Army Research Laboratory

Feasibility Studies of New High Altitude Electromagnetic Pulse Test Materials

by Max Polun

ARL-TR-3677 **November 2005**

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14. ABSTRACT
The danger of a high-altitude electromagnetic pulse (HEMP) is one of many threats that an Army facility must be capable of surviving. A standard method of testing the HEMP survivability of these facilities exists. However, it is not capable of being used in all situations. This feasibility study used a series of experimental test methods and unique antenna designs to evaluate more flexible methods. The findings indicate that several of the antennae tested have suitable dynamic range characteristics and that alternative system designs can be employed where space limitations and other factors preclude use of the standard method.

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Background

The danger of a high-altitude electromagnetic pulse (HEMP) is one of many threats that an Army facility must be capable of surviving. To this end the Army has been testing and hardening many of their facilities against the electromagnetic environment produced by the detonation of a nuclear weapon. There is a standard method of testing the HEMP hardness of a facility. However, it is not capable of being used in all situations, specifically due to space constraints in the test geometry.

A method using a fiber-optic system to electromagnetically isolate both the receiving and the transmitting antennae from a network analyzer and amplifier was devised. Additionally, alternative antenna designs were evaluated with a view to minimize physical space requirements while, at the same time, maximizing the measurable system bandwidth. As a result, this feasibility study used a series of experimental test methods to evaluate the performance of the unique antenna designs in a variety of configurations that could, as a result, offer more flexibility and require less physical space than is presently required.

Test Approach

The approach measures and compares the difference in power received from a transmission of a known signal over a known distance of air and the reduction of signal over a hardened interface. There are many ways that this general idea can be implemented, however. Previous methods using a frequency oscillator and spectrum analyzer were used to create the signal and view it. This approach is limited in that only a single test frequency can be monitored at a time. Because of the time involved in making such a measurement, this approach usually results in fewer frequencies being tested.

Improvements to this approach can be realized by using a network analyzer to both generate and analyze the signal, allowing a whole range of frequencies to be tested in less time than it would take to measure a single frequency. An additional benefit to this approach is that the data collected by the network analyzer can be easily transferred to a computer for analysis and storage. One important challenge to this setup is to minimize, or eliminate, electromagnetic interference (EMI) between the transmit and receive paths, which could be complicated since the network analyzer serves as signal source and receiver.

In order to be successful, the two network analyzer paths had to be electromagnetically separate from each other, yet still allow signal to travel between the two. Fiber-optic cables and data systems are ideal for this situation, as the cables are unaffected by EMI and can support a potentially broad frequency range of data signals and information. A highly effective test setup using a single length of fiber-optic cable with a corresponding transmitter and receiver (shown by figure 1) was used.

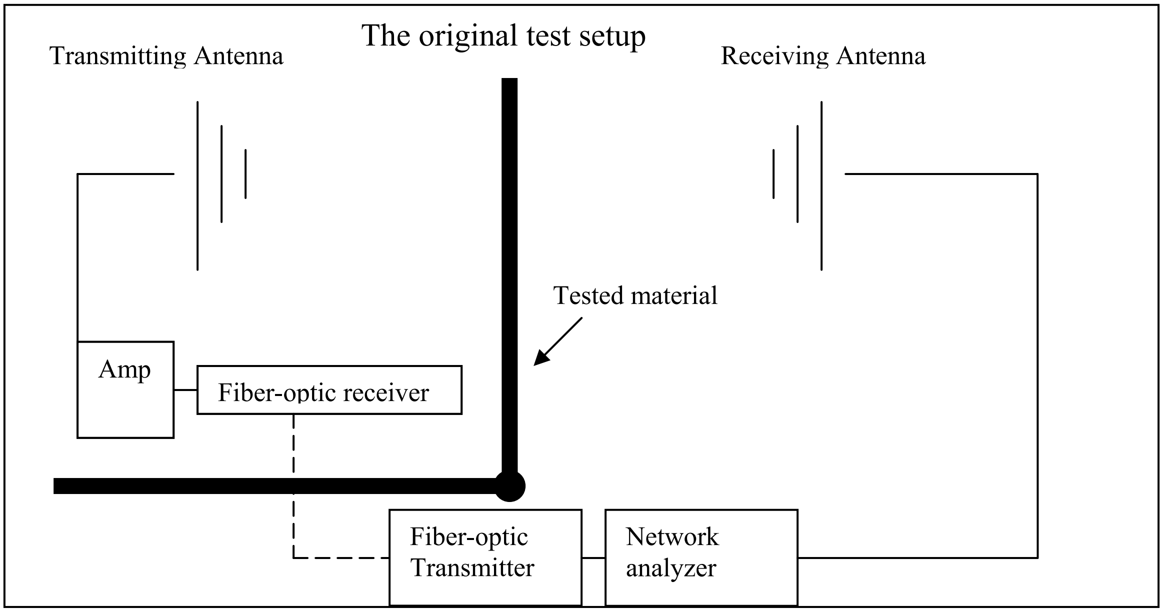

Figure 1. Single fiber-optic measurement approach.

This test approach is generally well understood, and can be reliably and accurately performed with fewer personnel than the original method using spectrum analyzers. However, there are limitations, based on physical constraints, that can prevent the test from producing measurable results.

One constraint encountered where there is no access port to allow a fiber-optic cable through the hardened material to the transmitting antenna. In this situation, the single frequency oscillator and spectrum analyzer method has to be used. Additionally, in some situations (due to the geometry of the location), there may be no way to ensure that the network analyzer is both separated from the transmitting antenna and, at the same time, connected to the receiving antenna. In such cases, it is better to separate the network analyzer from both the receiving and transmitting antennae than to allow EMI to induce distortions in the signal, and possibly change the electromagnetic signature of the system.

To avoid this, a new setup was assembled and studied. This approach used two fiber-optic systems (figure 2) and each separated section had its own independent and isolated power supply.

From the outset, it was generally believed that this setup should perform exactly like the original and be of more general use than its predecessors. However, some possible shortfalls were anticipated. For example, if the fiber-optic data systems are the most complicated part of the test setup, this new approach would essentially double the complexity of the test. As another example, the multi-fiber-optic system might experience too much unrecoverable signal loss due to converting the copper-carried signals to and from fiber-optics. This would result in the multi-fiber-optic system having insufficient dynamic range. As a result, an experiment was in order.

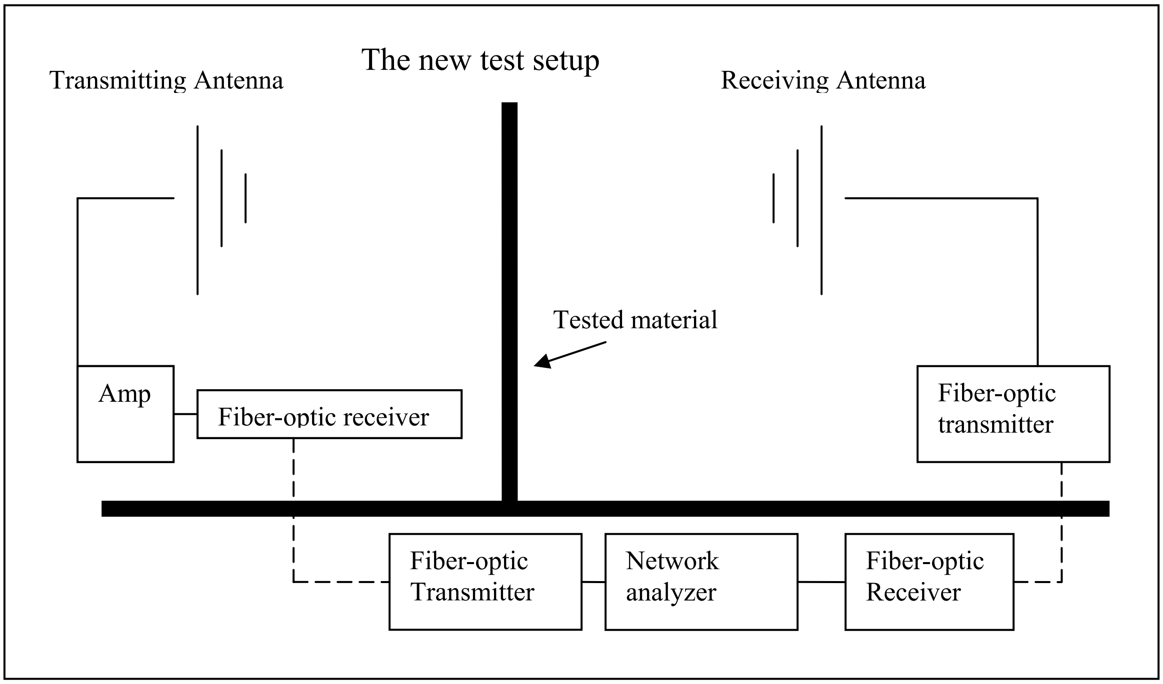

Figure 2. Multi-fiber-optic measurement approach.

Antenna Factors

In addition to determining the general suitability of this test approach, the other goal was to determine what alternative antenna types could be used that had sufficient dynamic range for meeting the data measurement requirements and still satisfy a reduced physical size. In order to resolve these questions, we tested a variety of antennae in the test setup. Among the types of receiving antenna used were two types created from slotted coaxial cables and one spiral antenna.

One coaxial antenna was fabricated using a type of cable manufactured by Andrews company. This is called “Radiax” and is noted to have reinforcing members and is very sturdy physically.

The other was fabricated by Times Microwave Systems (TMS) and was thinner and likely less durable.

The other receiving antenna types used were a wide-band spiral originally designed and fabricated at Army Research Laboratory (ARL) and two types of commercial off-the-shelf antennae, a loop and a bi-logic. Design of the spiral was based upon the following criteria:

Table 1. Logarithmic spiral equation.

(In polar coordinates):
The inner right spiral: $r = 0.5\ e^{0.1103*\theta}$
Outer right: $r = 0.5\ e^{0.1103*\theta + 0.1823}$
Inner left: $r = -0.5\ e^{0.1103*\theta}$
Outer left: $r = -0.5\ e^{0.1103*\theta + 0.1823}$

The resulting design was used in the fabricating process:

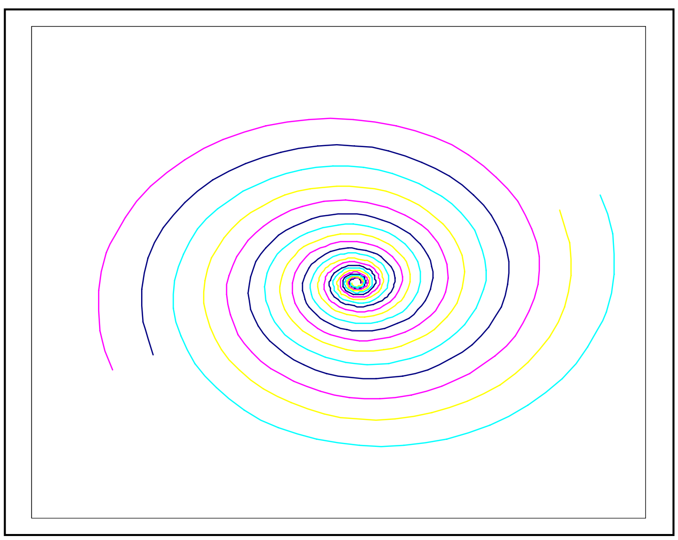

Figure 3. Rough spiral design – for fabrication.

The two types of transmitting antennae used were also the loop and the bi-logic. (Both loops and bi-logic antennae were manufactured by AH Systems).

The range of test frequencies was from 10 kHz to 1 GHz. Two network analyzers, both manufactured by Hewlett Packard, were used to satisfy the test data range requirements. One model had an operating range from 20 MHz to 3 GHz. The second network analyzer had an operating range from 10 kHz to 20 MHz. Two separate fiber-optic systems were also used for the study. One was manufactured by the Nanofast company, the other by EOD. Both fiber-optic systems had an effective operating range that included the 10 KHz to 1 GHz requirement.

The test was conducted at ARL's Scale Model Facility, with the network analyzer separated from the antennae sufficient distance to ensure no detrimental EMI effects. The general geometry for the tests were as described in figure 4. All three parts (transmitter, receiver, and analyzer) used separate power supplies to avoid any electromagnetic cross-talk. One used commercial power, one used an external generator, and one used a battery.

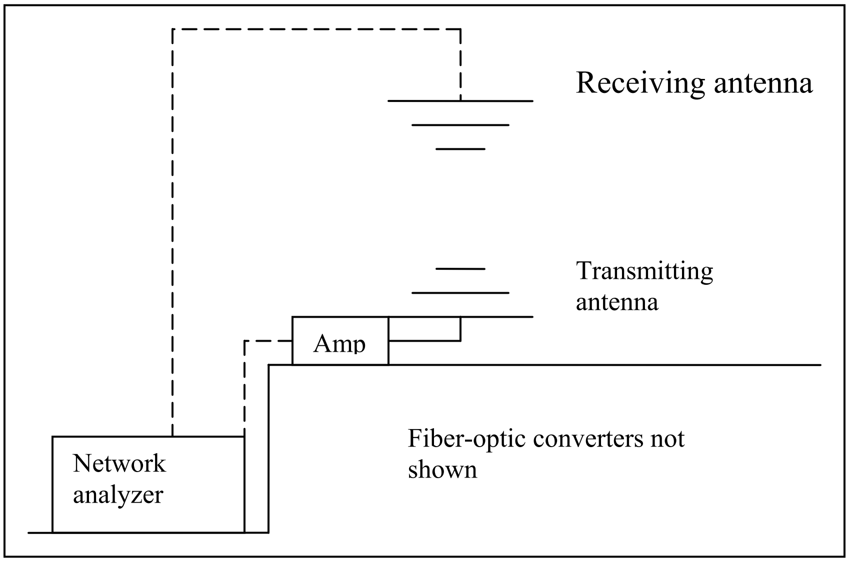

Figure 4. Scale model facility test bed.

The dynamic range of each tests set-up was calculated by taking the power response given by the network analyzer, and subtracting out any known attenuations (or amplification) and the measured background picked up by the antenna. The higher the dynamic range, the less power was lost in the signal. Therefore, a high dynamic range was desirable. The IEEE specifications were used to identify acceptable dynamic range characteristics.[1]

As an end-user requirement, acceptable dynamic range capabilities had to meet, or exceed for any given frequency (f), the following: $20*\log(f) - 62.1$ or 80 dB, whichever is lower.

Different polarities (physical positions) of the transmit and receive antennas were investigated. In some cases, these changes were dictated by the geometry of the antennae. Although measurements were made using three different polarities, "parallel", "perpendicular", and "coaxial", most combinations of antennae only used parallel or perpendicular orientations.

"Coaxial" polarization occurs when the planes formed by rotating the antennae intersect each other and the intersected area is within the physical area of only one antenna. This is graphically shown in figure 5.

[1] IEEE Std. 299-1997: IEEE standard method for measuring the effectiveness of electromagnetic shielding enclosures.

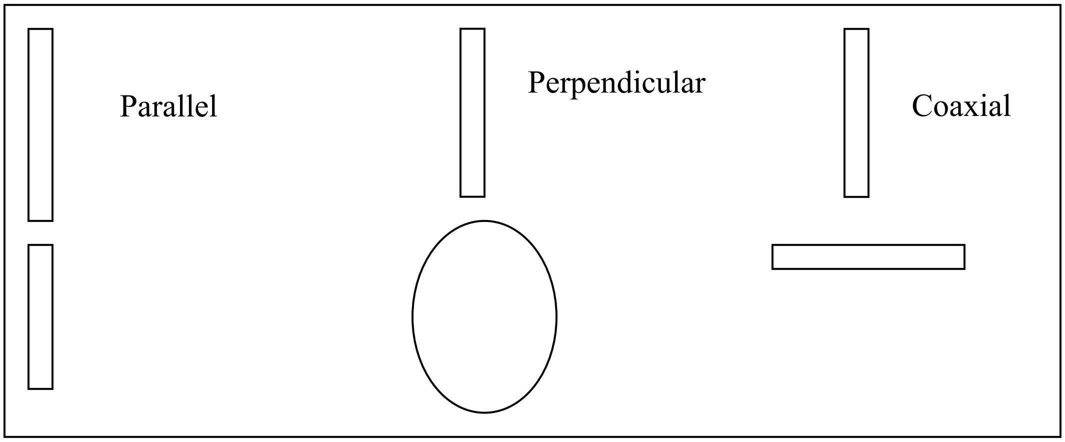

Figure 5. Antenna test set-up polarizations.

The Measured Data

The data collected for the study is shown in the following plots.

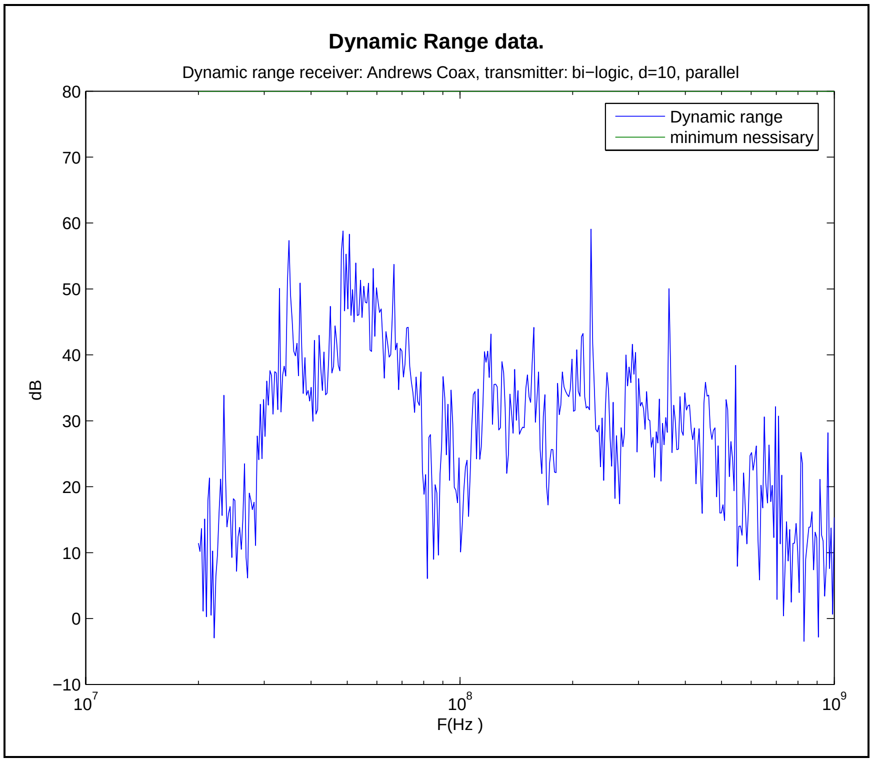

Figure 6. Andrews and bi-logic; parallel orientation.

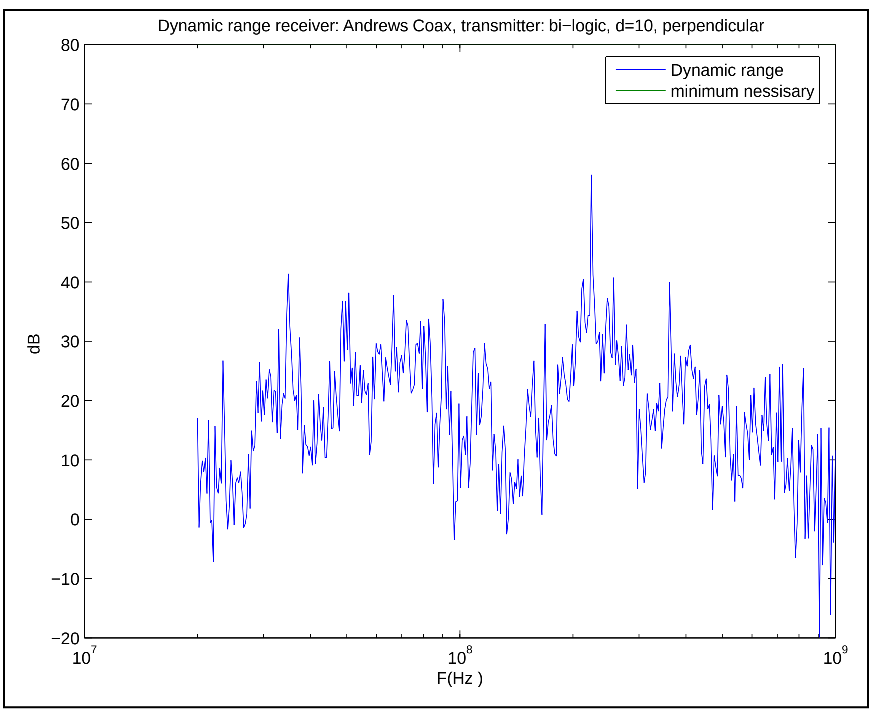

Figure 7. Andrews and bi-logic; perpendicular orientation.

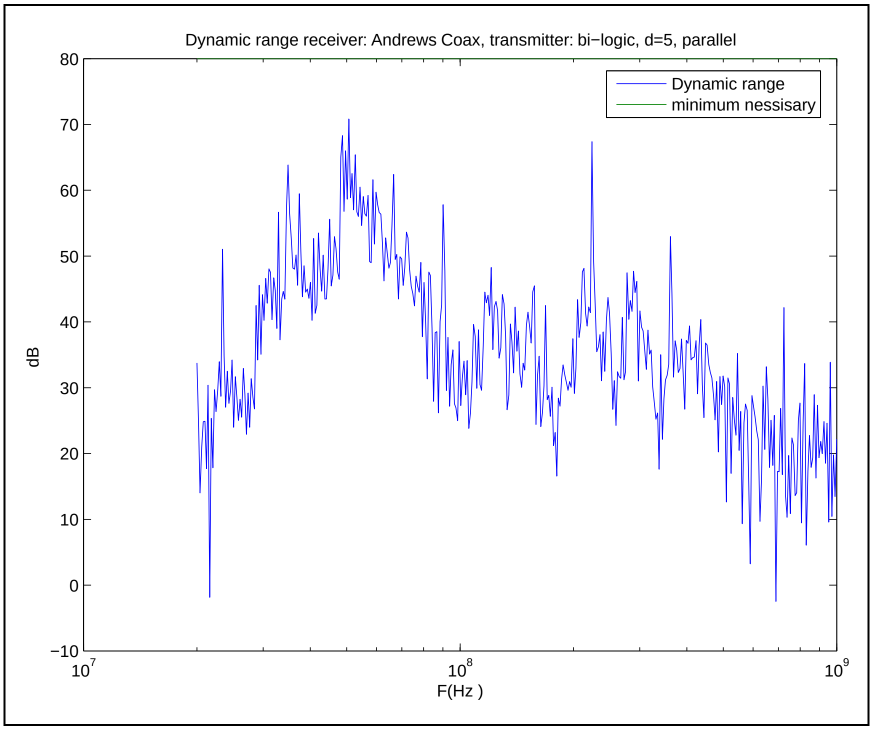

Figure 8. Andrews and bi-logic; parallel orientation.

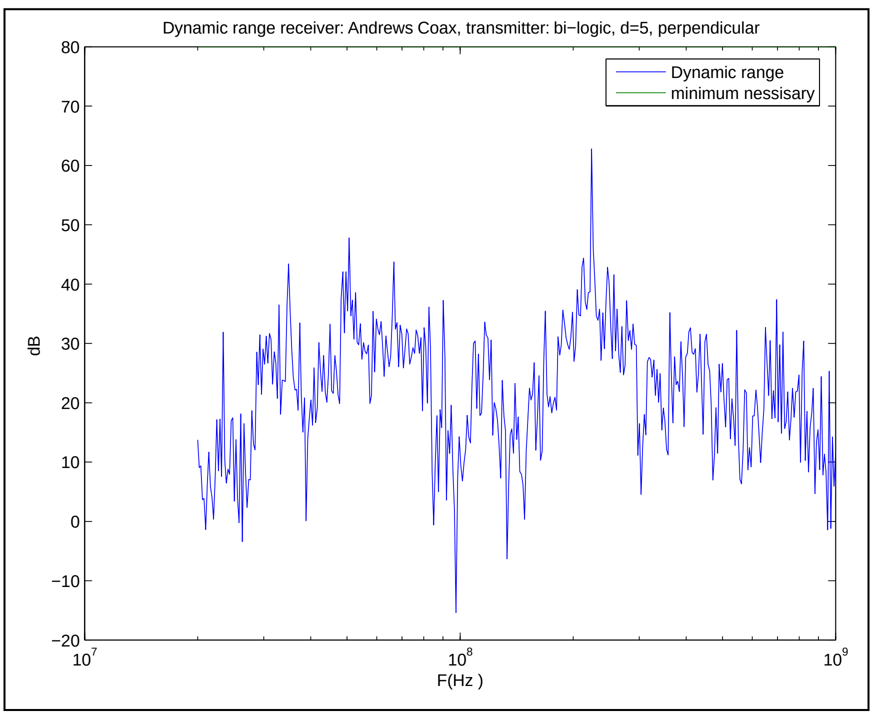

Figure 9. Andrews and bi-logic; perpendicular orientation.

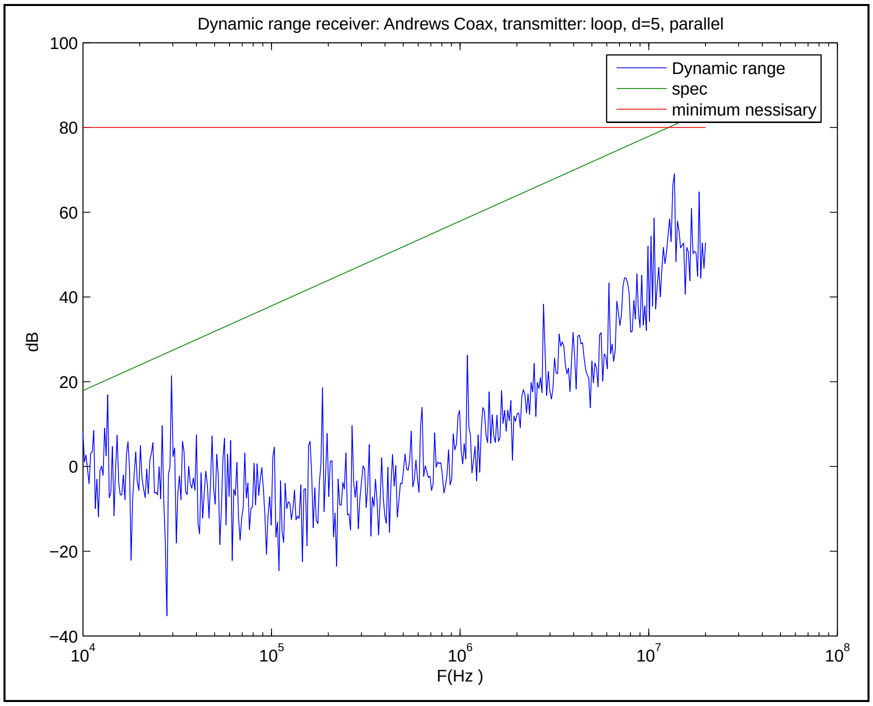

Figure 10. Andrews and loop; parallel orientation.

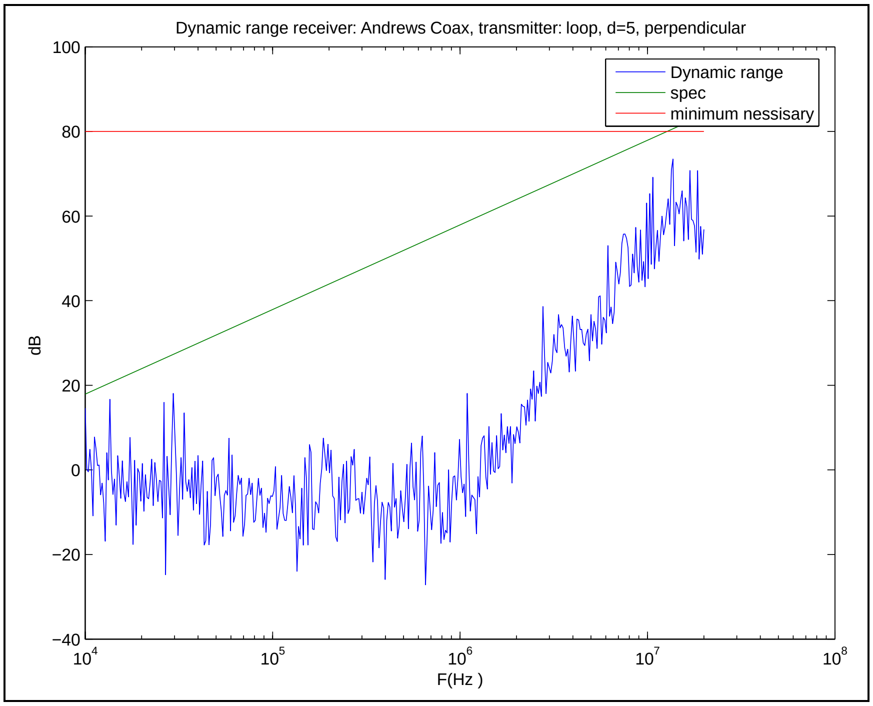

Figure 11. Andrews and loop; perpendicular orientation.

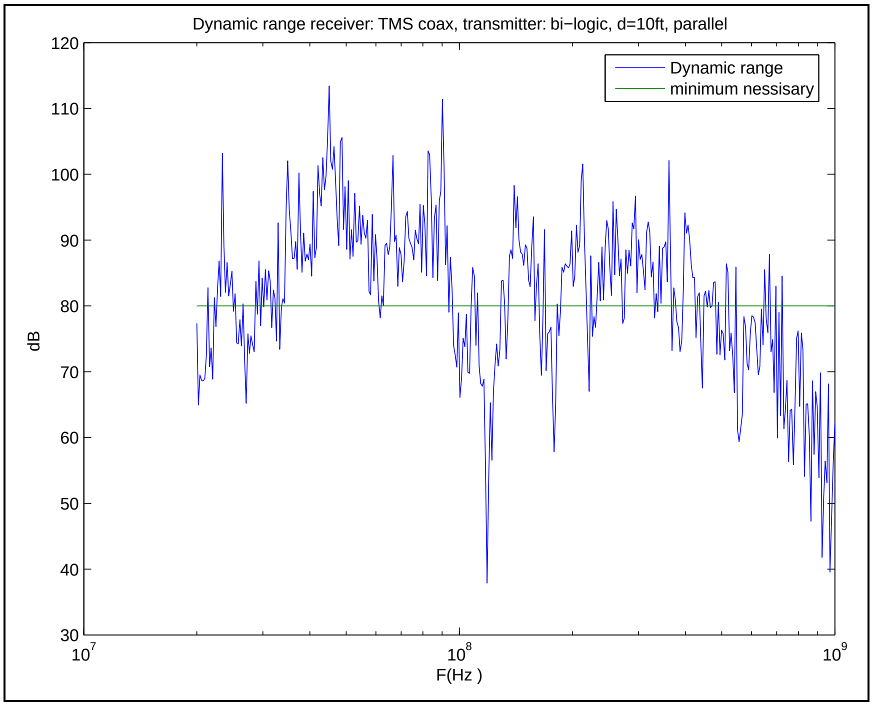

Figure 12. Andrews and bi-logic; parallel orientation.

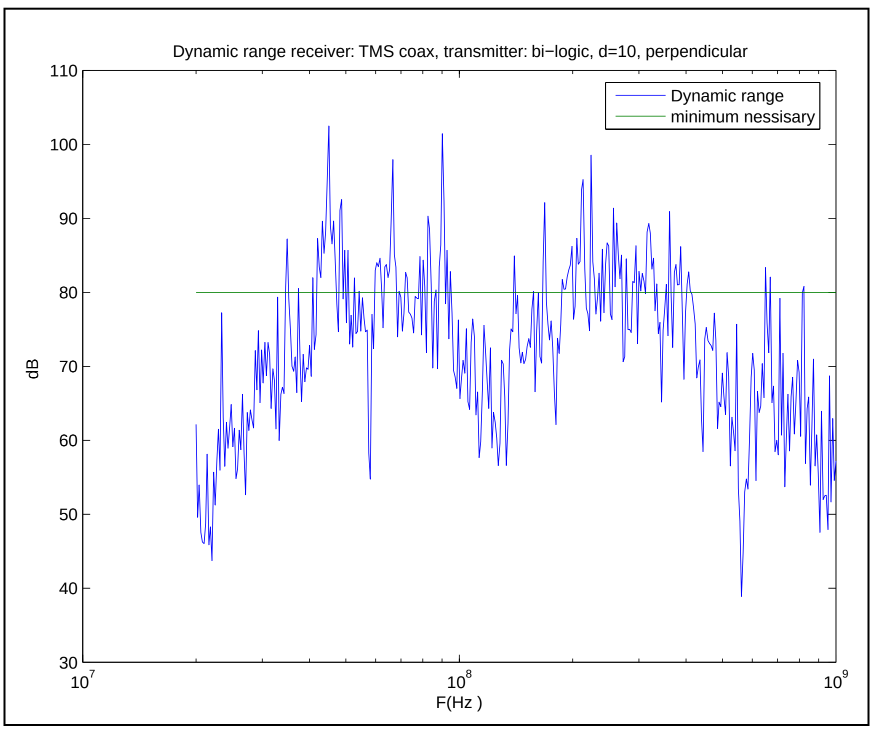

Figure 13. Andrews and loop; perpendicular orientation.

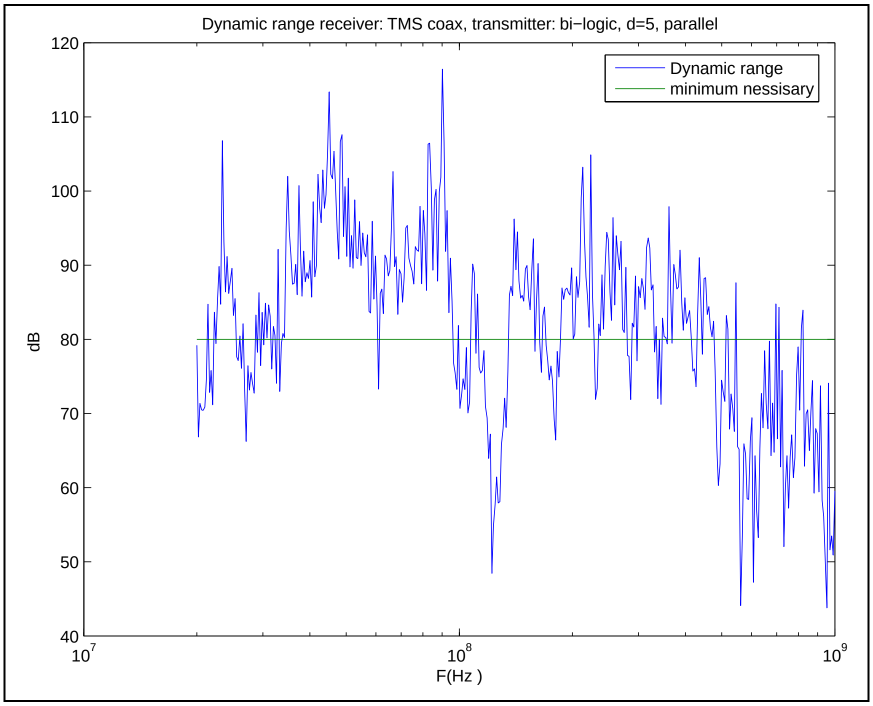

Figure 14. TMS and bi-logic; parallel orientation.

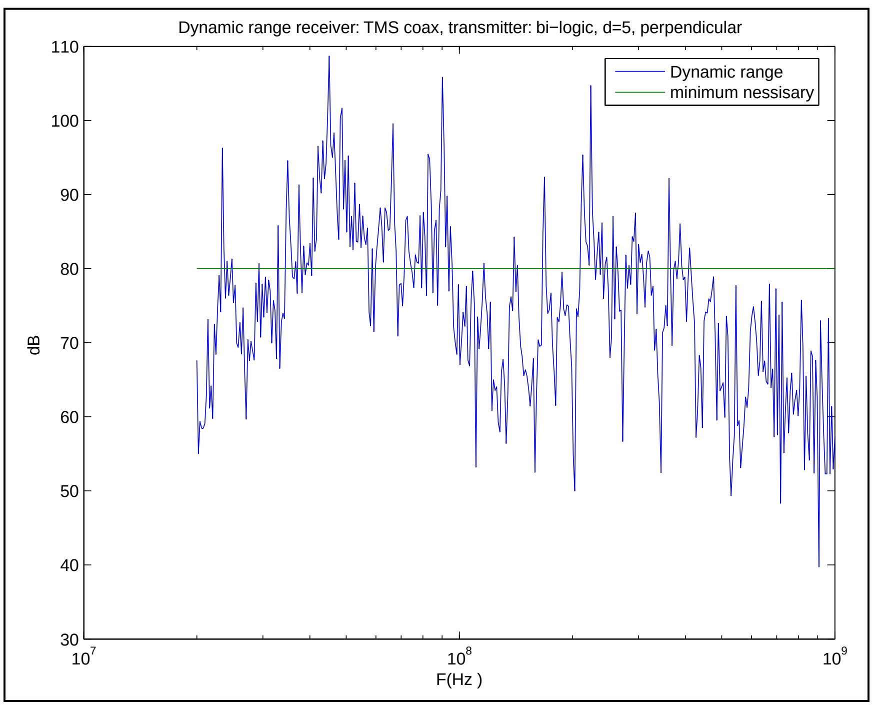

Figure 15. TMS and bi-logic; perpendicular orientation.

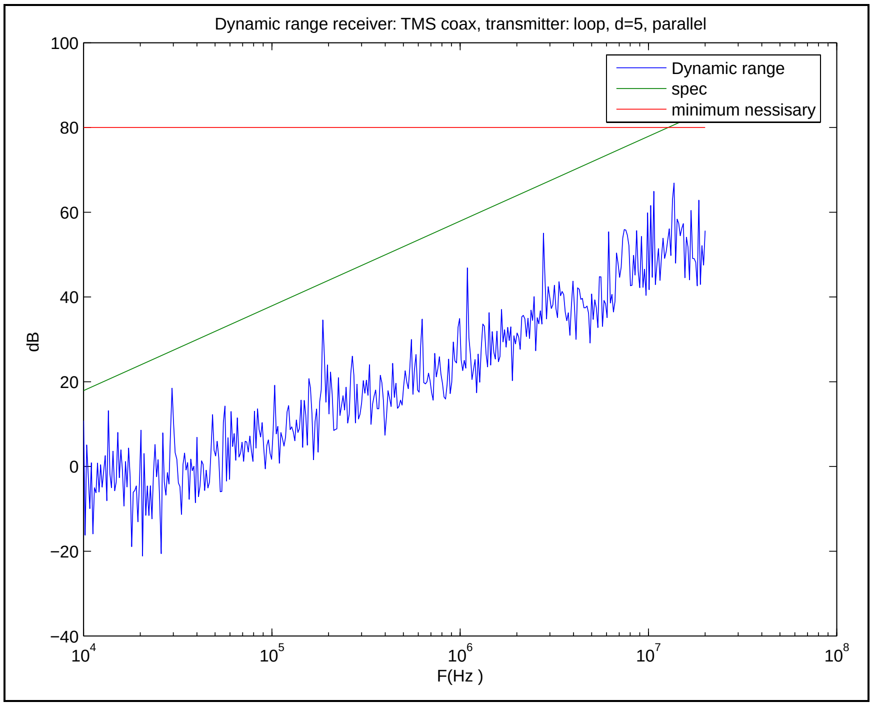

Figure 16. TMS and loop; parallel orientation.

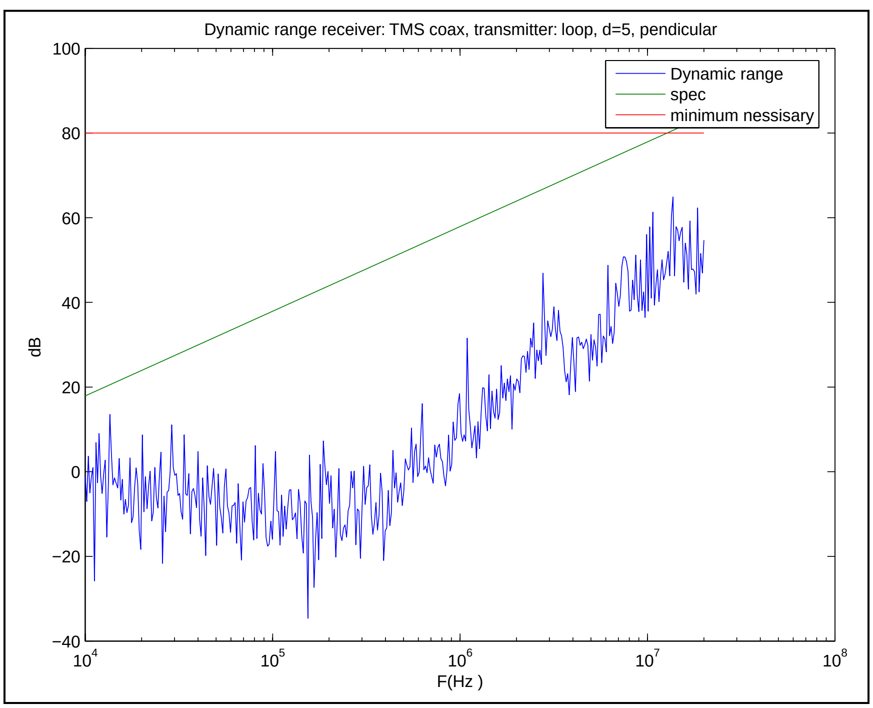

Figure 17. TMS and loop; perpendicular orientation.

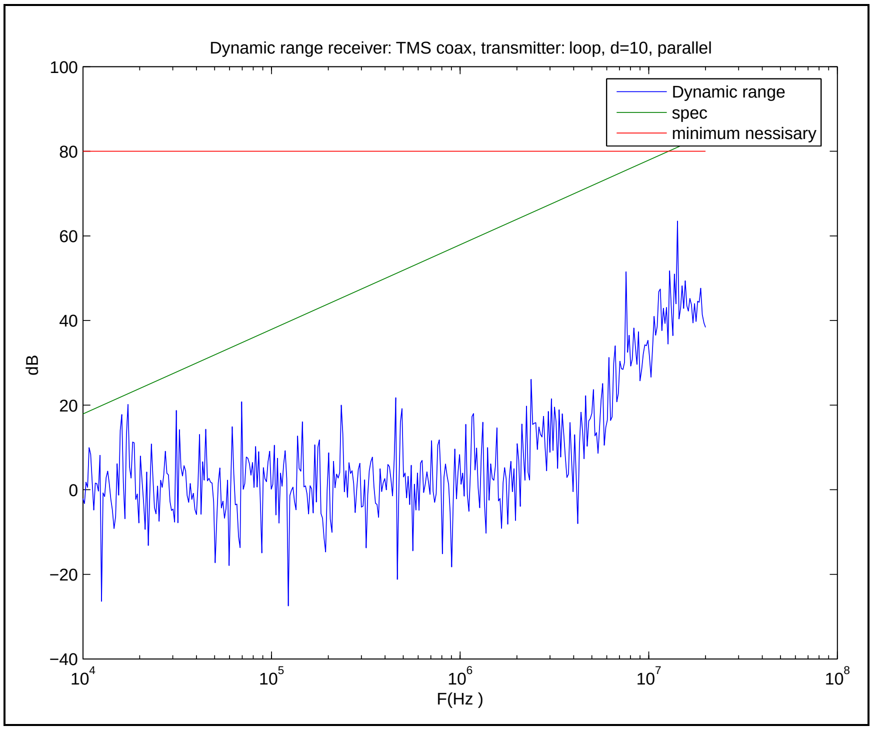

Figure 18. TMS and loop; parallel orientation.

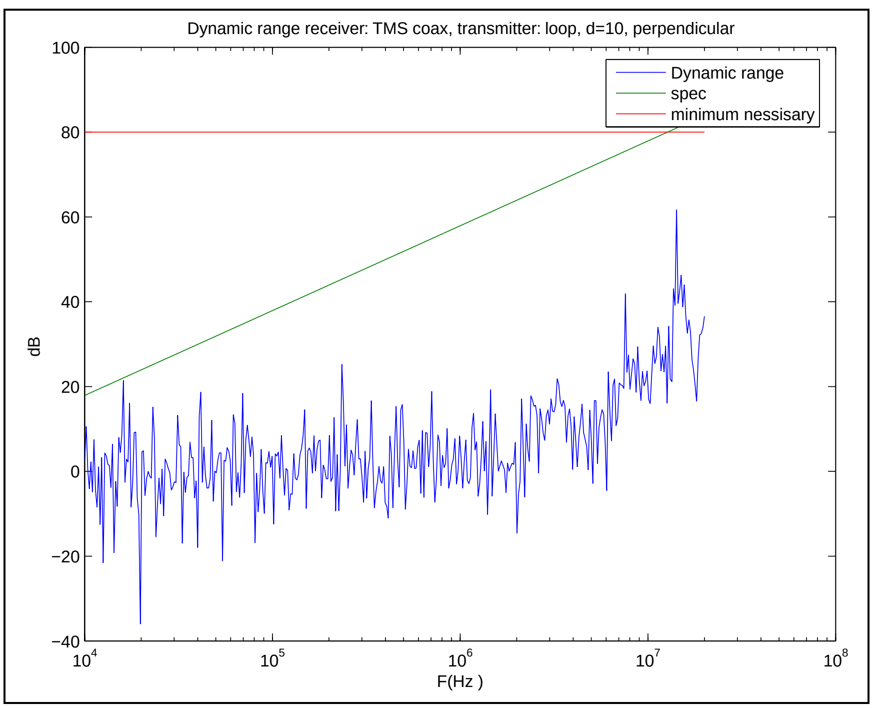

Figure 19. TMS and loop; perpendicular orientation.

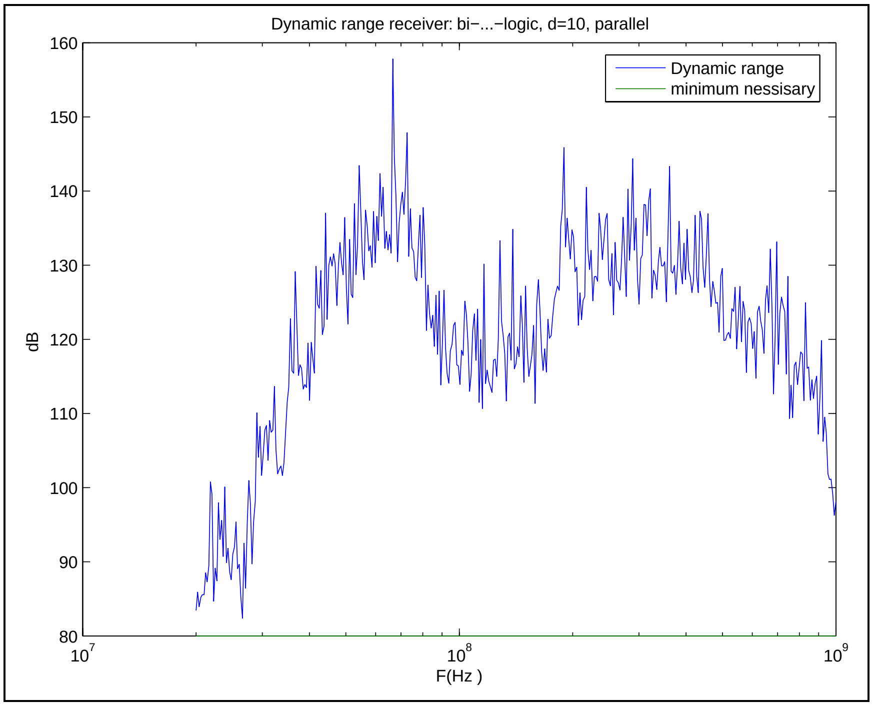

Figure 20. Bi-logic and bi-logic; parallel orientation.

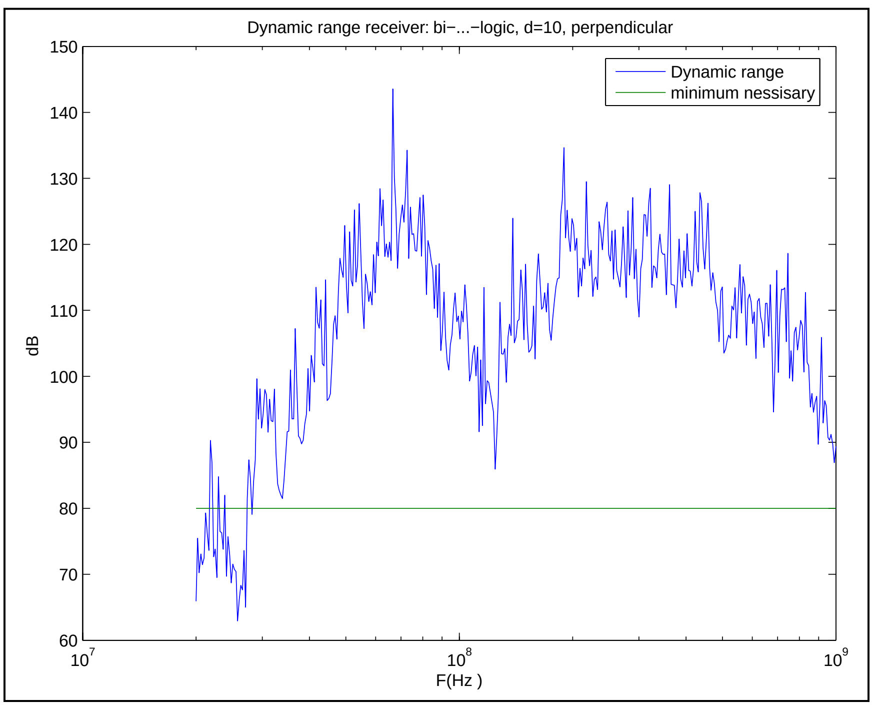

Figure 21. Bi-logic and bi-logic; perpendicular orientation.

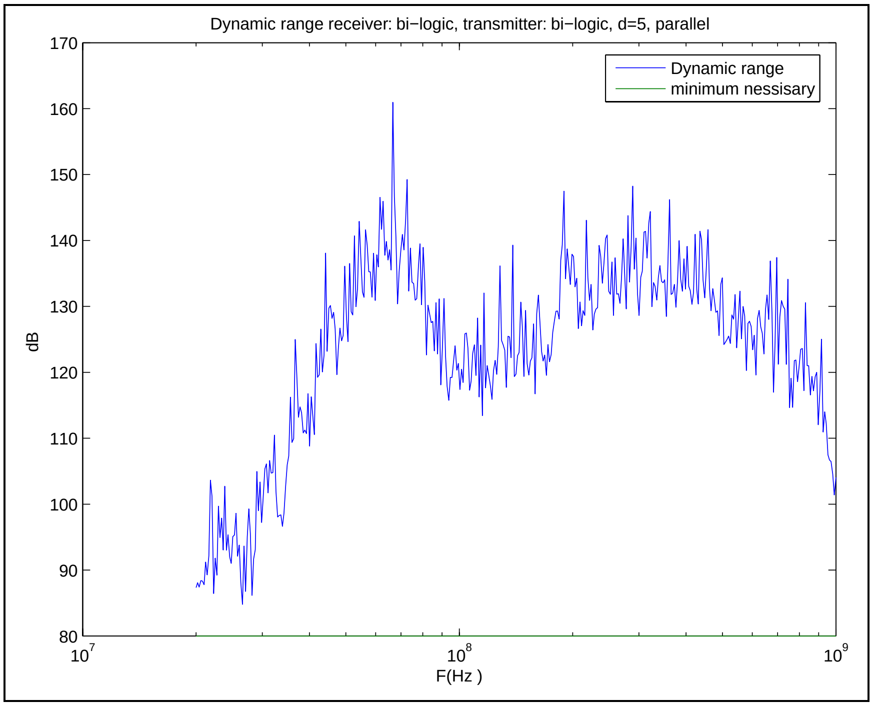

Figure 22. Bi-logic and bi-logic; parallel orientation.

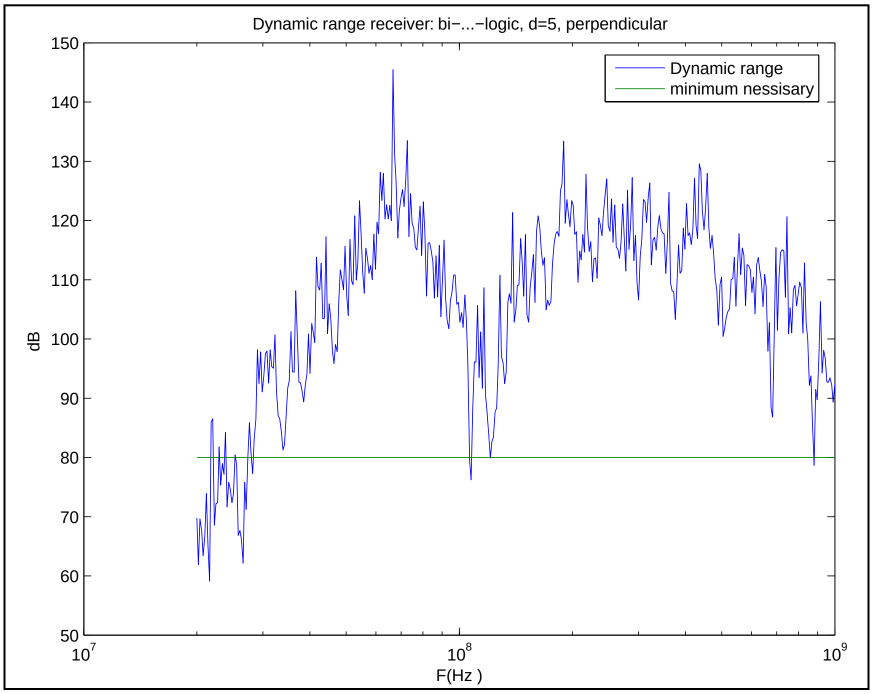

Figure 23. Bi-logic and bi-logic; perpendicular orientation.

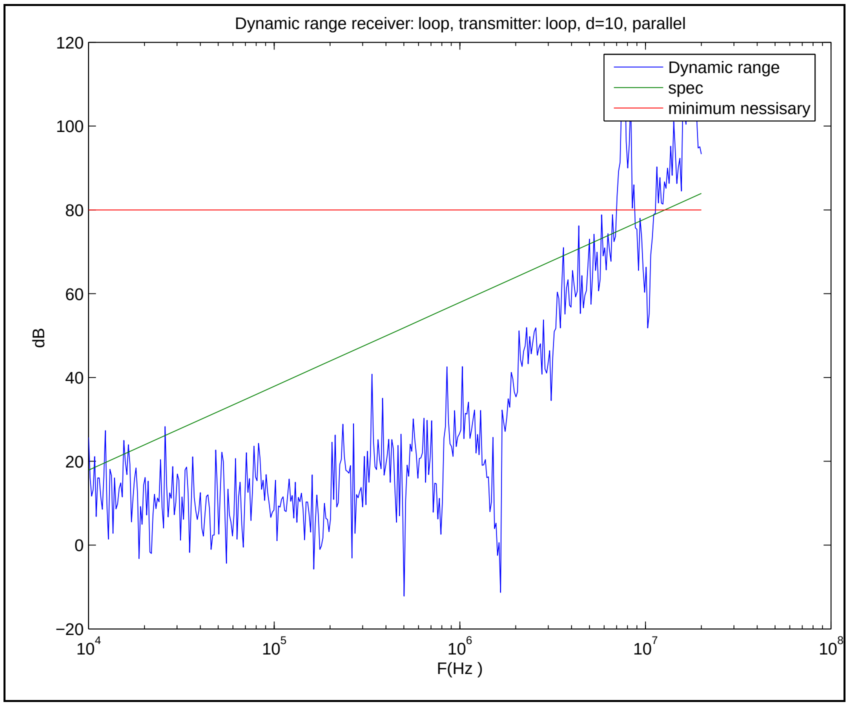

Figure 24. Loop and loop; parallel orientation.

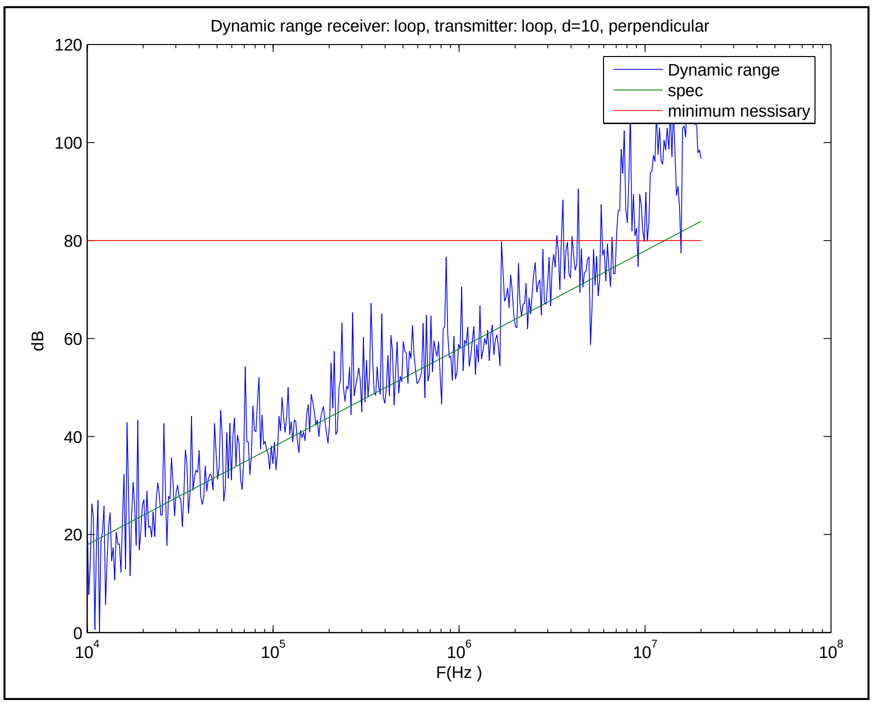

Figure 25. Loop and loop; perpendicular orientation.

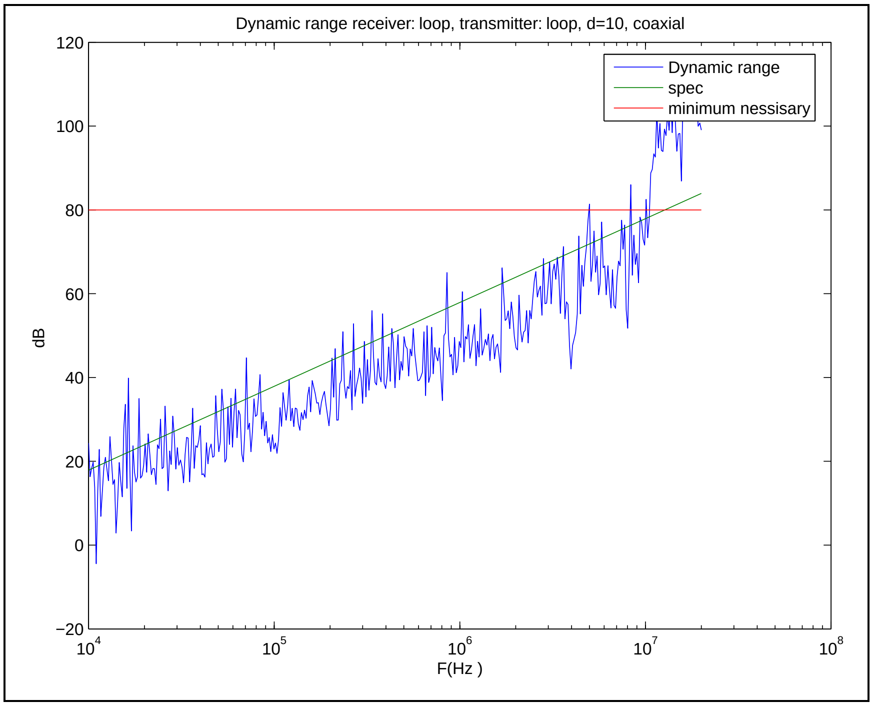

Figure 26. Loop and loop; coaxial orientation.

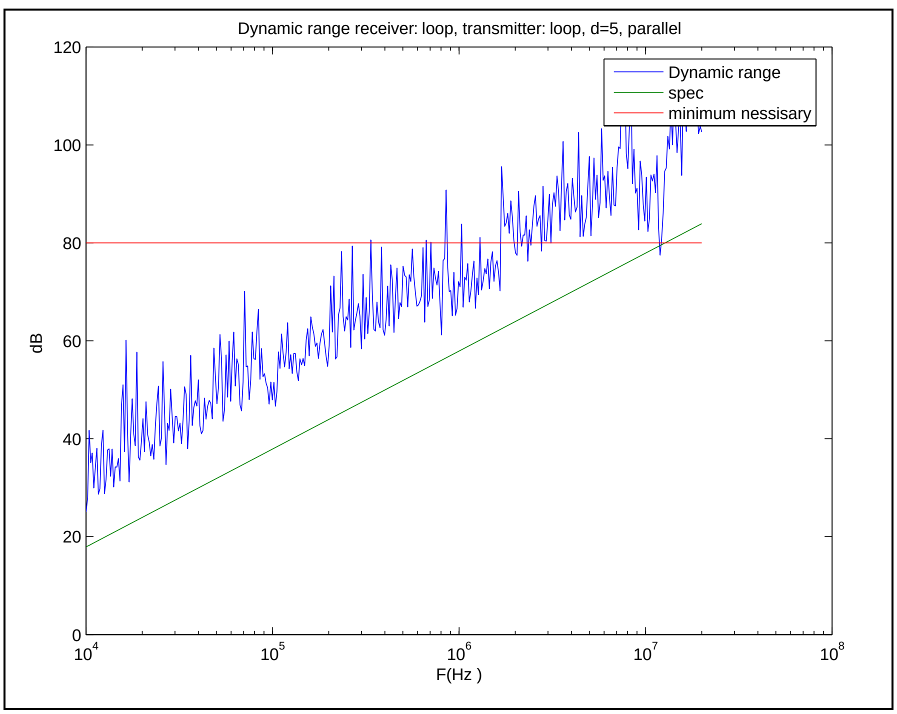

Figure 27. Loop and loop; parallel orientation.

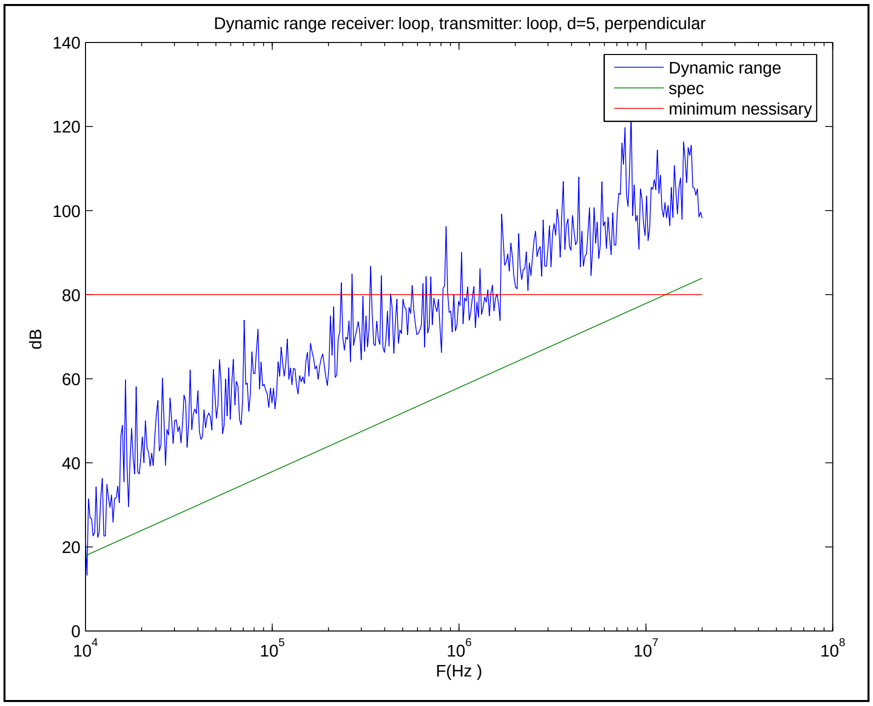

Figure 28. Loop and loop; perpendicular orientation.

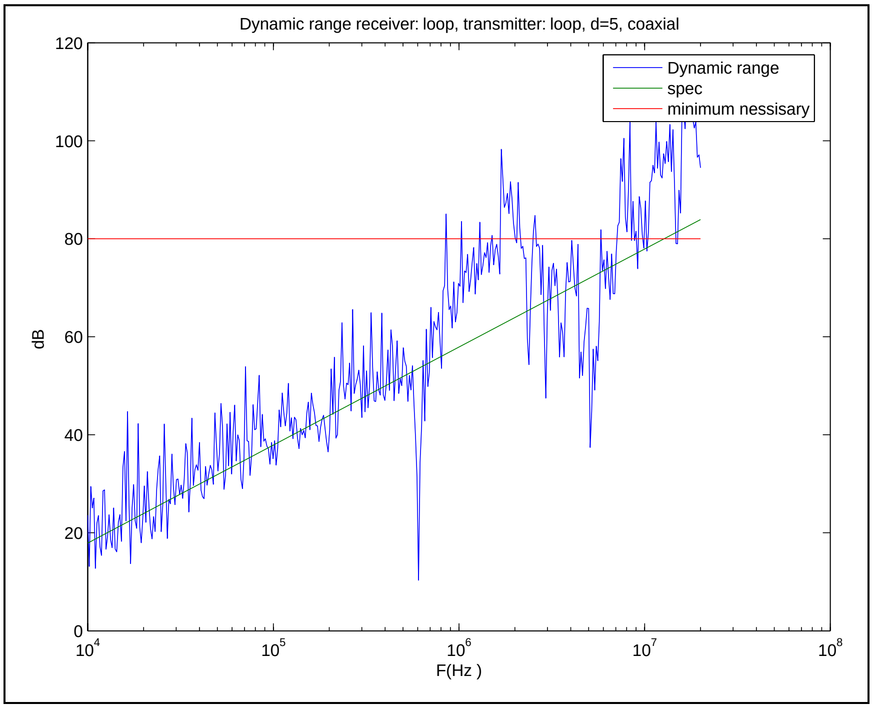

Figure 29. Loop and loop; coaxial orientation.

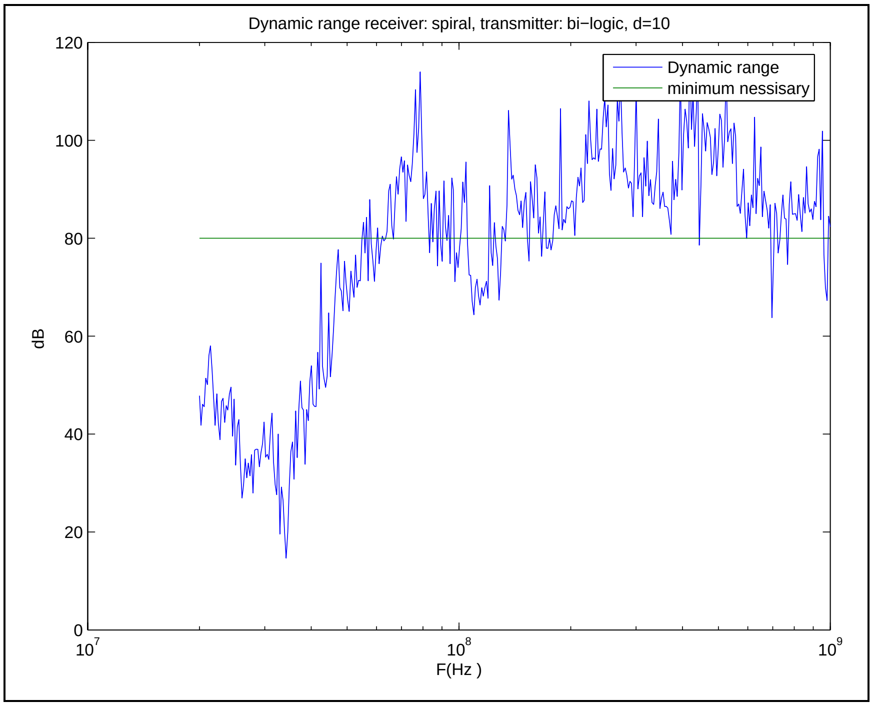

Figure 30. Spiral and bi-logic.

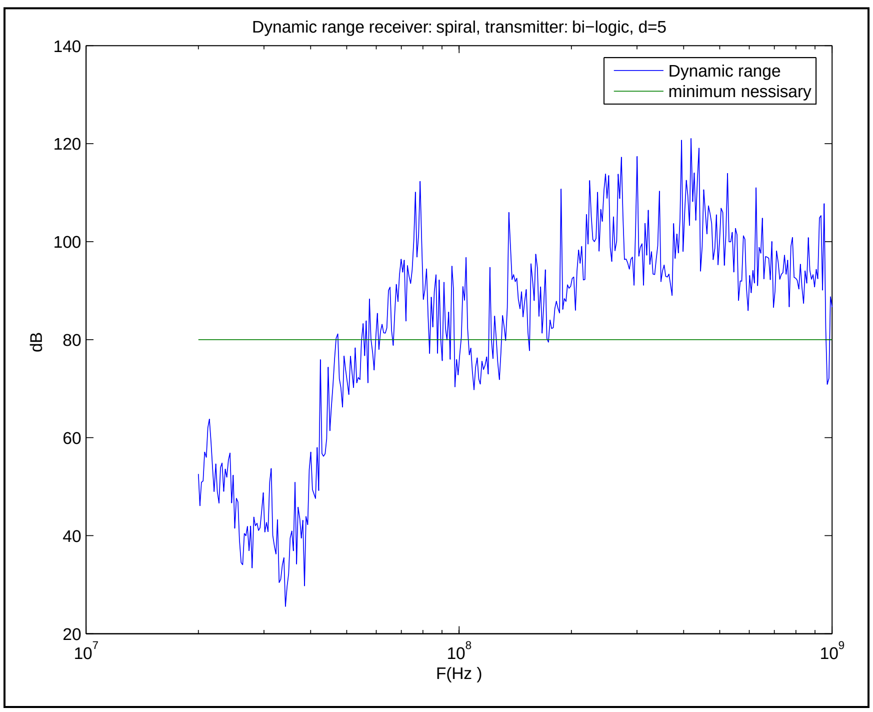

Figure 31. Spiral and bi-logic.

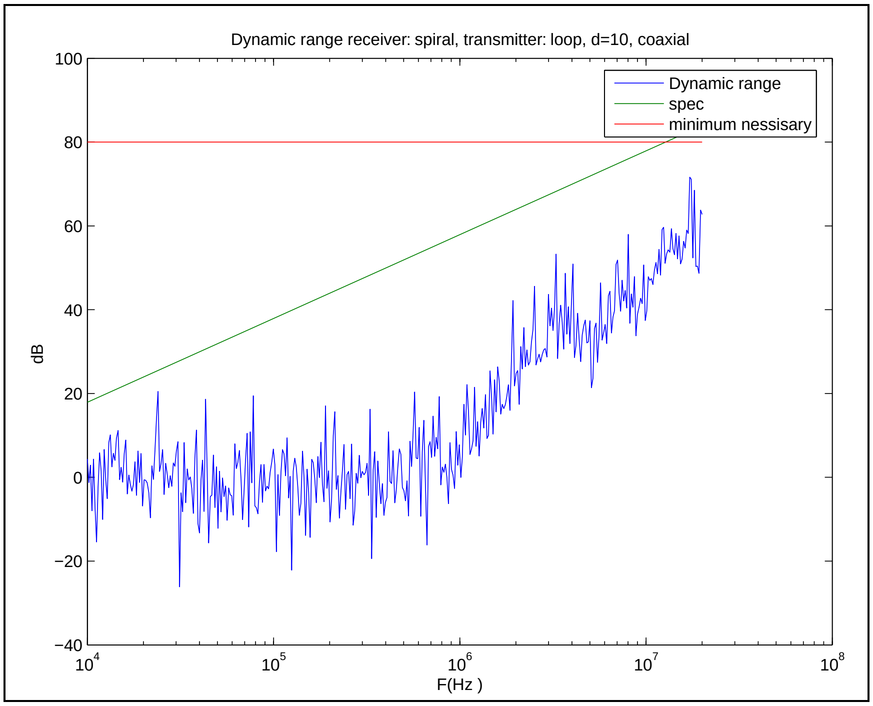

Figure 32. Spiral and loop; coaxial orientation.

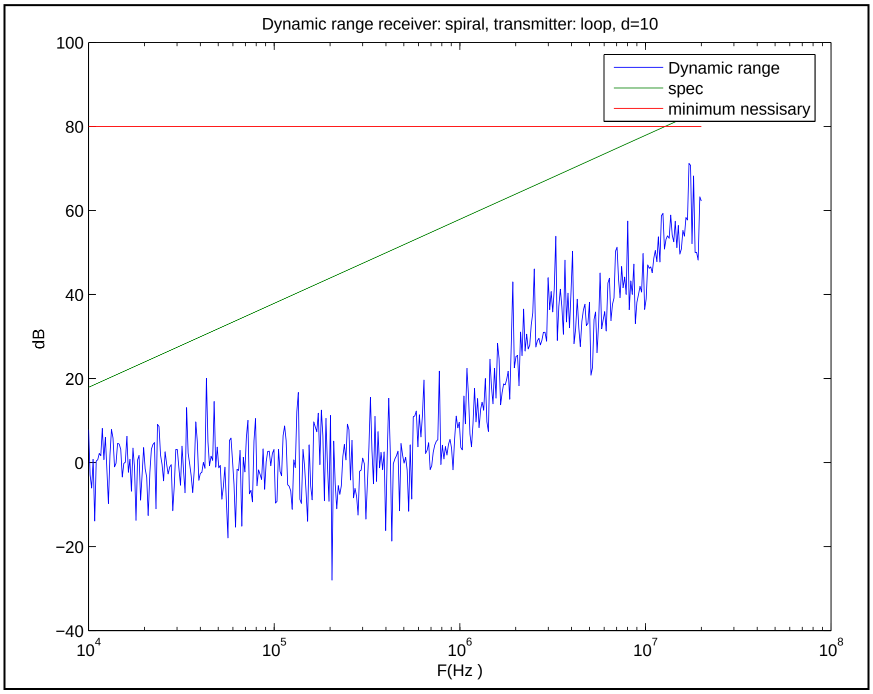

Figure 33. Spiral and loop; parallel orientation.

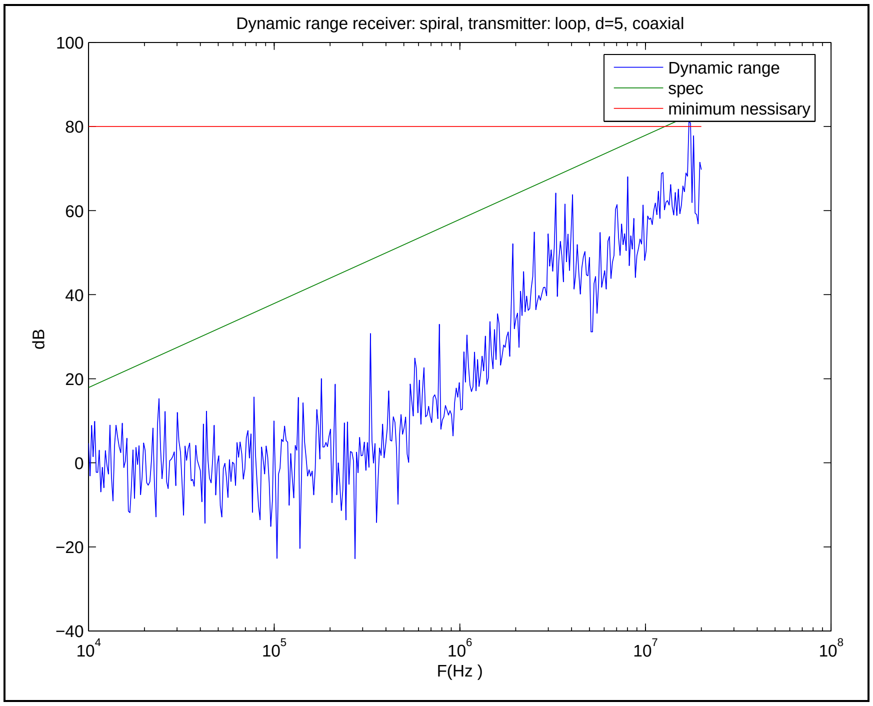

Figure 34. Spiral and loop; coaxial orientation.

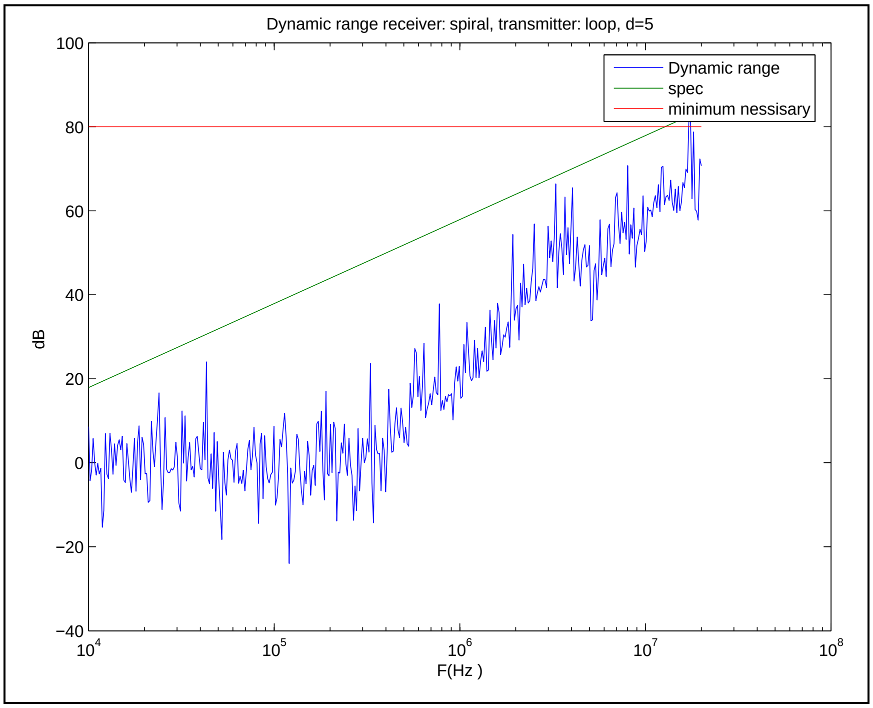

Figure 35. Spiral and loop; parallel orientation.

Conclusions

It appears that at least some combinations of antennae and polarizations have sufficient dynamic range to meet the minimum requirements. A dynamic range of 80 dB or more is recommended for higher frequencies, and certainly the bi-logic to bi-logic setup has more than that (in most cases a factor of 20 dB or more).

The spiral antenna results appeared quite promising. The advantage of the spiral antenna is that it would make possible measurements in places where measurements would have previously been difficult or impossible. There are uncertainties about the spiral antenna, however. The uncertainties about the spiral antenna's data only affects the lower range of frequencies, so as long as the antenna is only used to test high frequencies (on the order of 50-1000 MHz) it would likely produce acceptable results.

An advancement on the basic spiral antenna design would be to increase its' effective length (the length of the spirals). This could be done by fabricating a spiral antenna larger than the one used for the laboratory tests. The result would be in a useable range lower than the 50 MHz noted by the data plots.

A second improvement could possibly be realized through the use of a balun in the spiral antenna. A balun is a balanced load to unbalanced load transformer, and can typically increase the capabilities through more efficient electrical loading conditions.

One additional note is the "dip" in the dynamic range at about 100 MHz, which is caused by the characteristic profile of the bi-logic transmitting antenna and so is probably not a problem with the spiral itself.

The spiral's dynamic range results are as shown in figure 36.

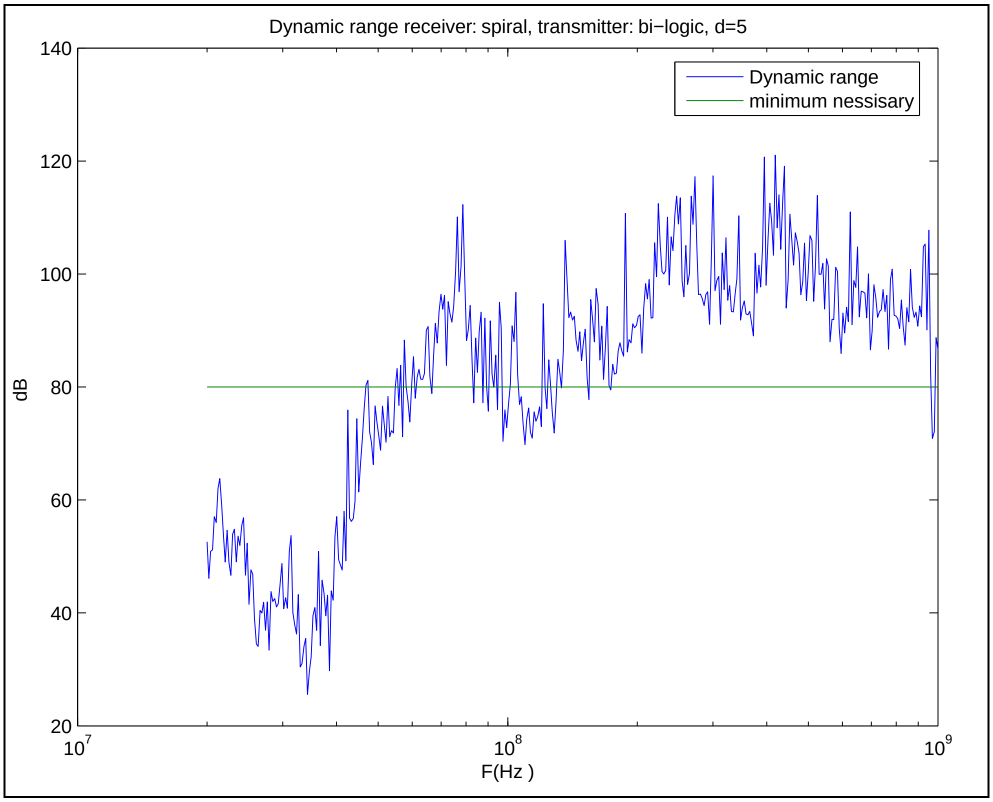

Figure 36. Dynamic range – spiral.

The Andrews Coax does not appear to be suitable as an antenna. The system was tested twice, with the better results shown in figure 37. Sufficient dynamic range cannot be achieved using this cable.

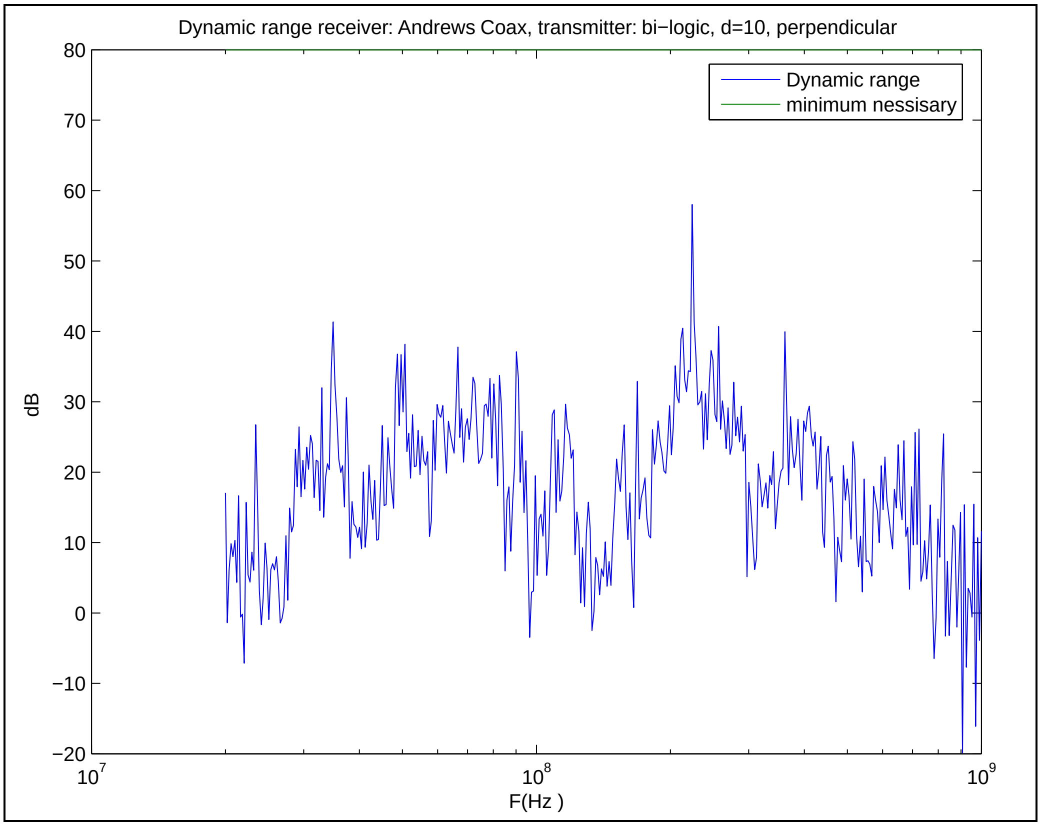

Figure 37. Dynamic range – Andrews coax.

The TMS coax does have sufficient dynamic range in the higher frequencies from about 50 MHz to about 500 MHz as shown in figure 38.

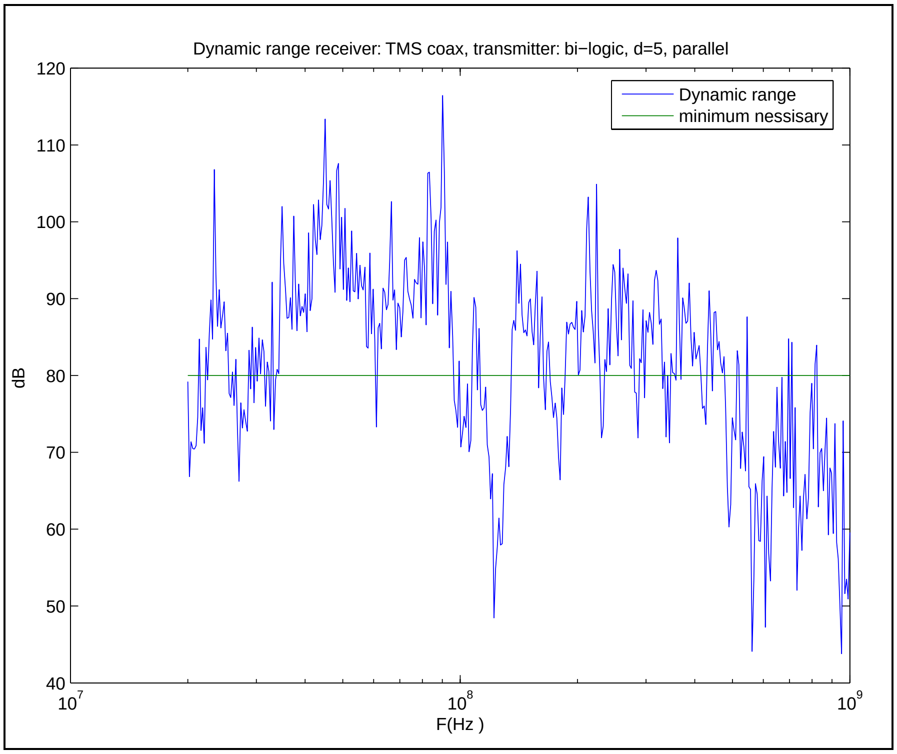

Figure 38. TMS coax – dynamic range.

Space permitting, the loop and Bi-logic antennae should be able to act as transmitters over the necessary range of frequencies. When space does not permit the Bi-logic or loop antennae to be used, variations of the TMS coax and spiral should perform adequately.

These new approaches, both single and multi-fiber-optic measurement systems, lend themselves to additional improvements and uses. The spectral characteristics of the antennae may be improved so as to increase the overall band-pass characteristics. Use of a higher power amplifier than the 10 watts used could also increase the dynamic range results for a variety of antenna combinations. Follow-on efforts that evaluate the variations and improvements are warranted and will be performed in the near-term in other-than-laboratory conditions.

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ATTN CHIEF OF LOGISTICS J EURY
ATTN S SHOAF
1435 PORTER STREET STE 100
FT DETRICK MD 21702-5046

ARMY MATL CMND
RSRCH DEV AND ENG CMND
ATTN AMSSB-SS-T J KRECK
9301 CHAPEK RD
FT BELVOIR VA 22060-5527

COMMANDING OFFICER
ATTN TSGT NOBLE
BLDG 494
RAMSTEIN FLUGPLATZ 435 CS/SCMTS
GERMANY

DIR AJCC FACILITIES–SITE R
ATTN MULLIGAN
201 BEASLEY DR STE 100
FT DETRICK MD 21702-5029

HDQTRS DEPT OF ARMY OFC ASSIST
SEC OF ARMY (ACQSTN, LOGISTC,
AND TECHLGY)
ATTN SAAL-TT M MILLER
2511 JEFFERSON DAVIS HWY STE 9000
ARLINGTON VA 22202

HDQTRS DEPT OF THE ARMY
ATTN DAMI-FIT B SMITH
2511 JEFFERSON DAVIS HWY STE 9300
ARLINGTON VA 22302-3910

HQ USAFE/SCNM
ATTN SMSGT M BOYD
BLDG 494
RAMSTEIN FLUGPLATZ
GERMANY

HQDA ODCS G-3/5/7
ATTN DAMO-SSD M F ALTFELD
400 ARMY PENTAGON
WASHINGTON DC 30210-0400

JOINT CHIEF OF STAFF J8/FDPAD
ATTN MAJ J CLARKE
PENTAGON, ROOM 1D940
WASHINGTON DC 20318-8000

US MILITARY ACDMY
MATHEMATICAL SCI CTR OF EXCELLENCE
ATTN LTC E NAASENS
ATTN LTC MORGAN
THAYER HALL RM 226C
WEST POINT NY 10996-1786

PEO EIS, PM DCATS
ATTN J JOO
FT MONMOUTH NJ 07703

PM DSCS TERMINALS, PM DCATS
ATTN AMSEL-IS-TSA-DSA C BENJAMIN
ATTN AMSEL-IS-TSA-DSA V HANEY
ATTN SFAE-PS-TS-DSC A B RICHMOND
ATTN SFAE-PS-TS-DSC M E BRYANT
ATTN SFAE-PS-TS-DSC R HYERS
ATTN AMSEL-IS-TSA-DSA D SINGLETON
ATTN AMSEL-IS-TSA-DSA G CHRISTOPHE
BLDG 209
FT MONMOUTH NJ 07703-5000

PM WIN-T
ATTN SFAE-C3T-WIN J R SHIELDS
BLDG 914
FT MONMOUTH NJ 07703

PROJECT MANAGER CLOSE COMBAT SYSTEMS
ATTN AMSTA-DSA-MC R ANDREJKOVICS
BLDG 162 N
PICATINNY ARSENAL NJ 07806-5000

RRMC-ENO
ATTN M ALLEN
201 BEASLEY DR STE 100
FT DETRICK MD 21702-5029

SMC/GPA
2420 VELA WAY STE 1866
EL SEGUNDO CA 90245-4659

TECOM
ATTN AMSTE-CL
ABERDEEN PROVING GROUND MD 21005-5057

US ARMY AIR DEFNS ARTILLERY SCHL
ATTN ATSA-TSM-F COL JASSEY
ATTN ATSA-CD M E COCHRANE
5800 CARTER ROAD
FT BLISS TX 79916-3802

US ARMY ARMOR CTR
ATTN ATZK-CDP M BOSEMER
ATTN ATZK-FD COL KALB
ATTN ATZK-MW S BLASKE
ATTN ATZK-TS COL C F MOLAR
FT KNOX KY 40121-5201

US ARMY AVN CTR & SCHL
ATTN ATZQ-TSM-C COL C L GANT JR
FT RUCKER AL 36362-5010

COMMANDING GENERAL
US ARMY AVN & MIS CMND
ATTN AMSAM-RD W C MCCORKLE
ATTN AMSMI-RD-ST-WF
D LOVELACE
ATTN AMSRD-AMR-AS-AC
G HUTCHESON
ATTN B MULLINS
REDSTONE ARSENAL AL 35898-5000

US ARMY AVN & MIS CMND
AVIATION APPLIED TECHNL DIRCTRT
ATTN AMSAT-R-TV G BIROCCO
ATTN SAVRT-R-TV J WOODHOUSE
FT EUSTIS VA 23604-5577

COMMANDER
US ARMY CECOM
ATTN AMSRD-CER-C2-AP-BA
M BRUNDAGE
ATTN AMSRD-CER-C2-AP-BA
M HENDRICKS
ATTN AMSRD-CER-C2-AP-BA
S SLANE
ATTN AMSRD-CER-C2-AP-BA
E PLICHTA
FT MONMOUTH NJ 07703-5703

US ARMY ELEC PROVING GROUND
ATTN STEEP-MT-E B WEEKS
FT HUACHUCA AZ 85613-7110

US ARMY EVALUATION CTR
ATTN CSTE-AEC-SVE-S D L SCOTT
ATTN USAEC-MS A LONCARICH
4120 SUSQUEHANNA AVE
ABERDEEN PROVING GROUND MD
21005-3013

US ARMY FIELD ARTLRY SCHL
ATTN ATSF-CD-FDD S WALKER
FT SILL OK 73503-5600

US ARMY INFANTRY SCHL
ATTN ATZB-BV COL T J STRAUSS
ATTN ATZB-CD COL R HOBBS
ATTN ATZB-FS COL J S GRIBSCHAW
ATTN ATZB-TS COL R M TESDAHL
FT BENNING GA 31905-5400

US ARMY INFO SYS ENGRG CMND
ATTN AMSEL-IE-TD F JENIA
FT HUACHUCA AZ 85613-5300

US ARMY INSCOM LAND INFO
WARFARE ACTVTY
ATTN LIWA-APD LTC R VRTIS
ATTN LIWA-APD S BERGMAN
8825 BELUAH ST
FT BELVOIR VA 22060-5246

US ARMY MATERIEL SYS ANAL
ACTVTY
ATTN AMXSY-C4I S CHISMAR
ATTN AMXSY-CA D LIBOWITZ
ATTN AMXSY-CA D PETERS
ATTN AMXSY-CA P TOPPER
ATTN AMXSY-J E ATZINGER
ATTN AMXSY-SC P BEAVERS
392 HOPKINS RD
ABERDEEN PROVING GROUND MD
21005-5071

US ARMY NATICK RDEC ACTING
TECHL DIR
ATTN SBCN-TP L SAMUELSON
ATTN SBCN-TP P BRANDLER
KANSAS STREET BLDG 78
NATICK MA 01760-5056

US ARMY NATL GROUND INTLLGNC
CTR
ATTN IANG-RMA T CALDWELL
2055 BOULDERS RD
CHARLOTTESVILLE VA 22911-8318

US ARMY NETWORK ENTERPRISE TECHNLGY CMND
9TH ARMY SIGNAL COMMAND
ATTN G4, OFFICE OF THE COMMAND ENGINEER D SCHOW
2133 CUSHING STREET SUITE 2313
FT HUACHUCA AZ 85613-7070

US ARMY NETWORK ENTERPRISE TECHNLGY CMND
9TH ARMY SIGNAL COMMAND
ATTN O WITT
2133 CUSHING STREET BLDG 61801 RM 3105
FT HUACHUCA AZ 85613-7070

US ARMY NUC & CHEM AGCY
ATTN MONA-NU R PFEFFER
7150 HELLER LOOP RD STE 101
SPRINGFIELD VA 22150

US ARMY RDECOM CERDEC
ATTN AMSRD-CER-C2-AP-ES A PATIL
ATTN AMSRD-CER-C2-AP-ES C BOLTON
ATTN AMSRD-CER-C2-AP-ES S MATHEWS
10125 GRATOIT RD STE 100
FT BELVOIR VA 22060

US ARMY RDECOM/ARDEC
ATTN AMSTA-AR-TD
ATTN AMSRD-AAR-AEW-E (D) B LAGASCA
ATTN AMSRD-AAR-EM H MOORE
BLDG 65N
PICATINNY ARSENAL NJ 07806-5000

US ARMY SIMULATION TRAIN & INSTRMNTN CMND
ATTN AMSTI-CG M MACEDONIA
12350 RESEARCH PARKWAY
ORLANDO FL 32826-3726

US ARMY SPC & MIS DEFNS CMND
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ATTN SMDC-TC-MT R SNEAD
ATTN SMDC-TC-TD W K HARDY
PO BOX 1500
HUNTSVILLE AL 35807-3801

US ARMY TACOM
ATTN AMSTA-ZT G BAKER
ATTN ATSTA-OE E DI VITO
WARREN MI 48397-5000

US ARMY TEST AND EVALUATION COMMAND
ATTN STERT-TE-E-EM J CRAVEN
REDSTONE TECHNICAL TEST CENTER
HUNTSVILLE AL 35898-8052

US ARMY TEST AND EVALUATION COMMAND
MATERIAL TEST DIRECTORATE
ATTN STEWS-NE J MEASON
ATTN STEWS-NR-MT-AM J TYREE
WHITE SANDS MISSILE RANGE NM 88002

US ARMY TRADOC ANAL CTR (TRAC-WSMR)
ATTN ATRC-WEA D MACKEY
WHITE SANDS MISSILE RANGE NM 88002-5513

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ATTN ATZL-CDB COL HEREDIA
FT LEAVENWORTH KS 66027-5300

US ARMY TRADOC HDQTR
ATTN ATCD-B
ATTN ATCD-GB W DIXON
ATTN ATCD-HW F TEAFORD
FT MONROE VA 23651-1061

NAV AIR WARFARE CTR AIRCRAFT
DIV
ATTN E3 DIV S FRAZIER CODE 5.1.7
UNIT 4 BLDG 966
PATUXENT RIVER MD 20670-1701

NAV AIR WARFARE CTR WEAPONS
DIV
ATTN CODE 2186 R RANDOLPH
ATTN CODE 526E00D M HENDERSON
1 ADMINISTRATION CIRCLE
CHINA LAKE CA 93555-6100

NAV RSRCH LAB
ATTN CODE 6653 P C GROUNDS
ATTN CODE 6653 T ANDREADIS
4555 OVERLOOK AVE SW
WASHINGTON DC 20375-5000

NAV SURFC WARFARE CTR
ATTN CODE B-20 D STOUDT
ATTN CODE B-20 J LATESS
ATTN CODE B-20 S GRIFFITHS
ATTN CODE B-20 S MORAN
ATTN CODE J-52 W LUCADO
17320 DAHLGREN RD
DAHLGREN VA 22448-5100

NAVAIRWARCENWPNDIV
ATTN CODE 47J100D CAPT K YOUNG
1900 N KNOX RD STOP 6609
CHINA LAKE CA 93555-6104

AIR FORCE INF WARFARE CTR
453RD EWS/EWC
ATTN AFIWC/SAA C GILMORE
102 HALL BLVD STE 331
SAN ANTONIO TX 78243-7038

AIR FORCE RSRCH LAB-DIRECTED
ENERGY DIRECTORATE (PHILLIPS
CTR)
ATTN AFRL W L BAKER BLDG 413
ATTN AFRL/DE M HARRISON
ATTN AFRL/DEPE D DIETZ
ATTN AFRL/WSP T W HUSSEY
ATTN AFRL/WST W WALTON
3550 ABERDEEN AVE SE
KIRTLAND NM 87117-5776

HQ ESC/MCW
AF TERMINALS PROGRAM OFFICE
ATTN J FISH
HANSCOM AFB MA 01730

MCS (HQ)
ATTN GIGSG/KCP J THORNE
HANSCOM AFB MA 01731-1620

US AIR FORCE RSRCH LAB-INFORM
DIRECTORATE
ATTN AFRL/IFED B CLARKE
32 HANGER RD
ROME NY 13441-4114

USSTRATCOMCL113
ATTN F J METZGER JR
901 SAC BLVD STE M102
OFFUTT AFB NE 68113-6300

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ATTN L-153 D GOERZ
PO BOX 808
LIVERMORE CA 94550

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ATTN MS H851 A ERICKSON
ATTN MS H851 M FAZIO
PO BOX 1663 MAIL STOP 5000
LOS ALAMOS NM 87545

SANDIA NATL LAB
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MS 1153
ATTN DEPT 15333 T MARRUJO
MS 1153
ATTN DIV 1244 L BACON
PO BOX 5800
ALBUQUERQUE NM 87185-1153

FEMMECOMP INC
ATTN R LOUNSBERY
14170 NEWBROOK DR
CHANTILLY VA 20151

ALION SCIENCE AND TECHNOLOGY
ATTN TACTICAL SYS DIV
E SCANNELL
8100 CORPORATE DR STE 400
LANHAM MD 20785

DIRECTED TECHNOLOGIES INC
ATTN N CHESSER
3601 N WILSON DR STE 650
ARLINGTON VA 22201

J D ENGEERING
ATTN J DANDO
3103 FOX DEN LN
OAKTON VA 22124

JAYCOR
ATTN W CREVIER
3700 STATE STREET STE 300
SANTA BARBARA CA 93105-3128

MISSION RSRCH CORP
ATTN M BOLLEN
8560 CINDERBED RD STE 700
NEWINGTON VA 22122

NATL INTLLGNC COUNCIL DIR
OF CENTRAL INTLLGNC
ATTN MG J LANDRY USA (RETIRED)
WASHINGTON DC 20505

SPARTA
ATTN R O'CONNOR
4901 CORPORATE DR STE 102
HUNTSVILLE AL 35805-6257

SURVICE ENGINEERING CO
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4695 MILLENIUM DRIVE
BELCAMP MD 21017

US ARMY RSRCH LAB
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LIB T LANDFRIED (2 COPIES)
ABERDEEN PROVING GROUND MD
21005-5066

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ATTN AMSRD-ARL-SL-E M STARKS
ATTN AMSRD-ARL-WM-TA
B ZOLTOSKI
ATTN AMSRD-ARL-SL-BB D BELY
ATTN AMSRD-ARL-SL-EC E PANUSKA
ABERDEEN PROVING GROUND MD
21005-5069

US ARMY RSRCH LAB
ATTN AMSRD-ARL-SL-B
D FARENWALD
EDGEWOOD ARSENAL MD 21010-5423

DIRECTOR
US ARMY RSRCH LAB
ATTN AMSRD-ARL-RO-EN W D BACH
PO BOX 12211
RESEARCH TRIANGLE PARK NC 27709

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