Is It Necessary To Use A Balun?

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Figure-1: W2DU Design 1:1 Current Balun

1. **Is it necessary to use a 'BALUN' with a 'Mono Band Center Fed Hertz (MBCFH) Antenna', is a very important question.** ***Figure-1*** *illustrates a 1:1 Current Balun based on the design by Walter Maxwell W2DU.*

2. Definitions:

    a. 'BALUN' is an acronym which comes from the two words in the term, 'BALanced to 'UNbalanced Transformation', which describes a certain circuit behavior in any Signal Source, Feed Line or Load.

        i. A Balun is a device most commonly placed between a Active Antenna's feed point connection and the RF Feed Line connected to that feed point.

            1. If 50 Ohm Characteristic Impedance Coaxial Cable RF Feed Line is used, *the appropriate place to install a Balun* is directly to the feedpoint of the Antenna and then connect the RF Feed Line to the Balun.

            2. If 300 Ohm Characteristic Impedance Twin Lead, 450 Ohm Characteristic Impedance Window Line, or 600 Ohm Characteristic Impedance Ladder Line are used as the RF Feed Line, *the appropriate place to install a Balun* is at the end of the RF Feed Line before it enters the Radio Station and then use a piece of 50 Ohm Characteristic Impedance Coaxial Cable RF Feed Line to connect to the Balun and feed this through the wall or window feed through panel and then connect this to a Manual Tune or Automatic Tune Impedance Matching Network (IMN). There must be no other significant path or coupling into the station.

    b. 'Mono Band Center Fed Hertz (MBCFH) Antenna', is the technically correct description for the terms of 'Hertz' or 'Hertz Antenna' and this is normally called by one of the following descriptions;

1. 'Dipole' or 'Dipole Antenna'.

2. 'Doublet' or 'Doublet Antenna'.

3. 'Ungrounded' or 'Ungrounded Antenna'.

4. 'Half-Wave' or 'Half-Wave Antenna'.

c. The **'Basic Hertz Antenna'** is a single wire fed at the center, with a wire length equal to approximately ½ of the wavelength (1/2 λ) of the RF Alternating Current (AC) signal to be transmitted.

i. In the remainder of this document, the terms 'Dipole' or 'Dipole Antenna' will be used rather than the terms 'Hertz' or 'Hertz Antenna'.

ii. A Dipole Antenna may be mounted in any of the following three configurations:

1. Horizontal

a. The center and the ends of the single wire are parallel to the Earth's surface and are normally equal distance above it.

2. Inverted-'V'

a. The center of the single wire is higher above the Earth's surface then the ends of the single wire, which are at equal heights closer to the Earth's surface then the center, so the wire looks like the letter 'V' upside down or inverted.

3. Slanting (Sloping)

a. One end of the single wire is higher above the Earth's surface than the other end of the single wire which is closer to the Earth's surface.

3. ***The decision whether or not to use a BALUN on a Dipole is a Personal Choice!***

a. ***What does a Balun do for a Dipole Antenna?***

i. It provides a ***Predictable Radiation and Reception pattern***!

ii. It provides ***Common Mode Current (CMC) Suppression***!

iii. It provides a ***Fixed Ratio of Impedance Transformation (1:1, 4:1, 6:1, 9:1 12:1 etc)***!

4. ***The remainder of this document will provide enough basic information to make an informed decision, whether to use or not to use a Balun and obtain its benefits.***

5. Most Radio Frequency Communication-Electronics Equipment (**RFCEE**) deal with 'Two-Conductor' Signal Sources, Feed Lines, and Loads.

    a. Any 'Two-Conductor' Signal Source, Feed Line and Load, operating in an '<u>ideal</u>' fashion, will have exactly 'Equal' and 'Opposite' Currents flowing through each of the conductors. Current flowing in one direction on one conductor will be matched or duplicated by an exactly 'Equal' current flowing in the opposite direction on the other conductor at any instant of time.

    b. Examples of Two-Conductor Signal Sources, Feed Lines and Loads:

        i. Signal Sources

            1. The Transmitter stage of a Transceiver during transmission.

            2. An Active Antenna during reception.

        ii. Feed Lines

            1. '<u>Unbalanced</u>' Two-Conductor - 50 Ohm Characteristic Impedance <u>Coaxial Cable</u> during Transmit and Receive.

            2. '<u>Balanced</u>' Two-Conductor - 300 Ohms Characteristic Impedance <u>Ribbon Line</u> during Transmit and Receive.

            3. '<u>Balanced</u>' Two-Conductor - 450 Ohms Characteristic Impedance <u>Window Line</u> during Transmit and Receive.

            4. '<u>Balanced</u>' Two-Conductor - 600 Ohms Characteristic Impedance <u>Ladder Line</u> during Transmit and Receive.

        iii. Loads

            1. An Active Antenna during transmission.

            2. The Receiver Stage of a Transceiver during reception.

6. If the RF Alternating Current (**RFAC**) flowing on either of the two conductors, ***<u>is not</u>*** 'Equal' and 'Opposite' in a Two-Conductor RF Feed Line system, it will 'Radiate' and 'Receive' unwanted signals.

    a. This is true no matter how good a shield is, or how many layers of shielding a cable has.

    b. In a perfect system even the inside of the grounded shield of a Coaxial Cable RF Feed Line has the same current as the center conductor.

7. The difference between ideally operating 'Unbalanced' and 'Balanced' Feed Lines lies in *'System Voltages'*, rather than the System Currents. *<u>Balance is referenced to voltage, not current, in an ideal system</u>.*

8. A '<u>Unbalanced</u>' **50 Ohm** Characteristic Impedance Coaxial Cable RF Feed Line has significantly different voltage from each conductor to ground.

    a. In a 'Perfectly' working 'unbalanced' 50 Ohm Characteristic Impedance Coaxial Cable RF Feed Line, the amount of voltage unbalance is infinite. One conductor (the shield) has zero voltage to the outside world, even while currents are equal and opposite.

        i. No matter how we feed or connect a Coaxial Cable RF Feed Line, all current on the CENTER Conductor <u>must</u> always be balanced and matched by an equal and opposite current on the INSIDE of the innermost shield.

        ii. If the two conductors of the load or source do not carry equal currents, some current will flow in a loop through the ground or along the OUTSIDE of the shield.

        iii. The outside of the shield or shields is isolated by the skin effect in the conductor wall. At Radio Frequencies (RF) the 'outside of the shield' can be treated as an *'independent third conductor'* connected to the 'inside of the shield' at the ends of the RF Coaxial Feed Line.

9. A '<u>Balanced</u>' **300-Ohm** characteristic impedance Twin Lead, **450-Ohm** characteristic impedance Window Line, or **600-Ohm** characteristic impedance Ladder Line, 'Perfectly' operating will have equal and opposite voltages, as well as equal and opposite currents, all along the length of the line.

    a. Any difference in opposing voltages along the line can cause the line to radiate, since that often means currents will become unbalanced.

    b. All operating balanced lines are surrounded by an external magnetic and electric fields. This effect is caused by the necessary separation of conductors in the line.

    c. **To minimize induced noise (interference) to balanced lines, they should be *'twisted'* or *'transposed'* at fractional wavelength intervals. If you look at older open-wire telephone or signaling lines, they are periodically transposed.**

    d. ***Twisting or transposing the RF Feed Line minimizes the effect of induced noise from external sources by allowing the noise to be equally induced in each conductor thus taking advantage of common mode rejection of the balanced line circuit.*** *With out twisting or transposing, the two wires are naturally at different distances from any noise source and thus receive different values of induced noise*.

10. The portion of RF Alternating Current (RFAC) flowing that ***<u>is equal</u>*** in amount and opposite in phase on <u>any</u> type of RF Feed Line is called the '*<u>Differential Mode Current (**DMC**)</u>*'.

    a. Differential Mode Current (DMC) operation, is the *normal desired method of operating a RF Feed Line, and it has impedance*. RF Feed Lines are designed and specified with a certain Characteristic Impedance Value (electronic symbol 'Zo'). This 'Zo' Value is established by the ratio of distributed inductance and capacitance in the RF Feed Line.

i. This is the 'Zo' which is referenced in the data specification sheets and is referred to as 50-Ohm, 75-Ohm, 300-Ohm, 450-Ohm, or 600-Ohm 'Zo'.

ii. This 'Zo' Value, if applied as a resistance across the line at the far end, would make voltage and current uniform along the line (except for the small normal power loss with distance).

iii. Because this 'Zo' Value relates directly to opposite flowing currents in each conductor, it is called DMC, because it deals with the 'across conductor' or 'between conductor' characteristics.

iv. A conventional two-conductor RF Feed Line, even if one conductor is called the 'shield', it must have exactly equal and opposite flowing currents into each conductor at each end. Without equal and opposite DMC flowing at every point in a RF Feed Line, the line will radiate and receive signals.

v. A RF Feed Line with purely DMC operation would never radiate or receive unwanted energy.

vi. This 'Zo' Value is different than the 'Common Mode Impedance (CMC)'.

11. The portion of current that ***is not equal*** in amount and opposite in phase on any RF Feed Line is known as 'Parallel Current' or '*Common Mode Current (**CMC**)*'.

    a. CMC is the portion of conductor currents not matched by exactly equal an opposite magnitude currents.

    b. This is the portion of total current responsible for a Feed Line behaving like a single wire line.

    c. CMC is most commonly caused by improper RF Feed Line installation or Antenna Design. The RF Feed Line, in effect, behaves like two very different RF Feed Lines connected to the Antenna and Equipment at the same time.

12. Most RF Feed Lines fall somewhere short of perfect examples, but the closer to perfect, the less energy lost as unwanted radiation.

    a. Perfection also means that the RF Feed Line does not pick up unwanted signals and noise, and Radio Frequency Interference (**RFI)** will not appear on equipment near the transmitter unless it is from Antenna or Equipment radiation.

    b. In short, your Antenna becomes the point of most signal radiation and reception.

    c. Most of us want the Antenna to be an Antenna, and the RF Feed Line NOT to be an Antenna, which often runs near computers, radios, TV sets, and noise sources!

13. Most of us are familiar with the terms '*Radio Frequency Interference (**RFI**)*' or also called '*RF in the shack*'.

a. Severe problems have obvious symptoms. We might get an RF burn when we touch a panel or knob. There may be odd equipment behavior such as transmit audio distortion, equipment lock-up, or erratic CW keying.

b. Lesser problems, on the other hand, are often not very obvious.

c. Unwanted coupling can carry noise back to the Antenna, and we might assume the noise is normal and unavoidable.

d. Unwanted RF currents also waste power that otherwise would be transmitted or received as a useful signal, and we probably wouldn't know the extent to which it is actually occurring.

14. Antenna site selection, and space limitations can force us to install Antennas close to the station operating position.

    a. When Antennas and the operating position are less than ½ wavelength apart, normal Antenna radiation fields can couple large amounts of energy directly into station wiring.

    b. Other than moving the Antenna or operating position, the only cure might be tying equipment and wiring grounds together with the shortest leads possible and using an artificial (counterpoise) ground system at or near the operating position.

    c. In other cases Antenna design might create a problem. One example is an Antenna intentionally worked against a poor ground, such as a longwire or vertical with a small radial system. RF Alternating Current exciting the Antenna might be finding a ground path through the Feed Line to station equipment and wiring. Once the unwanted RF current gets in to the station equipment, it can cause voltage differences between equipment and other things in the room. This can cause severe RFI and even RF burns. These are the cases where a properly installed Antenna Current Balun is beneficial.

15. As with Differential Mode Impedance (**DMI**) operation across the Feed Line conductors, parallel or Common Mode operation has impedance to 'ground', to other objects around the RF Feed Line, and to other points in the system. It is often useful to consider this the system impedance when fed like a longwire. Common mode voltage differences along the line cause current to flow, and the Common Mode Impedance (**CMI**) determines current flowing in that mode. The voltage that causes CMC almost always appears at the Antenna, since that is where major balanced to unbalanced transitions occur.

    a. Reducing unwanted CMC can be accomplished by use of a properly designed *'Current Balun'*, which inserts a large amount of CMI in series with the RF Feed Line without causing unwanted changes to DMC operation.

        i. *Do NOT use a 'Voltage Balun'.*

            1. A Voltage Baluns always try to force the output conductors to equal voltages, which means currents, can be far from even and this almost certainly guarantees some RF Feed Line radiation or reception, causing RFI, because there are very few 'perfectly balanced' loads.

b. The combination of proper grounding and high substantially increased CMI, provided by a Current Balun, the CMC on the RF Feed Line will be greatly decreased to immeasurable or unnoticeable values.

16. The terms **'Current Balun', 'Choke Balun'** and **'Isolator Balun'** are all interchangeable terms for the same basic device. The definitions are:

   a. It is called a **'Current Balun'** because it ***'Supplies Equal and Opposite Currents'*** to each output conductor regardless of load characteristics.

   b. It is called a **'Choke Balun'** because it ***'Chokes Off' unwanted Common Mode Current (CMC)'*** paths along a Feed Line.

   c. It is called a **'Isolator Balun'** because it ***'Isolates' Common Mode Current (CMC')*** paths along a Feed Line.

17. A Current Balun allows the output voltages, with respect to 'ground' or outside world, to float to any value required to provide 'Equal' and 'Opposite' flowing currents to each RF Feed Line conductor ensuring proper operation.

   a. In essence, it is a universal device that could be used with either 'Balanced' or 'Unbalanced' RF Feed Lines equally well.

   b. They isolate the device connected at one end from the device connected at the other end.

   c. They can also be used as broadband phase-invertors.

   d. To be the most effective a Current Balun must be located outside the station, before unwanted currents get near station wiring.

   e. If a 50 Ohm 'Zo' Coaxial Cable RF Feed Line is used, *the best appropriate place to install a Current Balun directly to the feedpoint of the Antenna* and then connect the RF Feed Line to the Current Balun.

   f. If 300 Ohm Characteristic Impedance Twin Lead, 450 Ohm Characteristic Impedance Window Line, or 600 Ohm Characteristic Impedance Ladder Line are used as the RF Feed Line, *the appropriate place to install a Balun is at the end of the RF Feed Line before it enters the Radio Station* and then use a piece of 50 Ohm Characteristic Impedance Coaxial Cable RF Feed Line to connect to the Balun and feed this through the wall or window feed through panel and then connect this to a Manual Tune or Automatic Tune Impedance Matching Network (**IMN**). There must be no other significant path or coupling into the station.

   g. *A Balun and proper grounding will not be as effective when a troublesome RF Feed Line parallels another conductor for any distance. Current will simply be induced in the other conductor, and give us one more conductor to worry about.*

18. Most Current Baluns make the outside shield of a 50-Ohm characteristic impedance Coaxial Cable RF Feed Line connection, a high impedance while not disturbing the inside operation.

a. The shield’s 'Outer' surface current is independent of the shield's 'Inner' surface current and the balanced center conductor current.

b. The outside of the shield can easily pick up currents by passing too closely to an operating Antenna. It will also radiate when excited with time-varying currents from an improper load or source.

19. A common 'Rule-of-Thumb' to determine the amount of Balun Common Mode Impedance (CMI) needed to reduce RF Feed Line CMC is 'one hundred-to-one'. Using this guideline, 5000-Ohms of CMI is enough for a 50-Ohm Characteristic Impedance RF Feed Line. ***Unfortunately this rule isn’t always correct. The Balun Common Mode Impedance (CMI) requirement can be nearly any value, depending on the system.*** **Isolation or choking impedance is not tied to RF Feed Line impedance or SWR, but rather the voltage exciting the RF Feed Line and the system CMI and in most cases we want to have the highest possible CMI.**

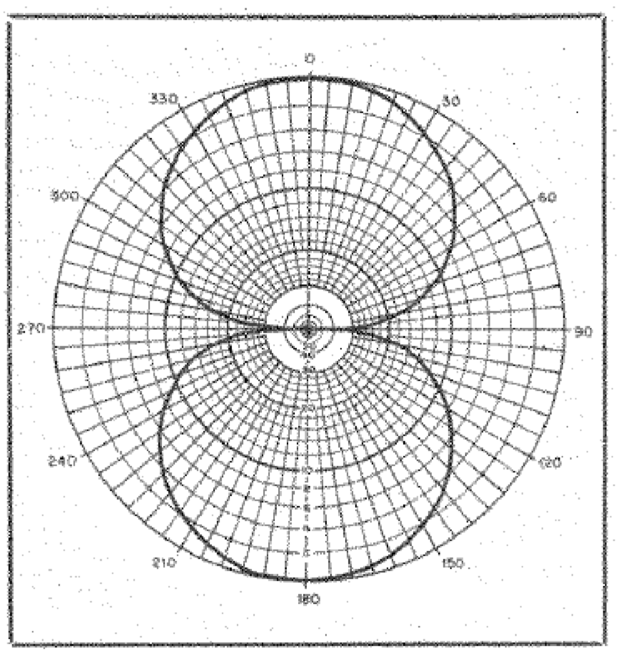

Fig. 1 — Classic response pattern of a half-wavelength dipole in free space. The concentric-circle scale is indicated in decibels down, relative to the response in a broadside direction from the axis of the dipole. The outer scale shows degrees of departure from one broadside direction. The axis of the conductor is common with the line between the 90° and 270° outer-scale markings.

Figure-1 Courtesy of the ARRL Antenna Book, 13th Edition 1974, which shows the classic 'Figure Eight' radiation pattern of a half wave dipole in free space.

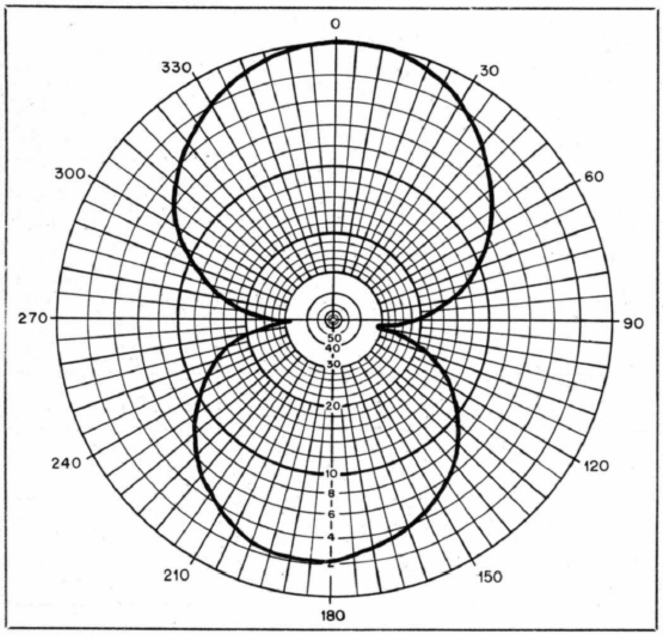

Fig. 2 — Response pattern of the balun-fed half-wavelength dipole in the rf anechoic chamber. The apparent front-to-back ratio exists because the antenna was not located at the exact center of the rotating support. This response and that of Fig. 3 are drawn to the same relative scale.

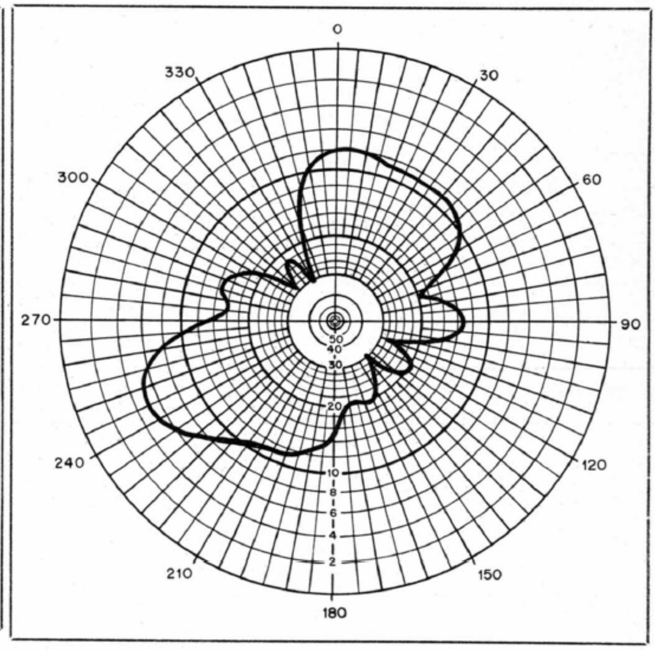

Fig. 3 — Response pattern of the half-wavelength dipole without a balun. The pattern changed significantly during tests if the coaxial feed line was relocated, no doubt caused by changes in the amplitude and phase of currents flowing on the outside of the line.

20. Figures-2 and Figure-3 above show the results of a 'Half Wave Dipole Antenna' test conducted by Bruce A. Eggers WA9NEW in an RF Anechoic Chamber at the North Carolina State University in 1980.

    a. Quoting his test conclusions:

        i. 'The results of this experiment should not necessarily be interpreted to mean that installing a Balun on your 80-meter dipole is going to result in any detectable differences. Remember, this Dipole was in 'free space'. '

        ii. 'The Antenna interacts with all kinds of reflecting and reradiating objects. Every piece of material in the vicinity of the Antenna has an effect. And it seems reasonable to assume that the number of nulls and peaks in Figure-3, and the depth of the nulls, is related to the length of the feed line. The pattern of your 80-meter Dipole might not look as bad as Figure-3, but you can rest assured that it probably doesn’t look like Figure-2 either.'

        iii. 'The majority of the variations between a real-world Antenna pattern and an idealized pattern, at least in regard to simple Antennas on the lower frequencies, will result from objects in the near field of the Antenna. *The additional variations introduced as a result of not using a Balun in an application of a coaxial-fed balanced Antenna will become most significant at higher frequencies with multi-element Antennas*.'