View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

NASA CR-103021

The Bendix Corporation
Electrical Components
Division

Sidney, New York 13838

Materials Investigation and Tests for the Development of Space Compatible Electrical Connectors

Final Report
Phase I
Task V
June 1 through
November 30, 1970

MSFC Contract
NAS8-26054

Prepared for
National Aeronautics and
Space Administration
George C. Marshall
Space Flight Center
Huntsville, Alabama
35812

Bendix **Electrical Components Division**

The Bendix Corporation
Electrical Components
Division

Sidney, New York 13838

Materials Investigation and Tests for the Development of Space Compatible Electrical Connectors

Final Report
Phase I
Task V
June 1 through
November 30, 1970

MSFC Contract
NAS8-26054

Prepared for
National Aeronautics and
Space Administration
George C. Marshall
Space Flight Center
Huntsville, Alabama
35812

Report

Materials Investigations and Tests for the Development of Space Compatible Electrical Connectors

Final Report

Phase I
Task V
(June 1 through November 30, 1970)

MSFC Contract NAS8-26054

Prepared by D.E. Clark date 18 DEC. 1970
D. E. Clark, Supervisory Engineer

J.E. McKeown date 18 DEC 1970
J. E. McKeown, Staff Engineer

Approvals by D.E. Michel date 12-18-70
D. E. Michel, Chief Engineer, Microelectronic Connections

John J Tyne date 12-18-70
J. J. Tyne, Chief Engineer, Electronic and Test Labs.

W.F. Hennessey date 12-18-70
W. F. Hennessey, Program Manager

Prepared for

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Huntsville, Alabama 35812

By

The Bendix Corporation
Electrical Components Division
Sidney, New York 13838

Abstract

As improved semiconductor devices become available, it is anticipated that faster digital pulses will be used to transmit digital information between circuits and systems. The work conducted in this survey indicates that conventional multipin electrical connectors will become inadequate to transmit this information as pulse rise times enter the sub-nanosecond region. This work outlines, in a broad sense, techniques which are capable of determining the threshhold of these rise times in existing connectors. Recommendations are made indicating that further work should be conducted to establish limits of adequacy of existing connectors for such applications.

Table Of Contents

Final Report - Phase I

Task V

Digital Efficiency

1.0 Introduction

1.1 The work reported here is part of a program covering Materials Investigations and Tests for the Development of Space Compatible Electrical Connectors. Task V is concerned with the effects of interconnect systems on the transfer of high speed digital signals.

2.0 Objective

2.1 The object of this task was to determine if present or future digital pulse information is or will be deleteriously affected by interconnects, such as cable-connector combinations, in the following parameter areas:

a. Wave Form Distortion With Respect to:
   1. Rise Time Characteristics
   2. Pulse Width
   3. Fall Time Characteristics
   4. Repetition Rate
   5. Phase Shift
   6. Amplitude Changes

b. Signal Change Due to Short Term Discontinuities.

c. Circuit to Circuit Crosstalk

d. Limitations on Integrated Circuit Fan-out Capabilities

3.0 Summary and Recommendations

3.1 Through literature searches and information obtained from digital equipment suppliers, it has been established that to increase the capabilities of digital controlled systems, efforts are being made to shorten the rise time and width of the digital pulse. At the same time efforts are being made to increase the repetition or clock rate pulse chains to meet future needs.

3.2 The losses in transmission lines and electrical interconnecting mechanisms affect the fidelity of transmitted pulses, and these losses increase with increasing frequency. In particular it is evident that as pulse rise times and widths continue to decrease, the conventional pin and socket multipin connectors will prove to be too lossy to serve as digital system interconnects. At the same time it is evident that presently available test methods are marginal for test work in the sub-nanosecond and picosecond time range. Thus the limitations of an electrical connector and its suitability for a specific digital application cannot now be determined in advance with certainty.

3.3 The conclusions derived from the study reported here indicate that further consideration is needed in the following specific areas:

a. Development of test methods suitable for establishing the limits of operation for interconnects in digital systems.

b. Measurement of multi-channel connector impedances in circuits handling fast digital pulses.

c. Measurement of pulse rise time, duration, and repetition rate capabilities of multi-channel connectors currently in use in circuits dealing with fast digital pulses.

d. Evaluation and determination of acceptable levels of cross-talk in multi-channel connectors currently being used.

e. Determination of ageing effects on the parameters determined in a, b, and c above.

3.4 At the completion of this task, if so dictated by the work outlined above, further effort should be directed toward the development of specific multi-channel connectors which are capable of dealing with anticipated rise times, signal levels, and pulse repetition rates in future applications.

4.0 Discussion

4.1 The digital pulse is the controlling parameter in such digitized equipment as computers, guidance systems, and multiplexing systems as to their ability to receive, store, retrieve, and display information in large quantities at rapid rates within reasonable equipment physical size and weight limitations.

4.2 The shape, amplitude, and repetition rate of the digital pulse are the pulse parameters which govern its ability to perform the necessary information transfer functions within a given digitized system. The normal shape of the digital pulse can be classified as square wave in nature. Figure 1 is a diagram which defines such parameters as rise time (T_1) pulse width (W) fall time (T2) and repetition rate (T) as time parameters. The amplitude (A) is usually defined as a voltage parameter.

4.3 The ability of a particular digital system to originate a defined pulse shape, transfer the pulse shape, and receive the pulse shape, meanwhile maintaining the pulse's integrity, can be defined as the digital efficiency of the system. The origination, transfer, and receive functions within a system will repeat many times during operation so that a loss of digital efficiency, though minor in nature on a one time basis, could, if repeated often enough, result in a complete degradation of the pulse shape to the point where system error or malfunction would result.

4.4 The objective section of this report defines those areas of possible pulse degradation that may result during the pulse transfer operations within a system. It addresses this study to the problems encountered from interconnect devices such as cable-connector combinations, with emphasis on the connector.

4.5 The study will:

a. Determine if interconnect problems exist in present system pulse transfer techniques.

b. Determine if interconnect pulse transfer problems will be aggravated in future systems.

c. Outline a detailed follow-on program for actual measurement and evaluation of connectors in use on present digital systems.

d. Outline an evaluation of proposed Phase I connector materials for their electrical properties as to their future application in improved design digital connectors.

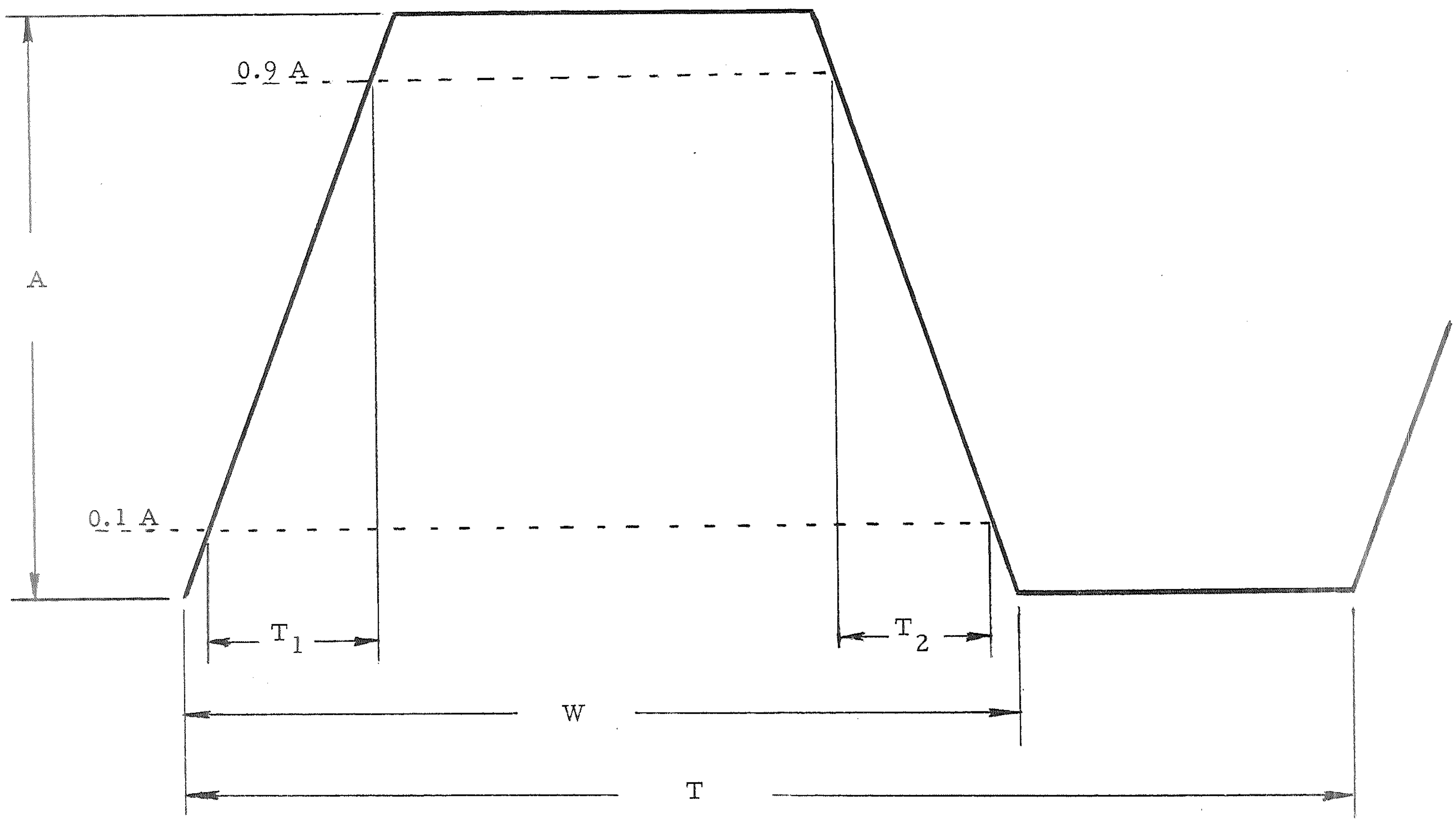

Figure 1. Digital Pulse Diagram.

5.0 Detailed Report:

5.1 Course of Action:

5.1.1 The study of digital interconnects and their related problems in pulse transformation was conducted as follows:

a. A search for pertinent literature on the subject was conducted in our library at Electrical Components Division (Bendix-ECD).

b. A letter survey was submitted to sixteen knowledgeable computer and avionic companies. The survey requested information pertaining to present and future problems relating to interconnects within their systems.

c. Follow-on telephone conversations were held with those respondents to the survey to determine if a personal visit would be necessary to obtain additional information.

d. Discussions were held at Bendix-ECD with several technical representatives of companies who manufacture test equipment used in digital type measurements.

e. A literature search was also conducted at our request by NASA Headquarters in Washington, D. C. The search was performed using a new technique: NASA/Recon. NASA/Recon is a direct-access, time shared, information retrieval service.

5.2 Review and Discussion:

5.2.1 In order to increase the capabilities of digital controlled systems, designers have been attempting to shorten the rise time and the pulse width of the digital pulse, while at the same time increasing the repetition or clock rate of pulse trains.

5.2.2 Prior to the advent of the present integrated circuit (IC) technology, pulse generation was limited in the 1930's to 1940's by inherent properties of vacuum tubes, mechanical switches and relays, and their related discreet component circuitry. The digital pulse in most cases was defined as to time parameters in milliseconds. They could be classed as hertz or kilohertz systems with respect to circuit pass band and wave length limitations.

5.2.3 The transistor and diode-resistor networks began to replace the earlier vacuum tube and mechanical devices by the mid-1950's. As the types of transistors multiplied, their rise time was less limited due to improvement in junction forming technology. The digital pulse generation capabilities had reached the microsecond range and was approaching the nanosecond range by the late 1950's. Most circuits consisted of discreet components. Even with the advent of printed circuit board techniques, the systems could be classified as megahertz systems.

5.2.4 Semiconductor technology continued to improve to the point where frequency generating capabilities within the junction approached a 4 gigahertz gain-pass band property. This made possible pulse rise time in the nanosecond time range. The semiconductors failed to achieve their capabilities consistently due to losses introduced by the hermetic packaging and necessary circuit connecting wires to the various semiconductor junctions. This was undoubtedly the first evidence of interconnect limitations on digital pulse generating systems.

5.2.5 The IC technology which became practical in the middle 1960's aided in reducing junction interconnect limitations by making possible shorter wiring techniques and also better control as to placement of interconnects. Compensation could be designed into the IC circuit to overcome many of the IC interconnect wiring losses and impedance mismatch losses. At the same time tunnel diode pulse generating devices in a chip form gave theoretical performance capabilities of 7 to 10 picosecond rise times. When placed in their operational environment the actual rise times were increased to approximately 20 picoseconds. The above technology improvements made possible a gigahertz generating system.

5.2.6 From the mid 1960's to the present time articles in trade and professional journals began to appear warning of cable-connector problems associated with the transmission of microwave frequencies necessary to assure the integrity of these picosecond or sub-nanosecond pulse rise times.

5.2.7 During this time interval more and more digital functions were being incorporated on a single chip resulting in the use of many medium scale integrated (MSI) systems to make up a complete digital operated system, such as a computer. The shift to MSI systems, has reduced the number of conventional cable-connector system interconnects within a functional digital system, but has not eliminated them. Interconnects will be required until systems such as a complete operational computer can be placed on a single chip,achieving the ultimate in large scale integration, (LSI). Some authorities feel the practicality of such an LSI system will not be achieved until the 1980's.

5.2.8 The MSI systems of today and in the next decade use the mother-daughter board concept to package the digital circuitry, making necessary the use of some form of cable-connector combination to marry the various board configurations into a complete digital system. In addition, cable-connector combinations are necessary to tie interface hardware such as remote programmers and readout devices to the digital system. The interface hardware cable-connector in some form will undoubtedly always be necessary even with the successful advent of complete LSI digital systems.

5.2.9 The study indicated that there are two areas in a digital system where interconnects will be a problem in the next 10 to 15 years. These areas are:

a. Where cable-connectors will be necessary to interconnect circuit boards within a system to facilitate function changes, ease of assembly, and serviceability.

b. Where cable-connectors will be necessary to interconnect a given digital system to its remote interface hardware.

The problems and solutions related to digital pulse transmission will be similar in both areas, with the former being more severe in nature in the immediate future.

5.3 Survey - General

5.3.1 The detailed survey which follows, while placing the heavier emphasis on the in-system interconnect problem, especially in the connector area, does not preclude relating the results to the interface hardware interconnects where digital pulses must be transmitted between two or more remote locations.

5.3.2 The Digital Pulse:

5.3.2.1 Factors that influence digital pulse transmission have been defined by many authors in the referenced articles. The following equations are from these references and have not been verified as to their correctness or source.

5.3.2.2 A digital pulse whose shape is represented by Figure 1 has a rise time of T_1 to traverse an amplitude change of 10% to 90% of its maximum amplitude. As T_1 approaches zero, the number of frequencies which must be generated and transmitted approaches infinity. Since T_1 has a finite value, a relationship between a particular rise time and its upper frequency component exists.

Eq. 1 $FT_1 = K$

where F is the upper frequency in MHz,
T_1 is the rise time in microseconds,
$K = .35$, where the rise time overshoot must be limited to 2 or 3 percent of the maximum. Table 1 was calculated from equation 1 and shows presently used and future possible digital pulse rise times and their upper frequency components. The electrical length of an interconnect device is,

Eq. 2
$$\lambda = \frac{300 \times 10^6}{\sqrt{E_R}\;F}$$

where:
λ = wave length in meters
300×10^6 = velocity of light, in meters/second
F = frequency in hertz
E_R = relative dielectric constant of medium

Table 1

Rise Times Vs. Frequency & Wavelength

Rise Time - T_1	Upper Frequency -F	Wave Length γ = meters in air (E=1)
10 microseconds	35 khz	8580 meters
1 microsecond	350 khz	858 meters
100 nanoseconds	3.5 mhz	85.8 meters
10 manoseconds	35 mhz	8.58 meters
1 nanosecond	350 mhz	.858 meter
100 picoseconds	3.5 ghz	.0858 meter
10 picosecond	35 ghz	.00858 meter
1 picosecond	350 ghz	.000858 meter

5.4 Survey Specific:

5.4.1 The results of companies surveyed are summarized in Table 2. Relating the results of the companies surveyed for present pulse rise times in Table 2 with Table 1 does show why interconnect problems appear to be minimal on present digital systems. If the present 100 picosecond rise time of company B is excluded for now from the analysis, the present digital rise times appear to fall between a maximum of 5 microseconds to a minimum of 10 nanoseconds. This means the upper frequency which must be transmitted undisturbed is from 70 KHz to 35 MHz.

TABLE 2

RESULTS OF DIGITAL INTERCONNECT SURVEY

COMPANY	RISETIME		AMPLITUDE		PULSE WIDTH		FALL TIME		REPETITION RATE		TEST METHOD	TYPE CONNECTOR NOW USED	REMARKS
	PRESENT	FUTURE	PRESENT	FUTURE	PRESENT	FUTURE	PRESENT	FUTURE	PRESENT	FUTURE			
A	10 NANOSECOND	<1 NANOSECOND	5 VOLT	5 VOLT	60 NANOSECOND	<5 NANOSECOND	5 NANOSECOND	< 1 NANOSECOND	8 MHZ	100 MHZ	NAVORD WS6157 WS6119	PRINTED CIRCUIT TYPE NAVORD WS 615712D	
B	100 PICOSECOND	1 PICOSECOND	100 μ VOLT	1 μ VOLT	100 PICOSECOND	1 PICOSECOND	100 PICOSECOND	1 PICOSECOND	100 PICOSECOND	1 PICOSECOND	IN CIRCUIT TEST	BOARD MOUNTING RECTANGULAR TYPE	EDGE BOARD CONNECTOR NOT USED
C											MIL-STD-188	VIKING, EECO WIRE WRAP	
D	5 MICROSECOND	1 MICROSECOND	5 VOLT	5 VOLT	20 MICROSECOND	3.5 MICROSECOND	5 MICROSECOND	1 MICROSECOND	25 MHZ	100 MHZ	IN CIRCUIT	DP SERIES BX TYPE F	CURRENT LOGIC TTL IMMEDIATE FUTURE COSMOS FUTURE LOGIC ECL
E	10-20 NANOSECOND	2-10 NANOSECOND	3-5 VOLT	2-5 VOLT	50-100 NANOSECOND	20-500 NANOSECOND	5-10 NANOSECOND	2-10 NANOSECOND	200-800 NANOSECOND	100-1000 NANOSECOND	NONE	BX CE SERIES S POL	
F	10-200 NANOSECOND	3-1000 NANOSECOND	.002-10 VOLTS	.002-10 VOLTS	.02-100 MICROSECOND	.02-100 MICROSECOND	10-200 NANOSECOND	3-1000 NANOSECOND	0-5 MHZ	0.36 MHZ	IN CIRCUIT TEST	PIN TYPE ITT TYPE MDM	

KEY	COMPANY
A	BENDIX NAVIGATION AND CONTROL DIVISION, TETERBORO, N.J.
B	IBM, OWEGO, N.Y.
C	BENDIX COMMUNICATION DIVISION, BALTIMORE, MD.
D	BENDIX ELECTRODYNAMICS DIVISION, NORTH HOLLYWOOD, CALIF.
E	BENDIX RESEARCH LABORATORIES, SOUTHFIELD, MICH.
F	SOURCE NOT DEFINITE

5.4.2 The present average relative dielectric constant in most transmission mediums is 4.0. (See Table 3 for various dielectric material parameters.) This means the wavelength, or one electrical length, for transmission interconnects will be between 214 to 4.18 meters, or 700 to 13.7 feet. If cable-connector lengths have had physical lengths which were much less than one quarter of these electrical lengths (175 to 3.4 feet), then degradation of digital pulses due to influences introduced by mismatch and changes in velocity constant would have been minimal. Also the effects of capacity loading due to interconnects would be less a factor at the above 35 MHz frequency limit. When rise times approach 1 nanosecond and less, then cable-connector electrical lengths decrease to fractional parts of an inch, and the effects on pulse shape with respect to velocity constant and electrical parameters, such as distributed capacity, inductance, and AC resistance of the interconnect must be considered.

5.4.3 The future rise time goals within the next 5 to 10 years for four of the five companies who responded shows that rise times are expected to be between 3 nanoseconds to 1 picosecond. The 1 picosecond goal is from the same company who is presently achieving 100 picosecond rise times. This same company has performed their own development on connectors for digital pulses, recognizing an existing problem.

5.4.4 As pulse times decrease, the present circuitry now in use appears to limit their amplitude. The normal digital pulse today is 5 to 8 volts in amplitude. Future pulse amplitudes are trending to millivolt and in some cases, microvolt levels. This will undoubtedly place limitations of pulse fanout capabilities assuming complementary improvements in line driver capabilities. Losses or vibration induced noise from connectors would be more noticeable to these low level pulse signals.

5.4.5 Cables

5.4.5.1 The coaxial cable is the preferred way to transmit picosecond-time digital pulses, followed closely by stripline transmission lines. They may in the future be replaced for some applications by laser beam transmissions.

5.4.5.2 As a point of interest, experimental work with laser beam transmission has progressed to the point where scientists have observed laser pulses as short as 1 picosecond in duration. Their application to digital pulse transmission systems in some form is certain to appear in the future.

5.4.5.3 The losses in present coaxial transmission lines affect the fidelity of the transmitted pulse. These losses appear as conductor or copper losses and as medium or dielectric losses and are as follows:

Eq. 3 Copper loss $A_{cu} = \left[\frac{0.434}{Z_o}\left(\frac{1}{d} + \frac{1}{D}\right)\right]F^{\frac{1}{2}}$ db/100 FT

Eq. 4 Dielectric loss $A_d = \left[2.78\ E_R^{\frac{1}{2}}\ R_P\right]F$ db/100 FT

Where D = diameter of inner surface of outer conductor, inches
d = diameter of outer surface of inner conductor inches
F = frequency, megahertz
E_R = relative dielectric constant at frequency F
R_p = power factor of dielectric at frequency F
Z_o = characteristic impedance of coaxial cable in ohms.

A study of Equations 1, 3, and 4 shows that losses within a coaxial line will increase as pulse rise times decrease and their upper frequency components increase. Both losses increase with increasing frequency. The effects of these losses on pulse shape is to attenuate the higher order of frequency components necessary to form and maintain the rise time slope. The result is a delay in or a longer rise time. For example, one foot of RG-9/u cable will increase an ideal (zero rise time pulse) to 20 picoseconds, while 8 to 10 feet of RG-58/u cable will increase the same ideal pulse to 1 nanosecond. Furthermore, the rise time does not necessarily vary linearly with length.

5.4.6 Connectors:

5.4.6.1 The amount of degradation to the digital pulse contributed by the connector in the inter-connect system has not been clearly defined by any literature studied or companies surveyed in this program. Several reasons for this lack of information on connectors can be advanced, and are as follows:

a) Some companies surveyed stated that connectors were a problem in their digital circuits, but when questioned further, could not define these problems such that a separation of electrical from mechanical problems could be determined. Table II also shows that most companies do not use methods of test to determine source and cause of component failures. They generally rely on "in circuit" testing and "debugging" on a system by system basis.

b) The connector has not been a culprit on most digital systems to date, as its electrical length has been short relative to the resulting pulse induced wave lengths.

5.4.6.2 The second reason appears the more valid of the two since the connector, while subject to the same loss factors as the cable, is several orders of magnitude physically smaller than most cable systems in use today. Where connector loss and impedance mismatch problems have been severe, high quality single circuit coaxial connectors are employed. Some typical coaxial connectors in use are the Amphenol precision 7-mm type APC-7, the General Radio GR type 874, and the 3-mm OSM connector.

5.4.6.3 Multipin connectors are in use in various forms for multi-interconnecting digital circuit boards and also to interface hardware. These connectors consist of the cylindrical MS and Pygmy types, the rectangular printed circuit, rack and panel, flat cable, dip socket, and TJS terminal junction system types. Most have appeared with one or more coaxial contacts installed in place of some of their normal pin and socket arrangements. These have been introduced at specific digital user requests where certain circuits passing through a particular connector must be controlled for losses due to the dielectric or impedance mismatches. The coaxial system also minimizes circuit to circuit crosstalk.

5.4.7 Multipin Connectors - Pin and Socket:

5.4.7.1 As pulse rise times decrease the conventional pin and socket multipin connectors will prove too lossy to serve as digital interconnects. These losses will occur mainly in the form of dielectric losses and pin to pin impedance mismatch losses. These losses will make it impossible to achieve narrower pulse widths and also increased repetition rates when they reach the picosecond rise time range. The common forms of pin and socket arrangements within their dielectric inserts will increase their circuit crosstalk potentialities.

5.4.7.2 Some typical dielectrics used in connector inserts are shown in Table 3 along with their relative dielectric constants and dissipation factors measured at 1 megahertz.

Table 3

Insert Dielectrics

Material	Die. Const.	Diss. Factor
Phenolic Mineral Filled	9-15	.07 - .20
Melamine Glass Fiber Filled	6.5-7.5	.013-.015
Alky D Glass Filled	5.2-6.8	.008-.023
Diallyl Phthlate Glass Filled	3.4-4.5	.009-.014
Silicone Glass Fiber Filled	3.2-4.7	.002-.020
Polycarbonate Glass Filled 10-40%	3.0-3.4	.007-.008

5.4.7.3 As stated in Equation 4, the dielectric loss at a given frequency is a function of the materials relative dielectric constant, E_R and its power factor or dissipation factor, R_P. The materials shown in Table 3 are mainly composite or filled materials whose mix proportions can vary. These mix variations are known to affect their electrical properties at the normal low frequency (1 MHz) measurement ranges. Very little is known about their behavior in the microwave frequency range. Physical arrangements of the contacts within the dielectric can give an infinite number of combinations of characteristic impedance for pair arrangements within a connector shell as shown by Equation 5 and Figure 2. A balanced shell shielded contact pair is used for example purposes.

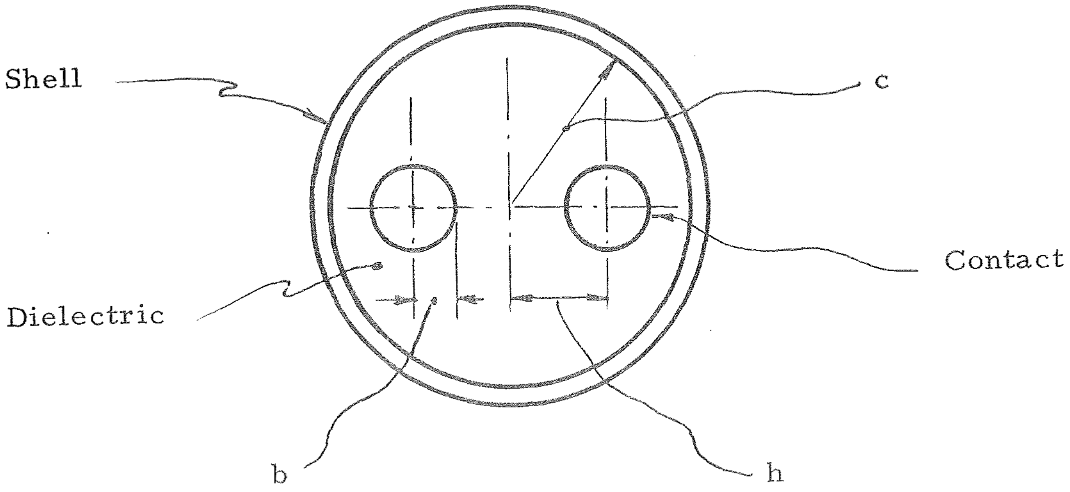

Figure 2 Shield Pair Balanced 2 Contact Connector

5.4.7.4 Equation 5 shows that the characteristic impedance of two contacts within a multipin connector is not only dependent upon the dielectric constant of the insert material, but also upon the contact's diameter, their spacing from each other, and their position distance from the inner diameter of the connector shell.

Eq. 5

$$Z_0 = \frac{120}{\sqrt{E_R}} \left[2.303 \ \mathrm{LOG} \left(2V \, \frac{1-\sigma^2}{1+\sigma^2} \right) - \frac{1+4V^2}{16V^4} \left(1-4\sigma^2 \right) \right]$$

Where: E_R = Relative Dielectric Constant of the Insert

$V = \frac{h}{b}$

$\sigma = \frac{h}{c}$

5.4.7.5 Variations of Equation 5 for cylindrical and rectangular type connectors versus various pair diameters, spacing, and position could be performed on a computer and would result in a large number of impedance values in today's more common connectors.

5.4.7.6 This exercise would yield nothing other than their inadequacy if an attempt were made to use them to transmit picosecond pulses where they must be impedance matched into 50, 75, 93, and 300 ohm source and detector pulse circuitry.

5.4.7.7 Another area where connectors of this type may prove their pulse transfer inadequacy is in the typical physical design areas of a pin and contact arrangement. Equation 5 assumes that radius b is constant throughout its length. This is not true of most pin and socket contacts. There are diameter undercuts on most, used for contact retention within the dielectric. There are also diameter changes at the mating areas of the pin to socket which vary in length, dependent upon insertion tolerances. These diameter variations can be as long as .250 inch in length for a size 20 contact. A time domain reflectometer (TDR) measurement using a 28 picosecond rise time pulse would show these diameter changes as impedance discontinuities along the length of the contact.

5.4.8 Pulse Measurement and Standards

5.4.8.1 As this study was pursued several additional factors pertaining to picosecond rise time generation became apparent. These factors were

(a) lack of a rise time standard for calibrating test equipment, and
(b) a scarcity of test equipment capable of measuring and displaying picosecond rise time.

5.4.8.2 The National Bureau of Standards has been working for two years on a rise-time calibration service (Page 43 E. D. N. March 1, 1970). The standard for this service will be a sampling scope whose response has been evaluated in the frequency domain. Its amplitude response was measured to 18 GHz, and its phase response to 9 GHz. Pulse voltage down to 1 volt amplitude will be measured from 20 picoseconds (at about 25 percent uncertainty limit), to 100 picoseconds (at better than 5 percent uncertainty limit) and on up (with 2 to 3 percent uncertainty limit). The pulse width will be limited to 300 picoseconds.

5.4.8.3 Realtime oscilloscopes such as the Hewlett-Packard model 183A has a band width of 250 MHz, and is the widest gain-band width oscilloscope on the market to date. The rise time of these scopes is 1.5 to 3.5 NS. The rise time measurement (T_1) is limited by the square root of the sum of the squares of pulse generated (T_G) and the pulse received (T_R).

Eq. 6 $$T_1 = \sqrt{(T_G)^2 + (T_R)^2}$$

For this reason these oscilloscopes would not be adequate for viewing picosecond pulses.

5.4.8.4 Sampling scopes with band widths in the gigahertz frequency range are available for pulse measurement. A 50 picosecond pulse rise time would have to be measured with a sampling scope whose band width was at least 7 GHz to meet the requirements of Equation 1. The sampling scope is limited by the fact that the pulse must be repetitive although with some scopes, the repetition need not be periodic. Also, jitter and drift can be limiting factors.

5.4.8.5 For component evaluation to pulse response, such as interconnects, the time domain reflectometer (TDR) is considered by most authorities in the field as the best instrumentation available today. Present state of the art TDR instrumentation can produce 35 picosecond pulse rise times. They can differentiate circuit impedance discontinuities as short as .250 inch.

6.0 Conclusions

a. Connectors have not been a severe source of digital pulse degradation where pulse rise times, pulse widths, fall times and repetition rates have been greater than 1 nanosecond in duration. This is due to the fact that operating wave length has been considerably larger than the connector electrical length.

b. The losses in pulse forming and receiving circuitry have exceeded those in connectors until the recently new advances in MSI technology which may alter this situation.

c. Connectors of future digital circuit technology will prove a limiting factor in signal transmission in both the area of circuit interconnects and the area of interface hardware interconnects. These limiting factors are as follows:

1. Slowing the pulse rise times by their losses.
2. Limiting the shorter pulse width capability.
3. Increasing pulse fall time.
4. Limiting faster repetition rates.
5. Pulse distortion may occur due to amplitude changes and jitter caused by contact movement from shock or vibration which may introduce transients or "glitches" on the incoming pulses.

6. Phase shift may occur through the connector due to impedance shifts from reactive impedance changes through the connector.

7. Fan-out of signals may be limited, where connectors introduce excessive losses to low level millivolt or microvolt pulse signals.

7.0 Detailed Recommendations

7.1 Introduction

7.1.1 As a result of the work conducted by this division of The Bendix Corporation under the sponsorship of the Marshall Space Flight Center on Phase I of the Materials Investigation and Tests for the Development of Space Compatible Electrical Connectors, it is evident that problem areas associated with the digital efficiency of connectors are eminent. As the need to deal with digital data at higher speeds increases, the digital efficiency of multi-channel connection mechanisms must also increase. Very little work has been conducted in industry on the problem of the digital efficiency of connectors and, in general, test methods have been confined to "in circuit tests". This approach, although satisfactory for existing needs, does not lend itself to establishing limits of operation in multi-channel connection mechanisms until problems become apparent.

7.1.2 It is, therefore, proposed that this division undertakes the task of developing test methods to define these limits. Having established these limits, testing on selected types of connectors will then be conducted to determine where these devices are no longer serviceable with respect to rise time, pulse duration, and pulse repetition rate.

7.2 Problem Statement

7.2.1 The final report pertinent to Task V, Phase 1 of the Materials Investigation and Tests for the development of Space Compatible Electrical Connectors indicates that, within the next 5 to 10 years, rise times in the order of picoseconds are expected in digital circuits. Due to this very fast rise time, pulse amplitudes will be restricted to 1 volt or less. The ability of existing multi-channel electrical connection mechanisms to deal with these speeds and amplitudes has not been clearly defined due to lack of available information. It also appears to be doubtful if existing connectors are capable of dealing with pulses having such parameters.

7.2.2 In dealing with pulses having sub-nanosecond rise times, small amplitudes and fast repetition rates, test and calibration equipment is extremely scarce. Some manufacturers do, however, sell equipment which is just adequate to observe and test the transmission of these fast pulses through networks.

7.2.3 It is, therefore, felt that further work should be conducted to develop test methods and techniques which can be used to define limiting parameters associated with the digital efficiency of existing connectors.

7.2.4 Although the above referenced report indicates that problems due to mechanical shock and vibration can exist in connectors handling fast digital pulses, it is felt that such problems would, by virtue of the relatively large mechanical masses associated with connectors, exhibit themselves by much longer duration effects such as completely missing portions of the signal for periods of time approaching or exceeding a millisecond duration. Such absence of signal would be apparent in connectors currently in use. The limitations of existing equipment to measure discontinuities are presently in the nanosecond range and further advances on these capabilities are limited by the state of the art. It is, therefore, felt that any test on these parameters would not provide satisfactory limits and conclusions. For these reasons, it was decided to omit testing in these areas.

7.2.5 In this portion of the work, it is proposed that test methods be established to determine impedances, rise time capabilities and cross talk limitations of existing connectors. It is further proposed that these specific tests be conducted on selected samples of connectors which are currently being used in circuits dealing with fast digital pulses in order to determine their limitations.

7.2.6 As this work progresses, observations will be made concerning the limiting factors and, if necessary, recommendations will be made as to how these frequency limitations can be improved in future connectors.

7.3 Planned Approach:

7.3.1 In this effort, it is planned to reference the work to three areas of testing as follows:

a. Impedance measurement which will be accomplished by frequency domain techniques.

b. Pulse rise time measurement as indicated by time domain testing.

c. Cross talk as determined by signal level detected on inoperative lines.

7.3.2 When the tests have been established, it is planned to select nine types of connectors to be tested and, by altering pin size and configuration, a total of 200 tests will be conducted. From these tests, operating limits pertinent to each of the nine types of connectors chosen will be established. A sample plan is included in Table 4. The choice of these nine connector types to be tested will be made jointly by this division of The Bendix Corporation and NASA. The types outlined in Table 4 are representative only and are subject to change. Substitutions of different types of connectors for the types shown in Table 4 can be made without altering the program effort provided that the total number of tests are unaltered.

7.3.3 Having established test procedures and specific connector types, test fixturing and hardware will be designed and manufactured to facilitate the large test program outlined above.

7.3.4 During the test portion, each test will be adequately documented. At the completion of all testing, this data will be reduced and evaluated using applicable techniques. From these results, limits of rise time, pulse duration, pulse repetition rate and cross talk will be established.

7.3.5 Analysis of these results will then be made and further necessary brief tests will be conducted to indicate, in a broad sense, what connector design parameters need to be modified to improve the digital efficiency of multi-channel electrical connection mechanisms.

Table 4

Testing Plan

Connector Configuration	Cylindrical		Circuit Board			Coaxial			
Connector Type	JT	PT	Centre P. C. B.	P. C. Edge-board	Cannon Mark II P. C. B.	GR-874	AMP Sub. Min.	OSM 3 MM	Bendix JT Type
Number of Shell Arrangements	2	2	2 (28) (126)	2	2	-	-	-	-
Contact Sizes	16&22	16&22	22	22	22	-	16&22	-	16
Number of Contact Pairs to be Tested on Each Type	4	4	4	4	4	-	-	-	-
Number of Test Operations	16	16	8	8	8	3	6	3	3
*Test Code Applying to Connector	A B C	A B C	A B C	A B C	A B C	A B	A B	A B	A B C
Total Number of Tests	48	48	24	24	24	6	12	6	9

*From paragraph 7.3, the following code is established:

A - Frequency Domain

B - Time Domain

C - Cross Talk

Appendix

Bibliography - Task V

The following list of references constituted the major source of information used in this study.

1. "Working with Sub-nanosecond Pulses" by Earl Dilatush, Technical Editor EDN dated March 1, 1970.

2. "Matched Impedance Connectors for Micro-strip and other Sub-miniature Transmission Line" by Robert Harwood AMP Inc., Harrisburg, Penna. as presented at NEPCON 70.

3. Hewlett-Packard application note 94 -"The Electromechanical Design of a Matched Impedance Connector" by H. H. Blonder and R. T. Evans - International Business Machines Corporation, Poughkeepsie, N. Y.

4. "Cabling Fast Pulses? Don't Trip on the Steps" by Thad Drehar, E-H Research Laboratories, Oakland, Calif. - The Electronic Engineer dated August 1969.

5. Radio Engineer's Handbook, First Edition, Third Impression, by Frederick Terman, Pages 174 and 176.

6. "How to Monitor Nanosecond Interruptions in Electrical Contacts" by S. Alessio, Amphenol Corporation, Broadview, Illinois, The Electronic Engineer dated November 1967.

7. "One-Chip Computer - How Soon?" by Robert E. Markle, Vice-president Cugar Corporation, EDN dated November 1, 1970.

8. "Intraconnections in Digital Equipment a Matter of Judgement" by A. Furnam, Electrotechnology dated January 1968.

9. "Precautions for Handling High Speed Digital Pulses" by Bob Botos, Motorola Semiconductor Products, Inc., Phoenix, Ariz., The Electronic Engineer dated October 1967.

10. Survey/Study of the Interconnection Problem in Microelectronics, NASA Contract NASW-919 by Moore-Peterson Associates dated July 20, 1965.