APPLICATION NOTE

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APPLICATION NOTE
RF Assembly Phase Matching

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REVISION HISTORY

REVISION	DATE	REVISED PAGES	REVISIONS
1	5/15/2025		Engineering Release

1.0 Electrical Length Measurements

An RF signal is an alternating current (AC) that continuously changes between a positive and negative voltage. The figure below depicts the distance from peak to peak, or one wavelength. One wavelength is divided into 360 degrees.

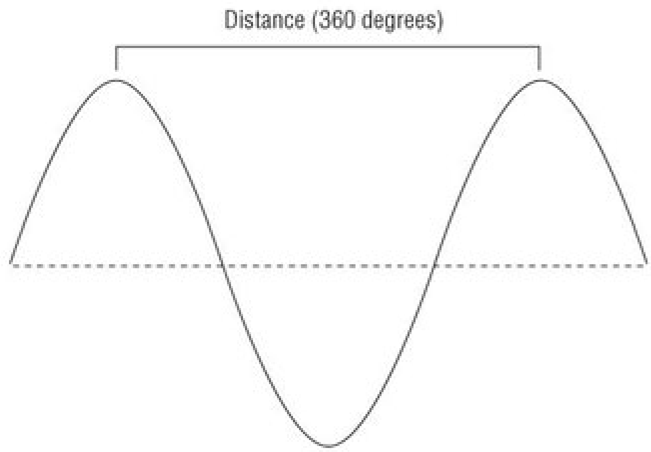

Figure 1. Wavelength

Frequency is the number of oscillation cycles per second, measured in hertz. For example at 18000 MHz (or 18 GHz), the rate is 18,000,000,000 cycles (wavelengths) per second.

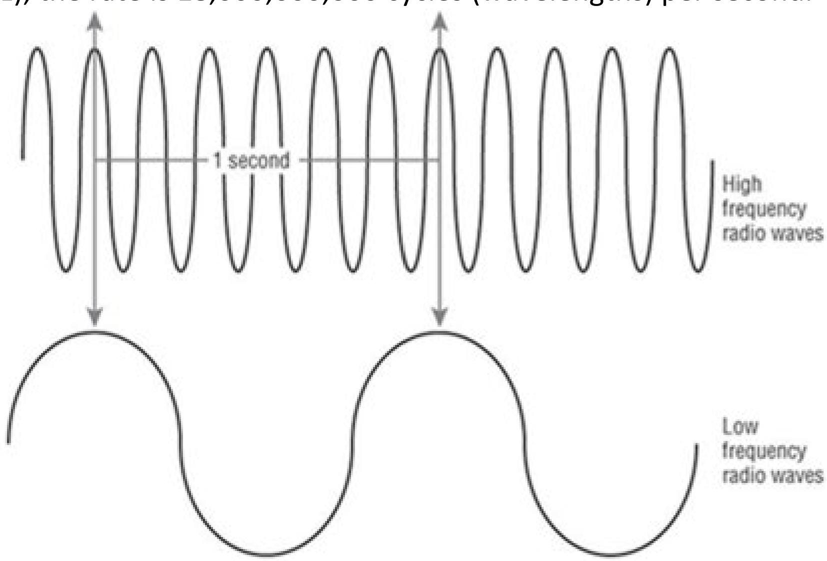

Figure 2. Frequency

The Electrical Length is the total number of degrees in an entire cable assembly at a specific frequency. This is referred to as the Phase Length. Many RF systems require cable assemblies to be a specific Phase Length.

RF cable assemblies can be manufactured and "Matched" in electrical length. This is called "Phase Matching". Phase Matching is typically specified by the customer based on their system requirements.

2.0 Types of Phase Matching

1. **Absolute:**
    a. Each cable assembly is electrically length matched to a phase length in a set number degrees at a specified frequency (this length can be supplied by the customer or determined during the first manufacture)
2. **Relative:**
    a. Each cable assembly (specified on the order) will be electrically length matched with all of the other cable assemblies ordered at the same time.
3. **Reference Standard ("Gold" Standard):**
    a. Each cable assembly is electrically length matched to a reference standard maintained by either Glenair or the customer. (reference standard can be manufactured during the first build of a cable assembly)
4. **"Soft" Standard:**
    a. Similar to a Reference Standard, except there is no "physical" standard kept, only a digital (electronic) reference.

3.0 Phase Matching Tolerance

When specifying a Phase Matching requirement, the minimum and maximum tolerance of the phase match are critical. The tighter the tolerance, the more difficult it will be to manufacture the cable assemblies. It will take more time, have higher scrap rates, etc.

Physical Length tolerances should be increased from a "standard" length tolerance to allow for variations in raw cable Velocity of Propagation (Vp). +/- 3% physical length tolerance is preferable. If Phase Matching cables of differing velocities, even greater physical length tolerance should be requested.

Below would be considered a "Standard" Phase matching tolerance.

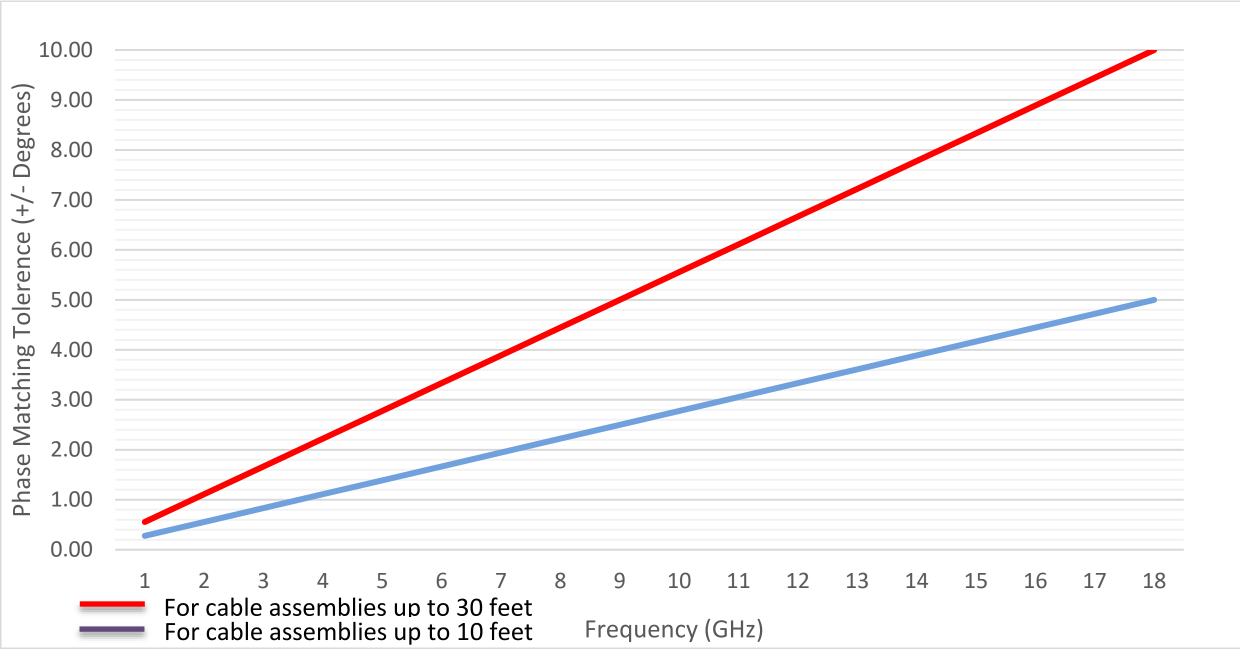

Figure 3. Standard Phase Matching Tolerance

4.0 Closeness of Phase Matching

How close the cable assemblies can be phase matched is dependent upon several parameters. These include:

1. **Highest frequency of operation**

   Typically, the higher the operating frequency, the more difficult it is to achieve a close match. The match limits in Figure 3 are generally offered with an additional cost to account for the additional processes in fabrication and testing. Tighter tolerance phase match requirements may require even greater effort, cost, or the use of phase adjustable connectors.

2. **Length of Cable Assembly**

   As the cable assembly grows in length, so does the difficulty in phase matching the assembly. Thus, longer assemblies require larger phase matching tolerance windows while shorter cable assemblies can typically be provided with tighter phase match tolerance windows. Figure 3 showcases limits that can be easily achieved for assemblies at the specified lengths on the graph. Longer lengths can also be addressed on a case-by-case basis. It is often necessary to balance system requirements and budgetary requirements to achieve the best solution.

3. **Variation of Velocity of Propagation (Vp)**

   Cables which have identical physical lengths, but different Vp's will have different electrical lengths. Tight control of Vp eases the matching process and results in assemblies with more similar physical lengths. For high Vp flexible coaxial cable assemblies, the Vp can usually be held to the nominal value within ±1%. For long assemblies, adjustment of the physical length to achieve a phase match can result in a variation of several inches. Thus, it is best to specify the electrical match and minimum mechanical length with length being the variable to achieve the desired phase match. Specifying both a tight phase match tolerance and a tight length tolerance decreases cable yield (more scrap) and increases cost.

For example, a 962-032-300 cable assembly, 120" long, @ 18 GHz. The 962-032-300 has a nominal Vp of 80% but due to variations in manufacturing and/or materials, the Vp can range from 79.0% to 81.0%.

To calculate Phase Length, we use the following formula:

ELECTRICAL LENGTH (degrees)

$$\phi = \frac{360 \bullet F \bullet L_{TH}}{984 \bullet V_{p\,100}}$$

$$F = Frequency\ (MHz)$$
$$L_{TH} = Length\ (Ft)$$
$$V_{P\,100} = Velocity\ of\ Propagation$$

$$\emptyset = \frac{360 \cdot 18000 \cdot 10}{984 \cdot 0.79} = 83{,}359°$$

$$\emptyset = \frac{360 \cdot 18000 \cdot 10}{984 \cdot 0.80} = 82{,}317°$$

$$\emptyset = \frac{360 \cdot 18000 \cdot 10}{984 \cdot 0.81} = 81{,}301°$$

Based on the calculation above, a change of just 1% in Velocity can cause a large change in electrical length

4. Temperature

PTFE dielectrics expand and contract with temperature. In the above example, the room temperature phase length is 82,317°. At -55°C the length would increase by 26°; at +125°C the length would increase by 57°; however, at 30°C the length would actually decrease by 1°.

5. Connectors

It is much easier to phase match cable assemblies with the same connectors on both ends than assemblies with different connectors. That doesn't mean that an assembly with straight connectors can't be matched to one with angled connectors; or one with TNC connectors matched to one with SMA connectors. It just adds to the difficulty and uncertainty of the match. In some applications it is necessary to account for the phase changes which occur during installation. Often the system software does this. It can also be accomplished with the use of phase adjustable connectors attached directly to the cable assembly.

6. Test Equipment Accuracy

It is highly recommended that a high-quality Network Analyzer be used for the measurement of electrical length. To achieve a high degree of accuracy, the test equipment and cable assemblies must be stabilized in a temperature-controlled room, have high quality adapters, and be calibrated regularly.

5.0 Final Notes

The Phase Data is presented in an "as tested" condition. In addition to any of the above conditions, cable handling, packing, and unpacking can all impact the phase measurements. If you have any questions regarding Phase Calculations or Phase Measurements, please reach out to your Glenair representative and they will provide you with more information.