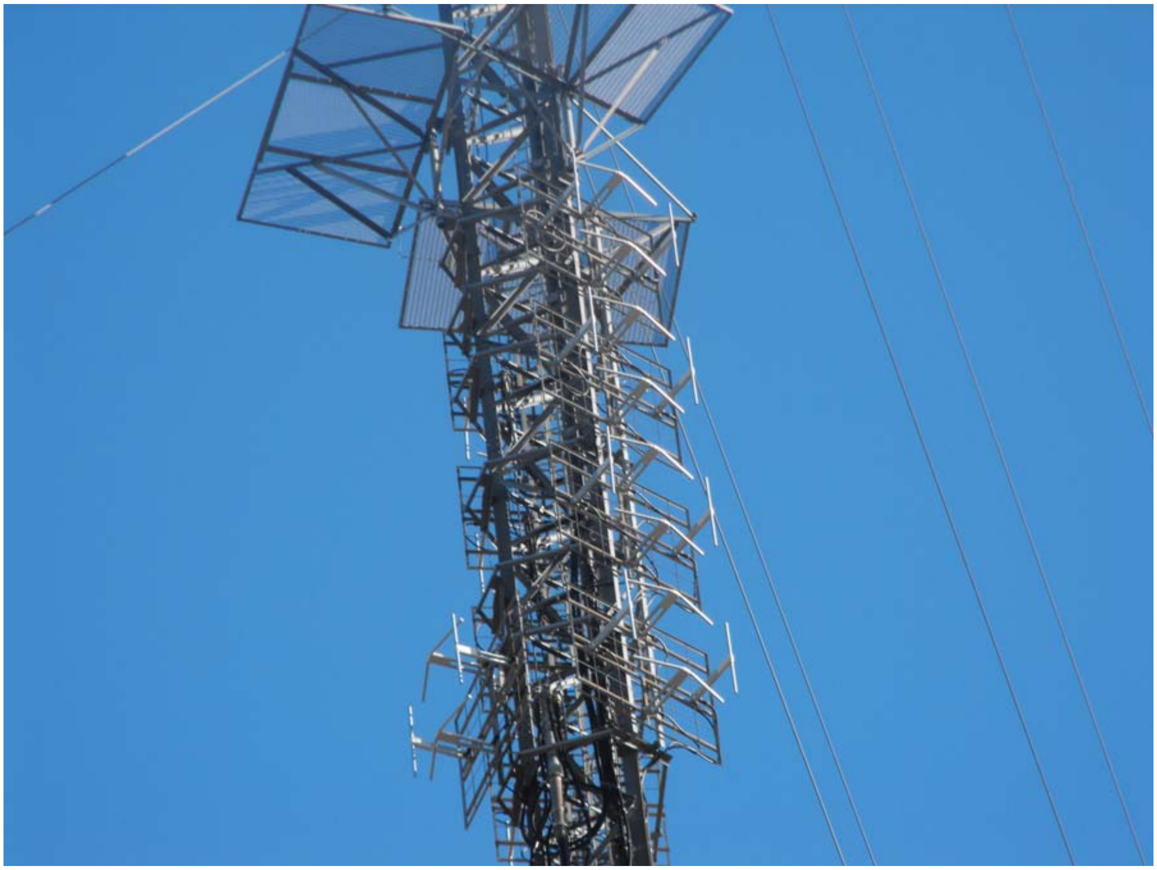
Antenna Repair and Splitter Cable Design



A failed splitter cable can render a broadcast antenna system unusable. It must be replaced immediately. Damaged lines should be replaced to ensure long-term reliability, especially at high power levels with multiple carriers. With adequate knowledge of splitter cable design the downtime for antenna repair can be minimized and associated costs greatly reduced.

Splitter cables are often damaged by kinks or dents during installation or tower maintenance, falling ice, abrasion and metal fatigue caused by vibration, bullet holes, arcing due to dipole failure, etc. Dehydrator failures may create condensation inside the lines causing internal corrosion and contamination on insulators.

When determining power capacity of an antenna system the limiting factor is often the splitter cable assembly. In order to accommodate new clients or services the full harness will require replacement with larger cables.

Manufacturer supplied replacement cables can be very expensive to purchase and have delivery times of several weeks. Exact replacement transmission line and connectors can have long delivery times. Replacement parts from other manufacturers are often readily available, but specifications may be different. We need to be able to adapt parts that are available for a cost effective permanent repair or upgrade.

Cable replacement could almost be considered standard repair for panel array antennas. Even full harness replacement happens following major failure or during rebuild. While it is unlikely we will be tasked to design a full new antenna system it is beneficial to understand how parts of the antenna work together.

Objectives

To determine suitable replacement splitter cable types.
Calculate proper cable lengths for antenna repair or upgrades
Perform testing of new cables and full arrays for moisture and other contamination
Better understand phasing techniques for elliptical and circular antennas, beam tilt and null fill

Theory

Radio waves propagate at the speed of light C = 186,282.396 mi/s
299,792,458 m/s
Approximately 300,000,000 m/s (<0.07% error)

The radio signal will travel through the cable at a velocity less than in free space. It is typically written as a percentage. Foam dielectric cables will have a lower velocity factor compared to air dielectric.
Velocity factor VF = V / C (V = propagation velocity in cable)

Wavelength in cable will also be less than in free space due to the reduced velocity.
Wavelength λ = (C x VF) / F
Length per degree L = λ / 360

Measuring velocity factor

Manufacturer specifications are not always accurate for performing calculations. A small error in VF can result in a replacement cable being several degrees off the required length. VF will vary depending on section of line being used and between cable batches. In order to get better results, a TDR should be used to confirm VF on original and replacement cables. Ideally a good working original cable should be supplied for testing and confirmation and a new cable built with the measured figures. The TDR may not be 100% accurate for determining electrical length, but when using it to compare two cable types, the relative error should be the same. This will cancel in the final calculations and the final product will be very close to required.

Carefully measure physical length, L1. The measurement is taken from the outer edge of the connector flange.
Use TDR, set VF=100%. Measure electrical length, L2
VF = L1/L2

Prior to installation of a new antenna system, the velocity factor of the cables should be measured and recorded in the antenna manual. Having this reference may prove useful later and will ensure best match for replacement cables following failure. Otherwise catalog data must be used and VF figures may not be correct. Alternately, a second known good cable could be removed from the tower to determine VF.

Example: January 2009. Replacement splitter cable measured 20 degrees error from design using published VF figures. Published VF from original manufacturer was 93% but measured 89%. Published VF for new cable was 91% but measured 92%. When built using the measured VF values the resulting cable measured within 1 degree.

Single cable replacement

Replacement cable with VF different than original
New line length L2 = VF2 x (L1 / VF1)

Original line 6500mm, VF = 92%. New cable VF = 85%
L2 = 0.85 x (6500 / 0.92) = 6005mm

Original line 6500mm, VF = 85%. New cable VF = 92%
L2 = 0.92 x (6500 / 0.85) = 7035mm

<u>Full harness replacement</u>
Calculate new phasing line lengths. If cables are being increased in size it is often a good idea to make the replacements slightly longer in order to accommodate a wider bend radius. Select a convenient length for the reference cable. As you design each new line, the length will be adjusted according to the phase difference and line length per degree.

Reverse calculations for array phasing. If the antenna documentation does not show the phase relationships between panels and bays you will have to calculate the numbers prior to designing a new harness.

Note: Longer cables will create a lagging phase. Shorter cables will create a leading phase.

Charlottetown FM antenna was relatively simple as the phase differences between bays and panels were supplied. The primary splitter cables determine beam tilt. This makes secondary cable design easier.

Yarmouth FM antenna had cable lengths only. Phasing had to be calculated based upon cable lengths supplied in the antenna manual and using manufacturer supplied velocity factors. The primary cables are equal lengths. The secondary cables create beam tilt and circular polarization.

A basic understanding of the phase relationships between panels and bays of an antenna will allow relatively simple redesign of the full system.

Design Examples

Charlottetown July 2007
FM antenna
Kathrein 755 238
Replacement Splitter Cables

Primary splitter cables
Andrew HJ12-50
82R gas pass 1-5/8" EIA flange connectors
Velocity factor 93%

1	9960mm
2	10000mm
3	9762mm
4	9801mm
5	10000mm

Secondary splitter cables
Heliflex HCA118-50
Spinner 711908 13-30 connectors. Drill for gas pass at both ends.
Velocity factor 92%. Five each required.

A	2800mm
B	3743mm
C	4686mm

Calculations
Speed of light (C) = 299798357.733 meters per second
Propagation speed in coaxial cable = Velocity factor (VF) x C
Wavelength in free space = 299.798 / F (MHz)

Primary splitter cables
Propagation speed in HJ12-50 = 0.93 x C
Wavelength in HJ12 = 278.812 / F(MHz)

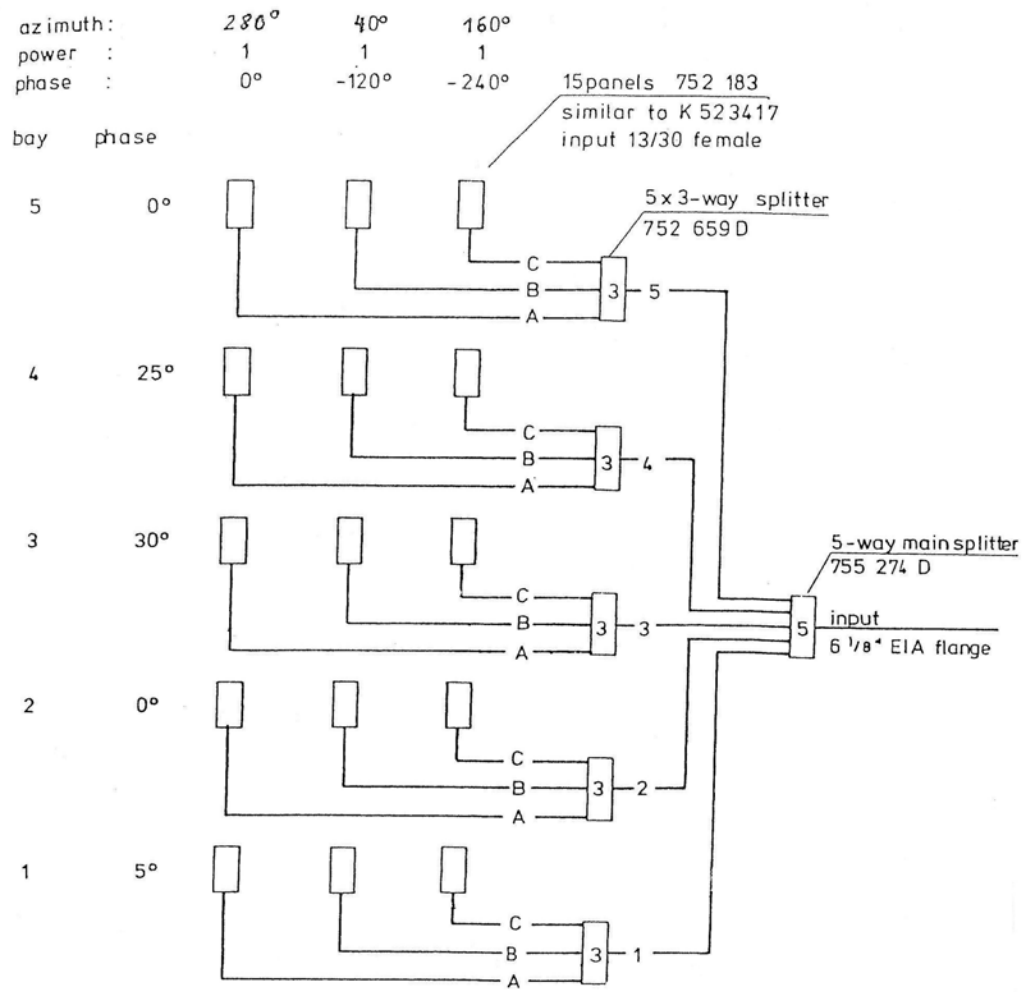
At 97.5MHz,
Wavelength = 278.812 / 97.5MHz = 2.8596 meters = 2859.6 mm
2859.6mm / 360° = 7.943mm per degree

0° 10000mm Reference
+30° 10000mm – (30 x 7.943mm) = 9762mm
+25° 10000mm – (25 x 7.943mm) = 9801mm
+5° 10000mm – (5 x 7.943mm) = 9960mm

Secondary splitter cables
Propagation speed in HCA118-50 = 0.92 x C
Wavelength in HCA118-50 = 275.814 / F(MHz)

At 97.5MHz,
Wavelength = 275.814 / 97.5MHz = 2.8289 meters = 2828.9 mm
2828.9mm / 360° = 7.858 mm per degree

0° 2800mm Reference
-120° 2800mm + (120 x 7.858mm) = 3743mm
-240° 2800mm + (240 x 7.858mm) = 4686mm



cable no.	length / mm	type	connectors	remark
1	9960	Andrew HJ12-50	1 5/8" EIA flange Andrew 82R	pressurized antenna system
2	10000			
3	9762			
4	9801			
5	10000			
A	2800	RFS Cablewave Heliflex HCA 118-50	13 / 30 male 711908	
B	3743			
C	4686			

July 2007 WS

phase at 97,5 MHz

KATHREIN	Tag 23.2.1984 Name OSL Nh	FM Transmitting Antenna CHARLOTTETOWN	Typ Nr. 755 238 Blatt: 115

New Charlottetown FM antenna cable chart

Yarmouth FM June 2008 WS
Antenna type number 752 753
Replacement cable harness
Design frequency – 98.0MHz

Replacement Primary splitter cables
Cable - Andrew HJ7-50, VF=0.92
Connectors – Andrew 87R, 1-5/8"EIA
All cables HiPot test to 5kV > 0.1uA leakage current

Cable number	Phase	Length
1, 2, 3, 4, 5, 6	0	12000 mm

Replacement Secondary splitter cables
Cable - Andrew HJ4.5-50, VF=0.92, 7.82mm/degree
Connectors - Andrew H4.5PDM, 7/16DIN
Drill all connectors to allow gas pass through to panels
All cables HiPot test to 4kV > 0.1uA leakage current

Cable number	Phase	Length	Measured phase
41, 42, 43, 44	-99°	6274 mm	-97.8 / -96.4 / -96.6 / -98.4
45, 46, 47, 48	-9°	5570 mm	-8.9 / -9.0 / -8.4 / -8.1
31, 32, 33, 34	-94°	6235 mm	-90.1 / -89.7 / -91.0 / -91.8
35, 36, 37, 38	-4°	5531 mm	-3.4 / -3.9 / -3.3 / -3.1
21, 22, 23, 24	-127°	6493 mm	-125.4 / -124.6 / -125.4 / -126.4
25, 26, 27, 28	-37°	5789 mm	-36.3 / -36.5 / -35.9 / -36.2
11, 12, 13, 14	-90°	6204 mm	-88.9 / -88.9 / -88.4 / -88.8
15, 16, 17, 18	0°	5500 mm	0 (ref) / +0.7 / +0.6 / +0.6
51, 52	-190°	6985 mm	-188.2 (+171.8) / -190 (+170)
55, 56	-100°	6282 mm	-99.6 / -99.6

Yarmouth - Replacement cable design

Primary Cables 1 – 6 are equal lengths, and thus equal phase. New cables can be any convenient length provided all are equal.

This antenna is circularly polarized. The starting point is a phase of 90 degrees within each panel. Checking the cable list, each panel has a difference of 685mm between horizontal and vertical elements. At the design frequency the cable length per degree is 7.72mm.

Next, phase between bays can be determined. The phase on all four bays at 0 and 150 azimuth are equal other than for beam tilt. Cables 15 – 18 are 5000mm. An easy number indicates this was the original design starting point.

Cables 15 – 18 are 5000mm. 0 degrees, reference
Cables 11 – 14 will be 90 degrees longer, 90 degrees.

Cables 25 – 28 are 5281mm. 281mm / 7.72mm = 36.4 degrees. Round to 37 degrees.
Cables 21 – 24 will be 90 degrees longer, 126.4 degrees. Round to 127 degrees.

Cables 35 – 38 are 5030mm. 30mm / 7.72mm = 3.9 degrees. Round to 4 degrees.
Cables 31 – 34 will be 90 degrees longer, 93.9 degrees. Round to 94 degrees.

Cables 45 – 48 are 5068mm. 68mm / 7.72mm = 8.8 degrees. Round to 9 degrees.
Cables 41 – 44 will be 90 degrees longer, 98.8 degrees. Round to 99 degrees.

Cables 55 – 56 are 5761mm. 761mm / 7.72mm = 98.5 degrees. Round to 100 degrees.
Cables 51 – 52 will be 90 degrees longer, 188.5 degrees. Round to 190 degrees.

New cable harness design
A design frequency of 98.0MHz was chosen.

Andres HJ7-50 was chosen as replacement primary cable. (Cable size increased from 1-1/8" to 1-5/8")
A length of 12000mm was selected for cables 1 – 6.

Andrew HJ4.5-50 was chosen as replacement secondary cable. (Cable size increased from 3/8" to 5/8")
Manufacturer spec for velocity factor is 0.92 or 92%.

299,792,458m/s x 0.92 / 98MHz / 360 = 7.82mm/degree

Cables 15 – 18 are chosen as the starting point. Its chosen length is 5500mm.
Cables 11 – 14 are 90 degrees longer. 5500mm + 90 x 7.82mm = 6204mm

Cables 25 – 28 are 37 degrees longer. 5500mm + 37 x 7.82mm = 5789mm
Cables 21 – 24 are 127 degrees longer. 5500mm + 127 x 7.82mm = 6493mm

Cables 35 – 38 are 4 degrees longer. 5500mm + 4 x 7.82mm = 5531mm
Cables 31 – 34 are 94 degrees longer. 5500mm + 94 x 7.82mm = 6235mm

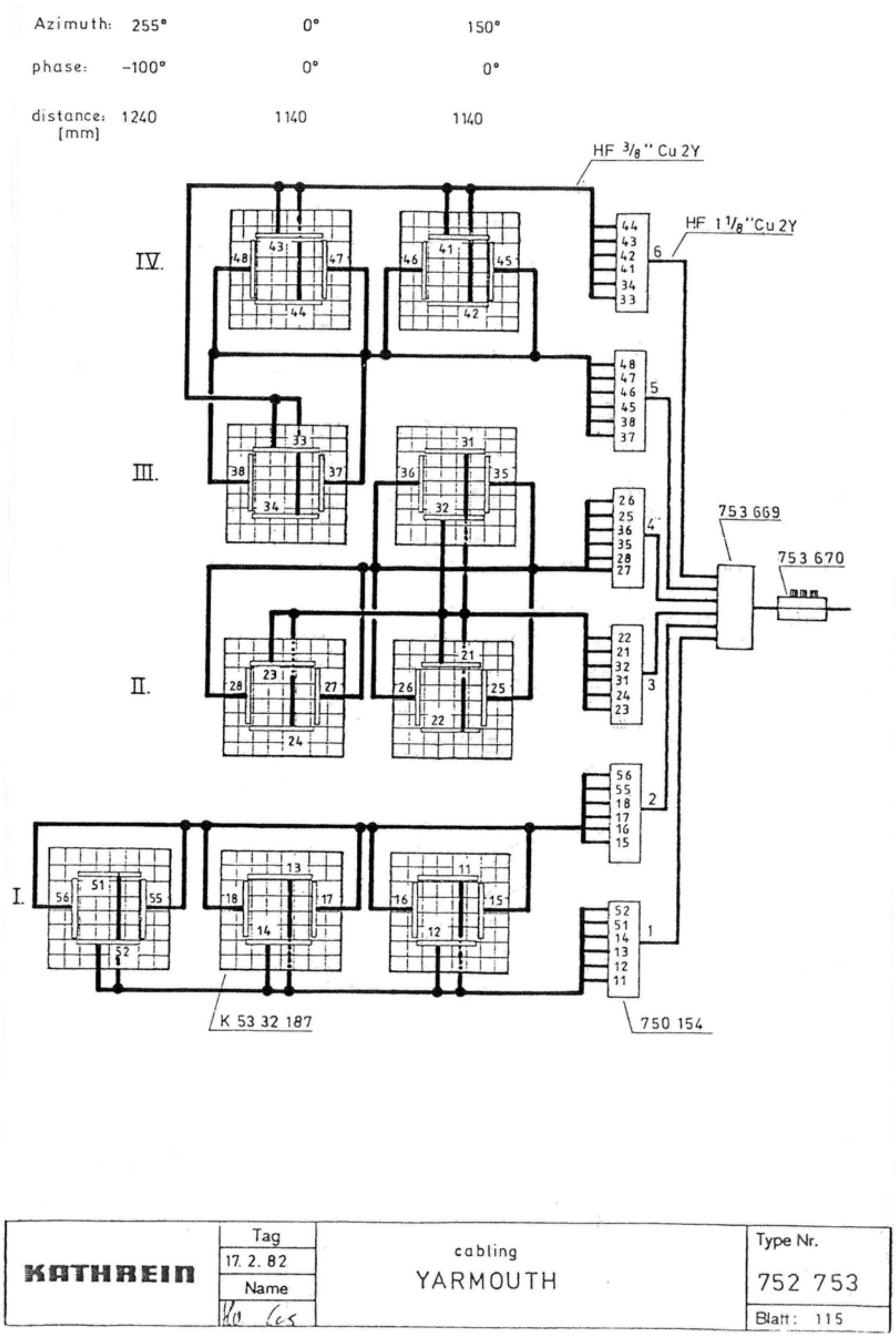
Cables 45 – 48 are 9 degrees longer. 5500mm + 9 x 7.82mm = 5570mm
Cables 41 – 44 are 99 degrees longer. 5500mm + 99 x 7.82mm = 6274mm

Cables 55 – 56 are 100 degrees longer. 5500mm + 100 x 7.82mm = 6282mm
Cables 51 – 52 are 190 degrees longer. 5500mm + 190 x 7.82mm = 6985mm

cable no.	length [mm]	type	connector		remarks
			splitter	antenna	
51,52	6445				
41,42,43,44	5753				
31,32,33,34	5715				
21,22,23,24	5966	Flexwell	7/16-	7/16-	connectors
11,12,13,14	5685	HF 3/8"	-Stecker	-Stecker	antenna end
55,56	5761	Cu2Y	BN97o615	BN97o6o8	are marked.
45,46,47,48	5o68				
35,36,37,38	5o3o				antenna (end
25,26,27,28	5281				of dehydra-
15,16,17,18	5ooo				ting system)
1,2,3,4,5,6	8ooo	Flexwell HF1 1/8" Cu2Y	1 5/8 " EIA BN 8582oo		

Original Yarmouth cable length table

A price estimate of between $6000 and $7000 was given by a local company to assemble the 42 new cables, not including cost of cable and connectors. Instead, about $300 was used to purchase tools and I spent about a week building cables. The knowledge and experience gained through the project was used to give a 2-day presentation to other technicians and the creation of this document. Since then, cable assembly is often performed in-house as needed. There is nothing magical about attaching connectors. Use the right tools and take appropriate care during assembly and testing. The final product can be every bit as good as that supplied by the original manufacturer at a fraction of the cost and time.


Azimuth: 255° 0° 150°
phase: −100° 0° 0°
distance: [mm] 1240 1140 1140
HF 3/8" Cu 2Y
HF 1 1/8" Cu 2Y
IV.
III.
II.
I.
753 669
753 670
K 53 32 187
750 154
KATHREIN
Tag
17. 2. 82
Name
cabling
YARMOUTH
Type Nr.
752 753
Blatt: 115

Connector installation

A workbench can be assembled for connector installation. Tools recommended – bench vice, miter saw, hack saw, measuring tape, side cutters, file, small hammer, flat screwdriver, large vice grips, wrenches, utility knife, torque wrench, flashlight, engraver, nylon rod or block, masking tape, cotton swabs, alcohol, heat gun, compressed dry air.

The HiPot tester is used for testing and isopropyl alcohol ensures the connectors and cable are clean.

Determine cutback length for connector installation. A square cut at the end of the line is required for attaching a connector. Once the cut is made, and before starting to trim the jacket put a piece of masking tape on the line. Put a mark 100mm from the end as a reference. Follow the procedure given in the connector instructions. When complete, measure the distance from the end of the flange back to the 100mm mark. The difference in length is required to cut the cable length precisely for the other end. If the new distance is 165mm, you must cut the cable 65mm shorter than the design length and the connector will make up the difference.

Keep cable as straight as possible during length measurement to reduce error. Measure twice, cut once.

The RF connector on some antennas provides a gas block. To better protect this connector make both ends of the splitter cable gas pass. This will prevent any moisture or other contamination from forming at the connector. It will also eliminate the possibility of having cables installed backwards with the gas block at the power divider and make it very easy to purge cables while riggers are on the tower.

Each cable must be labeled for the tower crew to install in the proper location. Plastic rings or tie wraps tend to break and fall off. An electric engraver or Dremel type rotary tool can be used to permanently mark the connector.

Install heat shrink tubing after final confirmation of DC leakage and phase. Thick wall heat shrink tubing is preferred. Even though most connectors are designed for outdoor use this added layer of protection will improve long-term reliability.

Testing

Phase measurement with network analyzer. When a full harness is built for an array one of the cables can be chosen as the 0-reference. All other cables will have their phase compared to this one. It is often the shortest cable. Calibrate the network analyzer S21 with the cable in place. It will show phase as 0 degrees across the FM band. The reference will be 98MHz or the design frequency. Replace the reference cable with others and measure phase difference. It should be within 2-3 degrees of design. Note that as frequency moves from reference the phase difference will increase. This is due to varying wavelength creating a different cable length per degree. Note that phase measurement on the network analyzer may display only ±180 degrees. +190 degrees will display as –170 degrees.

HiPot will detect moisture, dirt, and early stages of arcing. When connectors are installed use a high voltage insulation tester to measure DC leakage current. The applied voltage will depend upon cable size. For air dielectric lines use 5kV for 7/8”, 4kV for 5/8”, and 3kV for ½”. A clean dry cable will display less than 0.1uA leakage current, >200GΩ resistance. It may require a dehydrator to purge wet air from the cable. Extreme care must be exercised as high voltage can arc, creating problems if not used properly.

An antenna system that does not include a DC short can be tested as a complete system. This is useful to test for moisture or other contaminants as well as to detect early stage arcing or other damage. 2500VDC is usually adequate to detect problems. DC leakage current should be less than 0.1uA or at least 25GΩ. For high power antennas that use 7/8” splitter cables increase the test voltage to 5kV for resistance at least 50GΩ. Ideally the complete antenna should display a resistance >200GΩ or the upper measurement limit after the entire system has been given time to fully purge.

1kV Megger is useful for troubleshooting existing problems. Not as sensitive as 15kV HiPot. Newer electronic versions are available that do not use a hand crank. Sensitivity seems greatly improved.

Even one event during which water is allowed to accumulate on the copper surface of transmission line can cause serious damage. The copper will corrode and be partially dissolved in the water. Contaminants will flow over the spiral insulator with the water. When the water evaporates it will leave behind a trace of material that will reduce the high voltage breakdown of the cable. Once dry, the slight contamination will usually not affect the antenna return loss but it may be detected with high voltage leakage testing. Cable attenuation will increase. The only recourse to contaminated lines is replacement or power reduction.

The air drying system must be operating properly and monitored continuously. It must be shut off immediately and a second air source supplied if there is any indication of the air not being dry. Positive pressure and extremely low relative humidity (<1%RH) are essential.

At low power levels, up to a few kW there isn’t enough energy present to cause significant damage to transmission lines. The earliest indication of water could be reflected power shutting down the transmitter. While still a nuisance, letting the water pour out and drying the lines may be all that is needed to restore service. However, the line damage caused by moisture remains.

This is a 1-1/8 inch primary splitter cable that failed on the Yarmouth FM antenna. The failure point is at the low part of a loop where moisture and contaminants likely built up. Transmitter powers were 20kW, 10kW, 10kW, and 1kW. The cable was between the primary 6-way power divider and the secondary 6-way divider.

The cable was rated at over 12kW at 100MHz but had less than 7kW applied. Eupen 1-5/8” foam cable was installed as a temporary replacement. The connectors were drilled to allow an external air hose to bypass the foam section and keep the system pressurized.

At high power any contamination over insulators could create arcing and result in catastrophic cable failure. With multiple 10kW or 20kW stations feeding a common antenna there is plenty of power to burn through cables or other antenna components resulting in catastrophic failure. I’ve measured leakage resistance of only 2.4MΩ on a TV antenna that should have displayed at least 25GΩ. Clearly it is severely contaminated, but with only 5kW peak power applied there isn’t enough energy to destroy the cables. Receive antennas with foam line have measured as low as 20kΩ with a digital multimeter. Return loss measurements on both antennas were acceptable. I suspect line loss is greatly increased.

13-30 DIN connectors and 7/8 inch cable. Total FM transmitter power was over 60kW. This damage is likely the result of panel failure. Once a failure begins it can cascade throughout the system creating serious damage. Routine HiPot testing of the system would have discovered contamination. Further troubleshooting would have indicated the antenna was in poor condition with very high leakage current. Immediately after the initial failure the return loss appeared acceptable, even with burned cables and the center conductor hanging out of the panels.

Tower Installation

Most antennas have connectors on back of the panel to allow the splitter cables to exit behind the active element or backplane. Kathrein antenna connectors are often to the side of the dipole support tube and in front of the backplane. The cables should make a sharp bend at the connector and exit out the back as quickly as possible. The backplane is an active part of the antenna system. It will have very high RF voltage in places despite being solidly grounded to the tower. Splitter cables should never be attached to the backplane for support. Doing so will distort the antenna pattern and possibly lead to RF arcing through the cable outer jacket. Overheating the outer conductor can damage the spiral insulation around the inner conductor causing an internal impedance mismatch. It could also create a weak point for internal arcing. Holes can be burned through the outer conductor creating air leaks. Cables damaged in this manner should be replaced. The splitter cables in the cover page photo have been removed and reinstalled. Live and learn.

High RF voltages on the backplanes - not chafing, caused this cable damage. HiPot testing inside the cable was good. The grey coating is overspray from cold galvanize that was applied to the backplanes. An easy way to test for damage to the outer insulating jacket is to disconnect both ends of the cable and use a HiPot or Megger to measure leakage from the tower to the outer conductor of the cable. A damaged jacket will show higher leakage than the other cables. Damaged cables should be replaced.

From RFS Cablewave – Handbook FM Arrays
Care must be taken in planning the route of the distribution feeders.
The feeders should be run from the antenna input connector directly to the space inside the tower in **as short a run as possible**.
Also note the following:

- Feeders must not be routed outside or be fixed to the antenna back screen.
- Where the feeders enter the tower through the back screen a minimum 70 mm separation should be kept between the branch feeder and any screen member.
- Any excess length should be taken up inside the tower space.
- The distribution cables should run parallel to each other and parallel to the tower bracings if possible and should be supported at 0.5 meter intervals or less.
- Cables should not be coiled into loops to get rid of excess length, they should be run out and a single bend incorporated to get them to the position required.

Elliptical polarization
All antennas can be considered to have some form of elliptical polarization. Horizontal antennas are elliptical with the vertical polarization removed. Vertical polarization is elliptical with the horizontal component removed.

Circular polarization is a special case of elliptical where both horizontal and vertical power levels are equal and the signal rotates. To do this with dipoles requires a 90 degree phase difference between each driven element.

If the signal rotation is clockwise looking in the direction of propagation, the antenna polarity is right-hand-circular (RHC). If the rotation is counterclockwise, it is left-hand-circular (LHC). FM broadcast standard is right hand polarization.

Note that on the receive end, the rotation appears to be in the opposite direction. When looking at a RHC transmit signal it will appear LHC to the receiver. The antenna will need to respond to the correct rotation for proper reception.

Unequal power division design
An unequal output power divider can be used with horizontal and vertical dipoles to create an elliptical signal. The phase difference between dipoles remains 90 degrees to maintain signal rotation. It is relatively simple to calculate the impedance at each output of the power divider.

Modify a 2-output power divider for 70/30 split.
Where two 50 ohm lines meet at the output of the power divider, the impedance will be 25 ohms.
There will be two quarter wave stages (30, 42 ohms) to transform this back to the 50 ohm input.
The horizontal output needs to be 1/0.7 x 25 ohms = 35.7 ohms.
The vertical output needs to be 1/0.3 x 25 ohms = 83.3 ohms.
Quarter wave transformers are needed at each output.
Horizontal section Z = $\sqrt{(35.7 \times 50)}$ = 42.2 ohms
Vertical section Z = $\sqrt{(83.3 \times 50)}$ = 64.5 ohms

Alternately, transform back to a 50 ohm common point.
The horizontal output needs to be 1/0.7 x 50 ohms = 71.4 ohms
The vertical output needs to be 1/0.3 x 50 ohms = 166.7 ohms.
Quarter wave transformers are needed at each output.
Horizontal section Z = $\sqrt{(71.4 \times 50)}$ = 59.7 ohms
Vertical section Z = $\sqrt{(166.7 \times 50)}$ = 91.3 ohms

Similar math can be used to modify a 4-way power divider to supply 10/20/30/40 for another purpose.
Where the four 50 ohm lines would meet will be 50/4 or 12.5 ohms.
There will be two quarter wave stages (17.7, 35.4 ohms) to transform this back to the 50 ohm input.
10% output needs to transform to 1/0.1 x 12.5 ohms = 125 ohms
20% output needs to transform to 1/0.2 x 12.5 ohms = 62.5 ohms
30% output needs to transform to 1/0.3 x 12.5 ohms = 41.7 ohms
40% output needs to transform to 1/0.4 x 12.5 ohms = 31.25 ohms
Double check 125, 62.5, 41.7, 31.25 ohms in parallel to create 12.5 ohms.
Calculate the quarter wave transformer sections as above.

When doing this ensure the total adds up to 100%. Power out must equal power in!

Another possible use for unequal power division is to disable one port of a power divider in the event of antenna failure. It could allow restoration of service on a partial antenna. For example, instead of operating all five ports of a power divider, only four could be used.
The connection point of all five outputs will appear as 10 ohms. One output should have a shorted quarter wave line connected. The others will be supplied 25% output power each.
They must appear as 1/.25 x 10 = 40 ohms at the output terminals.
Each will require a quarter wave transformer. Z = √(50x40) = 44.7 ohms

Crossed dipole elliptical design
When the phase angle between horizontal and vertical dipoles in a 50/50 antenna is not 90 degrees an elliptical pattern will be created. Power division between horizontal and vertical remains equal, but the ellipse will be gradually angled up to ±45 degrees depending on phase being more or less than 90 degrees. The phase length of the cables will vary slightly above and below the design frequency. This characteristic is used in designing the crossed dipole array.

Splitter cable phasing can be used to create elliptical polarization. Crossed dipoles are oriented at 45 degrees from horizontal in the shape of a X. By adjusting the phase difference between dipoles the signal polarity can be anything from vertical to horizontal and anything in between including circular.

Assume an elliptical antenna with 70% horizontal, 30% vertical is required.
Normalize everything to assume 1 watt, 1 volt, 1 ohm.
70% power will be at 83.7% of the supplied voltage. (√0.7W = 0.837V)
30% power will be at 54.8% of the supplied voltage. (√0.3W = 0.548V)

Sec 0.837 = 33.2 degrees (Cos^{-1} 0.837)
Csc 0.548 = 33.2 degrees (Sin^{-1} 0.837)
Notice the angle for both is the same.

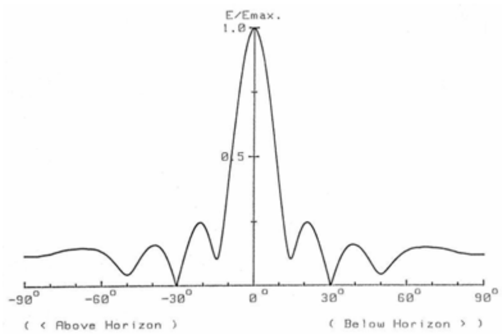
The upper dipole will require +33.2 degree phase shift from horizontal and the lower one –33.2 degree phase shift from horizontal, or more simply a 66.4 degree shift for the upper dipole compared to the lower one.

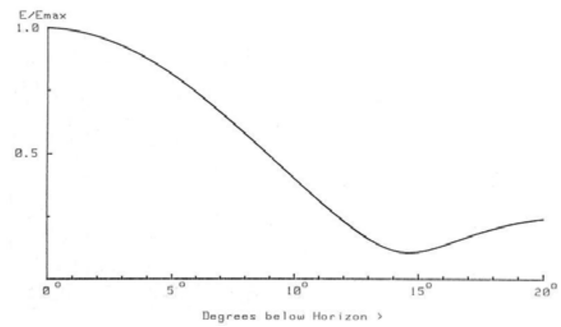
An elliptical Rymsa FM antenna was designed with a 66 degree phase difference between cables. This calculates to 70.3/29.7 power split, very close to the 70/30 design. The difference is insignificant when factoring in actual cable errors up to 2 degrees. The power division will also change as frequency moves away from the design frequency.

Design the same crossed dipoles for 50/50 split to create a circular polarized signal.
50% power is 70.7% voltage.
Sec 0.707 = 45 degrees
Csc 0.707 = 45 degrees
With ±45 degree cables, the total phase shift is 90 degrees.

<u>Beam tilt and null fill</u>

The angle of the main lobe can be adjusted up or down, commonly referred to as beam tilt. If you look at the vertical pattern of an antenna the amount of energy above and below the main lobe is roughly equal. Many antennas focus the RF energy horizontally and do not employ any form of beam tilt. The example below is a four bay antenna. It uses null fill is used to prevent the first null from going to zero. The main beam is focused horizontally. The audience relies upon the energy beneath the main lobe for reception. The majority of the signal travels over their head and beyond the horizon. Half the energy is sent upwards and is wasted.





By employing downward tilt the main lobe will intersect the ground. The audience beyond this point will rely upon energy above the main lobe for reception. This energy was formerly lost. People closer than the intersect point will have stronger signals due to the angle of reception. The desired beam tilt can be calculated based upon antenna height above average terrain and the distance to the desired ground intersect point. This could be a repeater station where you want to ensure maximum signal at all times. A beam tilt of 2º will increase signal level on the ground and still send 95% of the original signal strength at the horizon. While it may not be worthwhile to start swapping cables on an existing array, this is something to consider when a new antenna is being designed or during rebuild with a full new harness. Once beam tilt has been determined the cable lengths can be calculated.

The easiest technique for beam tilt of a small antenna is to physically point it up or down. This is how many cellular antennas are adjusted. An 8-bay FM array is about 24 meters long. To tilt the entire thing off the side of a tower to create 2 degrees down tilt will require the top element to be about 837mm away from the tower. This is impractical and there is an easier way.

$\sin 2^\circ = x / 24\text{m}$
$x = 24 \sin 2^\circ$
$= 0.837\text{m}, 837\text{mm}$

Broadcast FM wavelength is about 3 meters at mid band. 837mm / 3000mm = 0.279 wavelength or 100 degrees. The upper element will be 100 degrees ahead of the lowest element.

Now let's move the antenna back to the tower so all elements are vertical. We can make the upper element lead by 100 degrees through the splitter cable harness.

Assuming the coaxial cable is about 8mm per degree (see designs below) the cable to the upper element will be about 100 degrees x 8mm/degree or 800mm shorter than the bottom. Exact numbers must be calculated depending upon cable velocity factor and desired downwards beam tilt. The remaining cable lengths can be calculated using a similar technique.

Some antennas use a combination of mechanical and electrical beam tilt. Offset mounting an antenna panel can increase isolation between adjacent panels and improve return loss. The offset is factored into cable lengths when determining cable lengths for beam tilt calculations.

A multiple bay antenna will produce nulls in the vertical pattern. The nulls can be partially filled to reduce coverage holes in the broadcast pattern. It is done at the cost of a slight reduction in overall antenna gain. Looking closely at the harness of an antenna will often show that the upper half is a mirror image of what is done on the lower half. There is a slight upward tilt applied to one half and slight downward tilt to the other half. This will tend to modify the main lobe slightly to fill the nulls. Typical values are to change the phase by about 20 degrees between the inner and outer elements of the array.

Let's consider an antenna with a split feed arrangement. There will be a noticeable difference when operating half the array during maintenance. Depending on which half is on air there could be either upward tilt or downward tilt. Downward tilt is usually preferred because that is where the audience is. Operating with upward tilt will send the main lobe of the signal well above the audience. Look more closely at existing antennas to determine how the split feed is arranged. If new cables are being installed the beam tilt can be modified to prevent upwards tilt in either configuration. In some cases existing cables can be rearranged if it is considered feasible in terms of time and expense. Ideally, this is something to consider prior to installation when a split feed antenna is being planned and designed.

<u>Design example</u>
Build a 4-bay array with beam tilt and null fill for the Charlottetown antenna described earlier. Design null fill of 20 degrees between upper and lower halves with 1 degree downward beam tilt in the primary splitter cables. A 4-way power divider will feed secondary power dividers for each level. Use Andrew HJ7-50 cable. VF=0.92, 7.82mm/degree.

<u>Null fill</u>
Starting reference is 9200mm for the bottom cable. 20 degrees in HJ7 is 20 x 7.82mm/degree = 156.4mm
Round to 150mm, 19.2 degrees.
This will make upper and lower cables 9200mm, middle cables 9050mm.

<u>1 degree beamtilt</u>
Looking at the antenna main drawing, the total height is 15290mm for five panels. Height per panel is 3058mm. Center to center of the four remaining will be 9174mm. Let's draw a triangle.
The tower side is 9147mm
The lower angle is 1 degree

The upper panel will be offset from the tower by length L
Tan 1 = L / 9147mm
L = 9147 x Tan 1 = 160mm

The upper panel needs to lead the bottom panel by 160mm.
160mm x 0.92VF = 147.1mm. Round to 150mm (150mm / 7.82 = 19 degrees)
The upper panel will lead the bottom panel by 150mm or 19 degrees.
Divide this distance by three panels to 50mm increase per bay.

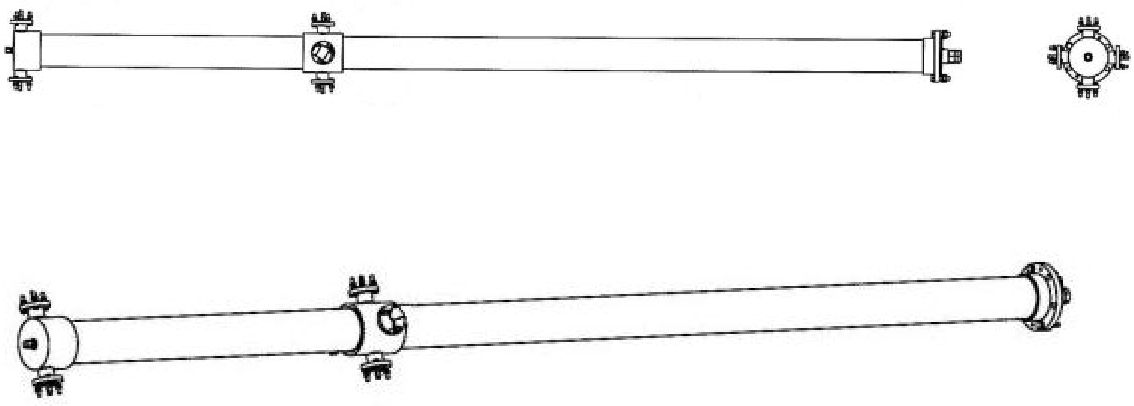
The top line will be 9200mm - 150mm = 9050mm (-19.2 degrees)
Third up will be 9050mm - 100mm = 8950mm (-32.0 degrees)
Second up will be 9050mm - 50mm = 9000mm (-25.6 degrees)
The bottom line is 9200mm (0 degrees, reference)

We now have a set of cables with null fill and 1 degree downwards beamtilt.

Before assembling cables confirm that none of the new cables are physically shorter than originally supplied from the manufacturer. You don't want to build cables that are too short to fit and have to start over.

<u>6-way power divider</u>

The Rymsa antenna mentioned earlier has a 6dB null in one direction. The power divider shown below creates the 6dB power reduction. Two outputs at the end of the divider are at -6dB compared to the other four outputs. I've calculated the line impedances to describe how the divider works. A similar technique could be applied to other ratios. Input at the right is 3-1/8" EIA. Six out outputs are 7/8" EIA.



Rymsa DA12-606 6-way non symmetrical power splitter 4:4:4:4:1:1 EIA 3 1/8" M - EIA 7/8· F

The power divider uses three quarter-wavelength transformers.
Four high power outputs are at 2/3 position.
Two -6dB outputs are at end of extra ¼-wavelength section.

Four 50 ohm outputs in parallel will create a 12.5Ω load impedance.
Power out at this point will be 16/18, with remaining 2/18 to -6dB outputs.

The -6dB outputs will receive 1/8 as much energy as the high power outputs.
Therefore the impedance at the end of its ¼-wavelength transformer will be 8x higher or 100Ω.

The two -6dB outputs will create a 25Ω load at the end of the transformer. The transformer impedance will be √(100 x 25) = 50Ω.

Impedance at the connection of 4 outputs and the –6dB section will be 12.5Ω parallel with 100Ω or 11.1Ω.

Two ¼-wavelength transformers bring it back to 50 ohms input impedance.
Mid point will be √(11.1x50) = 23.6Ω

Stage 1 impedance will be √(50x23.6) = 34.3Ω
Stage 2 impedance will be √(23.6x11.1) = 16.2Ω

Note that with this design the relative phase of the –6dB outputs will change compared to the high power outputs. This is due to the added ¼-wavelength transformer. The line section is designed to be 90 degrees at 98MHz. Velocity factor for an air line is typically in excess of 98%. At 88MHz the line will be about 81 degrees, and 99 degrees at 108MHz.

Split feed antenna 2-way power divider

This type power divider is typically ground mounted. It has a patch panel to provide flexibility to shut off one half of the antenna for maintenance or repair. The patch panel will sometimes allow the antenna to be split and operated as two independent antennas.

All input and output impedances are 50Ω. One input is split to two outputs at an internal tee.

Assume a straight two stage ¼-wave transformer. At the far end two 50Ω connections would appear as 25Ω. We need to transform 25Ω back to 50Ω. The mid point impedance is $\sqrt{(25x50)} = 35.4\Omega$

Let's replace the second stage of the transformer with a Tee and separate arms back to each output connector. To create a 35.4Ω midpoint, each arm must appear as 70.8Ω. We need two ¼-wave transformers from 50Ω to 70.8Ω.

Input transformer impedance will be $\sqrt{(50x35.4)} = 42.1\Omega$
Each output transformer will be $\sqrt{(50x70.8)} = 59.5\Omega$

Sira RFM-232/ST/U

The port at the top of the patch panel allows a second line to attach. The two antennas can be split and operated separately when this port is connected.

Main input is the center connector.

Below the Tee is a fine tuning stub. It also provides a DC short to ensure the center conductor of the combined antenna remains at DC ground potential.

Rymsa CC12-081
The Tee section is in the large box to the right.

Phase shift with frequency change

Let's assume a circular polarized crossed dipole antenna is designed at 98MHz but operated over the full FM band. The original 90 degree phase difference between cables will change with frequency, creating an elliptical signal. The antenna is circular only at 98MHz and will create an elliptical signal elsewhere.

Using HJ4.5-50 cable, the following cable lengths per degree can be calculated.
299,792,458m/s x 0.92 / 98MHz / 360 = 7.82mm/degree
299,792,458m/s x 0.92 / 88MHz / 360 = 8.71mm/degree
299,792,458m/s x 0.92 / 108MHz / 360 = 7.09mm/degree

90 degrees at 98MHz is 703.8mm
At 88MHz the cable will be 80.8 degrees
At 108MHz the cable will be 99.3 degreees

88MHz	Cos (80.8/2) = 0.761	Horizontal will be 58% (0.761^2) , Vertical 42%
98MHz	Cos (90/2) = 0.707	Horizontal will be 50% (0.707^2), Vertical 50%
108MHz	Cos (99.3/2) = 0.647	Horizontal will be 42 % (0.647^2), Vertical 58%

In the elliptical crossed dipole antenna designed for 70% horizontal and 30% vertical, the phase difference between cables is 66 degrees at the design frequency.
At 98MHz the cable length difference is 66 x 7.82mm = 516mm

At 88MHz the phase difference will be 59.2 degrees
Cos (59.2/2) = 0.869 Horizontal will be 76%, Vertical 24%

At 108MHz the phase difference will be 72.8 degrees
Cos (72.8/2) = 0.805 Horizontal will be 65%, Vertical 35%

This is characteristic of any panel type antenna that uses splitter cables for phasing. Beam tilt and null fill will behave in a similar manner. The antenna vertical pattern, gain, etc will change according to frequency. This is not to suggest wideband antennas should not be used. There are compromises in all aspects of antenna design.

Most ring type antennas are center fed. The wavelength between elements varies across the FM band and will change null fill and beam tilt. Power applied to the elements closest the feed point will be higher than those at the ends of the antenna. This power difference will create some null fill. When operating only half the antenna there will be either up or down tilt. Again, this is characteristic of the design and is something to be aware of.

This antenna was constructed from the upper half of a larger array. The feed point is at the bottom. The lower element will receive more power than the upper element, creating a slight upwards beam tilt.

Matching feedline length / phase for split feed antennas

Split feed antennas require two feedlines of equal length from the 2-way power divider on the ground to the two inputs at the tower. The closer to equal the lines can be made, the closer the installed beam tilt will be to the planned design. It should be relatively easy to get within a few mm even if the line is 200m long.

Considering that 2 degrees beam tilt required 100 degrees difference between the top and bottom elements, getting with half a degree is really not important. A cable length difference of 80mm or about 10 degrees at FM showed no noticeable difference with a beam tilt simulation program on an 8 bay array. Doubling frequency will half the cable length per degree. This makes measurements more critical as frequency increases. UHF television will be more critical than FM or low band TV. Ideally the lengths should be equal, but in practice it really isn't as critical as it sounds. Be careful with measurements, get as close as you can, and the results will likely be perfectly acceptable.

There are several techniques to equalize the lines. For this exercise, consider line 1 is higher on the tower than line 2. Line 2 will have an adjustable trombone section inside the building for fine tuning length and phase.

1. Spectrum analyzer / sweep generator. Line 1 must be terminated. Remove the line from the antenna power divider, install an adapter to Type-N with a shorted connector on the end. Inside the building connect a Type-N adapter to the patch panel where the line ends. Use a TDR to get an approximate distance for the line. The spectrum analyzer input and output ports connect together via jumper cables to a Tee connector. The output of the Tee connects to a line stretcher and then to the patch panel. The display will show a series of peaks and nulls. What you have is a long transmission line that is a multiple of a quarter wavelength. At even multiples (half wavelengths) it will present a short circuit at the Tee connector and produce a null on the display. At odd multiples it will appear as an open circuit and produce a wide hump on the display. Moving the line stretcher will cause the nulls to move up and down in frequency. Move the line stretcher to its mid range and choose a frequency where there is a pronounced null. Adjust span as needed to get the null centered on the display. Carefully measure and record the position of the line stretcher.

   Next move the shorted Type-N adapter to line 2. Use the TDR to measure the length of line 2. The purpose so far is not to get exact mm precision, but rather to ensure we are within the same half wavelength of line to get the proper null later. At 100MHz, a half wavelength is about 1.5m. Adjust the trombone section inside the building to get close to original length. It may be useful to stay several cm longer as the fine adjustments will be done next. Reconnect the spectrum analyzer, Tee connector, line stretcher, etc. Everything must be exactly the same as before to limit error. With luck, the null will be in the same location on the spectrum analyzer display. If not, move the line stretcher to move it in place. Measure the difference in line stretcher length and make adjustments to the trombone section. After each adjustment move the line stretcher to get the null back in place. When the null is correct with the line stretcher in the same position as line 1 the two lines will be equal lengths.

   Confirm with the TDR, but its accuracy will be lower than using the quarter wave nulls.

2. Network analyzer. Similar technique to the spectrum analyzer. Place a shorted Type-N connector at the far end of line 1. Use the TDR to get an approximate cable length or the distance to fault feature on the network analyzer. Connect the network analyzer and measure S11 phase for the reflected signal. Move to line 2 and use TDR to adjust the trombone section as closely as possible within the same half wavelength. Reconnect the network analyzer and fine tune to get the same S11 phase on the reflected signal. Again, use the same cables, terminations, etc as before to ensure best accuracy.
   The network analyzer can be used to display S21 Log Mag and perform in the same manner as the spectrum analyzer technique.

FM Peak power calculations

An FM transmitter output power is essentially steady. When two different frequency transmitters are combined the peak RF voltage will appear higher than expected.

Let's look at a 20kW transmitter terminated in a 50 ohm load.
$P=V^2/R$
$V=\sqrt{(P \times R)} = \sqrt{(20000 \times 50)} = 1000V$ rms
Peak voltage will be $\sqrt{2} \times 1000V = 1414V$ peak

When two 20kW transmitters are combined, the combined voltage will be 2000Vrms or 2828V peak. Compare to a single 40kW transmitter at 1414Vrms or 2000V peak.

An equivalent average power to produce this voltage can be calculated.
$P = 2000^2 / 50 = 80kW$

Four 10kW transmitters will supply 40kW to the antenna. 4x707V=2828Vrms. This voltage is equivalent to a single carrier at 160kW!

For equal power transmitters,
Peak power = TX power x (number of transmitters)^2

As more transmitters are added the peak voltage will climb rapidly. This peak voltage is critical, especially at high power with multiple carriers. Adding another transmitter isn't merely an extra power load. The increased voltages present within the transmission lines and antenna can be significant. If the antenna return loss is less than perfect, the VSWR - Voltage standing wave ratio will create even higher peak voltages throughout the system. Cables that have been compromised due to moisture or other contamination are more likely to fail. Similarly if the antenna is being run near its power limits with multiple carriers, any failure or temporary increase in VSWR such as during icing could start a cascading failure in splitter cables and power dividers.

Watt meters

Most RF watt meters measure current, not power. A directional sample will supply a current to an analog meter that is calibrated to display an equivalent power. Look at the meter face. It will likely indicate FS=30µA or FS=100µA. Mid scale will be about ¼ of full scale. It is not linear. When used in a multiple carrier system the peak RF voltages are much higher than with a single carrier. This causes the indicated wattage to be much higher than is actually present. This applies for both forward and reflected ports.

Although the actual numbers on the meter scale are somewhat meaningless, it is still useful to monitor the absolute reflected signal level. Any increase could indicate a problem within the antenna system. Place a small dot with a marker at the normal reflected power reading.

I've seen reflected power intermittently increase and then drop again. Sometimes it would trip the alarm and automatically clear. A rigging crew was called in to troubleshoot the problem on the tower. A visual inspection found several kinked cables. HiPot measurements discovered high leakage on other cables as well as badly contaminated power dividers. All questionable cables were replaced and the power dividers brought to the ground for cleaning. The problem has not returned and reflected power has remained stable since. This is a better approach than letting things continue to operate until catastrophic failure.

When monitoring reflected power, select a wattmeter element that will provide full scale reading if there is a problem. I've often seen full scale reflected elements selected at 10dB lower than the forward element. Consider using a 13dB full scale element instead. 1kW reflected for 20kW forward, 500W reflected for 10kW forward. Most transmitters will shut down at 14dB return loss. For instance, if main transmitter power is 1kW, reflected power above 40 watts will cause total shutdown. If the reflected element provides full scale reading of 250 watts the meter will barely lift. Select a 50 watt element instead. As the reflected signal begins to increase it will be much more evident. The trip point can be set more accurately as well.

Estimating transmission line length

When looking at the reflected signal from an antenna, S11 there will be regular dips in the response curve. These can be used to estimate the length of the transmission line.

Measure the difference in frequency between the dips, ΔF.
Using the velocity factor of the cable, the line length will be

$$L = \frac{VF \times C}{2\,\Delta F}$$

A more detailed explanation can be found here.
http://www.microwaves101.com/encyclopedia/Cable%20ROT.cfm

Measuring line loss

It is not difficult to measure transmission line loss, even when the far end is hundreds of feet up a tower. Get the tower crew to disconnect the power divider or antenna and place a short circuit across the line. Carefully calibrate sweep gear to measure return loss and connect to the line. As the signal will travel to the short circuit and back, return loss will be twice the line loss. Divide the number by 2 and you will have a measurement of line loss. This should be measured when new lines are installed and compared any time the line is open. Moisture and other contamination will increase line loss as the conductor surface becomes corroded.

Antenna power vs transmitter power

RF power levels at the antenna end of a transmission line are often considerably less than on the ground. Sometimes extra power can be fed into the system without exceeding the antenna rating.
Assume a 600 foot feedline of Andrew HJ8-50 cable. At 100MHz, attenuation is 0.473db/100 feet. Total line attenuation is 2.838dB. Maximum transmission line power is 40.47kW. The antenna rating is 20kW.

Line loss = 10 log P1/P2 P1 = antenna power, P2 = transmitter power

P2 = P1 / (10^(dB/10))
= 20kW / (10^(-0.2838))
= 38.44kW

38.44kW of transmitter power fed into the feedline will result in 20kW arriving at the antenna.

Transmission line multiple carrier power capacity

HJ8-50 power rating is 43.42kW at 88MHz, 40.47kW at 98MHz, 38.79kW at 108MHz.
If transmit power is 20kW at 88MHz and 15kW at 98MHz, what extra capacity remains at 108MHz?

We need to calculate the percentage of power level capacity at each frequency.
88MHz, 20/43.42 = 46%
98MHz, 15/40.47 = 37%
Total capacity 83%
There is 17% capacity remaining.

At 108MHz, 0.17 x 38.79kW = 6.6kW

Calculating cable power ratings
Cables specs will often give ratings at various frequencies, but not always the frequency of interest.
$P2 = P1 / \sqrt{(F2/F1)}$

P1 = known power rating
P2 = power rating at second frequency

If the cable (or connector) is rated 5kW at 20MHz, its rating at 100MHz can be calculated.
$P2 = 5000 / \sqrt{(100/20)}$
$= 2236$ watts

Note that cables will have maximum ratings that should not be exceeded, regardless of the calculated value. This is typically more important at lower frequencies and for peak ratings such as multiple carriers.

Variable return loss test loads
For testing transmitter foldback and shutdown threshold, a variable return loss load can be useful by allowing reflected power to be varied. This is better than attempting to operate a transmitter into an open or short circuit or pushing a screwdriver through a hole in a transmission line. A gradual change in return loss will allow us to monitor the behavior of the transmitter over a wide range of mismatch.

Fine matchers
Tuning elements on a fine matcher are spaced at 1/8 wavelength intervals at the design frequency. This is about 15 inches at 98MHz, 2 inches at channel 58 - 735MHz. With one element in each quadrant of a Smith chart, the response curve can be pulled in whatever direction is needed to approach a 50 ohm non reactive load.

Start with all tuning elements pulled out. Move the elements inwards one at a time until an improvement is seen. Peak this one for the best response. The element next to this one will be used to fine tune the response. Only two of the elements should be needed. Note that the first and fourth elements are essentially next to each other, spaced 3/8 wavelength apart on the Smith Chart.

A fine matcher can also be used to create a mismatch. Adjust the tuning elements to detune the test load or antenna and create reflected power. As the load gets worse the transmitter should begin an RF foldback to limit reflected power. As the mismatch continues to worsen the transmitter should eventually shut down entirely.

The fine matcher does not have to be designed for the frequency in use. The purpose is to create a mismatch, so any fine matcher will do. Ensure it is capable of handling the power levels in use. You may have to experiment to find a suitable fine matcher for the intended application. Just as a fine matcher is not capable of compensating for a terrible return loss, neither is it capable of turning a perfect load into something totally unusable.

3dB coupler
A 3dB coupler with two open ports will send the input signal to the dump load. As long as the two unused ports have the same type termination the return loss will be very good. Both can be left open, shorted, or with equal lengths of transmission line. Install a piece of line on one port and an equal length line stretcher on the other. Return loss will be good if the line stretcher is adjusted to the same length as the other line. Varying the line stretcher will allow a wide adjustment range for return loss. The 3dB coupler should be designed for the frequency in use.

A variable attenuator can be made with two 3dB couplers. Attaching them back to back should provide a very low loss system. As the line length in one branch between them changes, the phase relationship of the input signals will vary. The output signal will split with some going to the dump load. With a 90 degree phase shift, all energy will go to the dump load. This is in essence a variable 0-30dB attenuator. Power rating is whatever the couplers and dump load will handle. If the transmitter uses a switchless combiner, it can become a variable attenuator for use during tower maintenance. Add another set of switch end points that can be moved to the appropriate position.

Pull out a spectrum analyzer and a few parts and do some experimentation. There is no reason to be limited to using RF components only in the manner they are usually installed. A 3dB coupler can be a signal combiner or splitter, part of an AGC or phase adjusting circuit, group delay corrector, and many other uses.

<u>More pictures</u>

It isn’t just splitter cables that fail due to contamination. When these antennas were rebuilt, each panel was pressurized to ensure the insides remained clean and dry. The goal is to provide a controlled environment to the entire antenna system and prevent moisture or dirt accumulation. Proper dehydrator monitoring is essential. The air must be <1%RH. A Honeywell HIH4000 sensor works well for monitoring.

Inside a 5-way power divider following splitter cable failure. 6 inch input connector with 1-5/8 inch output connectors. The power divider has been repaired. New parts were machined and it was fully dismantled for cleaning. The main feed line was severely contaminated and needed to be replaced.

Further information

This document started as a 2-day presentation given to other technicians in August 2008 following antenna rebuilds described. It has since been greatly expanded with antenna design, tower installation, and failure pictures.

These are my personal notes and thoughts from the past several years. My research and writing takes place after work hours, on my own time, and purely out of personal interest. I've done my best but can not guarantee 100% accuracy throughout. Do your homework and double check before using the information in any critical application. I appreciate constructive suggestions and ideas for improvement. Please let me know if you have found the information useful or if you find errors or typos.

I've written this document in hopes of assisting others. Feel free to distribute. It is simply impossible to recognize every piece of information that I have come across. I try to reference things and give credit as appropriate. If you find something that should be acknowledged please let me know. It is not my intention to steal credit from anyone.

I'd like someone to assist with proof reading and translation to French. Please email if you are interested in helping out.

Latest changes and updates will be available on my personal web page.
http://members.rennlist.org/warren/SplitterCableDesign.pdf

Other items I've been working on.

FM Combiner tuning and testing. Signal flow, intermod calculations, pictures, etc.
http://members.rennlist.org/warren/FMCombinerTuningAndTesting.pdf

Relative humidity measurement and remote monitoring, dehydrator theory.
http://members.rennlist.org/warren/RelativeHumidityAndDehydrators.pdf

Construct a simple and inexpensive dew point monitor for monitoring dehydrator performance.
http://members.rennlist.org/warren/DewPointMonitor.pdf

Broadcast and RF related grounding ideas.
http://members.rennlist.org/warren/grounding.pdf

Please contact me with any feedback or questions.
VO1KS@eastlink.ca

Last change 28 December 2011

"The four most beautiful words in our common language: I told you so." Gore Vidal

"The first principle (of science) is that you must not fool yourself, and you are the easiest person to fool." Richard Feynman