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Feasibility Studies of New High Altitude Electromagnetic Pulse Test Materials

by Max Polun

ARL-TR-3677 November 2005

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ARL-TR-3677 **November 2005**

Feasibility Studies of New High Altitude Electromagnetic Pulse Test Materials

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
November 2005	Final	May 2005

4. TITLE AND SUBTITLE Feasibility Studies of New High Altitude Electromagnetic Pulse Test Materials	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Max Polun	**5d. PROJECT NUMBER** 5NY1YY
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-SE-DE 2800 Powder Mill Road Adelphi, MD 20783-1197	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-TR-3677
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

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.

15. SUBJECT TERMS

HEMP hardening, antenna, fiber-optic

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Max Polun
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	UL	42	**19b. TELEPHONE NUMBER** (*Include area code*) (301) 394-2016

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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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.

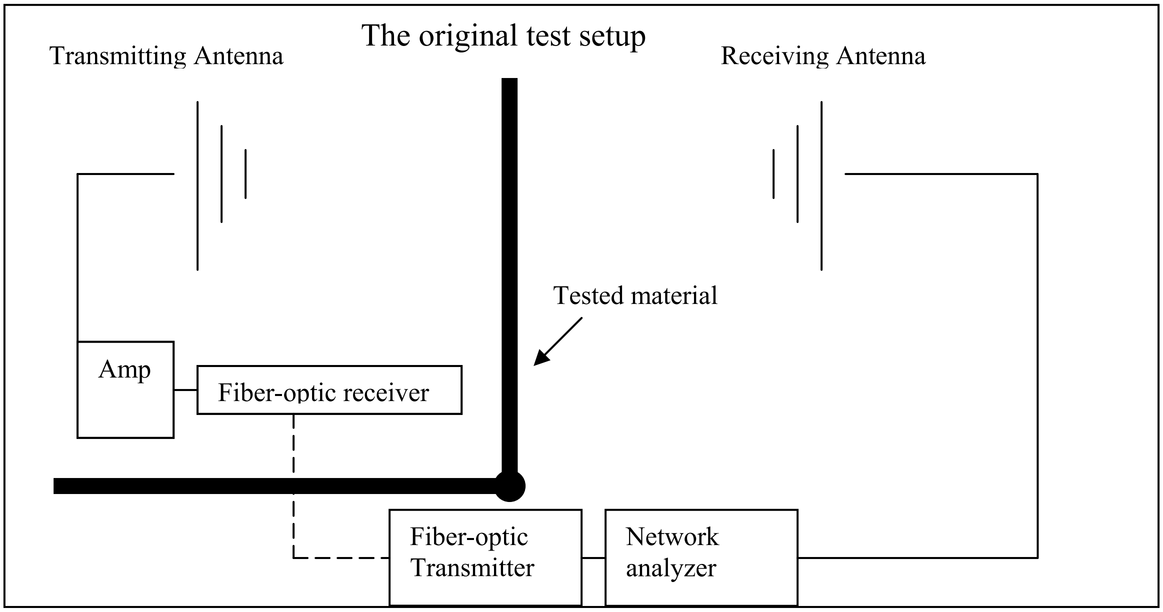

Figure 1. Single fiber-optic measurement approach.

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.

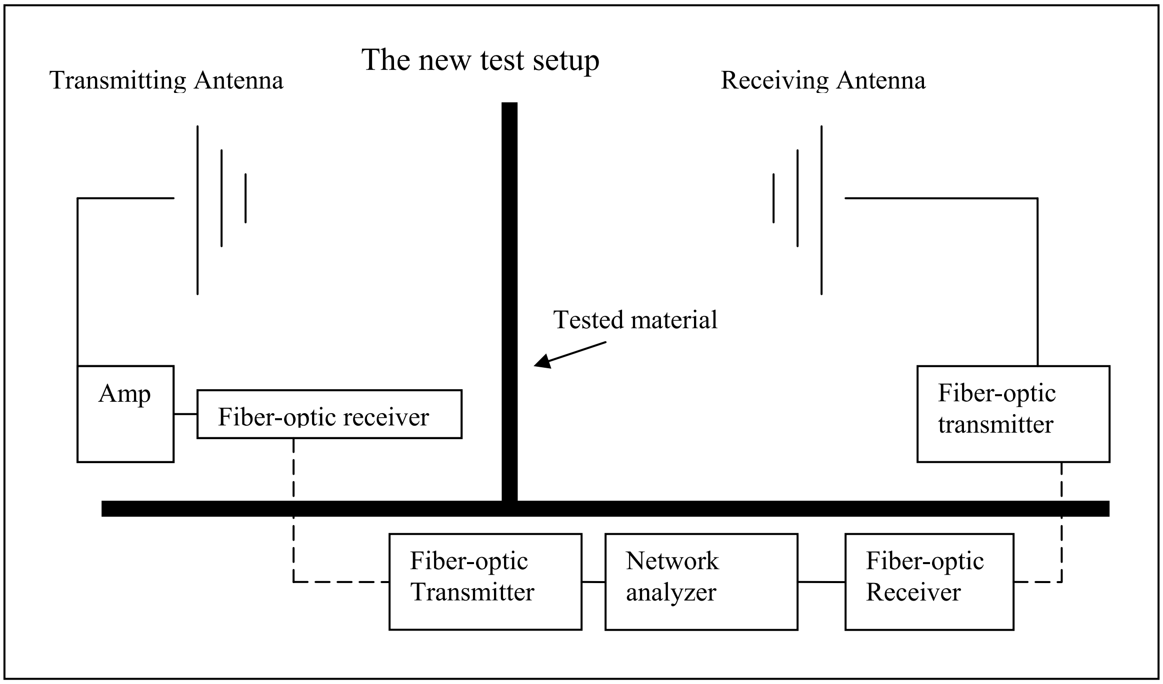

Figure 2. Multi-fiber-optic measurement approach.

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:

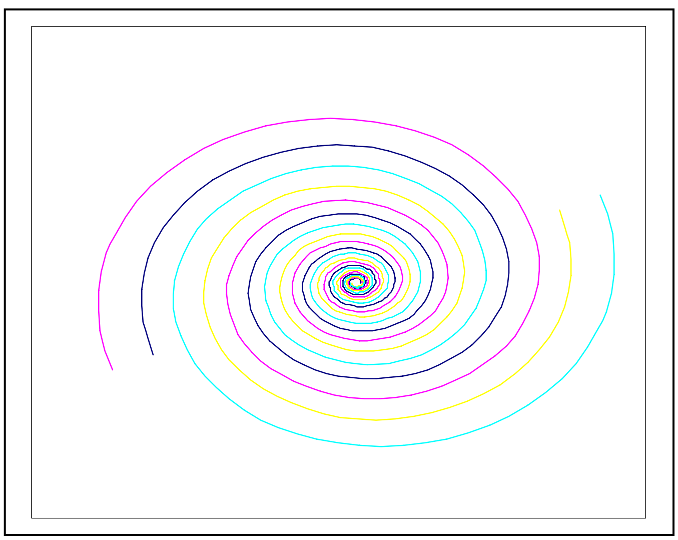

Figure 3. Rough spiral design – for fabrication.

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.

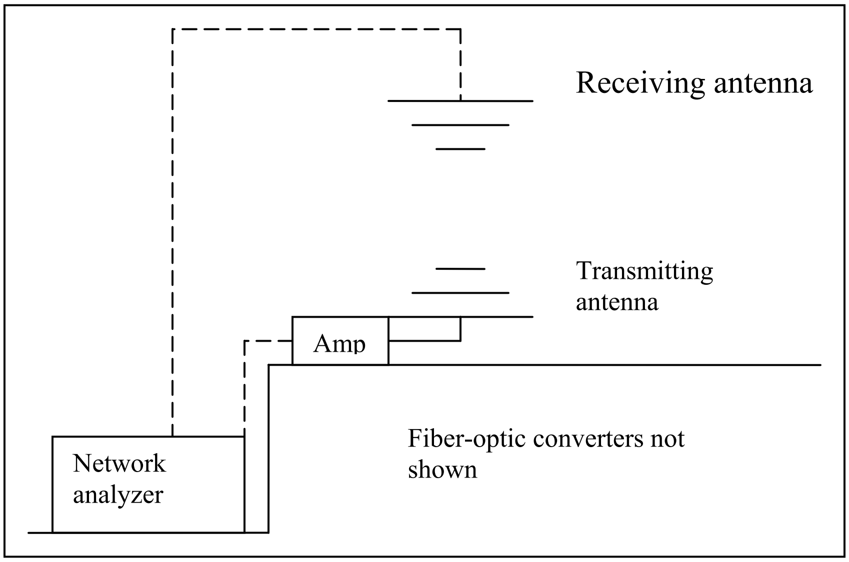

Figure 4. Scale model facility test bed.

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.

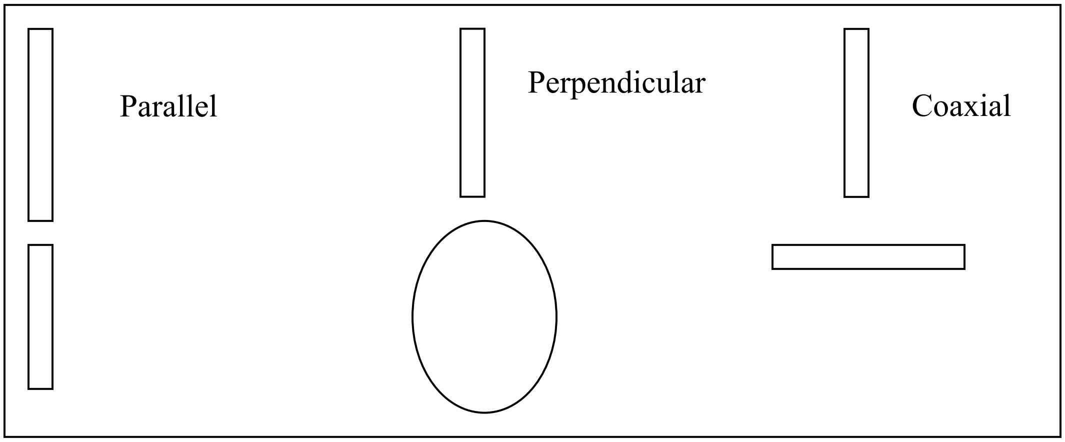

Figure 5. Antenna test set-up polarizations.

The Measured Data

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

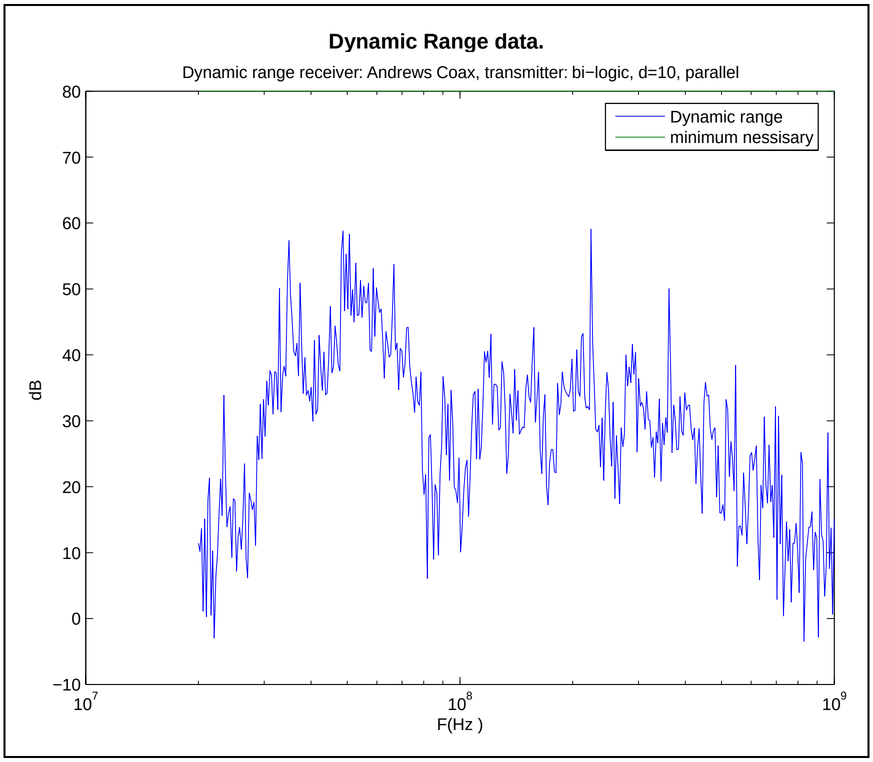

Figure 6. Andrews and bi-logic; parallel orientation.

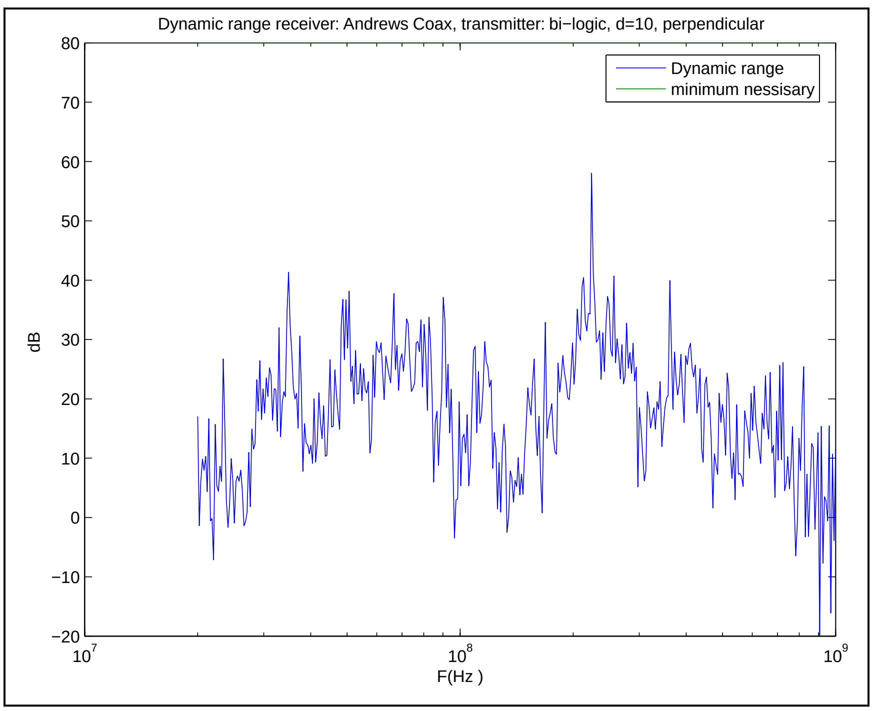

Figure 7. Andrews and bi-logic; perpendicular orientation.

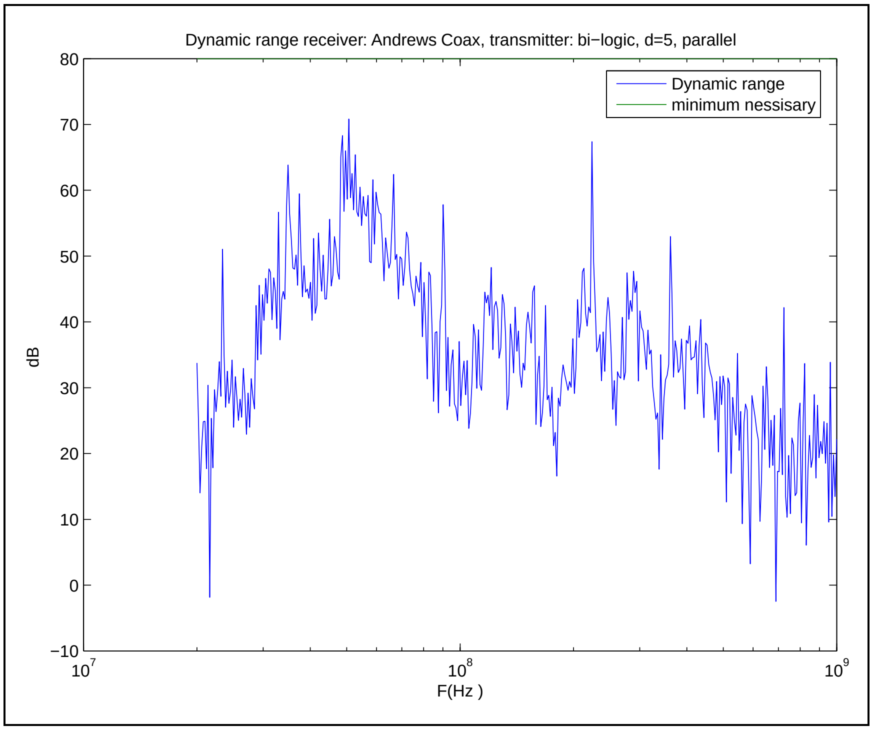

Figure 8. Andrews and bi-logic; parallel orientation.

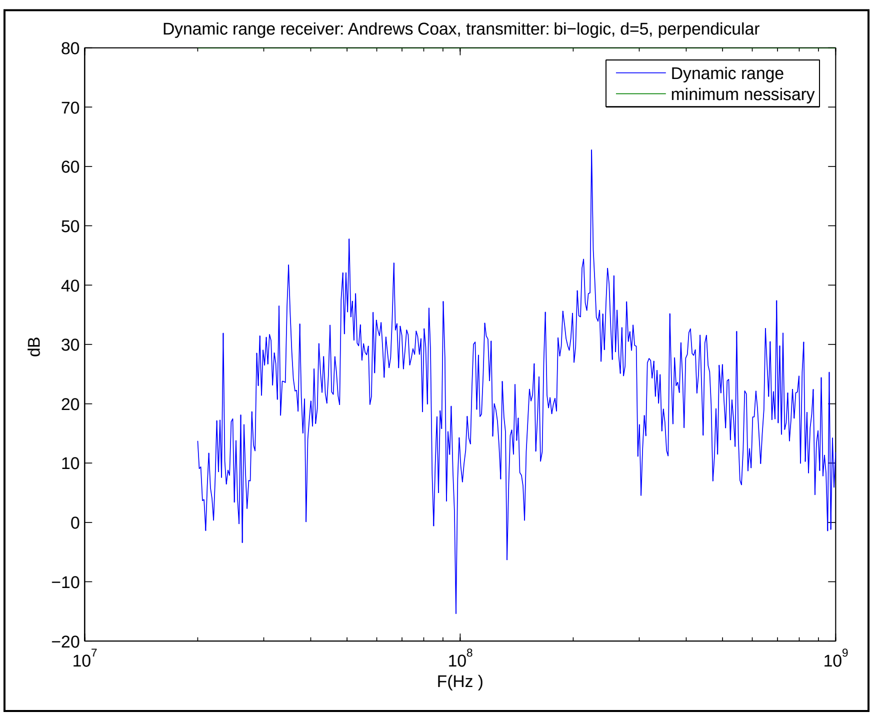

Figure 9. Andrews and bi-logic; perpendicular orientation.

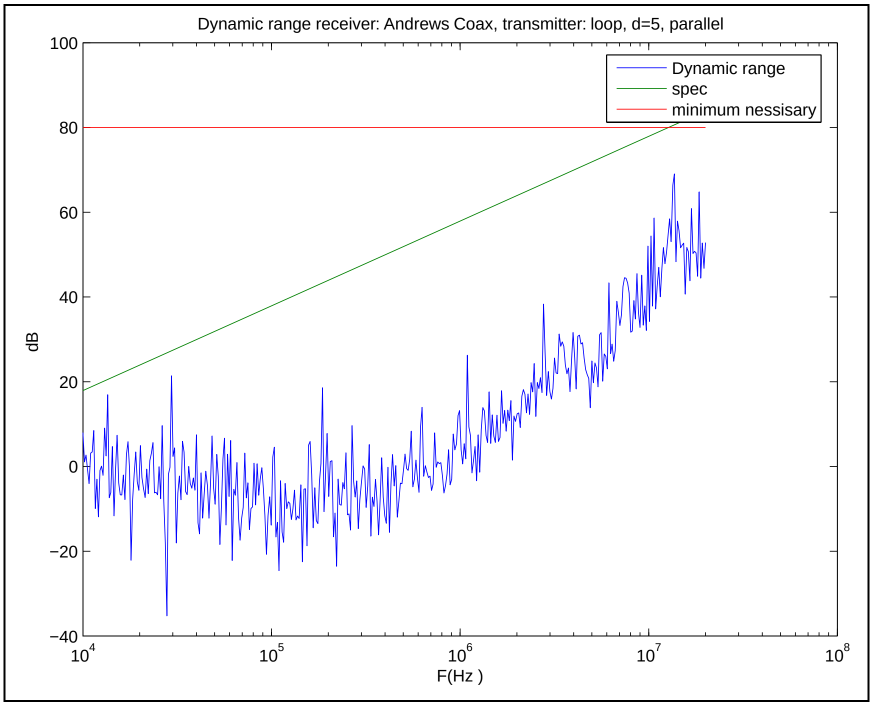

Figure 10. Andrews and loop; parallel orientation.

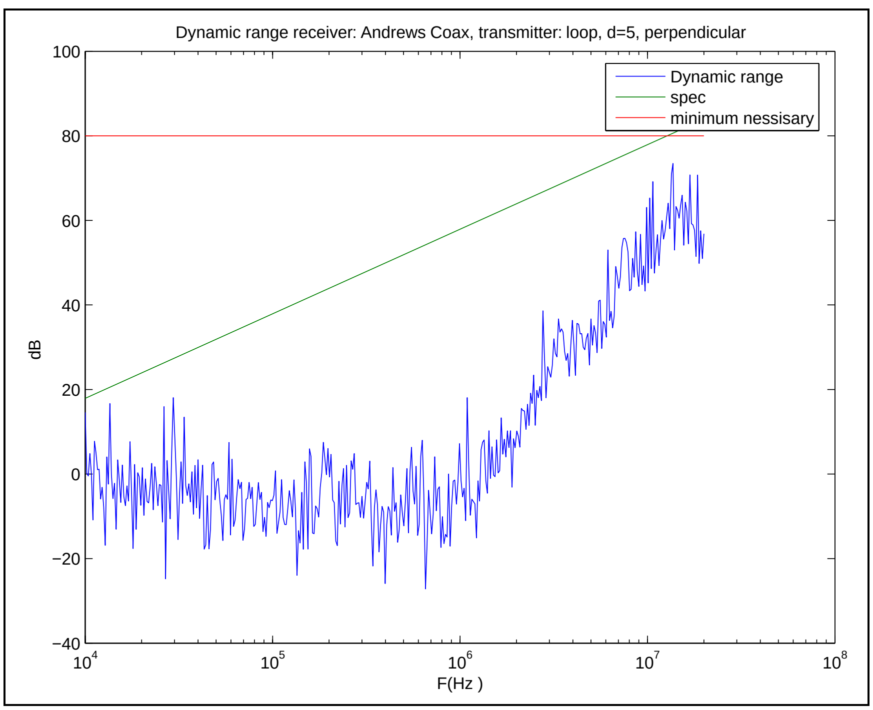

Figure 11. Andrews and loop; perpendicular orientation.

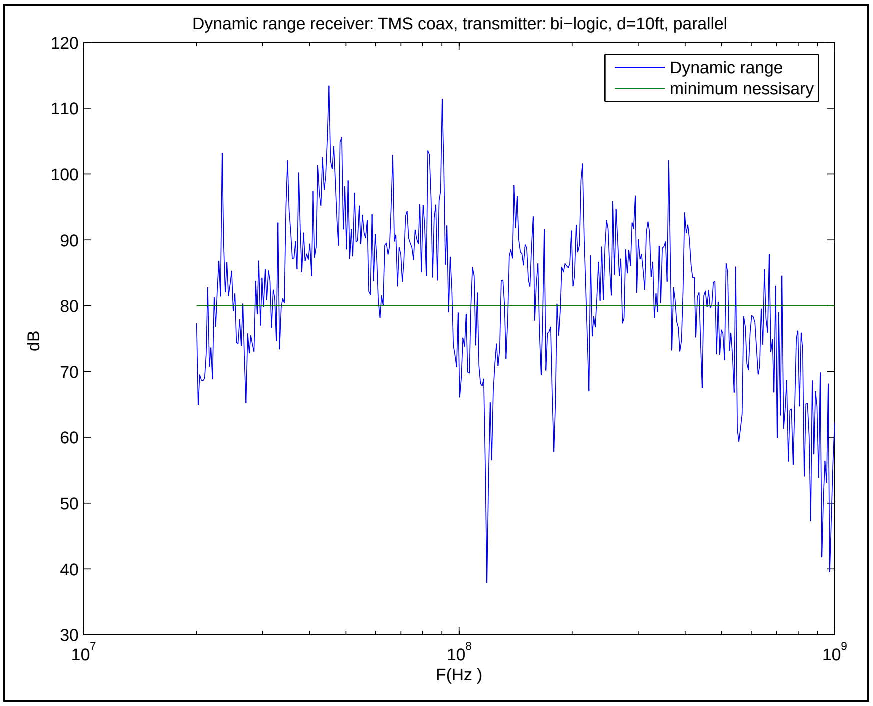

Figure 12. Andrews and bi-logic; parallel orientation.

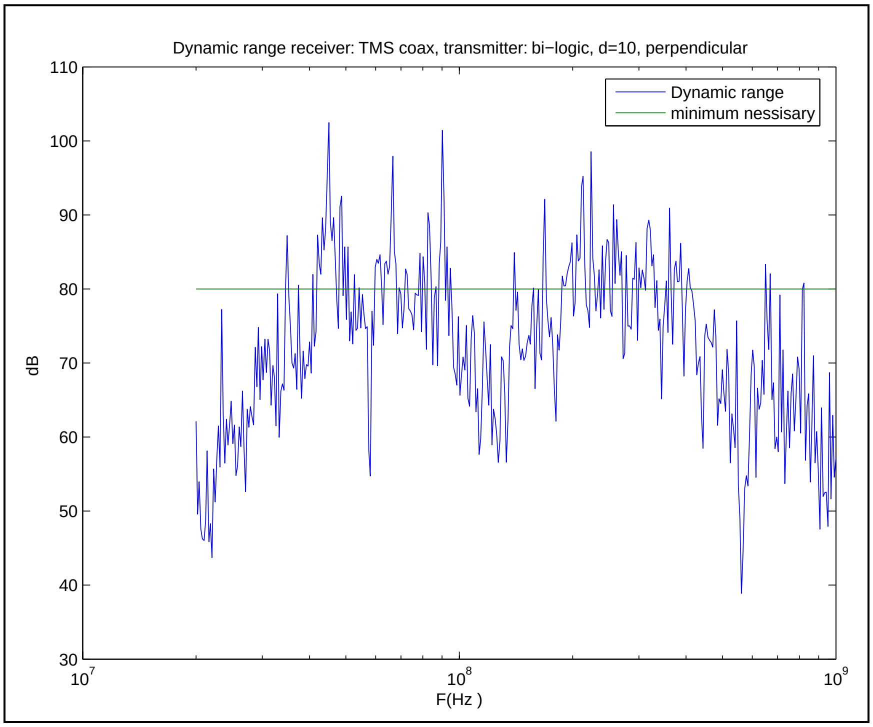

Figure 13. Andrews and loop; perpendicular orientation.

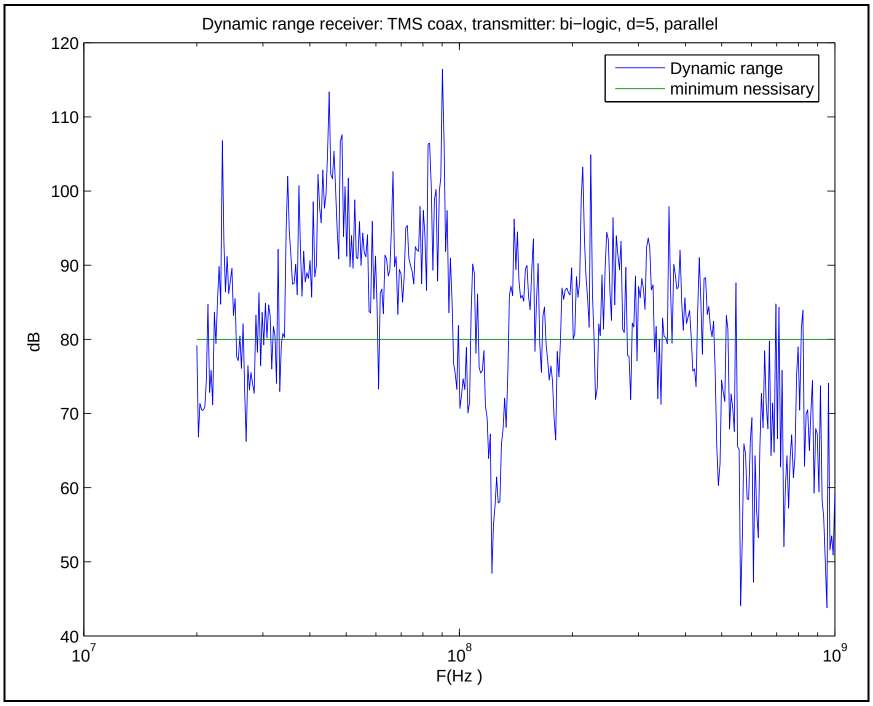

Figure 14. TMS and bi-logic; parallel orientation.

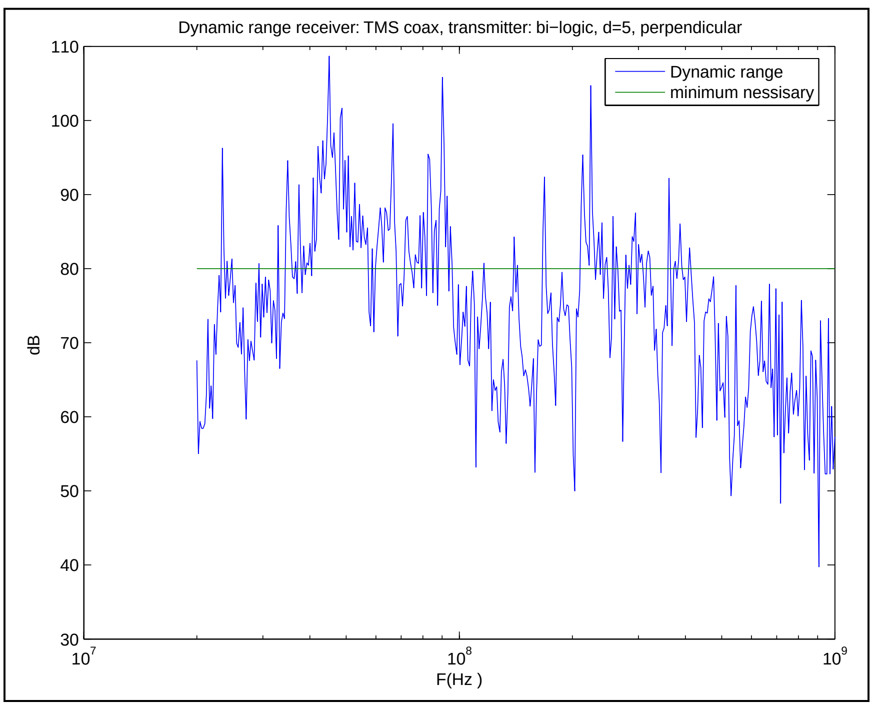

Figure 15. TMS and bi-logic; perpendicular orientation.

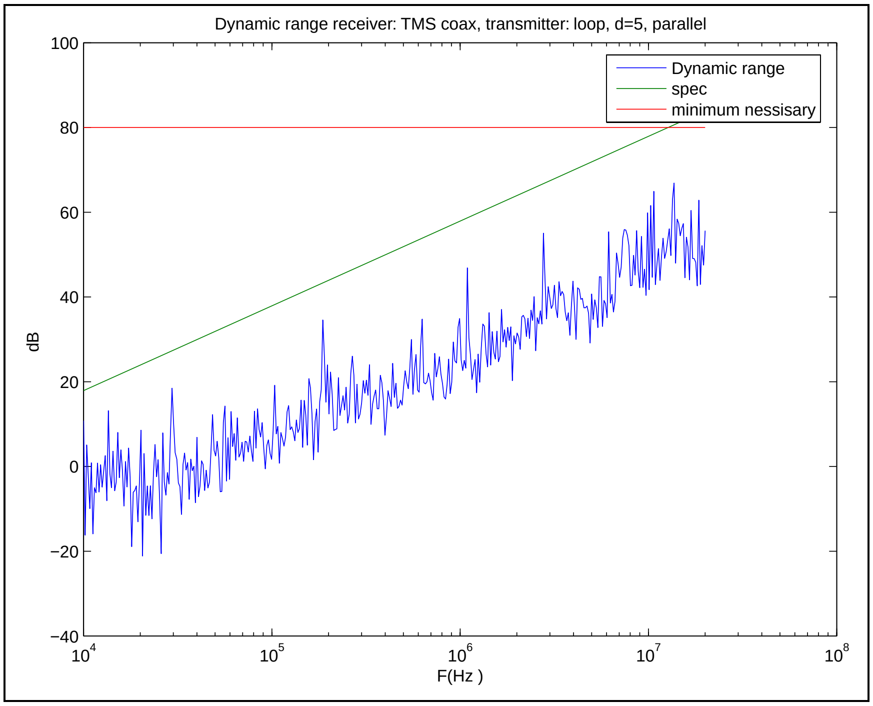

Figure 16. TMS and loop; parallel orientation.

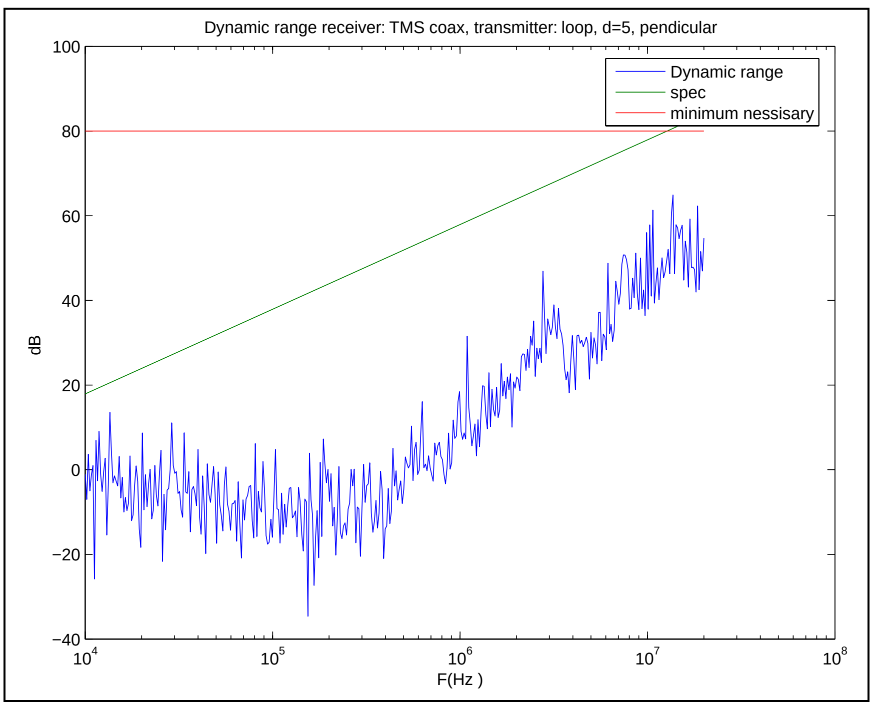

Figure 17. TMS and loop; perpendicular orientation.

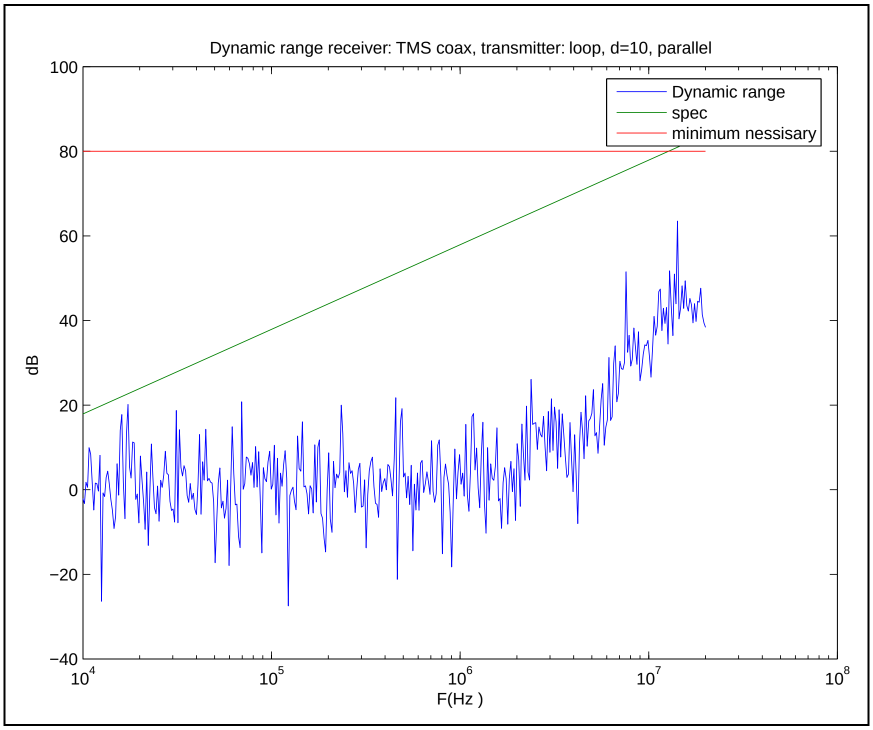

Figure 18. TMS and loop; parallel orientation.

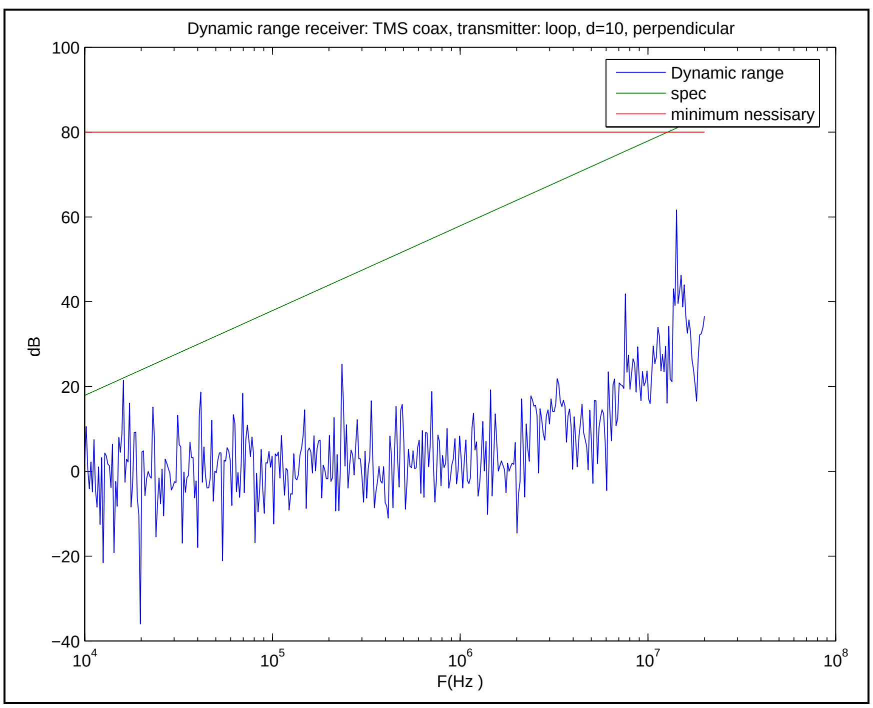

Figure 19. TMS and loop; perpendicular orientation.

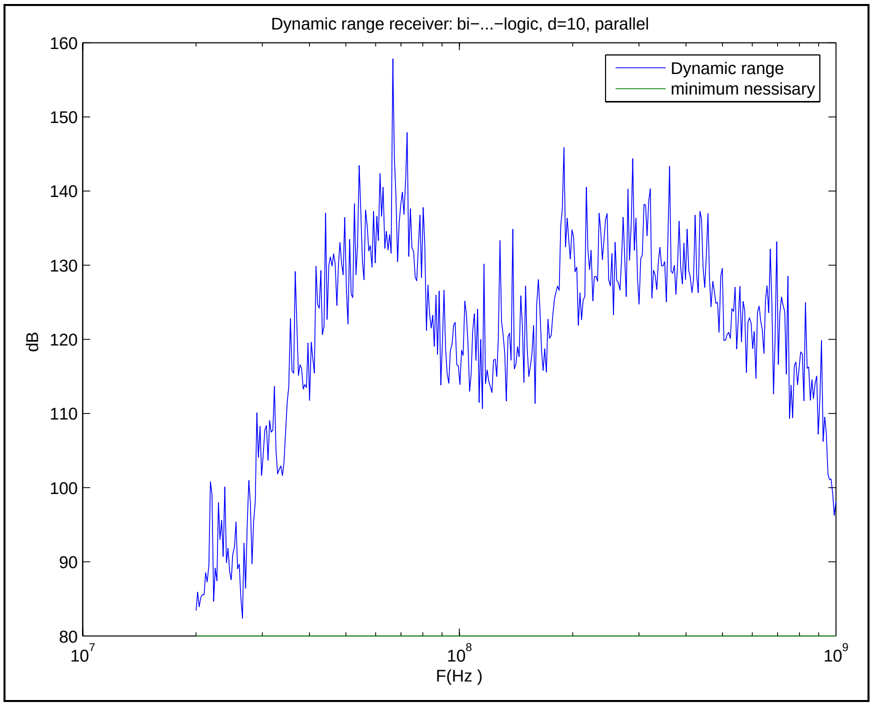

Figure 20. Bi-logic and bi-logic; parallel orientation.

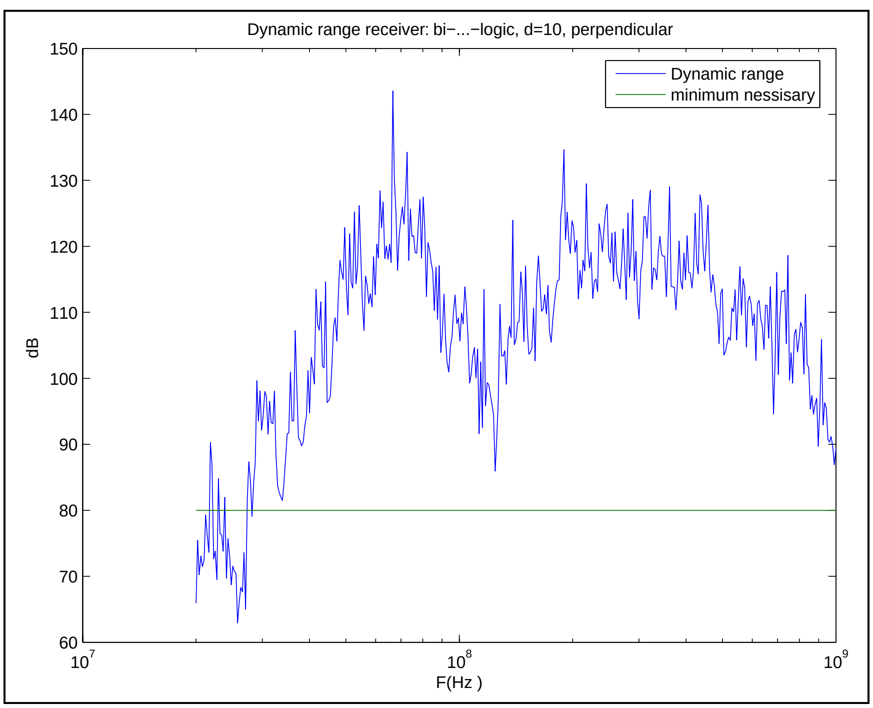

Figure 21. Bi-logic and bi-logic; perpendicular orientation.

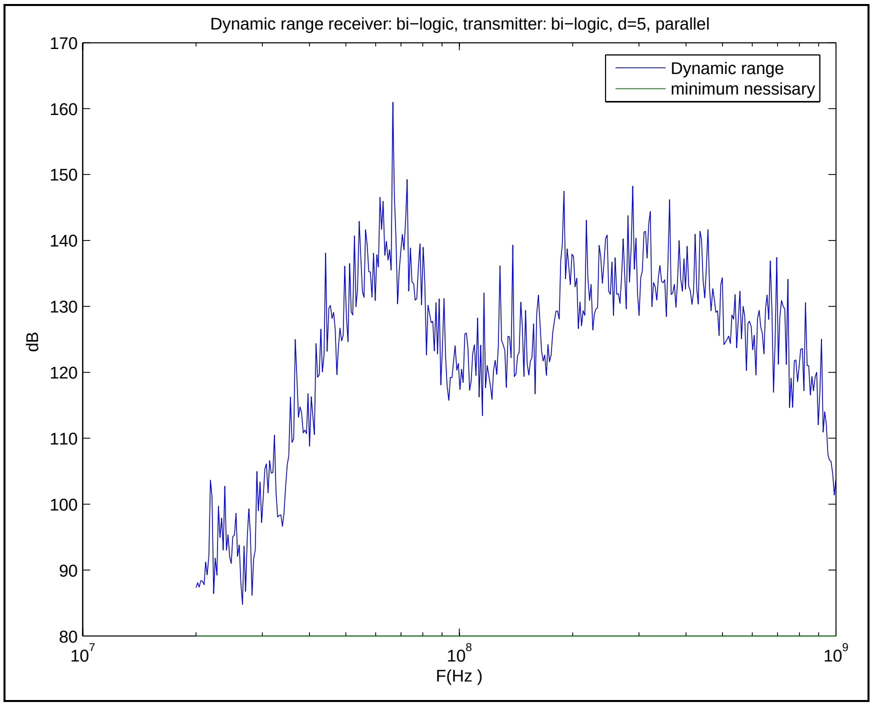

Figure 22. Bi-logic and bi-logic; parallel orientation.

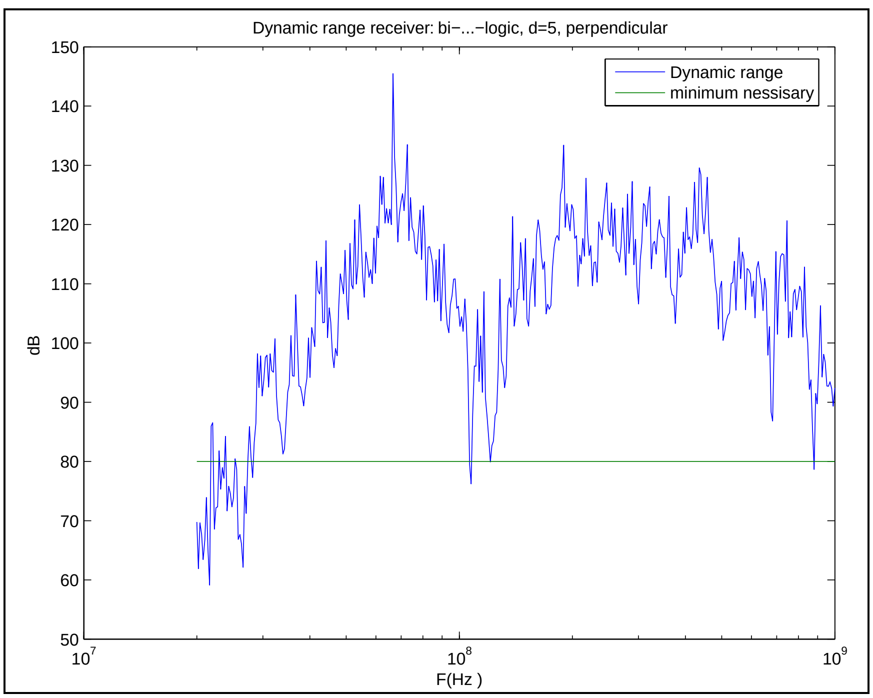

Figure 23. Bi-logic and bi-logic; perpendicular orientation.

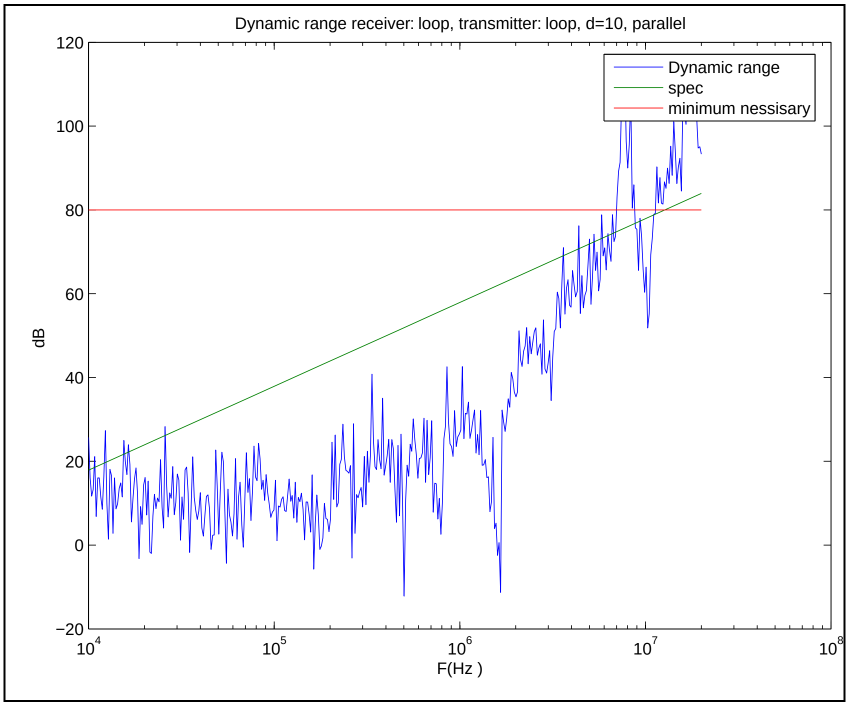

Figure 24. Loop and loop; parallel orientation.

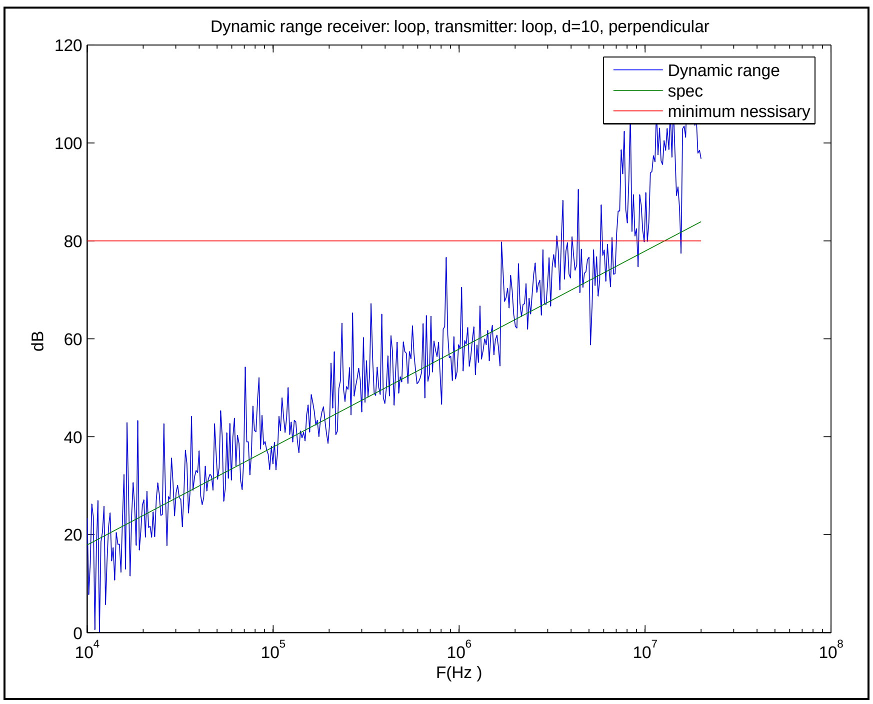

Figure 25. Loop and loop; perpendicular orientation.

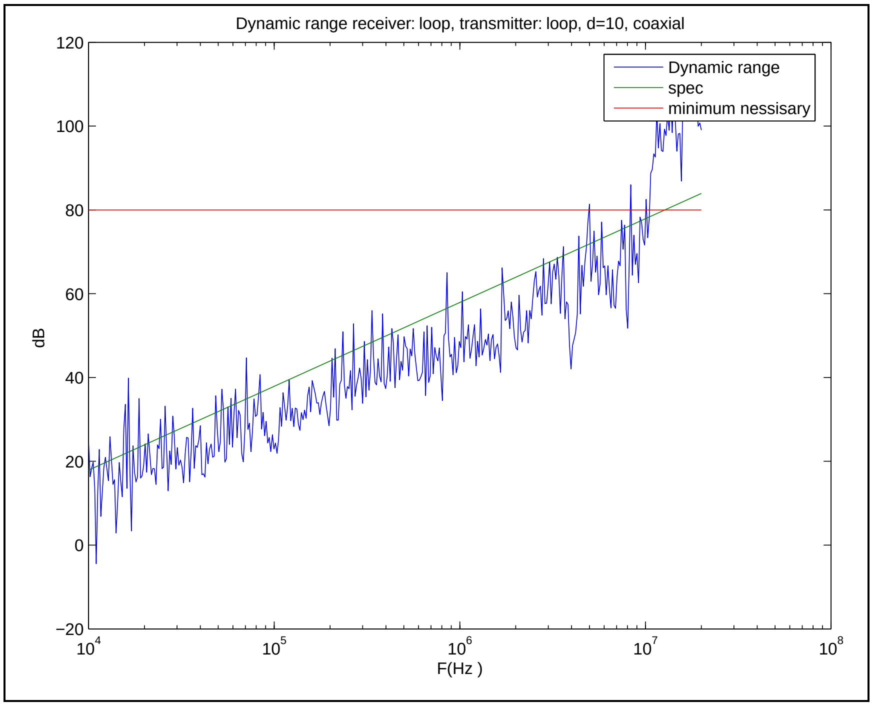

Figure 26. Loop and loop; coaxial orientation.

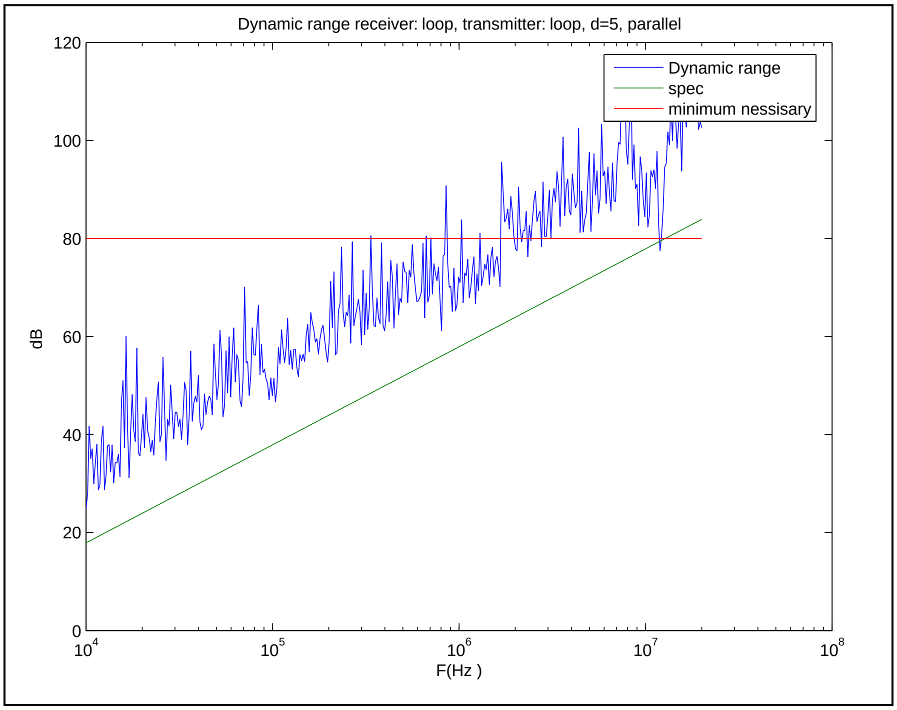

Figure 27. Loop and loop; parallel orientation.

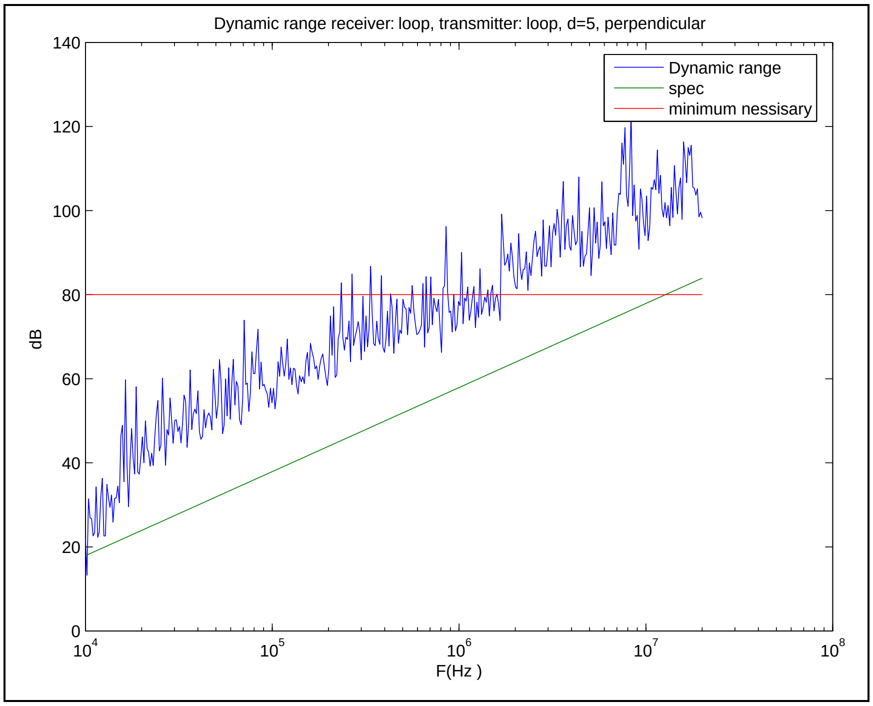

Figure 28. Loop and loop; perpendicular orientation.

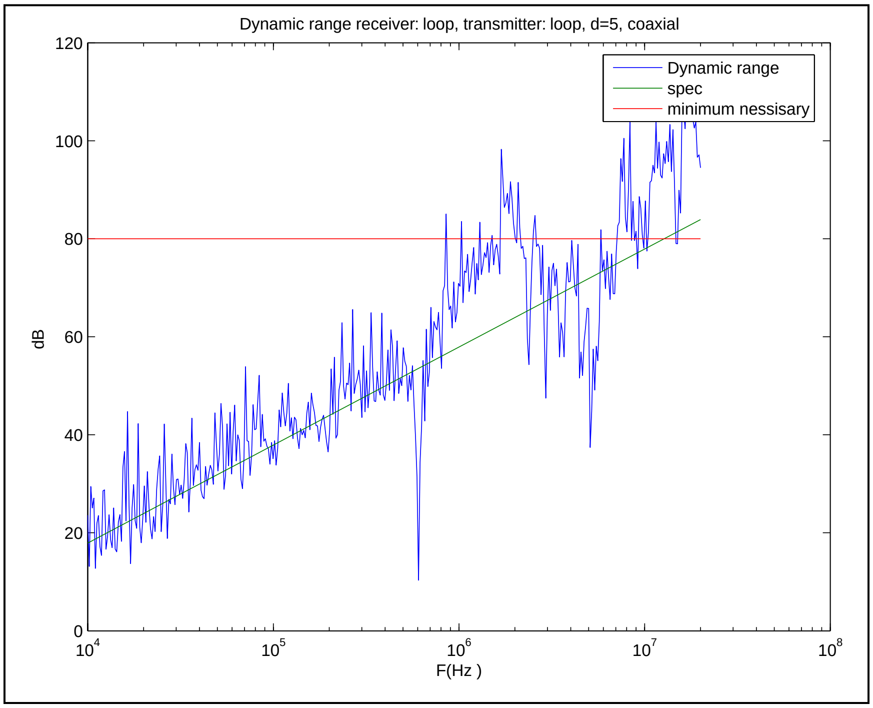

Figure 29. Loop and loop; coaxial orientation.

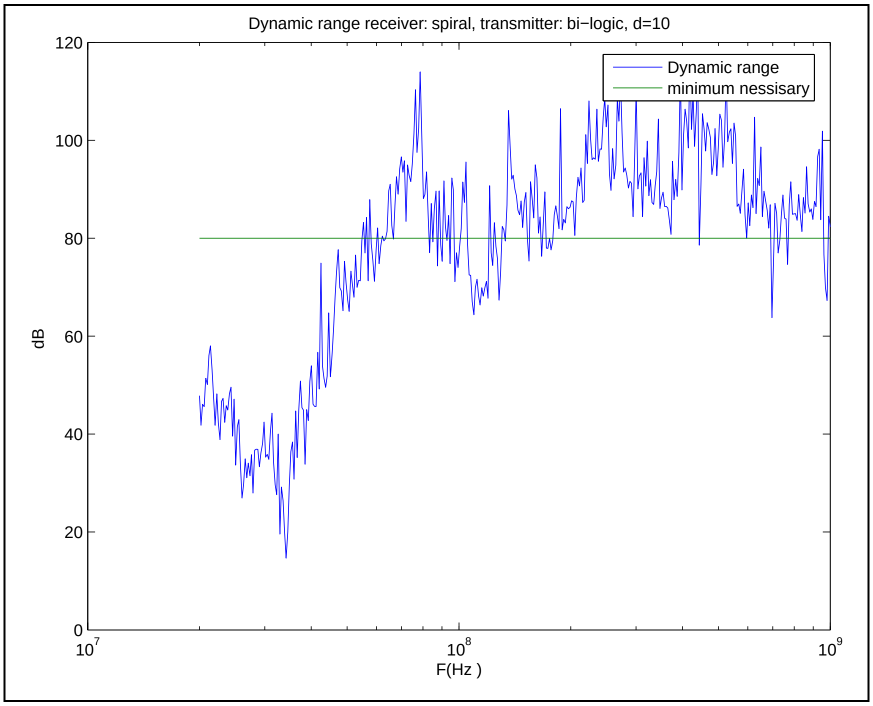

Figure 30. Spiral and bi-logic.

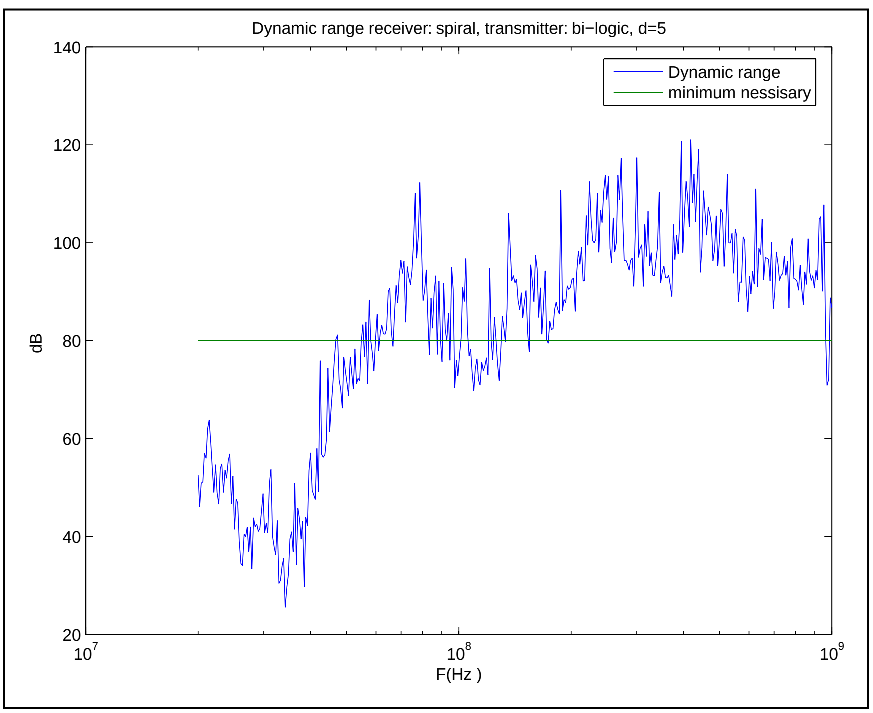

Figure 31. Spiral and bi-logic.

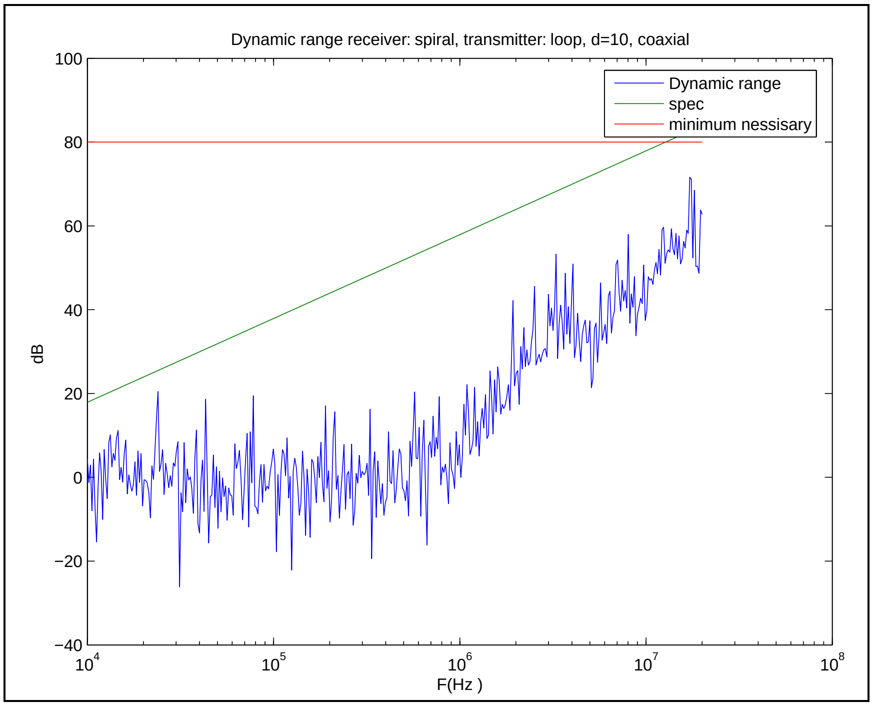

Figure 32. Spiral and loop; coaxial orientation.

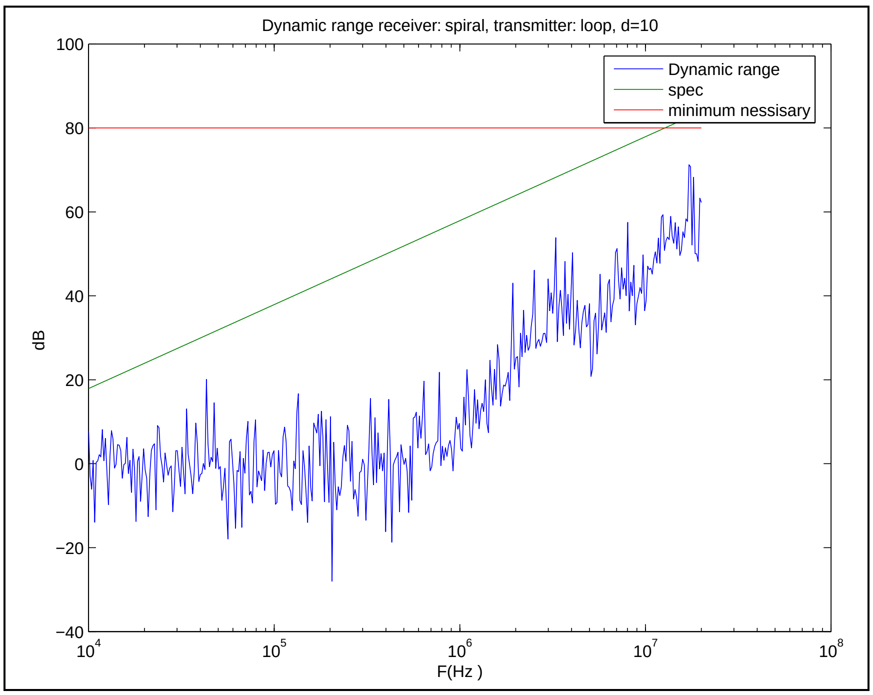

Figure 33. Spiral and loop; parallel orientation.

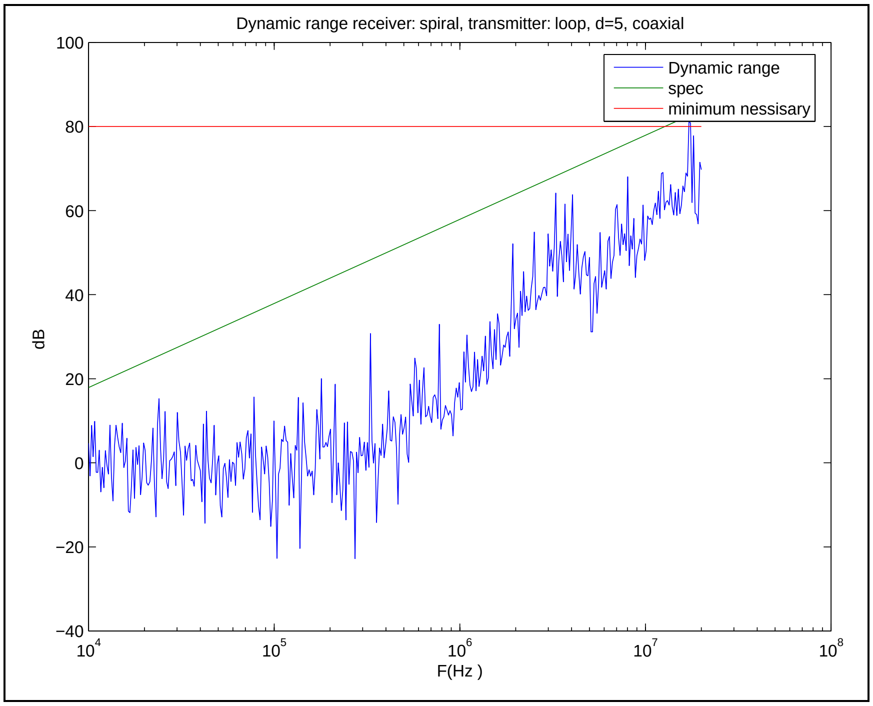

Figure 34. Spiral and loop; coaxial orientation.

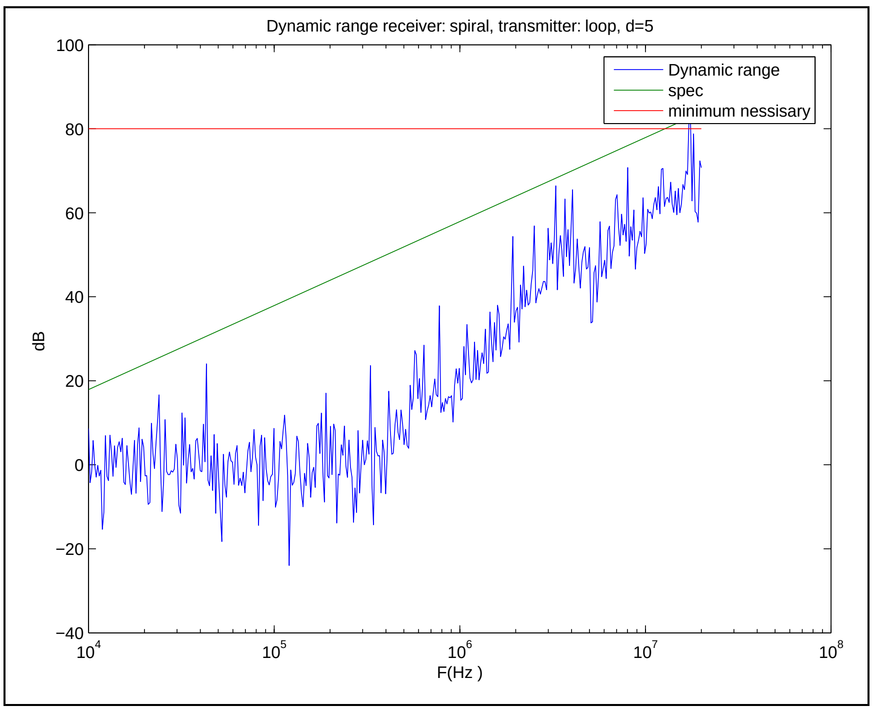

Figure 35. Spiral and loop; parallel orientation.

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.

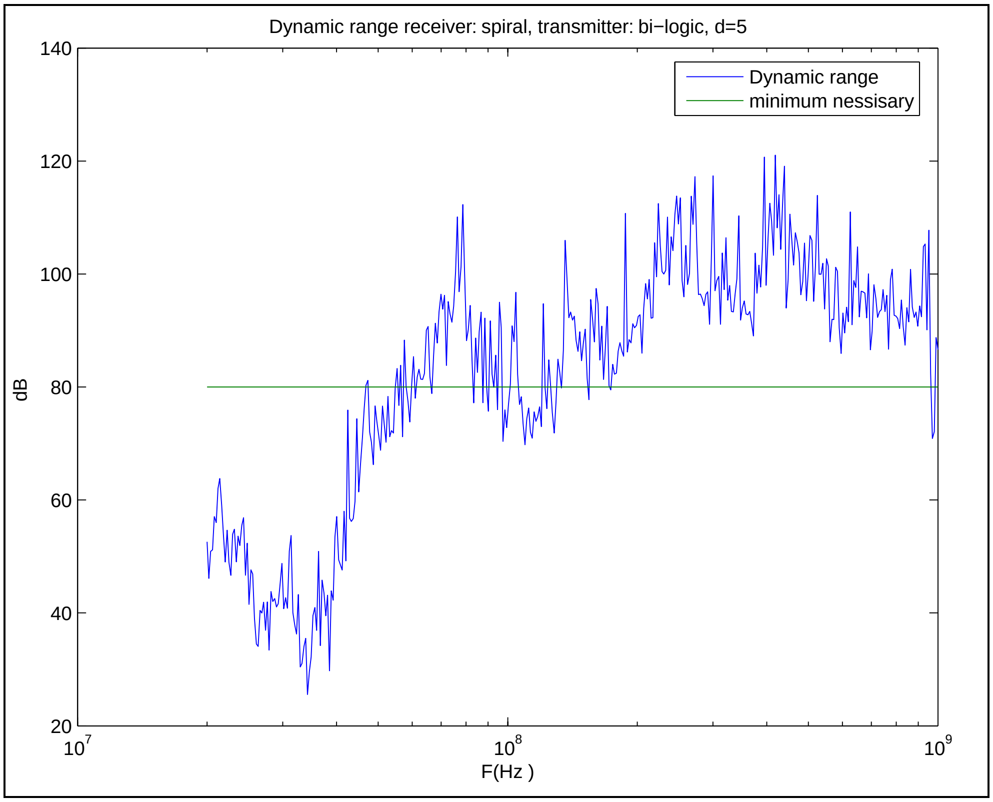

Figure 36. Dynamic range – spiral.

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.

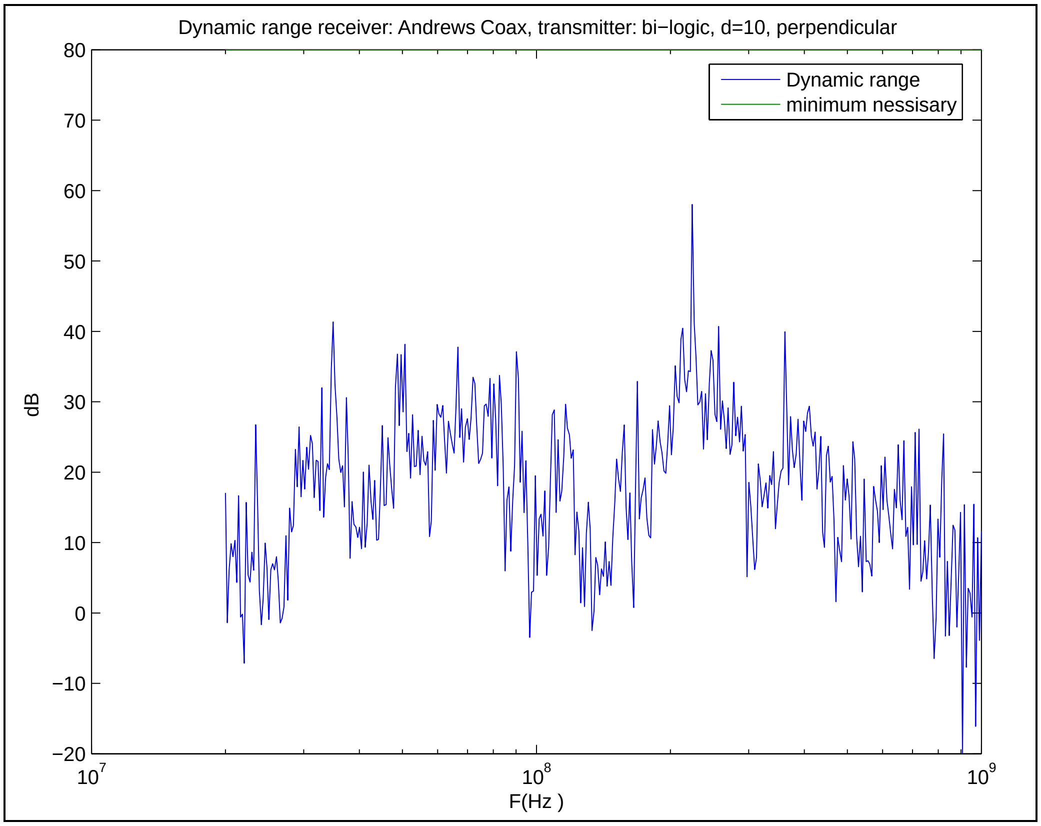

Figure 37. Dynamic range – Andrews coax.

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.

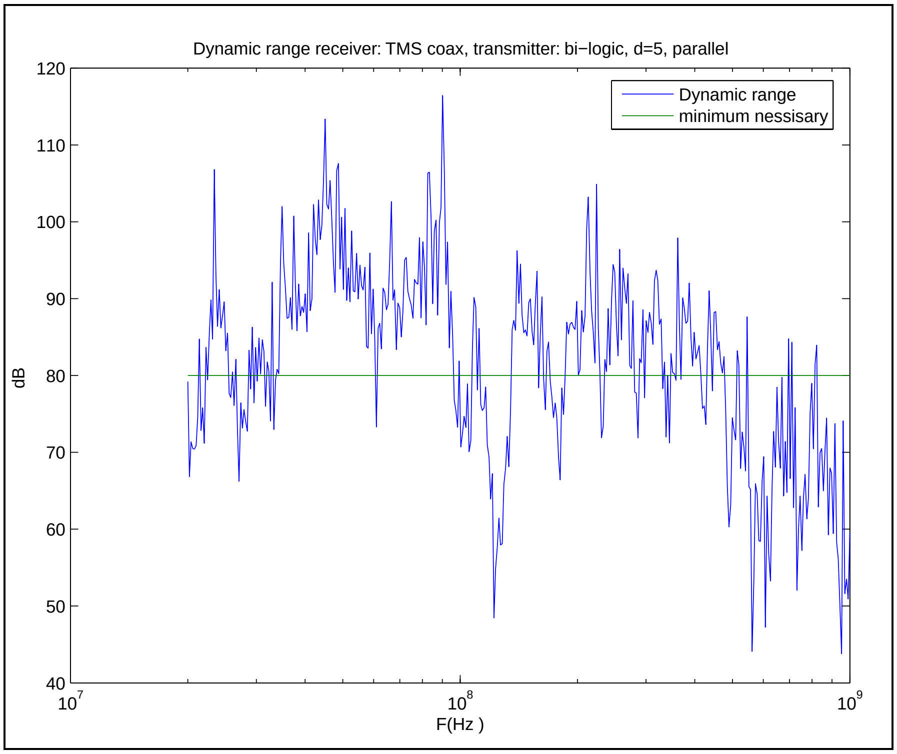

Figure 38. TMS coax – dynamic range.

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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