White Paper

Anritsu envision : ensure

Accuracy of DTF Measurements on New Spools of Transmission Line

The coaxial transmission lines that move RF signals from the base station to the top of the tower are one of the most critical components in an RF site. Once properly installed on the tower, they can move high levels of RF power with very low loss from the shelter to the top of a tower.

The core measurements for the transmission line installed at an RF site are return loss and insertion loss vs. frequency and return loss vs. distance (DTF). Measurements of the installed transmission line system are common practice in the field.

Cable vendors, specify the performance of their transmission line. A common specification for corrugated copper transmission line is VSWR of 1.13:1 (return loss of 24.3 dB), attenuation per 100 ft of 1.2 dB (at 1 GHz) , and impedance of 50 ohms ±1 Ohm (40 dB return loss).

For most non broadcast applications, hard line copper cable diameters range from ½ inch to over 1 5/8 inch. Transporting and installing these cables must be done with care to prevent performance degradation from denting, kinking or stretching. The cost of installing the cable on the tower can exceed the cost of the cable itself. Measurements on the spool when delivered can identify shipping damage. Measurement of just the cable after hauling up the tower can identify handling damage (e.g., someone stepping on the cable). Measurement of just the cable after attachment to the tower can identify crushing from adjusting the cable clamps too tight. Measurements of the cable from manufacturing to arrival at the job site through installation can support improvements in construction practices, resulting in lower site cost and improved base station performance.

Figure 1.

Figure 2.

The technique of measuring installed antenna systems differs somewhat from the measurement of raw cable. The jumpers, connectors, adapters, lightning protection, and filters combine to reduce the typical acceptable values to the 15 to 20 dB range. Measurement of raw cable can verify that 50 ±1 Ohm cable (40 dB RL) has arrived to the job site. The DTF return loss of the entire spool can be accurately measured but requires putting a termination on the far end of the cable. Distance to fault measurements can indicate the location of physical damage on a spool.

Let’s talk a bit about the differences in the Return Loss vs. Frequency and the Return Loss vs. Distance tests. It should be noted that both tests collect data the same way. A swept frequency signal is applied to one end of the cable. A directional coupler separates the incident vs. the reflected signal as the signal is swept in frequency. The result of the frequency test is influenced by the uncertainty in the instrument and calibration components. The frequency test indicates the total return loss of all components being measured. For a raw cable this includes the near connector, the cable, the far connector, and the termination on the far end. This test cannot differentiate what component is responsible for what part of the return loss. So, the specification of Return Loss vs. Frequency is a composite of the 2 connectors installed on the cable plus the cable itself. This test cannot verify just the cable being tested. An additional effect can occur on long length higher loss cables. If a defect is at the far end of the cable the true return loss will be masked by the cable loss. A significant defect at the far end can be measured as OK.

The Return Loss vs. Distance test is also influenced by the uncertainty in the instrument and calibration components, plus the cable under test. Using well understood mathematical transforms, the return loss vs. frequency measurement data is manipulated into Return Loss vs. Time coordinates. With knowledge of the propagation velocity of the cable under test, the time coordinate can be scaled to distance. The DTF algorithm can automatically compensate for cable loss. The DTF display can now show the contributions to return loss by connectors or imperfections in the cable. It is possible to verify the cable performance independent of the connectors. A DTF test can have issues if there is more than one significant defect in a cable. At the point where a major defect occurs most of the incident energy is reflected. The significant defect will likely be above the impedance specification of the cable and the cable will nonetheless be called into question.

DTF measurements are not commonly used by manufacturers to detect damage, and cable manufacturers are not comfortable accepting incoming inspection failure claims based on DTF measurements. Anritsu, as the leading supplier of cable and antenna test solutions, has recently been asked to explain the accuracy of DTF measurements to support improved testing practices.

A typical configuration will be studied: a 100 ft of 7/8" corrugated copper hardline with DIN (7/16) male connectors installed on both ends of the cable. The return loss of a properly installed DIN (7/16) connector on hard line is ~30 dB or greater. Anritsu DTF test instruments have N female test port connectors. A N male to DIN female phase stable test port cable will be used. A DIN (7/16) male OSL calibration component will be used to calibrate the instrument at the end of the test port cable. The termination of an Anritsu DIN (7/16) female OSL calibration component will be used to terminate the far end of the cable under test. To detect damage near the far end of the cable (inside the spool) it is important to reduce the reflection there. If the inside end is not accessible on the spool it may need to be terminated prior to spooling. This configuration represents best practice components for the analysis. Figure 3 shows an ideal configuration.

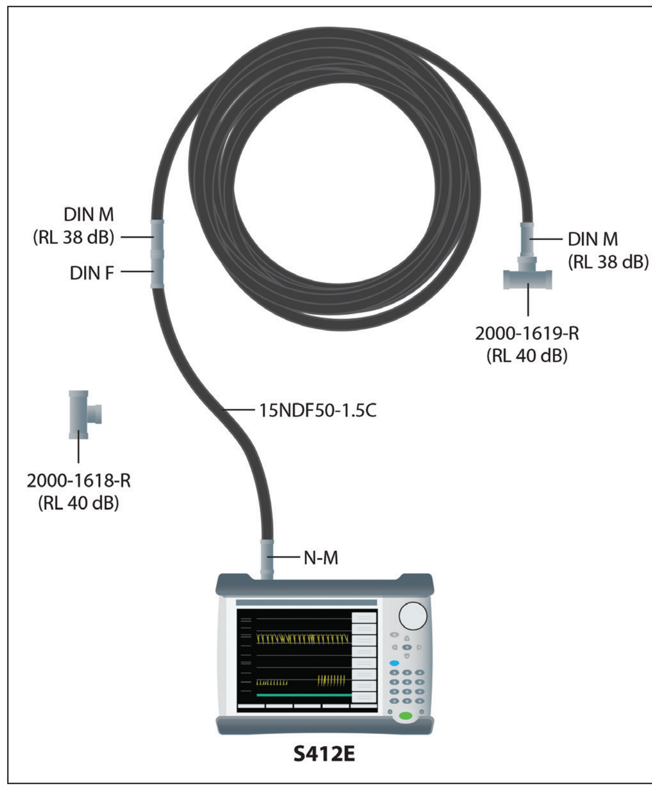


Figure 3.

Setting up the instrument correctly is critical. Given we are measuring raw cable we can sweep a wide frequency span. This will give the best distance resolution. Anritsu DTF instruments offer selectable measurement point counts for each sweep. An increasingly higher point count is needed for increasing lengths of cable. Anritsu instruments offer a DTF aid or information page to support proper setup of span and point count. It is critical that the cable characteristics (loss and velocity factor) are entered into the setup. Anritsu DTF instruments support entry by selection of a cable model number or by hard entry of loss / ft and velocity factor. The velocity factor is assumed to be constant along the length of cable. Anritsu DTF instruments apply the entered cable loss values to the chosen frequency span using the common loss profile of sqrt(f). While uncertainties in frequency domain reflection and S-parameter measurements have been explored in the literature extensively, a similar discussion of the time domain representation (or DTF) has been less ubiquitous. Part of the reason is that the transformed result has long been used as a troubleshooting or diagnostic aid rather than an end result in itself and part may be due to the complexity of the analysis itself. For the above scenario of testing just the feedline there is value in revisiting the uncertainty analysis of DTF in a more rigorous fashion. With a sufficiently bounded measurement problem, it is possible to come up with uncertainty values that trace back to well established impedance standards long used as the bedrock of frequency domain uncertainty analysis.

Why is the problem sometimes challenging to analyze? The basic time domain result can be represented as an integration of the frequency domain data:

$$x(d) = K \int_{f\,\min}^{f\,\max} X(f) \cdot e^{-j2\pi f \frac{d}{v_{ph}}} df$$

Where X(f) is the frequency domain parameter of interest (usually just a reflection coefficient), f is the frequency, d is the distance at which the time domain result is being evaluated (x(d) is that result) and vph is the phase velocity through the DUT. Information is already available about uncertainty in X(f) (which could be the frequency domain S11) on a point-by-point basis. The immediate complication is that the uncertainty in x at some point d is dependent on the uncertainty in X at ALL frequencies. Thus the correlation model (that defines the uncertainty relationship between frequencies) is critical. To see this, consider the case where the short calibration standard had a different offset length than was expected. The result is a ripple in X(f) (S11(f) in this case) that could be quite high speed (in the sense of frequency).

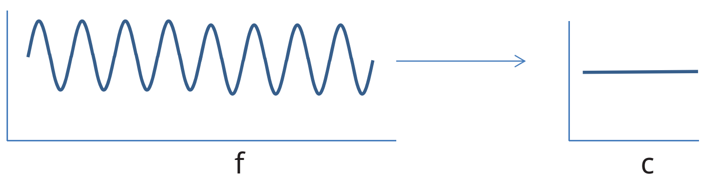


Figure 4. Highly oscillatory errors in the frequency domain tend to be reduced in effect in the time domain.

If this ripple is fast enough (large enough offset length error), the integration process just averages out the frequency domain uncertainty to very little time domain uncertainty (except perhaps in a reference plane shift that would just move the peaks). In a real-world case, the cancellation is not so complete but it can still be significant. On the other end of the spectrum, consider an error in frequency domain of a slope with frequency (from perhaps drift of a cable attached to the VNA before the desired reference plane).

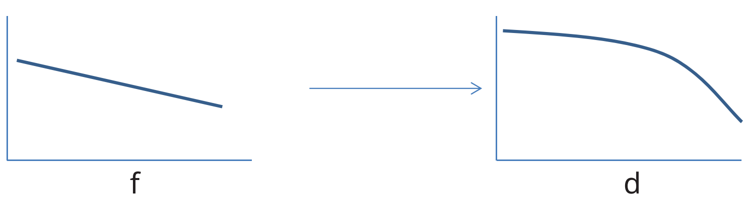


Figure 5. Monotonic-like errors in the frequency domain can become amplified in the time domain.

In this case, the integration process can amplify the effect. Again, the depiction above is overly simplified but the longer-frequency-scale effects do have more of an impact in time domain representations.

Because many of the frequency domain uncertainty components are highly dependent on the DUT characteristics, it could be difficult to make general statements about the time domain uncertainties. It may be useful to constrain the problem to something more compatible with generalized statements while still being useful. Obviously minimizing the frequency domain structure helps and one practical problem that fits that characteristic is the quantification of a DUT with a single time domain defect (or at least a situation where defects are widely spaced). This could correspond to a cable length with a dent or other defect somewhere along its length. The reflection frequency response would be gently sloping due to some combination of loss and slight impedance differences and with a certain amount of embedded ripple from calibration residuals and connector mismatch. From the earlier discussion, much of this ripple will integrate out. The time domain response is then dominated by a single impulse and we can focus on the uncertainty in the amplitude of that impulse. This constraint of the problem also radically reduces the impact of windowing choices as there are no multiple impulses to interfere with each other in a sidelobe sense (or equivalently, run into problems from attenuation of extreme frequency data).

Because this is a nonlinear propagation of uncertainties problem, one of the easier ways to analyze it is through Monte Carlo computations (e.g., Supplement 1 to the Guide to the Expression of Uncertainty in Measurement). Many runs (i.e., calculations of the final time domain result) are performed and on each run, the various error mechanisms are allowed to randomly move in their parameter space (magnitude and phase) and the final time domain result found. By doing enough runs, and assuming the base frequency domain uncertainty models are adequate (including terms of correlation), a statistical base of the time domain result is established and one can quote an uncertainty on that measurement. The measurement will be of a cable terminated in a load and these terms will be included:

- Calibration errors due to open and short standards being of incorrect offset length. The length is the most likely error problem at these frequencies and establishes a simple correlation between frequencies. In determining the bounds to use, the dimensions of the calibration components are characterized (and traceability is through dimension).
- Calibration errors due to load imperfections. This is a little trickier in terms of maintaining the correct correlation with frequency. At frequencies up to 10 GHz, the loads can be well modeled as a series R-L circuit where both the resistance can move from 50 ohms and the inductance can be non-zero. The load standards are characterized in terms of impedance (and that is the traceability path) which facilitates developing bounds for these parameters.
- Errors in the terminating load at the end of the cable. The same model as for the calibration standard was employed.
- Connection repeatability. This can also be challenging to model. It is assumed that all connectors are in good condition so that there are no resonances in-band and it is assumed that consistent and appropriate torque is applied during connections. In this case, the errors tend to a combination of an offset error in magnitude and phase and a sloped error in magnitude and phase (with bounds on both). All of those parameters were allowed to vary within the bounds established for the given connector type. The bounds on connector repeatability variables also trace back to impedance-derived measurements.

– Drift of the VNA itself and related components. It was assumed that a calibration was performed within an hour of the measurement and that, if any pre-reference-plane cables were used, that the temperature between calibration time and measurement time did not change by more than 5C.

Example calculations were run for a 7/16 100 foot cable as the DUT using a 2 GHz frequency sweep. In one case, a ~ –45 dB defect was placed about 33 feet into the cable run and in another case, the same size defect was placed 83 feet in. Values for an AVA5-50FX Heliax cable were used for this calculation. 1000 Monte Carlo runs were done for each (and the total calculation time was about 20 seconds on a modest-performance laptop). The results for both cases (with the various Monte Carlo run results overlaid) are shown in Figs. 7 and 8.

On a two-sigma basis, the uncertainty on each was ~ ±1 dB. In this case, there was a weak dependence with position. This would change if loss increased significantly as signal-to-noise and signal-to-effective-directivity limits would become more important. The uncertainty increased for smaller amplitude defects (becoming several dB by –50 dB) and reduced somewhat for larger defects ~ ±0.7 dB at –40 dB.

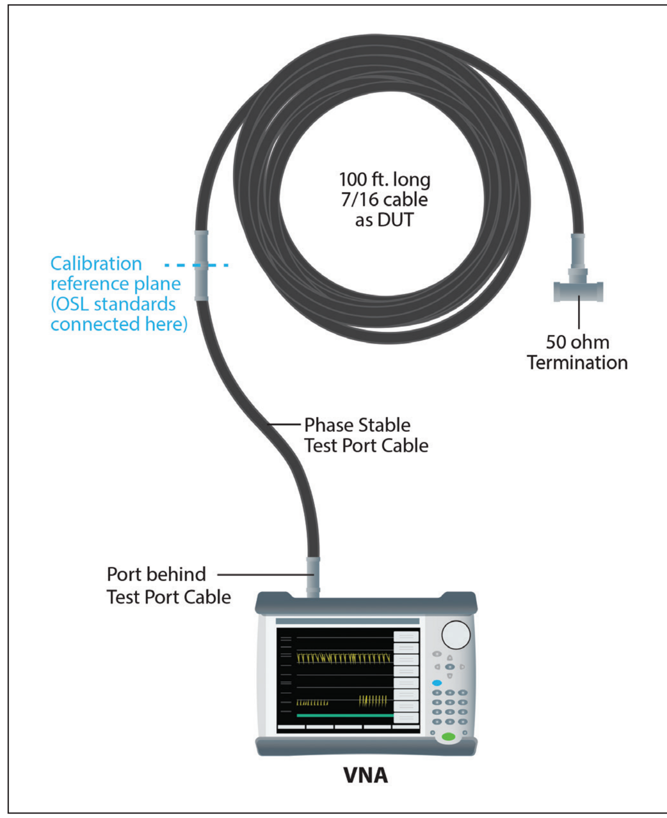


Figure 6. A diagram of the setup used for the uncertainty computations is shown here. A defect will be assumed somewhere along the DUT length and the uncertainty in the resulting time domain impulse amplitude will be evaluated.

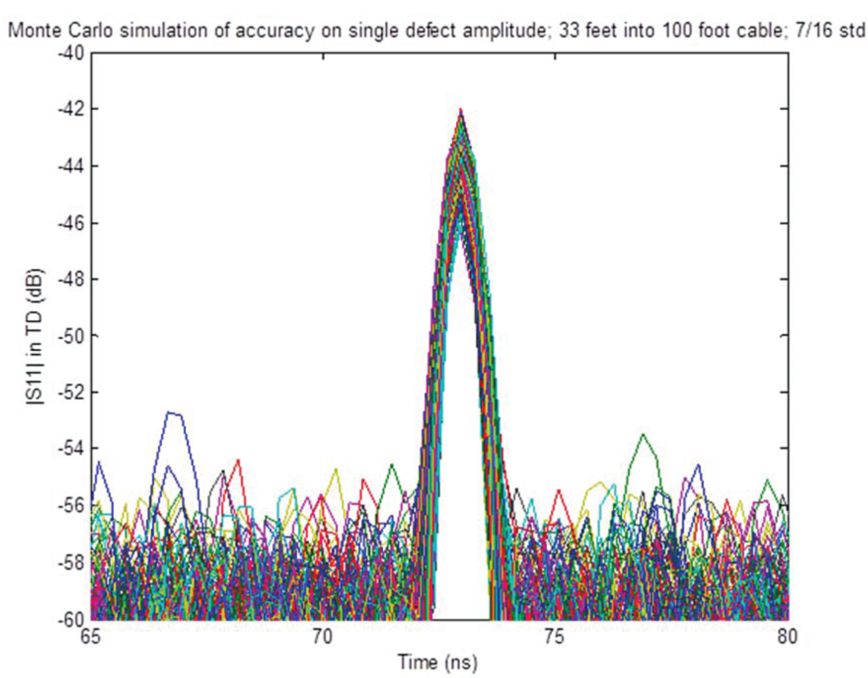


Figure 7. The Monte Carlo runs for the case when the defect was 33 feet into the cable are shown here.

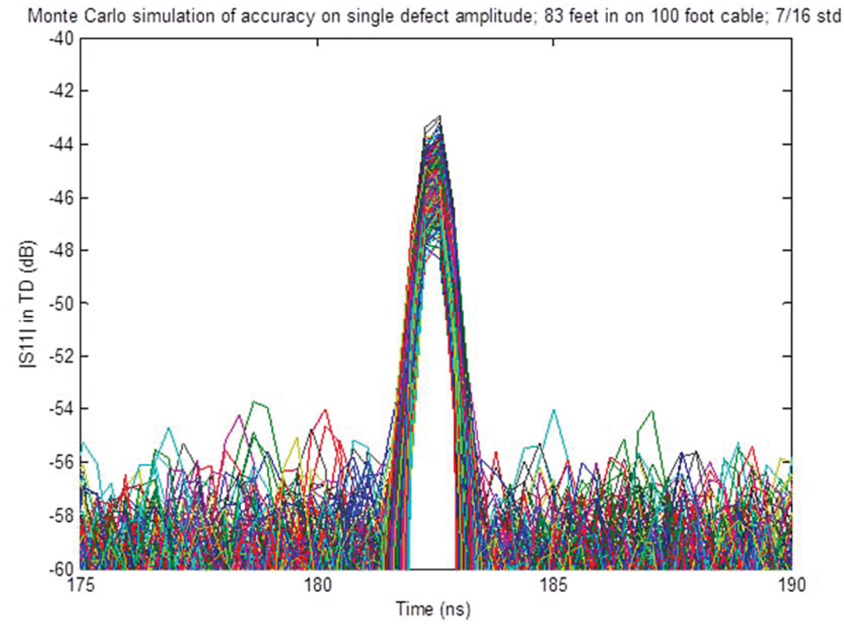


Figure 8. The Monte Carlo runs for the case when the defect was 83 feet into the cable are shown here.

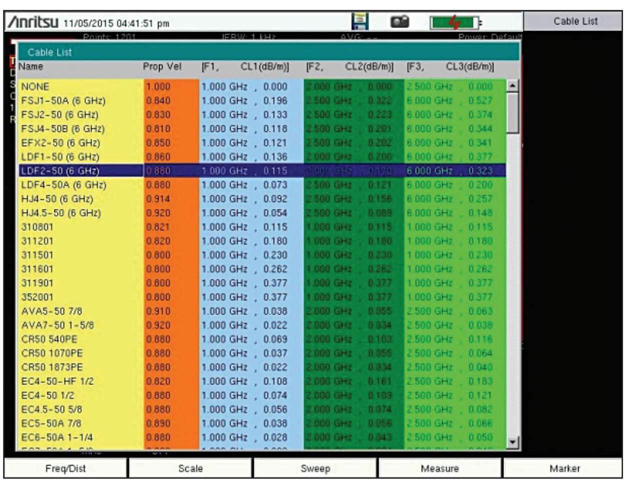
Sidebar: Measurement example.

An Anritsu S412E LMR Master was used to make example DTF measurements on a 605 ft length of Andrew (Commscope) LDF-2. A 15NNF50 test port cable was used between the spool of cable and the S412E. The S412E and test port cable were calibrated with OSLN50. The far end of the cable was terminated with an OSLNF50. 1 kHz IF bandwidth and 1% smoothing were used.

A 605 ft length of LDF-2 with N-M connectors installed, S412E, 15NNF50 test port cable, OSLN50

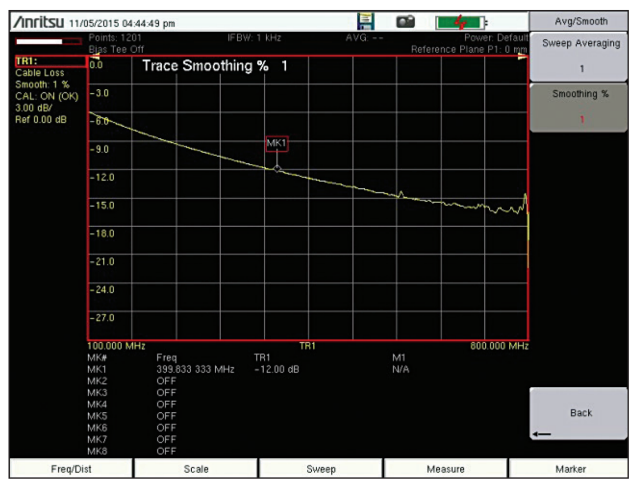
Commscope prints incremental distance marks on the cable to support installers. The length is easily determined by reading the marks near the ends. N Male connectors were installed on both ends of the cable.

The Commscope LDF-2 cable was marked every meter.



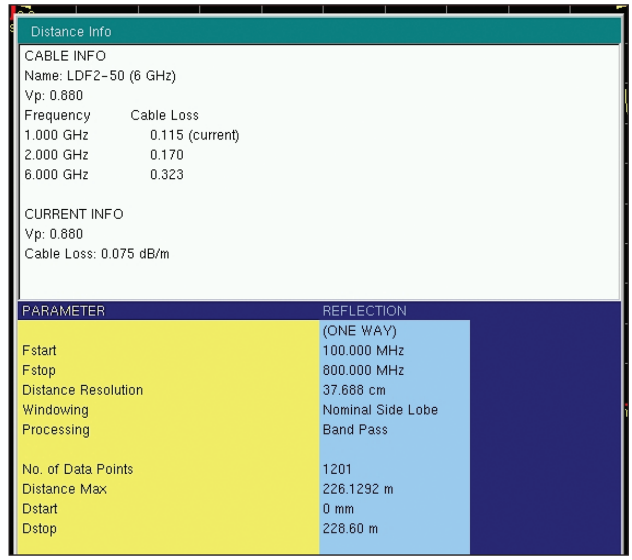
Name	Prop Vel	[F1, CL1(dB/m)]	[F2, CL2(dB/m)]	[F3, CL3(dB/m)]
NONE	1.000	1.000 GHz , 0.000	2.000 GHz , 0.000	2.500 GHz , 0.000
FSJ1-50A (6 GHz)	0.840	1.000 GHz , 0.196	2.500 GHz , 0.322	6.000 GHz , 0.527
FSJ2-50 (6 GHz)	0.830	1.000 GHz , 0.133	2.500 GHz , 0.223	6.000 GHz , 0.374
FSJ4-50B (6 GHz)	0.810	1.000 GHz , 0.118	2.500 GHz , 0.201	6.000 GHz , 0.344
EFX2-50 (6 GHz)	0.850	1.000 GHz , 0.121	2.500 GHz , 0.202	6.000 GHz , 0.341
LDF1-50 (6 GHz)	0.860	1.000 GHz , 0.136	2.000 GHz , 0.200	6.000 GHz , 0.377
LDF2-50 (6 GHz)	0.880	1.000 GHz , 0.115	2.000 GHz , 0.170	6.000 GHz , 0.323
LDF4-50A (6 GHz)	0.880	1.000 GHz , 0.073	2.500 GHz , 0.121	6.000 GHz , 0.200
HJ4-50 (6 GHz)	0.914	1.000 GHz , 0.092	2.500 GHz , 0.156	6.000 GHz , 0.257
HJ4.5-50 (6 GHz)	0.920	1.000 GHz , 0.054	2.500 GHz , 0.089	6.000 GHz , 0.148
310801	0.821	1.000 GHz , 0.115	1.000 GHz , 0.115	1.000 GHz , 0.115
311201	0.820	1.000 GHz , 0.180	1.000 GHz , 0.180	1.000 GHz , 0.180
311501	0.800	1.000 GHz , 0.230	1.000 GHz , 0.230	1.000 GHz , 0.230
311601	0.800	1.000 GHz , 0.262	1.000 GHz , 0.262	1.000 GHz , 0.262
311901	0.800	1.000 GHz , 0.377	1.000 GHz , 0.377	1.000 GHz , 0.377
352001	0.800	1.000 GHz , 0.377	1.000 GHz , 0.377	1.000 GHz , 0.377
AVA5-50 7/8	0.910	1.000 GHz , 0.038	2.000 GHz , 0.055	2.500 GHz , 0.063
AVA7-50 1-5/8	0.920	1.000 GHz , 0.022	2.000 GHz , 0.034	2.500 GHz , 0.038
CR50 540PE	0.880	1.000 GHz , 0.069	2.000 GHz , 0.103	2.500 GHz , 0.116
CR50 1070PE	0.880	1.000 GHz , 0.037	2.000 GHz , 0.055	2.500 GHz , 0.064
CR50 1873PE	0.880	1.000 GHz , 0.022	2.000 GHz , 0.034	2.500 GHz , 0.040
EC4-50-HF 1/2	0.820	1.000 GHz , 0.108	2.000 GHz , 0.161	2.500 GHz , 0.183
EC4-50 1/2	0.880	1.000 GHz , 0.074	2.000 GHz , 0.109	2.500 GHz , 0.121
EC4.5-50 5/8	0.880	1.000 GHz , 0.056	2.000 GHz , 0.074	2.500 GHz , 0.082
EC5-50A 7/8	0.890	1.000 GHz , 0.038	2.000 GHz , 0.056	2.500 GHz , 0.066
EC6-50A 1-1/4	0.880	1.000 GHz , 0.028	2.000 GHz , 0.043	2.500 GHz , 0.050

The S412E menu to allow selecting the Commscope LDF-2 cable type with loss of 0.115 dB/m and VF of 0.88

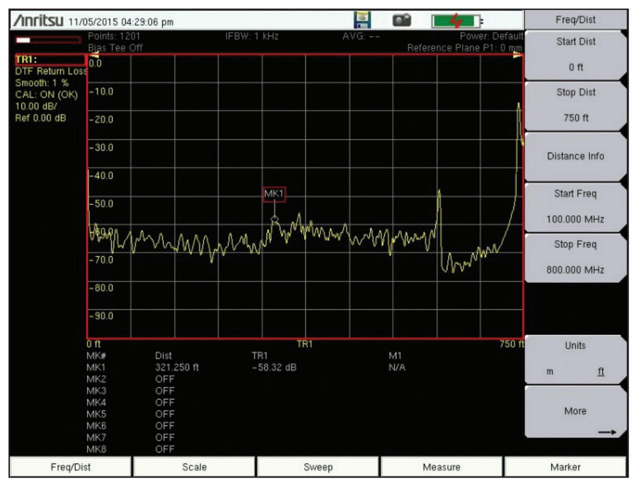


The measured cable loss at 800 MHz was 16.5 dB. The specification for the LDF-2 is < 0.03 dB/ft., with 605 ft. giving 18.9 dB. The cable is within specification

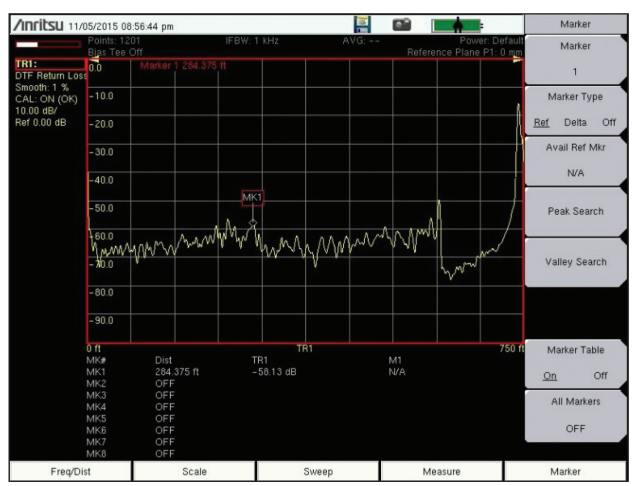
The distance info page shows the first setup using 1201 points, start frequency 100 MHz, stop 800 MHz giving a maximum distance of 741 ft.



The DTF results confirm the cable length of 605 ft. A very small flaw of 58 dB return loss was marked at 321 ft

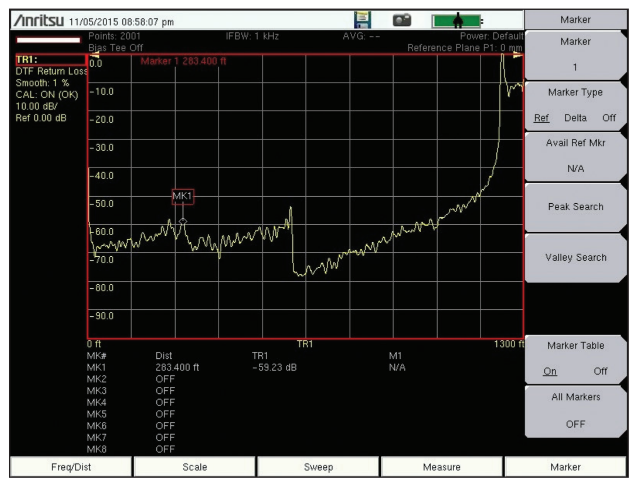


Same flaw measured from the opposite end of the spool again shows a return loss of 58 dB

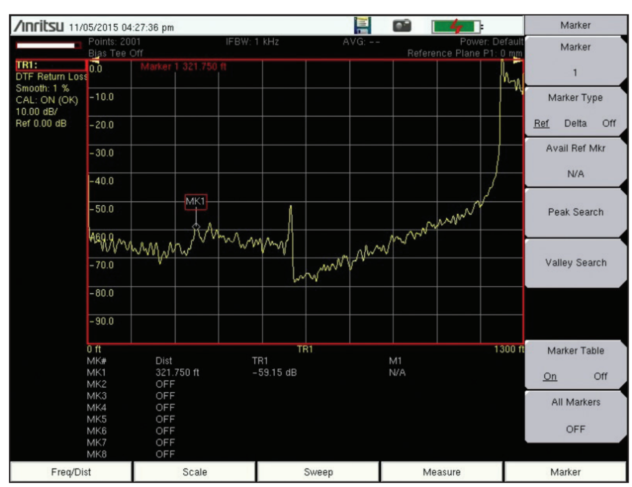


The distance info page shows the second setup using 2001 points, start frequency 100 MHz, stop 800 MHz giving a maximum distance of 1236 ft

The DTF results again confirm the cable length of 605 ft. The small flaw at 321 ft showed a return loss of 59 dB



Same flaw measured from the opposite end of the spool again shows a return loss of 59 dB



Conclusion

With proper consideration and technique, DTF measurements of raw spools of cable can be made accurately enough in the field to identify handling damage with a reasonable uncertainty bound. This complements the other specification based measurements already done on the spools using frequency domain data.

It is crucial to note that the same cannot be said for DTF testing of complete antenna systems. In this circumstance the frequency limiting aspects of the system and the ambiguity in the load termination (antenna) make pass/fail testing of components in the entire system problematic. As is mentioned in other literature the best course is to take a measurement when the system is new and consider this a baseline for future comparison.

Specifications are subject to change without notice.

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