(NASA-CR-162729) EXPERIMENTAL LOOP ANTENNAS FOR 60 KHz TO 200 KHz (Ohio Univ.) 9 p HC A02/MF A01 CSCL 17G

N80-15063

Unclas
G3/04 46679

TECHNICAL MEMORANDUM (NASA) 71

EXPERIMENTAL LOOP ANTENNAS FOR 60 KHz TO 200 KHz

A series of loop antennas have been fabricated and evaluated for possible use with Loran-C and other VLF to LF band receivers. A companion low noise and very high gain preamplifier circuit has been devised to operate the loop antennas remote from the receiver. Further work is suggested on multiple loop antenna systems to provide omnidirectional coverage and reduce E-field noise pickup in navigation or communications systems.

by

Ralph W. Burhans

Avionics Engineering Center
Department of Electrical Engineering
Ohio University
Athens, Ohio 45701

December 1979

Supported by

National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Grant NGR 36-009-017

I. INTRODUCTION

Some preliminary results with broadband loop antennas may be of interest. A primary goal has been to investigate some simple systems for possible Loran-C receivers which require a bandwidth of greater than 20 KHz. A bifilar wound balanced loop system has been devised which shows considerable promise. The same loop winding can be made to operate from 60 KHz to 200 KHz with bandwidths of 10 to 100 KHz, depending on the application. Designs are presented for a 60 KHz WWVB antenna, several Loran-C variations, and some 1750 meter band antennas. Signals have been received on all these, including one airborne experiment where a Loran-C receiver gave the correct time difference reading within 1 microsecond while flying on a straightline course. An additional problem with Loran-C is the phase reversal when the direction of travel changes 180°. This can be partially solved by operating pairs of crossed loops oriented 90° with respect to each other to obtain an omni-directional amplitude pattern. The advantage would be the reduction of electrostatic precipitation noise in airborne use. This may also be an advantage in reducing E-field 60 Hz harmonic noise in urban ground use of Loran-C. However, with Loran-C there still remains a phase reversal problem requiring additional receiver processing independent of amplitude variations. For the 1750 meter band communications or time signal use the loop antennas also reduce E-field noise pickup, and a single loop may be used as a direction finder or to null out strong interference.

The advantage of a wideband loop is that the main tuning is all done at the receiver circuit, and the loop may be mounted remote from the receiver location. The preamplifier circuit devised for use with these loops is capable of summing the output of several loops in parallel either to provide more sensitivity or omni-directional coverage. For this multiple loop application, an additional JFET 1st stage amplifier is used for each loop with a common summing of the current to each JFET by connecting the drain terminals in parallel. A quad omni-directional Loran-C loop is presently being considered.

Another advantage of this antenna system is the very small size. A 4 to 7 inch long ferrite rod of 1/2 to 3/4 inch diameter in a suitable electrostatic shield appears to provide adequate sensitivity but requires very low noise performance and very high preamplifier gain. A gain of 50 dB is typically required to make this antenna comparable in sensitivity to a 2 meter E-field whip antenna at the same signal intensity.

The best single reference on loop antenna designs is [1]. The best design reference on grounded gate low-noise JFET preamplifiers is [2].

---

[1] Pettingill, R. C., H. T. Garland and J. D. Meindl, "Receiving Antenna Design for Miniature Receivers", IEEE Trans. Ant. and Prop., Vol. AP-25, No. 4, pp. 528-530, July 1977.

[2] Burwasser, Alex, "Broadband JFET Amplifiers", Ham Radio, Vol. 12, No. 11, pp. 13-19, November 1979.

II. LOOP DESIGN

A. Balanced Loop. To minimize E-field pickup, a symmetrical loop winding is desirable. This can be obtained by using a bifilar coil wound with parallel insulated transmission line such as low-power audio speaker cable. Opposite sides of the winding are grounded at each end, resulting in a symmetry with respect to a ground plane or shield trough. The ungrounded opposite ends then become the loop terminals. The inductance of a single winding of one winding of the pair will be 1/4th the total inductance of the two pairs in series. The series common ground connection is a center-tap for the loop. The output power from one end is 4 times the output power available from a single winding, but the effective number of turns for sensitivity is twice that of a single winding. In other words, two, 50 turn windings become 100 turns for sensitivity computations with respect to the H-field, but the inductance is 4 times the inductance of a single 50 turn winding of the same length. (See Figure 1.)

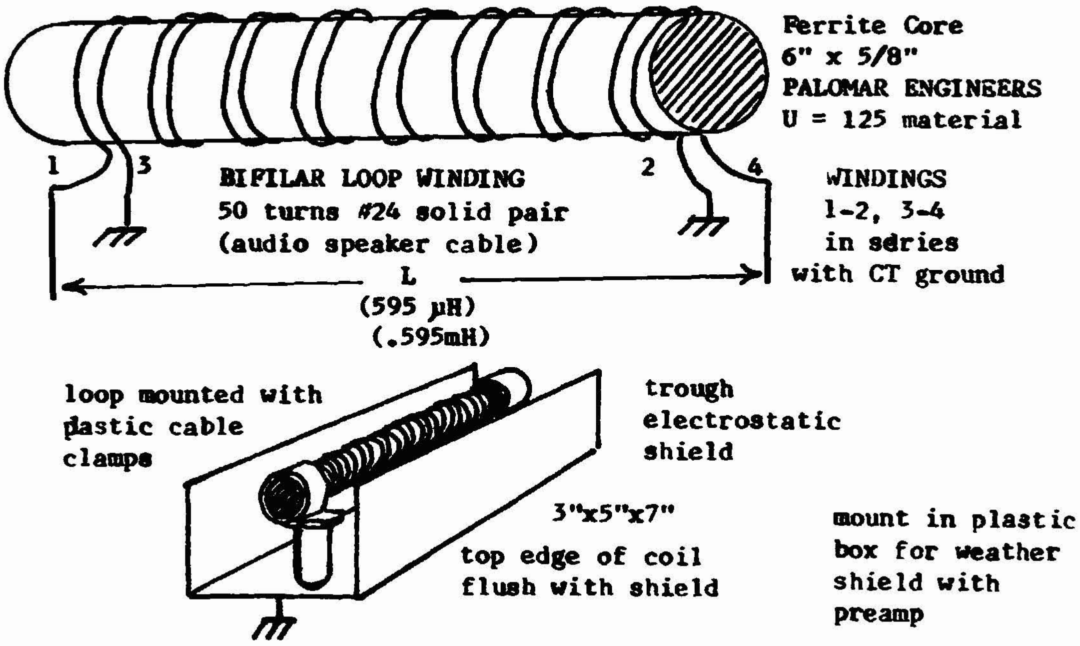


Figure 1. Broadband Balanced VLF Loop Antenna Design.

III. LOOP CALCULATIONS

For optimum coupling of loop winding to H-field use single layer winding over the entire length of the ferrite rode. For wideband performance use a low L - high C, resonant circuit with relatively large wire size.

Q_u = unloaded Q of loop inductance with capacitor at operating frequency with no load or only a very high Z scope connection for measurement.

Q_L = loaded Q of loop antenna in operating circuit.

R_p = effective parallel resistance of loop winding on core $= Q_u X_L$.

R_L = load resistance of circuit $= Q_L X_L$.

Solve for $Q_L = \frac{Q_u R_L}{Q_u X_L + R_L}$

note that if $X_L = R_L$, then $Q_L = 1$ (approx.) and $Q_L = 1$ implies a reasonably wideband circuit.

Choose input R_L circuit for very low noise, but low input impedance such as a grounded gate JFET circuit.

$R_{in} = 1/G_m$ for grounded gate JFET, typical 2N5457 JFET will have $G_m = .001$ mhos, then the input R_L = about 1000 ohms.

Output circuit of JFET will effect overall bandwidth. Use a wideband transformer coupled from first stage to second stage with LC loading across transformer to control output bandwidth. Stagger tune loop slightly with respect to transformer output loading to adjust final bandwidth desired. At VLF to LF range, a 600 ohm line-to-line transformer in subminiature size is suitable. Note that high frequency roll-off of transformer will effect shape of overall response, particularly at high end of range like 200 KHz.

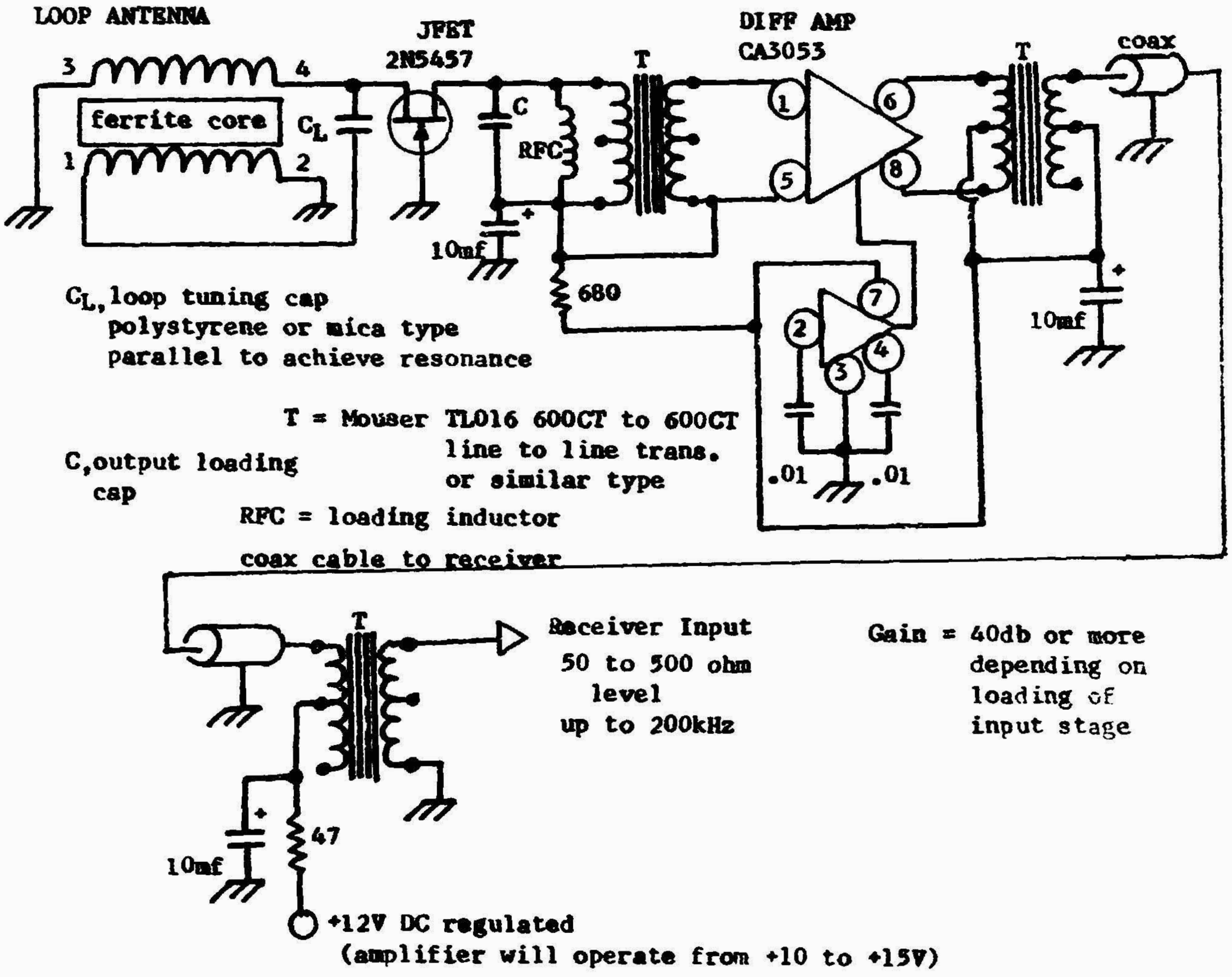
A. Effective Height. The sensitivity of a loop antenna will be quite low and will be:

$$H_e = \frac{2\pi n A U_{rod} F_a}{\lambda} \qquad \lambda = \text{wavelength (usually in meters)}$$

where F_a = averaging factor of coil and rod (typically 0.5 to 0.7) and n = number of turns total, and A = cross sectional area of one turn. Be sure to use numbers all in the same units, such as meters.

A typical 6" (15cm) ferrite rod will have an effective height H_e = 3 millimeters, which requires a very high gain and low-noise preamplifier circuit. A 35 to 50 dB gain system is suggested such as a single grounded gate JFET driving a differential amplifier with the output transformer coupled to a transmission line back to the receiver.

For wideband systems, the maximum number of turns on low U ferrite material spread out over the entire core appears to offer more sensitivity than a high U material because the inductance of the coil will usually be too high for a reasonable sensitivity number (H_e). A compact multiple turn coil centered on a long core rod may achieve very high Q but will suffer poor sensitivity compared to a long solenoid of the same Q. (See Figure 2.)



C_L, loop tuning cap
polystyrene or mica type
parallel to achieve resonance

T = Mouser TL016 600CT to 600CT
line to line trans.
or similar type

C, output loading cap

RFC = loading inductor

Gain = 40db or more
depending on
loading of
input stage

Figure 2. Active Loop Preamplifier System Mounted at Antenna.

IV. LOOP ANTENNA DESIGN (See Figures 3 and 4)

Frequency Range	Loop Tuning Capacitor	1st Stage Load RFC	1st Stage Load Cap.	Band Width	Reactance X_{Loop}
1750 Meters (A)	1400 pf	1 MH	none	75KHz	500 ohms
1750 Meters (B)	1400 pf	1 MH	270 pf	65KHz	500 ohms
Loran-C	4200 pf	5 MH	none	36KHz	360 ohms
Loran-C	4000 pf	2.5 MH	430 pf	29KHz	360 ohms
Loran-C	4200 pf	1 MH	2200 pf	21KHz	360 ohms
WWVB 60KHz	10,000 pf	10 MH	none	12KHz	240 ohms

Table 1.

A. Loop Antenna Winding.

Wire = 2 conductor No. 24 solid insulated pair speaker cable (Radio Shack Cat. No. 278-1509).

Width of one turn = approx. 0.12".

Thickness of winding = approx. 0.0625" (1/16).

Winding length = 6.0" = (b) (single layer solenoid).

Effective diameter of one turn = 0.6562" = (a).

Number of turns of pair = 50 (100 turns total both wires).

Core = 6" length of Palomar engineers U = 125 rod (originally 5/8" x 7½").

Effective permeability of rod = 38.4 = U_{rod}.

Length of wire used = approx. 10 feet.

Inductance of single winding = 148 microhenries.

Inductance end-to-end with opposite ends common ground (=X4) = 595 microhenries.

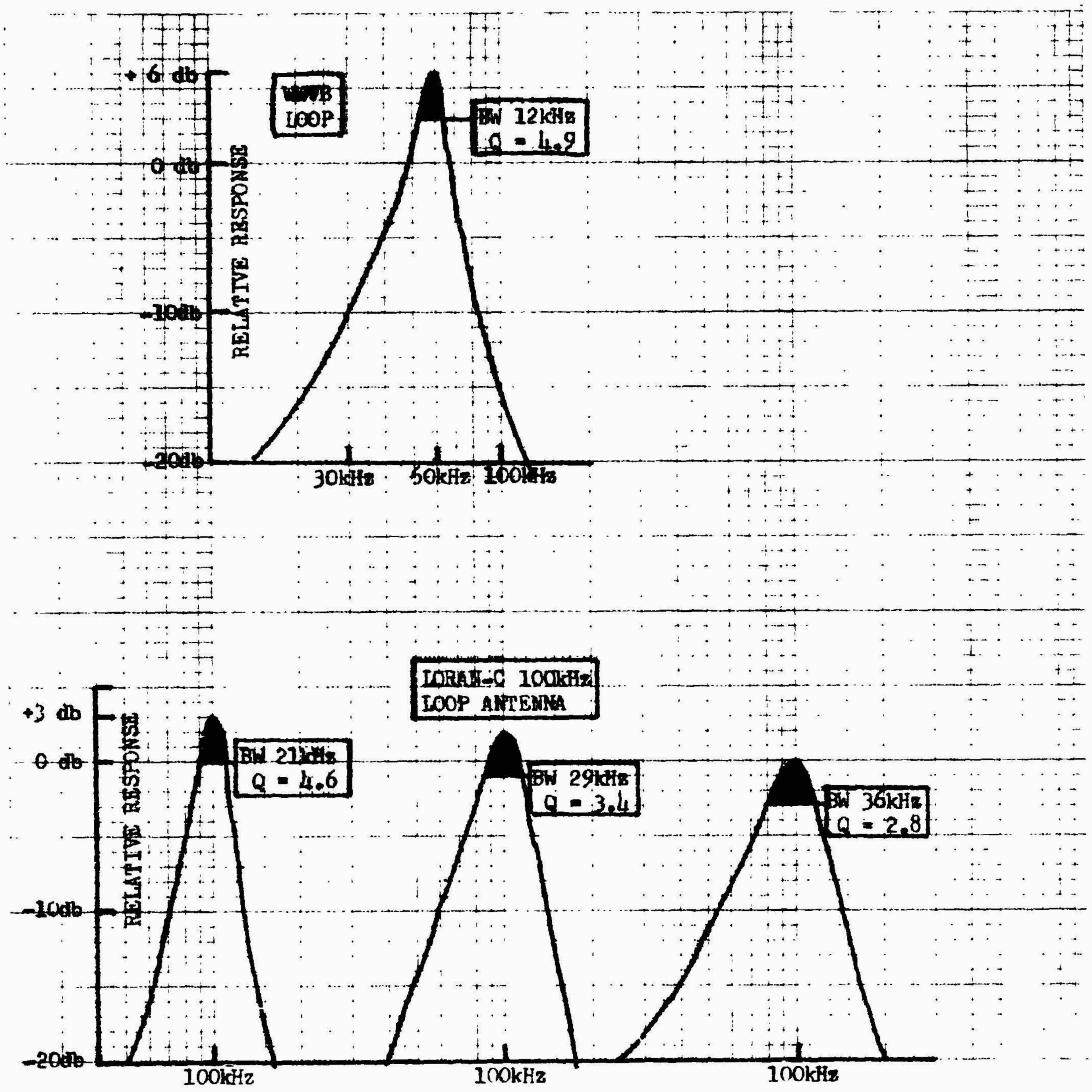


Figure 3. Loaded Q of Loop Antennas.

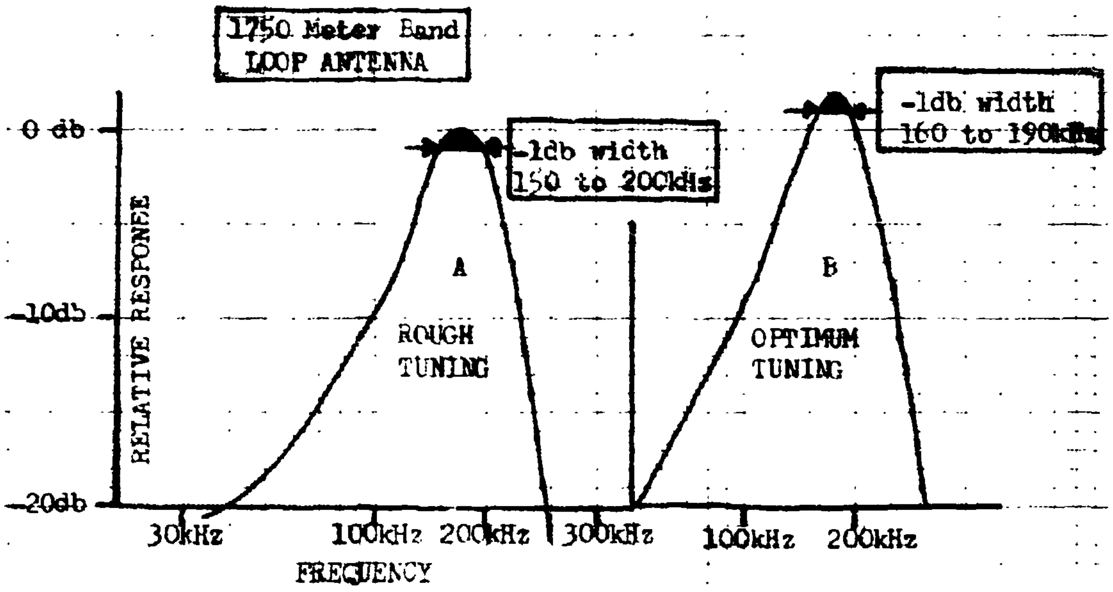


Figure 4. LF Citizen Band Loop Response.

B. Formulas.

Inductance of solenoid air core $= L_{\mu h} = \dfrac{0.2\,a^2 n^2}{3a + 9b}$
(single layer)

a = diam inches
b = length inches
n = number of turns

Inductance of loop on core $= L_{loop} = L_{air} \times U_{rod}$

Rod Permeability $= U_{rod} = \dfrac{U_{ferrite}}{1+D\,(U_{ferrite} - 1)}$

D = demagnetization factor for rod $= 0.37m^{-1.44}$

m = length to diameter ratio for rod = b/a

V. SUMMARY

Some design data on low-frequency loop antenna systems is presented. Loop antennas may be desirable for airborne and mobile Loran-C receivers to reduce E-field noise pickup. However, the phase reversal of the signal from the antenna for a direction change of 180° creates an additional problem for the receiver processor. An envelope manipulating receiver which averages the phase code from the Loran-C signals might be made to work with a crossed pair of loops or a quad loop combining circuit. Another approach suggested in the early literature [3] is to square the signal at a low level and add the result from 90° oriented loop pairs. This results in a processing signal at twice the signal frequency or 200 KHz for a 100 KHz Loran-C pulse. Squaring also further delays the third cycle rise time of the pulse envelope. Thus an entirely different type of Loran-C receiver circuit would be required using squaring methods to eliminate the phase reversal from loop antennas. Alternatively, the receiver navigation processor and a direction sensor on the vehicle could be used to reverse the phase or switch loop polarity. However, this requires a much more complex and more expensive receiver processor for Loran-C.

For other applications, such as communications or time signal reception, this loop antenna can improve the performance of receivers by reducing E-field and 60 Hz harmonic noise pickup. Additionally, the loop antenna provides a very simple direction finder or null circuit for reducing strong interference.

VI. ACKNOWLEDGEMENTS

This work has been supported by NASA Langley Research Center, Grant NGR-36 009-017. The help of James Irvine and Daryl McCall is appreciated in collecting preliminary airborne test data on experimental Loran-C loop antennas.

---

[3] Cheng, D. K., and R. A. Galbraith, "Stagger-Tuned Loop Antennas for Wide-Band Low-Frequency Reception", Proc. IRE Vol. 41, pp. 1024-1031, August 1953.