Switching Four Polarizations on a 70 cm Crossed Yagi (Part 1)

by Domenico Marini, I8CVS, domenico.i8cvs@tin.it

Introduction

Switching horizontal/vertical RHCP and LHCP polarizations on a 2 meter crossed Yagi has been described in [1] and [2] but very little has been written for 70 cm. Additionally, all commercially available satellite antennas are actually designed to switch only between RHCP and LHCP. The need to design a four polarization switcher started when the downlink of FO-29 at 435.850 MHz was masked at low satellite elevations by vertically polarized white noise generated and radiated by a powerful TV station located on the top of a hill 15 km away from my location.

The vertically polarized noise as received by my RHCP helix antenna in that direction was about 20 dB above the noise floor and the only way to cancel out the noise was to receive FO-29 from AOS and during the first critical part of the orbit using not circular, but the opposite linear polarization to the offending signal, i.e., horizontal polarization. So a new antenna with four switching modes from linear to circular was required.

By the way, a switchable capability from linear to circular polarization is not a waste of time because a 70 cm crossed Yagi can be used with maximum performance for satellite and tropo communications.

The switcher discussed above (Photo 4) was designed around four inexpensive and light weight commercially available 50 ohm TOHTSU model CX 120 P coax relays originally developed for printed circuits in 2 meter and 70 cm preamplifiers. The following results were obtained:

1) VSWR = 1.5:1 maximum on each polarization
2) Circularity RHCP and LHCP = 2 dB max
3) Cross-polarization RHCP to LHCP = 15 dB min
4) Axial ratio linear H to V = 17 dB min
5) Overall attenuation = 0.5 dB max
6) Power handling = 300 watt CW nominal
7) Weight = 800 grams and waterproof to IP-55

In this polarization switcher (Figure 1) the needed phase difference (φ) is determined only by the electrical length λe of the coaxial cables and it is not necessary to take the delay time of the relays into consideration, as long as they are identical in each branch, i.e., if both pairs of relays, even if built by a different manufacturers, have the same electrical length.

All input and output connections as well those between coax relays are made using Teflon insulated (PTFE) coax cables, which withstand high soldering temperatures to allow all braids and center conductors to be soldered directly to relay ports eliminating twelve unnecessary connectors thus greatly reducing cost and insertion loss (Photos 1 and 2).

In addition, PTFE has a constant and stable velocity factor ($V_f = 0.694$), which permits calculation and cutting of the length of the coax cables with great accuracy to get the needed electrical wavelength λe for each delay line.

The use of a printed circuit boards is not recommended here because any microstrip effects from the PCB's will introduce differences in the length of the delay lines, which are impossible to evaluate and trim out without having access to a network vector analyzer.

Theory of Operation and Function

This switcher has been designed and built around an existing 70 cm antenna (the KLM 435-40CX), but any other type of crossed Yagi can be used provided the elements are physically spaced over the boom by 1/4λo (Figure 1).

The original KLM CS-2 circularity switcher was designed only for RHCP and LHCP and so it was removed, but the rest of the antenna was left in its original condition including both the 1/2 λo coax balun BN with 4:1 impedance ratio connected across the folded dipoles.

The schematic diagram in Figure 1 shows the new polarization switcher with relays RL1 and RL2 feeding the rear dipole via coax cable X1 and relays RL3 and RL4 feeding the front dipole via coax cable X2.

Note that the individual branches of this switcher are only loaded with half the output power distributed evenly to both relay pairs and to both dipoles in all polarization modes. Since the nominal power of each relay CX 120 P is 150 watts, the nominal power capability of this switcher becomes 300 watts.

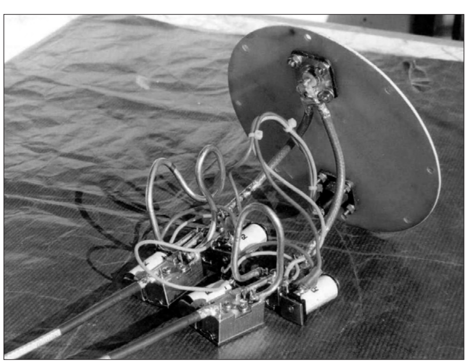

Photo 1

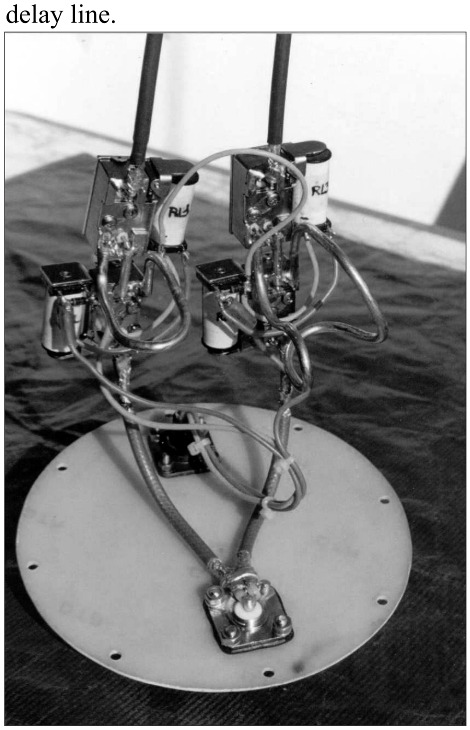

Photo 2

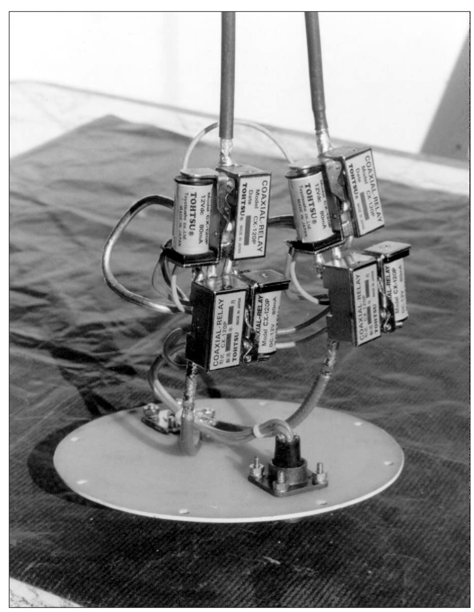

Photo 4

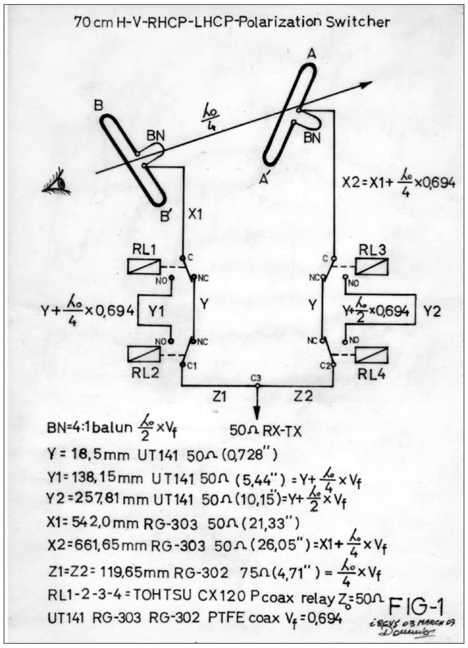

Figure 1: Switcher schematic.

Coax lines X1 and X2 are made with PTFE RG-303coax, Zo=50 ohm and velocity factor V_f = 0.694. X1 can be cut to any convenient length but X2 must be longer than X1 by 1/4 λe at 435.0 MHz, that is, 119.65 mm longer, because the electrical wavelength λe is calculated with λo x V_f where λo is the free space wavelength. Since in this prototype X1 has been made 542.0 mm for reference, then X2 becomes 661.65 mm long.

When RL1-RL2-RL3-RL4 are not energized a short piece of coax Y connects the NC contact of RL1 to the NC contact of RL2 and an equal length Y connects the NC contact of RL3 to the NC contact of RL4. The connecting coax Y is Teflon insulated UT141 semi-rigid cable and it is made 18.5 mm long just for mounting and soldering convenience (see Photo 3). Y1 is a delay line made of UT141 coax and it is cut for 1/4 λe at 435.0 MHz plus 18.5 mm for Y.

Since the velocity factor V_f of Teflon is 0.694, the full length of Y1 becomes 119.65 + 18.5 = 138.15 mm. When RL1 and RL2 are energized, a delay line with an effective length Y1 - Y = 119.65 mm is added into the circuit of coax X1 feeding the rear dipole.

Y2 is a delay line made of UT141 coax and it is cut for 1/2 λe plus 18.5 mm for Y and the full length of it at 435.0 MHz is 239.31 + 18.5 = 257.81 mm so that when RL3 and RL4 are energized a delay line with an effective length of Y2 - Y= 239.31 mm is added into the circuit of coax X2 feeding the front dipole.

Using this arrangement the whole length of branch RL1+Y+RL2 is the same of branch RL3+Y+RL4. The internal length of the relays plus that of the joining coax Y do not change the effective electrical length λe on delay lines Y1 and Y2 because switching the system to any polarization mode, as shown in Figure 1, the same common length of 18.5 mm for coax Y is entered into the circuit of X1 and X2 in any switching condition when relay's are energized or not energized.

The impedance of each branch at the common port C1 of relay RL2 and port C2 of relay RL4 is very close to 50+j0 ohms (return loss > 26 dB at 435.0 MHz) and the simpler light weight matching method to feed the switcher to a 50 ohm transmission line down to a transceiver was to transform the impedance of each branch from 50 ohms to about 112 ohms by means of a 1/4 λe matching lines Z1 and Z2 made with 75 ohm RG-302 PTFE coax with V_f = 0.694 and each matching line at 435.0 MHz is 119.65 mm long.

Both impedances, 112 + 112 ohms, are then connected in parallel in C3 and the resultant impedance at the antenna feed point becomes again approximately 50 ohms.

Referring to Figure 1, the rear dipole B-B' and the front dipole A-A' are spaced in free space along the boom by 1/4 λo. Looking the dipoles standing behind the antenna as indicated in the drawing we see that the center lead of X1 feeding the rear dipole B-B' is connected to side B' for a rear observer while the center lead of X2 feeding the front dipole A-A' is connected to side A and it is anticipated that the indicated polarizations of H-V-RHCP-LHCP in this switcher can be generated only if the above mentioned connections of the coax center leads to the dipole studs as seen from the back reflectors are made according to Figure 1.

The letters B-B' and A-A' at the tips of both dipoles in Figure 2A allow us to compute the direction of the electric field at the center P of the front driven element using the very comprehensive method suggested in "*The Satellite Experimenter's Handbook*", pages 7-11, Chapter 7, written by Martin Davidoff, K2UBC, [3].

To easily visualize how the linear and circular polarizations are generated, the rear dipole B-B' in the drawing Figure 2A is represented horizontally and the front dipole A-A' vertically, but in real operation, to show the horizontal and vertical polarizations, the elements of the antenna must be oriented 45 degrees to the boom in X configuration as in Figure 1 or in Figure 2F. More on this will be discussed later.

Horizontal Polarization (H)

When RL1-RL2-RL3-RL4 are not energized, the branch Z2+RL4+Y+RL3+X2 is 1/4 λe longer than Z1+RL2+Y+RL1+X1 and, as shown by the diagram in Figure 2B, the RF current feeding the front dipole A-A' is supplied with a lag of 90° with respect to the current feeding the rear dipole. Looking from the back of Figure 2A in the direction of forward gain with the aid of Figure 2B and Table 1 in Figure 2, we see that during one cycle of the RF current, the rear dipole B-B' at time 1 shows the maximum field at 3 o'clock. Since the front dipole A-A' is supplied with a delay of 90°, Table 1 shows that at time 1 the field in A-A' is zero but at time 2 it rises to maximum at 12 o'clock.

Focusing our attention at time 2 when the field in front dipole A-A' is maximum at 12 o'clock, we note that the field that was maximum at time 1 and 3 o'clock in the rear dipole B-B' is actually propagated through free space in direction of the front dipole A-A' arriving after 1/4 of a RF cycle at time 2 in the same plane P in which the front dipole A-A' lies. (See Table 1 in Figure 2A.)

As a consequence at time 2 in point P we have 2 fields linearly polarized with the same magnitude at 3 and 12 o'clock and the contribution of the above components is a resultant field which vector is oriented at 45 degrees to the dipoles as shown in Figure 2C and by the arrow in the last column P of Table 1.

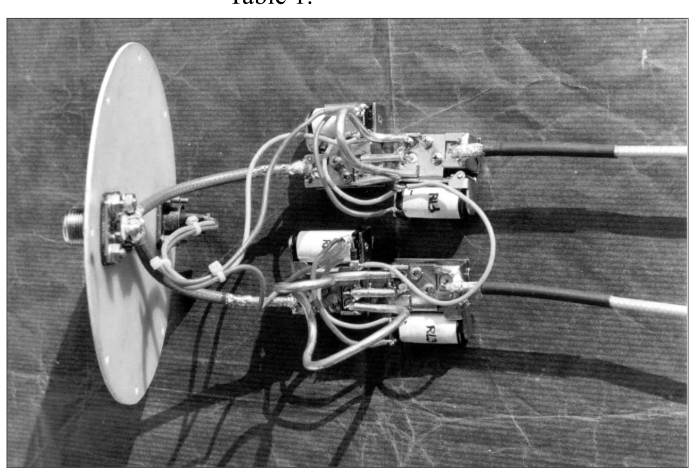

Photo 3

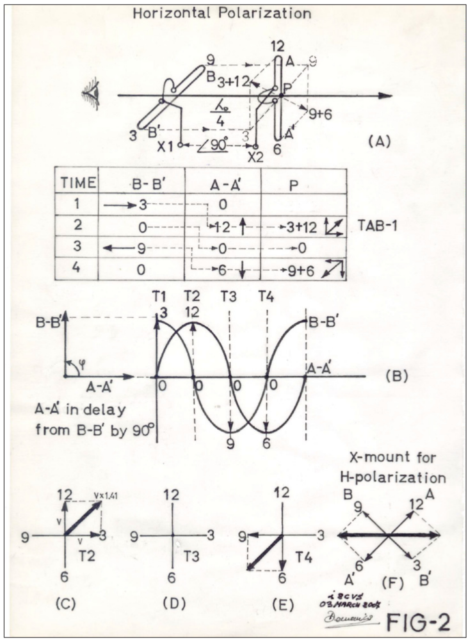

Figure 2: Horizontal polarization mode.

The magnitude of the voltage of this resultant field is 1.41 times that of the voltage V of each component because the power that was equally split in two parts between the driven elements is actually available in the field of the resultant vector (see Figure 2C and 2E). As a consequence, the power capability of this switcher is 300 watts because the maximum power permitted for a relay CX 120 P in each branch is 150 watts.

Since the elements are not cross-mounted but are X mounted as in Figure 2A over the boom as in Figure 1 or in Figure 2F it follows that when the antenna is in operation, the resultant vectors in Figures 2C and 2E are rotated by 45° clockwise with the boom and as shown in Figure 2F, the radiated field becomes horizontally polarized (H).

Vertical Polarization (V)

When only RL3 and RL4 are energized, the delay line Y2 is switched into circuit and the branch Z2+RL4+Y2+RL3+X2 becomes 3/4 λe longer than Z1+RL2+Y+RL1+X1 and so, as shown in Figure 3B, the RF current feeding the front dipole A-A' is supplied with a lag of 270° with respect of the current feeding the rear dipole B-B'. That is to say that the current feeding A-A' leads by 90° the current feeding B-B'. Table 2 in Figure 3 shows the direction and magnitude of maximum field in dipoles B-B' and A-A' at each of the times 1-2-3-4 as every quarter cycle has elapsed for the currents in the diagram Figure 3B.

Focusing our attention at time 2 when the field in front dipole A-A' is maximum at 6 o'clock, we note that the field that was maximum at time 1 and 3 o'clock in the rear dipole B-B' is propagated through free space in the direction of the front dipole A-A' arriving after 1/4 of an RF cycle at time 2 in the same plane P in which the front dipole A-A' lies (see Table 2). Thus, a linear resultant field from components at 3 and 6 o'clock is actually generated at –45° as indicated by the resultant vector in Figure 3C and by the arrows in the last column P of Table 2. Rotating the boom in Figure 3A by 45° clockwise makes the elements physically mounted in an X configuration as in Figure 3F so vertical polarization (V) is produced.

Right Hand Circular Polarization (RHCP)

When only RL1 and RL2 are energized the delay line Y1 is switched into circuit and the length of branch Z1+RL2+Y1+RL1+X1 becomes the same as branch Z2+RL4+Y+RL3+X2 and so, as shown in Figure 4, the RF currents feeding the driven elements B-B' and A-A' are supplied in phase and φ = 0 degrees.

Following Table 3 in Figure 4, we start our observations at time 2 when the RF current is producing at the same time a maximum field at 3 o'clock in the rear dipole B-B' and at 12 o'clock in the front dipole A-A'. Time 3 occurs after a quarter-cycle has elapsed when the RF current in both driven element is zero.

In the last column by vectorially adding together, we fill for each time the field at the center of A-A' and the field that was produced at the center of B-B' a quarter of a cycle earlier which is just reaching P. Standing behind B-B' from our observation point in back of the antenna in Figure 4A and looking in the direction of maximum gain, we see the resultant vector of the electric field generated at point P rotate from 12 o'clock to 3 o'clock during a quarter cycle of the RF currents and therefore as shown in Figure 4C-D the wave rotating clockwise is right hand circularly polarized (RHCP).

Left Hand Circular Polarization (LHCP)

When all relays RL1-RL2-RL3-RL4 are energized, both delay lines Y1 and Y2 are switched into circuit but since Y2 is 1/4 λe longer than Y1, only the resultant difference Y2-Y1 corresponding to an effective delay line 1/4 λe or 119.65 mm long is added in circuit to coax X2 feeding the front dipole A-A'. In this condition the branch Z2+RL4+Y2+RL3+X2 is 1/2 λe longer than Z1+RL2+Y1+RL1+X1 and as shown in Figure 5B the RF currents feeding the driven elements B-B' and A-A' are supplied in anti-phase i.e., 180° out of phase.

With the aid of Table 4 in Figure 5 we start our observations at time 2 when the RF current is producing a maximum field at each driven element and looking at the last column of Table 4 remembering that the contribution of element B-B' at point P was actually produced by B-B' a quarter-cycle earlier, we see that the resultant electric vector at point P as seen from the back of the antenna in Figure 5A, rotates from 6 o'clock to 3 o'clock, i.e., by 90° counterclockwise

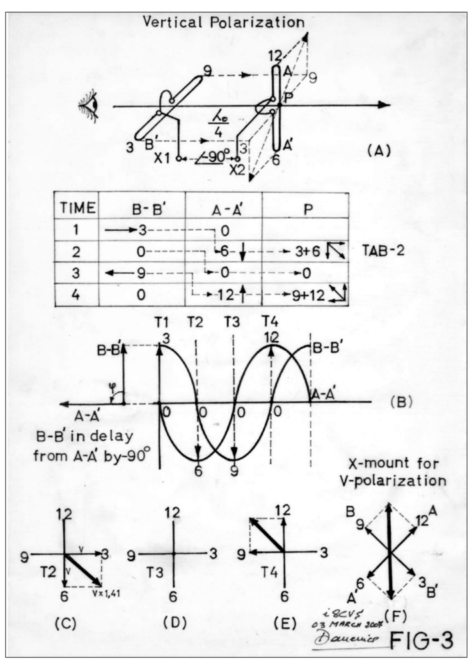

Figure 3: Vertical Polarization mode.

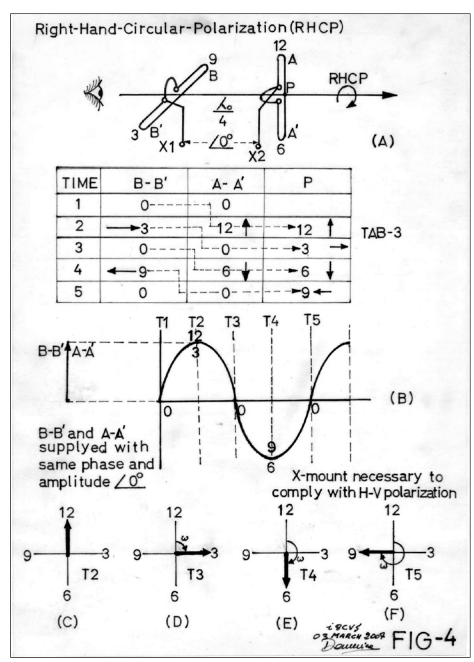

Figure 4: Right-Hand-Circular Polarization.

during one quarter-cycle of the RF currents and therefore, as shown by the arrows in the last column P of Table 4 and by the vectors in Figures 5C-D-E-F, we see that the wave is left hand circularly polarized (LHCP).

Switching Polarizations

Switching H-V-RHCP and LHCP from the shack is accomplished using only a three-conductor wire with a single pole, four-position switch and four 1N4007diodes. The schematic diagram in Figure 6 is self-explanatory and the diodes D3, D4 across the coils are used only to shunt the inductive kickback generated during circuit opening.

Polarization	Relays Energized
Horizontal	-------------
Vertical	RL3 + RL4
RHCP	RL1 + RL2
LHCP	RL1 + RL2 +RL3 + RL4

For maximum contact life of the coax relays it is mandatory that polarization is not switched while transmitting, particularly when using high power. This practice is valid for any type of polarization switcher unless a suitable interlock between the switcher and transmitter is included.

Changes Using Different Antennas

Another good candidate antenna for this switcher is the Cushcraft 738XB because the folded dipoles are physically spaced by 1/4 λo over the boom and the 1/2 λe 4:1 coax balun is supplied so that the above antenna can be immediately adapted to work with this switcher provided that both folded dipoles are connected to feed-lines X1 and X2 according to Figure 1.

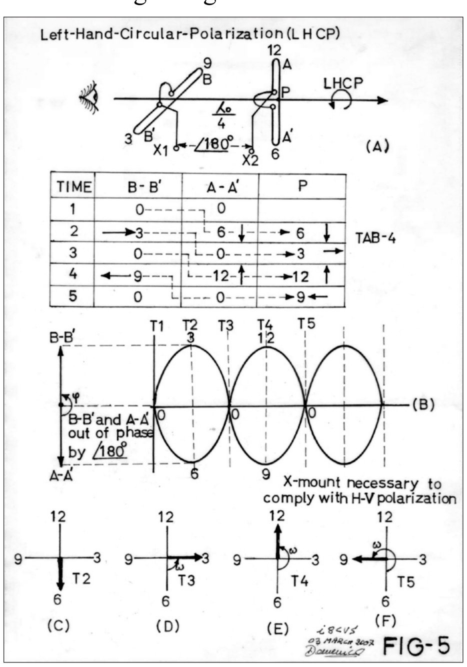

Figure 5: Left-Hand-Circular Polarization.

If the driven elements of a candidate antenna are spaced 1/4 λo over the boom but they are matched to a 50 ohm feed line using a gamma match, then a balun is not required in an unbalanced matching system and, with reference to Figure 1, the gamma arm must be oriented in direction of tip A for the front dipole and in direction of tip B' for the rear dipole while the braid of the coax cable must be grounded in the usual manner to the center of each element and to the boom.

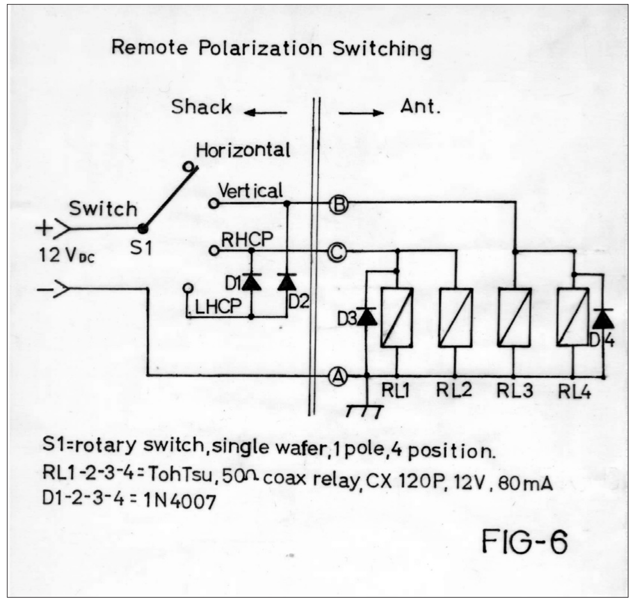

Figure 6: Remote switching circuit.

If the driven elements are spaced by 1/4 λo over the boom and they are matched to a 50 ohm feed line by a T-match, which is a balanced matching system, then a balun with a suitable impedance ratio between the impedance of the driven element and 50 ohms is required and both arms of the T-match must be connected to X1 and X2 according to the orientation of tips A and B' on folded dipoles Figure 1.

If the driven elements are close spaced over the boom by a distance D < 1/4 λo then the length of the coax line X2 must be equal to X1 + (D x V_f).

Example:

The center-to-center dipole spacing of an early design 10 + 10 element crossed Yagi built by Cushcraft is D = 18 mm over the boom. The equivalent length for the RG-303 coax cable is D x V_f = 18 x 0.694 = 12.49 mm

X1 = 542.0 mm for reference
X2 = 542.0 + 12.49 = 554.49 mm

If instead the driven elements are spaced over the boom by a distance D >1/4 λo, then the actual length of coax line X2 must be increased by a quantity equal to (D-1/4 λo) x V_f.

Example:

The folded dipole spacing of a Tonna 2 x 19 element crossed Yagi model 20438 is D= 199.4 mm over the boom. This spacing is greater than a free space 1/4 λo that is 172.4 mm at 435 MHz and so:

(D-1/4 λo) x V_f = (199.4 – 172.4) x 0.694 = 18.74 mm

Line X2 = 661.65 + 18.74 = 680.39 mm including the length of the N male connector and obviously X2 must be connected to the front dipole.

Note that the folded dipoles of the above antenna are matched to 50 ohms by a strategic distance from the first director so that they can be directly connected to a 50-ohm coax line. However, for unknown reasons in spite of the balanced feed point in the folded dipole, no balun has been used by the manufacturer. Anyway, the folded dipole uses N connectors encapsulated into a black plastic body carrying a small bump indicating for reference the side of the dipole which is connected to the connector body and hence to the coax braid. As a consequence the side of the dipole opposite to the above bump is the hot side of the dipole connected to the inner pin in the N connector and so the above hot side must be oriented in X-mount configuration to comply with tips A and B' in Figure 1.

Note: The second part of this article in the next issue will deal with construction and testing of the switcher.

References

[1] "*A Remote Polarization Switching Unit for Crossed-Yagi Antennas*" by H. Stoll, DF7SO, VHF Communications, 1/1980

[2] "*Notice sur la Polarization Circulaire sur 144/146 MHz et 432/438 MHz*", by F9FT http://f5ad.free.fr/QSP_Antennes/ANT-QSP_F9FT_polcircfr.pdf

[3] *The Satellite Experimenter's Handbook,* by Martin Davidoff, K2UBC, ISBN 0-87259-318-5, ARRL Order No. 3185.

[4] http://www.g6lvb.com/fibermetalboom.htm