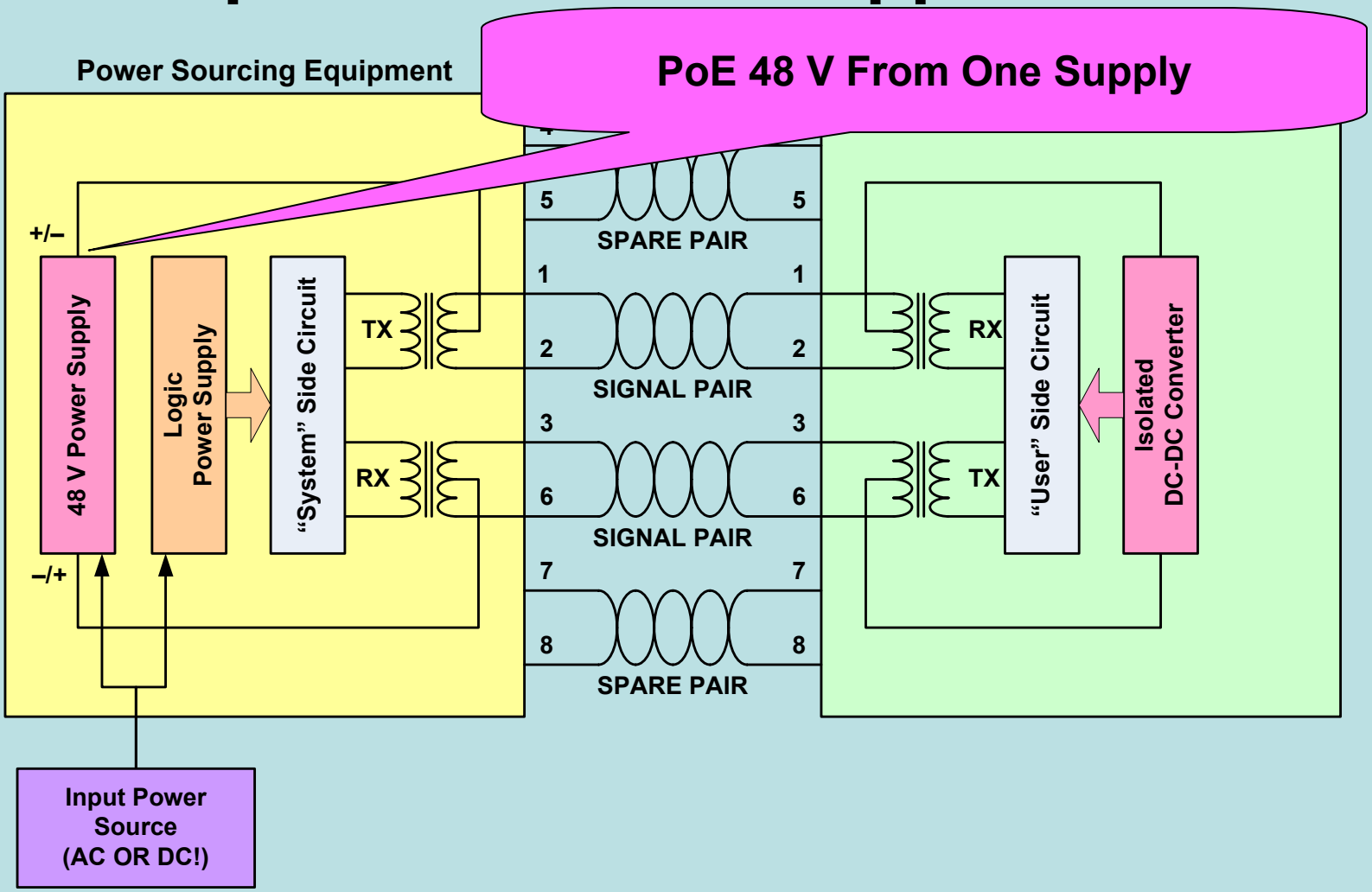

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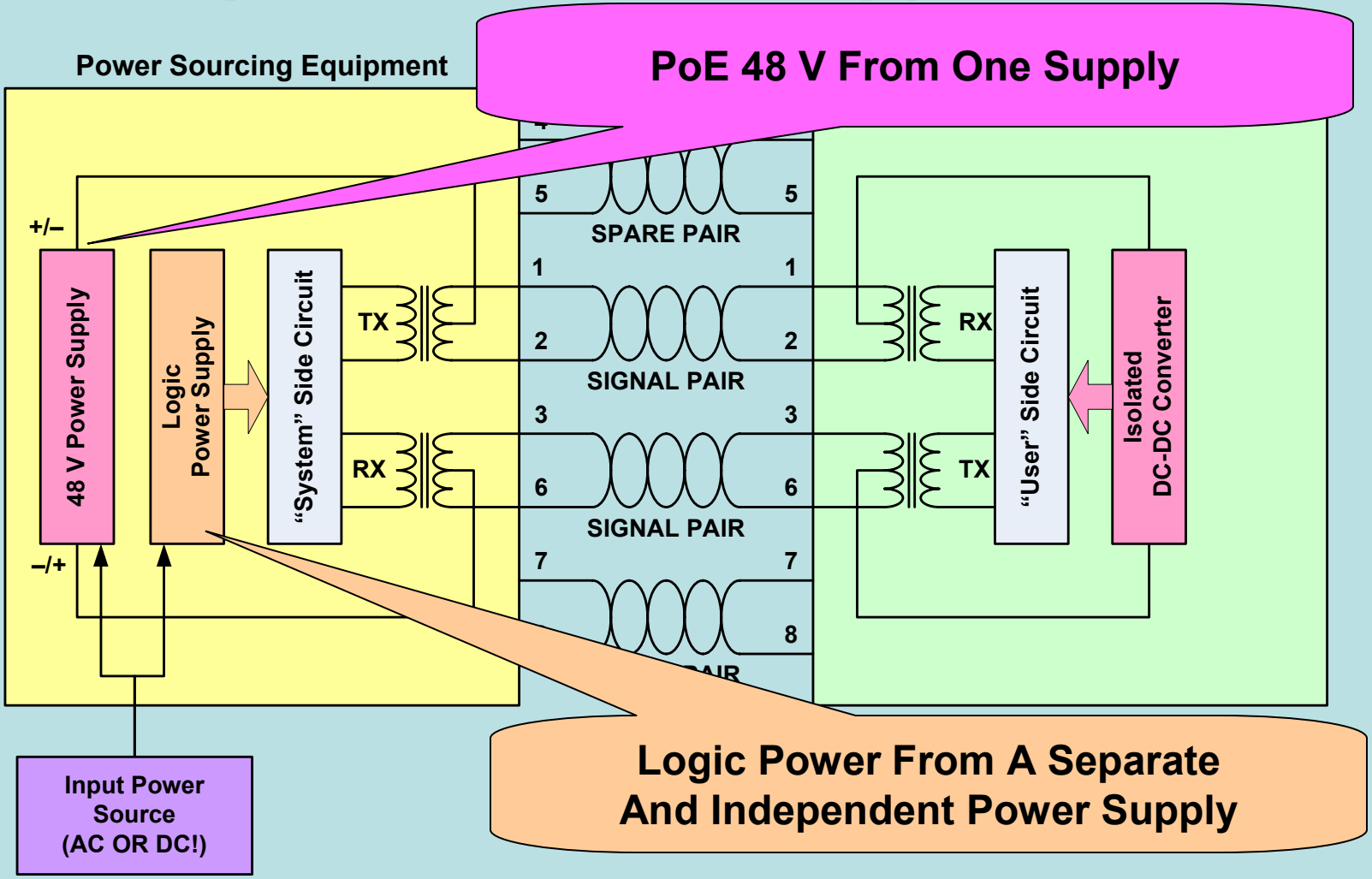
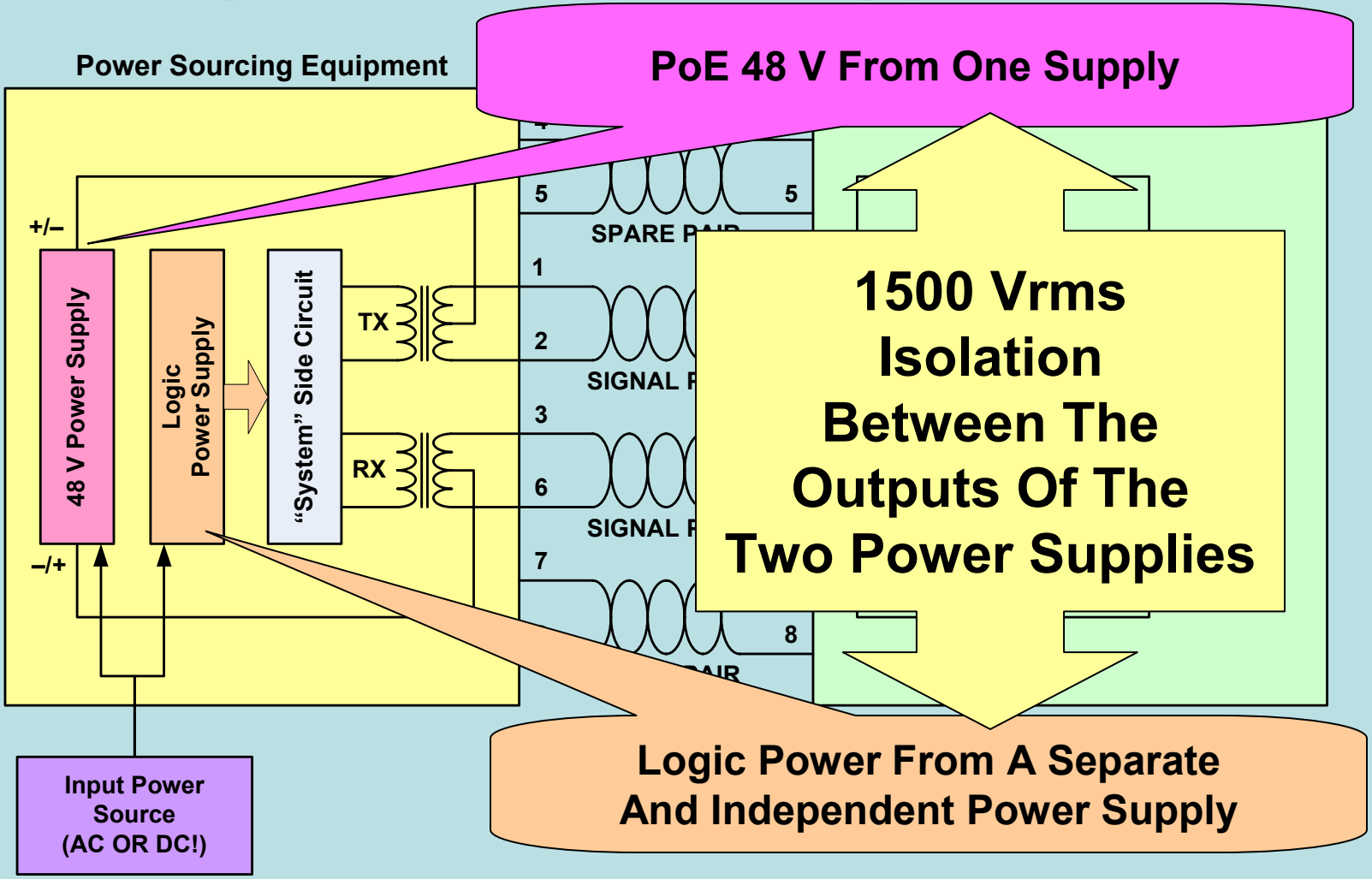
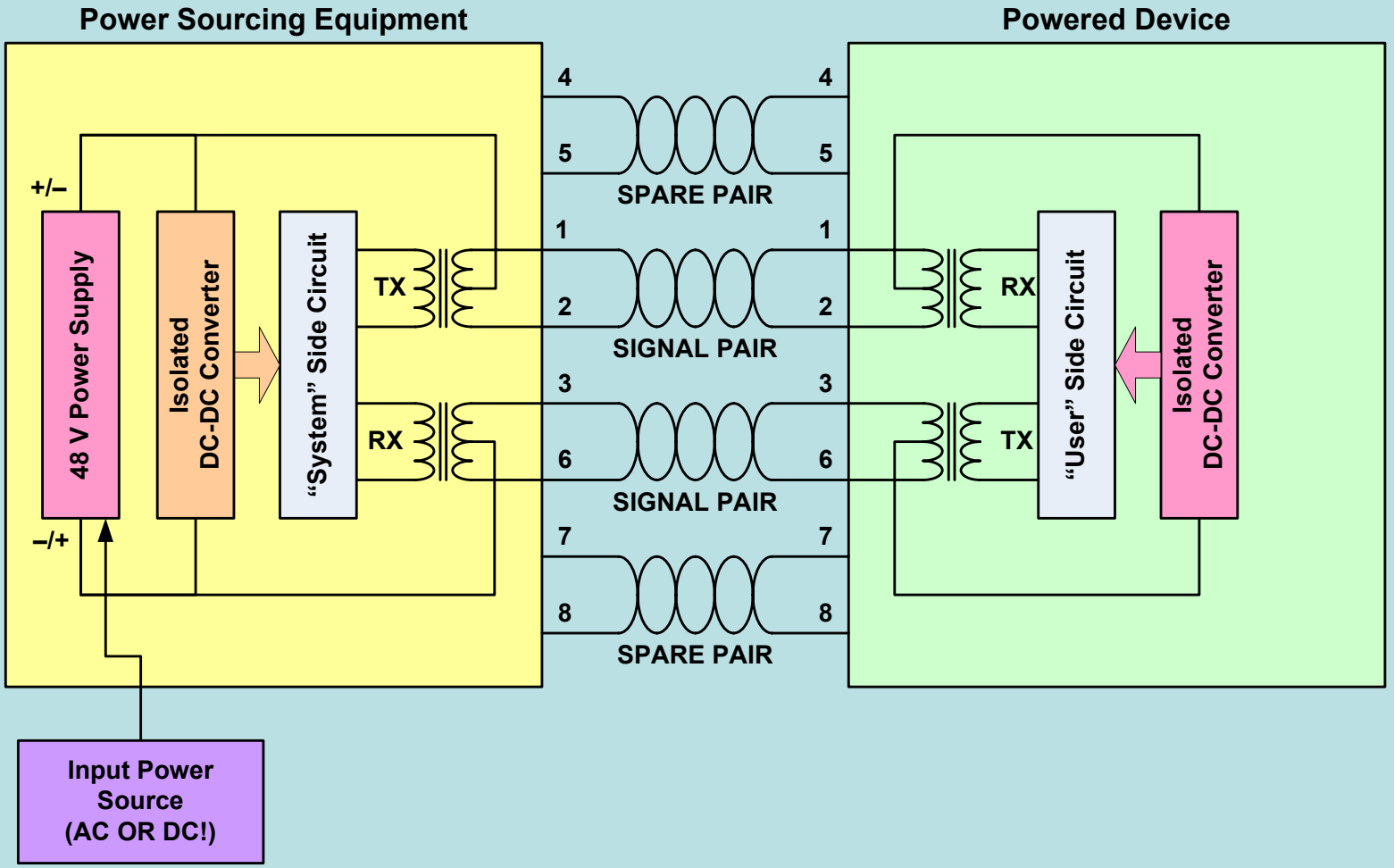


Architecture 1: Two Independent Power Supplies



Architecture 2: Cascade
Input Power > 48 V > Logic Power



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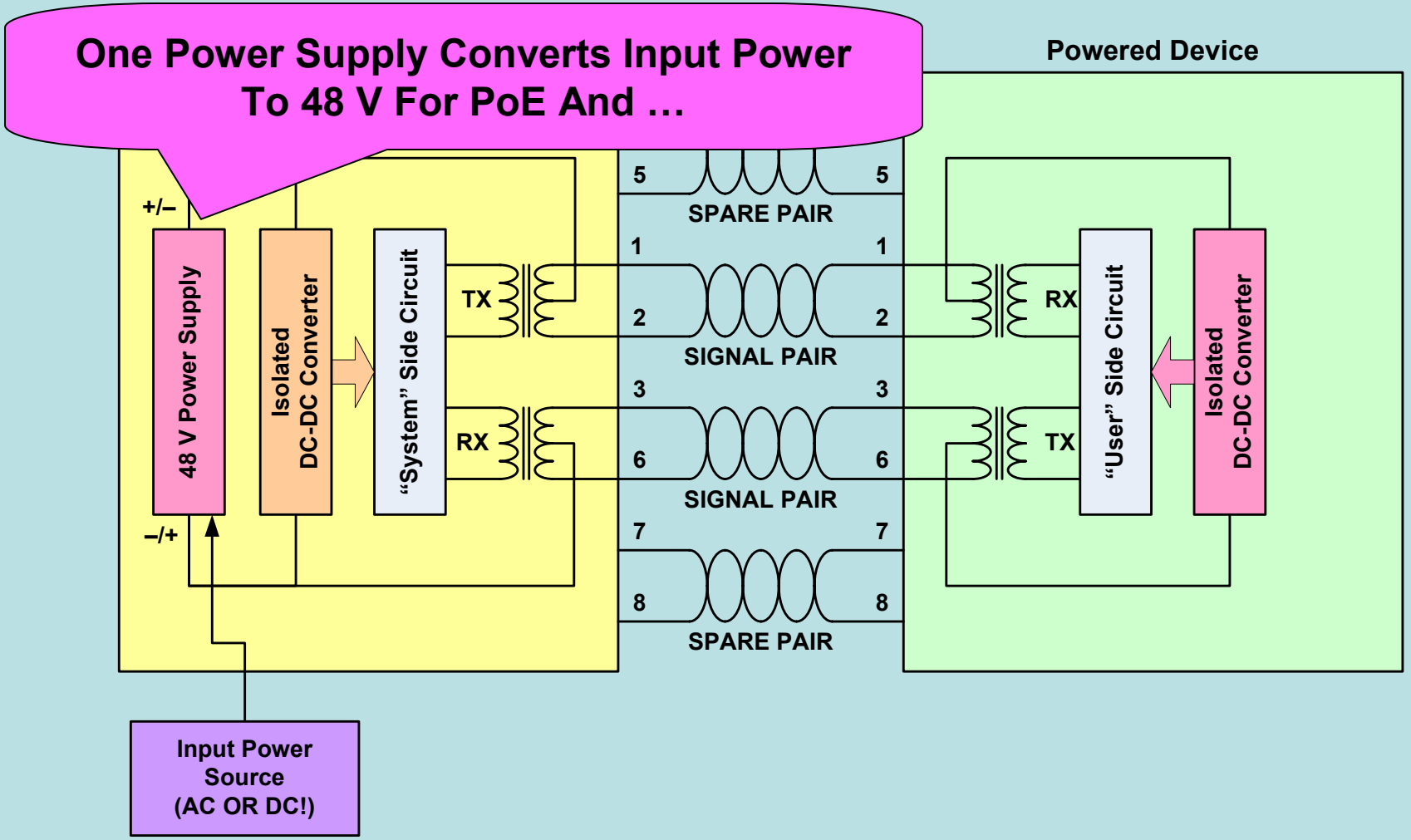

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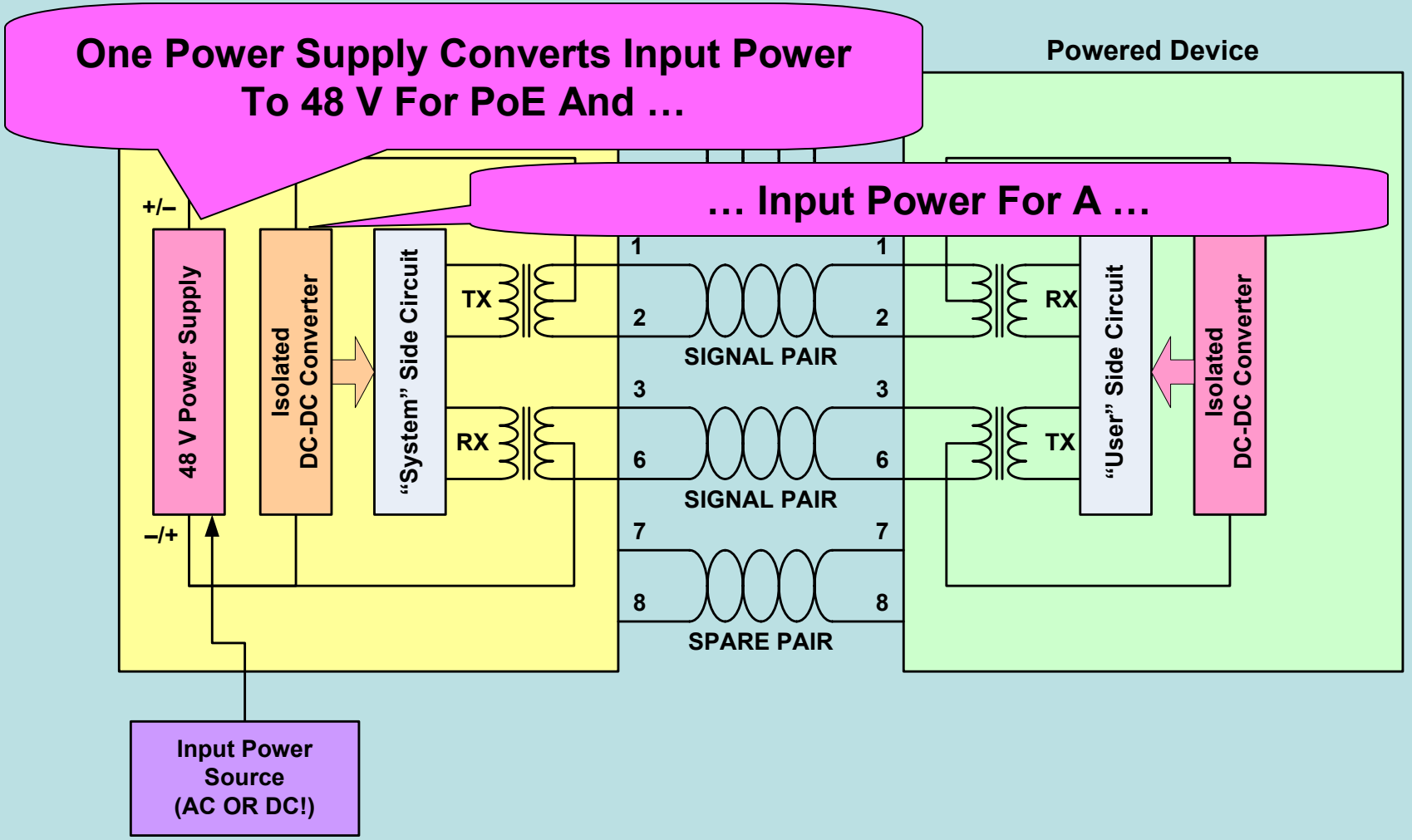

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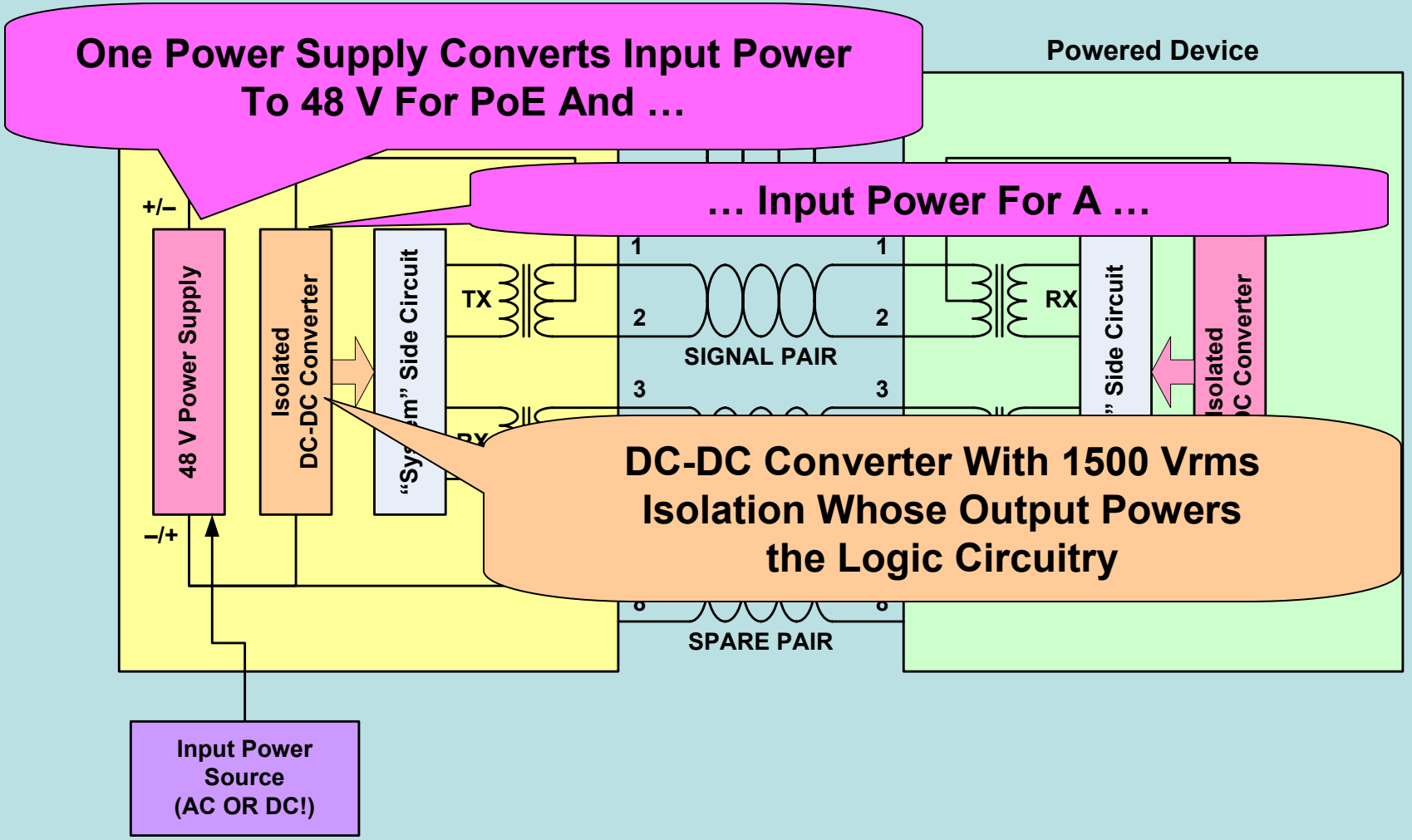
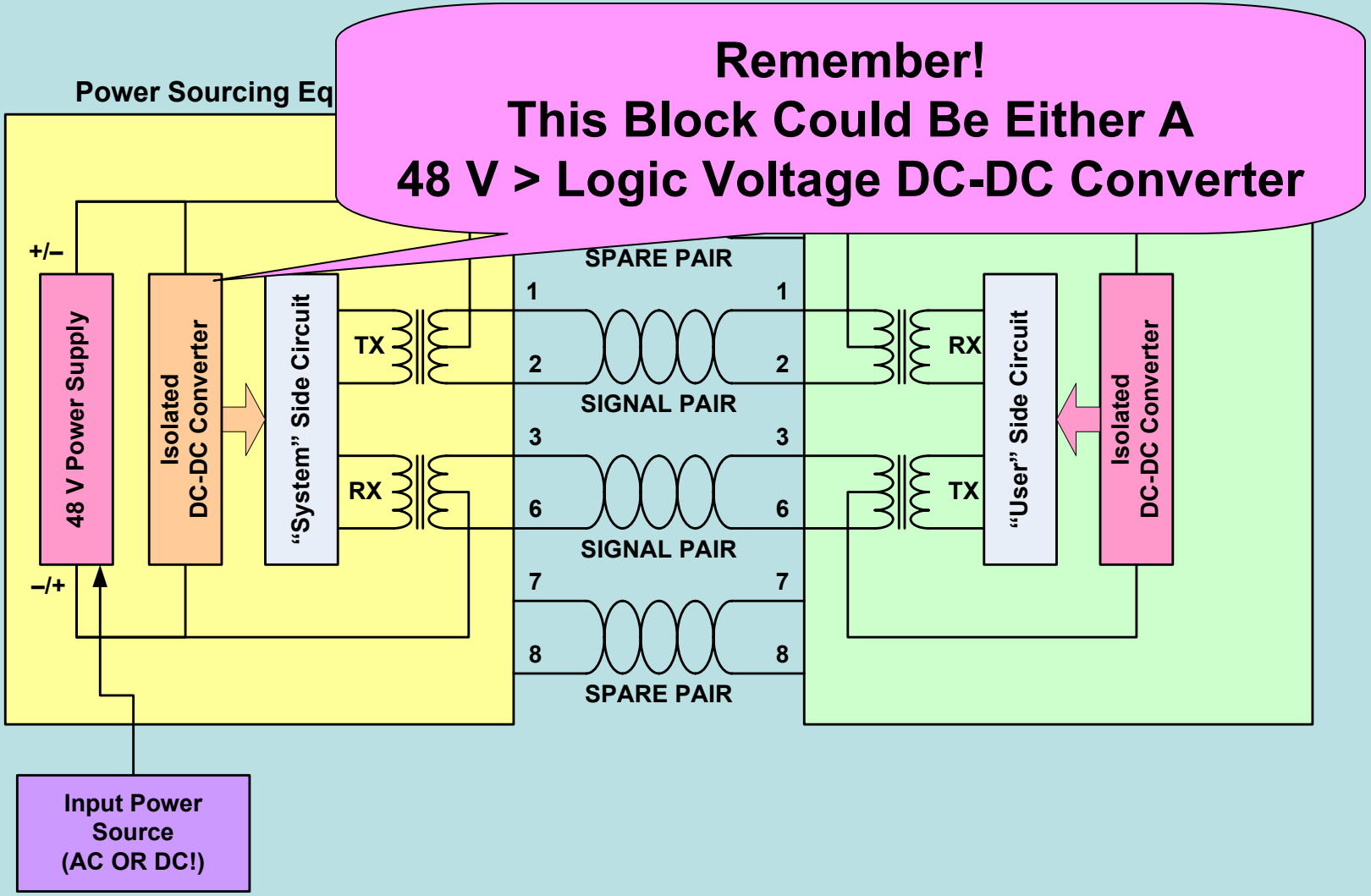
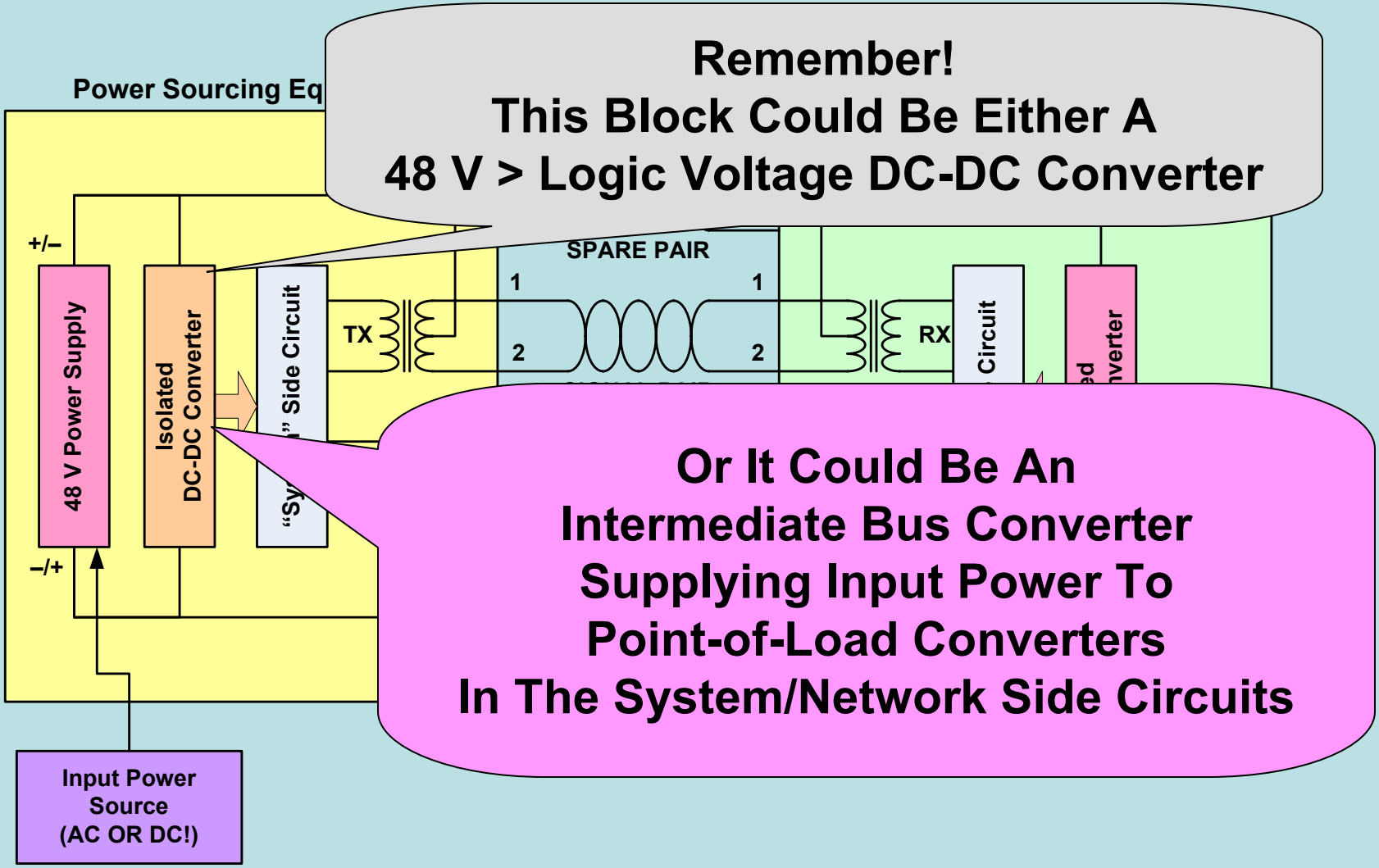
Input Power > 48 V > Logic Power



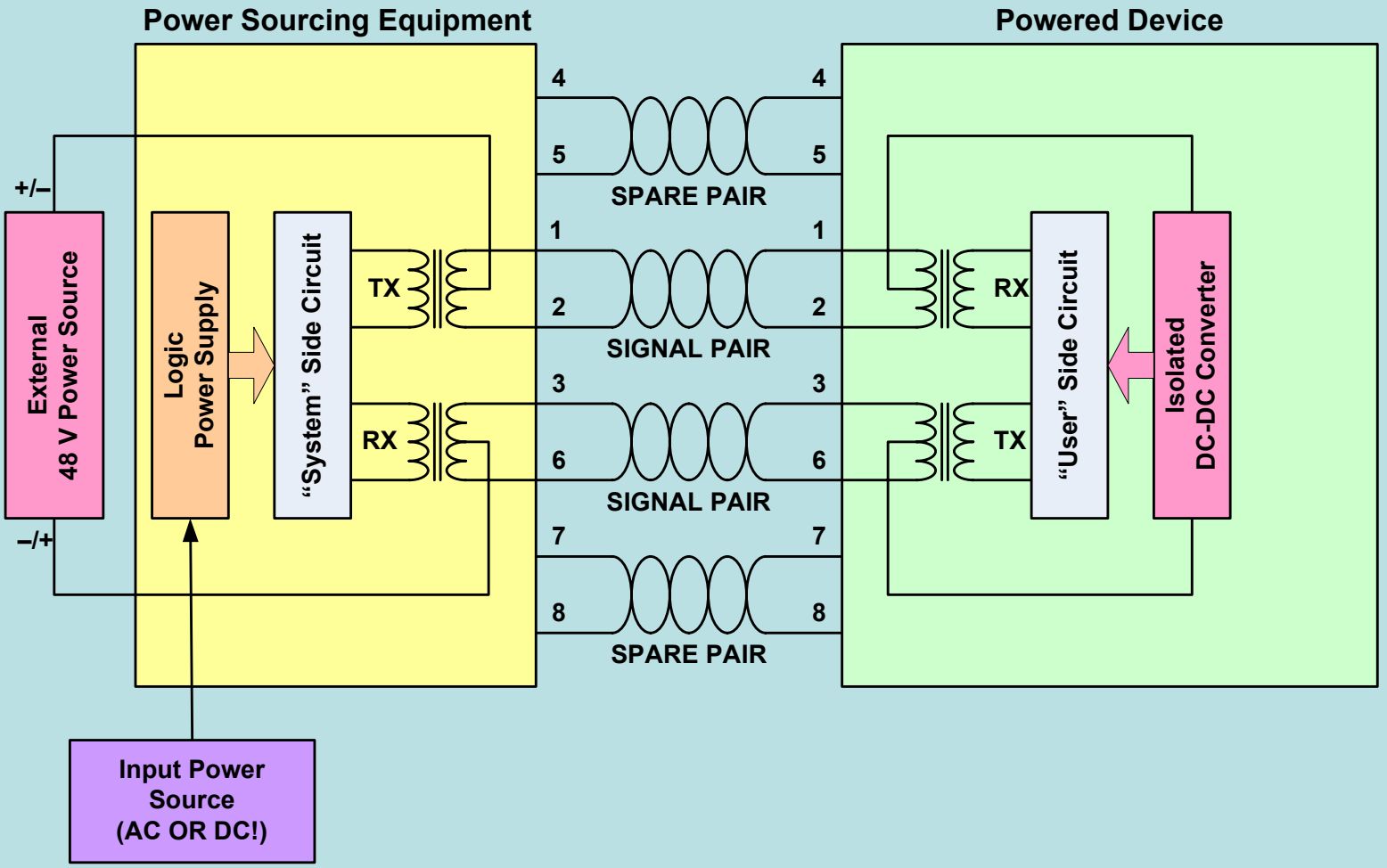
PSE Input Power Architecture



PSE Input Power Architecture



Architecture 3: Two Sources, Two Power Supplies



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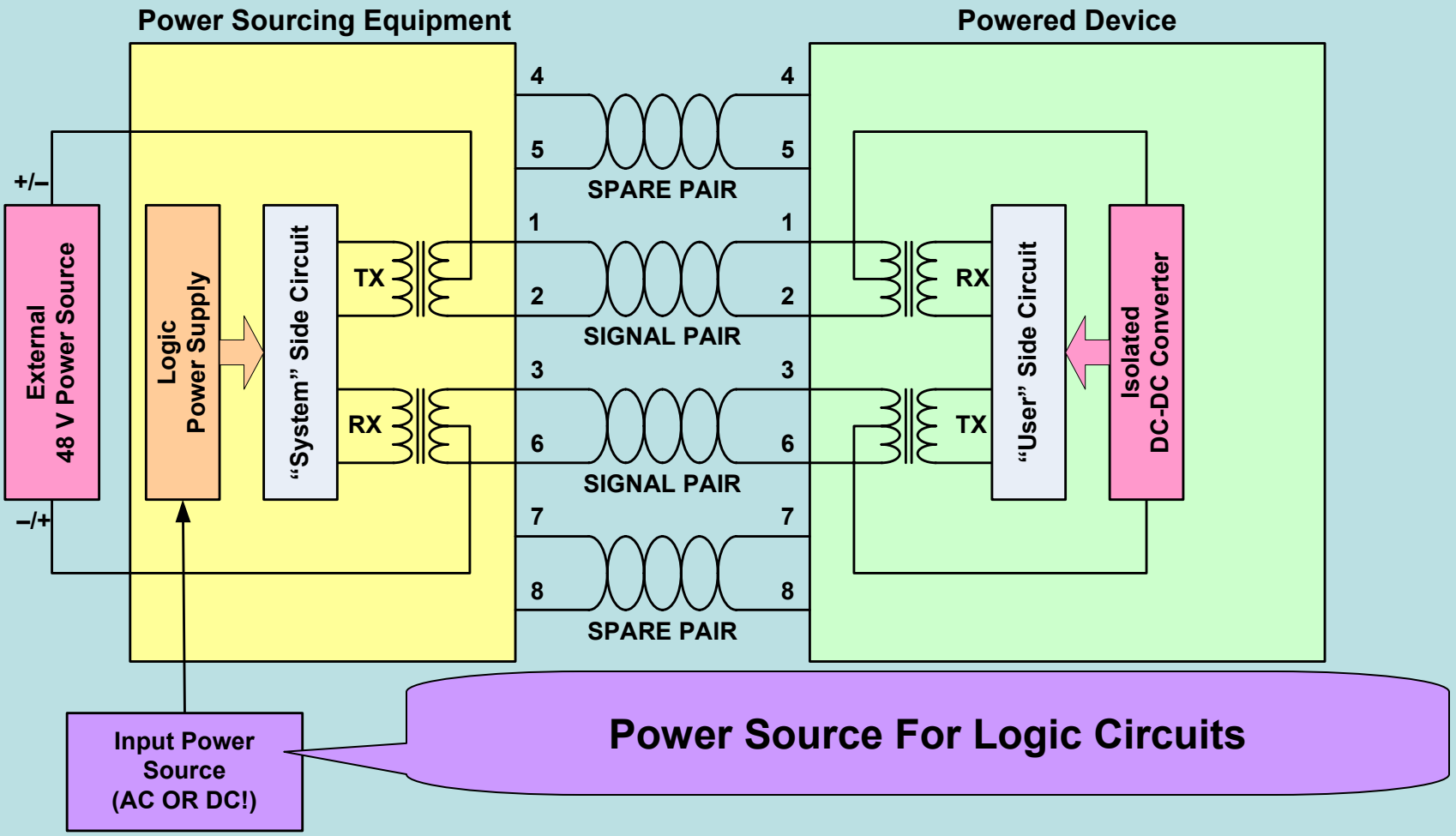

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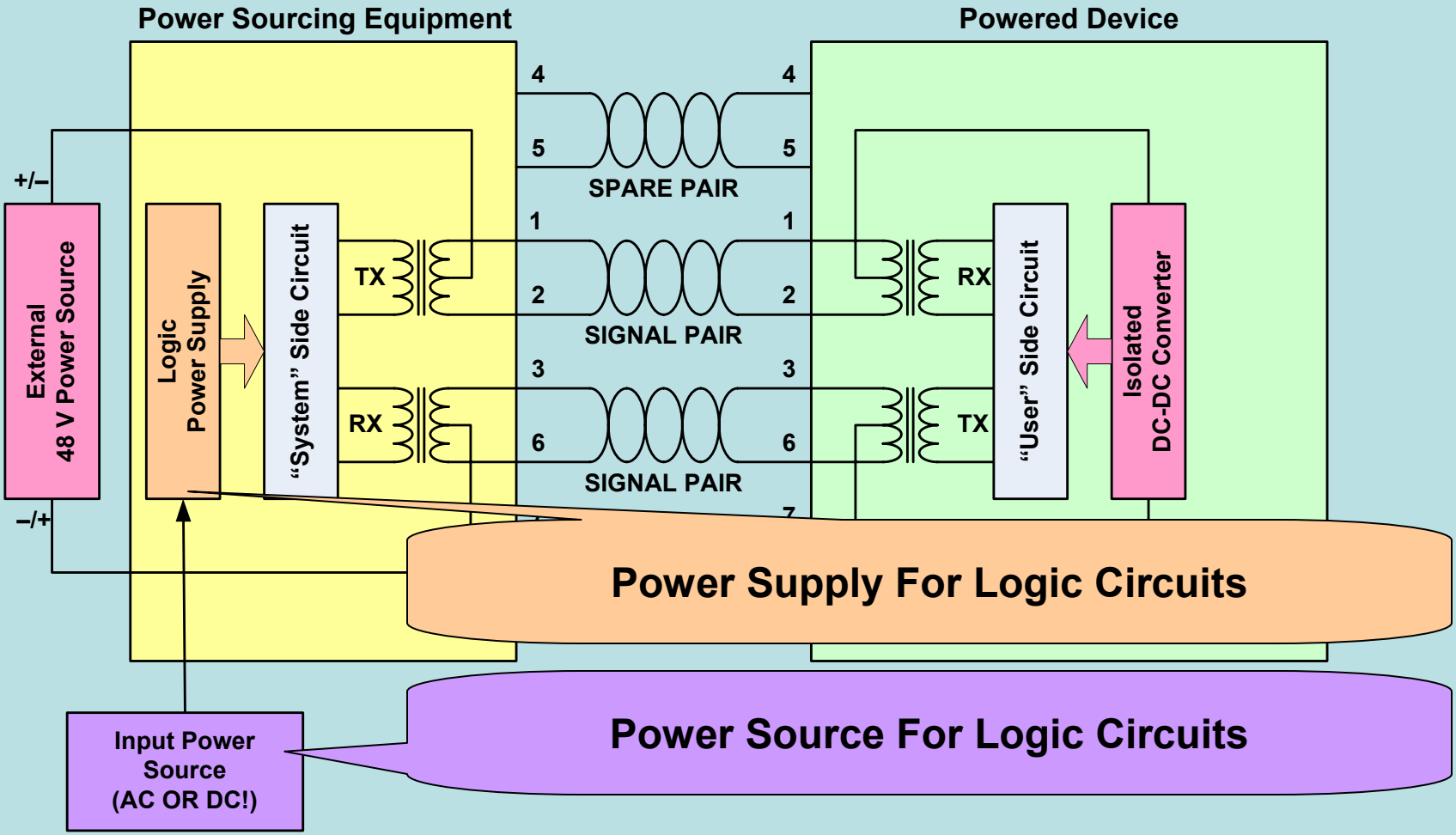

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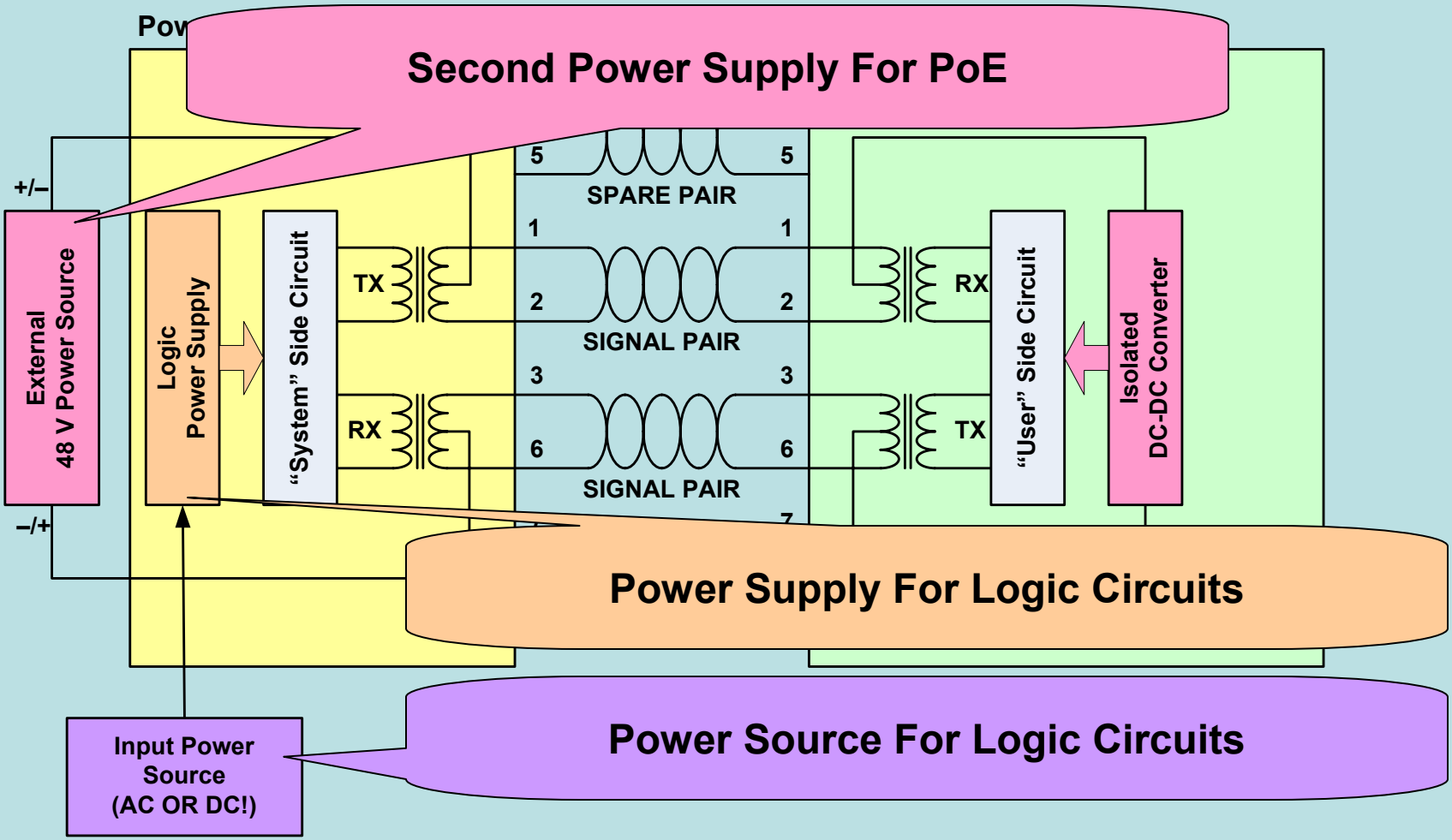

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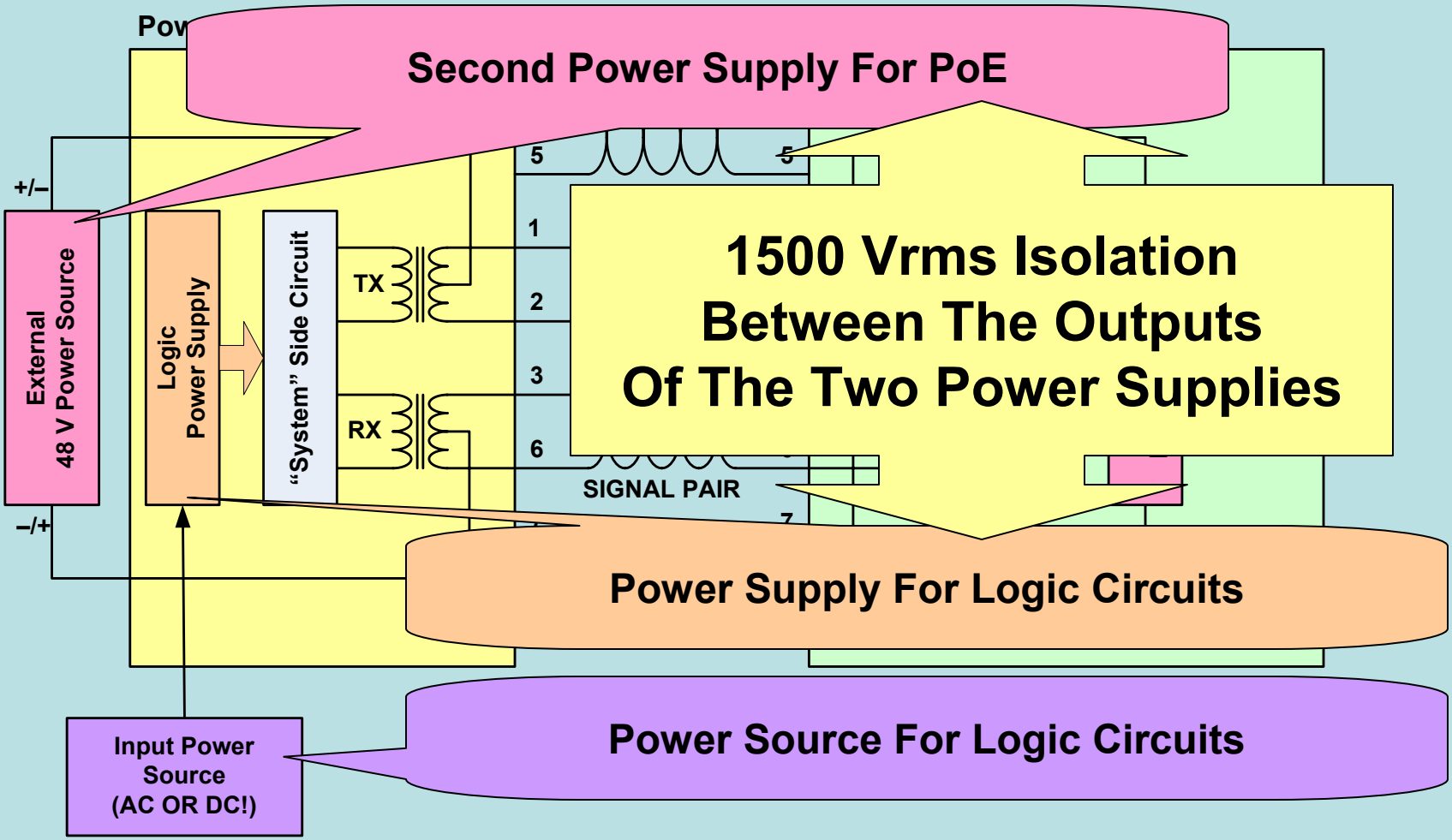
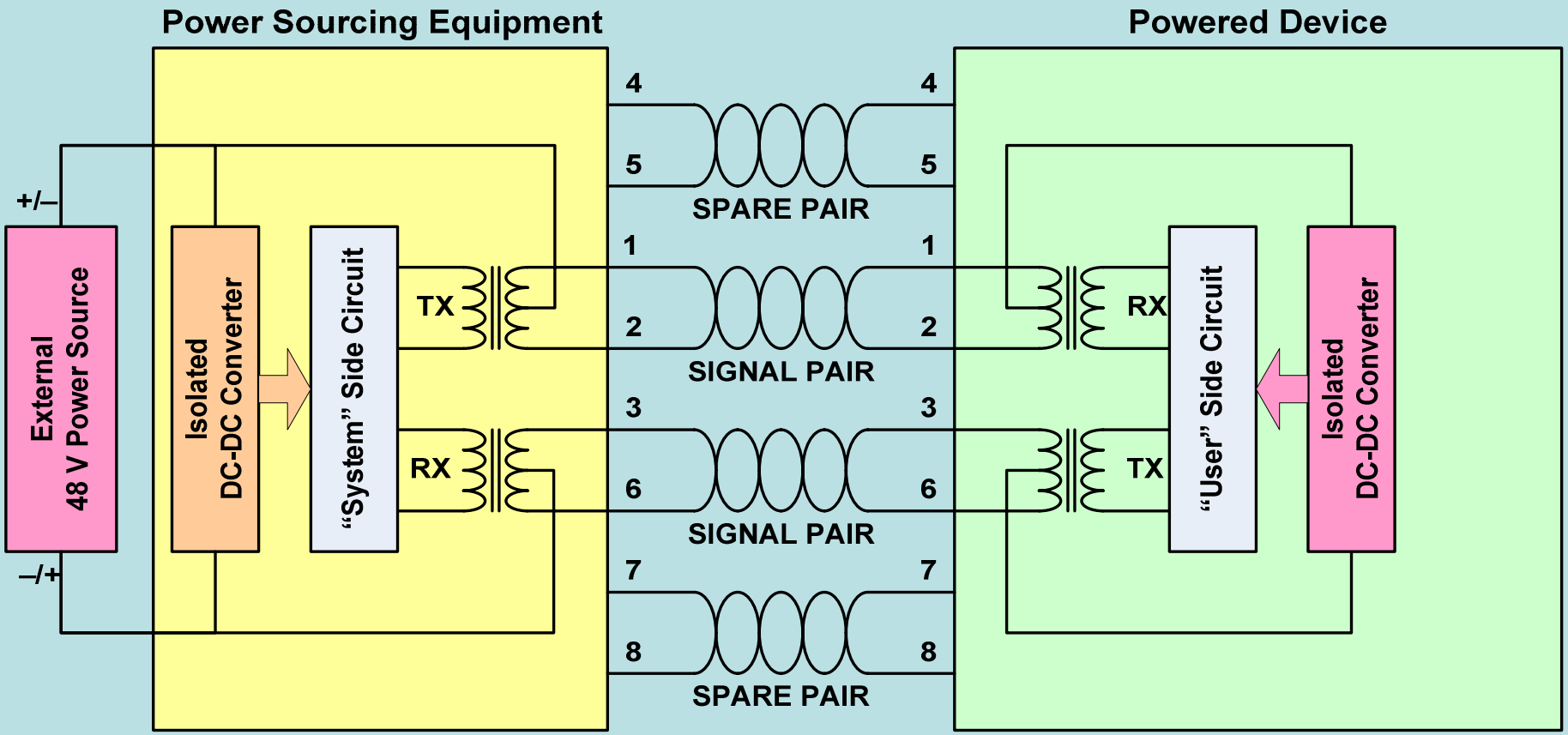


Architecture 4: Cascade Variation External 48 V For PoE



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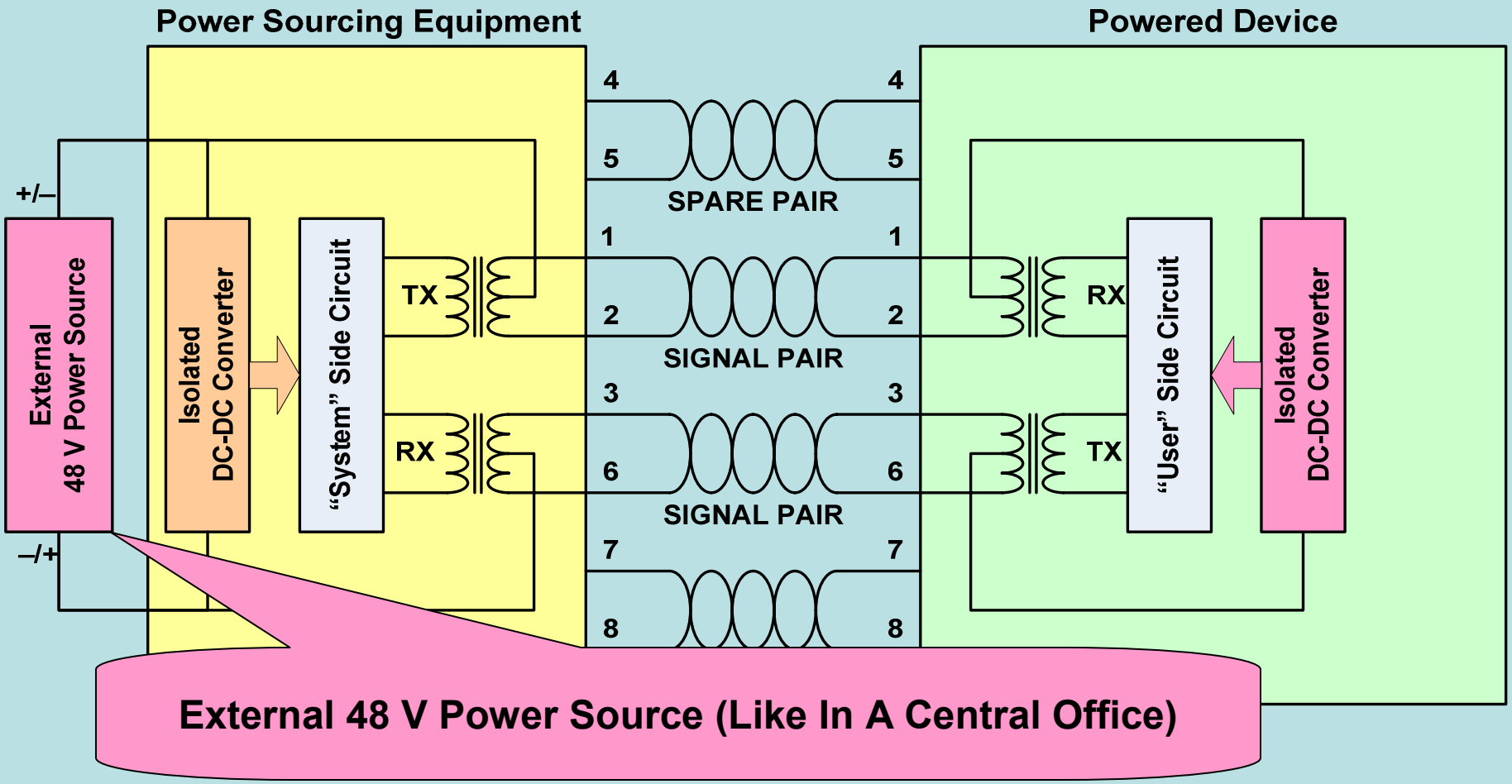

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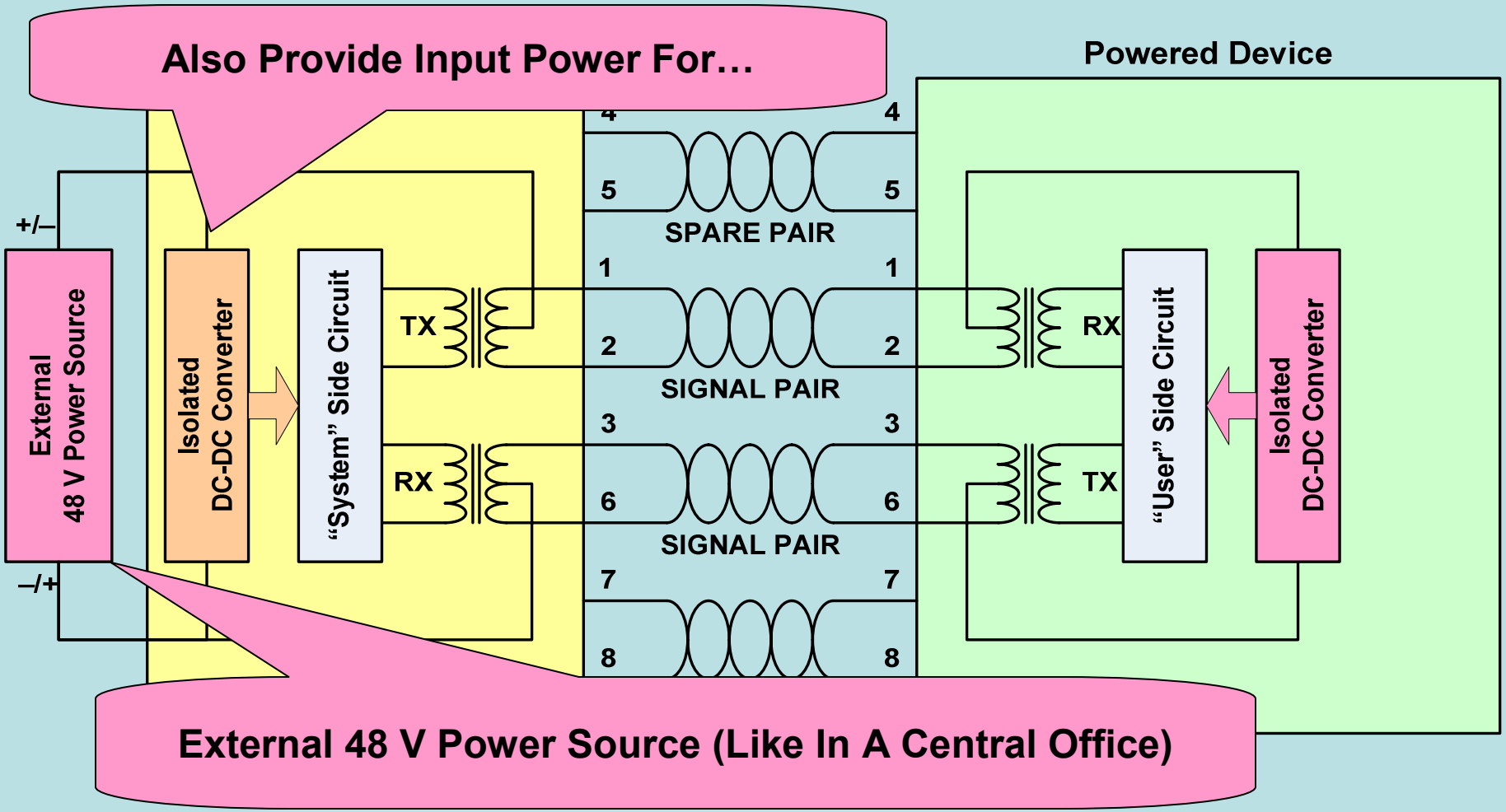

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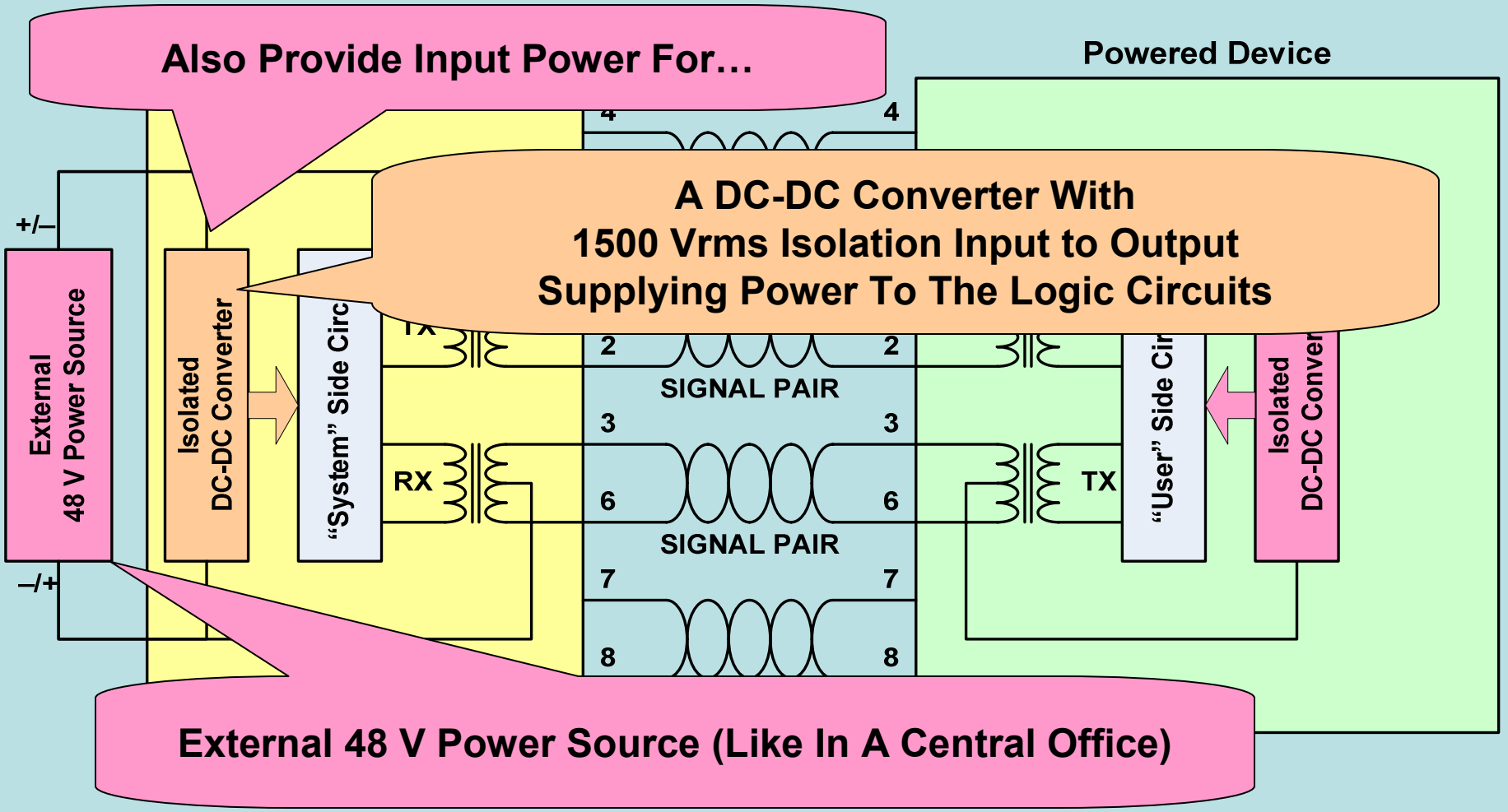
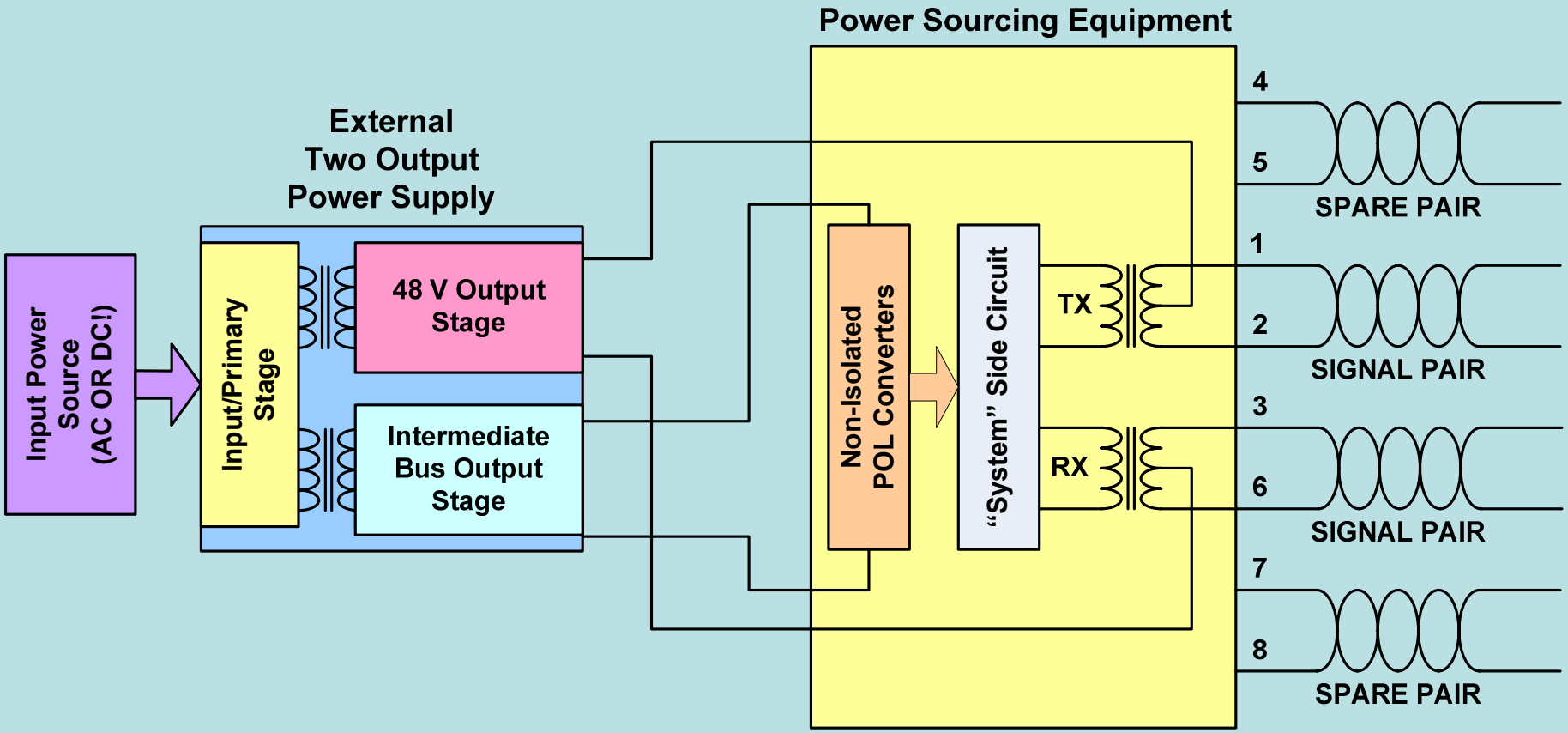
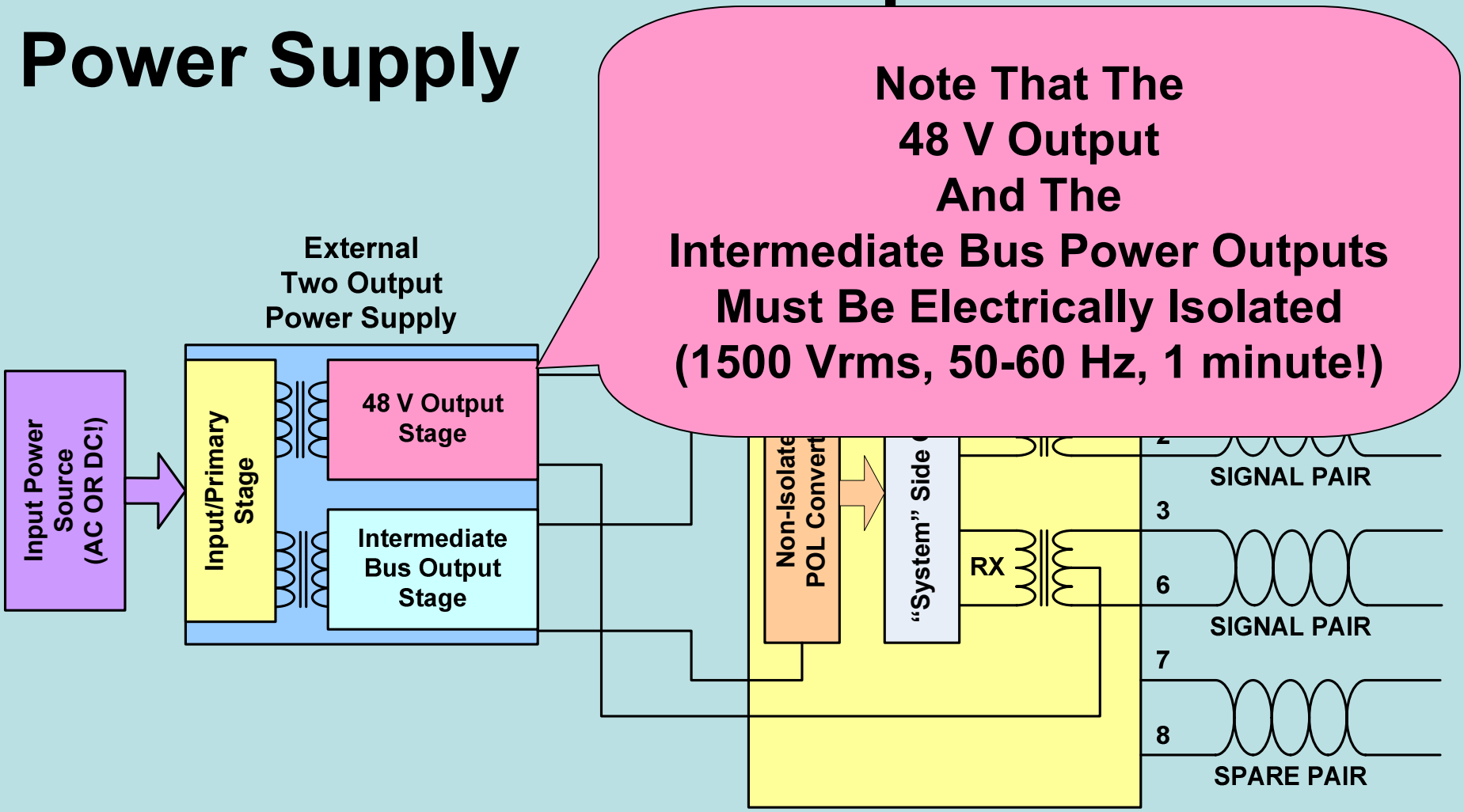


Architecture 5: Two Output Power Supply



Architecture 5: Two Output Power Supply



Summary

- Methods For Transmitting Power Over Ethernet Cables Reviewed
- PoE Isolation Requirements For PSE Reviewed
  - Not The Same As for Ethernet!
- Five Power Architectures Presented And Isolation Requirements Highlighted

Thank You For Your Time And Attention