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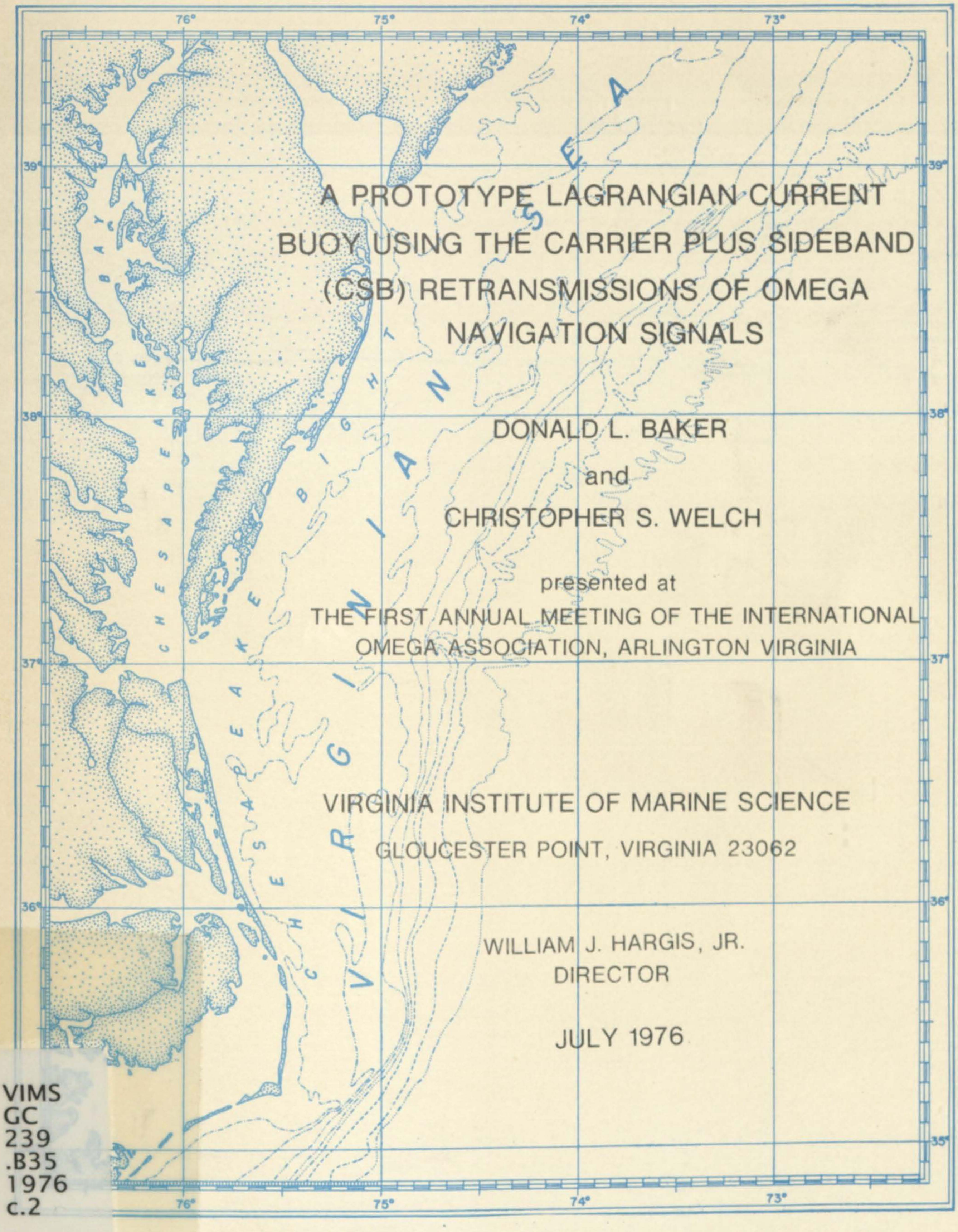
Recommended Citation

Baker, D. L., & Welch, C. S. (1976) A prototype Lagrangian current buoy using the carrier plus sideband (CSB) retransmission of Omega navigation symbols. Virginia Institute of Marine Science, William & Mary. https://scholarworks.wm.edu/reports/2352



A PROTOTYPE LAGRANGIAN CURRENT BUOY USING THE CARRIER PLUS SIDEBAND (CSB) RETRANSMISSIONS OF OMEGA NAVIGATION SIGNALS

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presented at
THE FIRST ANNUAL MEETING OF THE INTERNATIONAL OMEGA ASSOCIATION, ARLINGTON VIRGINIA

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JULY 1976

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by

Donald L. Baker and C. S. Welch

ABSTRACT

As part of the continental shelf investigations of the Virginia Institute of Marine Science (VIMS), electronics were developed and tested to track an ocean-current-following (Lagrangian) buoy by the retransmission of Omega navigation signals to a shore station using medium frequency (2.398 MHz) ground wave propagation and equal-carrier-upper-sideband modulation. The buoy electronics include sharp clipping and filtering for noise reduction and Omega signal equalization. The carrier and upper sideband are transmitted with equal power to maintain the relative phases of separate Omega station signals on demodulation. The base station is a 2.4 MHz receiver/demodulator feeding a commercial Omega navigation receiver, with minicomputer processing for teletype printout and digital magnetic tape recording.

Field trials of this navigation system were performed at VIMS in spring, 1975. Using the Omega signals received at the base station as a reference, the differential tracking error with LOP (line-of-position) pairs AC/BD is about 620m RMS for the navigation receiver and 910m RMS for the retransmission system. The retransmission errors may be reduced by improving the phase/ amplitude characteristics of the buoy and base station receivers and by improving the sensitivity and bandwidth of the base station receiver with another demodulation method. The extrapolated range

for the test was 9 NM with a falloff of 26.5 dB/decade (8 dB/ octave). A gain of 40 dB in system sensitivity is needed for operation to 150 NM.

INTRODUCTION

There are a limited number of methods for the Lagrangian mapping continental shelf circulation that employ cheap, expendable devices, that can be tracked from shore, once deployed. The cheapest are marked floats or cards that provide only the beginnings and ends of their tracks. For real-time current tracking, it is necessary to employ radio-location buoys (passive reflecting radar, active radar transponder, radio direction finding (RDF), beacons) or the retransmission of radio navigation signals (Omega, Raydist, Loran-C, Loran-A). For greater than line-of-sight ranges, RDF and over-the-horizon radar methods using ground wave propagation in the 2 to 10 MH band have been proven feasible. However, the tracking errors increase at least linearly with distance. Recently the retransmission of Omega and Loran-C navigation signals has been used. The theoretical advantage of differential radio navigation tracking is the elimination of distance dependent errors and errors due to local shifts in the radio navigation network due to ionospheric changes.

E. Michelena (Ph.D. Dissertation, U. Mich., 1975) developed an Omega retransmission buoy system transmitting on 2.398 MHz and 2.4082 MHz, the lower sideband and carrier produced using 10.2 KHz Omega signals. Following his work, a similar buoy system was developed at the Virginia Institute of Marine Science (VIMS) in 1974 and 1975, using differential Omega tracking also.

RETRANSMISSION MODE

An FCC experimental license for 13.6A9H emissions on 2398.0 and 2408.2 KHz at 10 watts PEP was obtained for VIMS by R. Lobecker in November 1973. The frequencies were previously used by E. Michelena at Gloucester Point, Virginia and on Lake Michigan. Groundwave propagation over saltwater in the 2 to 10 MHz band has the advantage of single-path reception over distances of up to 200 NM with transmission powers on the order of 100 mW. This avoids the phase distortion inherent in multiple-path skywave propagation and allows a small battery powered buoy to operate in Atlantic continental shelf waters for up to one month.

This mode of transmission starts with mixing and filtering the 2398.0 KHz carrier and 10.2 KHz Omega signals to obtain equal power carrier and upper sideband signals at 2398 KHz and 2408.2 KHz. When the 2398 and 2408.2 KHz signals are mixed together in a multiplier (or product detector) the 10.2 KHz output component retains its original autocorrelation in phase. This holds true if the carrier and sideband signals experience exactly the same phase shifts in all of the circuits and propagation paths between the mixer in the buoy and the detector in the shore station receiver.

BUOY RECEPTION AND RETRANSMISSION OF OMEGA

The prototype Omega Buoy electronics consists of input and output antenna couplers, six 10.2 KHz receiving stages, two 2.4 MHz transmitting stages, a 2.398 MHz oscillator and a mixer (Fig. 1). The receiving antenna is two electrodes 2 and 7 meters below the water surface. Underwater electrodes are used because 2.4 MHz attenuates 52 db/m faster than 10.2 KHz in seawater, providing some shielding for the input. Signals and impedences in the antenna are on the order of 0.5 μVpp into 3 ohms, requiring a low noise front end with impedence matching for the best signal-to-noise ratio.

Most of the noise is due to atmospherics, other VLF transmissions and feedback from the transmitter. Other VLF signals are effectively reduced by a tuned receiving antenna coupler and a tuned low-noise front end. Atmospherics are removed by alternating tuned and clipping amplifiers to reduce the level of noise spikes and the ringing they cause. A 10.2 KHz mechanical filter with a 50 Hz bandwidth follows the first three receiver stages. The following three stages serve to equalize the incoming Omega signals by further clipping.

Another source of noise is phase noise. The base station 2.4 MHz receiver was shown to have a 22° shift in 10.2 KHz output signal for a 50 db range of input signal. There were also phase shifts with amplitude in the buoy Omega receiver section, associated primarily with the conduction of clipping diodes for higher amplitude signals. There was no way to measure the phase noise of the phase-locked-loop CSB demodulator. The problem is especially critical in the buoy receiver where phase shifting can occur before the Omega station amplitudes are equalized.

The modulator (Fig. 2) is an RCA CA3028A integrated circuit operating very much like an unbalanced single-sideband modulator. A 2.398 MHz crystal oscillator and driver provide the carrier signal. The 10.2 KHz Omega signal is provided by a single-ended input. The output is balanced through a two-crystal filter which provides a passband with two peaks at 2.398 and 2.4082 MHz, the carrier and upper sideband frequencies. With no load, the output is virtually undistorted with no harmonics of either the carrier or the 10.2 KHz envelope apparent. The relative amplitudes of the carrier and upper sideband are adjustable over a fairly wide range by a potentiometer at the 10.2 KHz input.

The R.F. stages provide about 96 mWrms into a 50Ω load. An antenna coupler was built to match a bottom-loaded commercially-available tuned whip R.F. antenna. However, not all of the problems of matching a transmitter to a short antenna at low frequencies were solved and it is doubtful that all 96 mW were radiated.

SHORE STATION

The shore station consists of a 2.4 MHz receiver and demodulator, a Litton Amecom ORN-101 Omega navigation receiver, and a Data General NOVA 1220 minicomputer with teletype and nine-track digital tape peripherals. The 2.4 MHz receiver, subcontracted to fill certain input and output specifications, allowed us to perform the field test, but would not be satisfactory in an operational system. In particular, a local station on 2.370 MHz transmitting at 1000 watts power came through on a spur of its AGC crystal filter and pulled its demodulator loop out of lock when the buoy was any more than a few miles distant.

The demodulated Omega signal from the 2.4 MHz receiver is fed through an attenuator to the ORN-101. The Omega receiver can track any two pairs of stations, or lines-of-position (LOPs). It provides 24-hour clocktime, two LOPs and Omega signal-to-noise information in binary and BCD coded outputs to a 16-bit general purpose interface in the minicomputer. The minicomputer decodes and records these values in IBM-compatible form on 9-track magnetic tape and in printed form on the teletype. The minicomputer has the capability, if programmed, to switch the Omega receiver input between a base station Omega antenna and one or more demodulated Omega Buoy signals to track the buoys in real time by differential Omega. At present only one buoy channel is available and signal switching is done manually.

EXPERIMENTAL RESULTS

The only Omega stations available in the VIMS area consistently during the field trial were A (Norway), B (Trinidad), C (Hawaii) and D (North Dakota). Using the published LOP tables for AB, AC, AD, BC, BD, and CD, the LOP gradients were determined for the VIMS area. From these gradients, the longest diagonal, l_t, for one-lane-width-parallelograms was calculated for each of the 15 possible pairs of LOPs. The combination of station pairs with the shortest diagonal, l_t, is the best choice. The best choices for a given missing station are shown in Table 1:

TABLE 1: BEST CHOICE LOP PAIRS FOR VIMS AREA

Missing Station	Best Pair	l_t (N.M.)
none	AC/BD	15.47
A	BD/CD	25.02
B	BD/CD	106.47
C	AB/AD	16.77
D	AB/AC	17.33

The signal quality of an Omega station signal is indicated by the Litton Omega receiver. The indication is a "Good/Bad" binary output depending on a given received signal to noise ratio threshold. For 63.5 hours of recorded reception via the base station antenna and the buoy retransmission from marker N30 in the York River, the percentage of "Good" reception is shown in Table 2:

TABLE 2: PERCENTAGE "GOOD" RECEPTION

			Percentage "Good" for			
Date	Period	Source	A	B	C	D
3/31/75	18.5 hr	Buoy	16	99.1	99.1	100
4/10/75	18.65 hr	Base	40	99.1	99.7	100
4/11/75	26.33 hr	Base	37	98.7	99.5	100

In the periods noted, the commercial navigation receiver digital output was recorded once every 9 2/3 minutes. Table 2 suggests that, except for Station A, the retransmission process does not detract significantly from the signal to noise ratio. It is also evident that for the dates in the table, the pair BD/CD is the best choice of LOPs.

Several tests were made to determine the range and differential accuracy of the Omega Buoy system. The buoy was towed to successive channel marker buoys on the York River. At each buoy the retransmitted and base station Omega coordinates were taken for ten minutes each. Since the Omega receiver has a time constant of several minutes, only the last several minutes of coordinates were taken and averaged. To test range, a 50 ohm step attenuator at the antenna input of the 2.398 MHz receiver was increased until the phase-locked detector lost lock. Then it was gradually decreased until lock was required. The attenuation in db at that point was used as an indication of signal strength.

The range of the Omega Buoy is indicated in Figure 3. The data are from tests made on 6 January, 10 January, 27 January, 21 February, and 10 March, 1975. They indicate that lock-in could not be achieved with the buoy more than 9 miles from the base station. At least a 30 db improvement would be needed for a range of 100 miles. The last range test was performed with a commercially available radio beacon buoy, transmitting C.W. on 2.398 MHz. The commercial buoy was tested because of its superior R.F. antenna design and a proven effective range of 150 miles over salt water using an available communications receiver with a loop receiving antenna. The results of this test in Figure 4 show an effective range of 44 miles and an attenuation rate of 26.5 db/decade (miles) when used with the 2.4 MHz receiver. The RMS power in C.W. transmission is four times that of CSB transmission for the same peak power. Therefore, the radio beacon buoy would have a range of better than 23 miles if retransmitting Omega (a 12.2 db advantage over the VIMS buoy). To get a range of 150 miles would require another 28 db of gain in the 2.4 MHz receiver, or a demodulation system with lower requirements (such as Michelena's recombination of the carrier and sideband in a product detector).

Table 3 is a summary of the best differential Omega measurements using the AC/BD pair. The measurements with poor signal indications are not shown. The Defense Mapping Agency Wash., D.C. provided a special set of lane tables that were used to make overlays for the York River area navigation map (C & GS #495). The "map" values in the table were derived from those overlays. It is evident that there is a consistent 50 centilane error in the retransmitted BD line of position. If this is removed, the position errors shown in Table 3 have an RMS value of 0.59 NM (1095 m). The RMS error of the navigation receiver for AC/BD in the VIMS area is about 0.33 NM (618 m) (assuming an RMS accuracy of ±2.5 centilanes). Therefore, the retransmission system adds 0.49 NM (910 m) RMS error to the total error in a root-sum-of-squares fashion.

Figures 5a and 5b illustrate the measurements in Table 3. Figure 5a is traced from CGS chart #495 with the ten centilane lines for LOPs AC and BD overlayed. The lower end of the York River is shown with the George P. Coleman Bridge in the lower right corner (spans open). VIMS is north of the bridge with the base station to the east of a small marina. Figure 5b shows the base station and the four nun buoys used for position references. The buoy positions are outlined by 2.5 centilane parallelograms for the ORN-101 RMS error. The calculated differential positions of the Omega Buoy are shown by circled dots.

CONCLUSIONS

The results obtained at VIMS substantially concur with E. Michelena's work. It was shown that the Omega Buoy must have adequate design in the following areas to perform well electronically: impedence matching of the receiving antenna with a low noise front end, narrow reception bandwidth without ringing due to atmospherics, supression of atmospherics, good phase shift vs. amplitude characteristics, amplitude equalization of Omega station signals, generation of equal carrier and sideband signals without harmonics, good matching of R.F. transmitter to the antenna-ground system, good shielding and filtering between the transmitter and receiver. In the base station it was found that the 2.4 MHz receiver using phase-lock-loop detection was inadequate in several respects and should be replaced with a receiver using Michelena's recombination of the carrier and sideband in a product detector. In all, the concept of differential Omega tracking of drifting drogues was shown to be workable given further development.

Future directions include a resolution of the problems mentioned with the addition of improvements. It should be possible to use another modulation/demodulation scheme (such as FSK or pulse modulation at 10.2 KHz zero crossings) to reduce the transmission/reception bandwidth and improve the signal to noise ratio. The cost and complexity of a base station can be reduced by recording Omega receiver digital outputs with a time code on digital tape for later processing. Lane skipping can be corrected by the use of automatic radio direction finding antennas at two or more automatic base stations. With a new transmission mode, it may be possible to add other telemetry such as water temperature and the 11.6 and 13.4 KHz Omega signals.

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TABLE 3: DIFFERENTIAL OMEGA BUOY ACCURACY

DATE 74-75	TIME	CHANNEL MARKER	RANGE (NM)	BUOY - BASE LOP FROM MAP		BUOY - BASE LOP MEASURED		MODULO 1 DIFFER.		POSIT. ERROR (NM)
				AC	BD	AC	BD	AC	BD	
30 DEC	1400	N28	0.4	.02	.04	-.01	.58	-.03	.54	0.16
31 DEC	0940	N28	0.4	.02	.04	-.01	.54	-.03	.50	0.31
6 JAN	1414	N30	1.21	.03	.15	.02	.69	-.01	.54	0.39
6 JAN	1445	N32	2.53	.08	.31	.14	.85	.06	.54	0.61
6 JAN	1522	N34	4.10	.17	.50	.07	.00	-.10	.50	1.05

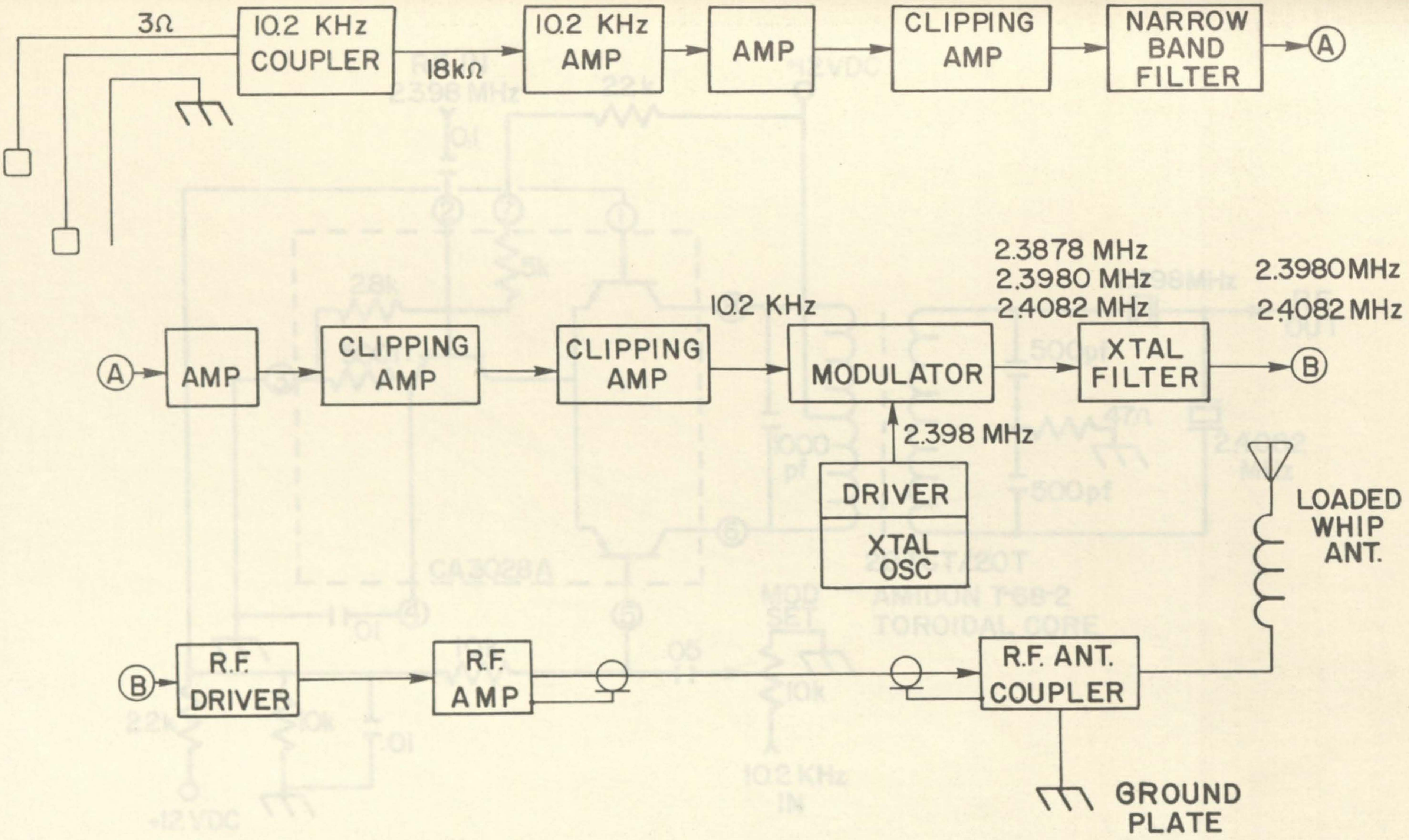


FIGURE 1: BUOY ELECTRONICS

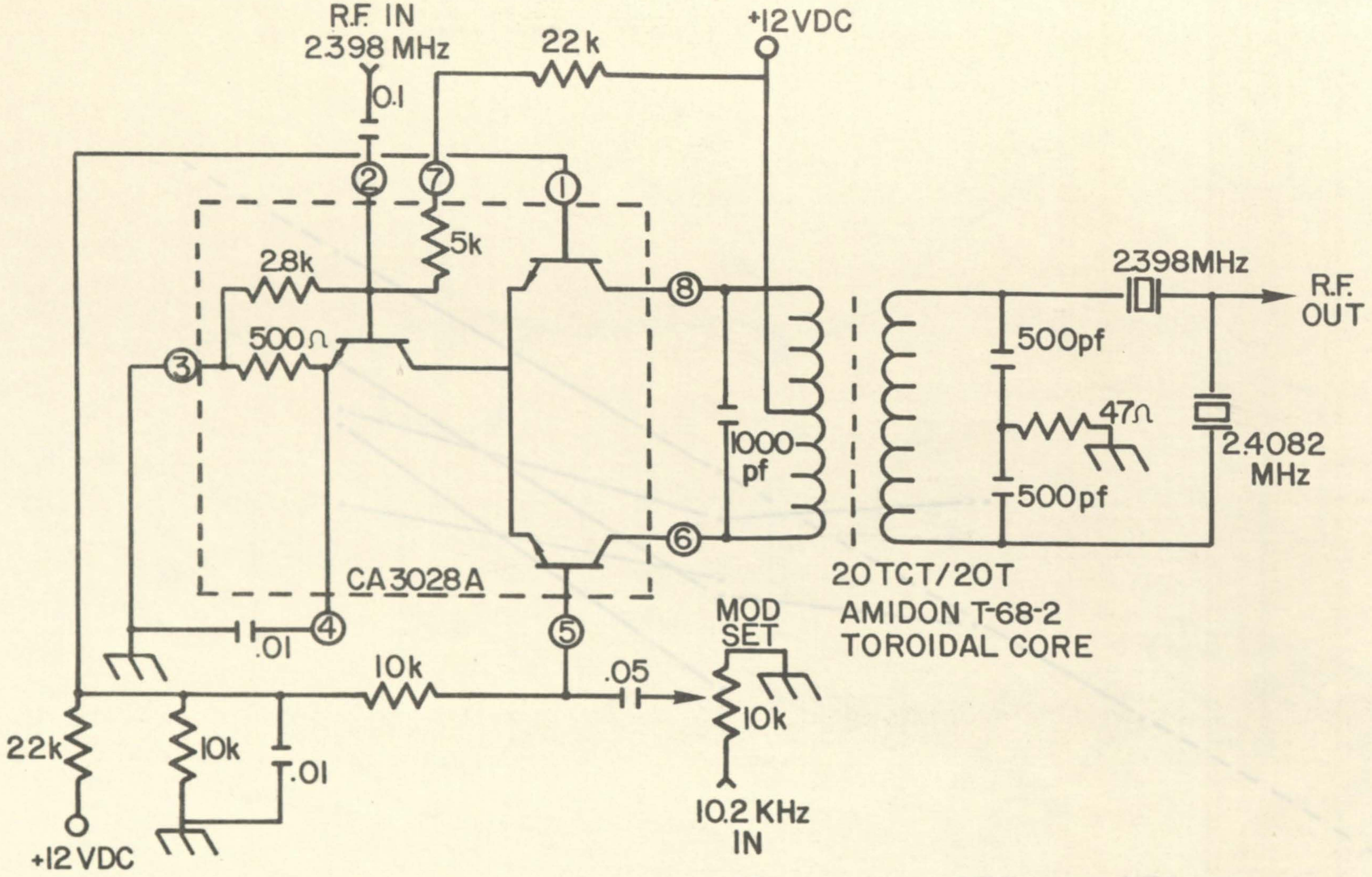


FIGURE 2: CSB MODULATOR

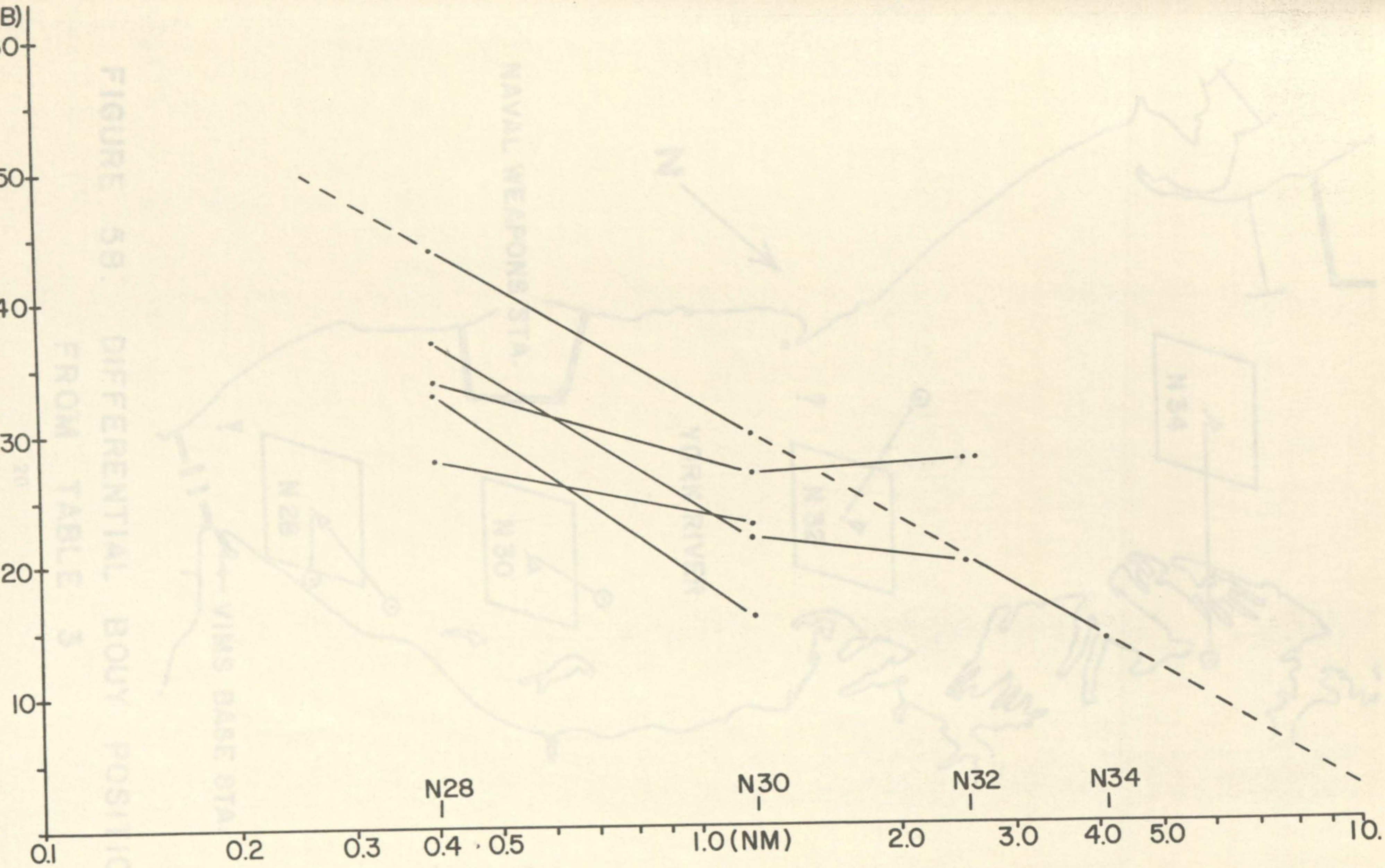


FIGURE 3: OMEGA BUOY RANGE TESTS

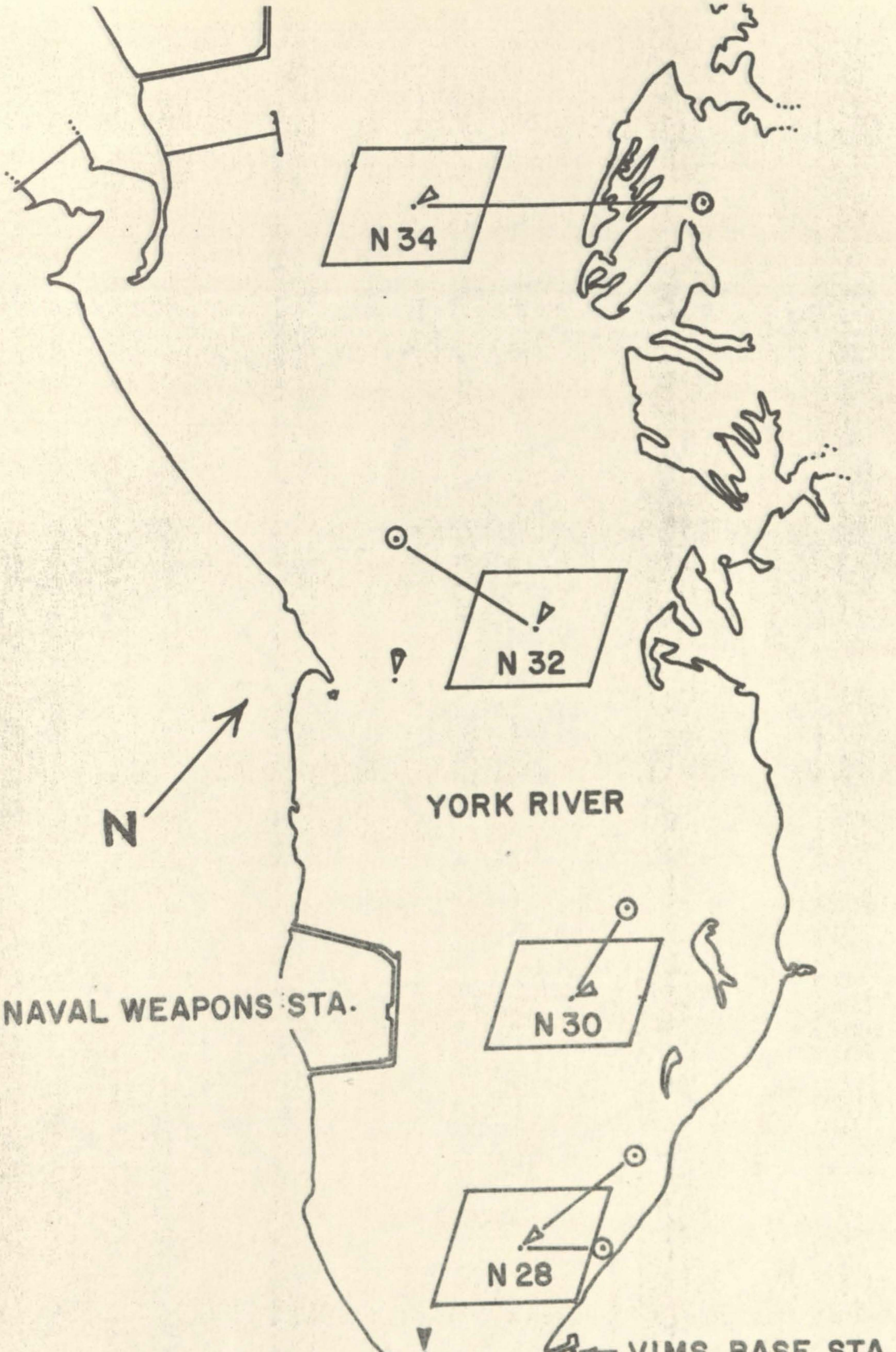


FIGURE 5B: DIFFERENTIAL BOUY POSITIONS FROM TABLE 3

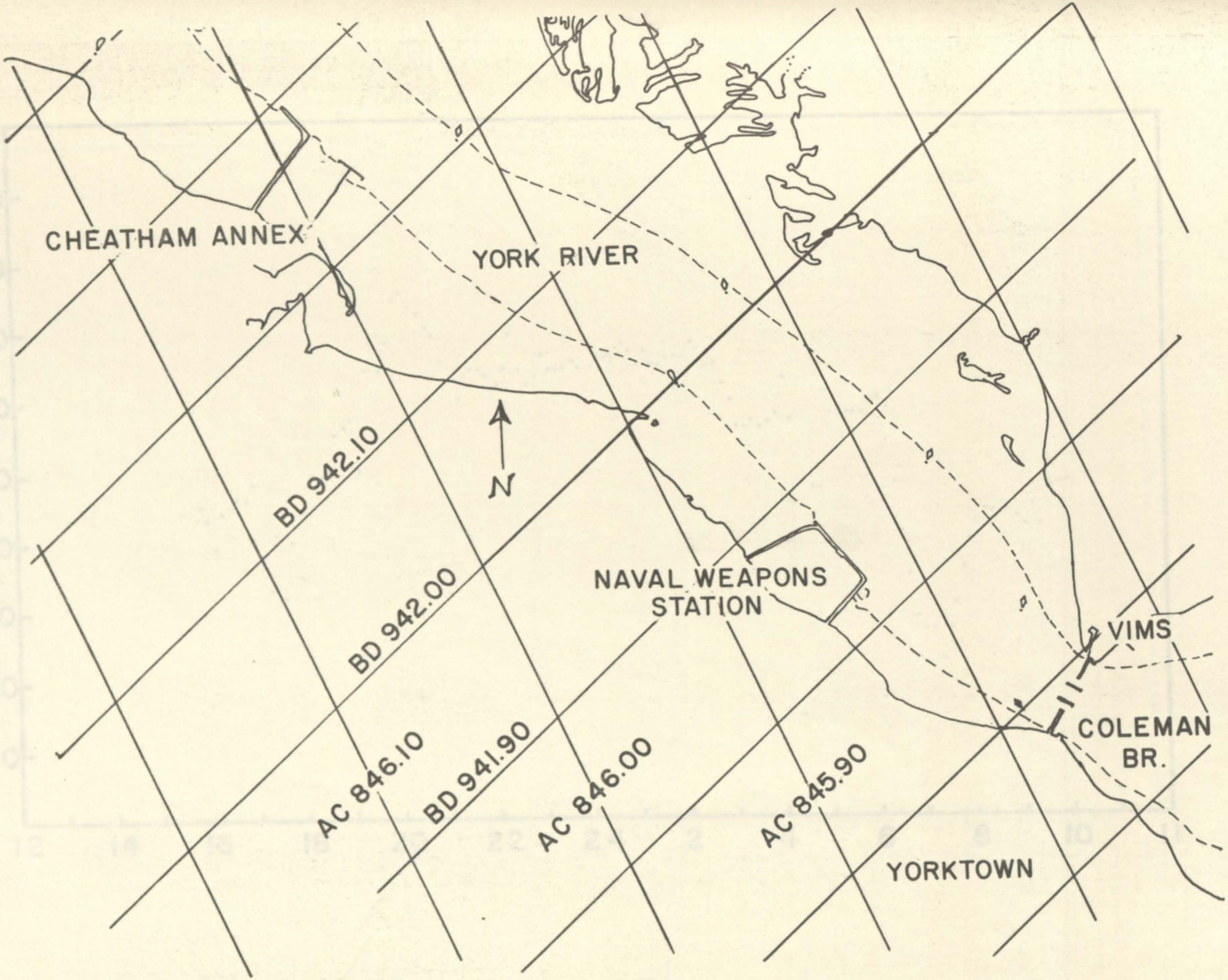
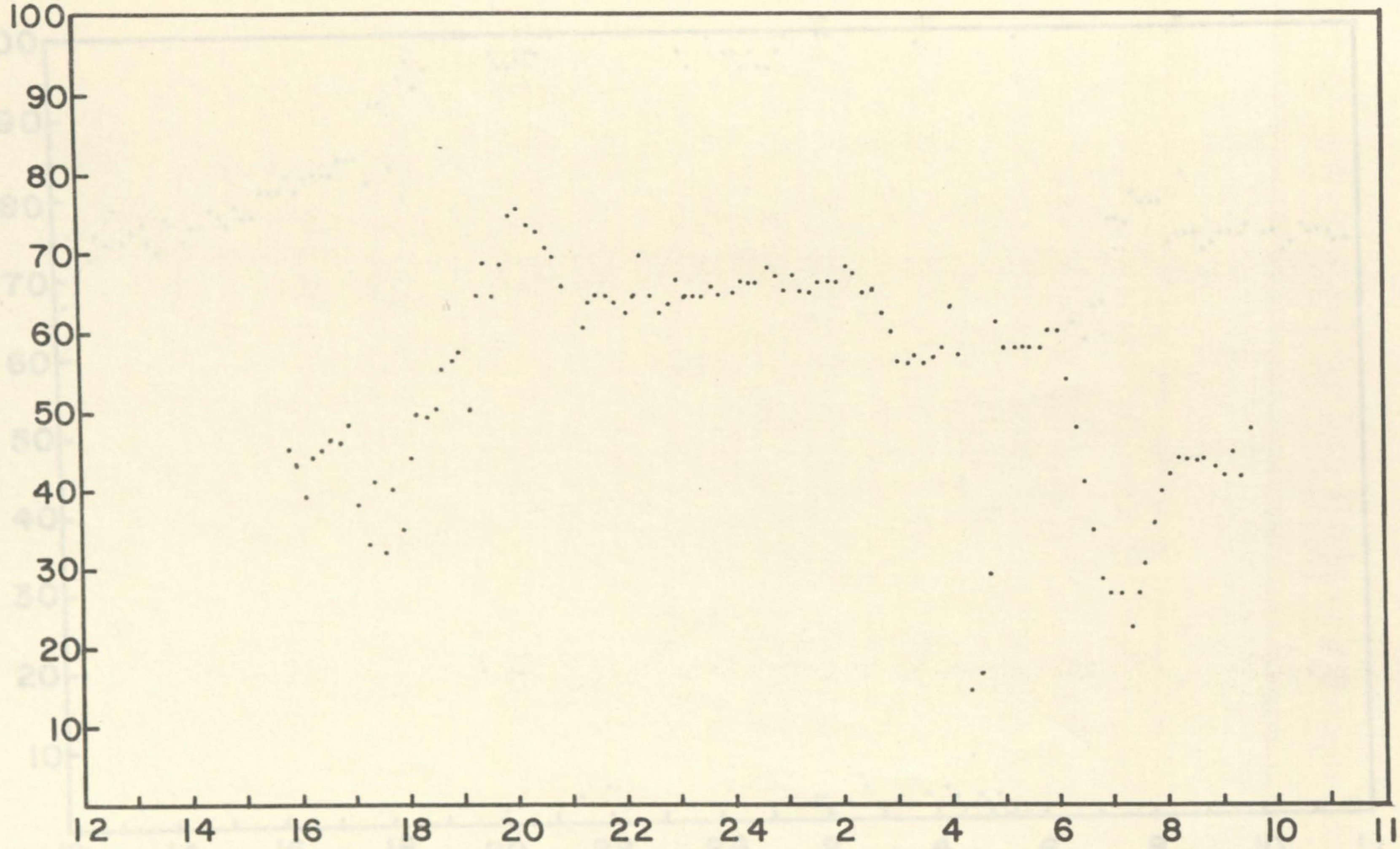


FIGURE 5A: AC/BD OMEGA GRID IN VIMS-YORK R. AREA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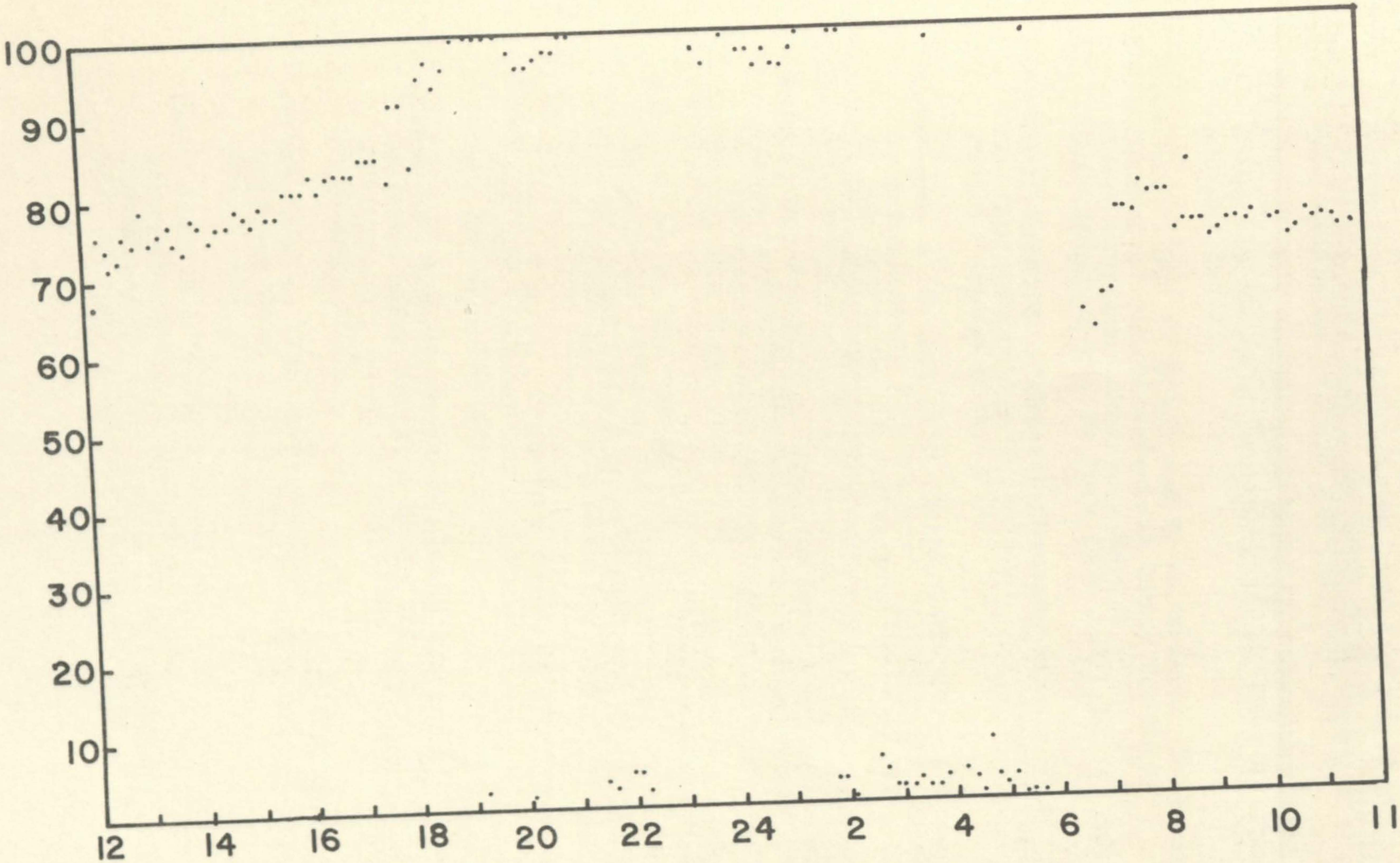

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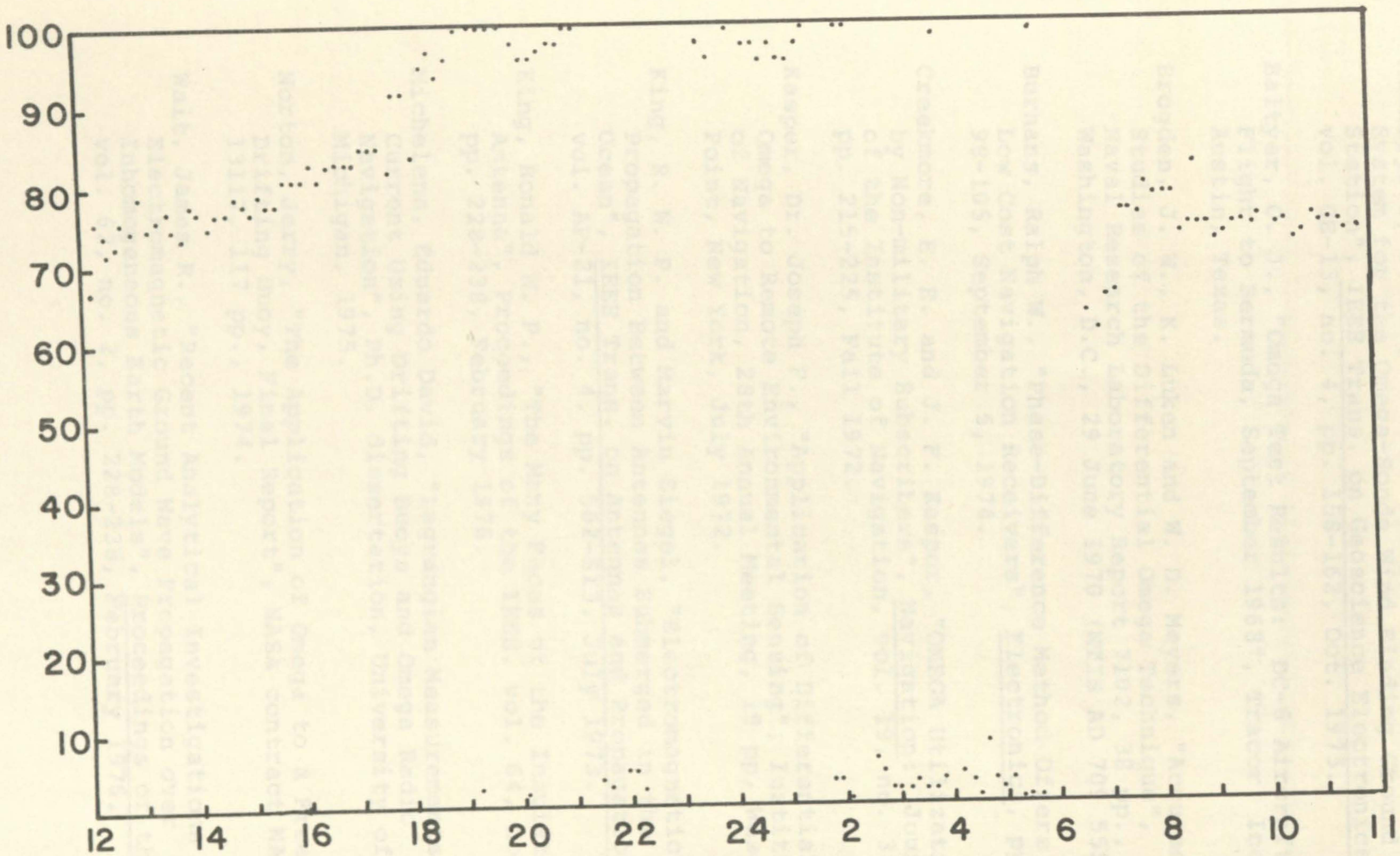
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