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Modeling and Experimental Support for Detection of Linear Conductors
Task Authorization 6: Phase Characterization

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C-CORE Report Number R-17-072-1336, Revision 1.0

PSPC Contract Number: W7702-175832
Technical Authority: Scott Irvine, Defence Scientist
Contractor's date of publication: March 2018

Defence Research and Development Canada

Contract Report
DRDC-RDDC-2018-C175
September 2018

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IMPORTANT INFORMATIVE STATEMENTS

This document was reviewed for Controlled Goods by Defence Research and Development Canada using the Schedule to the *Defence Production Act*.

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DRDC Suffield

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The correct citation for this report is:

C-CORE. 2018. "Modeling and Experimental Support for Detection of Linear Conductors—Task Authorization 6: Phase Characterization." Report R-17-072-1336, Revision 1.0.

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REVISION HISTORY

VERSION	NAME	DATE OF CHANGES	COMMENTS
1.0	M. Royle	03/06/2018	Released to client

DISTRIBUTION LIST

COMPANY	NAME	NUMBER OF COPIES
DRDC Suffield	Dr. Scott Irvine	Electronic

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1 Introduction

There is an ongoing research program at Defence Research and Development Canada (DRDC) Suffield Research Centre (SRC) to explore electromagnetic (EM) scattering from linear conductors to better understand the physical phenomena governing this effect. The purpose of this contract is to provide technical expertise to supplement the efforts at DRDC by furthering the research on EM scattering through experimental and theoretical means.

The need to detect linear conductors is pertinent to military and commercial interests. A number of commercial applications would benefit from a reliable method to detect buried infrastructure such as wires, pipes, rods and other infrastructure critical to the delivery of crucial services to consumers. Detection of these conductors would help to significantly reduce the number of occurrences resulting in interruptions to power, water and communications services that result from excavation operations. This would directly result in time and money savings for businesses and consumers alike and help alleviate associated safety and environmental concerns.

The work undertaken is an evaluation of the phase of antenna displacements for linear conductor detection. This is done through experimental measurements of the phase delays introduced by antenna displacements due to the antenna cable properties including length and flexure. Characterizing these phase delays due to changes in these physical properties is key to understanding the effects on any resulting signal received by the antenna. The output of the work is a calibrated cable set for use by DRDC in future testing.

1.1 Scope

This report provides an overview of the work carried out to test and characterize a set of microwave cable assemblies for varying lengths and bending radii. Relevant performance characteristics are extracted and presented.

1.2 Definitions

Acronym	Definition
CUT	Cable Under Test
IL	Insertion Loss
VNA	Vector Network Analyzer

2 Test Plan

The proposed experiment consists of characterizing a set of microwave cable assemblies with varying lengths for a number of bending radii. A vector network analyzer (VNA) will be used to measure cable performance over a range of frequencies. Measurements will be performed as each cable is wound into coils with diameters of 20, 25, and 30 cm. Full Two-Port S-parameters will be recorded and insertion loss, phase, and delay extracted from the results. As a VNA measures only magnitude and phase values at discrete frequency points, the delay must be estimated from:

$$\tau_g(f) = -\frac{1}{2\pi}\frac{d\varphi}{df} \tag{1}$$

where:

τ_g = group delay of cable
f = measurement frequency
φ = insertion phase in radians

A set of cables suitable for operating frequencies up to 18 GHz have been acquired for testing purposes. Cable lengths range from one to five metres with additional details found in the below Table 1

Table 1. Test Cables.

Part No.	Ser. No.	Connectors	Length (m)	Velocity Factor	Approx. Delay (ns)
SF104/11N/11N/1M	324533	N (M) to N (M)	1	.77	4.33
SF104/11N/21N/1M	324501	N (M) to N (F)	1	.77	4.33
SF104/11N/11N/3M	324502	N (M) to N (M)	3	.77	12.99
SF104/11N/21N/3M	324492	N (M) to N (F)	3	.77	12.99
SF104/11N/11N/5M	324507	N (M) to N (M)	5	.77	21.64
SF104/11N/11N/10M	324494	N (M) to N (M)	10	.77	43.29
SF104/11N/11N/20M	324497	N (M) to N (M)	20	.77	86.58

2.1 Required Equipment

The equipment required for the proposed test is listed below in Table 2. The ZNB20 VNA and its cables are calibrated using its automatic calibration unit. As the VNA cables are configured with female SMA connectors, female SMA to female N type connectors are required to interface VNA cables to the Cables Under Test.

As both the VNA cables and ZV-Z53 calibration unit are equipped with SMA connectors, the calibration can only be performed to the end of VNA cables. Thus, the effects of the NF-SF50+ adapters are unaccounted for in the calibration and their characteristics are included in the measurement results. As detailed S-parameters for the adapters were unavailable from the manufacturer, it was not possible to remove their characteristics. However, insertion loss data was available and duplicated in Figure 1. The low loss suggests their inclusion should not impact results significantly. Additionally, their short length was considered to be negligible relative to the cable length when extracting cable phase and delay.

Table 2. Required Laboratory Equipment.

Description	Manufacturer	Model Number
ZNB Vector Network Analyzer, 4 Port, 20 GHz	Rohde & Schwarz	ZNB20
Automatic Calibration Unit, 300 kHz – 24 GHz	Rohde & Schwarz	ZV – Z53
SMA Female to N Type Female Adapter	Mini-Circuits	NF-SF50+

Figure 1. NF-SF50+ Adapter Insertion Loss (Mini-Circuits 2014).

2.2 Example Measurement

As an initial example, a five metre cable (P/N SF104/11N/11N/5M) was characterized while coiled in a 20 cm diameter. The VNA was configured to sweep from 400 kHz to 20 GHz in 10 MHz steps. The full 2 port S-parameter matrix was recorded and insertion loss and phase extracted and plotted in Figure 2. Additionally the delay was calculated using Equation (1) and plotted in Figure 3. It may be noted that the calculated delay of 21.7 ns is very close to its expected value of 21.6 ns determined from its length and specified velocity factor.

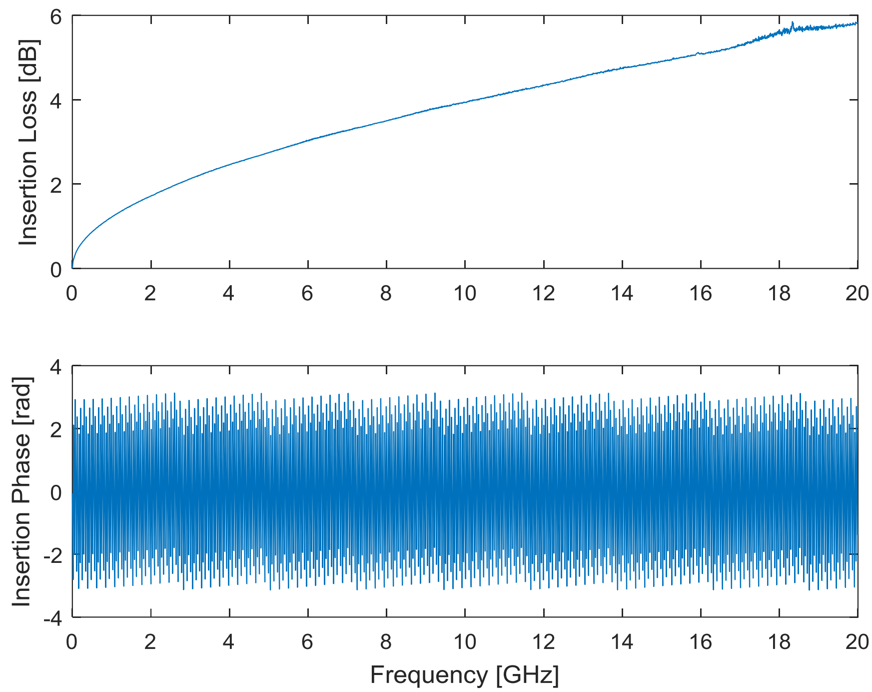

Figure 2. Example Insertion Loss and Phase.

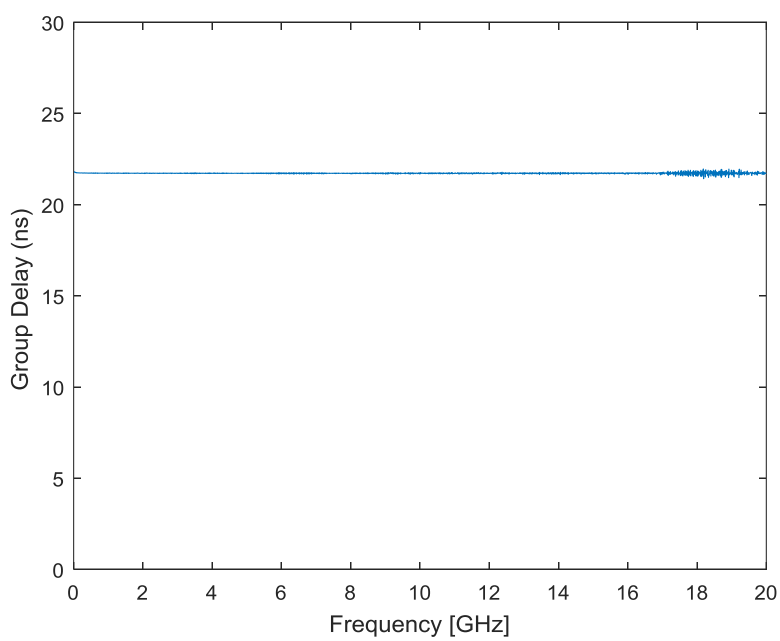

Figure 3. Example Delay.

3 Experimental Results

The experiment was carried out for each of the cables listed in Table 1. The resulting plots of insertion loss, phase, and delay are included in the following section. For all cables negligible differences were observed in insertion loss, phase, and delay as each cable diameter was varied. Figure 4 through Figure 17 depict the results of testing.

3.1 SF104/11N/11N/1M

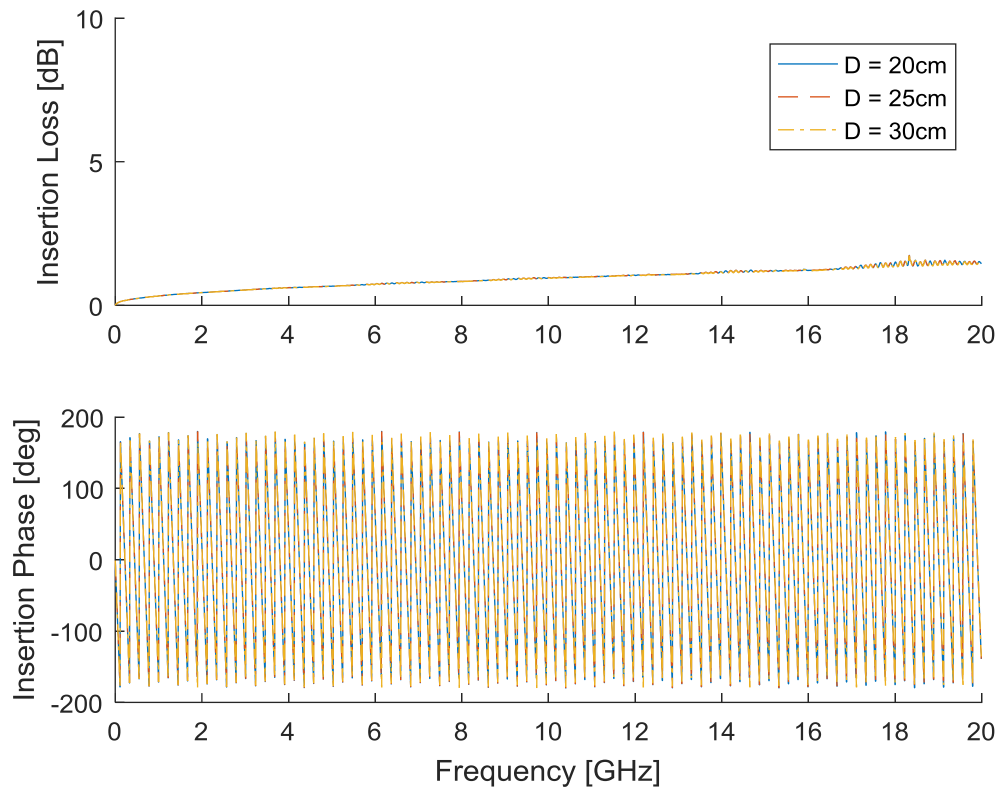

Figure 4. Insertion Loss and Phase.

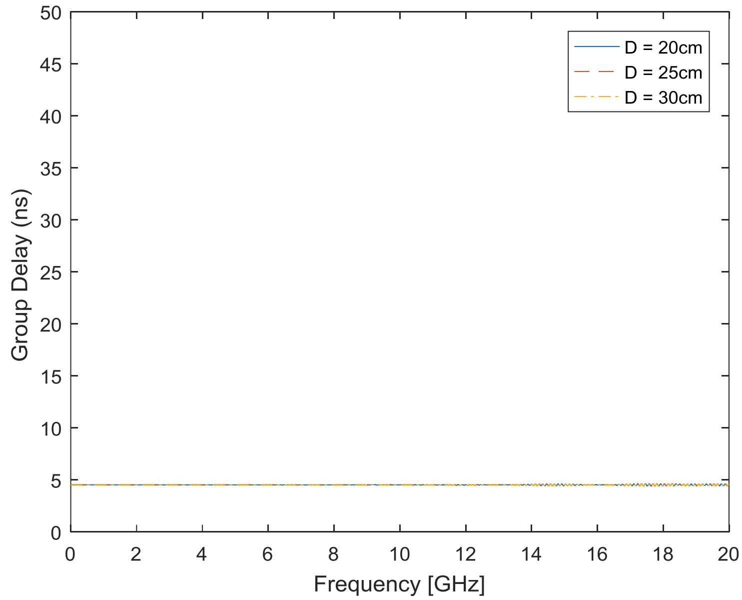

Figure 5. Delay.

3.2 SF104/11N/21N/1M

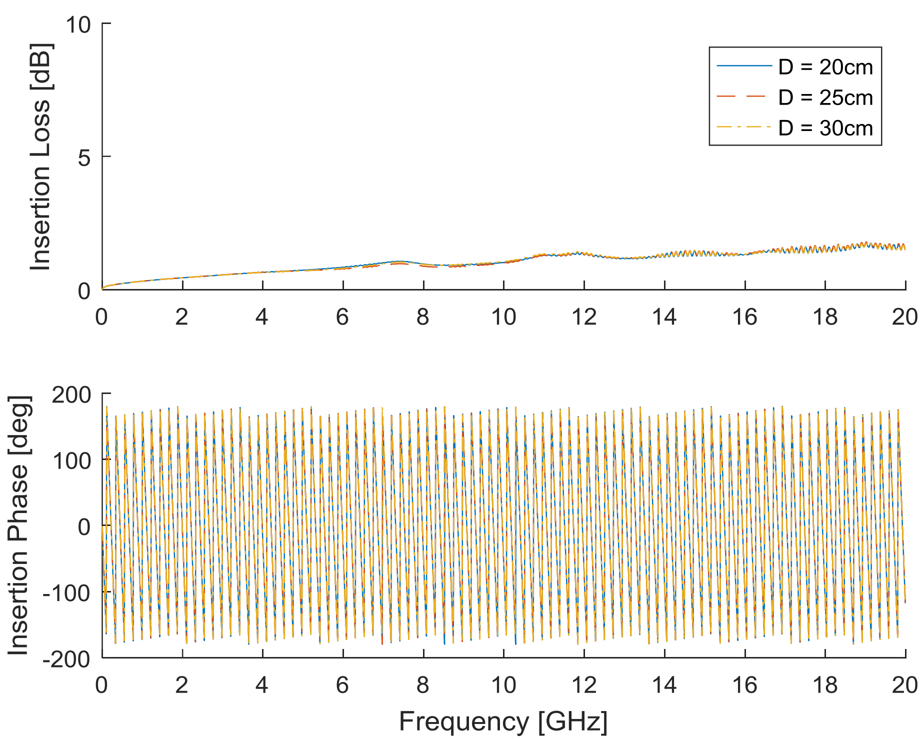

Figure 6. Insertion Loss and Phase.

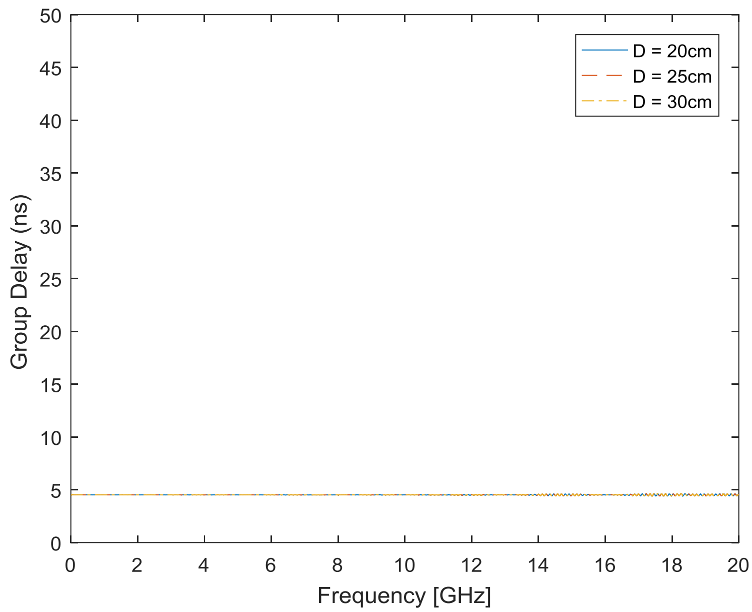

Figure 7. Delay.

3.3 SF104/11N/11N/3M

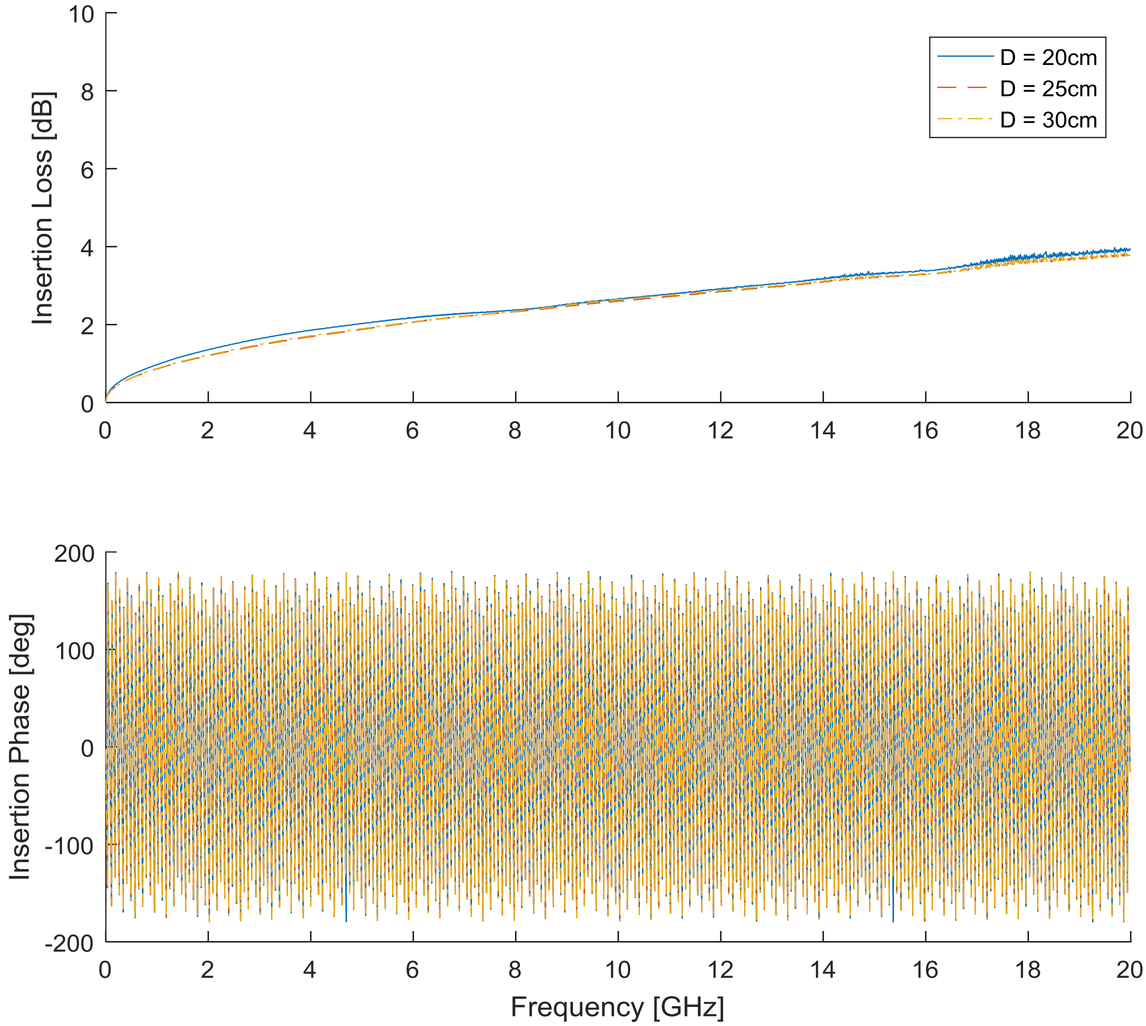

Figure 8. Example Insertion Loss and Phase.

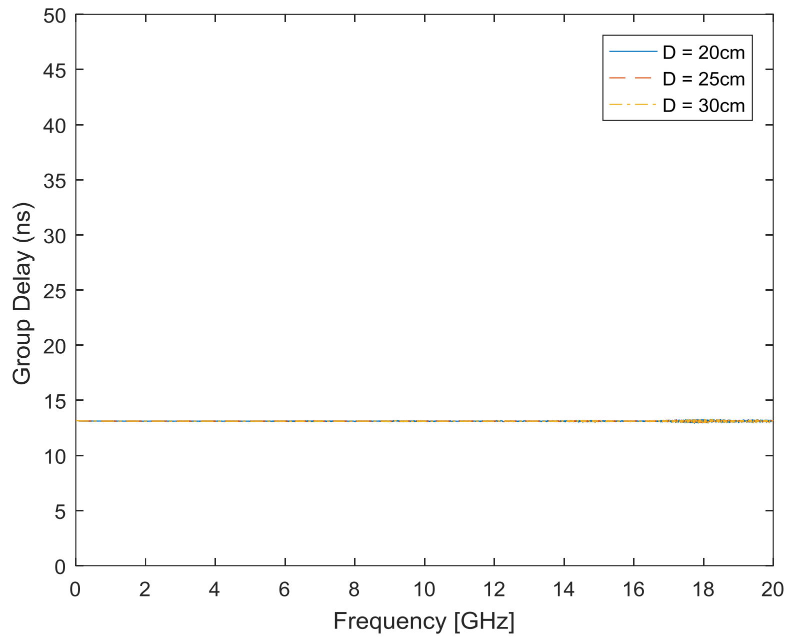

Figure 9. Delay.

3.4 SF104/11N/21N/3M

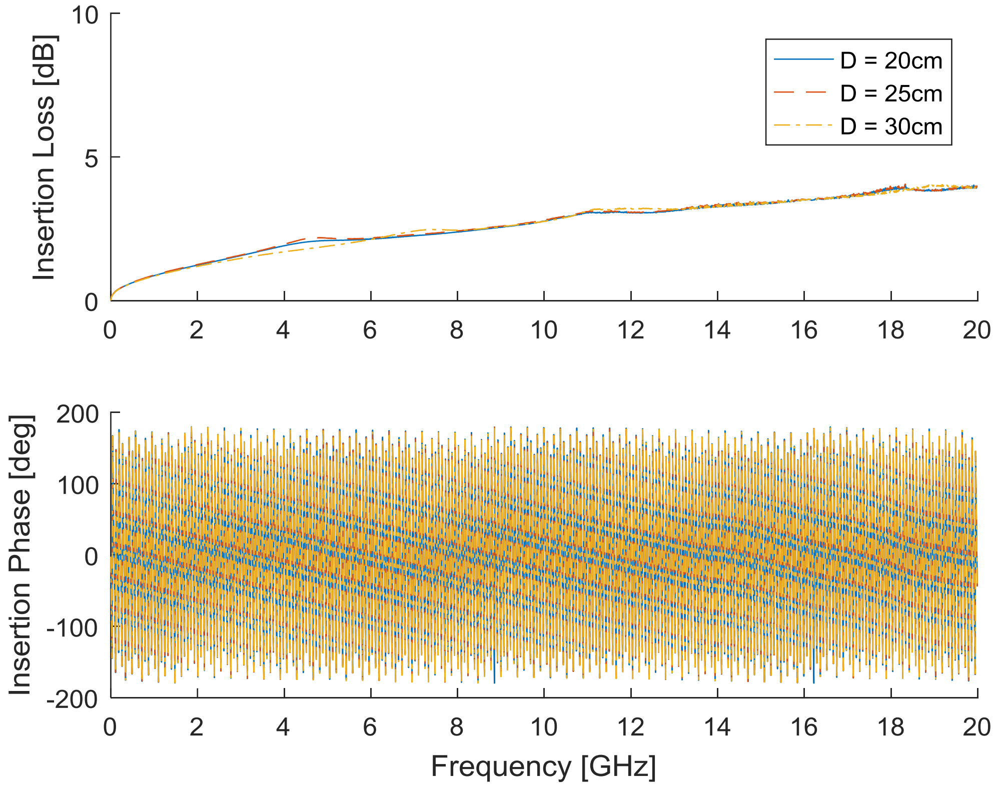

Figure 10. Insertion Loss and Phase.

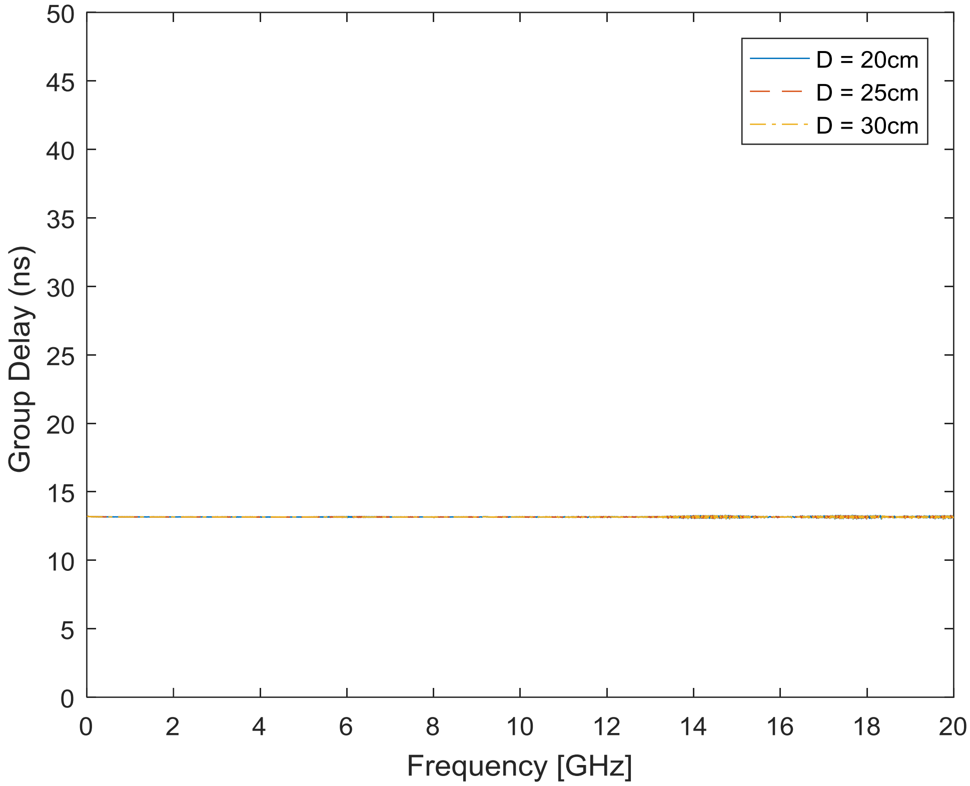

Figure 11. Delay.

3.5 SF104/11N/11N/5M

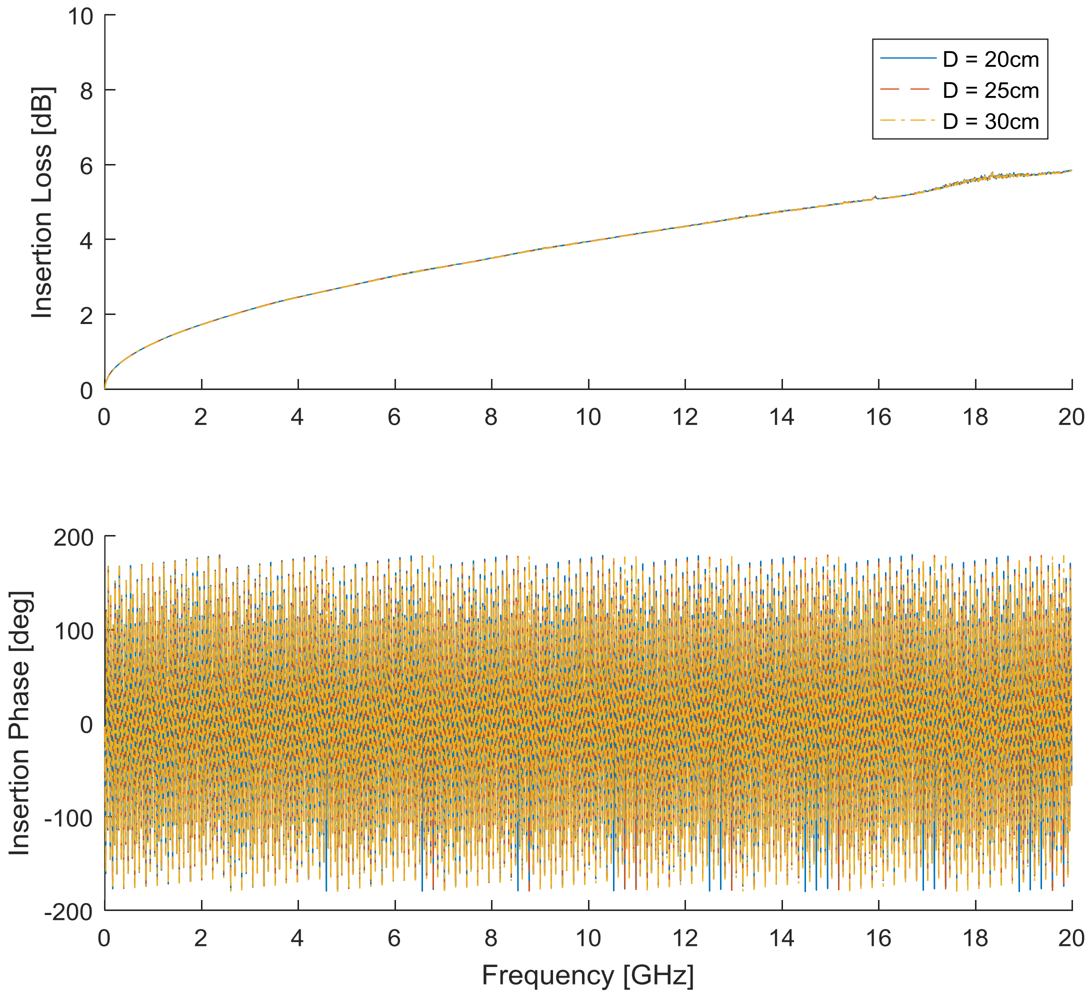

Figure 12. Insertion Loss and Phase.

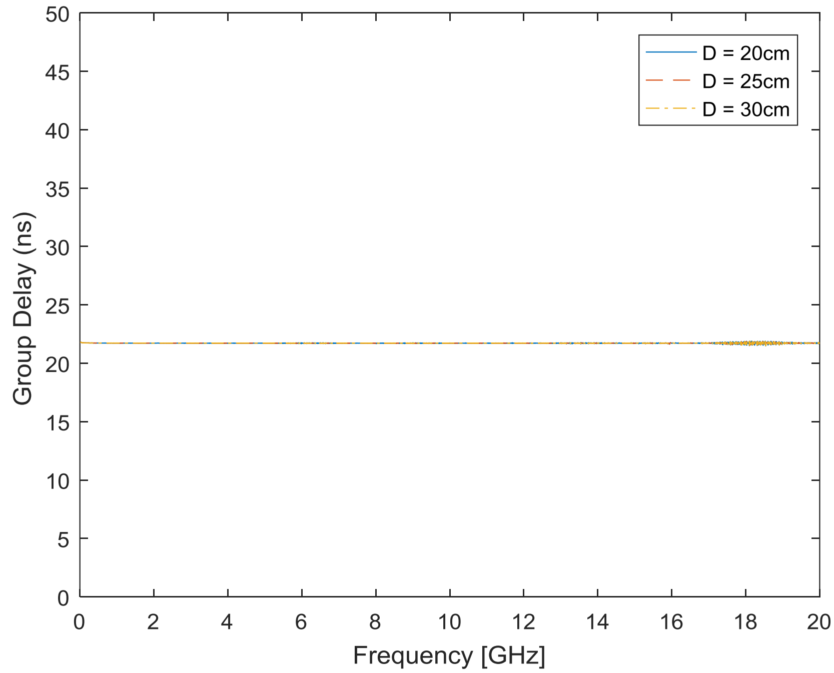

Figure 13. Delay.

3.6 SF104/11N/11N/10M

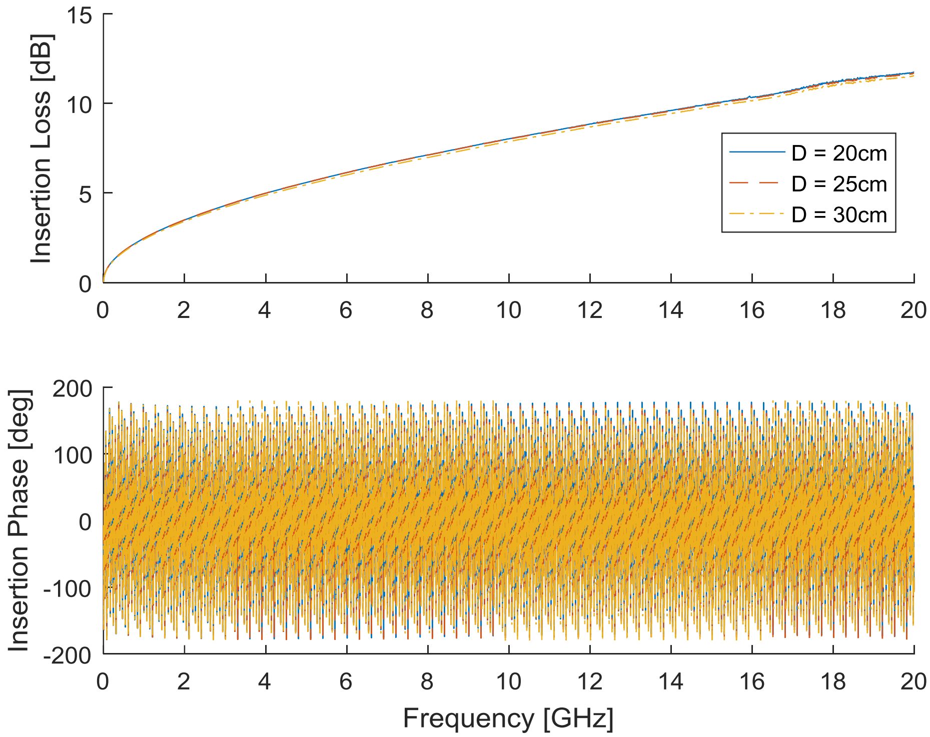

Figure 14. Insertion Loss and Phase.

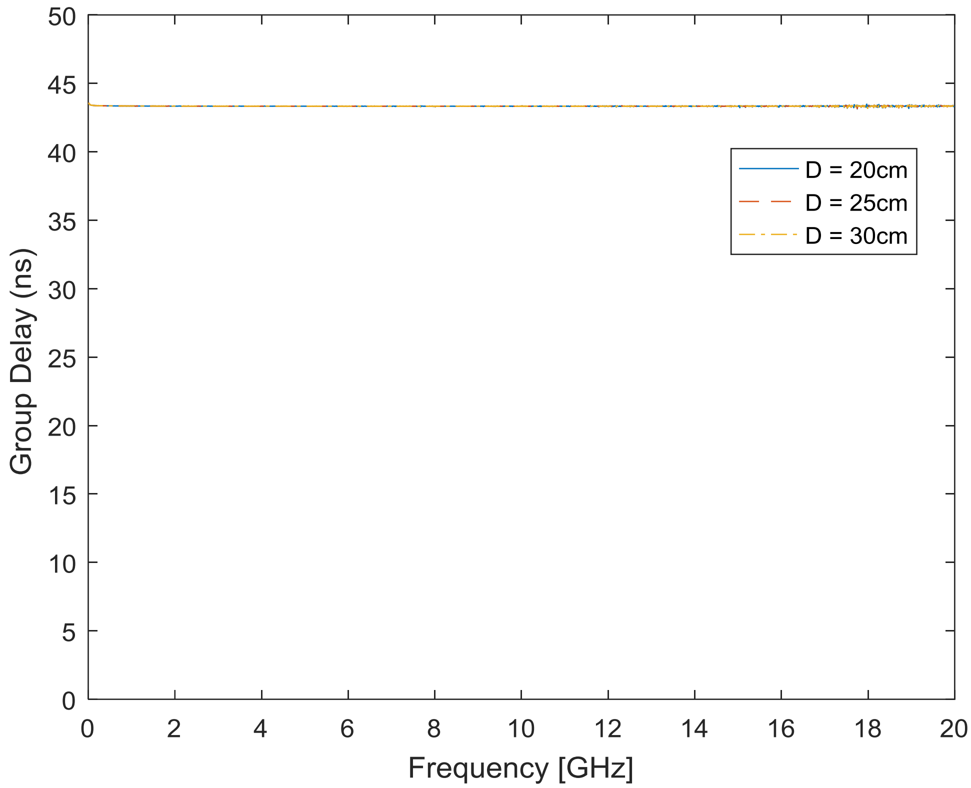

Figure 15. Delay.

3.7 SF104/11N/11N/20M

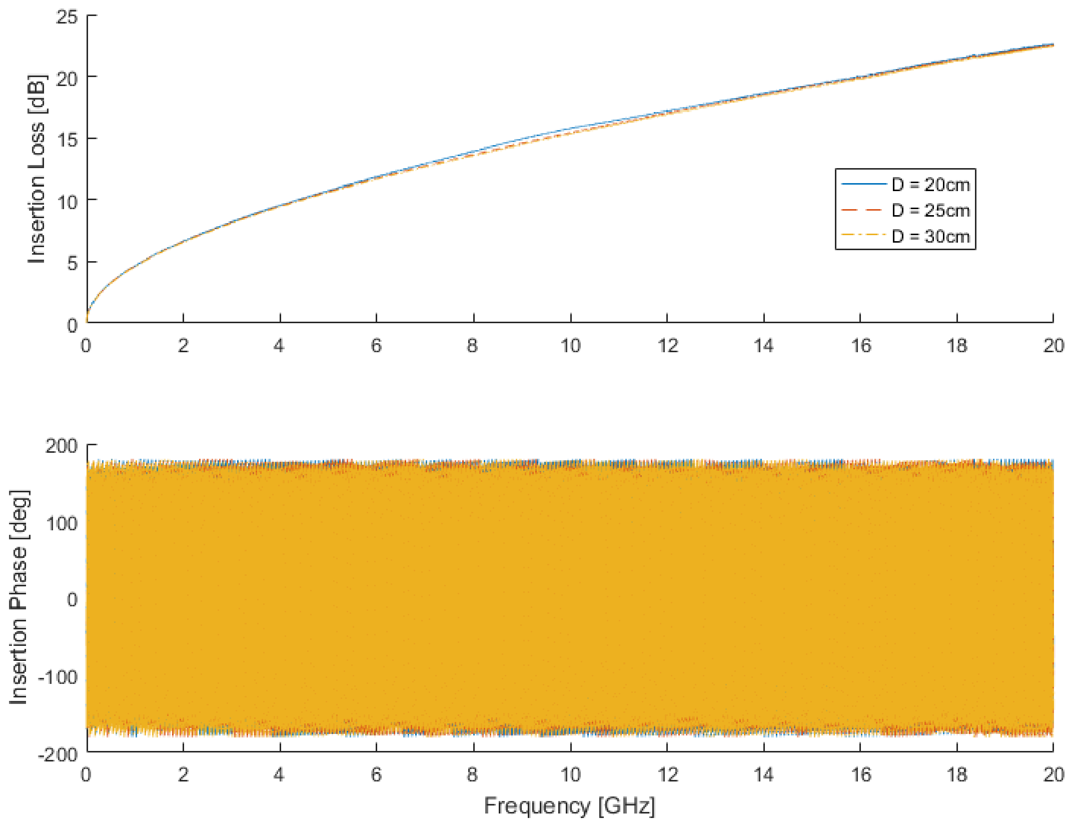

Figure 16. Insertion Loss and Phase.

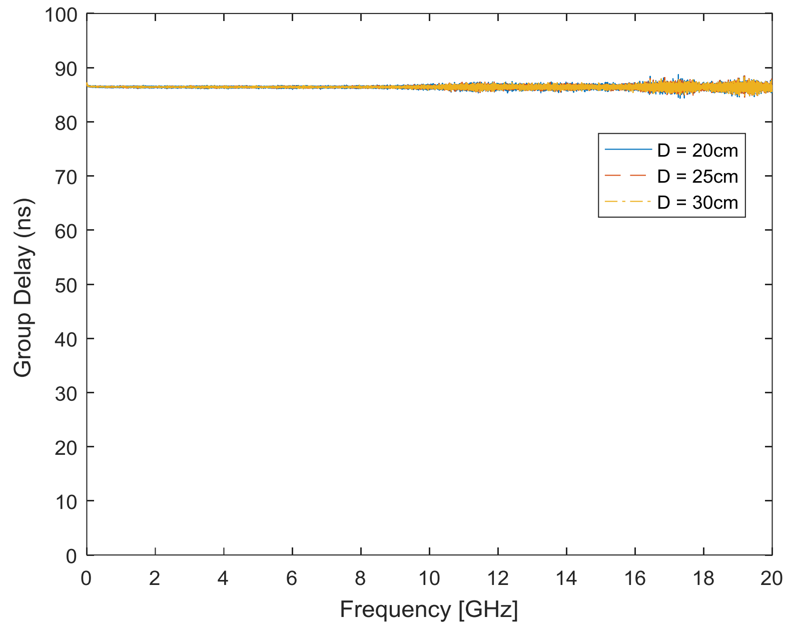

Figure 17. Delay.

4 Conclusions and Recommendations

A series of RF cables were characterized using a VNA. Different lengths and bending radii were used, according to the test plan in Section 2. The recorded measurements are presented in Section 3. Across all cable lengths, the bending radii was observed to have a minimal impact on the record insertion loss and calculated group delay. The work serves as a verification of the manufacturer specifications (Huber+Suhner 2014).

5 References

Huber+Suhner. 2014. “Data Sheet SUCOFLEX_Stock Assembly.” DOC-0000414169 B. https://www.hubersuhner.com/en/documents-repository/technologies/pdf/rf-stock-assemblies/sucoflex-assembly-84017153.aspx.

Mini-Circuits. 2014. “Adapter, NF-SF50+, Typical Performance Curves.” https://www.minicircuits.com/pages/s-params/NF-SF50+_GRAPHS.pdf.

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*Security markings for the title, authors, abstract and keywords must be entered when the document is sensitive

1. ORIGINATOR (Name and address of the organization preparing the document. A DRDC Centre sponsoring a contractor's report, or tasking agency, is entered in Section 8.) C-CORE Captain Robert A. Bartlett Building Morrissey Road St. John's, NL Canada A1B 3X5	2a. SECURITY MARKING (Overall security marking of the document including special supplemental markings if applicable.) CAN UNCLASSIFIED 2b. CONTROLLED GOODS NON-CONTROLLED GOODS DMC A

3. TITLE (The document title and sub-title as indicated on the title page.)

Modeling and Experimental Support for Detection of Linear Conductors

Task Authorization 6: Phase Characterization

4. AUTHORS (Last name, followed by initials – ranks, titles, etc., not to be used)

Green, D.; Fowler, C.; Royle, M.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total pages, including Annexes, excluding DCD, covering and verso pages.)	6b. NO. OF REFS (Total references cited.)
March 2018	27	2

7. DOCUMENT CATEGORY (e.g., Scientific Report, Contract Report, Scientific Letter.)

Contract Report

8. SPONSORING CENTRE (The name and address of the department project office or laboratory sponsoring the research and development.)

DRDC – Suffield Research Centre
Defence Research and Development Canada
P.O. Box 4000, Station Main
Medicine Hat, Alberta T1A 8K6
Canada

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
02da—Manoeuvre through Adaptive Dispersed Operations (ADO)	W7702-175832

10a. DRDC PUBLICATION NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)
DRDC-RDDC-2018-C175	

11a. FUTURE DISTRIBUTION WITHIN CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

Public release

11b. FUTURE DISTRIBUTION OUTSIDE CANADA (Approval for further dissemination of the document. Security classification must also be considered.)

12. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Use semi-colon as a delimiter.)

compliance testing; phase

13. ABSTRACT/RÉSUMÉ (When available in the document, the French version of the abstract must be included here.)

An evaluation of the phase of antenna displacements for linear conductor detection is presented. This is done through experimental measurements of the phase delays introduced by antenna displacements due to the antenna cable properties including length and flexure. Characterizing these phase delays due to changes in these physical properties is key to understanding the effects on any resulting signal received by the antenna. The output of the work is a calibrated cable set for use by DRDC in future testing.