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Verification of On-Wafer (SOLT) Calibration

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Verification of On-Wafer (SOLT) Calibration

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1.0 ABSTRACT

This paper presents a detailed examination of the electrical characteristics associated with the standards used to perform a full 2-port on-wafer SOLT calibration using the Cascade 101-190 ISS (Impedance Standard Substrate) and Infinity I40 GSG 150uM probes. The standards are characterized and their equivalent electrical characteristics are extracted in order to verify the accuracy of the calibration. The PEL transforms used to extract the individual cal. coefficients as well as those used to perform the 'open' and 'short' de-embedding are provided.

2.0 Verification of SOLT Calibration

From a qualitative standpoint, verification of an on-wafer, or VNA calibration is predicated upon measurement of the individual standards and extraction of their equivalent electrical characteristics. The cal. is judged to be valid (verified) only if the extracted electrical values agree with those quantities that were input to the VNA as cal. kit standard definitions during the calibration process. The (frequency) range of validity of the calibration can be readily judged on this basis simply by observing the frequency response characteristics of each standard.

2.1. '**OPEN**' Standard

Since this is a reflection standard, the quantities that are of primary importance are the input (Port-1) and output (Port-2) impedances, or more specifically, the capacitances (Copen) associated with Ports-1 and 2.

2.1.1 Input (S11) and Output (S22) Impedances

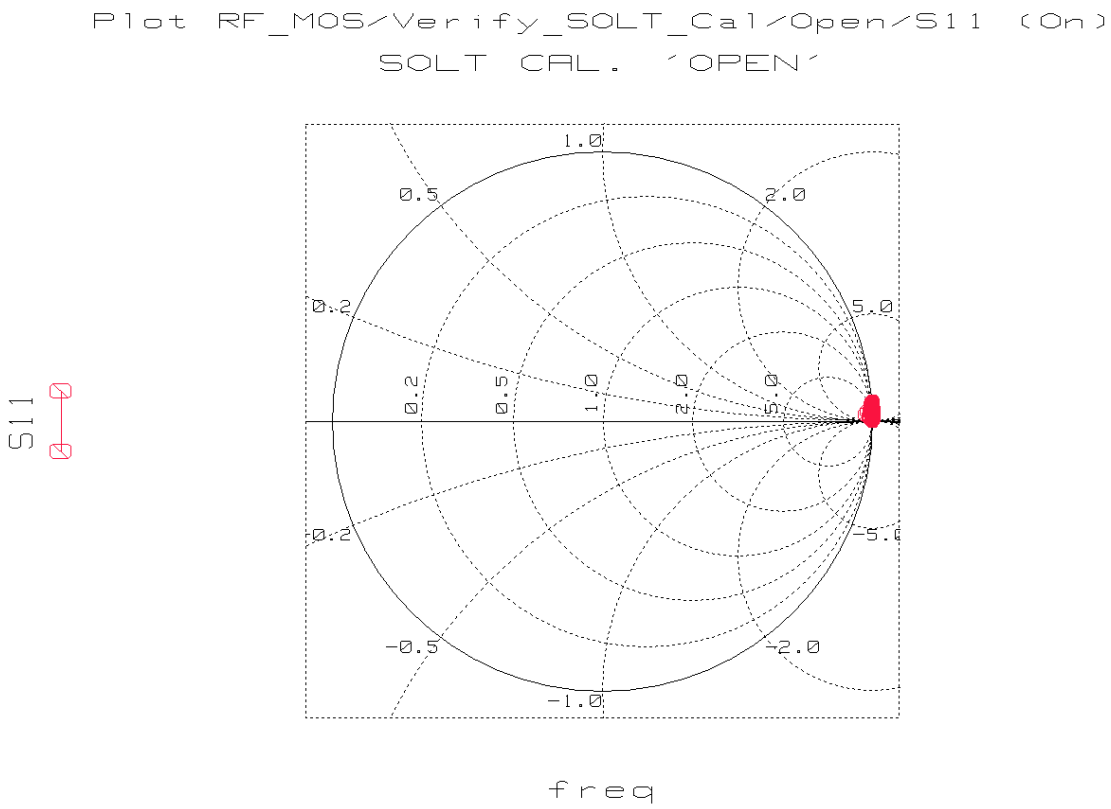

Figure 1. ISS 'OPEN' Input Impedance Characteristic

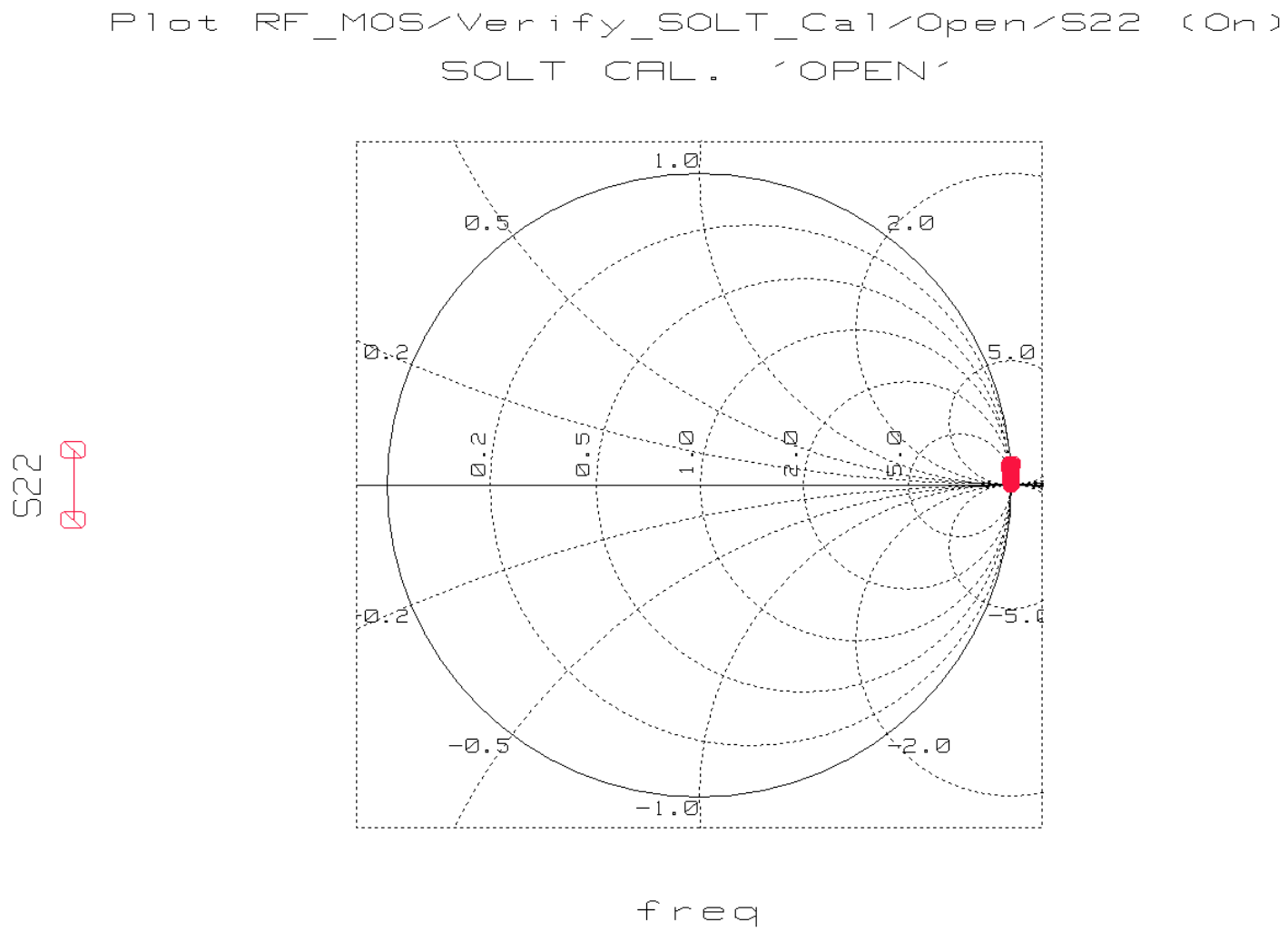

Figure 2. ISS 'OPEN' Output Impedance Characteristic

2.1.2 Extraction of Equivalent Input and Output Capacitances

The equivalent capacitances associated with ports-1 and 2 of the 'open' calibration standard are extracted from the measured S-Parameters following conversion to Y-format using the built-in IC-CAP "TwoPort" function, where (referring to Appendices A and B):

C11 = (Imag (Y11+Y12)) / (2*pi*freq.) C22 = (Imag (Y22+Y21)) / (2*pi*freq.)

2.1.3 Equivalent Capacitance Characteristics

A plot of the equivalent capacitances associated with ports-1 and 2 of the SOLT 'open' standard is shown in Figure 3 below. The capacitance is "extracted" directly from the imaginary part of the measured S-Parameters after S-to-Y conversion. Note that the value of the 'OPEN' capacitance entered into the WinCal software for the I40 GSG 150uM pitch probes is **–6.7fF**.

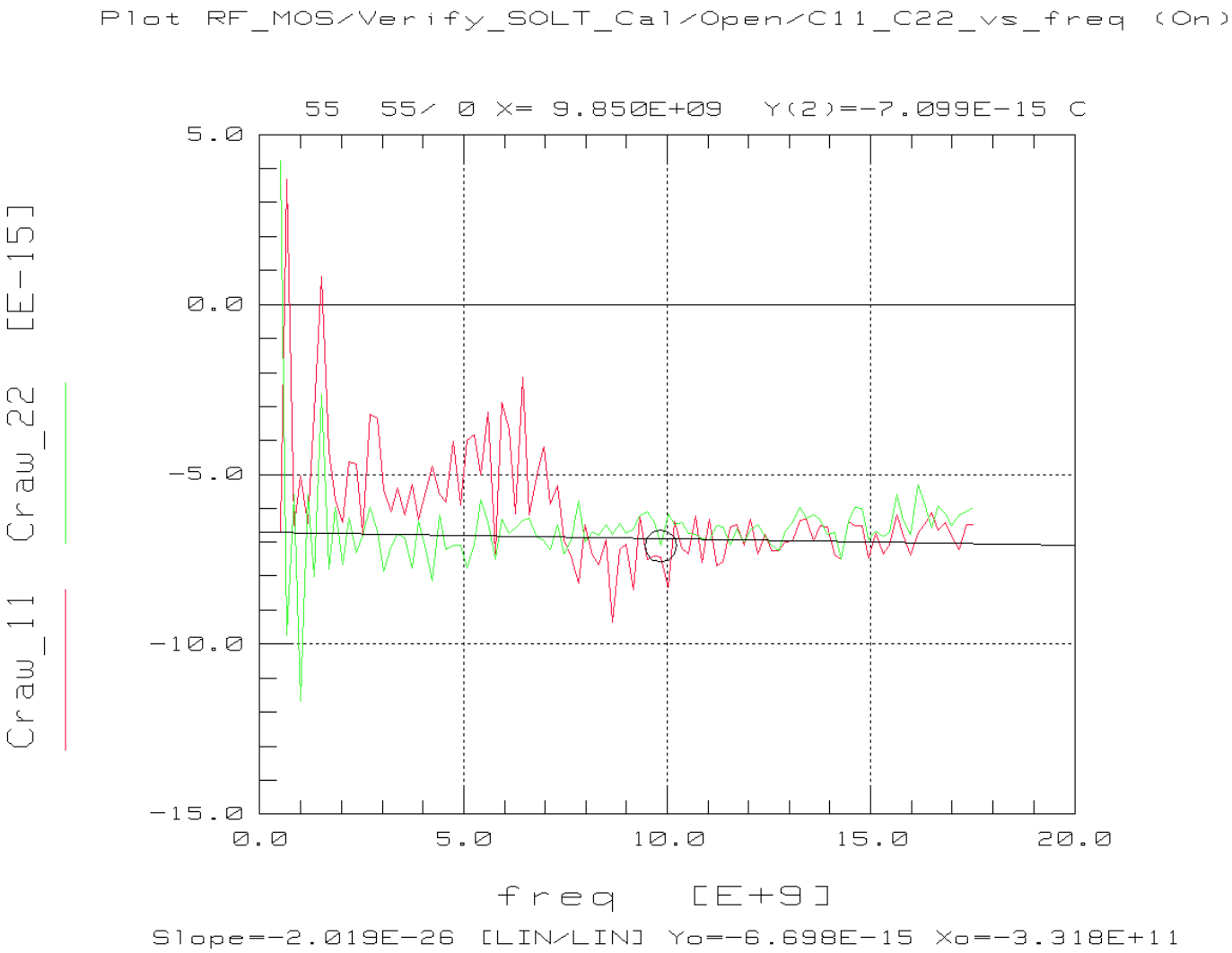

Figure 3. ISS 'OPEN' Port-1 / Port-2 Equivalent Capacitance Characteristics

2.2 '**SHORT**' Standard

Since this is a reflection standard, the quantities that are of primary importance are the input (Port-1) and output (Port-2) impedances, or more specifically, the inductances (Lshort) associated with Ports-1 and 2.

2.2.1 Input (S11) and Output (S22) Impedances

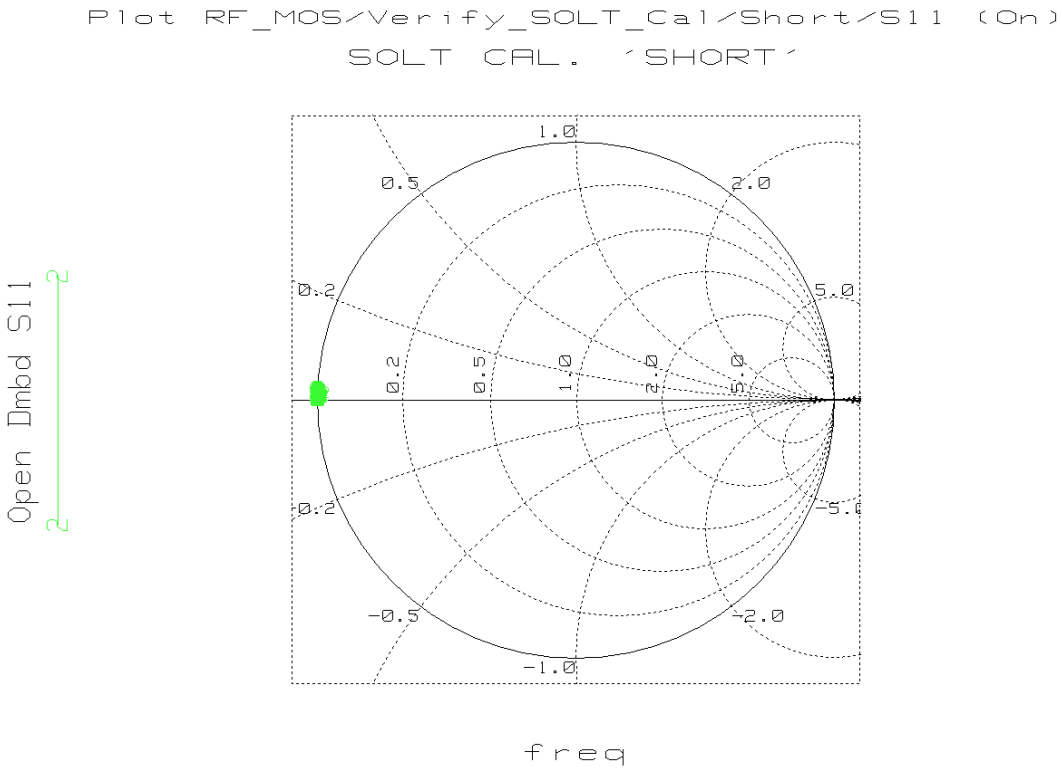

Figure 4. ISS 'SHORT' Input Impedance Characteristic

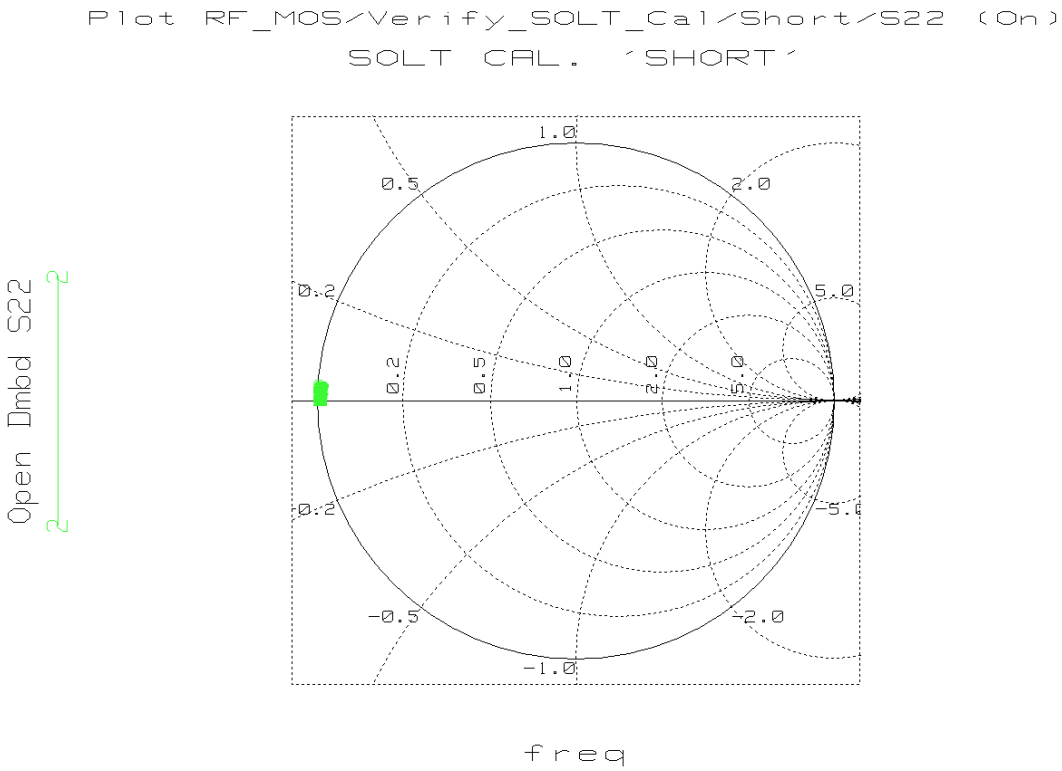

Figure 5. ISS 'SHORT' Output Impedance Characteristic

2.2.2 Extraction of Equivalent Input and Output Inductances

The equivalent inductances associated with ports-1 and 2 of the 'short' calibration standard are extracted from the 'open' de-embedded S-Parameters (Appendix H) following conversion to Z-format using the built-in IC-CAP "TwoPort" function, where (referring to Appendices C and D):

L11 = (Imag (Z11-Z12)) / (2*pi*freq.) L22 = (Imag (Z22-Z21)) / (2*pi*freq.)

2.2.3 Equivalent Inductance Characteristics

A plot of the equivalent inductances associated with ports-1 and 2 of the SOLT 'short' standard is shown in Figure 6 below. The inductance is "extracted" directly from the imaginary part of the measured S-Parameters after S-to-Z conversion, following de-embedding the 'open' S-Parameters (Appendix H). Note that the value of the 'SHORT' inductance entered into the WinCal software for the I40 GSG 150uM pitch probes is **8.2phy**.

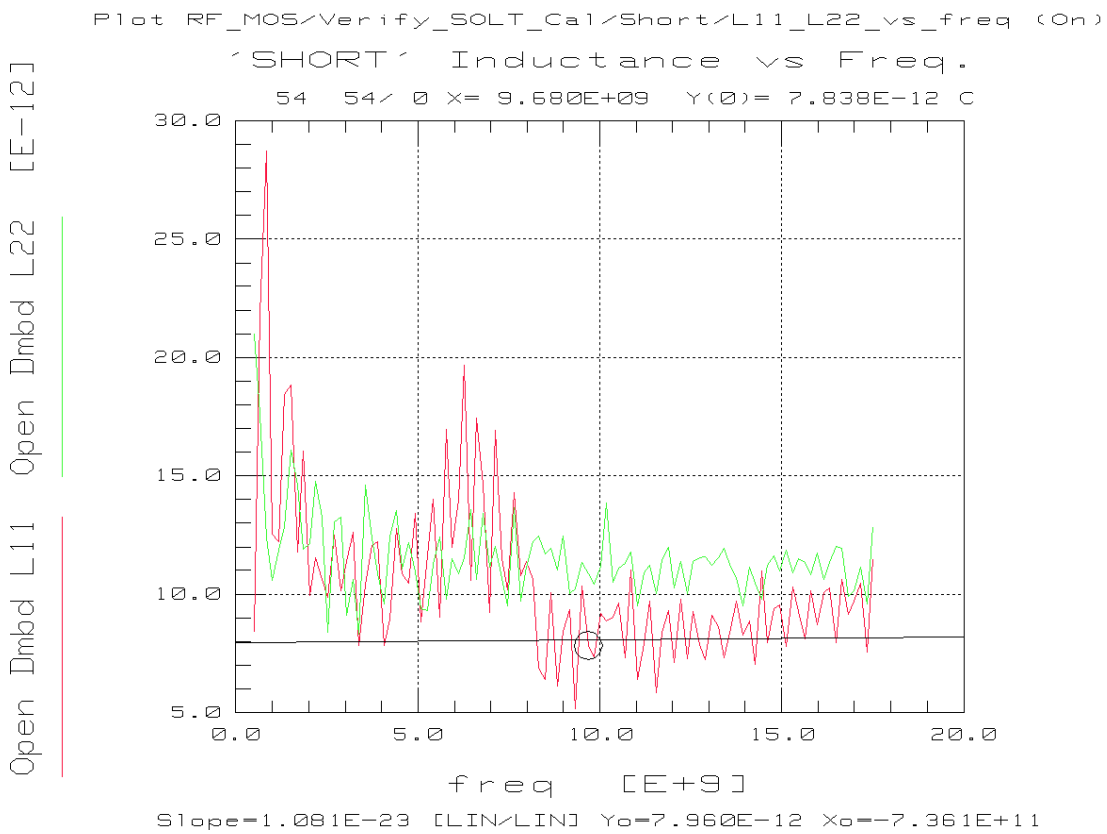

Figure 6. ISS 'Short' Port-1 / Port-2 Equivalent Inductance Characteristics

2.3 '**LOAD**' Standard

Since this is a reflection standard, the quantities that are of primary importance are the input (Port-1) and output (Port-2) impedances, or more specifically, the resistances (Rterm) associated with Ports-1 and 2.

2.3.1 Input (S11) and Output (S22) Impedances

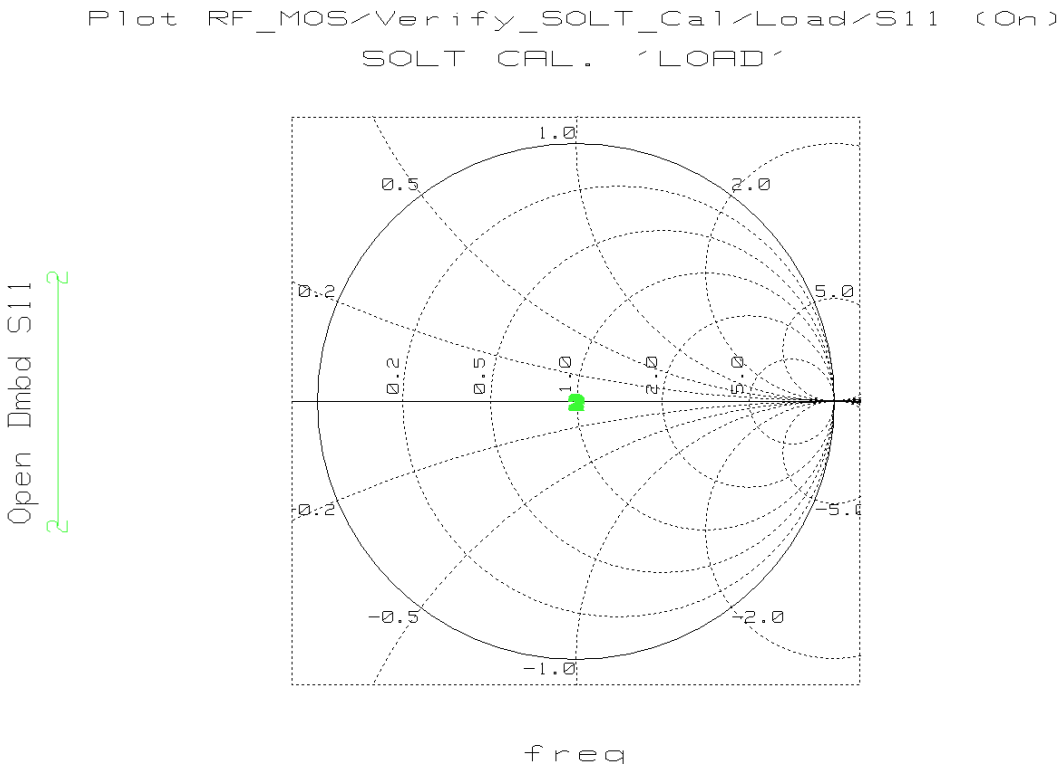

Figure 7. ISS 'LOAD' Input Impedance Characteristic

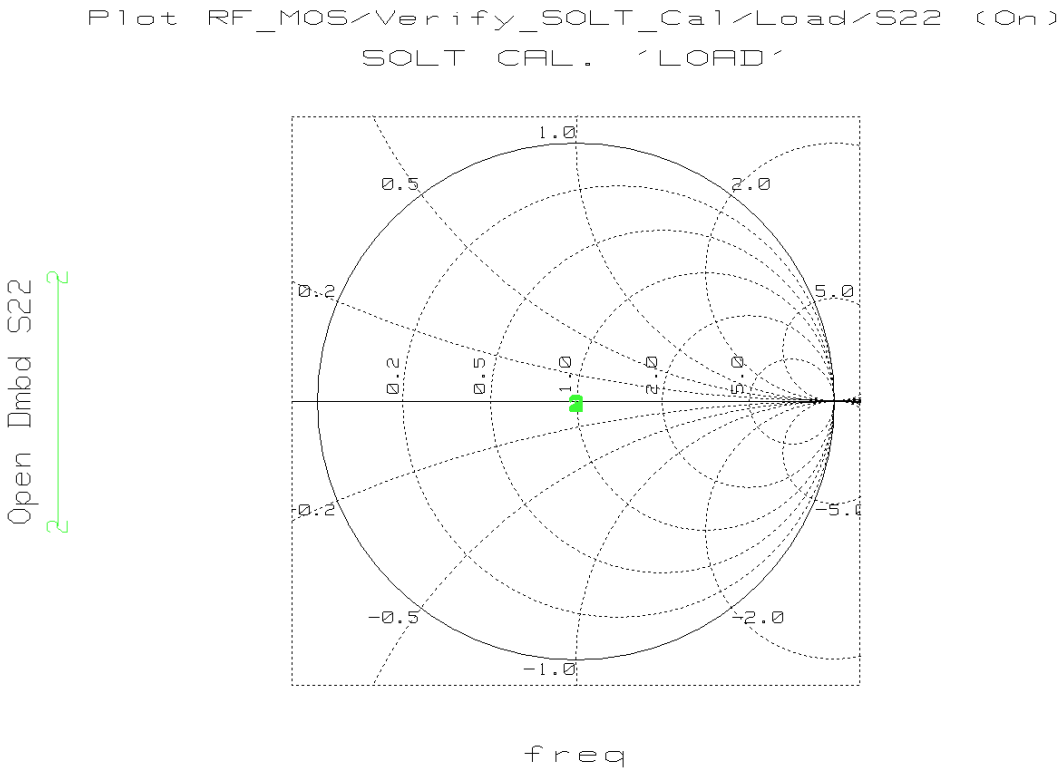

Figure 8. ISS 'LOAD' Output Impedance Characteristic

2.3.2 Extraction of Equivalent Input and Output Resistances

The equivalent resistances associated with ports-1 and 2 of the 'load' calibration standard are extracted from the 'open' de-embedded S-Parameters (Appendix H) following conversion to Z-format using the built-in IC-CAP "TwoPort" function, where (referring to Appendices E and F):

R11 = Real (Z11-Z12) R22 = Real (Z22-Z21)

2.3.3 Equivalent Resistance Characteristics

A plot of the equivalent resistance associated with ports-1 and 2 of an SOLT precision (laser trimmed) 'load' standard is shown in Figure 9 below. The resistance is "extracted" directly from the real part of the measured S-Parameters after S-to-Z conversion, following de-embedding the 'open' S-Parameters (Appendix H). Note that the value of the 'LOAD' resistance entered into the WinCal software for the SOLT calibration is **50.0 Ohms**

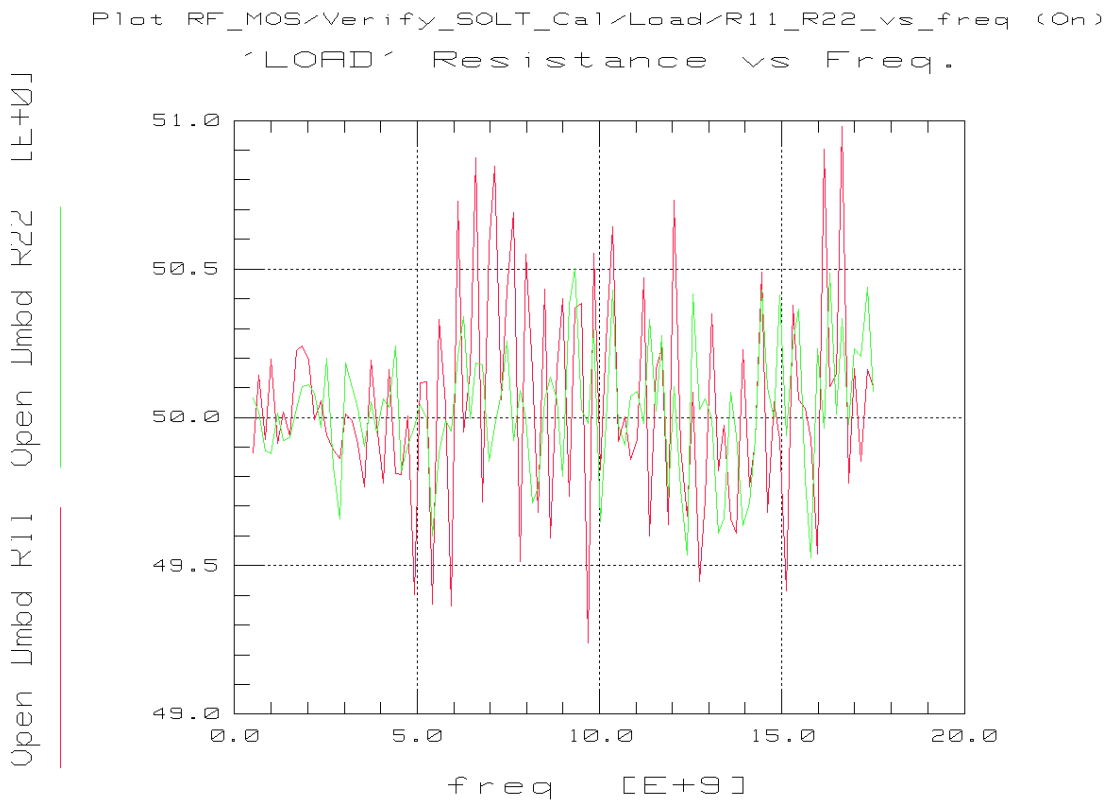

Figure 9. ISS 'LOAD' Port-1 / Port-2 Equivalent Resistance Characteristics

2..4 '**THRU**' Standard Delay

Since this is a transmission standard, the quantities that are of primary importance are the forward (S21) and reverse (S12) transmission coefficients, or more specifically, the forward and reverse delay.

2.4.1 Forward (S21) and Reverse (S12) Transmission Characteristics

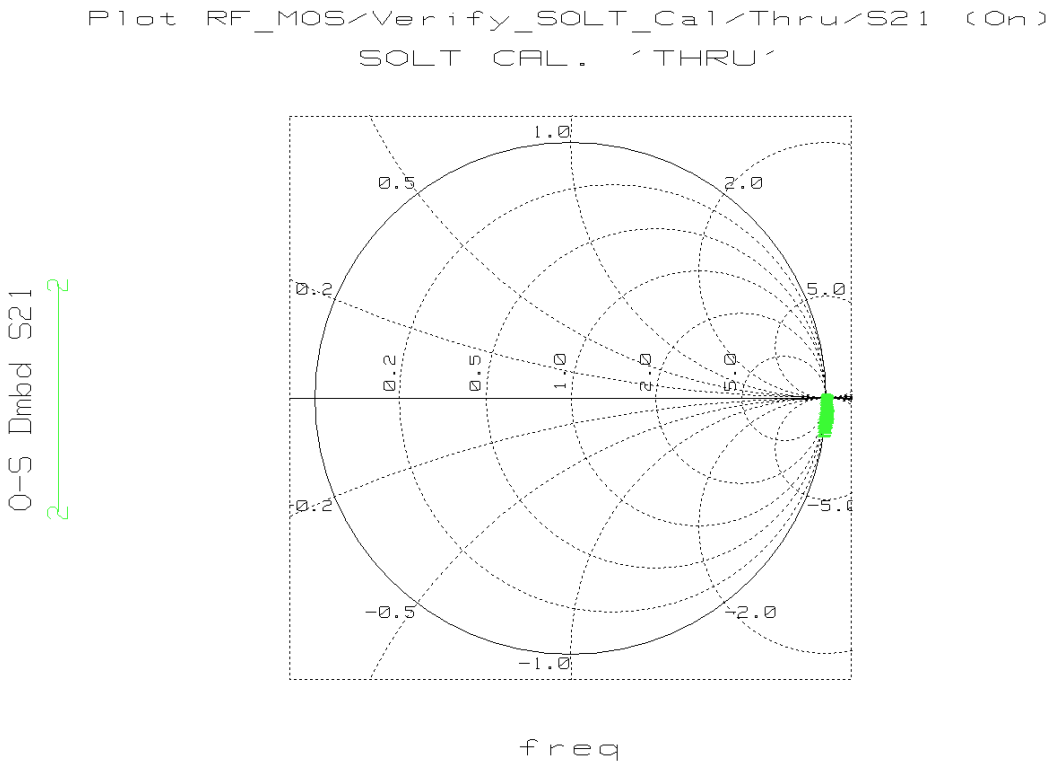

Figure 10. ISS 'THRU' Forward Transmission Characteristic

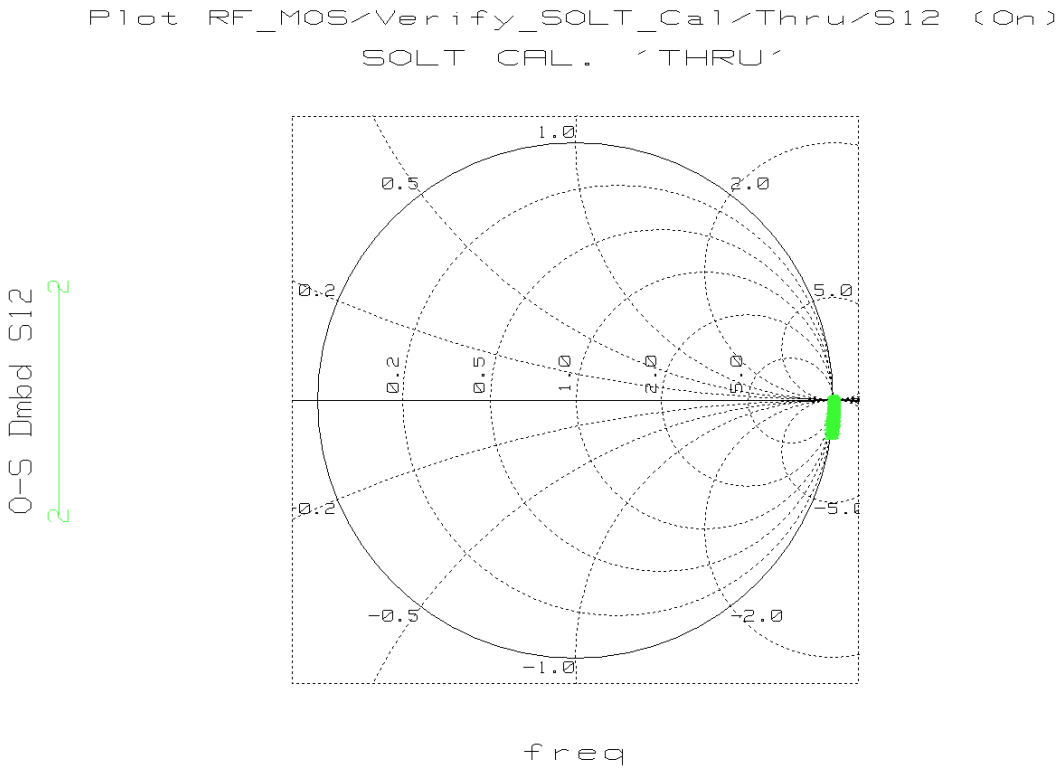

Figure 11. ISS 'THRU' Reverse Transmission Characteristic

2.4.2 Extraction of Forward and Reverse Delay

The delay is computed directly from the phase of the forward and reverse transmission characteristics following 'open-short' de-embedding (Appendices H and I), where (referring to Appendix G):

Fwd. Delay = Phase (S21) / (2*pi*freq.) Rev. Delay = Phase (S12) / (2*pi*freq.)

Note that this also serves as a final verification that the complete 'open-short' de-embedding process has been properly implemented.

2.4.3 Equivalent Delay Characteristics

A plot of the forward and reverse delay associated with the SOLT 'thru' standard is shown in Figure 9 below. The delay is "extracted" directly from the phase of the measured S-Parameters after S-to-Z conversion, following de-embedding with both an 'open' and 'short' S-Parameters (Appendices H and I). Note that the value of the 'THRU' delay entered into the WinCal software for the I40 GSG 150uM pitch probes is **–1psec**

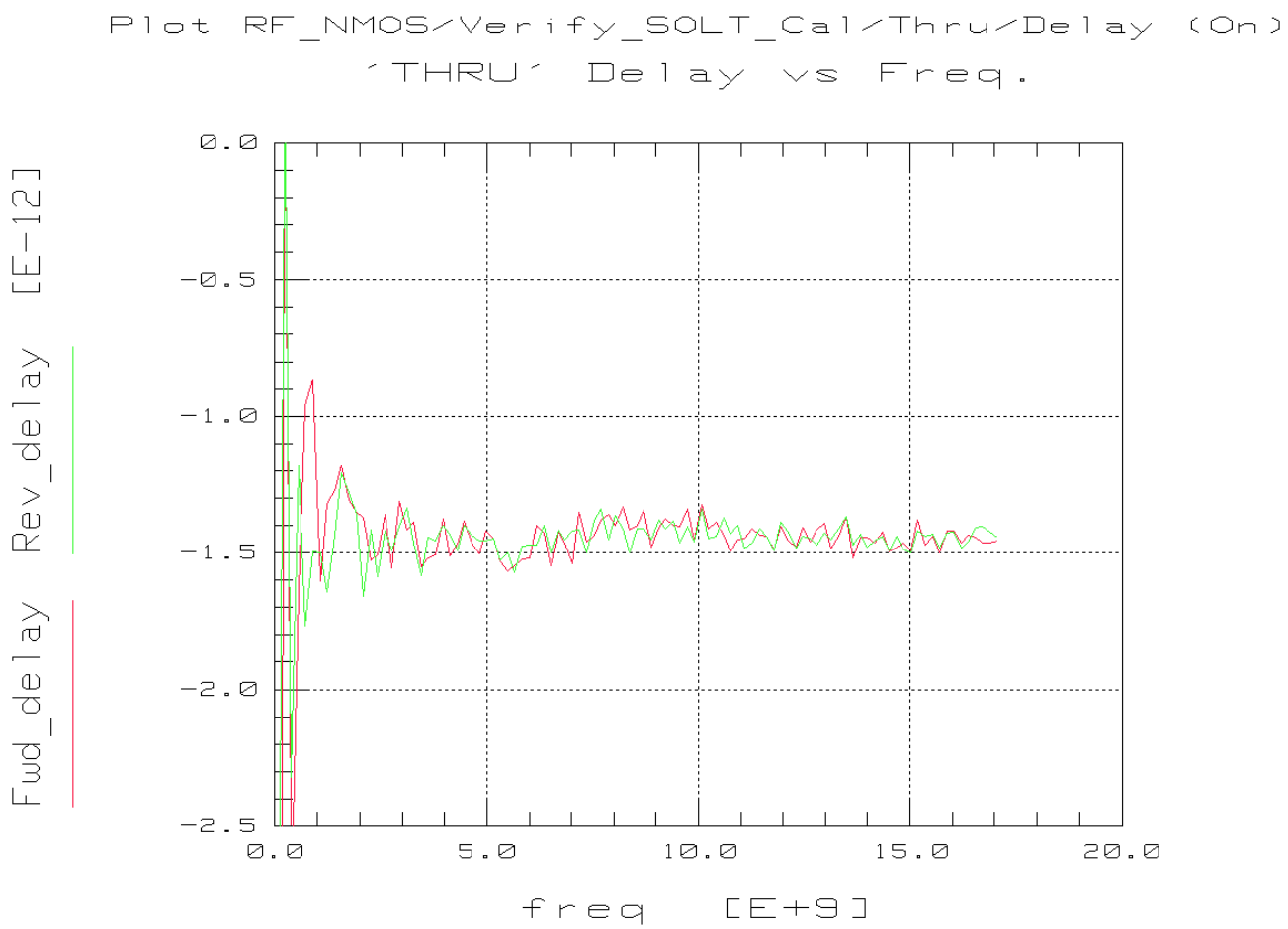

Figure 12. ISS 'THRU' Delay Characteristics

Appendix A. 'Open' Input Capacitance Transform

```
LINK XFORM "Craw_11"
{
View block_edit 0 "0,0"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates C11 from Y-parameters for "PI"
 ! configured network
 !****************************************
 !
 y_raw=TwoPort(s.m,"S","Y")
 !
 length=size(y_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=imag(y_raw.11[i]+y_raw.12[i])
      i=i+1
 end while
 !
 ii=xx//2//pi//freq
 !
return ii
```

Appendix B. ‘Open’ Output Capacitance Transform

```
LINK XFORM "Craw_22"
{
View block_edit 0 "0,37"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates C22 from Y-parameters for "PI"
 ! configured network
 !****************************************
 !
 y_raw=TwoPort(s.m,"S","Y")
 !
 length=size(y_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=imag(y_raw.22[i]+y_raw.21[i])
      i=i+1
 end while
 !
 ii=xx//2//pi//freq
 !
 return ii
```

Appendix C. ‘Short’ Input Capacitance Transform

```
LINK XFORM "Ldmbd_11"
{
View block_edit 0 "0,0"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates L11 from Z-parameters for "TEE"
 ! configured network
 !****************************************
 !
 z_raw=TwoPort(S_dmbd_open.m,"S","Z")
 !
 length=size(z_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=imag(z_raw.11[i]-z_raw.12[i])
      i=i+1
 end while
 !
 ii=xx//2//pi//freq
 !
 return ii
```

Appendix D. ‘Short’ Output Capacitance Transform

```
LINK XFORM "Ldmbd_22"
{
View block_edit 0 "0,0"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates L22 from Z-parameters for "TEE"
 ! configured network
 !****************************************
 !
 z_raw=TwoPort(S_dmbd_open.m,"S","Z")
 !
 length=size(z_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=imag(z_raw.22[i]-z_raw.21[i])
      i=i+1
 end while
 !
 ii=xx//2//pi//freq
 !
 return ii
```

Appendix E. 'Load' Input Resistance Transform

```
LINK XFORM "Rdmbd_11"
{
View block_edit 0 "0,0"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates R11 from Z-parameters for "TEE"
 ! configured network
 !****************************************
 !
 z_raw=TwoPort(S_dmbd_open.m,"S","Z")
 !
 length=size(z_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=real(z_raw.11[i]-z_raw.12[i])
      i=i+1
 end while
 !
 !
 return xx
```

Appendix F. 'Load' Output Resistance Transform

```
LINK XFORM "Rdmbd_22"
{
View block_edit 0 "0,0"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates L11 from Z-parameters for "TEE"
 ! configured network
 !*****************************************
 !
 z_raw=TwoPort(S_dmbd_open.m,"S","Z")
 !
 length=size(z_raw)
 !
 COMPLEX xx[length]
 !
 i=0
 while (i<length)
      xx[i]=real(z_raw.22[i]-z_raw.21[i])
      i=i+1
 end while
 !
 !
 return xx
```

Appendix G. 'Thru' Transmission Delay Transform

```
LINK XFORM "Fwd_delay"
{
View block_edit 0 "0,87"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! Calculates delay from De-Embedded S-Parameters
 !**********************************************
 !
 COMPLEX xx[num_freq]
 !
 i=0
 while (i<num_freq)
      xx[i]=(phase(S_dmbd_short.m.21[i])//pi)*180
      xx[i]=xx[i]//2*pi*freq[i]
      i=i+1
 end while
 !
 ii=xx^-1
 !
 return ii
```

Appendix H. ‘Open’ De-Embedding Transform

```
LINK XFORM "S_dmbd_open"
{
View block_edit 0 "0,351"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! PEL Transform to perform 'open' de-embedding via
 ! Y-Parameter subtraction
 !**************************************************
 !
 total=s.m
 !
 dummy_o = Verify_SOLT_Cal/Open/s.m
 !
 size_dummy_o=SIZE(dummy_o)
 !
 COMPLEX dummy_o_act.22[SIZE(total)]
 !
 i1=0
 i=0
 WHILE i < SIZE(total)
   dummy_o_act.11[i]=dummy_o.11[i1]
   dummy_o_act.12[i]=dummy_o.12[i1]
   dummy_o_act.21[i]=dummy_o.21[i1]
   dummy_o_act.22[i]=dummy_o.22[i1]
   i1=i1+1
   IF i1>=size_dummy_o THEN i1=0
   i = i + 1
 END WHILE
 !
 xtor=TwoPort(total,"S","Y")-TwoPort(dummy_o_act,"S","Y")
 xtor=TwoPort(xtor,"Y","S")
 !
 RETURN xtor
```

Appendix I. 'Short' De-Embedding Transform

```
LINK XFORM "S_dmbd_short"
{
View block_edit 0 "0,390"
data
{
HYPTABLE "Link Transform"
{
element "Function" "Program"
}
BLKEDIT "Program Body"
{
 ! PEL Transform to perform 'short' de-embedding via
 ! Z-Parameter subtraction after 'open' de-embedding.
 !**************************************************
 total=S_dmbd_open.m
 !
 dummy_s = Verify_SOLT_Cal/Short/s.m
 !
 size_dummy_s=SIZE(dummy_s)
 !
 COMPLEX dummy_s_act.22[SIZE(total)]
 !
 i1=0
 i=0
 WHILE i < SIZE(total)
   dummy_s_act.11[i]=dummy_s.11[i1]
   dummy_s_act.12[i]=dummy_s.12[i1]
   dummy_s_act.21[i]=dummy_s.21[i1]
   dummy_s_act.22[i]=dummy_s.22[i1]
   i1=i1+1
   IF i1>=size_dummy_s THEN i1=0
   i = i + 1
 END WHILE
 !
 xtor=TwoPort(total,"S","Z")-TwoPort(dummy_s_act,"S","Z")
 xtor=TwoPort(xtor,"Z","S")
 !
 RETURN xtor
```

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Revised: March 27, 2008

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Printed in USA, September 10, 2003
5989-9467EN

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