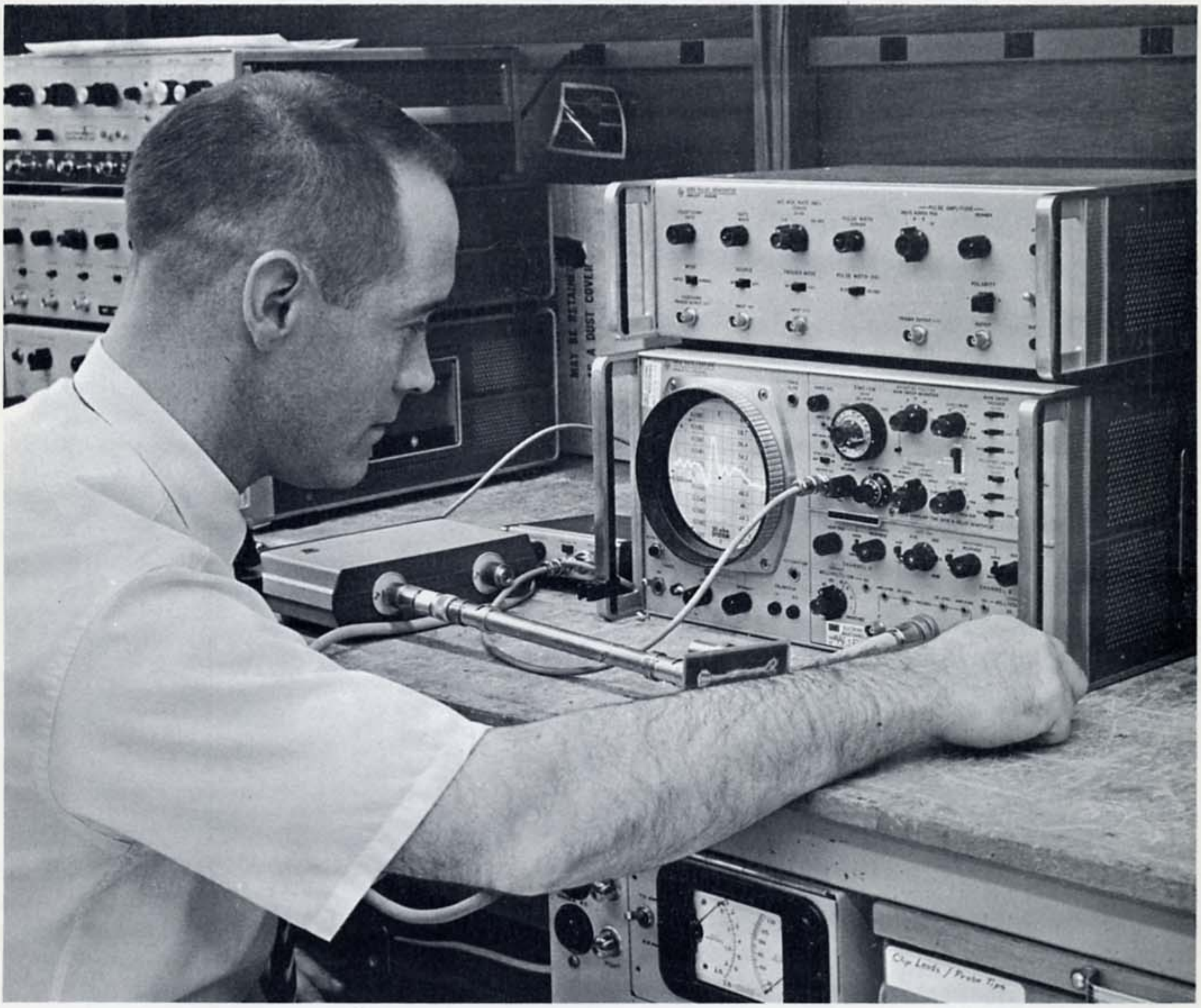
APPLICATION NOTE 94

CONNECTOR DESIGN EMPLOYING TDR TECHNIQUES



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THE ELECTROMECHANICAL DESIGN OF A MATCHED IMPEDANCE CONNECTOR

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ELECTROMECHANICAL DESIGN OF A MATCHED IMPEDANCE CONNECTOR

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SUMMARY

This paper describes the development of a matched impedance cable connector that minimizes impedance discontinuities during the sending and receiving of extremely-fast risetime digital data pulses through transmission lines. The authors discuss:

1. the hermaphroditic design concept and its importance.

2. the mechanical specifications required by the contact system for high reliability.

3. the use of computer-aided design in obtaining impedance characteristics of a cross section of a rectangular-within-rectangular geometry. The formulations include off-center conditions and rounded corners due to normal process considerations and tolerances.

4. the electrical specifications required for undistorted pulse transmission with rise times as fast as 150 picoseconds.

5. the techniques and results of a 28 picosecond risetime, time domain reflectometry examination of physical parts of the connector, and the ability to relate this data to the mechanical contact configuration and the theoretical design.

INTRODUCTION

With faster and faster risetime pulses being developed for line transmission and retrieval of digital data, the need to minimize impedance discontinuities becomes increasingly important.

If circuit technologies are to be compatible with miniature-packaging techniques for high performance computers, these technologies must provide for matched impedance interconnection and increased density. A high performance interconnection system -- one that will provide for transmission line disconnect between critical signal paths -- is needed.

To adequately describe and evaluate a pulse transmission system, we must be concerned with the following parameters:

a. Reflections due to:

   1. Connector impedance mismatch

   2. Termination mismatch

   3. Cable impedance mismatch

b. System delay due to:

   1. Propagation delay

   2. Phase delay due to reflections

   3. Risetime degradation

   4. Connector delay

c. Finite Risetime Response

   In digital system applications, we encounter the fact that digital circuits have finite transition times. As circuits achieve faster transition times, a greater requirement for transmission system integrity is generated and methods of interconnection of this transmission system become a matter of importance.

With the above requirements in mind, IBM's Product Technology group in Poughkeepsie has designed a matched impedance connector that is highly reliable both mechanically and electrically. The connector, which employs coaxial contacts, allows undistorted pulse transmission at risetimes as fast as 150 picoseconds (ps).

BACKGROUND

Our group decided to develop the connector "hardware" concept around the accepted I/O interconnection system currently in use in IBM. A cursory review of IBM's production packaging techniques will help the reader to better understand the development.

IBM System/360 requires a machine interface (usually called a "tailgate") to enable transition from the logic areas' flat transmission cables to the sheathed coaxial cables communicating among the various functional units (i. e., channels, control units, central processing units, etc.) See Figure 1.

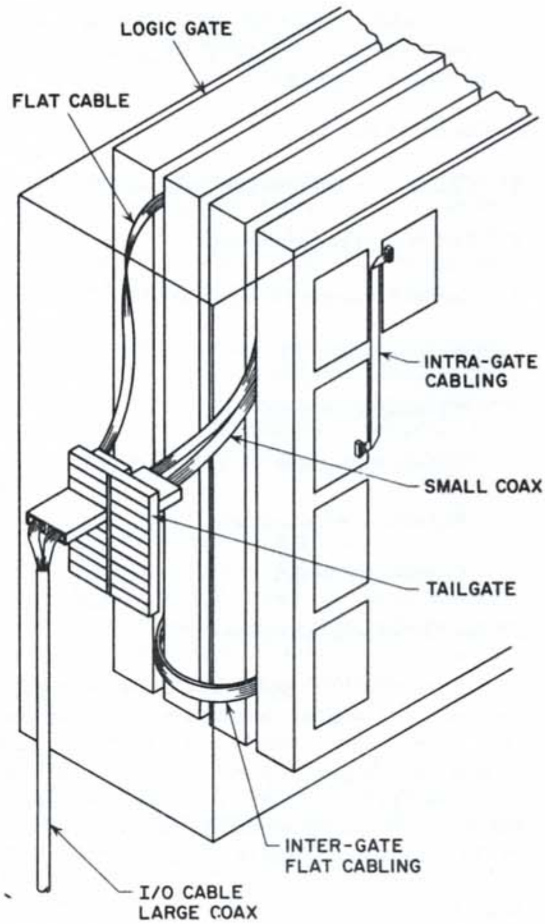


Fig. 1. Frame cabling configuration for IBM System/360.

Two different types of transmission lines are used in System/360 because:

a. Flat transmission cables provide a low-cost, high-density, packaging means for intraframe design. The flat transmission cable to which we refer has a characteristic impedance of 95 Ω with a cross section as shown in Figure 2.

b. Coaxial cables are used for interframe communication where signal runs of up to 300 feet require a minimized d-c resistance (presently 5 Ω/100 ft.) along with a rugged sheathed construction to withstand the below-floor installation environment. A typical transition between these basic transmission lines was accomplished as shown in Figure 3.

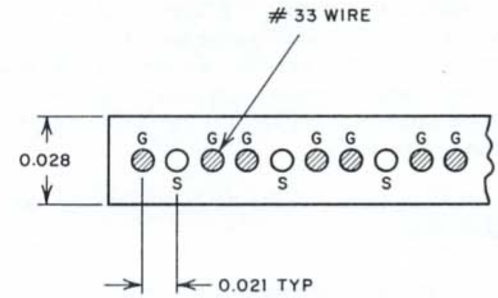


Fig. 2. Flat transmission cable.

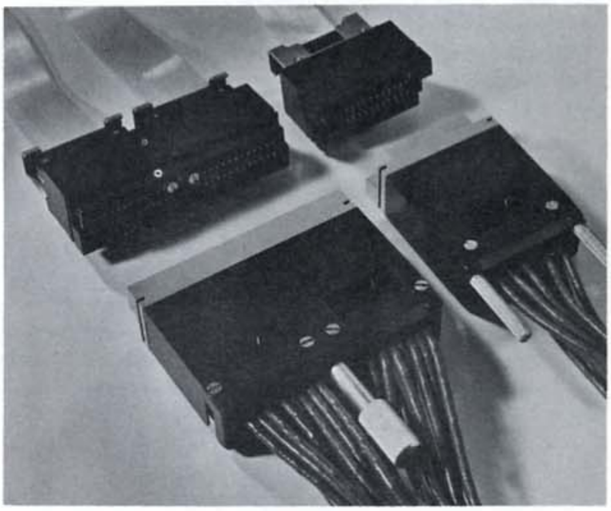


Fig. 3. Coaxial to flat transmssion cable transition.

Serpent Contact

We developed a special contact to meet the specialized design requirements of IBM System/360. The basic contact (Figure 4) is a hermaphroditic* dual-mating surface contact which we dubbed the "serpent" due to the appearance of the contact leaf.

*One part serving as both a plug and a receptacle.

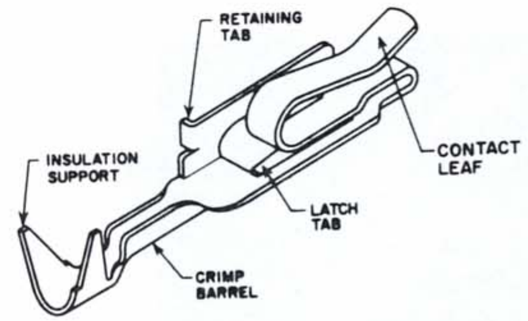


Fig. 4. Serpent contact.

A hermaphroditic connector housing provides a mating configuration of contacts as shown schematically in Figure 5.

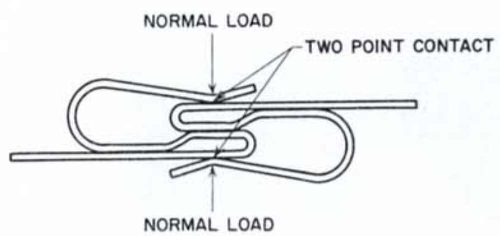


Fig. 5. Serpent mating configuration.

Serpent Termination -- The termination of serpent contacts to coaxial cables is accomplished as shown in Figure 6.

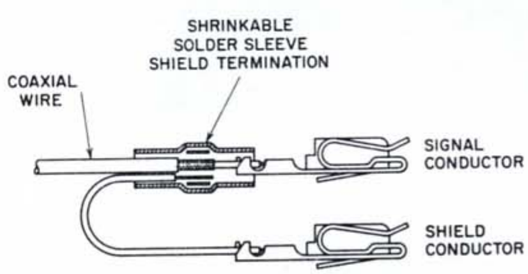


Fig. 6. Termination of coaxial cables to serpent contacts.

Although the serpent termination is non-coaxial, it proved satisfactory for present-day needs. Noise coupling between signal lines was minimized by designating a signal-to-ground relationship to achieve maximum ground proximity. See Figure 7.

In a terminated condition, this contact system presented a discontinuity in a signal path as shown in the series of scope traces having increasing rise time responses (Figure 8).

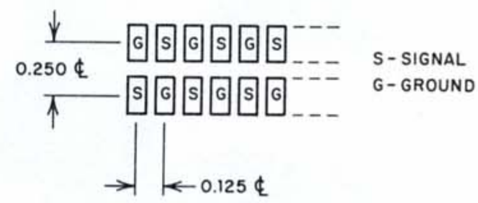


Fig. 7. Serpent contact placement to minimize signal noise coupling.

Although the serpent contacts are satisfactory for most present-day applications whose rise times are in the 2-5 ns range, we realized that more stringent impedance matching would be required in the near future. With this background and anticipated need, we established an overall electromechanical contact design specification.

DESIGN SPECIFICATIONS

Mechanical Specifications

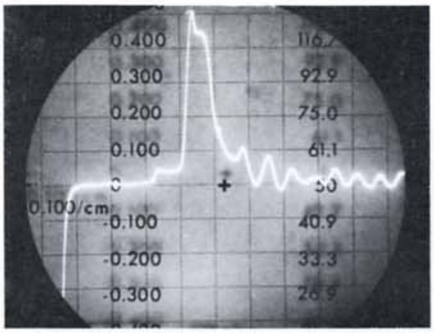
1. Mechanically compatible with serpent connector housings.

2. Double the packaging density of serpent connectors for coaxial lines (i. e., achieve basic 32 coaxial contacts/in^2).

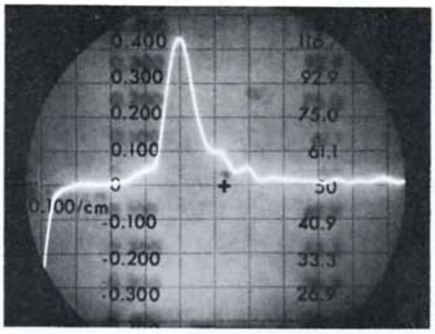
3. Life: 500 insertions and withdrawals with no base metal exposure.

4. Individual contacts to withstand 5-lb pull within housings after five installations and removals.

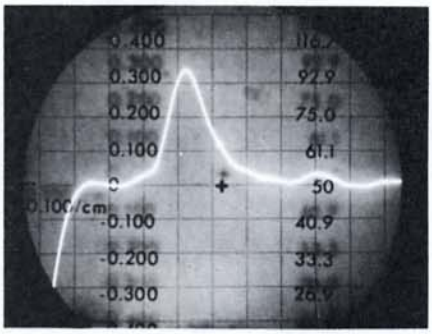
5. Withstand machine vibrations of 10-55 hertz at amplitudes of 0.030 in.



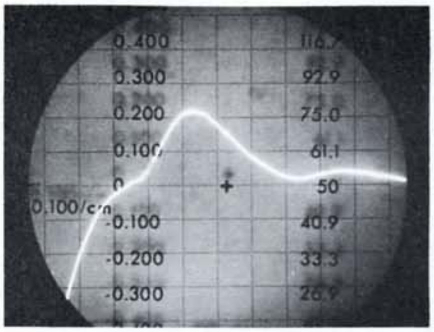
150 ps risetime
response



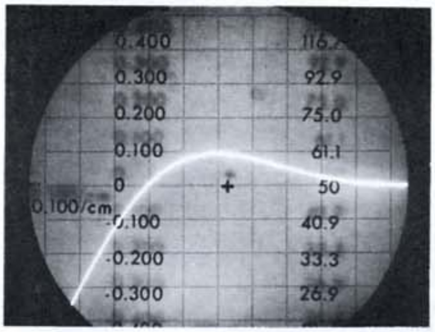
500 ps risetime
response



1 ns risetime
response



2 ns risetime
response



5 ns risetime
response

Fig. 8. Serpent signal path discontinuities at increasing risetimes.
<u>Note:</u> All responses appear relative to a 50 ohm base line.
Horizontal scale-- 1 ns/div.
Vertical reflection coefficient-- 0.1/div.

"Serpco" Coaxial Contact Physical Design -- In order to maintain compatibility between the contact and the serpent connector cavity, we designed the shape of the impedance matched contact to be rectangular. See Figure 9.

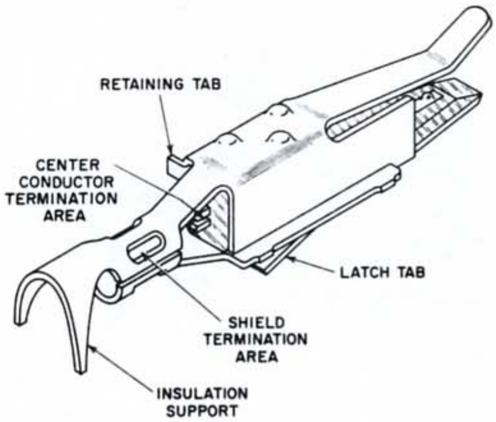


Fig. 9. Serpco contact.

We dubbed our new design "serpco" to signify a "serpent" coaxial connector. The serpco consisted of an inner rectangular copper-alloy conductor surrounded by a Teflon* dielectric within a full-hard phosphor bronze outer conductor (Figure 10). Teflon was used as the dielectric both for its low dielectric constant and for its resistance to high temperatures encountered during soldering. The terminated contact slides into the rear of the block thus depressing a latch tab which locks it in the backward direction and stops it in the forward direction with the retaining tab. The present termination method utilizes a reflow of solder for both center conductor and shield termination.

Hermaphroditic Design -- We felt that a hermaphroditic connection offered us the following advantages:

a. Contact forces could be supplied for both the signal and shield members through the opposing action of the shield beam member. This assured us of a minimum normal load of 100 g on each side of the dual contacting surfaces.

b. Dual contacting surfaces provide a redundancy in the functional contact surfaces. Each of the two contacting points (spherical contact points are used to maximize normal pressures) are available for both the signal and shield contacts.

c. A well defined electrical plane of reference is established. The effect of geometry changes on electrical characteristics can be more easily related to the complete interconnection when the mating portions are identical. **

d. Tooling costs and manufacturing control are reduced.

e. Part number and application usage are simplified (i.e., the same part number is used for external or internal use).

f. The need for off-line utilization (i.e., plugging cable halves together to physically bypass a unit) can be more easily accomplished without intermediate connectors.

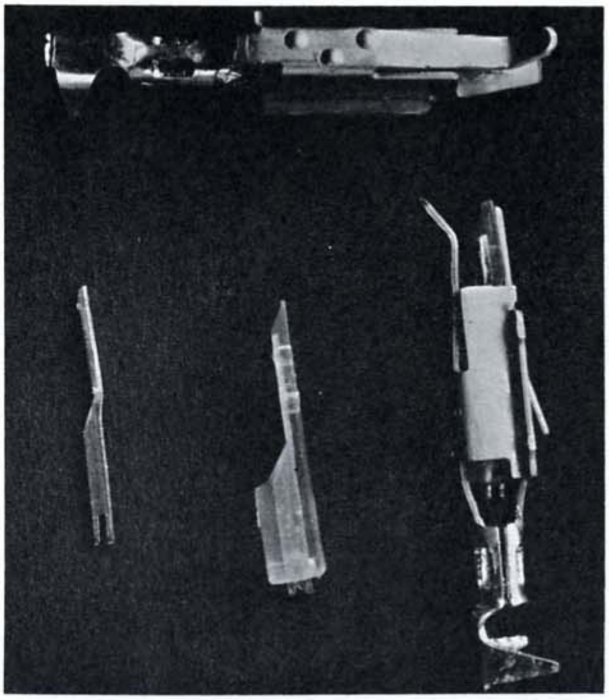


Figure 10. Serpco contact components.

*Trademark of the E.I. Dupont de Nemours Co., Inc.

** Previously, hermaphroditic coaxial connectors had existed only for precision microwave connections.

Mechanical Reliability Aspects -- An abbreviated statement of our reliability objective is that lead-to-lead connection shall have a failure rate of less than 0.0005% per 1000 hours throughout an expected life of 100,000 hours and 500 cycles of operation.

From a mechanical standpoint, the following conditions have been built into the design to ensure this long term requirement.

Worst Case Tolerance Analysis -- Although we recognize the pessimistic and unrealistic nature of taking all dimensions at the tolerance extremes to produce conditions of concern, we use this form of mechanical analysis because:

a. it is simpler to relate than is statistical information.

b. it provides a "safety" factor in that it is extreme (although it has not been "unknown" for some dimension to run beyond limits and thereby negate such a cushion).

c. during the early stages of design, it points up areas where design modifications and/or tolerance adjustments could be used beneficially.

We made this type of analysis on the serpco contact and serpent connector blocks to ensure:

1. proper engagement of contacts having extremes in vertical and horizontal dimensions. This was arrived at by dimensional analysis, and ensures that all surfaces pass freely or provide a camming action into proper alignment.

2. proper engagement of contacts having angular conditions of the mating blocks. This was accomplished by layouts and overlays of 10-time size components. This is an attempt to "fool proof" the engagement of connector halves without damaging the contacts. See Figure 11.

3. that, after engagement, the variations in final location always provide bypass of the center contact points and that no mechanical interferences result.

Contact Forces -- The desire to ensure a reliable low-voltage contact system over our equipment's life span has led to a relatively severe environmental evaluation. In general, we have found that normal contact loads in excess of 100 g. associated with a porous-free, noble metal plating will meet our qualification requirements.

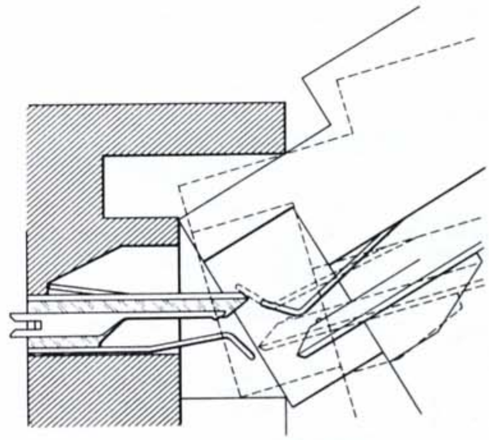


Fig. 11. Angular engagement of serpco contacts.

As electronic packaging dictates increased density at all levels, it becomes increasingly difficult to meet this minimum load with more miniature sliding beam members. Thus, a contact system like serpco allows the outer members to establish the loadings for both its own shield contact and the signal.

The free-body diagram in Figure 12 illustrates this design concept.

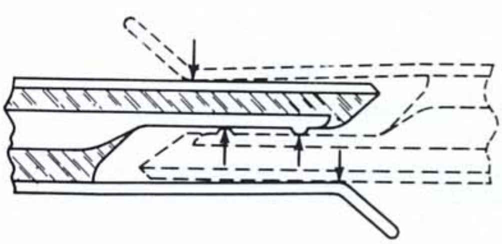


Fig. 12. Serpco dual-force relationship.

Computer Analysis (Mechanical) -- To optimize our contact loading, we wrote, debugged, and ran a Fortran program on our IBM 1050 terminal. This remote terminal allows conversational processing with an IBM 7044 time-sharing system. The Fortran program provides:

a. a minimum deflection to achieve worst case loading of 100 g without exceeding the proportional limit for the material (full-hard phosphor bronze P. L. = 60,000 psi minimum). Once again, a worst case condition (e. g., minimum thickness, maximum length, etc.) provides a safety factor since the 100 g load could only be obtained with all pertinent dimensions at their extremes.

b. An allowable maximum deflection range to check for a maximum allowable load of 300 g. This is not a physically significant value because it places us in excess of our allowable stressing condition, but it does give us an indication of the insertion forces that are to be minimized for ease of our multiple connector applications (e. g., 48 position) as well as limiting the wear conditions on our contact surfaces.

The preceeding analysis was made for all practical incremental values of length and thickness, with only within-allowable-range results printed out for our scrutiny.

Electrical-Mechanical Compatibility

The connector provides a transmission line disconnect. Consequently, to preserve transmission line integrity, the connector should match the impedance of the transmission line on which it is mounted as closely as possible without adding reflections that would affect system performance.

However, the connector, being a disconnect point, must also be mechanically suited to maintain adequate electrical contact of both center conductor and shield member over repeated operations of connecting and disconnecting.

It is the mechanical dimensions, i. e., ratio of inner conductor to outer conductor, and dielectric constant that determine the impedance of the connector.

In designing serpco, we were restricted in maintaining the outside shield member dimension to 0.104 X 0.080 in. Using a stock thickness of 0.010 in, our inside dimension of the design section which comprised the major length of the contact system was to be 0.084 X 0.060 nominal (Figure 13). This restriction was based on the requirement that serpco be compatible with serpent, its noncoaxial predecessor in the mounting hardware as it existed in IBM System/360.

Computer Analysis (Electrical) -- Using this inside shield design dimension we initiated a preliminary study of existing rectangular-within-rectangular configurations to see whether a 50 Ω design was mechanically feasible with Teflon as a dielectric.

Using the formulation of Cruzan and Garver,[1] we wrote a short computer program that yielded a table of design dimensions for CC and DD (Figure 13).

The results of this analysis are graphically tabulated in Appendix A. The calculations in Appendix A applied to the case where the center conductor was centered within the shield member and where all corners were rectangular.

We obtained a computer solution for the characteristic impedance of a rectangular coaxial cross section in order to further examine the effect of mechanical tolerances on impedance such as:

1. Off-center center conductor

2. Rounded corners on center conductor

3. Rounded inside corners on shield member

A general program description is presented in Appendix B.

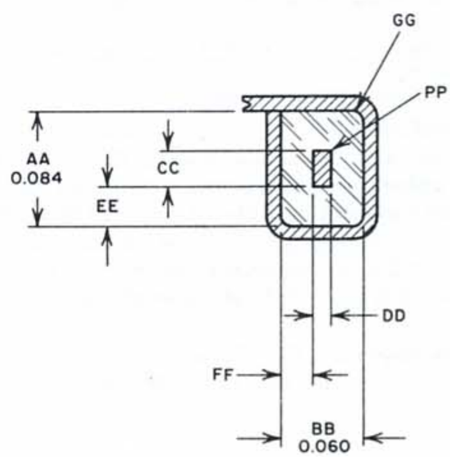


Fig. 13. Design section for impedance calculation.

Electrical Specifications

Having the computer-aided solutions available, and knowing the basic mechanical design criteria, we formulated a set of electrical performance specifications based on transmission system requirements. They are as follows:

1. The contact was to be impedance matched, within ± 5%, to the coaxial line on which it was mounted.

2. The impedance specification was to hold for pulse inputs with risetimes as fast as 150 ps.

3. The method of characterization was to be Time Domain Reflectometry* rather than Frequency Domain Reflectometry because we were concerned with transient digital pulse performance rather than with sinusoidal steady-state performance.

4. Coupled noise (crosstalk) between adjacent lines was not to exceed 25 mV.

5. Termination-to-termination contact resistance was not to exceed 0.050 Ω under all operating conditions.

Using the joint electromechanical design specifications as a goal, we constructed several development designs with different center conductor sizes. The performance and analysis of this design is discussed in subsequent paragraphs

ELECTRICAL EVALUATION

Resolution Accuracy with Time Domain Reflectometry

Resolution accuracy is the ability to locate, in distance and time, an electrical reflection from a pulse, and relate the electrical response to the mechanical configuration. This ability to resolve reflections using Time Domain Reflectometry (TDR) is dependent upon the input pulse risetime to the system being evaluated.

Two different Time Domain Reflectometer systems were used in our evaluation:

* The basic theory of Time Domain Reflectometry is not discussed in this paper. For further information, refer to references 2, 3, and 4 as well as the general literature.

1. 28 ps risetime system
Hewlett-Packard 1430 A Sampler with 1105A/1106A Tunnel Diode Pulse Generator.

2. 150 ps risetime system
Hewlett-Packard 1415 A Time Domain Reflectometer. Using the appropriate accessory pads, we were able to degrade the risetime response to 500 ps; 1, 2, 5 and 10 ns.

The following are the responses of a precision 50 Ω Airline which was undercut to 75 Ω sections (Figure 14) as displayed on both risetime systems.

Using the delay of the pulse in air of 84.73 ps/in, and the fact that the TDR round trip time is twice the propagation delay, we get the theoretical response as: Round Trip Time = 84.73 ps/in X 2 = 169.46 ps/in.

Dimension (in)	Round Trip Time (ps)
0.625	105.91
0.500	84.73
0.250	42.36
0.125	21.18

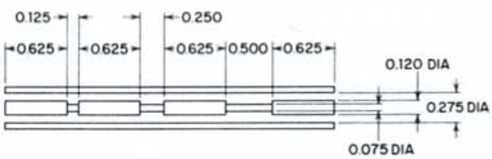


Fig. 14. Notched coaxial 50 Ω airline.

The theoretical response is plotted in Figure 15A using a scale of 100 ps/div. Comparison of this response with the 28 ps risetime response in 15B shows that the actual delay corresponds to the 50% points on the rise and fall of the response.

As one can see with the 28 ps risetime input, the individual discontinuities show up as discrete discontinuities, whereas in the 150 ps risetime response, they are merged in one overall reflection (Figure 15C).

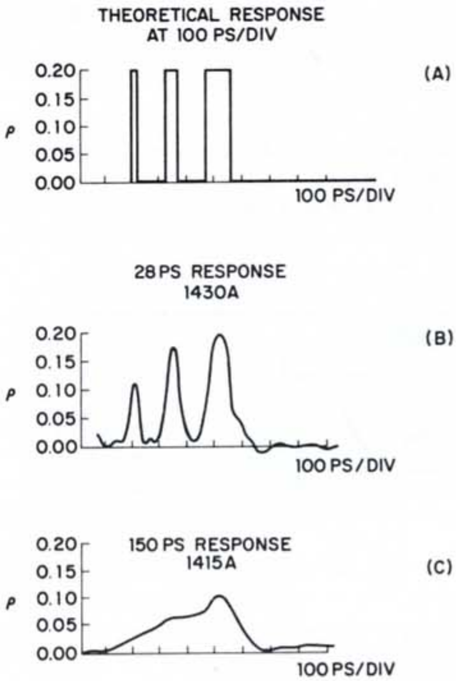


Fig. 15. Notched coaxial airline responses.

This ability to resolve various mechanical distances in time constitutes a new analysis tool in achieving an impedance matched contact system that did not exist with the slower risetime measurement systems.

The ability to resolve two adjacent discontinuities is a function of system risetime. The distance to a discontinuity on a coaxial line as displayed on a TDR[2] is shown in Figure 16.

$$X = \frac{C}{\sqrt{\epsilon_r}} \frac{RTT}{2} \qquad (1)$$

Where C = velocity of light = 11.802×10^{-3} in. /ps

ϵ_r = relative dielectric constant

RTT = round trip time, or elapsed time between input pulse and reflected pulse.

The distance between two adjacent discontinuities is:

$$X_2 - X_1 = \frac{C}{\sqrt{\epsilon_{r_2}}} \frac{RTT_2}{2} - \frac{C}{\sqrt{\epsilon_{r_1}}} \frac{RTT_1}{2} \qquad (2)$$

Where $X_2 > X_1$

$RTT_2 > RTT_1$

To simplify, if we are in the same dielectric media:

$$X_2 - X_1 = \frac{C}{\sqrt{\epsilon_r}} \frac{RTT_2 - RTT_1}{2} \qquad (3)$$

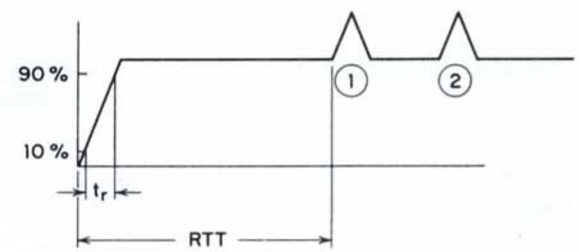


Fig. 16. Response of two adjacent discontinuities.

If $RTT_2 - RTT_1 = \frac{1}{2}$ system risetime t_r, the separate discontinuities merge into one single discontinuity.

The system risetime t_r is defined as the risetime up to the point of measurement. We assume the risetime is possibly degraded with each reflection.

$$t_r = \sqrt{t_{rg}^2 + t_{ro}^2 + \Delta t_1^2 + \Delta t_2^2 + \ldots \Delta t_n^2} \qquad (4)$$

Where t_{rg} = step generator risetime

t_{ro} = scope risetime

Δt_1 = difference in risetime before and after reflection 1

Δt_2 = difference in risetime before and after reflection 2

Δtn = difference in risetime before and after reflection n

If the reflections across each discontinuity are small (i.e., less than 10%, and are frequency independent (i.e., pure, real impedances), the transmitted wave, in going through these discontinuities, is not degraded with respect to risetime (i.e., 10 - 90% points on wave).

Consequently,

$$t_r \approx \sqrt{t_{rg}^2 + t_{ro}^2} \tag{5}$$

Therefore our resolution accuracy between adjacent discontinuities is

$$X_2 - X_1 \approx \frac{C}{\sqrt{\epsilon_r}} \quad \frac{t_r}{4} \tag{6}$$

For the Hewlett-Packard 1430A ps Sampler and 1105A/1106A Tunnel Diode Pulse Generator, the risetime is specified at < 35 ps.

For our system which exceeded specifications

$$t_r = \sqrt{t_{ro}^2 + t_{rg}^2} = 28 \text{ ps} \tag{7}$$

Consequently, the resolution accuracy becomes

$$X = \frac{0.0826 \text{ in}}{\sqrt{\epsilon_r}} \tag{8}$$

For the 150 ps TDR Hewlett-Packard 1415A, the resolution accuracy is

$$X = \frac{0.4425 \text{ in}}{\sqrt{\epsilon_r}} \tag{9}$$

Reflection Resolution -- Reflection resolution is allied with resolution accuracy relative to distance. The propagation delay though an impedance discontinuity of distance X is

$$RTT_2 - RTT_1 = \frac{2X\sqrt{\epsilon_r}}{C}$$

The magnitude of the reflection from this impedance discontinuity is

$\rho\, e(t)$

Where e(t) is a finite risetime ramp input with risetime t_r. Consider a finite input ramp with linear rise of t_r (Figure 17).

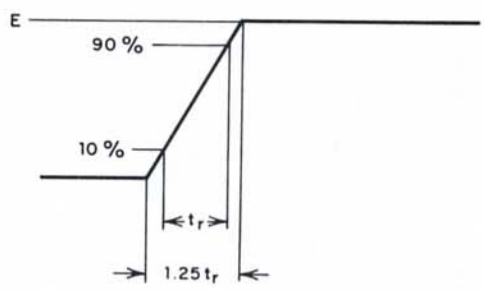


Fig. 17. Input ramp e(t).

For approximation purposes, we will neglect pulse aberrations such as preshoot, overshoot, and rounding because these parameters are small.

The waveform in Figure 17 can be represented by

$$e(t) = \frac{E}{1.25t_r}\, t\,U(t) - \frac{E}{1.25t_r}\, t\,U(t - 1.25t_r) \tag{10}$$

Where U (t) is the unit step.

Assume that an impedance discontinuity of length X exists at some distance down the line. The reflection at the point of discontinuity will have a magnitude ρ E and will reach the value ρ E in $\rho\, 1.25t_r$ ps (Figure 18).

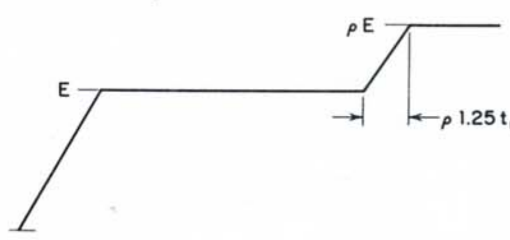


Fig. 18. Reflection response for e(t) input.

The duration of the discontinuity X in time is

$$\frac{2X\sqrt{\epsilon_r}}{C}$$

It will reach a final value of ρ E if

$$\rho\, 1.25t_r \leq \frac{2X\sqrt{\epsilon_r}}{C}$$

Consequently, we have developed a decision criteria as to whether our measurements are actually reaching the proper impedance level.

Substituting for $C = 11.802 \times 10^{-3}$ in/ps

$$\rho\, t_r \leq 13.56\sqrt{e_r}\cdot X \text{ picoseconds}$$

Where X is in inches

As this holds for both positive and negative reflections

$$|\rho\, t_r| \leq 13.56\sqrt{\epsilon_r}\cdot X \text{ picoseconds}$$

A plot of this decision level is included in Figure 19.

All readings for ρ below the line will be valid for the risetimes and relative dielectric constants indicated.

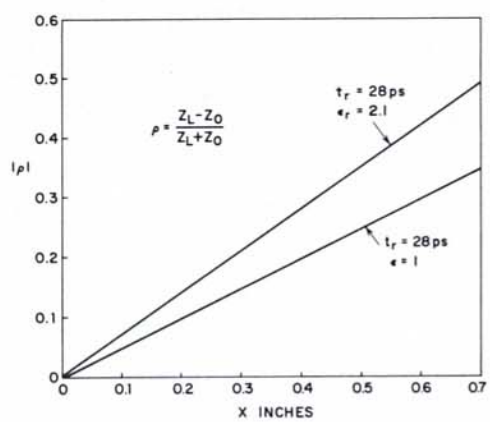
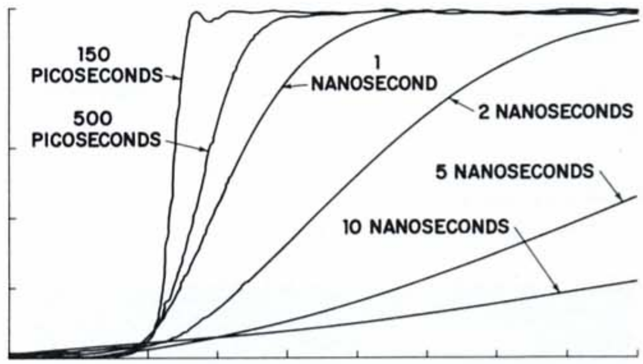


Fig. 19. Resolution accuracy for

$$|\rho| = \frac{13.56\sqrt{\epsilon_r}\,X}{t_r}$$

Finite Risetime Contact Characterization

As mentioned previously, various risetime pads are available for transmission system characterization. Since the resolution accuracy is a function of electrical length, reflection coefficient, and input risetime, we find that as the input pulse risetime is degraded by the use of the various pads, small discontinuities are not resolvable nor are of particular concern. Figure 20 shows the various input risetimes available. Figure 8 shows the serpent contact responses as they appear with various risetime inputs.



HORIZONTAL 400 PICOSECONDS / DIV
VERTICAL REFLECTION COEFFICIENT 0.2/DIV

Fig. 20. Time domain reflectometer step output to 50 Ω termination.
Note: Various risetime pads can be used as above to provide a variety of ramps to characterize transmission lines and connectors in finite risetime pulse transmission systems. The advantage of this method is that it reduces small discontinuities that are not of particular interest in the transmission system.

SERPCO RESPONSE

Lumped parameters do not exist with respect to a coaxial transmission system including a coaxial connector. All pertinent parameters are actually distributed in distance and time. Our inability to resolve these responses leads one to attribute a lumped parameter response to the various sections in time.

A connector such as serpco is best represented by an interconnection of short transmission lines of various impedances. Because the connector is only 0.76 in long in a mated condition between coaxial termination and uses, for the most part a Teflon dielectric $\epsilon_r = 2.1$, its theoretical electrical length is approximately 93 ps.

As displayed on the TDR, the contact delay would appear with a round trip time of twice the propagation delay or approximately 186 ps.

From the cross section of the contact system, there are basically three different transmission line sections which we can resolve with a 28 ps risetime step input (see Figure 21).

1. Coaxial cable termination section (1) and (5).

2. Design section (2) and (4)

3. Mating section (3)

For this risetime, our resolution accuracy is approximately 0.06 in.

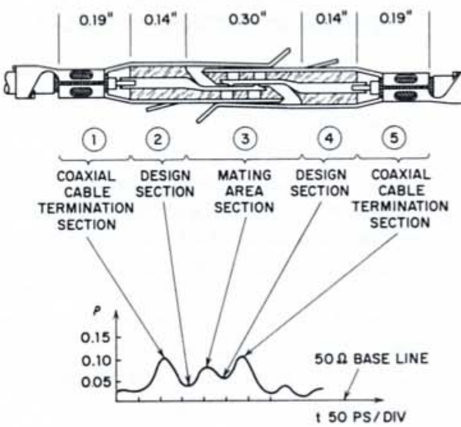


Fig. 21. Mated serpco impedance profile.

The hermaphroditic mated contact system is symmetric about the mating area. In this connector system, the reflection response is also symmetric about the mating area, as evidenced in the photos shown in Figure 22.

Relative to the actual responses shown, there is some time resolution obscurity because it is hard to define where each discontinuity actually begins and ends.

There is some spreading of the theoretical response as indicated previously in the notched airline response.

Taking the average reflections from the various contacts which were fabricated between the 50% points on the first rise and the last fall, the round trip time is approximately 200 ps as compared with the 186 ps theoretical delay calculation. Possible contributing factors to resolve this time obscurity are:

1. scope jitter, typically less than 20 ps, time base accuracy ± 3%, linearity ± 0.5%

2. risetime degradation.

3. pulse aberrations from sampler and pulser.

All things considered, this accuracy is the best the state-of-the-art offers in this type of measurement. What is relevant to this technique of analysis is that at least the three sections appear as discrete discontinuities in comparison with the 150 ps risetime response adjacent to the photos in which they are merged (Figure 22).

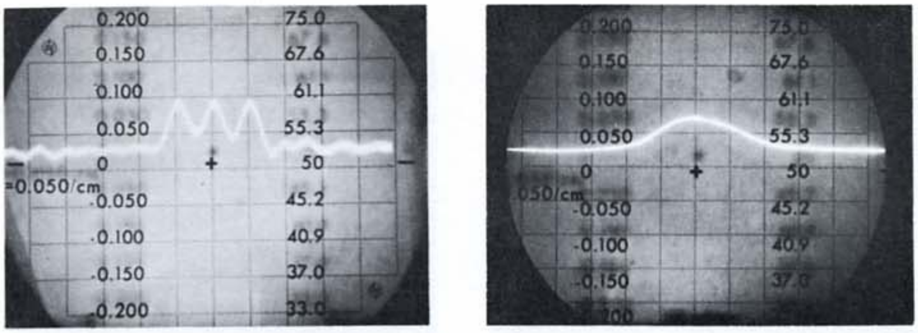
Contacts A and C represent glass filled polypropylene parts ($\epsilon_r = 2.5$) and have somewhat longer delays than the FEP parts whereas contacts B, D, E, and F are FEP ($\epsilon_r = 2.1$). All contacts appear relative to the impedance of the IBM coaxial cable on which they are mounted, which is typically 52.8 ohms, and to which the match was designed. Several designs as shown with different center conductor sizes are compared by the responses with the 150 ps, response shown adjacent to it.

Contacts D, E, and F pass the impedance design specifications of ± 5% in a 150 ps environment, whereas contacts A and B are ± 10%. Contact C had a larger design section and was intended as a 35 Ω development design.

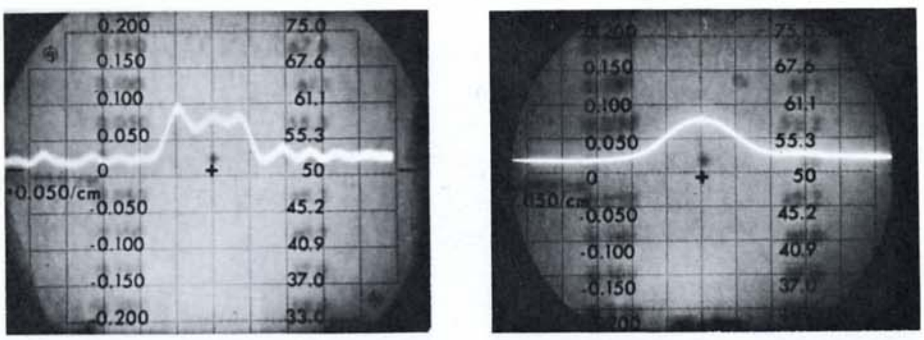
Using the serpco contact system, we can match other impedance coaxial cables by altering the center conductor pin size. As a performance comparison, three commercially available pin socket subminiature coaxial contact responses are shown in Figures 22 G, H, and I.

These contacts are not impedance matched to this risetime.

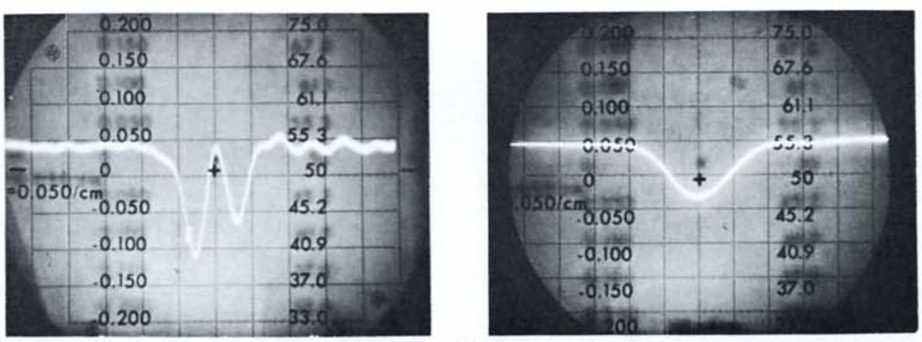
28 ps risetime response | 150 ps risetime response



A



B

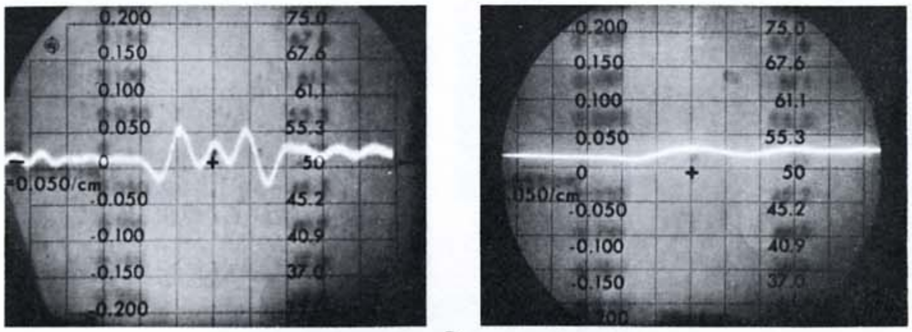


C

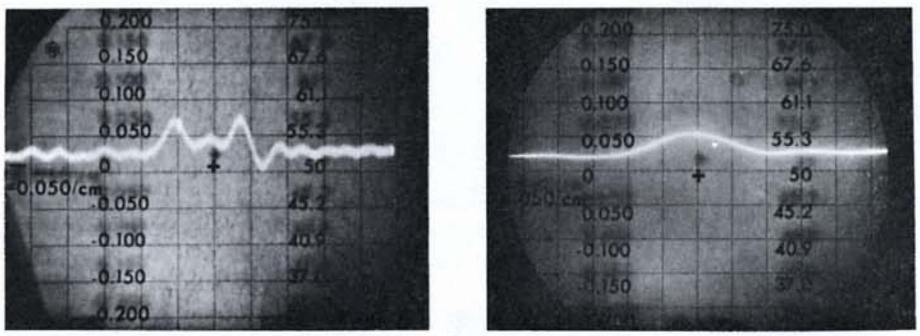
Fig. 22. Contact responses (28 ps and 150 ps).
Horizontal scale--100 ps/div.
Vertical reflection coefficient--0.05/div.
Note: The corresponding impedance scale appears vertically on right side of each photograph.

28 ps risetime response

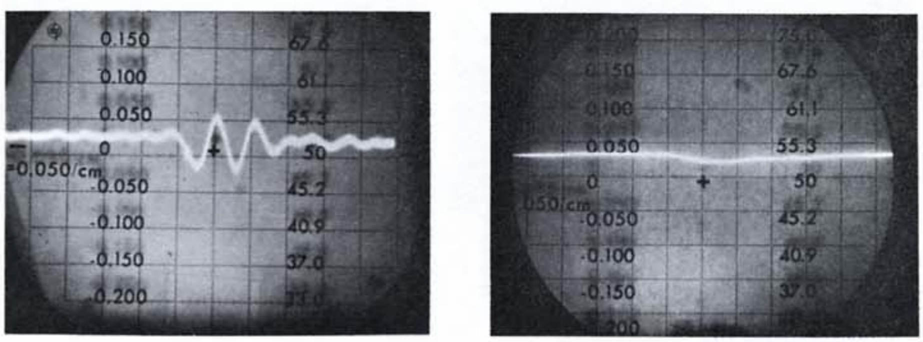
150 ps risetime response



D



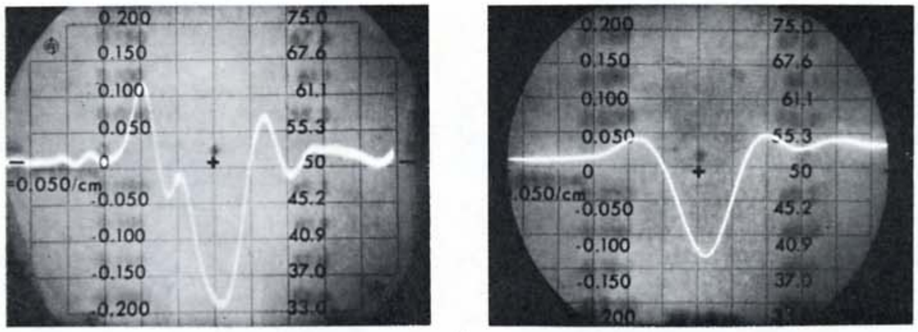
E



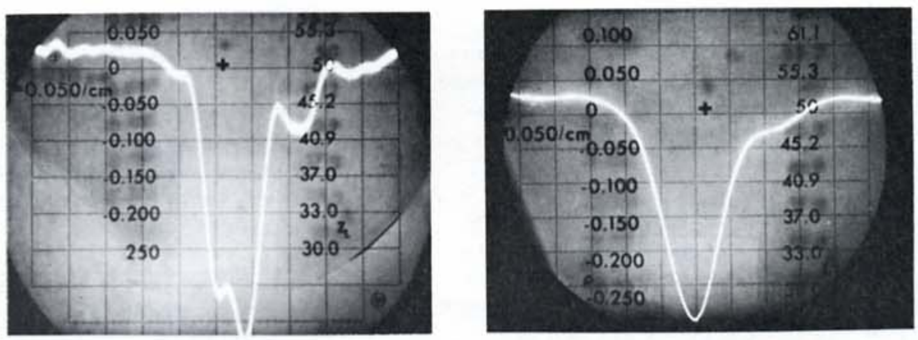
F

Fig. 22 (cont.).

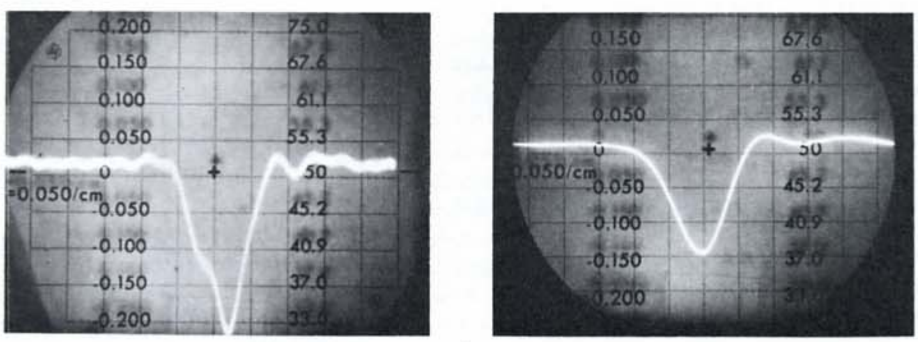
28 ps risetime response | 150 ps risetime response



G



H



I

Fig. 22 (cont.).

CONCLUSIONS

1. From the data taken to date we have demonstrated that predetermined electromechanical design objectives can be achieved in a practical and inexpensive contact design.

2. "Serpco," as a coaxial I/O contact system, could provide adequate performance in coaxial transmission systems with pulse transition times far less than the 150 ps design specification.

3. Although crosstalk test data is not discussed in this paper, we are conducting tests with various contact population densities. Due to the shielded impedance matched design, we foresee no major coupled noise problem.

4. Time domain analysis is <u>the</u> analysis technique for digital transmission system characterization and performance evaluation because it provides an accurate method of locating impedance mismatches relative to time and distance.

5. Computer-aided design, although only applied to a portion of the overall contact configuration in this paper, could be used through more complex boundary value analysis to ensure that a constant impedance cross section is achieved throughout the entire length of the contact system.

6. Hermorphroditic impedance matched contact designs are achievable on a miniature coaxial basis. They provide the ability to intermix coaxial signal lines with the previous serpent design, thus adding more flexibility in I/O applications.

This design concept produces the desirable mechanical feature of providing dual coaxial contact loadings through one beam member, while providing an electrically symmetrical plane of reference.

ACKNOWLEDGMENTS

The authors wish to thank Mr. Hayward W. Young for his mathematical analysis and preparation of the computer program to evaluate the various effects of mechanical tolerances on the design impedance. (See Appendix B.)

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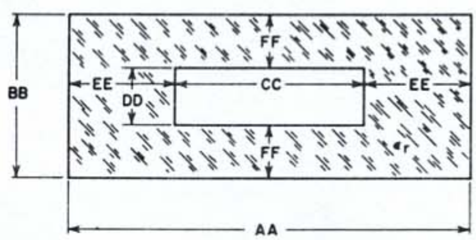
APPENDIX A

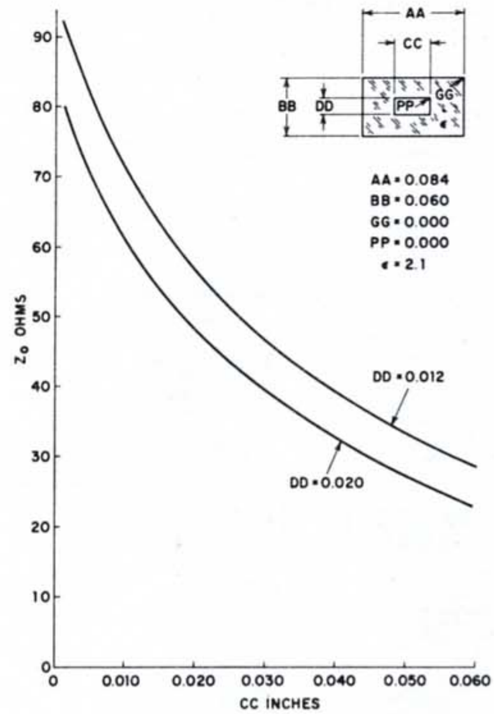
The general solution for a rectangular coaxial cross section was developed by Cruzan and Garver.[1] The closed form solution for the impedance based on the centered configuration below is given by:



$$Z_o = \frac{376.62}{\sqrt{\epsilon_r}} \quad \frac{1}{4\ CAP + 2\frac{CC}{FF} + 2\frac{DD}{EE}}$$

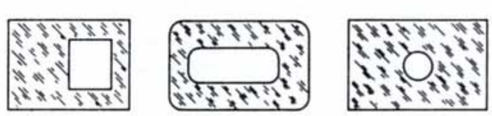
Graphs for CAP, the corner capacity, are given in Reference (1) and are not included in this paper. A computer program using the above formulation was written yielding a set of design data.

The following graph shows the impedance variations for our nominal design dimensions, and different center conductor sizes.



APPENDIX B

A computer program was developed to calculate the characteristic impedance Z_o of a pair of uniform conductors (separated by a homogeneous isotropic dielectric) having a cross section composed of a rectangle (with or without rounded corners) within a rectangle (with or without rounded corners) as below.



(A) (B) (C)

The method of solution was:

1. La Place's Equation is solved numerically for the potential at points within the dielectric.

2. The flux of a gradient of the potential through a surface enclosing the inner conductor is evaluated to give the net charge enclosed.

3. The capacitance per unit length is calculated.

4. The characteristic impedance is then calculated from the capacitance per unit length.

A closed form solution was not to be achieved using this analysis technique. Typical input data would be dimensions, dielectric constant, and radii. Output data yielded:

1. Capacitance

2. Z zero $\epsilon = 1$ air

3. Z characteristic ϵ_r = dielectric constant

This program has the capability of solving the most generalized cases of rectangular configurations and has applications for other transmission line designs and boundary value problems.

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