Three Cluster Field Day Antenna System - Measurements and Findings from Pre- Field Day setup

The 3 clusters of antennas to support Phone, CW and Digital for Field Day were setup in April 2020 along a 500 feet line on a ridge in the fields at the QTH of KA2C.   This allowed about a week of leisurely testing and findings. The measured SWR's, bandwidths and resonant frequencies for each antenna cluster are documented in separate papers. This paper discusses the isolation measurements, isolation tuning and receiver performance for phone when operating in the same band with CW with some frequency separation.

The antennas were setup in a very open area on a slight ridge in a farm field. The trap dipole was erected at one end of the 500 feet span between a 25 feet pole at the end of the 500 feet span to a 30 feet pole at about 100 feet along the 500 feet span.   The widespread inverted vee for 80/40/20 phone was located at about 200 feet into the 500 feet span (about 100 feet from the closest support for the trap dipole), and it was perpendicular to the 500 feet line. And the 80/40 vertical was located at the far end of the 500 feet span with the 20/15/10 vertical about 75 feet closer to the inverted vee.

The 80/40 meters vertical is to the far right, and the R5 vertical is next. In the distance to the left is a mast for the 80/40/20 meters inverted vee, and the 2 masts for the trap dipole are barely visible to the far left.

The trap dipole is in the center background on 2 masts. To the far right is the center mast for the inverted vee. The 2’ by 4’ center spreader is visible near the top of the mast, and 3 separate posts to tie off independently the separate wire elements for 80, 40 and 20 meters for one side are visible across the picture.

This was the setup for transmitting CW at 100 watts on the nearby verticals using a Yaesu FT-991A. A small generator is faintly visible about 100 feet down the lane. A contest keyer sent a test signal and station ID repeatedly during each test sequence.

This is the setup for receiving on a Yaesu FT-950 near the inverted vee (the FT-991A is also setting on this table in this photo). A small 12V battery under the table was used to power the FT-950 for most tests to ensure no signal coupling over power cables. The bandpass filters used to eliminate out of band noise and signals are visible behind the FT-991A, and the small portable oscilloscope is visible near the FT-950.

This is a small portable battery-run scope used to measure interference signal levels and used to guide tuning the antenna positioning to maximize isolation.

A first set of measurements were taken of isolation using an oscilloscope connected to a receiving antenna while transmitting on a different antenna. It was found that it is important to use the appropriate bandpass filter in front of the oscilloscope to significantly reduce out-of-band noise. It was important to use a linear scope to tune the antenna leg positions versus using a receiver and S-meter, because it was possible to see small improvements in isolation to guide the adjustment process. For isolation tuning, a CW test signal was sent; then one person observed the scope response of the interference while a second person walked the antenna leg back and forth slowly to find a best null. After finding a null, a post was driven into the ground and the antenna leg was tied off. This was done starting at 80 meters, then 40 meters, and finally 20 meters.

The worst case isolation between the trap dipole and the verticals was about 57 dB on 40 meters. No adjustments were subsequently made to change or improve the isolation between the vertical cluster and the trap dipole cluster.

Verticals to trap dipole

80	60 dB
40	57 dB
20	~70 dB
15	~70 dB
10	67 dB

The trap dipole to inverted vee isolations were:

80	56 dB
40	57 dB
20	58 dB

The worst case isolation between the inverted vee and the verticals was about 52 dB on 40 meters. After the initial measurements, adjustments were made to the inverted vee legs to improve the isolation with the verticals. With adjustments, it was possible to achieve about 70 dB of isolation.

The initial isolations were

80	53 dB
40	52 dB
10	54 dB

A Yaesu FT-991A was used to transmit CW at 100 watts into the transmit antennas, and a Yaesu FT-950 was used as a receiver. The key issues are 1) RX front end overload and 2) TX amplifier noise. A few TX spurs were also observed (RX Inter-modulation may also have played a role). It appears with 15 to 30 dB of isolation provided by the bandpass filters for inter-band operations, there should not be any interference that is noticeable when combined with the antenna isolation although some TX harmonics or spurs may still appear. For intra-band operations simultaneously on CW, phone and digital, interference is not noticeable with 50 to 100 KHz of frequency offset when about 70 dB of isolation is achieved. Achieving 70 dB of isolation is not easy, but we were able to come close to that for the verticals to inverted vees isolations on 80, 40 and 20 by carefully tuning the positions of the inverted vee end points. Achieving 55 to 60 dB of isolation was possible in an open field just by installing the antennas carefully, and in that situation, operations on the same band are possible by disabling the RX preamp and possibly enabling some attenuation.

TX amplifier noise was a key challenge. ARRL tests of the FT-991A shows about an -125 dBc (dBc means power per Hz relative to the carrier power) noise floor at 100 KHz offset from the TX carrier. In a 500 Hz bandwidth and with 100 watts of TX power, that is a noise power of -48 dBm that is transmitted. With the preamp off, the noise floor of the FT-950 is about -120 dBm on 80 meters. If antenna isolation of 72 dB is achieved, then the transmitted noise is received at the noise floor of the receiver (with the preamp off) and is barely perceptible. Even with the preamp on, the transmitted noise is typically not noticeable due to background noise. If the antenna isolation is about 60 dB, then the transmit noise will be about 12 dB above the background noise at the receiver, even with the preamp off, and noticeable but not damaging to moderately strong signals. Avoiding RX overload appears to require a bit less isolation than the level required to make TX amplifier noise imperceptible.

Adjustments on the inverted vee legs allowed the isolation from the verticals to the inverted vee to be significantly improved. Isolations of about 70 dB were achieved on 80, 40 and 20 meters. Simulations with EZNEC show that this requires an angle error less than 2 to 3 degrees in the placement of the inverted vee legs and this appeared consistent with observations.

The independent end points of the legs of the inverted vee for each band allowed each band to be independently optimized for isolation and was necessary as shown in the picture. Once this isolation was achieved, CW interference from the verticals into the phone inverted vees resulted in imperceptible interference with 50 to 100 KHz separation on 80 or 40 or 20 meters.

Phone operations are the most sensitive to TX amplifier noise interference. This is due to the large bandwidth required for phone of about 2800 Hz which means the noise spread over 2800 Hz is heard. CW operations are less sensitive to TX amplifier noise interference and it is about 10 dB less sensitive to noise than phone assuming a receiver bandwidth of about 300 Hz. And digital PSK31 is the least sensitive to TX amplifier noise interference and it is about 20 dB less sensitive to noise than voice with a matched RX filter bandwidth of only 31 Hz. This means that isolation of the antennas for voice should be given priority which is supported by this system by using the inverted vees for voice which supports quick and easy adjustments for isolation with the verticals for CW. However, digital should be given next priority, even though it has major advantage to reject additive noise, because CW operations are the most problematic in causing interference. Placing the digital antennas at the far end of the antenna system with maximum separation with the CW antennas helps isolate the digital trap dipole although adjustments for isolation are not easily performed.

While additive TX amplifier noise interference is the most difficult to manage in terms of required isolation for phone operations, front end RX overloading will affect any mode somewhat similarly. Overloading of the RX front end preamp, mixer and IF stages by interstation interference prior to roofing filters or channel selection filters is not significantly mitigated by downstream RX filtering. Hence it is important for all modes to avoid RX front end overloading. Fortunately typical modern rigs are OK with interference signals around 0 dBm (50 dB of isolation for a 100 watt interferer) if the preamps are disabled. So, as long as isolations are at least 50 dB and if preamps are disabled, front end overloading should not be a problem as long as there is >50 KHz of separation in frequencies of operations.

It may not be easy to tell the difference between front end overloading and additive TX amplifier noise interference. This problem can be reduced by actually calculating when disabling preamps and enabling attenuators should be needed to eliminate front end overloading (this requires knowledge of the antenna isolation and 1 dB compression points on the rigs,….). Harmonic interference can be determined as appearing as CW tones as opposed to broadband noise for CW interference, and for digital and voice harmonic interference, the interference will be concentrated at specific frequencies.

Conclusions

Setting up these clusters of antennas carefully but without any adjustments for isolation actually results in good performance (assuming no major obstacles or nearby reflectors). The use of 3 polarizations between the 3 clusters of antennas can provide good performance in the field albeit not as good as ideal models. Isolations in the 50 to 60 dB range can be achieved by careful setup alone. That is sufficient that inter-band interference should be negligible when bandpass filters are also used. Some harmonics or TX spurs may still be observed on certain frequencies, but front end RX overloading and broadband interference should not be observed between bands.

For operations on the same band, which are desirable to maximize QSO opportunities, assuming separations greater than 50 to 100 KHz, interference should not be perceptible when isolations of about 70 dB or greater are achieved. However, achieving 70 dB of isolation is possible but not easy. For isolations of 50 to 60 dB, preamps should be disabled and possibly attenuators enabled to avoid front end RX overloading and to mask TX amplifier noise. For the widespread 80/40/20 meters inverted vee, isolation from CW on verticals can achieve about 70 dB by adjusting the end point positions of the inverted vee independently for each band. Isolation is reciprocal, so by optimizing the CW to phone interference (verticals to inverted vee) this also optimizes the phone to CW interference. Since operations with a bandwidth of about 2800 Hz is most vulnerable to additive TX amplifier noise interference compared to CW or digital operations, it is important that phone operations can be well isolated, especially from CW transmissions.

Around 70 dB of isolation was achieved on 20, 15 and 10 meters between the verticals for CW and the trap dipole for digital, and around 60 dB was achieved on 80 and 40 meters without any adjustments. It should be possible to also adjust the trap dipole isolation to CW on verticals, but that may involve moving the masts which support the ends of the trap dipole. The trap dipole and the CW verticals are spaced far apart at the ends of the 500 feet antenna area which helps for isolation, and this is consistent with higher isolation in general for 20, 15 and 10 meters. The narrow bandwidth of digital transmissions with an RX matched filter of only 31 Hz for PSK31 means that it has significant advantages against additive TX amplifier noise interference, but this advantage does not extend to any problems with RX front end overloading.

The isolation between the inverted vee and trap dipole cannot be independently adjusted, given adjustments for isolation between the inverted vee and the verticals and possible adjustments for isolation between the trap dipole and the verticals. However, even with adjustments to the inverted vee to achieve nulls for isolation with the verticals, which are incremental in scope, the trap dipole and inverted vee will still be approximately in different polarities and achieve a significant degree of isolation. In these tests, 50 to 60 dB of isolation was achieved between the inverted vee and trap dipole.

If significant interference due to wideband noise (not harmonics) is found during operations even with the usage of bandpass filters and antennas with good isolation, the first additional solution should be to disable any RX preamps. Disabling the preamp should only impact fairly weak signals in terms of operations. If that is not sufficient to address the interference, then RX attenuation may be added, although this may obscure some desired signals also. As a final resort, the interfering TX may reduce power from 100 watts to 30 watts or even to 10 watts, or the operators may choose separate bands for operations. Real time communications among operators and logging of status such as operating bands and any significant observed interference will help to control and minimize interference and also provide information for review and future improvements.

Future Options for Improvements

Two masts spaced 30 to 50 feet apart with 2 pulley ropes could be used on the far end of the trap dipole to adjust the angle of the trap dipole to optimize the isolation. However, that would not provide independence to adjust each band's isolation separately. Also, the bend of the dipole and the droop of the center fed point play a role, and it would be helpful to support the center point on its own mast to control the droop. It is for further study how to organize a multiband dipole to allow easy isolation optimization in the field and with independence on each band.

A rotatable multiband dipole such as the MFJ-1775 would provide an excellent method to optimize isolation between the verticals and dipoles, although it would not be independent on each band, and 80 meters would not be supported. Another option would be to use two hamsticks setup as a horizontal dipole. The hamsticks are single band, but 80 meters would be supported. One multiband option would be a combination of hamsticks for 80 meters and an MFJ-1775 for 40/20/15/10 meters mounted on a shared mast. Rotatable dipoles would need a more substantial and stable mast or tower than what is needed for a dipole end support, so that may be a challenge.

The problem of how to optimize and adjust antenna positioning in the field between all 3 clusters of antennas for isolation between all clusters is more challenging. This is a fundamental problem of degrees of freedom in possible adjustments. Non uniformity in the environment, reflecting objects and non-ideal antenna structures limit what can achieved for all 3 possible isolation links on each band. For any 2 isolation links, antenna adjustments can optimize the isolation. For example, given fixed verticals in one cluster, inverted vees in a second cluster can be adjusted for isolation, and dipoles in a third cluster can be adjusted for isolation with the verticals. But isolation between the inverted vees and the dipoles is not optimized by those adjustments in non uniform environments although fair to good isolation may be achieved, especially in open areas with relatively flat uniform ground.

One could resort to using RF cancellation circuits to optimize performance for the third set of isolation links (in this case inverted vee to dipole links) without disturbing the carefully optimized isolations on the other links achieved by antenna design and orientation. Such a circuit would use an RF coupler to sample an interference signal at the interfering TX at about -30 dB and then couple it to a cancellation circuit/box near the victim receiver over a long coax. The cancellation circuit would contain phase adjustments over 360 degrees; attenuators on the interference signal sample; and an RF combiner which then would feed the RX. These circuits would be adjusted to null the interference. It would need to support moderately strong signals on the order of 1 watt maximum with excellent linearity and dynamic range and off-the-shelf RX noise canceling circuits would typically not be appropriate due to the strong signals. Fully passive circuits would probably be best. This circuit would be bypassed during transmissions from the TX that is paired with the victim receiver. It should be possible to automate the required tuning of such an interference nulling circuit with a microprocessor. Unfortunately such a system is not reciprocal and it is also fairly complex, but it is feasible.