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DIT-MCO TECHNICAL BULLETIN

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CCS
Capacitance Comparator Subsystem

INTRODUCTION

Automatic electrical testing of wired assemblies is traditionally accomplished by measuring the DC resistance of the most conductive path between two selected product points. The test decision can be based upon the presence or absence of this path. The test system is designed to provide a very low resistance access to each product point and a very high resistance between each access point. Many innovative techniques have been developed for the construction and use of these systems to characterize the selected path through the assembly.

There is an increasing need to also characterize the relationship between these conducting paths. The high frequency performance of twisted pair, coaxial, and multiconductor shielded cable assemblies depend upon the relationship between conductors. The value of assembly capacitors and the location of an open circuit are also very difficult to obtain with resistance testing. Capacitance testing however, can provide this information and complement the results of a resistance testing program.

The economical approach to begin automatic capacitance testing is to adapt a resistance testing system by adding capacitance measuring capabilities. Understanding and controlling the many new variables can also make this economical approach very successful.

SYSTEM MODEL

Unlike resistance testing, automatic capacitance testing requires consideration of the testing system AC response characteristics and their effects upon the measurement. Every conductive path is capacitively coupled to the surrounding paths and to the system ground. This coupling is distributed along the entire length of each path with each small segment of length adding to the total result.

Resistance testing with the circuit in figure 1 can be accomplished by verifying that terminal 2 is connected to 3 and terminal 1 is connected to 4 and 5, but not 2. The wire between the tester and assembly terminals 5 has no effect on the measurement between terminals 1 and 4.

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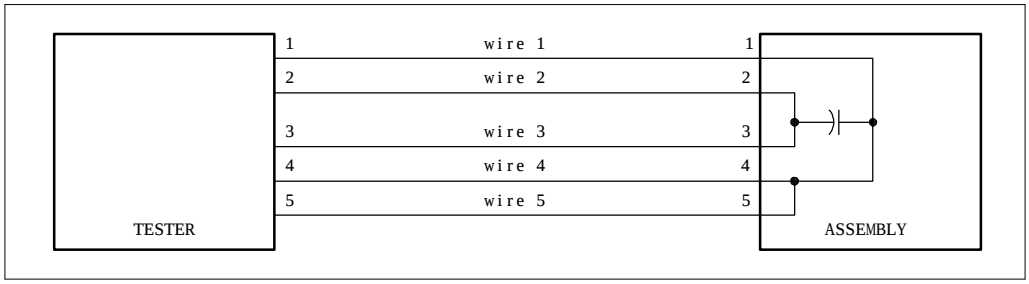

Figure 1.

When measuring the assembly capacitor, all of the connections can be significant. The total capacitance between tester terminals 1 and 2 will include the inter-wire capacitance between wires 1 & 2, 3 & 4, and 3 & 5 as well as the assembly capacitor. In addition, the capacitance of each wire, the tester, and the assembly to the system ground will contribute to the total measurement.

CAPACITANCE MODEL

The simplified capacitor model in figure 2 represents the summation of these capacitance effects.

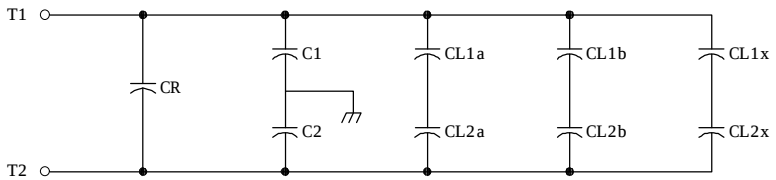

Figure 2.

Capacitor CR represents the summation of the direct inter- wire capacitances and the assembly capacitor. Capacitors C1 and C2 represent the summation of all the capacitances to ground for each respective conductive path. Capacitors CL1 and CL2 represent the summation of all respective path capacitance to conductive paths and points that are not shown. For simplicity the capacitance to ground for these intermediate points is not shown separately but included in C1 and C2.

Capacitor CR is sometimes called the "desirable" capacitance because it represents the direct relationship between the two paths. In very controlled conditions this value can be extracted however, such systems are economically justifiable by only the most serious of users.

The capacitance between terminals T1 and T2 of the model is composed of the sum of all the branches. The branches with series capacitors will be less than the smaller of the two capacitors in that branch. Therefore, the total will not exceed CR plus the smaller of each of the two capacitors in the other isolated branches.

Complex guarded tester switching systems can be purchased to ground the junction between the CL1 and CL2 capacitors in all the CL branches. The contribution for these branches then becomes less than the smaller of the sum of all CL1 or CL2 capacitors. This total CL branch value can be significantly larger than that obtained with an existing switching system.

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Example #1:

		Unguarded Branch
CL1a = 100pF	CL2a = 10pF	9.1pF
CL1b = 50pF	CL2b = 50pF	25.0pF
CL1x = 10pF	CL2x = 100pF	9.1pF

The total CL branch capacitance if unguarded is 43.2pF

Guarding connects the CL branches together for:
CL1 = 160pF CL2 = 160pF

The total CL branch capacitance if guarded is 80pF

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The capacitor model can now be further simplified to a three capacitor model as in figure 3. The contribution by the CL branches has been included in the CR capacitor for the unguarded system and the C1 and C2 capacitors for the guarded system.

Figure 3.

The capacitance between terminals T1 and T2 has been reduced to two elements. The use of a capacitance measuring instrument that is referenced to ground or a grounded assembly will significantly increase the value of one branch. Instead of the series combination of C1 and C2, the measured value will include the entire value of either C1 or C2.

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Example #2: (Reference Figure 3.)

CASE 1.	CASE 2.
CR Value = 710pF	CR Value = 710pF
C1 Value =6000pF	C1 Value = 4000pF
C2 Value =6000pF	C2 Value =12000pF

The total capacitance between T1 and T2 is 3710pF in both cases. A grounded instrument will measure the case 1 value as 6710pF. In case 2, the instrument will measure 4710pf or 12710pf depending upon which terminal is ground referenced.

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MODEL APPLICATION

The model can be applied to the testing system, the assembly, and the combination of both. The testing system variables are controlled and removed from the measured value to allow the assembly variations to determine the test results. Determining the appropriate dividing line between the testing system and the assembly variables may not always be easy.

In very general terms, an automatic test system alone will have the value of C1 or C2 significantly larger than CR. The primary contribution to C1 and C2 is the tester terminal selection array and the primary contribution to CR is the wiring between the tester and the assembly being tested. A two point only connection to the assembly provides a total value for each capacitor that is the summation of the system and the assembly values.

Each additional connection between the testing system and the assembly can add to the complexity of this summation process. In figure 1, wires 3, 4, and 5 can be removed and the assembly capacitance can be found as the difference between the total value and a measurement with the assembly disconnected at points 1 and 2 of the assembly. Repeating the same two measurements and calculation with wires 3, 4, and 5 connected would produce a resultant capacitance that is greater.

In addition, connections between the testing system and the assembly which do not directly effect the path length may produce variations in the results. This effect occurs in the CL branches as in figure 2 when two or more testing system branches are connected through the assembly.

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CCS SYSTEM

The DIT-MCO Capacitance Comparator System (CCS) is designed for use in a wide variety of applications with existing or new switching systems. The instrument produces a maximum signal of 10 volts for safe operation in all applications. It operates in the time domain for maximum noise immunity and resolution. It performs frequent self calibration to maintain its basic 1% accuracy. It performs ungrounded measurements to minimize the figure 3, C1 and C2 branch capacitance contribution to the total value. And, it does not require a guarded switching system for proper operation.

The system also includes a wide variety of application oriented software tools. These tools considerably reduce the time required to initiate and maintain a successful capacitance testing program.

TARE MAPPING

If there are no extra connections or the effects are known, the assembly can be disconnected and the testing system capacitance mapped and stored. The actual testing file is used to determine the test point addresses and the entire measured value is stored in the tare map file. Variations in the values that would occur when testing grounded assembly points can be eliminated be specifying that point in a ground map file. When the tare mapping operation encounters one of these points, the point is automatically grounded for the tare measurement.

A tare map editor is provided to allow manually changing the stored values. The effects of additional connections can be added to the appropriate mapped values.

If there is only a few of these extra connections in the assembly, the testing system can be jumpered during this tare mapping operation. This procedure should be limited to cases where a few short jumpers can be used.

Another tare mapping option has been provided for the cases where the assembly capacitance or, more importantly, the allowable capacitance variation, is known. This option requires a "golden" or "known good" assembly be connected to the system. The actual testing file is used to determine the test points and the anticipated product values. Each capacitance test in the file is completed as a measurement. The median value between the test file limits is subtracted from the total measured value and the result is stored in the tare map file.

The major variables of ground coupling in the switching system and relative conductor position in the adapter cables do not change significantly in normal use. The tare map may be edited or reinitiated after maintenance to the switching system or adapter cables.

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INSTRUMENT ACCURACY

A major consideration for automatic capacitance testing is the relative values of the total measured capacitance and the allowable assembly variation. Assembly variations that exceed 1% of the total measured value, (tester plus assembly,) are generally detectable. The system tare can be an important portion of this total measured value.

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Example #3:

Assembly Cable

P1 Branch Value = 200pF
P2 Branch Value = 250pF
P3 Branch Value =1000pF
Total Assembly Value =1450pF

Tester Tare Value =3710pF
Total Measured Value =5160pF

Testing a perfect assembly would provide a value within 52pF, (1%) of the total system value. With the tester connected to P1, a break in one of the paths from P1 or to P2 or P3, at the junction, would result in a measured value that is reduced by 1250pF, 250pF or 1000pF respectively. Therefore, the error would be detectable and the result value would indicate which of the branches was not connected.

In this example the error is detected as a variation of (1250/5160) 24%, (250/5160) 5% or (1000/5160) 19% respectively with a CCS. Using the system tare values from example #2, case 2, a grounded instrument would require an accuracy of (250/14160) 1% to reliably detect the error in the P2 branch of a perfect assembly.

The use of the CCS will allow a reasonable manufacturing tolerance between these assemblies. A grounded instrument may not reliably detect errors in the P2 branch of these normal assemblies.

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TARE REDUCTION

Several methods are available for reducing the tare of the testing system. One is to disconnect any connectors that are not essential to completing the test. Another is to access the two assembly points through different switching system connectors. In some cases exchanging the input and output addresses will change the tare value.

If the minimum tare value is necessary, it can be achieved with specially constructed adapter cables. The cables should be as short as possible and contain only one wire per assembly path. The switching system connection should be made so that any given capacitance measurement accesses the two assembly paths through different switching system connectors. The two wires for each test should be kept as far apart as possible between the switching and assembly.

TEST ACCESS POINT SELECTION

In some cases the assembly access point can make a difference in the allowable product variance. Accessing a Y or T configured wiring structure should be done through the shortest leg. This will allow detection of the larger capacitance variation if there is a problem at the wiring junction.

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Example #4:

Assembly Cable

P1 Branch Value = 200pF
P2 Branch Value = 250pF
P3 Branch Value =1000pF
Total Assembly Value =1450pF

Tester Tare Value =3710pF
Total Measured Value =5160pF

From example #3, the variation created by a break at the common point from P1 or to P3 or P2 would be 1250pF, 1000pF or 250pF when tested at P1. By testing the cable at P3, the same errors would produce a variation of 200pF, 450pF or 250pF respectively.

In this example, the 50pF variation between the P1 and P2 branch errors is slightly less than 1% of the total measured value of 5160pF. The CCS would detect the error however, the value would not indicate which error.
As explained in example #3, a ground referenced instrument may not even detect two of these three possible problems. Even in the best possible case of example 2, a grounded instrument would require a greater variation

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than the CCS to reliably detect the same error.

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TERMINATORS

Terminators can also be helpful in detecting some problems. An open circuit that occurs near the unconnected end of the assembly may create little capacitance variation. A known termination however, can enhance this variation to make it more detectable. One very effective termination is a "known good" assembly. Care should be taken when using a terminator to insure that the variation due to a problem will be enhanced while not hiding other problem sources by the overall increase in capacitance.

OTHER APPLICATIONS

In some applications it is helpful to know the relationship of one conductive path to several others in an assembly. These applications include determining the location of an open path and verifying the proper connection to some shield conductors. The DIT-MCO CCS system can provide this function through the use of the bulk switching commands.

Using a bulk switching command for capacitance testing requires that a double limit be used to prevent scanning. The tare map does not include the type of bulk test so the test file sequence should not be changed after the mapping operation. It is recommended that the all points (T) bulk be used to eliminate any sequencing dependency in the manual mode of operation.

DETERMINING DISTANCE

The distance to the open point in a path is obtained by comparison to the value for the full path. The full path value may be known from a prior measurement or estimated from a measurement on a similar path. In either case the testing system tare value should be extracted before the comparison.

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Example #5:

Assembly capacitance P1-1 to all others = 850pF
Assembly capacitance P1-3 to all others = 825pF
System tare value P1-1 to all others = 1210pF
System tare value P1-3 to all others = 1450pF

Manually locating an open between P1-3 and P3-2 can be accomplished by:

1. Disconnect the assembly and do an all points, measure only capacitance to the address of P1-3 and P1-1. The

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result should be the tare values of 1450pF and 1210pF respectively.

2. Reconnect the assembly and repeat the two tests. The first value will be between 1450pF and 2275pF while the second will be 2060pF.
3. Subtract the first test value (tare) from the second (total) for each point. The first point will be between 0 and 825pF while the second will be 850pF.
4. Divide the first (open) point result by the second point result. The result should be between 0 and 0.97.
5. Multiply this number by the total length of the path, (65ft.) to get an estimate of the distance from P1-3 to the open location.

Since the likely open points are the connectors, the result should be very small, near 25, or near 65.

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Another method of using this capability for troubleshooting is to create a short troubleshooting file. The file would contain a capacitance parameter set with measure only, an enable digitize and tare subtraction directive, a tare map reference, and two all point bulk tests. The addresses of the bulk commands could be edited each time for the failed point and a point with a similar path. A tare map could be made with the assembly disconnected and then the test file executed with the assembly connected again. The resulting report would show the estimated location of the problem by the ratio of capacitance values.

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Example #6:

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A,CCS,M,1S
ENB DIG,TCM
CTF OPEN.CTM
AT06703
AT06701
END
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