DOE/OR/22398--T1

UNMANNED AIRBORNE VEHICLE (UAV): FLIGHT TESTING AND EVALUATION OF TWO-CHANNEL E-FIELD VERY LOW FREQUENCY (VLF) INSTRUMENT

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U.S. GEOLOGICAL SURVEY
1998

INTRODUCTION

Measurements at very low frequencies (VLF)-between 15kHz and 25 kHz-became a practical geophysical tool in the 1960s when Vaino Ronka designed and developed the first portable VLF apparatus. This original design measured the tilt angle and ellipticity of the magnetic component (H-field) of the VLF electroagnetic field. During this same decade the U.S. Navy completed the construction of a network of powerful VLF transmitters designed for submarine communications. This inexpensive reliable signal source opened up the research and development of VLF geophysical instruments. Another attractive feature of VLF measurements is the ease of theoretical solutions for a number of models. The plane-wave excitation is much easier to handle theoretically than dipole or large-loop sources. In the late 1960s and early 1970s techniques for using the electrical field (E-field) of the VLF signal was developed. This technique allows for the measurement of the in-phase and quadrature components of the horizontal electric field and the in-phase component of the vertical electric field. The ratio of the quadrature component of the horizontal E-field and of the in-phase component of the vertical E-field describes wave tilt and Can be used to calculate earth resistivity. This method is applicable and suitable for airborne resistivity surveying.

Using VLF frequencies, transmitted by the Navy's network, for airborne remote sensing of the earth's electrical, magnetic characteristics was first considered by the United States Geological Survey (USGS) around the mid 1970s. The first VLF system was designed and developed by the USGS for installation and operation on a single engine, fixed wing aircraft used by the Branch of Geophysics for geophysical surveying. The system consisted of five channels. Two E-field channels with sensors consisting of a fixed vertical loaded dipole antenna with pre-amp mounted on top of the fuselage and a gyro stabilized horizontal loaded dipole antenna with pre-amp mounted on a tail boom. The three channel magnetic sensor consisted of three orthogonal coils mounted on the same gyro stabilized platformas the horizontal E-field antenna. The main features of the VLF receiver were; narrow band-width frequency selection using crystal filters, phase shifters for zeroing out system phase variances, phase-lock loops for generating real and quadrature gates, and synchronous detectors for generating real and quadrature outputs.

In the mid 1990s the Branch of Geophysics designed and developed a two-channel E-field ground portable VLF system. The system was built using state-of-the-art circuit components and new concepts in circuit architecture. Small size, light weight, low power, durability, and reliability were key considerations in the design of the instrument. The primary purpose of the instrument was for collecting VLF data during ground surveys over small grid areas. Later the system was modified for installation on a Unmanned Airborne Vehicle (UAV). A series of three field trips were made to Easton, Maryland for testing and evaluating the system performance

SYSTEM FUNCTIONAL DESCRIPTION

Refer to figure 1 for the following functional description. Two identical dipole antennas develop VLF signals across matched loads. The signals are developed 180 degrees out of phase across the opposite antenna elements.

DISCLAIMER

After being amplified and buffered the differential signals are transmitted through a twisted pair shielded cable to a post pre-amp. This method provides excellent common mode noise rejection. The post pre-amp converts the differential signal to a single-ended component, the signal is then amplified, and passed through a 6kHz/36kHz band-pass filter. The post pre-amp also provides phase shifting circuitry for each channel. This allows for adjusting out the different phase shifting characteristics between channels (phase zeroing).

VLF station tuning is accomplished by band-pass filter selection or bypassing the filters and connecting the signal directly to the frequency mixer. The receiver provides location for two crystal filters (X1,X2) for each channel. The crystal filter frequency response is highly selective with half power points at approximately 125 Hz. See figure 2.
Refer to figure 3 for a description of the local oscillator. The local oscillator is precisely controlled by a crystal oscillating at 11.5 MHz. The output frequency is selected by a divide circuit dependent upon the frequency select switch. The VLF signal from the crystal filter and the local oscillator signal are mixed and the output is selected at the intermediate frequency band (IF). The IF filter/amplifier is tuned at a center frequency of 5 kHz.

A final amplifier stage provides output amplitude information of the signal's real component for both the vertical (VR amp) and horizontal (HR amp) channels. The amplifier uses automatic gain control (AGC); therefore, these output's are AGC dc voltage levels necessary to maintain a constant 1 volt p-p amplitude of the IF signal. This 1 volt signal from the vertical channel is used by pulse shaping and phase shifting circuit to generate a quadrature gate. The quadrature gate is directed to both the horizontal phase (HQ phase) and horizontal amplitude (HQ amp) synchronous detectors. The other input to the HQ phase detector is the 1 volt p-p signal from the final AGC amplifier. Output from this detector is a dc voltage level that indicates the phase relationship between the vertical reference signal and the horizontal signal. The HQ amp synchronous detector's second input comes from the horizontal IF filter/amplifier. This detectors dc output is a measurement of the horizontal field's amplitude. All dc level outputs are calibrated to provide actual amplitudes and phase measurements at the antenna source.

The remainder of the system includes a four channel, 16-bit analog to digital converter and serial RS-232 output port. Data acquisition is controlled by software in a palm top computer. The data is stored on a flash card. Plus and minus 12 VDC power is supplied by two lead acid batteries mounted inside the system package.

UAV FLIGHT TESTING AND EVALUATION

UAV`s were supplied by BAI AEROSYSTEMS,Inc. of Easton Maryland. BAI personnel were responsible for all launches, flight maneuvers and recoveries. All flight tests of the VLF instrument were conducted on an isolated island runway located approximately 30 miles south of Easton Maryland. Flight path, directions, altitudes, and number of passes were all pre-planed by USGS-MRP and ORNL team survey members. A total of three field trips were completed.

The first flight test was successfully completed in September of 1996. The VLF receiver was installed in a high wing, single engine aircraft. A vertical type dipole antenna with pre-amp was mounted near the right wing tip. The horizontal antenna consisted of placing two strips of conductive copper tape parallel to the wings leading edge. The horizontal pre-amp placed at the center of the two strips connected the two elements. After repeated attempts at finding an engine that would perform satisfactorily, the UAV was launched and data was collected over the island, using Jim Creek (NLK) as the VLF signal source.

In April of 1997 the second test of the VLF was attempted. The same aircraft , called the Porter, was scheduled for the test flying. During operational testing of the Porter, a failure of aileron controls occurred on landing and the aircraft was damaged beyond repair. The VLF system was not installed at the time. Since no backup UAV was available the test was postponed.

The last of the VLF flight tests was conducted in August of 1997. A different model UAV was flown for this flight test. A much smaller high wing aircraft was used. TheCutler (NAA) transmitter was used as the signal source. A group of line crossings at different altitudes was successfully flown. The telemetry system malfunctioned; therefore no video or GPS data was recorded.

DATA

VLF Data was recorded using a HP 100 LX palm top computer and later transferred to 3.5" diskettes. Flight path video and GPS position data was provided by BAI AEROSYSTEMS, Inc. The four channels of VLF information in addition to current date/time were recorded by the computer at a 100 ms sample rate. Table 1 shows a sample printout of actual recorded data. The following lists the channel assignments;

CHANNEL ASSIGNMENT

CHANNEL	TYPE DATA
0	DATE/TIME
1	VR amp
2	HR amp
3	HQ amp
4	HQ phase
5	+12 VDC
6	-12 VDC
7	TEMP.

Figure 4 shows a sample of VR amp, HR amp, and HQ amp from the 8/16/97 data. the data are shown to illustrate the rise in noise level on HR amp and HQ amp when the engine is started. Only the hrizontal data are affected possibly because of the antenna orientation, or more probably because the horizontal channels use a factor of five more gain.

SUMMARY

VLF data was successfully acquired from two of the field trips. Since the NAA transmitter was off the air during the first trip it was necessary to test using a much weaker signal from the NLK source. Along with the low resistivity of the target area and an increase in noise resulting from the receivers close proximity to the aircraft power plant the quality of the data was somewhat degraded. The proximity of the receiver to the engine's ignition source was even closer using the aircraft model flown during the last flight test. Further studies will be necessary to evaluate and reduce the effects of UV aircraft ignition noise

REFERENCES

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Arcone,S. A., 1978: Investigation of a VLF airborne resistivity survey conducted in northern Maine: Geophysics, v. 43 (7) p. 1399-1417.

McNeill, J. D. and **Labson**, V. F., 1988: Geological Mapping using VLF Radio Fields: in Electromagnetic Methods in Applied Geophysics, Nabighian, m.N.(ed), V 2, p521-640.

TWO-CHANNEL E-FIELD VLF RECEIVER

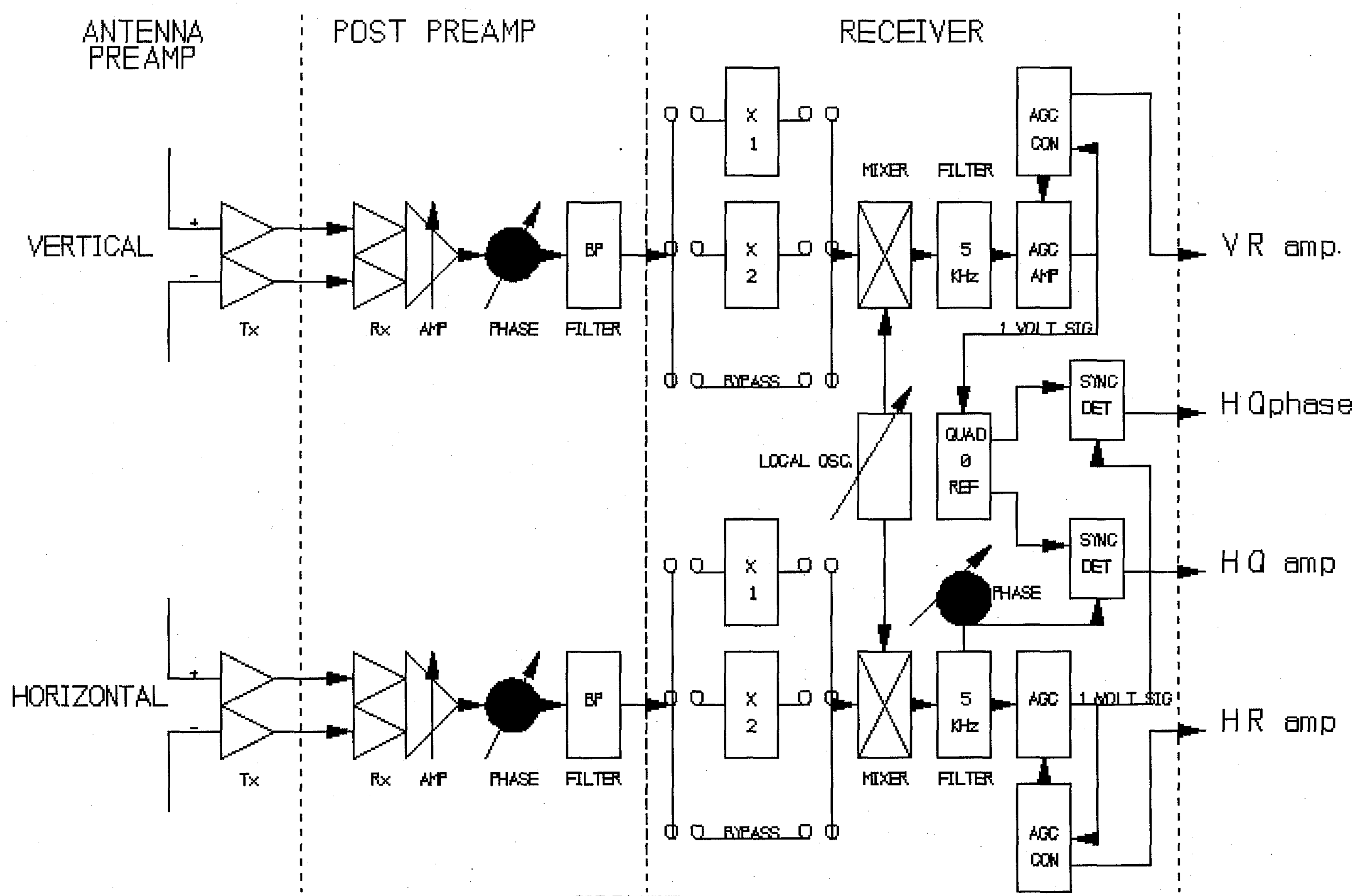


FIGURE 1

VLF CRYSTAL FILTER RESPONSE

fc=24kHz Ein=100mv p-p Rin=5kohm Rout=5kohms

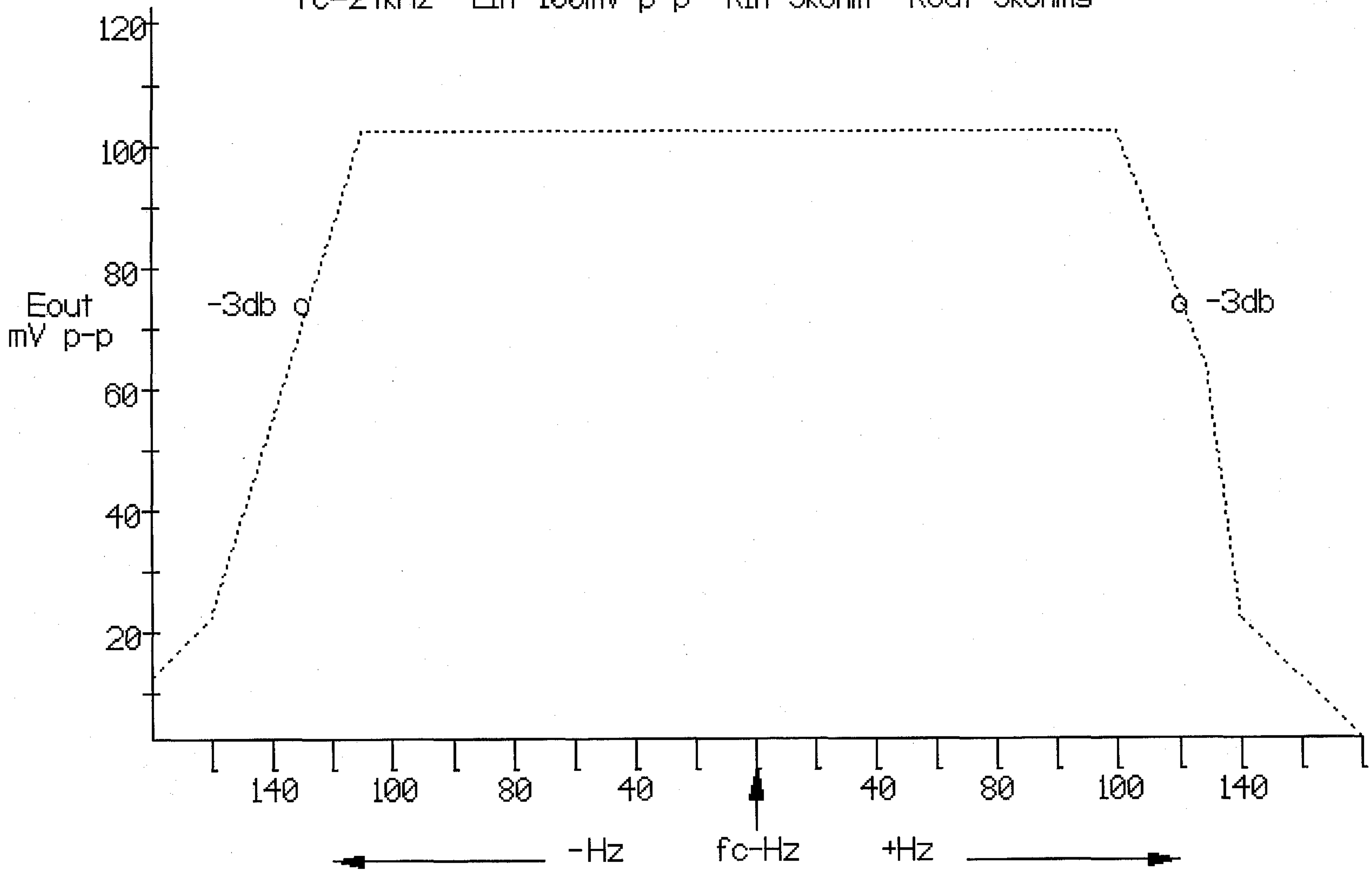
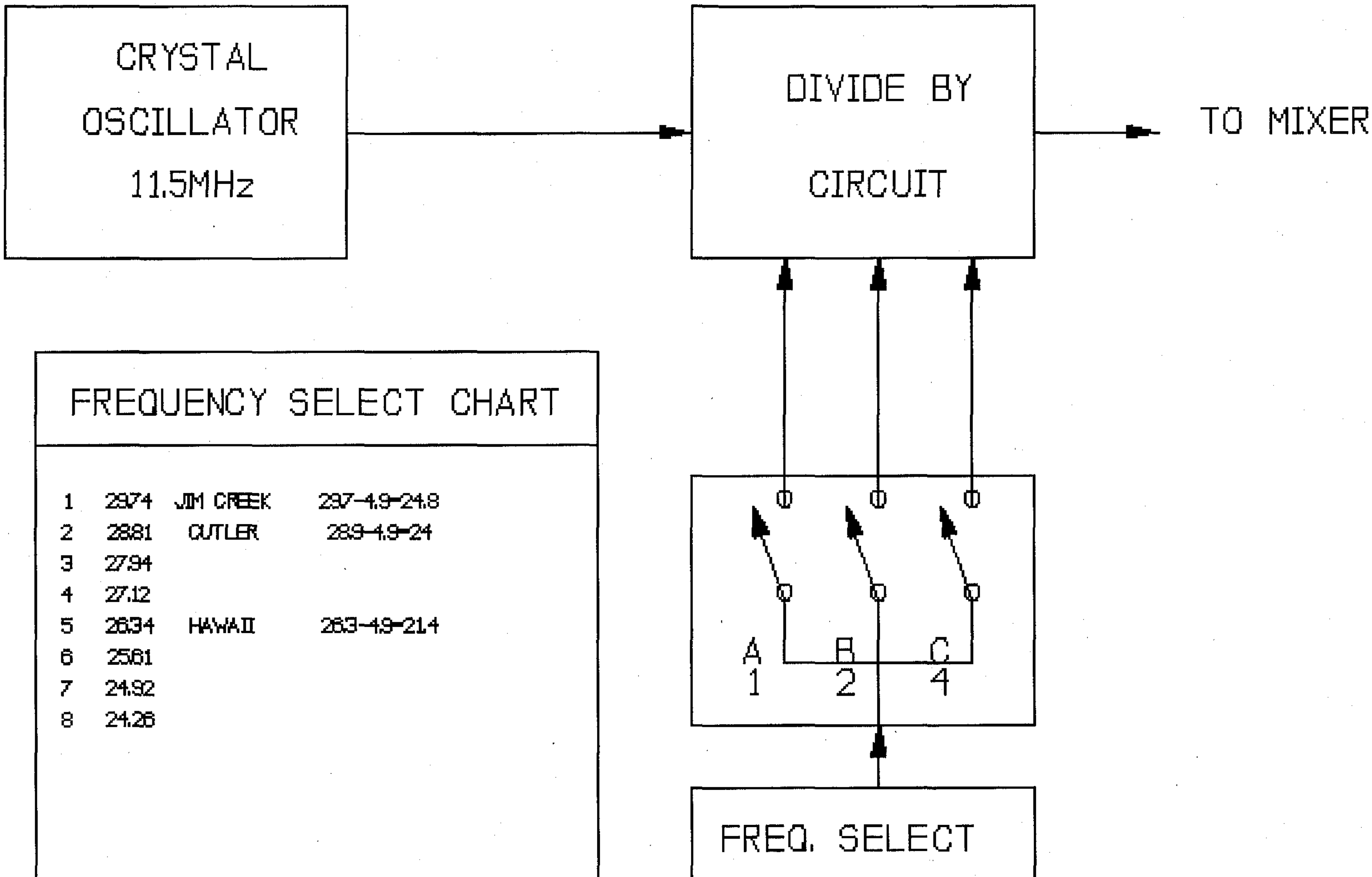


FIGURE 2

LOCAL OSCILLATOR



FREQUENCY SELECT CHART

1	29.74	JIM CREEK	29.7-4.9=24.8
2	28.81	CUTLER	28.9-4.9=24
3	27.94		
4	27.12		
5	26.34	HAWAII	26.3-4.9=21.4
6	25.61		
7	24.92		
8	24.26		

FIGURE 3

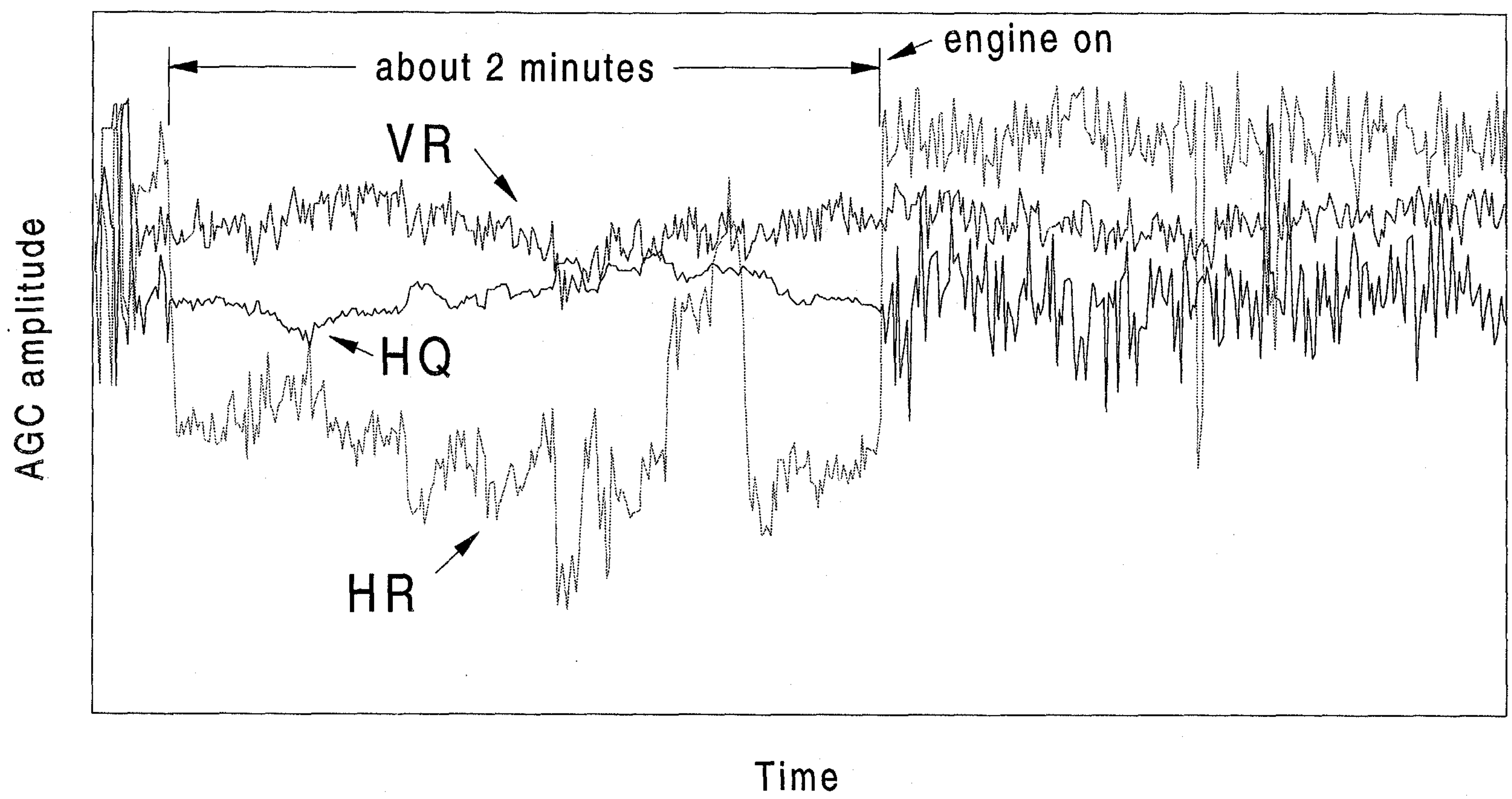


Figure 4. Plot of VLF data showing the VR amp, HR amp, and HQ amp channels. The horizontal data gets more noisey when the power plant is turned on.

VLF DATA FORMAT

4 : .775625
5 : 1.2365625
6 :-1.24875
7 :-.4559375
4 ,19960411,10:44:32
1 : 3.504375
2 : 1.4621875
3 : 2.3540625
4 : .775625
5 : 1.2371875
6 :-1.249375
7 :-.813125
4 ,19960411,10:44:42
1 : 3.5375
2 : 1.749375
3 : 1.819375
4 : .7778125
5 : 1.235625
6 :-1.249375
7 :-.6109375
4 ,19960411,10:44:51
1 : 3.790625
2 : 1.7953125
3 : 1.47
4 : .7775
5 : 1.2365625
6 :-1.24625
7 :-.424375
4 ,19960411,10:45:00
1 : 3.6796875
2 : 1.3859375
3 : 1.81375
4 : .779375
5 : 1.234375
6 :-1.249375
7 :-.638125
5 ,19960411,10:45:39
1 : 3.500625
2 : 1.8153125
3 : 2.233125
4 : .779375
5 : 1.23375
6 :-1.2509375
7 :-.6778125

TABLE 1