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CLUTTER REDUCTION TECHNIQUES

FINAL REPORT

(7 March 1973 to 7 March 1974)

March 1974

by

W. E. Meyer

Prepared Under Contract N00019-73-C-0280

for

Naval Air Systems Command

Department of the Navy

by

Electronics Research Division

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CLUTTER REDUCTION TECHNIQUES

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ABSTRACT

This report contains a description of work performed on Contract N00019-73-C-0280 toward constructing and testing surface acoustic wave devices for signal processing methods to reduce clutter and interfering signals in operating radar systems. The specific system to be used as a test bed to determine the validity of the concept in system environment was the APG-59.

The report is written in three parts. Part I describes the general system interface problems and design parameters of surface acoustic wave devices, followed by discussion of the fabrication and testing of the experimental tapped delay line. Part II discusses the recommendations for future effort, while Part III is a collection of reference material providing a more detailed technical background for understanding the operation of acoustic devices.

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PART I

This report was prepared by the Electronics Research Division of Rockwell International under Contract N00019-73-C-0280. All design and test activities were performed within the Physical Sciences Department.

The program includes both a study and a design/fabrication phase. The study report has been presented under a separate cover. The purpose of that report was to evaluate surface acoustic wave device applications to radar systems in cluttered signal conditions. This report will concentrate upon the device design and performance as well as the considerations given to interface problems in the intended radar test bed.

The purpose of the program will be discussed further in the following section and the device design for that application is reviewed in Section 3. Section 4 dicusses briefly some of the surface wave transducer fabrication considerations. Following that specific device performance and performance data are discussed. Conclusions and recommendations are given in Part II and a short Bibliography in Part III.

1. PURPOSE

The objectives of this program were to design and fabricate a surface acoustic wave device circuit, which can be readily incorporated in an existing radar system, to improve performance in a cluttered environment. Any system changes were to be minimal with little or no modifications in the transmitter section. The system selected as a test bed by the U. S. Navy was an APQ-59 because of bench test facilities and system versatility. The surface wave device restrictions were to use no more than two delay lines and minimal control or amplification electronics. These restrictions and that of a selected radar limited the range of possible surface wave devices but the simplicity of modifications warranted the restrictions.

2. DEVICE/SYSTEM INTERFACE CONSIDERATIONS

Major considerations in using the APG-59 as a bench test radar involved that of locating a point of addition which did not compromise the remainder of the system's signal processing. Of equal importance was that of matching the pulse compression capabilities of the system or of not degrading that performance figure. Other obvious concerns were those of center frequency, bandwidth, and signal levels.

Pulse compression or compression gain was the initial concern as the best test point was found to be that where the present dispersive delayline was inserted. Consequently, the design of the tapped delay line clutter device had to have the same compression gain without compromising the concept of variability in frequency response nulls for shifts in codes or frequency. It is believed that the device designed on this program can be interfaced at that point without a loss in pulse compression performance.

The adjustable bandwidth feature (1.8 to 2.5 MHz) of the system's sum amplifier chain was of particularly interest in that narrow and wide correlation pulses may both be tested with the system. This changeable bandwidth provides the option for testing higher chip rate tapped lines.

An additional advantage in substitution at the previous delay line point is realized as this greatly simplifies the supporting electronic circuitry as the electronic inversion of signal is no longer required when two complementary coded and matched lines are used. Without inversion the oscillator and mixers are no longer required and may be removed or disabled.

An added advantage of an interface at the delay line point will be that of comparison between frequency dispersive delay lines and time dispersive delay lines using biphase coding.

3. DEVICE DESIGN AND FABRICATION

Tests conducted during the study phase demonstrated that nulls could be readily shifted in frequency by adjusting the space between groups of taps on an existing 60 MHz tapped delay line with all taps coded as "1"s. The design phase proceeded at this point around that concept and the assumption that the circuit would be inserted at the point where the present dispersive line was installed. Signal levels were to be maintained with integral amplifiers where required.

The longest lead item in surface wave lines is generally that of the mask design; consequently, primary consideration was given to a mask designed to make it versatile to several requirements so that only one design would have to be fabricated. Both the short (2 in.) and long (4 in.) tap lines were desired to accommodate any coding sequence which may be desirable and to match the radar delay requirements. In order to do this the mask design presently used was conceived. This mask design allows the number of tap configurations to be adjusted on each part fabricated. The input transducer length and chip rate can be varied by a factor of 5 from a high chip rate to low chip rates. The values of chip rate available are in step intervals of 0.1609 μsec.

Of the several materials considered, ST-cut quartz is most suited. Good temperature stability eliminates the need for temperature control for minimizing any temperature null shift effects.

The smallest chip rate was selected in order that one might want to phase code one of the pulse modes of the radar system. The longest bit rate or lowest frequency of chip rate was determined by the present dispersive line used in the system. For this mode of operation the same compression ratio and bandwidth were used.

In the design of tapped lines the capacitance and radiation resistance of the input transducer are important parameters. The radiation resistance, along with the coil resistance, finger resistance and other resistance components in the circuit, determine what resistance component is presented to the input circuit. The total capacitance of the transducer determines whether the unit may be tuned by a simple inductor. If the value of capacitance is too small the required value of inductance may not be obtainable because of self-resonant effects in the inductor itself. Since the design calculations indicated that the capacitance value may be marginal, tuning experiments with toroidal core inductors were performed in order to determine if the small capacitance of the designed input transducer could be tuned. One of the bounds on the maximum size of the capacitance is the width of the material, and since the available materials were no wider than 0.3 in. it was desirable to keep the width of the transducer below this value. It was found that T25-6 Micrometals coil wound with No. 36 wire was capable of tuning capacitances much smaller than those expected in the input transducer circuit. The coils were operating on their self-resonant curve, meaning that the effective series loss was higher for very small transducer capacitances, whereas, the value of this spurious resistance contributed by the coils was almost negligible for the very large transducer. A summary of the final design parameters for the mask are given in Table 1, and 2 with a schematic representation of one finger pair given in Figure 1. Another consideration in the design of a tapped line is the output signal level from the taps. Each of the taps obviously cannot equal the design of the input transducer, as the resulting capacitance of the inactive taps would severely load the output signal of an active tap when it was delivering signal to the load. For example, if a typical line has 100 taps, 99 of those taps will be shunting the signal coming from the first. In order to limit this insertion loss a level of 50Ω at the center frequency is usually selected. When this is done a long tapped sequence will have one, two or three finger pairs for each tap instead of the five or more for the input transducer.

The mask was manufactured using an automatic computer controlled photo-composer with 250 μ in. stepping capabilities, which defines the exact center frequency of the tapped lines. A five finger pair section was chosen for the basic transducer length since this also provided a value in agreement with the compression gain and bandwidth requirements of the system's dispersive mode when five of these units were used as a composite input transducer. The design parameters for these input transducers are given in Table 1.

The value or R_a chosen for this application was 26Ω in order to allow for finger resistance and coil resistance. These parameters when added to the value for R_a will tend to provide a match to 50Ω and provide the extra resistance required to lower the electrical Q. This will not be sufficient resistance, however, to prevent the electrical Q from dominating the input circuit when only using one 5λ section. This dominance decreases however when additional sections are used on the input transducer because of the reduction of the capacitive reactance. The resitance R_a can be calculated by the formulas.

$$\hat{R}_a = \frac{1800}{W_\lambda} \qquad W_\lambda = \text{Transducer width in wavelengths.}$$

Table 1. Transducer Parameters

λ (N)	T (μsec)	BW (MHz)	Total Length (Mils)
5	0.16092	6.21	20
10	0.3218	3.11	40
15	0.4827	2.07	60
20	0.6437	1.55	80
25	0.8046	1.24	100

Table 2. Design Parameters

N	C_T	-jX	λ_o = 0.004 in. f_o = 31.070866 MHz (v = $1.24283(10)^{+5}$ in./sec)
5	1.822 pF	2.75 K	
10	3.644	1.36	Input Transducer Aperture = 0.270 in. (67.5λ) Ra = 26.6Ω
15	5.465	0.903	
20	7.287	0.68	Tap Transducers Aperture = 0.200 in. (50λ) = 36 Ω
25	9.109	0.54	Maximum number of taps 160 Minimum spacing .020 in. (0.1609 μsec)

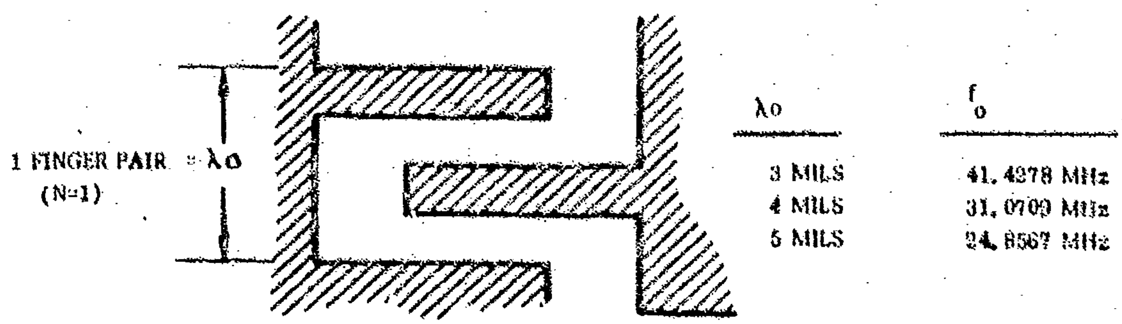


Figure 1. One Figure Pair

where w_λ = the aperture width in wavelengths. For $w_\lambda = 67.5$, $R_a = 26.6$ this corresponds to a physical aperture w = 0.270 in. — a width that will fit on a 0.300 in. quartz bar with room for bonding pads. The next parameter determined was the value of the input transducer capacitance, C_T. For this the relationship

$$C_T = C_K m w$$

w = width in inches

N = number finger pairs

m = 2N-1

C_K = 0.7497 pF/in.

The value of C_K has been determined by many measurements of transducer fabricated in ST quartz. Using this formula, the values of C_T for input transducer sections up to 25 finger pair long were determined.

Experiments were performed in order to ensure that the smallest value of input transducer capacitance could be tuned with an inductance. It was found that a Micor-metals T25-6 toroidal core could be wound with sufficient turns to provide the correct inductive reactance to tune out the 1.822 pF before the coil became self-resonant. But because the coil was approaching self-resonance a significant value of series resistance above that due to the wire was added to the circuit. This was not detrimental however, since additional resistance should be added to the circuit for this small value of capacitance if the electrical circuit Q dominance was to be removed.

The next parameter to be considered was the tap ladder transducers. Because of the multiple purpose nature of this mask design, all the details of the tradeoffs will not be described; however, a discussion will be given to provide an outline of the thinking involved. The final design was set to accommodate tap ladders up to 4 in. long even though the initial use of the mask for the laboratory experiments would only require 2 in. of tap ladder.

Consideration must be given to the loading of a single tap by all of the taps electrically in parallel with it. For this reason the values of R_a and C_T are much different than that of the input transducer. The value of R_a is calculated as above but for a width of 0.200 in. (50 λ). C_T is also calculated by its respective formula but for a width of 0.200 in. and for only three finger pairs (N=3).

The values for R_a and C_T are 36 Ω and 0.749 pF (-j6.85 K). The impedance which will shunt the working tap will be ≈0.90-j171.3 when 40 taps are in the tap ladder (the laboratory experimental case). From these values and the values of impedance for the input transducer a value of insertion loss to the first tap can be obtained. The tap loss is calculated to be 38.5 dB and the input transducer loss 7.1 dB. When bi-directional loss, surface loss, and geometric loss are added, the total value becomes 53.7 dB. This represents the loss from input signal level to the first taps output level.

Figure 2 shows the geometric layout of a tapped delay line. The input transducer is on the left end. Each of the metalized fingers is spaced one-half wavelength, center-to-center distance. The length in the direction of propagation of each of the fingers is one-quarter of the center frequency wavelength. At the upper and lower ends of the

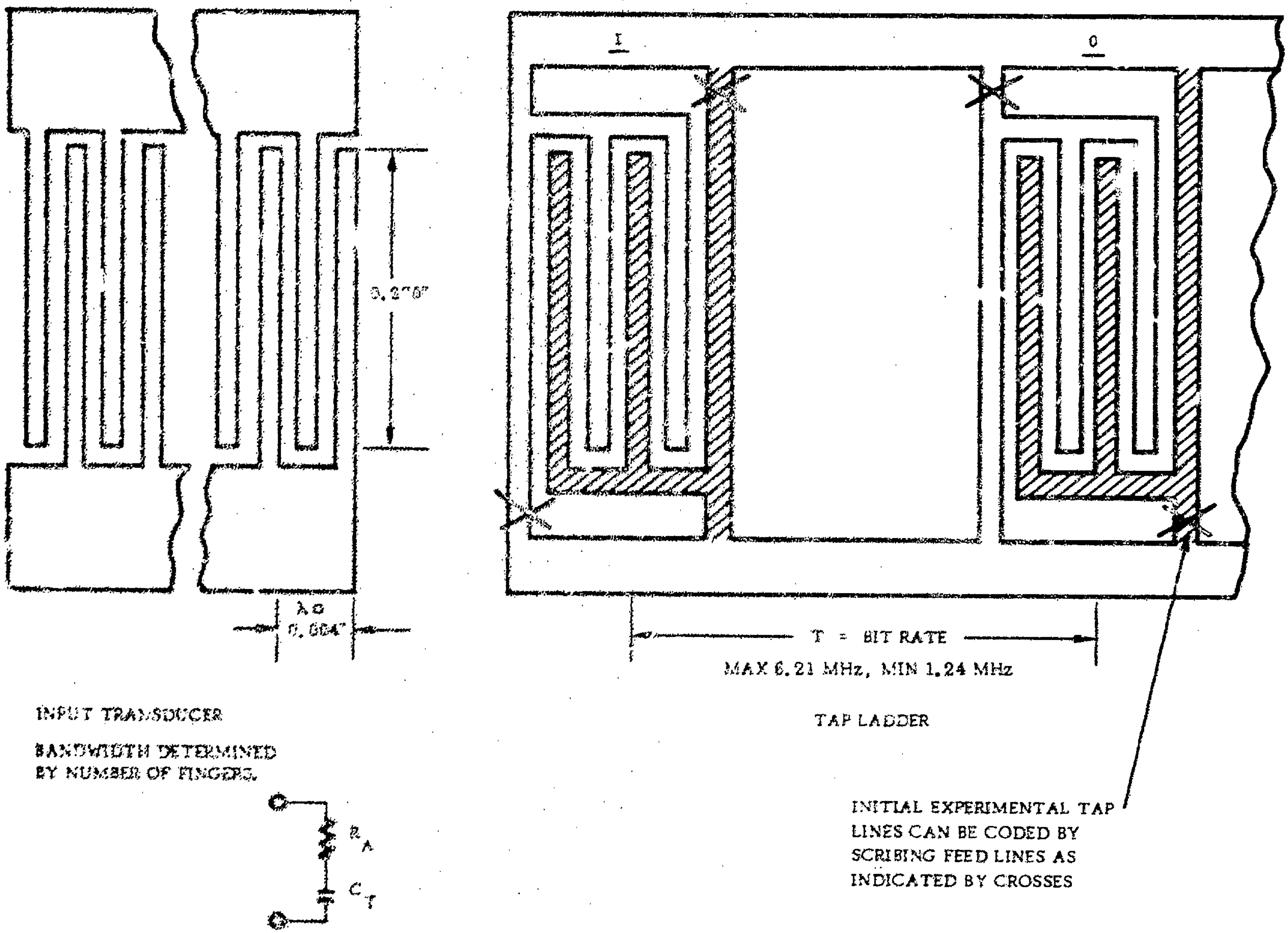


Figure 2. Mask Design Parameters

fingers are pads which connect all fingers together and act as wire bond points. The distance between the input transducer and the first tap is determined by the space that is required to RF shielding the tap ladder from the input. This shield must be wide enough to prevent energy from coupling directly between the input transducer and the tap ladder feed lines. It also must be conveniently wide enough so as not to hamper fabrication.

Each of the taps in this figure is made of three finger pairs. The X's indicate the place of scribing through the aluminum by which the taps can be coded either as 0 or 180 deg phase output. The crossover bars allow this phase change to occur. The center-to-center spacing between taps determines the chip or bit rate and is identical in value to that of the input transducer length. The taps are designed to produce a maximum signal with a minimum loading of a tap which is active. In the lower left-hand corner is the simple electrical equivalent circuit of either a single tap or the input transducer. The primary difference lies in the value of R_a and C_T for each of the units. In the design, used for laboratory bench testing, there were a maximum of 80 taps in the tap ladder. The design allows the length of the input transducer and a selection of taps so that a number of taps can be chosen which are proper for the input transducer being fabricated.

4. FABRICATION AND PREPARATION OF TAPPED DELAY LINES

The fabrication and preparation of tapped delay lines is a standard procedure in the laboratory. Extreme care must be taken at all stages in order to produce a device which has no defects. The initial step after obtaining the polished quartz is to clean the quartz thoroughly so that the aluminum which is to be evaporated on the acoustic propagation surface holds firmly and does not peel up at a later time. Once the substrates are thoroughly cleaned and dried they are placed in a vacuum chamber and a controlled thickness of aluminum evaporated onto their surface. This aluminum thickness may be as thin as 200Å or as thick as 8000Å, depending upon the device to be fabricated. For the tapped lines in this program, values between 1000Å and 4000Å were evaluated. After the bars are prepared with aluminum the next step is to coat the aluminum with a photoresist, expose the photoresist on the aluminized bars through the mask, and etch the exposed area away. After this process the bars are cleaned with a second solvent which is designed to dissolve the remaining photoresist. Figure 3 through 5 show a photograph of two completed typical lines, one photograph shows the shorter input transducer used in the all "1"s configuration and the other the longer one which was used in the coding experiments. The bars are then delivered to the laboratory where the thickness of the aluminum is measured and a measurement of the input transducer's capacitance is made. The delay line's tap ladder is then coded by scribing through the aluminum of the small bars attaching the transducer tap fingers to the main pads. After these processes the lines are then bonded using gold wire. The quartz substrate is next mounted in a box for protection during handling and testing and the gold wires from the transducers connected to appropriate output points on the ends or sides of the boxes. Experimental electrical measurements can now be accomplished.

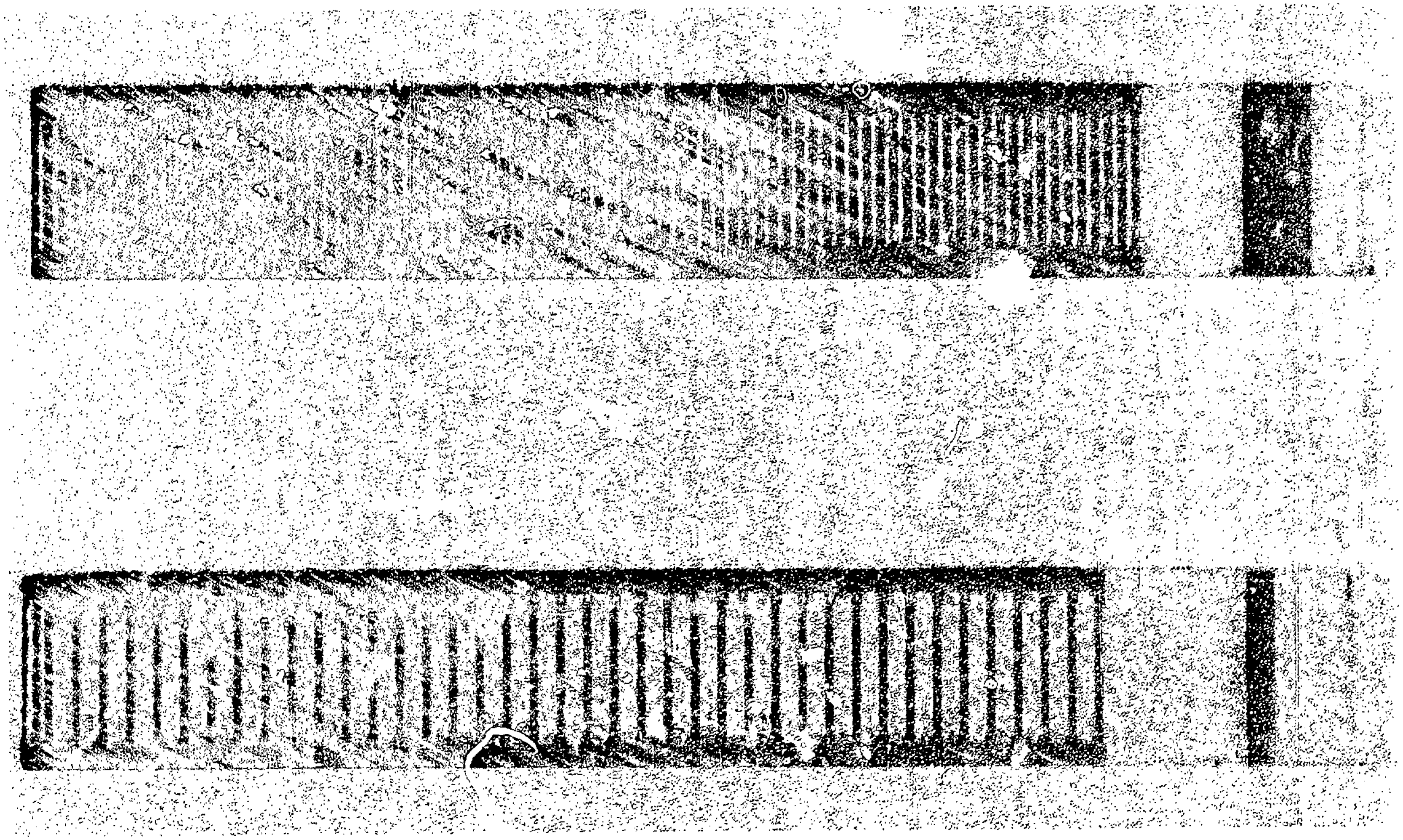


Figure 3. Tapped Delay Lines with all Taps and Five Sections of Input Transducer

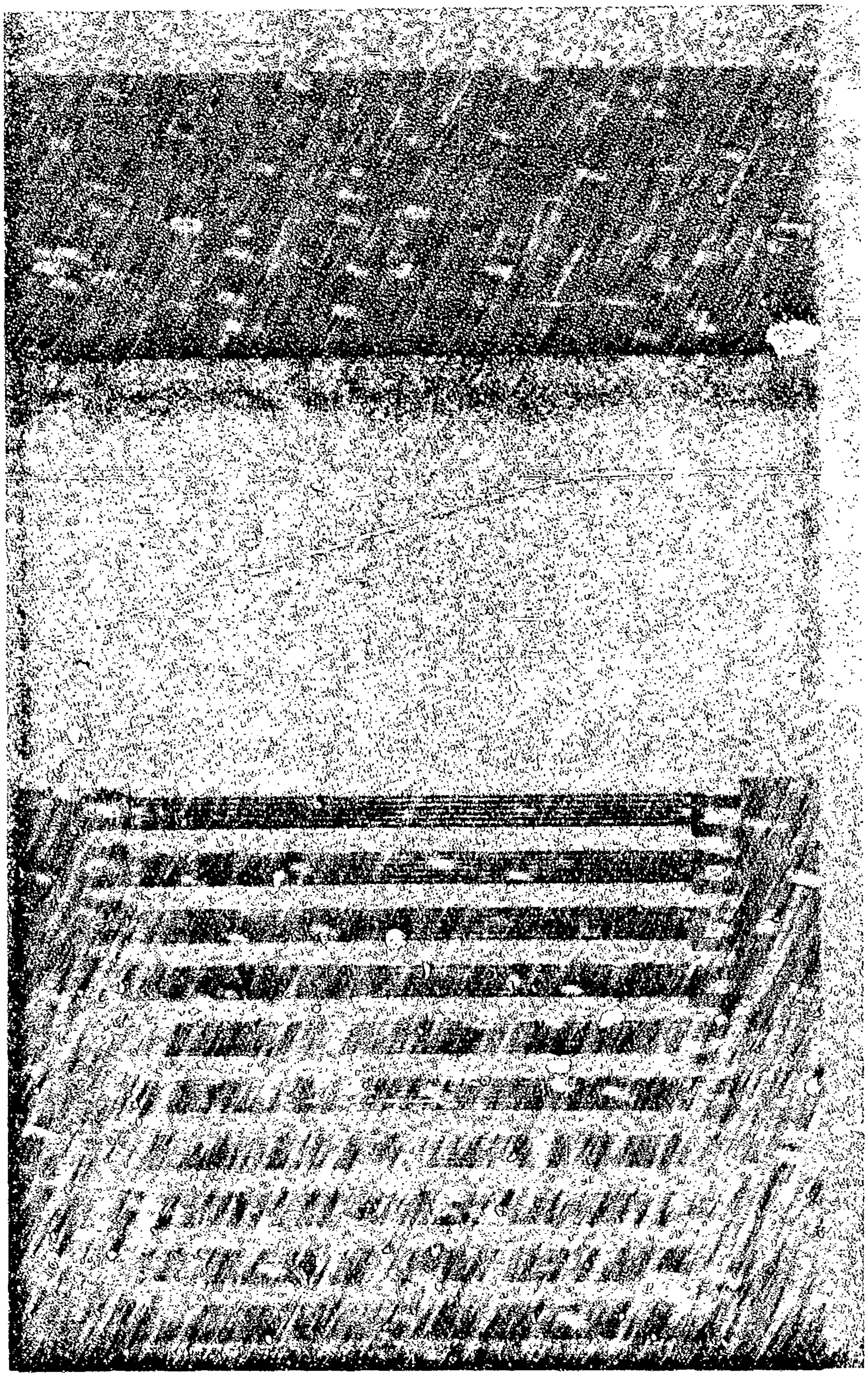


Figure 4. Details of Five Sections of Input Transducer, 25 Finger Pairs

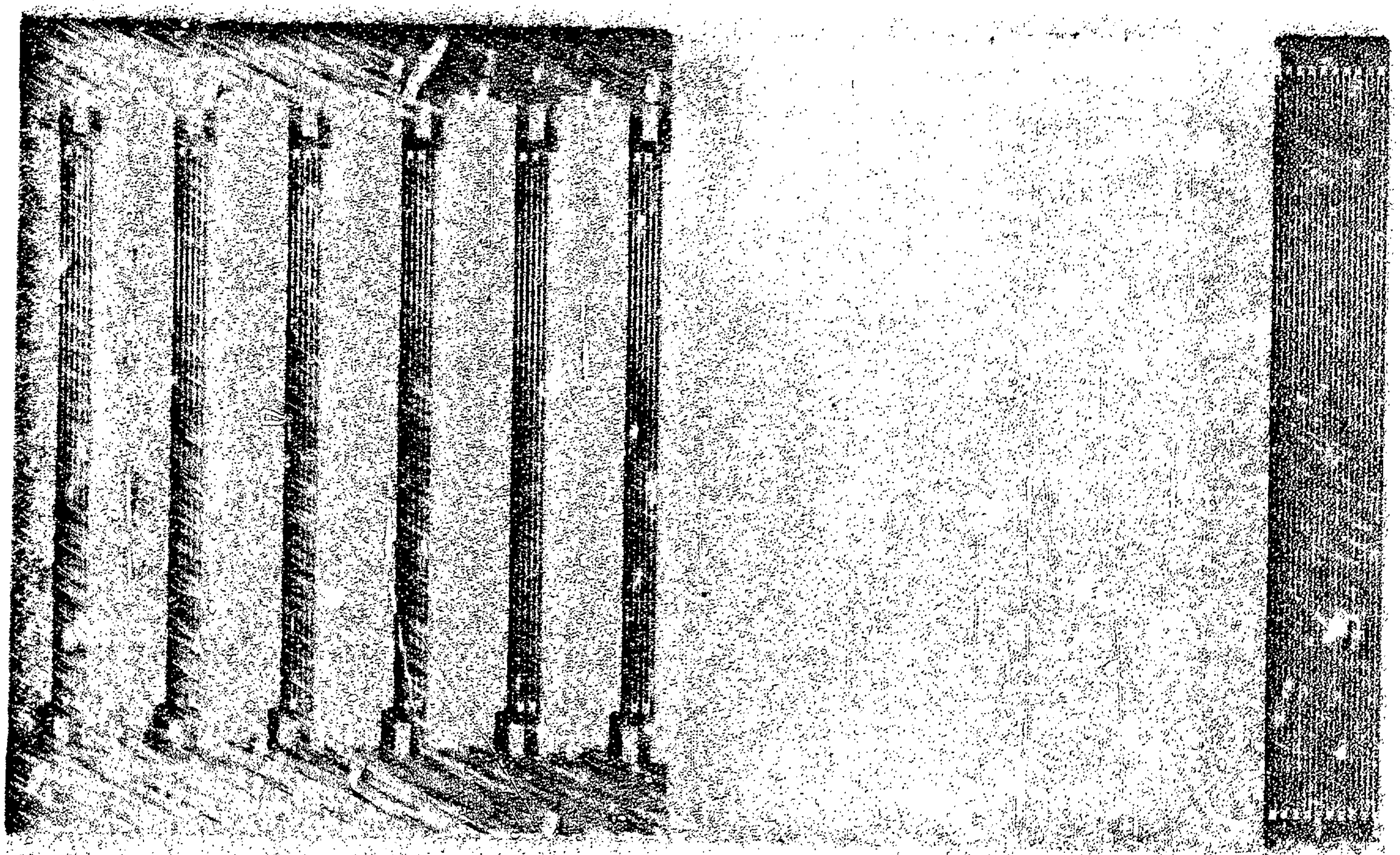


Figure 5. Ten Finger Pairs Input Transducer

5. AUXILIARY AMPLIFIERS

Two amplifiers, a preamplifier, and a post amplifier, are used with each tapped line in order to return the processed signal to the original level after passing through the tapped delayline. One amplifier of each type has been constructed and tested in order to verify the design and uncover any possible interface problems between the units and the tapped lines.

Experimental amplifiers are presently packaged in individual cases designed to connect to the SAW tapped delay line by means of the SMA connectors (see Figure 6.) This packaging concept was adapted in order to provide a more convenient means of changing sets of coded tapped lines in the radar system chassis during the system testing phase. The amplifiers as presently constructed are 0.75 x 0.75 x 0.375 in. with SMA connectors on each end. Each amplifier package consists of a Fairchild MA733 amplifier chip sealed in a TO70-can. These amplifiers are also available in chip form, a factor to be taken into consideration for the final packaging concept. A schematic diagram of each of the amplifier circuits and its interface with the tapped delay line is shown in Figure 7. The gain, and input and output impedances, have been set in order to provide a proper interface with the tapped delay line. Each of the amplifier units gain can be adjusted by means of connections external to the chip mounting case, as indicated in the schematic note. The low voltage and current requirements of the amplifier will allow them to be run from any available system DC source or even separate batteries if a low noise, low ripple source is required. Figure 6 shows the units constructed for the laboratory tests while Figure 8 is a schematic picture of the units to be used in the system tests.

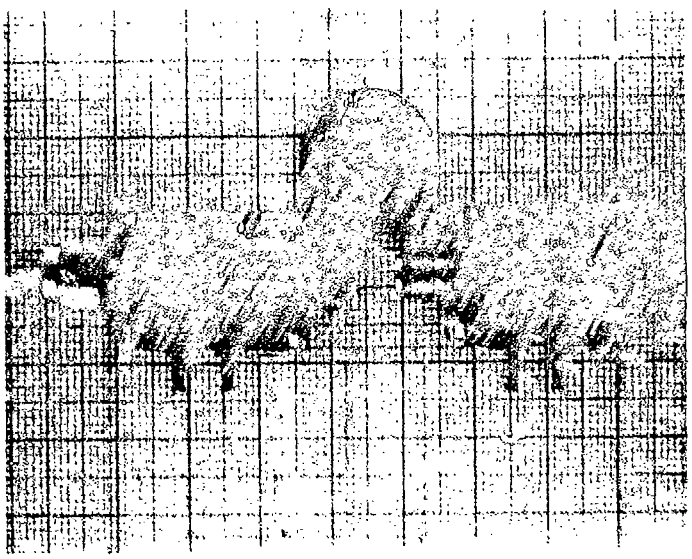
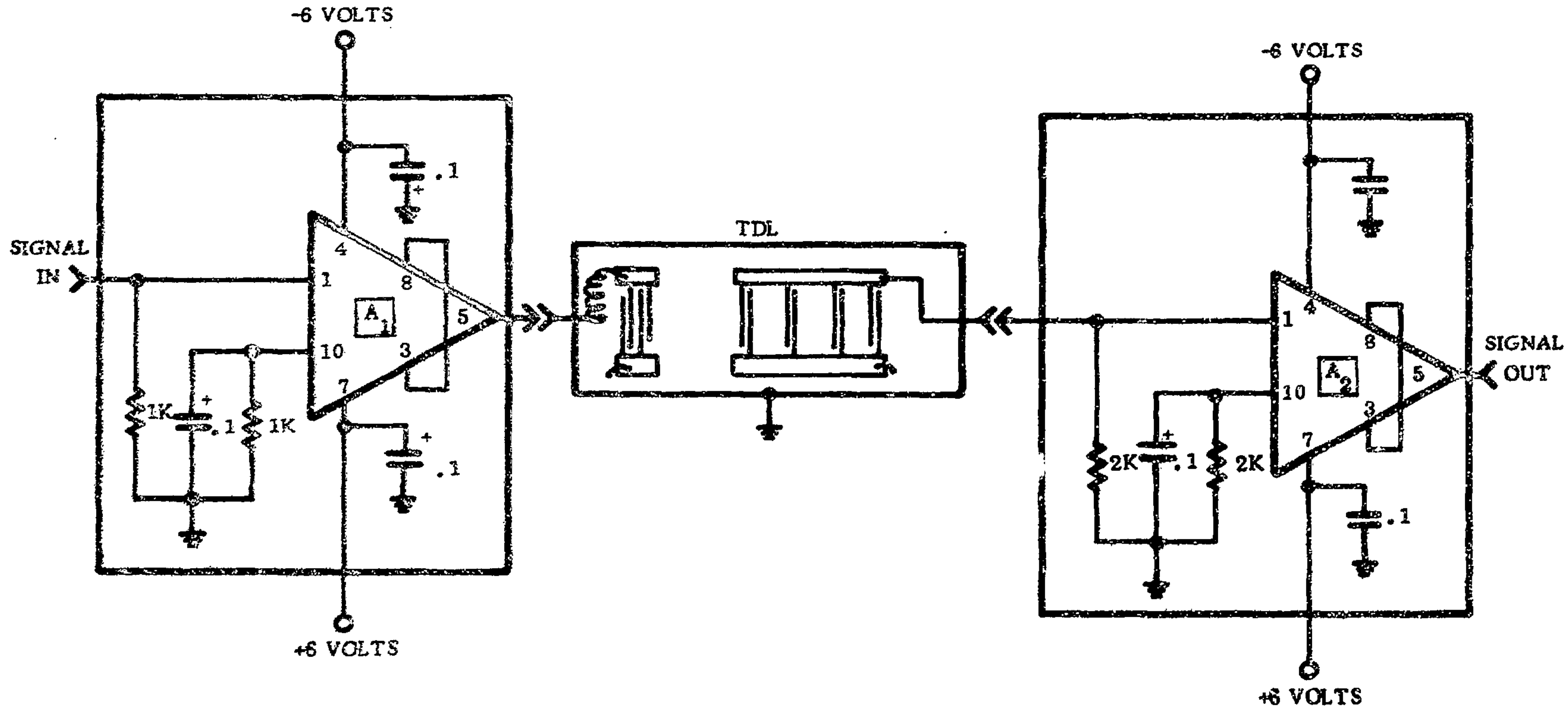


Figure 6. Input/Output Amplifiers



A_1, A_2 - MA733

NOTE: ADD RESISTANCE BETWEEN PINS NO. 3 AND NO. 8 TO REDUCE GAIN AND INCREASE BANDWIDTH.

Figure 7. Amplifier Circuits and Interface

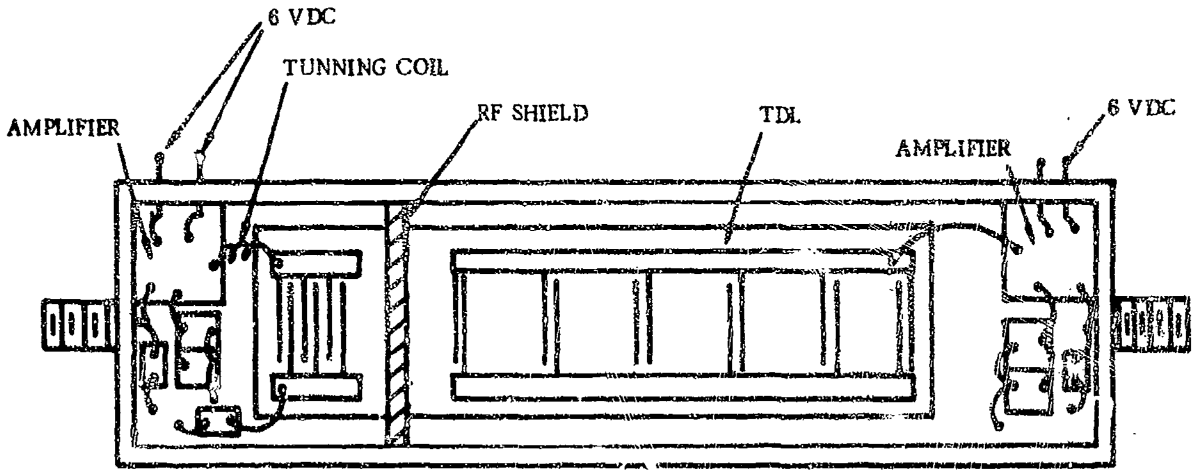


Figure 8. System Configuration for TAP Line and Amplifiers

In the final packaging configuration for the system tests the clutter reduction device could be made into a single compact package. Utilization of the present type of amplifier and their associated passive components, in chip form, minimize the size of the device. The size of the package in its final form would be approximately 0.5 x 0.75 x 4.0 in. The length of the packaging will be primarily determined by the tapped line length which in the system tests could be up to 4 in. long. The type of connectors required would have to be determined by the system interface requirements when this phase of the program begins.

Tests of the amplifiers have been made between 50Ω source shown and they each have a measured gain above 30 dB. The units were also tested on the input and output of a tapped delay line and operated satisfactory.

The packaging of the tapped lines for system tests is in U shaped channel boxes, the box being sufficiently long to accommodate the line used. At each end of the box will be a small chip amplifier. The amplifiers chosen for this function were Fairchild μA733 which have frequency responses up to 500 MHz. These units are also very low voltage devices and should have no problem in obtaining power from the normal test bed system. Each of the amplifiers provides an optimum impedance on its input and output to the system or tapped delay line. It is thought that an improvement in the tapped line can be obtained be obtained by utilizing a high impedance input to the amplifier rather than trying to match it to 50Ω as is the normal practice. The output of this amplifier can be adjusted to match the systems characteristic impedance. On the input end of the amplifiers input is adjusted to that of the system output and the output of this amplifier adjusted to provide the correct impedance in order that the Q of the input transducer inductor combination do not dominate the bandwidth of the unit. The figure shows an artist's concept of this configuration. In practice the ampifiers may be built to be portable between lines and consist of connectors at the tapped line amplifier interface instead of direct connection by wire as indicated in the drawing.

6. EXPERIMENTAL DATA

The first electrical measurement to be made on the tapped delay lines was the input transducers capacitance. This immediately gives a value of capacitance with which to work in designing a coil to tune out the capacitive reactance of the input transducer. Some typical measurements for the short .160 μ sec input transducer and the longer .320 μ sec transducer are shown in Table 3. The tap ladders are also inspected and measured to see if there are any shorts in the taps and if the capacitance values are in reasonable agreement when compared to the design value. As mentioned in the section on fabrication and preparation, the aluminum thickness is also measured. In our case we customarily prepared the lines with an aluminum thickness which had a nominal value of 1000Å. But calculations indicated that this value would be too thin and make the finger resistance too large. The original lines were then prepared with a thickness of 1800Å and even this thickness proved to be too thin. The photograph in Figure 9b shows a variation of insertion loss between the two different tap phasings. There is a measured difference of 2 dB between the "1"s and the "0"s taps in this line. This is caused by the high series resistance of the thin aluminum line crossing over tap aperture in order to provide the 180 deg phase reversal. This problem was resolved by use of thicker aluminum. The photograph in Figure 9c was also included to show the effect of missing taps. The final sets of lines which were fabricated were prepared at 3900Å and were found to have eliminated the problems of series resistance loss in the fingers. After the aluminum thickness has been measured the line is checked for coding errors.

When this measurement is completed the line is then ready for its input transducer to be tuned. A coil is made using a toroidal ferrite core. The type of coil form used for this project was a Micrometals T25-6. The completed coil is measured on a bridge to determine what spurious series resistance will be added to the resonant system and whether the coil has sufficient inductance to tune out the input transducers capacitance. The actual tuning of the input to the center frequency f_0 is done on an H-P Network Analyzer. The preferred method of doing this is to use the polar display and observe the sweep as the inductance of the coil is adjusted. This method immediately determines what the mismatch will be when the line is completed and also gives a measurement of the Q of the input circuit. Figure 10 shows the traces as presented on the Smith chart when the input is tuned. The trace in Figure 10a shows the effect of high finger resistance combined with high series resistance of the coil. This should be compared with Figure 10b in which these spurious values have been reduced.

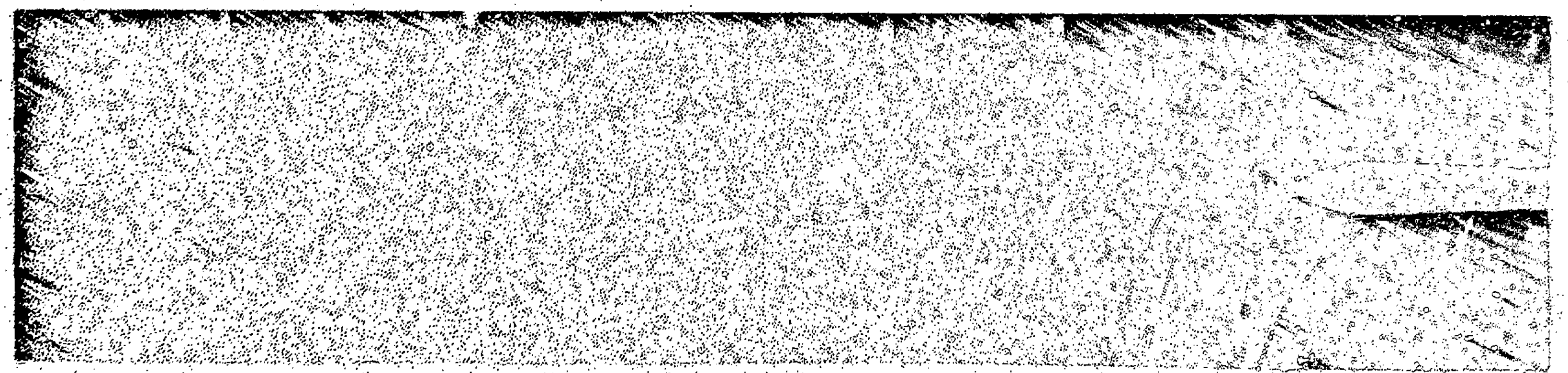
An approximate value of f_0 is obtained by observing the acoustic interaction with the electrical circuit on the Smith chart. This interaction usually shows itself as a group of small circles or little cusps occurring along the smooth curve at the frequency which the line will operate.

Table 3. 31 MHz Tapped Delay Line Parameters

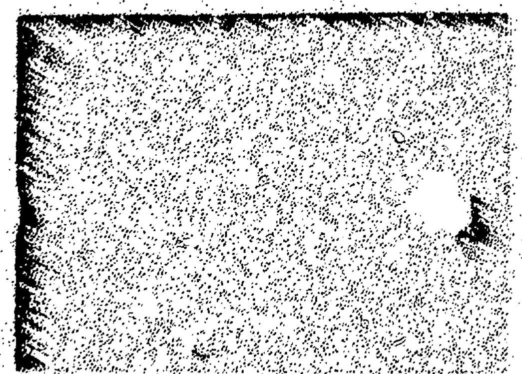
Input Transducer						Tap Ladder						
Line Designation	Metal Thickness A°	C_T (pf)	Length λ's (F.P.)	Length Time (μsec)	Tuning Coil Data	No. of Taps Used	Code Used	Chip Spacing Rate (MHz)	Chip Spacing Time (μ sec)	End to End Taper (dB)	Tap to Tap Variation (dB)	Insertion Loss (dB)
A	1800	1.763	5	0.1609	T25-6 59T, #36	80	All ones	6.21	0.1609	2	-	54
B	1800	1.776	5	0.1609		80	All ones	6.21	0.1609	-	-	-
1	1800	3.079	10	0.321	T25-6 53T, #36	40	$\bar{A}$	3.11	0.321	2	2	55
2	1800	3.188	10	0.321		40	A	3.11	0.321	2	2	-
3	3300	3.25	10	0.321	T25-6 54T, #36	40	A	3.11	0.321	2	2	54
4	3600	3.347	10	0.321		40	$\bar{A}$	3.11	0.321	0.5	0.5	-

Material Used: S-T Quartz, 2 in. long.
Design Frequency: 31.070286 MHz
Mask Design: Length, up to 3+" Quartz
Chip Rate: 0.1609 to 0.804 μsec
Bandwidth: 1.24 — 6.21 MHz
Codes; - Any Bi Phase Code up to 160 Chip Long (0.16 μsec spacing)

Measured Frequencys: 31.085366 MHz
31.072876 MHz



a. DETAILED PICTURE OF TAP LADDER OUTPUT OF ALL1'3LINE (31.07 MHz, 1800A Å)



b. 20 CENTER TAP OF 40 TAP LINE (A_L = 1800Å)

c. 40 TAPS OF 40 TAP LINE, 3 TAPS MISSING (AL = 3300Å)

Figure 9. Output Signal from Tapped Delay Line Encoder

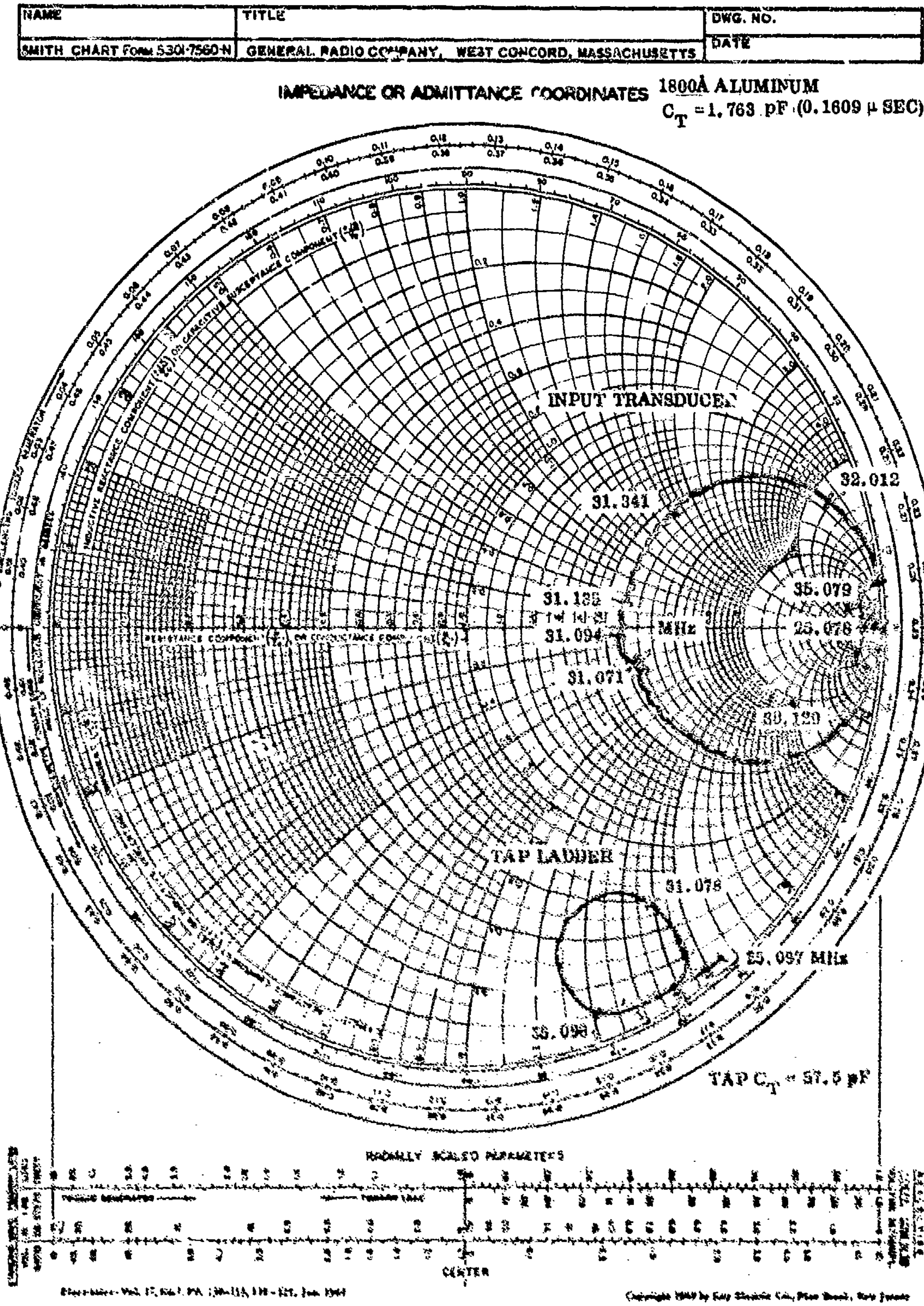


Figure 10. Input Impedance of Tapped Delay Lines

NAME	TITLE	DWG. NO.
SMITH CHART FORM 5301-7560-N	GENERAL RADIO COMPANY, WEST CONCORD, MASSACHUSETTS	DATE

IMPEDANCE OR ADMITTANCE COORDINATES

3600 Å ALUMINUM
C_T = 3.188 pF (0.32 μ SEC)
CODE A

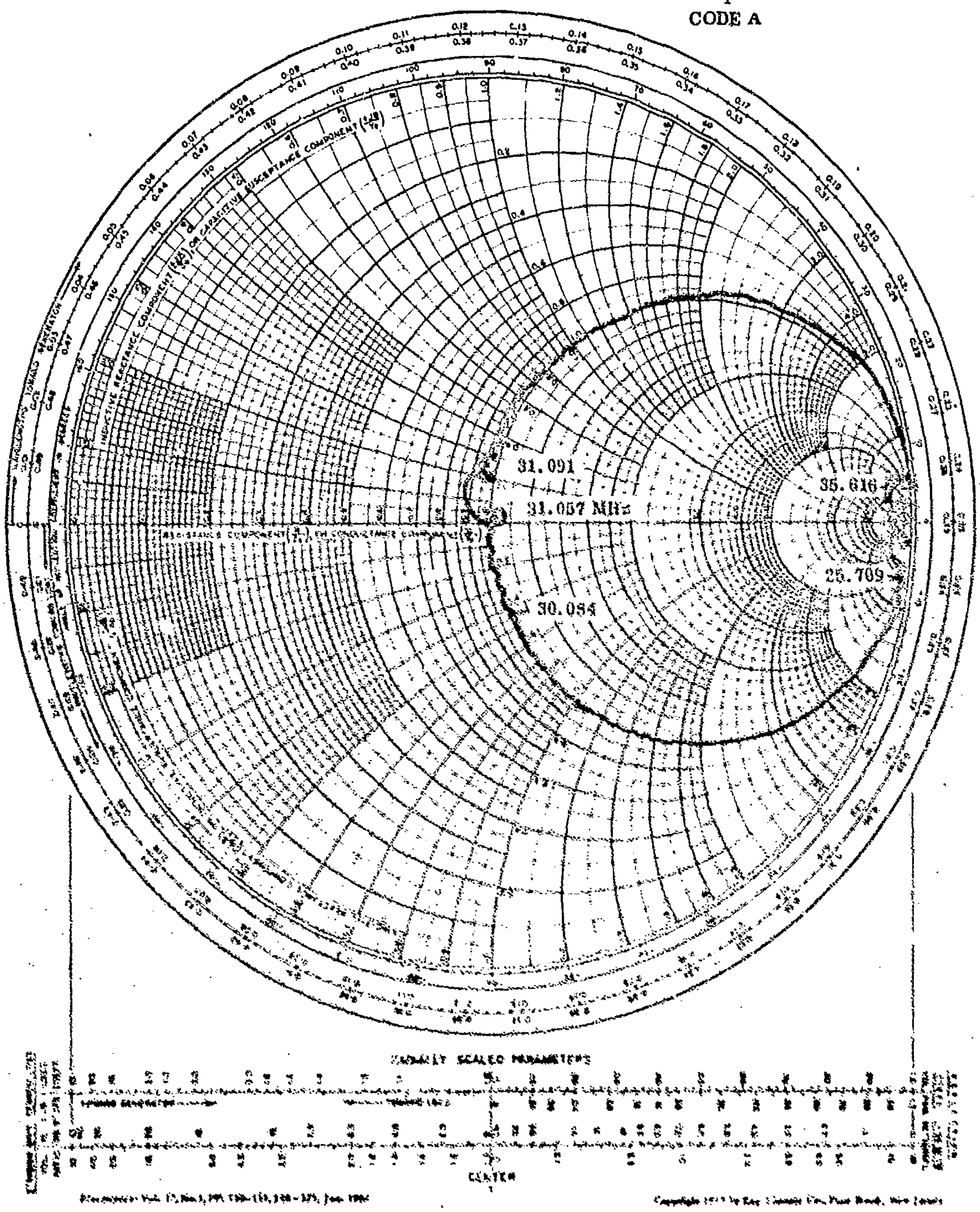
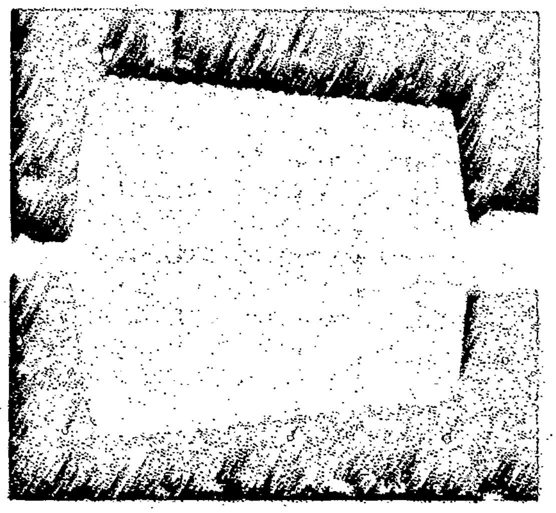


Figure 10. (Cont)

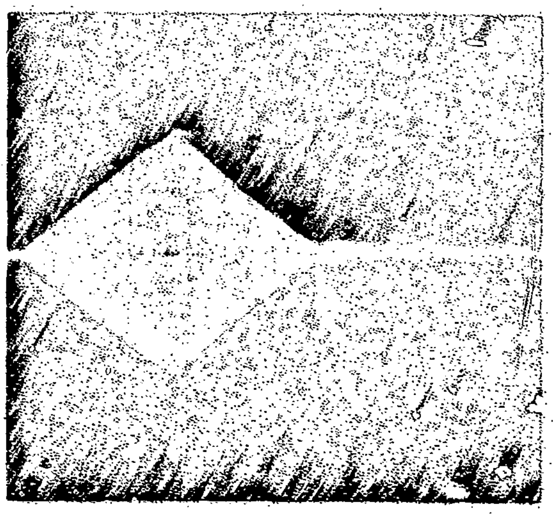
The next step in measurements on the tap lines is to measure the line in the time domain. To do this the frequency of a signal generator is set at the center frequency of the line and its output fed into a switch. This carrier frequency is then gated by a pulse generator whose pulsewidth is set to the time length of the input transducer or the propagation time between taps. In this case the time length of the input transducer for the lines being measured was either 0.160 μsec for the all "1"s coded line, which was used to determine the center frequency of the lines for purposes of checking mask design. The observations of the tap output level give values for the insertion loss to the first tap and the change in loss or taper as the signal progresses down the tap ladder. An example of a measurement taken on the all "1"s line is given in the composite photograph of Figure 11a and 11b. This line is the unit which was used to determine the accuracy of the center frequency of this design. It should be also noted that in photographs of the coded tap line outputs there is a taper from the first tap to the last. This taper was measured and found to be in the order of 2 dB.

In order to measure the frequency of the line accurately a very long pulse is put into the input transducer. A correlation triangle Figure 11b is then formed and by adjusting the signal generator's frequency and measuring the value with a counter the exact frequency of this line's operation can be determined. The photograph in Figure 11b which shows the pyramid-like shape indicates the type of data which allows us to determine this frequency information. The output level of the peak of this triangle below the input pulse level also gives a measure of the expected correlation gain when two lines are used in a normal coded pair configuration. It should also be noted that the taper for the thinner aluminum line (Figure 11a) is greater than that of the heavier aluminum line (Figure 9c). This is caused by resistive losses which are inherent in the pads and in the transducer fingers.

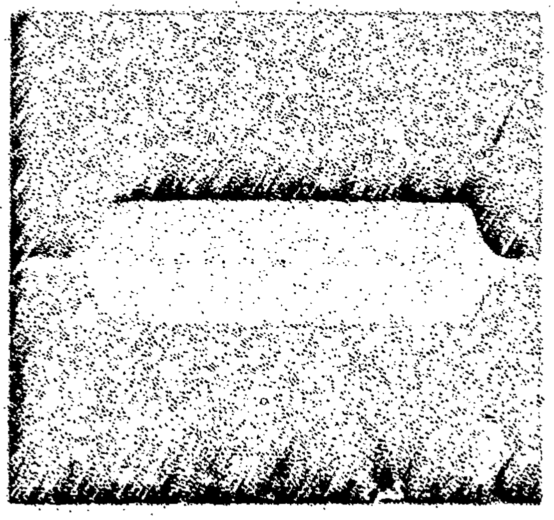
A measurement of the coded lines correlation peak and sidelobes was immediately obtainable by using coded sequence which was generated by a double balanced mixer capable of biphase modulating the 30 MHz signal. This mixer was driven by a Moxon data generator which supplied the biphase pulse sequence to generate the coded waveform at the line's center frequency. This biphase coded RF sequence is normally generated by a second coded line. This method of testing with the data generator allows independent adjustment of the RF carrier frequency and the chip rate of the code sequence. The data generator technique also allowed arbitrary variations of the code by means of its pin programmable words and thereby would allow a determination of how code variations affected the correlation peak and sidelobe levels. Measurements of the correlation peak and sidelobe levels were also made by using two complementary coded lines since this will be the method by which the code will be generated and decoded during the system's test. The photographs of Figure 12a show results of these measurements. In addition to these measurements the units were also tested with their auxiliary input and output amplifiers. This was done to determine whether there would be any detrimental effects when using these amplifiers with the coded lines. It was found much to our surprise that the output taper of the coded lines was reduced to a very small value (≈1/2 dB) when the tapped output of the lines was feeding the μa 733 amplifiers. This effect was not explored in depth but it was suspected that the effect was caused by the higher impedance of the amplifier causing less output loading on the tap ladder.



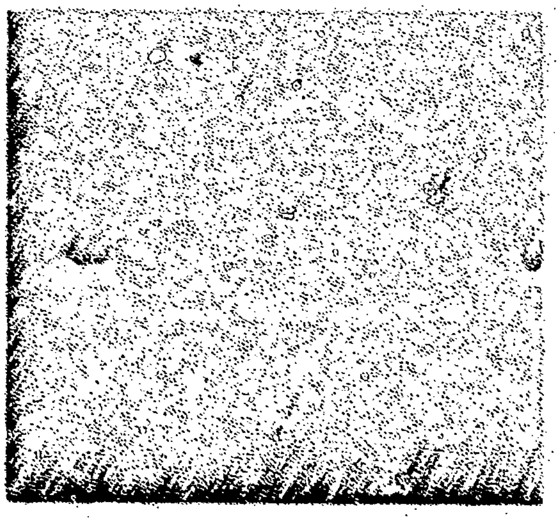
a. TAP LADDER OUTPUT OF ALL "1s" LINE WITH ≈2 dB TAPER (0.1609 μSEC PULSE)



b. OUTPUT OF ALL "1s" LINE WITH LONG (≈12 μSEC) INPUT PULSE

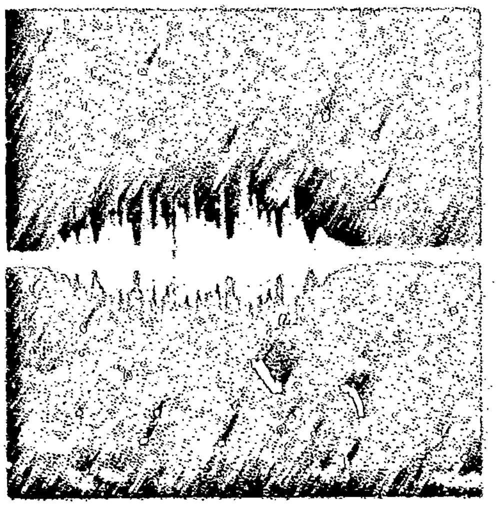


c. DECREASE IN TAP LADDER AMPLITUDE VARIATION WHEN AMPLIFIERS ARE USED (≈ 1/2 DB SLOPE)

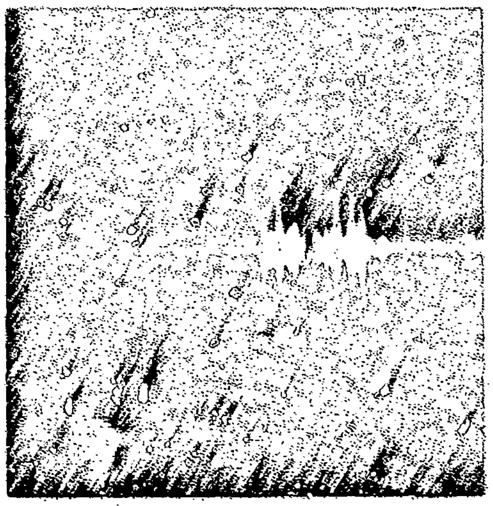


d. OUTPUT SHOWING SATURATION OF INPUT AMPLIFIER

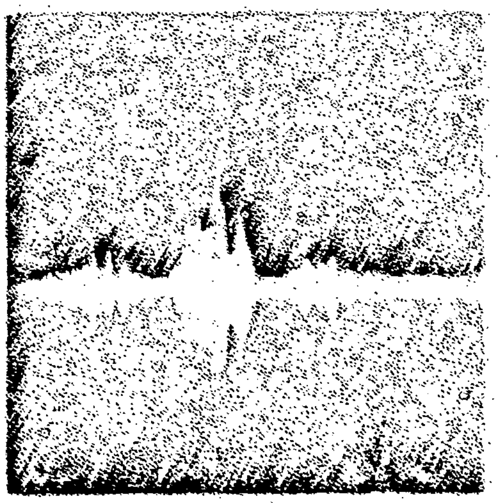
Figure 11. Tap Ladder Output in Time Domain



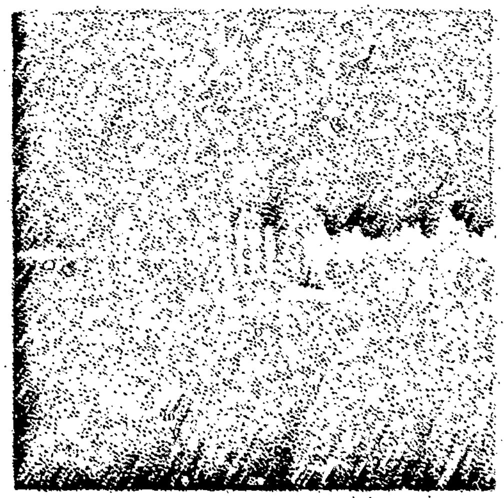
a. CORRELATED OUTPUT PEAK OF TWO 40 TAP CODED LINES, CHIP RATE 0.321 μSEC, FREQ 31.08 MHz AL-1800Å, CODE A&Ā



b. CORRELATION OUTPUT PEAK OF SAME LINE AS IN a. USING ONLY TWENTY (20) TAPS IN CENTER OF LINE.



c. CORRELATION OUTPUT PEAK OF SAME LINE AS IN a. USING TEN TAPS ON EACH END OF BOTH LINES (20 TAPS PER LINE).



d. UNCORRELATED OUTPUT OF LINES USING TEN TAP ON EACH END WORKING WITH THE TWENTY TAPS IN CENTER OF SECOND LINE.

Figure 12. Measurement Results

Data was also taken to determine at what level the amplifiers would saturate and the effects on the line performance. The photograph with the sharp, flat section on the lower half of the trace (Figure 11d) indicates that when the amplifiers are overdriven they saturate in one direction. It should also be noted that the tap output still remains flat to 0.5 dB. The next set of data taken is the information about null shifting which was of much interest because of its application to the new concept. We divided the tap ladders of both lines into groups of five taps. In the first split code experiment we then took two groups of five taps on the far ends of the tapped line and set this up to be used as the encoder. A similar set of taps were connected on the complementary or decoder line. We then observed how these two lines using these tap groups correlated (see Figure 12c). The configuration using the twenty central tap is shown in Figure 12b. After these line pairs were measured in the time domain, the line pairs were measured for their frequency transmission properties on the network analyzer. This was done to determine at what frequencies the nulls occurred. Following this experiment an identical number of taps but now in the center of one line and on the ends of the complementary coded line were connected and their non-correlating properties were observed (Figure 12d), after which data was obtained from these new line configurations on the position of their nulls. From first set of information obtained it was possible to determine how far the nulls shifted for two extreme tap groupings and whether this corresponded with the calculated shift. As one can see from the data (Figure 13) there was a definite shifting in the nulls but the general pattern of response was different than the response originally observed with the 60 mc lines which was an all "1"s configured line. The data does indicate that the nulls can be moved around with respect to a given frequency and that by adjusting the tap groups (by a programmable electronic system) the nulls could be placed over a signal which was to be eliminated.

For a basis of comparison (Figure 12a) is a photograph of two lines correlating when all 40 taps in both lines are functioning.

7. SUMMARY OF DEVICE PERFORMANCE

Preliminary devices were made and the frequencies checked against the desired frequency. The measured frequencies were very close to the design differing by only 14.5 kHz and 2 kHz for the all "1" lines constructed. A slight excess loss in the all "1"s line was observed. Also the line was checked for tap integrity, impedance of the taps and capacitance of the input transducer, all of which fell within reasonable limits of the expected design values. A set of coded lines was then fabricated using a more useful transducer time length (0.320 μsec) and tap ladder configuration. This first set of biphase coded lines worked well showing a definite correlation peak. Some improvement could be obtained however since the evenness of the tap output was not adequate and it was also observed that the sidelobe level in the correlating line pair could be improved upon. Again the losses were slightly larger than the theoretical calculations but this is not unusual since there are a few minor sources of parasitic resistance which are not included in the calculations. In order to determine if the unevenness of the taps could be remedied a second set of lines was made with heavier metalization for the transducers. It was hoped that this heavier metalization would reduce the resistance and allow the tap outputs to be more equalized. While tests progressed on the original set of coded lines the second set was being fabricated. The second set proved to be imperfect in that one of the lines had three taps missing but were more than adequate to show the effect of the metalization. Additional tests showed

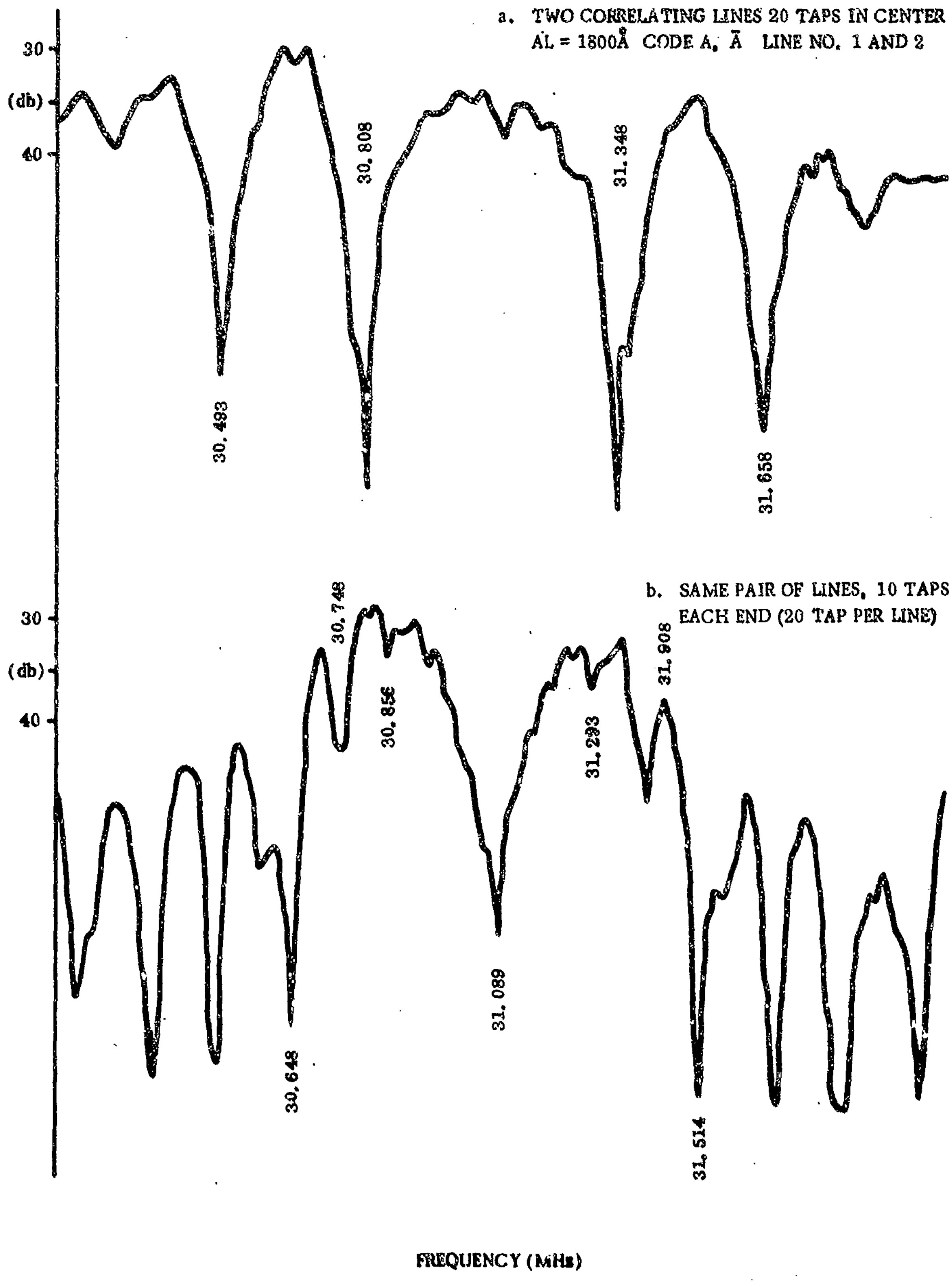


Figure 13. Frequency of Shift and Nulls when Tap Configuration is Changed

that changes in the tap configuration would change the null positions. Each of the correlation gains was identical for all of the configurations when the same number of taps were used. The nulls showed a 'fill-in' which was slightly greater than that expected when the tap configurations were changed. The deterioration of the peak to the sidelobe ratio from that observed with the fully coded lines was not objectionable. In fact it was the same order as that observed in the experiments with the fully coded line pairs.

The auxiliary amplifiers were fabricated and then tested with the tapped lines. Saturation effects were observed at high input signal level. These effects may not be detrimental since it appears that the amplifiers act simply as limiters. Additional tests should be performed in order to determine what phase shift if any is indicated by the saturation effect. A large improvement in tap output taper was quite apparent. The gain of the amplifier pair was more than adequate to make up for the signalloss to the tapped line (approximately 30+dB/amplifier).

Before additional bench tests are performed on the 'follow-on' contract, sets of additional lines should be fabricated. At least one set of the longer 4 in. type of tapped line should be tested so that system tests may be performed with a variety of lines, codes, and line lengths. Additional auxiliary amplifiers should also be available to speed up the comparison tests of the laboratory bench and in system tests when they are performed.

8. IMPLEMENTATION OF TESTS IN SYSTEM

After thorough testing in the laboratory to determine the parameters of the tapped lines and the degree of null shifts the next phase will be to insert the line into a radar system. The test bed system for this project is the APQ-59. It is intended that the tapped line be placed in the circuitry parallel to the dispersive line in the transmit generation section. The present 40 μsec dispersive line can then be compared directly with the tapped line performance. The tapped line would be placed with its auxiliary amplifiers so that its output would go to the sum line IF amplifiers and its data be processed in a manner similar to that of the present dispersive line. Referring to the block diagram Figure 14 one tapped line would be used for encoding the transmitted signal. This line would be driven by short bursts from the systems 30 MHz oscillator in the same manner the dispersive line is now being executed. The control voltage and timing circuits would turn a switch on and off at the PRF rate and allow short bursts to enter the 30 Hz line encoder. The output of the encoder line would then be amplified and mixed with a microwave signal source (f_1) which differed from the transmitter signal by 30 MHz. The two signals would mix yielding the transmitted signal and then pass through a narrow band filter in order to eliminate the other products obtained in the mixing proces At this point the encoded microwave signal is routed to the power amplifiers and out the antenna. Upon returning from the target the signal would be downconverted and amplified and now as an IF signal would be presented to a tapped line decoder which was placed in circuit parallel with the normal dispersive line. When the tapped line is in the circuit it would be possible, either by electronicly programmable taps switching lines with different tap configurations to adjust the tap pattern in both the encode and the decode line. By this switching arrangement it would be possible to shift the nulls over undesired signals such as ground return clutter or main beam clutter. In order to compensate for the Doppler shift an adjustable local oscillator would be provided so that the entire null patterns could be shifted in frequency. In this manner the incoming signal could be transferred along the frequency domain so that the

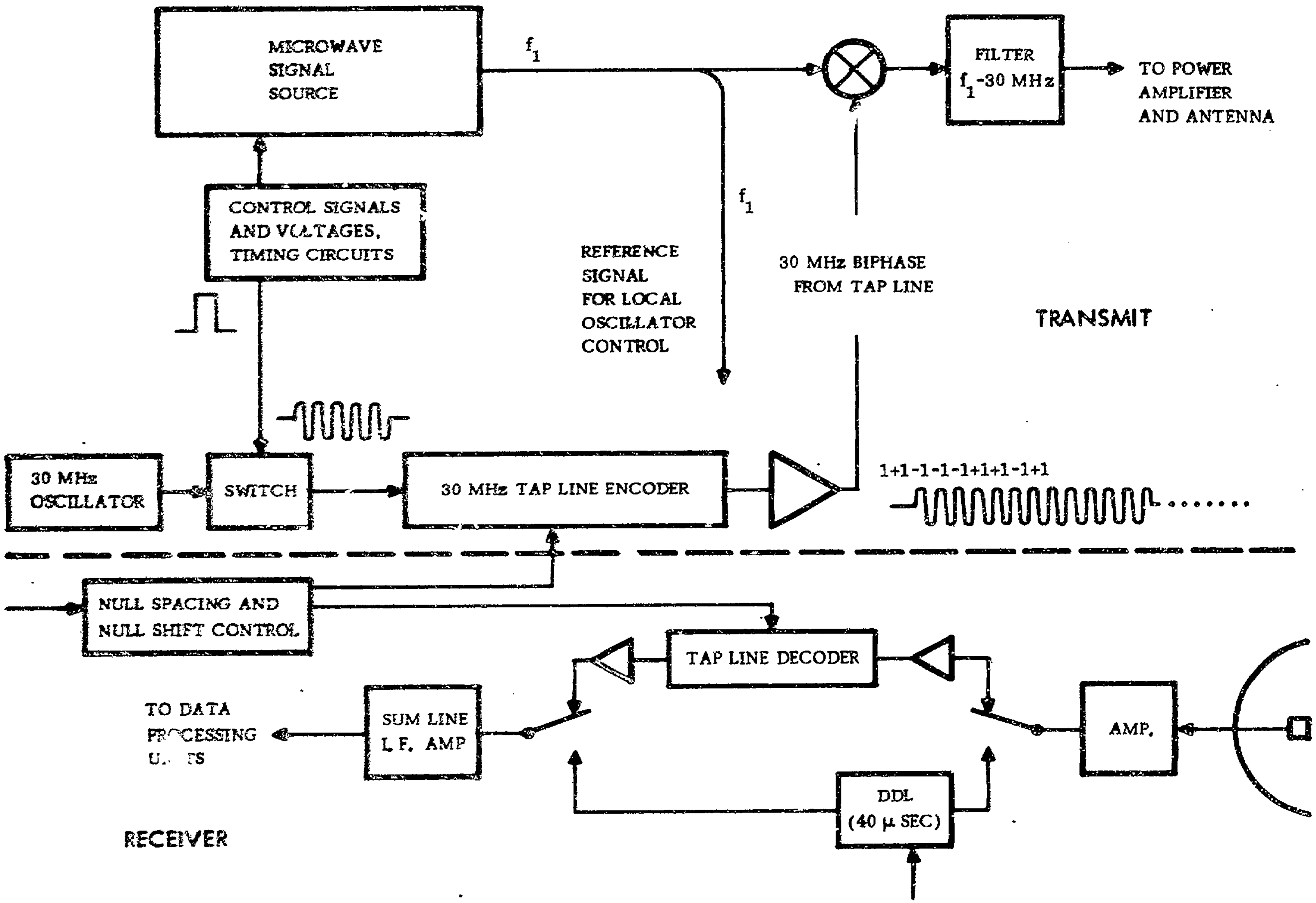


Figure 14. Tapped Delay Line Test Setup

nulls could be placed exactly over the undesired signal. The output of the tapped line decoder ~~would be a sharp spike~~ 0.8 μsec wide. This signal which is similar to the dispersive line output would then be applied to the sum line IF amplifier and subsequently processed in the system. It would be possible to observe at the output of the sum line amplifiers the exact information which was being produced by the tapped line biphase encoding system.

PART II

1. RECOMMENDATIONS AND CONCLUSIONS

Surface acoustic wave devices are capable of solving many radar problems and improving radar performance in areas other than that of analog matched filters. The very fact that the signal can be intercepted, sampled, and modified between input and output opens up the whole signal processing and clutter reduction area.

The results of this program show that the tapped delay line can serve in the dual role of coding signals and provide correlation gain in addition to performing a clutter reduction function if an appropriate selection of taps and tap spacings is chosen. The effectiveness of the device under system operating conditions has yet to be determined through test in a system, thus the following recommendations are made:

1. Test of the present device in a bench test configuration of either an existing system or a mockup of any Doppler system.

2. Development of a programmable structure following the bench tests to provide clutter reduction and coding changes on a pulse to pulse basis.

3. Evaluation of the Fourier analysis clutter reduction approach as well as tapped delay line reflection techniques.

Additional effort should also be applied to the study of "split" and "defective" codes in order to optimize the selection of codes for the tapped lines to be used in the system tests.

PART III

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