Using Frequency Diversity to Improve Measurement Speed

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ABSTRACT

Conventional antenna measurement systems use a multiplexer or polarization positioner to sequence polarization and or antenna elements as a function of time, requiring two or more measurement intervals. However, a simpler, more cost effective, and faster technique can be implemented by using frequency diversity to distinguish between polarizations or antenna elements. This paper describes how two slightly different frequencies can be used to make two measurements simultaneously instead of sequentially, cutting the measurement time in half or even more. Additional considerations must be taken into account to achieve good measurements. This paper addresses these issues. Actual measurements are presented.

1.0 APPROACH

With this technique, two polarizations or elements are transmitted at the same time, requiring no multiplexing or control. The multiplexer at the source antenna is replaced by a power splitter and two modulators. Each modulator is fed with a different modulation frequency. This produces a spectrum at the output of each modulator with the carrier and two side bands separated by the different modulation frequency used. The output of each modulator drives a separate polarization or antenna element.

The signal input to the receiver consists of both channels simultaneously, but at slightly different frequencies, all within its IF bandwidth. The reference input to the receiver is formed by summing the outputs of the two modulators. The receiver measures each frequency in a separate frequency channel, yielding both measurements simultaneously.

By using a highly selective dual frequency receiver, the polarizations can be de-multiplexed by using frequency diversity.

2.0 PROOF OF CONCEPT

To implement this concept, the MI-750 Receiver has been modified to make two measurements simultaneously in its signal channel, and the design can be further extended. The modified Receiver is equivalent to two receivers that are precisely synchronized in time. Frequency division multiplexing has many benefits, such as:

- No multiplexer required
- No synchronization required
- Simultaneous sampling of two signals

Simultaneous sampling of two signals effectively doubles the sample rate, and it also eliminates time skew between the two signals being measured.

Using the multi-frequency technique, two or more antenna channels can be measured without multiplexing them in time. This eases range design in two ways: the multiplexer (or a polarization positioner) can be eliminated, and control signals are not required to provide timing for the multiplexer. In large outdoor ranges this can provide a considerable cost savings.

When implementing this technique for an antenna measurement system, there are several considerations that have the potential to affect system performance in some applications. These are discussed in more detail later:

- Reference Channel Isolation
- Phase deviation
- Frequency spacing
- Source phase noise
- Propagation path variations

Actual measurements have been made using an enhanced MI-750 Receiver and the performance documented. Data has been collected at frequency spacing of 6 to 150 KHz on both clean and noisy sources.

As a proof of concept, the digital IF processing section of the MI-750 Receiver was modified to process two distinct signals within the bandwidth of the IF. Two signals spaced +/-150 KHz from the nominal test frequency appear in the received IF spectrum as shown in figure 1. The receiver's analog IF bandwidth is sufficient to pass both signals through to the digital section of the receiver, and the two signals are separated and measured using digital signal processing (DSP) in the IF Processor.

The ability to separate the signals sufficiently to make a valid measurement is a function of the receiver's spurious signal rejection. Without good filtering, the signals interact with each other much like crosstalk.

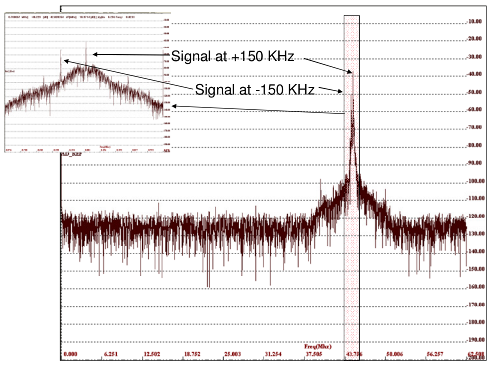

Figure 1 – IF Spectrum

The broadband phase noise of the source may also be a limiting factor. The plot shown in Figure 1 is for a relatively noisy source. The performance differences using relatively clean and noisy sources are discussed in more detail later.

3.0 MEASUREMENT COMPARISON

Measurements were made of an X-band monopulse antenna in the lab using both conventional single frequency measurements and the new dual frequency measurement technique. Figure 2 shows the test configuration where the AUT is illuminated with a dual polarized feed. The horizontal polarization is fed with a signal at one frequency and the vertical with another frequency. The two signals are very close in frequency and can be considered to be the same frequency as far as the AUT is concerned.

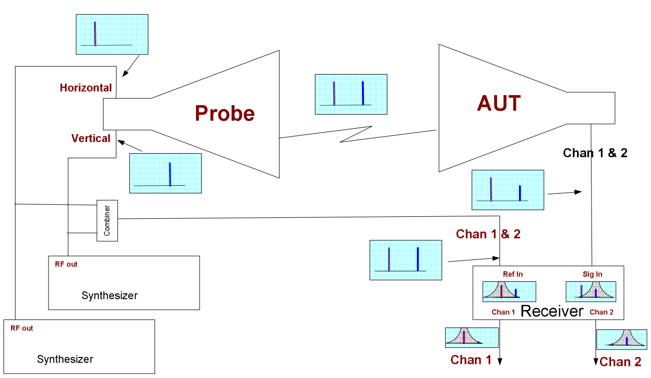

Figure 2 - Frequency coding of Horizontal and Vertical polarizations

With this setup, no synchronization of the transmitter and receiver is required, and no multiplexer is required. The reference is formed by summing the two signals and sending them to the receiver.

For the conventional single frequency measurements, the synthesizers were turned on one at a time, with the other synthesizer turned off. One scan of the Azimuth difference beam was made for the co-polarized case and another scan for the cross-polarized case. Both measurements were made at 10.000010 GHz.

The synthesizer output signals for the dual frequency measurements were offset +/- 10 KHz being 10.000020 for the co-polarization channel and 10.000000 GHz for the cross polarization channel. Both synthesizers were turned on at the same time, and with a single scan, the co-polar and cross-polar measurements were made simultaneously.

To collect data, the positioner was moved manually in 0.5 degree increments and the data collected at each increment in a semi-automated fashion. The data was recorded to a file which was imported into a spreadsheet and plotted. Data was collected from -90 to +90 degrees of azimuth. The elevation was set at 0 degrees and the height was adjusted to be close to the boresight condition.

The co-polarization amplitude data from both the conventional and dual frequency measurements are overlaid in Figure 3A. At higher signal power levels, the agreement between techniques is excellent. At lower power levels there is still fairly good correlation between the two, but some deviation is observed.

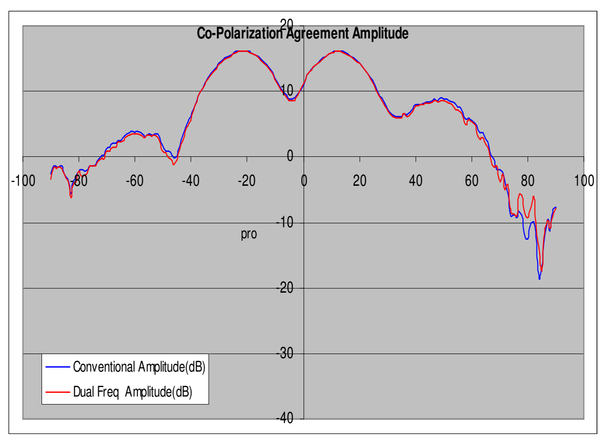

Figure 3A – Co-polarization Amplitude

As shown in Figure 3B, the co-polarization phase data also showed reasonably good agreement between techniques. The deviations in phase also correspond with lower power levels.

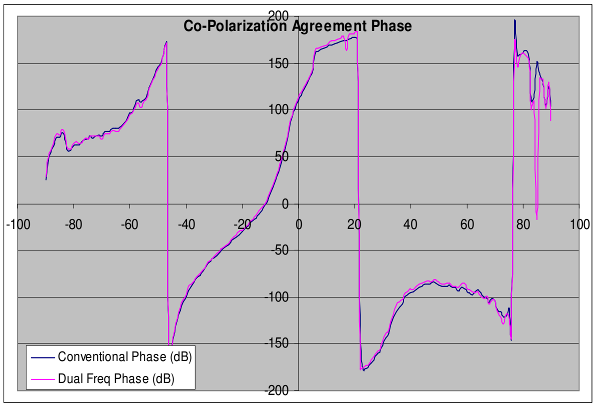

Figure 3B – Co-polarization Phase

Because an anechoic chamber was not available at the time of this writing, the tests had to be performed in an open laboratory environment. The main beam of the antenna intercepted equipment racks, file cabinets, and other obstructions. Although attempts were made to minimize the effects, multi-path interference is a factor in the test results. In spite of these limitations in the test environment, the results are good enough to be promising.

The scans were repeated several times for each technique using the same settings. The variations seen in the data sampled using the conventional technique and the variations seen comparing between techniques was similar. These variations were small near the peak of the signal - on the order of 0.1 dB in amplitude and 1.5 degrees of phase. These are respectable, given no absorber in the room and just a little around the face of the antenna. Multipath into the back lobe of the antenna could produce the observed effects which are estimated to be approximately 38 dB below the peak of the beam, which is consistent with the ripple on both cross-polar and co-polar measurements.

Overall, the co-polarization data collected has good agreement between techniques, given the conditions under which it was measured.

The cross-polarization amplitude comparison shown in Figure 3C is of course at a much lower signal level than the co-polarization measurements. At lower signal levels, distortions from multipath effects in the test environment have a larger impact on the measurement.

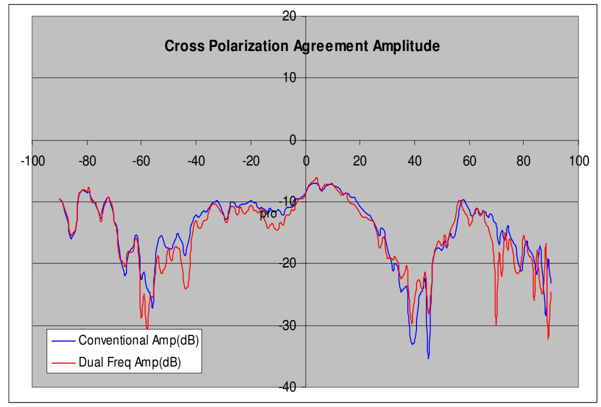

Figure 3C – Cross-polarization Amplitude

Likewise, the cross-polarization phase comparison shown in Figure 3D has similar issues at low signal levels.

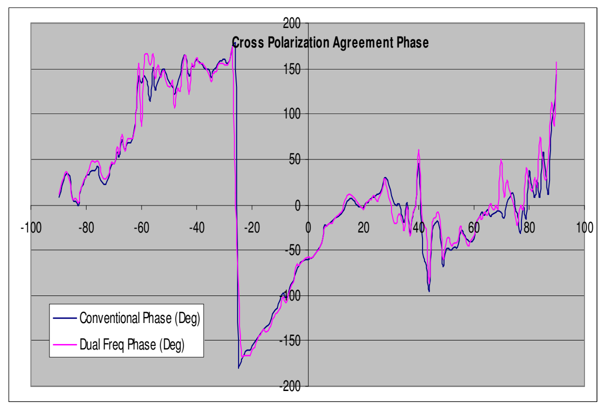

Figure 3D – Cross-polarization Phase

Although the cross-polarization data has more variation due to lower signal levels, the data collected still has sufficient correlation between techniques to warrant further investigation.

The data presented agrees within the repeatability of the test setup over the time the data was taken. By the time the paper is presented, it is expected that additional data will have been collected in the controlled environment of an anechoic chamber to provide more conclusive results.

4.0 BENEFITS OF DUAL FREQUENCY MEASUREMENTS

Using the dual frequency measurement technique provides several benefits that reduce range complexity and cost. With the conventional single frequency approach, the requirement to have a multiplexer complicates a range and increases the cost. Beside the cost of the multiplexer itself, the multiplexer has to be controlled in synchronism with the measurement system. This dictates some form of real-time control using a real-time link. The multiplex interval needs to be short enough that the distance traveled by the positioner between measuring the ports is not enough to skew the data. This is of most concern where the slope of the phase and amplitude data is high, as in the case of a mono-pulse antenna. However, very short measurement intervals usually reduce dynamic range.

The dual frequency or multiple frequency receiver can overcome these problems. The frequencies are always present requiring no control. All the frequencies are measured at the same time eliminating the skew incurred using multiplexing.

Figure 4 shows a five frequency case where a mono-pulse antenna is being measured. It is nearly identical to the two frequency case. Rather than use 5 independent signal sources, multiple modulators can be used with a single source to create the frequency spectrum.

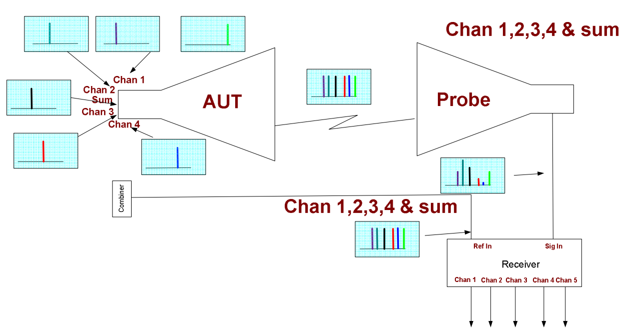

Figure 4 - Mono-pulse antenna being tested

Another potential application is in Planar Near-Field systems. Near-field acquisitions could be sped up by a factor of two or more. Figure 5 shows a case where a near field (NF) scanner is sped up by a factor of ten by using a probe with 5 dual-port feeds, each port set for a slightly different frequency. Each probe is excited with both the horizontal and vertical polarizations. The receiver measures each polarization of all channels at exactly the same time, eliminating phase skew due to the probe movement between measurements. Using frequency multiplexing, near field scanners can be operated at very high speeds and still maintain relative phase accuracy.

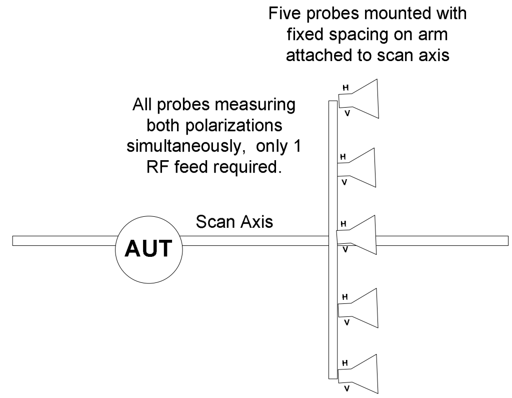

Figure 5 - Five feed probe for a linear scanner

The dual frequency measurement concept may also be extended in such a way as to reduce frequency switching time in far field, compact range, and near field measurement systems. If the frequency spacing required is closer than 100 MHz, one or more of the frequencies could be measured simultaneously.

Although the measurements made used a dual polarized antenna to demonstrate the concept, dual frequency measurements are not limited to only that application. With further refinement of the concept, it has the potential to be applied to a wide variety of measurements.

5.0 REFERENCE CHANNEL ISOLATION

One factor that could affect the accuracy of the dual frequency technique is the isolation between the two frequency channels. The isolation in this test setup was measured to be 45 dB. The isolation was mostly limited by the couplers forming the reference path. In this configuration, the receiver has 60 dB of isolation between the channels, well below the reference path isolation level. In future tests, the reference path could be improved with additional components to get better isolation, but 45 dB was considered acceptable for the proof of concept. Since the cross-polarization for this antenna never exceeds 35 dB, isolation of 45 dB is adequate to make reasonably accurate measurements.

6.0 PHASE DEVIATION

Another system performance consideration is that since different frequencies are used, path length variations can affect phase accuracy. When multiple frequencies are used, there are slightly different wavelengths for each frequency. As the AUT or probe moves, the phase will vary with distance differently for one frequency than the other. The calculation of the phase error is straightforward:

Phase error (degrees) = (delta distance traveled / wavelength)*360 degrees

This error can be minimized by using smaller frequency spacing. If the two frequencies are spaced 20 KHz apart and the AUT moves 10 feet, the differential phase error will be 0.07 degrees. Chart 1 provides a table of some frequency spacing, distance, and associated phase errors. It should be noted that most positioners are designed such that the phase center will remain stationary as the AUT is rotated and as a result will not experience phase errors. For planar scanners, most of the phase differential can be calculated and removed. Table 1 shows the calculated worst case uncorrected errors.

Frequency (KHz)	Delta distance (feet)	Wavelength (feet)	Phase Error (Deg.)
1000	1.00	1000	0.360
1000	3.00	1000	1.080
1000	10.00	1000	3.600
1000	30.00	1000	10.800
150	1.00	6667	0.054
150	3.00	6667	0.162
150	10.00	6667	0.540
150	30.00	6667	1.620
20	1.00	50000	0.007
20	3.00	50000	0.022
20	10.00	50000	0.072
20	30.00	50000	0.216

Table 1 – Calculated Phase Error

The phase distortion effect was verified by measurements. The phase was measured before and after an 8.2 foot cable was inserted in the signal path. The receivers output was measured at frequency spacings of +/-10 KHz and +/-500 KHz. The measured phase difference agrees with what is calculated for the cable with a cable speed of 0.8 being assumed. Table 2 shows the measured results. For each measurement the amplitude and phase for each channel was measured 5 times to verify repeatability. The amp and phase difference between the frequency channels was calculated and set as the reference phase and amp difference. The 8'2" foot cable was added and the measurement was repeated. The channel differences were recalculated. The change in phase difference between the two measurements was then calculated.

Frequency Separation (KHz)	Delta Cable Length (ft)	delta Phase change (deg)
20 KHz	8.17	0.07
1000 KHz	8.17	3.37

Table 2 – Measured Phase Error

Note that for a large 8 foot variation in distance, the phase error is 3.4 degrees with a 1 MHz spacing and is significantly reduced to 0.07 degrees for a frequency spacing of 20 KHz. If a 1 degree of phase error can be tolerated over this 8 foot range, a 300 KHz frequency separation can be used. At this separation we will experience about 0.11 degrees of differential phase per foot of travel, which is acceptable for many applications.

7.0 CROSSTALK CONSIDERATIONS

The phase noise of the source must also be considered. Figure 1 shows the spectrum of a relatively noisy source. The spectrum of the source is zoomed to a +/- 1 MHz span and a resolution BW of 244 Hz. The phase noise introduces an effective cross talk due to part of signal 1 being in signal 2's band and vice versa. The figure shows that out to +/- 100 KHz the noise density is about -40 dBc per 1 KHz of BW. At 300 KHz separation the noise drops to -60 dBc per 1 KHz of BW which is -50 dBc in a 10 KHz BW.

Measurements were made on the noisy source to determine the crosstalk introduced by its noise side bands for four conditions: +/- 150 KHz @10 KSPS, +/- 150 KHz @1 KSPS, +/- 25 KHz @1 KSPS and +/- 5 KHz @ 1 KSPS. Data was also collected for a cleaner source with +/-10 KHz @ 10 KSPS and with +/-3KHz @ 10 KSPS. Crosstalk was measured using two different techniques. The first way was to measure the signal in the adjacent channel with the adjacent channel signal turned off. The residual signal in the off channel is the leakage from the on channel. The second way was to measure the change in a signals power with the opposite channel turned on and off. The results are documented in Table 3.

It should be noted the receiver still has its full dynamic range (~100 dB at these sample rates). The receiver is limited by the difference in the two channels and not the variation in the channels. In H and V measurements the signals track within 30 – 40 dB, so the accuracy of the cross polarization are only minimally affected. It is the ratio between the channels that is affected by the crosstalk. When the two channels track this closely, as in polarization measurements, the crosstalk has minimal effect on the measurement. The sidebands are nearly white noise. More dynamic range can be obtained by using a narrower BW (slower sample rate), typically 10db more dynamic range as the sample rate is decreased 10X. More dynamic range can also be obtained by separating the frequencies farther. Wider separation moves the interfering signal down on the noise slope.

Measurements for six conditions are shown in Table 3. As the sample rate is decreased the noise is reduced and the isolation improves. This is true for both the clean and noisy sources. As the frequency separation is increased, the crosstalk decreases once past the pedestal. (The pedestal is seen in figure 1.) Close in to the center frequency, the Phase Lock Loop (PLL) creates a reduction in phase noise due to the PLL loop BW. In this narrow BW, the PLL determines what the crosstalk will be.

The chart shows many conditions where accurate measurements can be made with both the noisy and clean sources. Clean sources are always preferable, but due to cost or switching speed it may be desirable to use a relatively noisy source. It is seen that accurate measurements are possible even when a less expensive source has to be used.

8.0 SUMMARY

Frequency multiplexing has applications in both far field and near field systems. It can reduce the complexity of systems by minimizing synchronization issues and eliminating costly multiplexers. It provides increased data rates as multiple measurements are made simultaneously and provides synchronous measurements which can reduce skew.

It has been shown that benefits are obtained for dual polarization measurements, near-field scanners, frequency multiplexing, and measurement of mono-pulse antennas.

Frequency spacing	Clean/ noisy source	Sample rate	Measured cross talk with opposite source blanked	Amplitude Deviation with source turned on and off	Phase deviation +13 dB interference	Phase deviation -13 dB interference
6 KHz	clean	1 KSPS	98 dB	0.03 dB	0.2	0.04
20 KHz	clean	10 KSPS	57 dB	0.03 dB	1.1	0.004
10 KHz	noisy	1 KSPS	40 dB	0.01 dB	0.4	0.6
50 KHz	noisy	1 KSPS	43 dB	0.03 dB	1.5	0.04
300 KHz	noisy	1 KSPS	60 dB	0.03 dB	4.9	0.04
300 KHz	noisy	10 KSPS	50 dB	0.14 dB	4	0.04

Table 3 - Measured amplitude and phase deviations