Chapter 21A

How the W2DU Ferrite Bead Balun Originated

It is interesting to know that the original design of the W2DU ferrite bead balun is a spin-off from the development of antenna systems designed for spacecraft built by RCA's Astro-Electronic Division, specifically the antenna system developed by the author for the World's first weather spacecraft, TIROS 1, and its successors.

Because the radiation patterns of the antenna system are vital to the successful operation of the spacecraft, many measurements of the patterns were required during the development stage to discover the correct physical and electrical properties of the antenna that would produce a satisfactory pattern while attached to the spacecraft.

To obtain realistic radiation patterns of the antenna it must be mounted on the spacecraft during the measurements, because the spacecraft is in the radiation field of the antenna, and therefore distorts, or modifies the shape of the field that would be radiated from the antenna if it were operating in free space, i.e., without being mounted on the spacecraft.

Consequently, to measure the patterns from all angles around the entire radiation sphere of the antenna, the spacecraft was mounted on a revolving pedestal having a freedom of motion that allows the spacecraft to be rotated on two separate quadrature-related axes, i.e., 90° between the axes.

In the measurement setup used at RCA's antenna test range, the entire spacecraft with its antenna was immersed in an electromagnetic field radiated from a ground-mounted log periodic antenna aimed at the spacecraft. The field comprised an RF signal modulated by a 1 KHz audio tone received by the spacecraft antenna. The received audio signal tone was conducted down the pedestal through a coaxial downlead cable and routed to the control room where it was recorded during the rotation of the spacecraft, recording the RF signal level…….

However, the vertically-oriented coax downlead distorted the radiation pattern when measuring either the vertical or circular polarization of the spacecraft antenna, but not when measuring with horizontal polarization. It was thus obvious that because the downlead was also immersed in the RF field, re-radiation from the downlead as a second source of RF, was distorting the field illuminating the spacecraft antenna and thus distorting its radiation pattern. Proof that the downlead was the culprit was obtained when manually moving the downlead three or four inches in any direction caused a variation in pattern level greater than 3 dB in any antenna orientation where the pattern level was a few dB below the maximum. Unacceptable.

Consequently, to obtain true radiation patterns from the spacecraft antenna it was necessary to eliminate radiation from the downlead. I knew that a conductor of length $\lambda/4$ or less could not sustain an RF current, but at the VHF/UHF frequencies involved in the measurements the downlead was several wavelengths long. One way to solve the problem would be to break the downlead into individual lengths, $\lambda/4$ or shorter, and connect them with resistors that would effectively impede the RF, but allow the audio to travel. But the mechanical construction for this solution seemed impractical.

During this era a new method of restricting flow of RF current on conductors was coming into vogue with the use of ferrites. Ferrite beads placed around a conductor allowed DC to flow, but restricted the flow of RF. I contemplated what would happen if I were to place an appropriate bead around the downlead at every λ/4 point along the coax at the measurement frequency. This arrangement would effectively break the coax into λ/4 RF sections electrically, but leave it intact physically. So I experimented with No. 43 bead material placed around the RG-58 cable at λ/4 intervals, and voila'—no more radiation from the downlead and thus no more distortion of the radiation pattern from movement of the downlead. Accurate radiation patterns from the spacecraft antennas at last!

Several months later, while listening to on-the-air discussions of problems that occurred when using wire-wound voltage baluns constructed around a ferrite core, a light bulb turned on in my mind. My immediate thought was, if beads impeded current flow on the downlead in the radiation pattern measurement setup, why wouldn't it also impede common mode current flow on the outside of the coax feed line resulting from the **bal**anced input of the antenna terminating the **un**balanced coax? Why not indeed! I knew current was flowing on the outside of *my* feedline, because when measuring the impedance at the input terminals of the line using the General Radio GR-1606-A RF impedance bridge, the indicating null would disappear while running my fingers along the line. I knew from those symptoms that the common mode current on the feedline was also destroying the accuracy of the impedance measurements.

I then reasoned that a bead resistance of at least ten times the impedance looking into one half of the dipole should reduce the current flow on the outside of the coax shield to one-hundredth of the power delivered to the dipole half connected to the shield, an insignificant amount.

After researching the various terminal impedances that would be encountered with dipoles throughout the HF bands the worst case situation appeared to occur on the 75-80 m band, when operating at the low end of the band at 3.50 MHz with the antenna resonant at 3.75 MHz. At 3.778 MHz the terminal impedance of my nearly resonant 125-ft dipole was 64.83 + j0.18 ohms, for a 1.28 SWR. However, at 3.50 MHz the terminal impedance was 53.17 – j144.35 ohms, for a 9.6 SWR. (These values can be seen in Table 15-5, Page 15-14, and from Fig 15-1 on Page 15-15.) The magnitude of this impedance is 153.8 ohms at 69.8°. However, this is the total input terminal impedance of the dipole, while the dipole half fed by the shield, or outer conductor of the coax is only one half of this value, or 76.9 ohms. Thus a bead resistance of approximately 800 ohms should provide adequate reduction of common mode current on the outside of the feedline in this worst-case situation.

After studying the specifications of several ferrite beads I ordered 300 No. 73 beads from The Wireman for experimentation. A brief report of some of the experimental data that led to the design of the commercial version of the W2DU balun are shown in Sec

21.6, Page 21-7. Additional data can be seen in Fig 21-3, Page 21-8, which shows the impedance, resistance, and reactance of 50 No. 73 beads versus frequency. Observe that the bead impedance at 3.50 MHz is slightly greater than 1000 ohms, amply sufficient to reduce the common mode current on the feedline of the 80-m dipole to insignificance.

In addition to showing the impedance plot of my 80-m dipole from 3.45 to 4.075 MHz, the graph of Fig 15-1 also provides evidence that the common mode current on two different coaxial feedlines is insignificant when the 50-bead W2DU balun is inserted between the feedline and the antenna. As mentioned earlier, common mode current on the outer surface of the coax will destroy the accuracy of any measurement of impedance a the input of the coax. When measuring the terminal impedance of an antenna by measuring the impedance at the input of its *calibrated* feedline, the same impedance reading will be obtained regardless of the length of the feedline as long as its calibration is accurate. However, if a common mode current exists on the outer surface of the coax, different input terminal impedances will result if the impedance is measured using coax of different lengths, even though both are accurately calibrated. The greatest difference will prevail if the difference in lengths is $\lambda/4$.

Observe that in Fig 15-1 the solid lines represent measurements of the resistance, reactance, and SWR of my 80-m dipole made with a $\lambda/4$ length feedline, while the dashed lines represent measurements made with a $\lambda/2$ length feedline. Observe also that the difference between the solid and dashed lines is almost non-existent, indicating insignificant errors in measurement, and showing negligible common mode current flowing on the lines, thus proving the effectiveness of the W2DU balun in eliminating the common mode current. Note that the dipole data measured with both the $\lambda/4$ and $\lambda/2$ length feedlines plotted in Fig 15-1 appears in Tables 15-4 and 15-5.

Thus endeth the story of the evolution of the W2DU ferrite bead balun.