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NEW RECEIVING TECHNIQUES

PROGRESS REPORT DURING

JULY 1960-MARCH 1961

[redacted]

This is the ninth in a series of monthly letter reports on a feasibility study to examine the principles and limitations of the frequency time transformation as applied to a self adjusting spectrum filter, together with breadboarding of some critical circuits.

The final report is presently being typed and will be forwarded during the next interval.

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NEW RECEIVING TECHNIQUES
PROGRESS DURING
February 1961

This is the eighth in a series of letter reports on a feasibility study to examine the principles and limitations of the frequency time transformation as applied to a self adjusting spectrum filter, together with breadboarding of some critical circuits.

The last of the breadboard circuits needed to complete the system has been finished. The entire system was assembled, aligned, and compression and dispersion characteristics measured. In addition tests were made of the effectiveness of amplitude shaping for signals of different input frequencies.

In the breadboard system (Figure 1) a 27 Mc input signal is mixed with a 37 Mc swept L.O. producing a 10 Mc swept signal which is fed into the first compressive network. The network output is then mixed successively with a second 37 Mc swept L.O. and a 53 Mc crystal oscillator to produce the 6 Mc compressed output. The dispersion process begins with mixing the 6 Mc output with the second 37 Mc swept L.O. and inverting with a 33 Mc crystal oscillator to produce the 10 Mc input to the second compressive filter. The output of this filter constitutes the dispersed waveform. Actually a third swept L.O. should follow this filter output to produce a signal equivalent to the input. Since this mixing would have no effect on the output amplitude it was not included.

The reason for mixing the compressed output with a second swept L.O. and then inverting the process by mixing again with the same L.O. may not be readily apparent. This was done to allow the insertion of an amplitude shaping network between the two mixers. If two input signals enter the compression system they produce similar swept sin x/x outputs differing only in time of occurrence and center frequency. If an amplitude shaping network is designed to effectively suppress the sidelobes of one signal it must have a frequency response centered at that frequency. Therefore it could not effectively suppress the sidelobes of one signal it must have a frequency response centered at that frequency. Therefore it could not effectively suppress the sidelobes of the second signal. If a second L.O. is placed before the shaping network, synchronized with the the first sweep and delayed from it by a time equal to the average delay through the compressive filter, the center frequencies of different sin x/x pulses will be the same. Thus the amplitude shaping network will suppress sidelobes on all signals entering the system. The second mixing process is then necessary to restore the frequency dependence of the compressed outputs before beginning the dispersion process.

The 53 Mc and 33 Mc crystal oscillators are used to invert the compressed output before dispersion. Normally the network used to disperse the compressed waveform would have a slope equal and opposite to the slope of the compressive network. Since both our networks are identical, the same effect is obtained using the inversion process. This reverses the frequency spectrum of the compressed waveform and causes it to be dispersed in the second network.

Tests of both compression and dispersion were made with three different input frequencies. Figures 2, 3, and 4 show the compressed outputs for inputs of 26.5, 27.0 and 27.5 Mc. Figures 5, 6 and 7 show the same outputs with sin x/x shaping added. Figures 8, 9 and 10 are the outputs of the dispersive filter. These photos show there is a great dependence upon the frequency of the input signal to sidelobe level, with and without shaping. These differences can only be attributed to variations in the time delay characteristic. However, the shaping network gives noticeable improvement of sidelobe level over most of the frequency band. Output after the dispersive network shows considerable amplitude variation over the sweep period which is also dependent upon the input frequency. Both phase and amplitude variations can cause this result. The amplitude response of the two networks can only be compensated within 6 db due to erratic variations of their amplitude response with frequency. These amplitude variations are seen directly in the output. In addition, phase errors in the system cause peaks and nulls in the recombined output.

This completes the major breadboard portion of the study project. There are a few items of doubtful importance which may receive some attention, but it is anticipated that the main effort from now on will be in assembling the data and writing a final report.

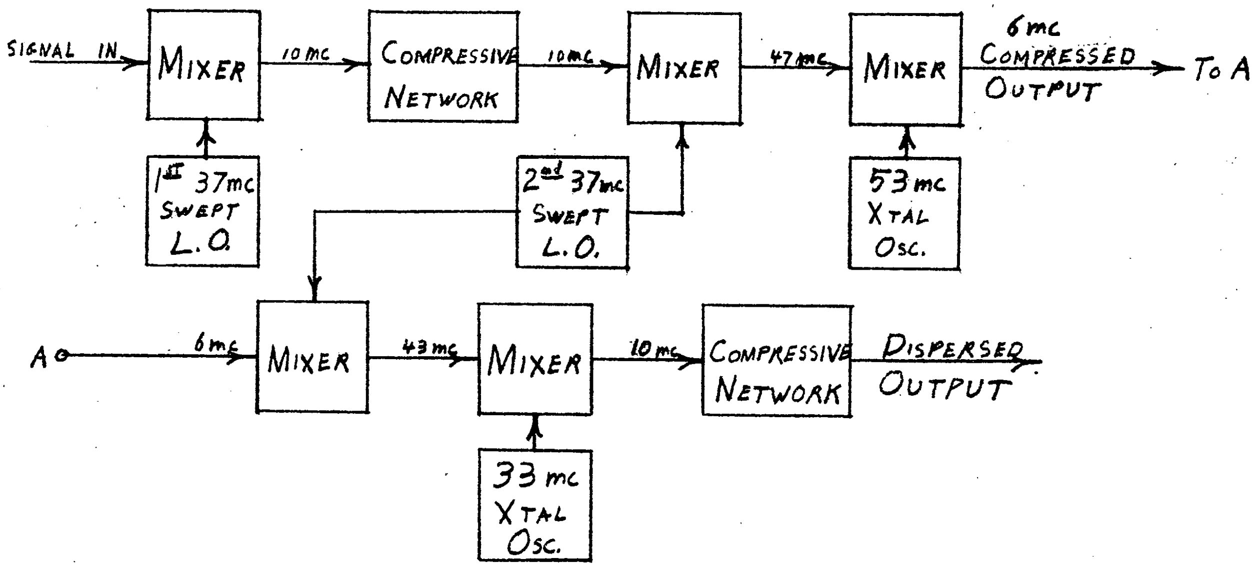

SIGNAL IN
MIXER
10 mc
COMPRESSIVE NETWORK
10 mc
MIXER
47 mc
MIXER
6 mc COMPRESSED OUTPUT
To A
1st 37mc SWEPT L.O.
2nd 37mc SWEPT L.O.
53 mc XTAL OSC.
A
6 mc
MIXER
43 mc
MIXER
10 mc
COMPRESSIVE NETWORK
DISPERSED OUTPUT
33 mc XTAL OSC.

FIGURE 1

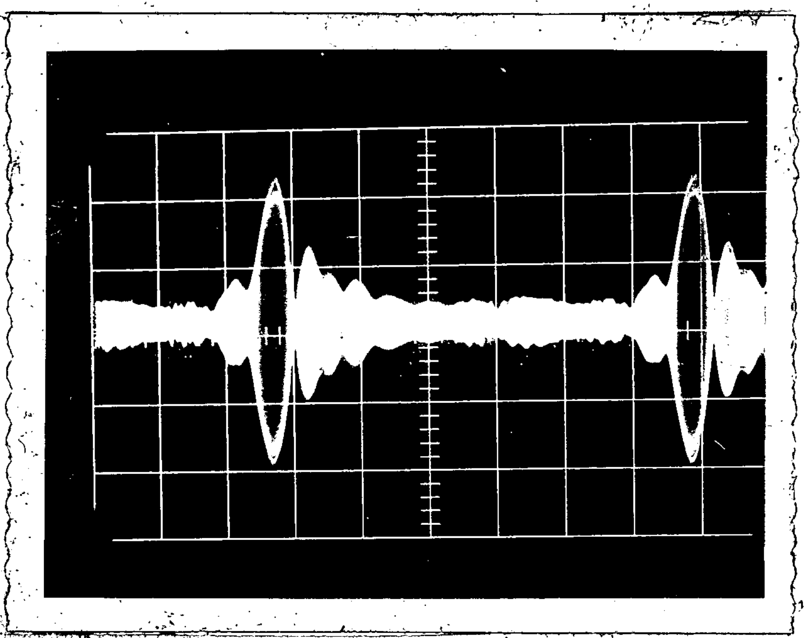


FIGURE 2

26.5 Mc

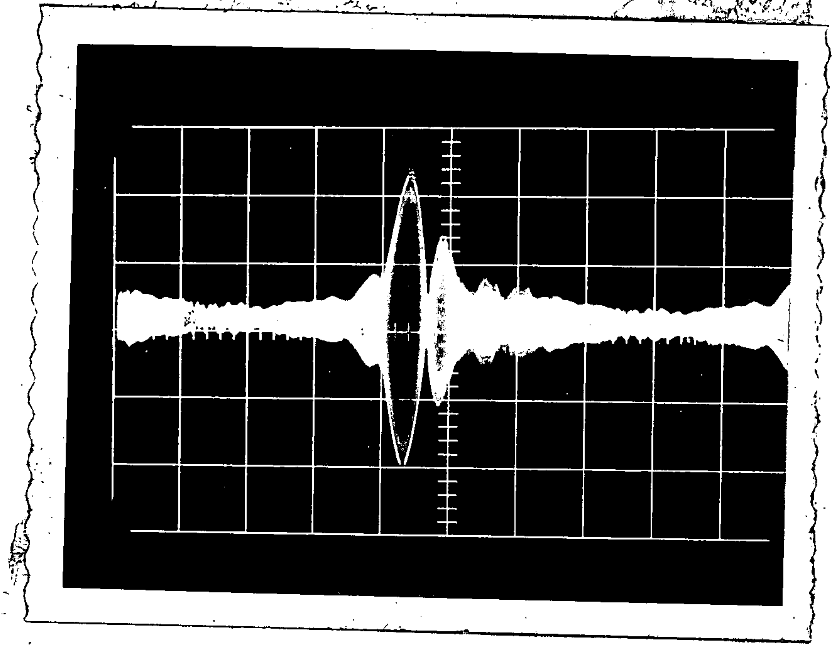


FIGURE 3

27.0 Mc

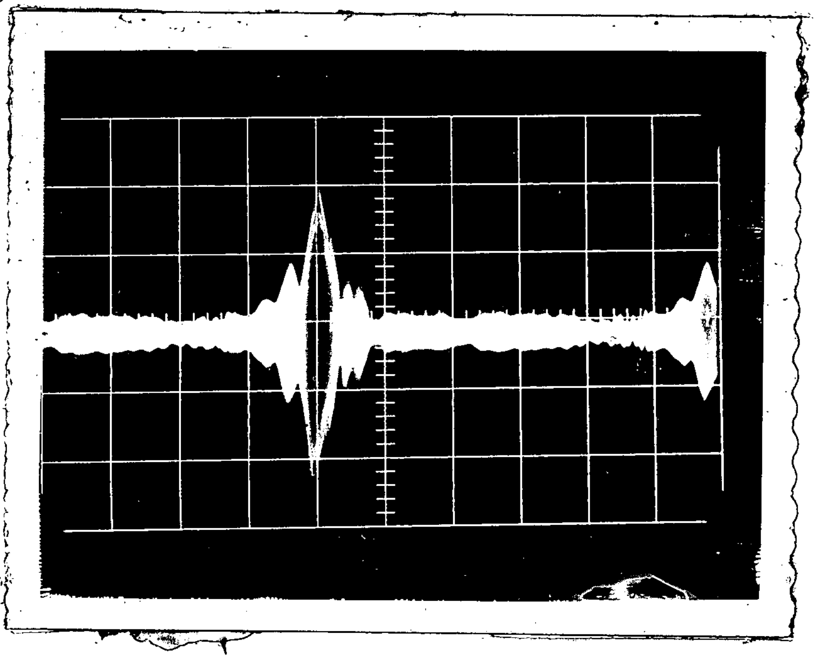


FIGURE 4

27.5 Mc

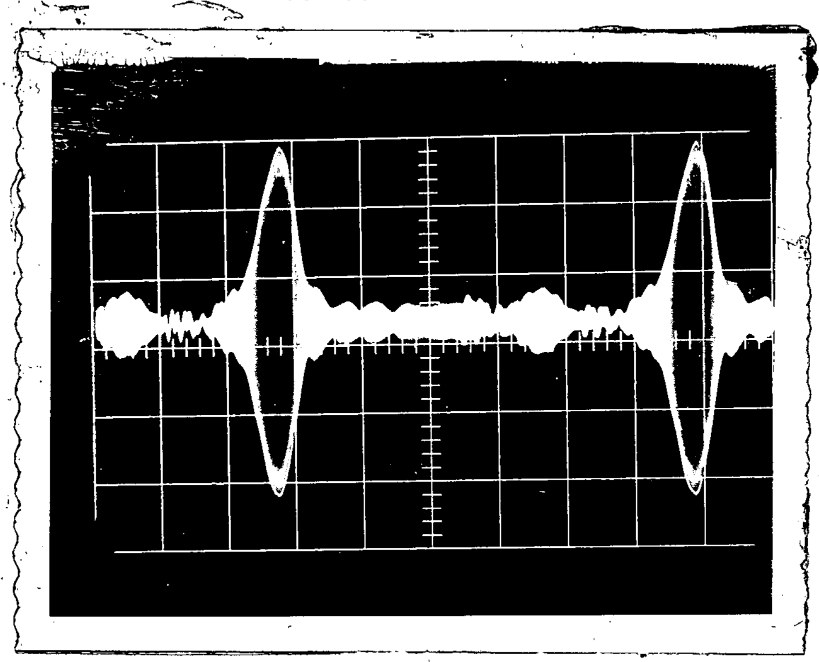
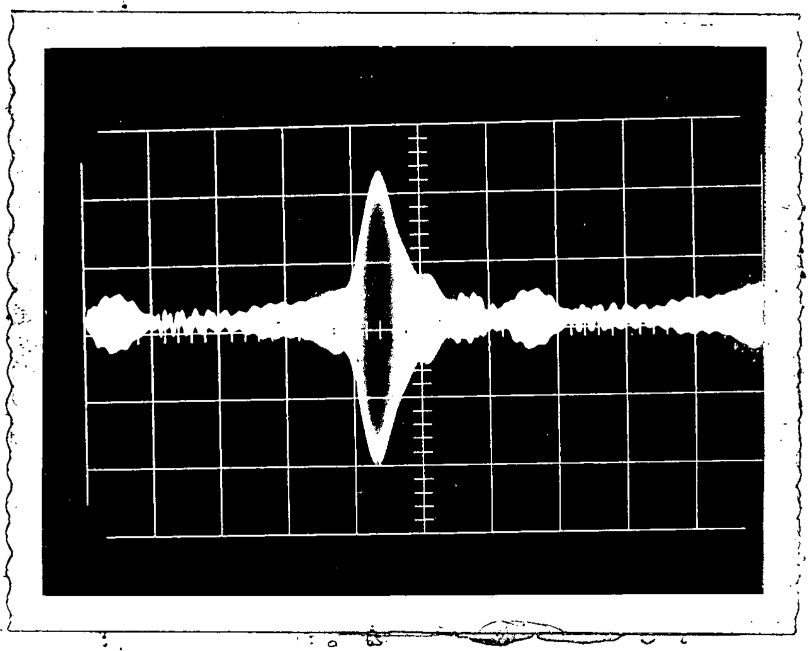


FIGURE 5

26.5 Mc

FIGURE 6

27.0 Mc



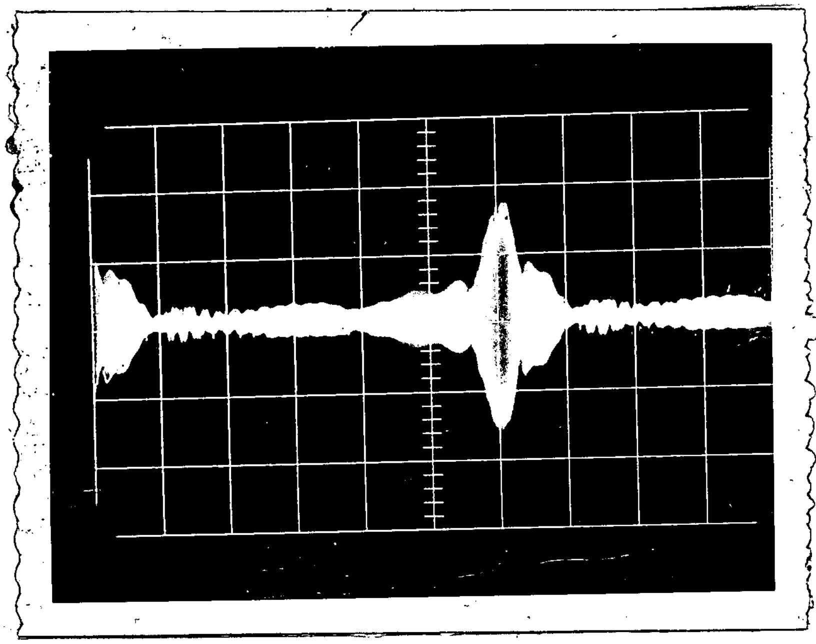


FIGURE 7

27.5 Mc

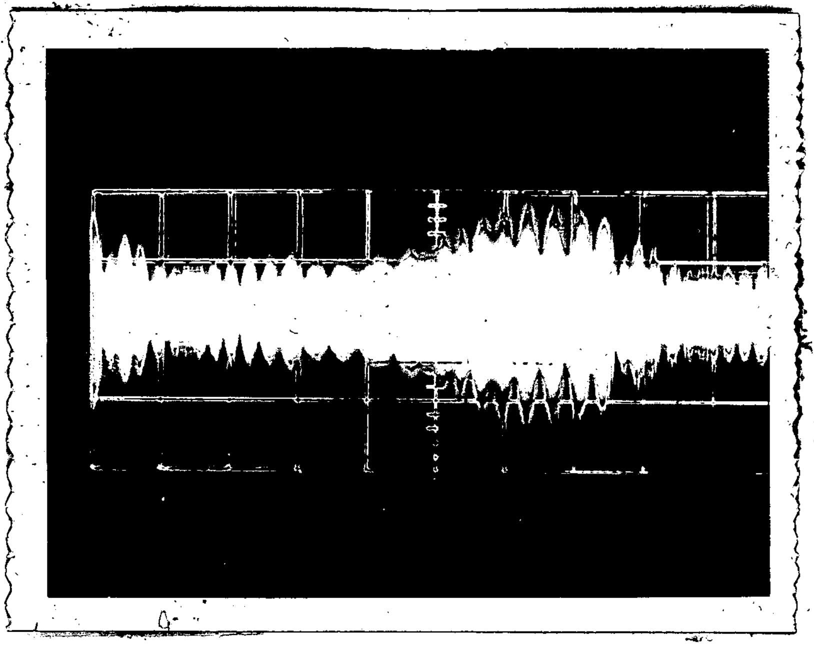


FIGURE 8

26.5 Mc

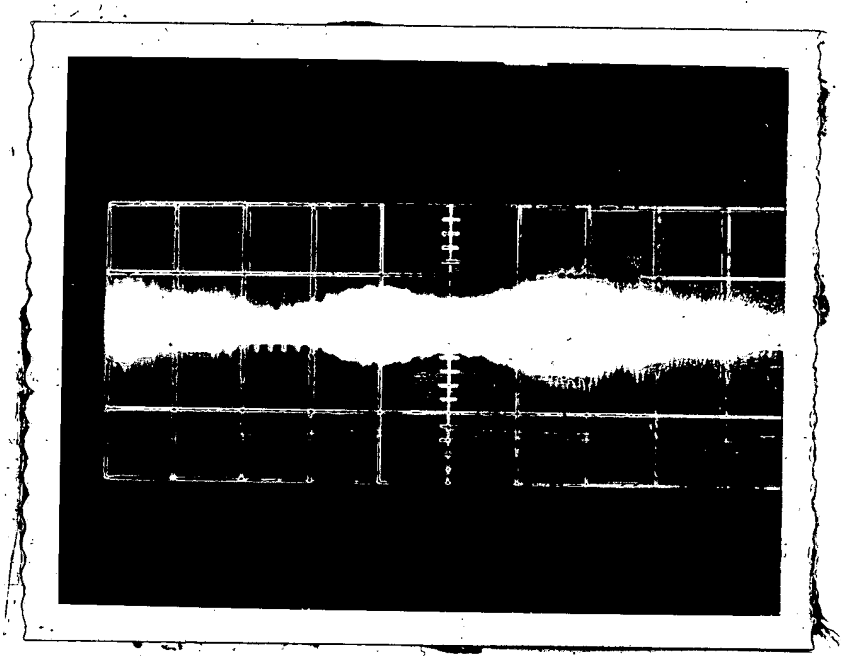


FIGURE 9

27.0 Mc

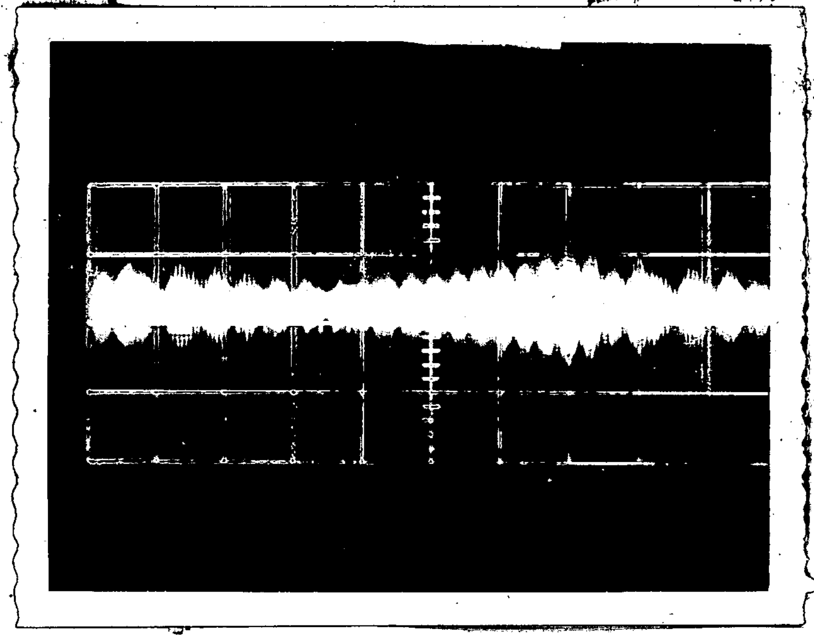


FIGURE 10

27.5 Mc

NEW RECEIVING TECHNIQUES
PROGRESS DURING
January 1961

This is the seventh in a series of letter reports on a feasibility study to examine the principles and limitations of the frequency time transformation as applied to a self adjusting spectrum filter, together with breadboarding of some critical circuits.

This last month has seen the completion and testing of the second compressive network, continuation of efforts to complete the system, addition of a more linear sweep drive, and positive results from the computer effort to analyze the effect of time delay errors in the system.

The second network was completed using great care to reduce all errors in alignment. Leads were shortened to minimize stray inductance. Where lead length had to be appreciable (up to 2 inches), low inductance copper strips were used to make connections. In tuning resonant circuits, a frequency counter continuously monitored the input frequency to insure a proper setting. The resultant network was then tested using the same method previously used to measure the phase response of the first network; measuring the frequency difference between successive nulls of the arithmetic difference between input and output. The first network response was then measured again. The resultant time delay curves are shown in graphs 1 and 2. Despite all the cares taken in building the second network the magnitude of the time delay errors of both networks is about the same. Also, the slopes and linear ranges are remarkably equal.

Work has continued to complete the system. At present just a few small chassis are needed in addition to the present set-up.

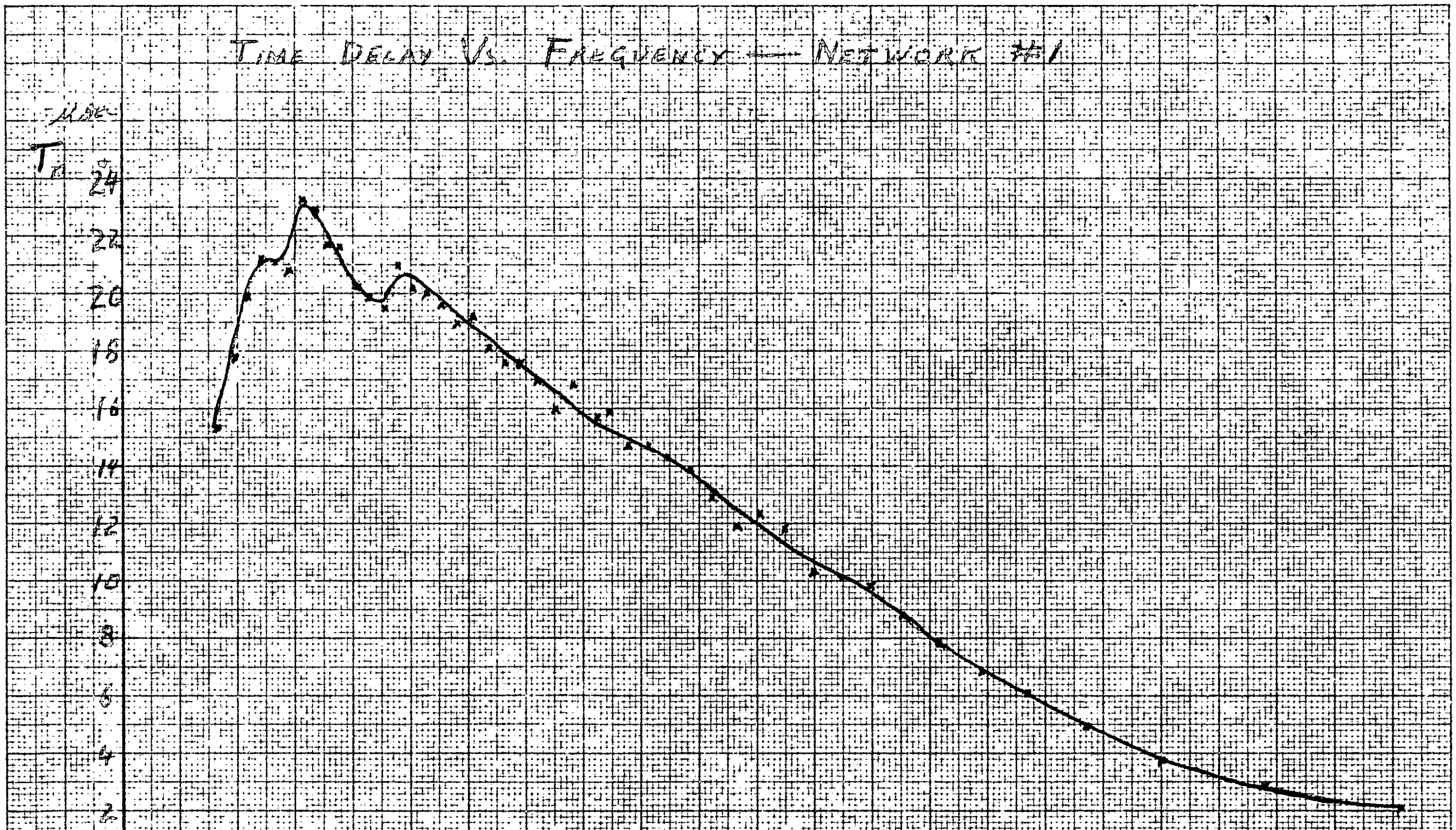
The linear slope generator used to drive the swept oscillators were rewired to provide a delayed inverse sweep voltage. In addition the slope linearity was improved and the flyback time was reduced to one usec.

In the computer department, an analytic solution has been found which predicts the difference between the observed output and a sin x/x waveshape due to errors in the system phase response. First, by minimizing mean square error, a "best fit" linear time delay curve was found from the experimental data. The phase error, $\Delta \varphi$, was then approximated by the function,

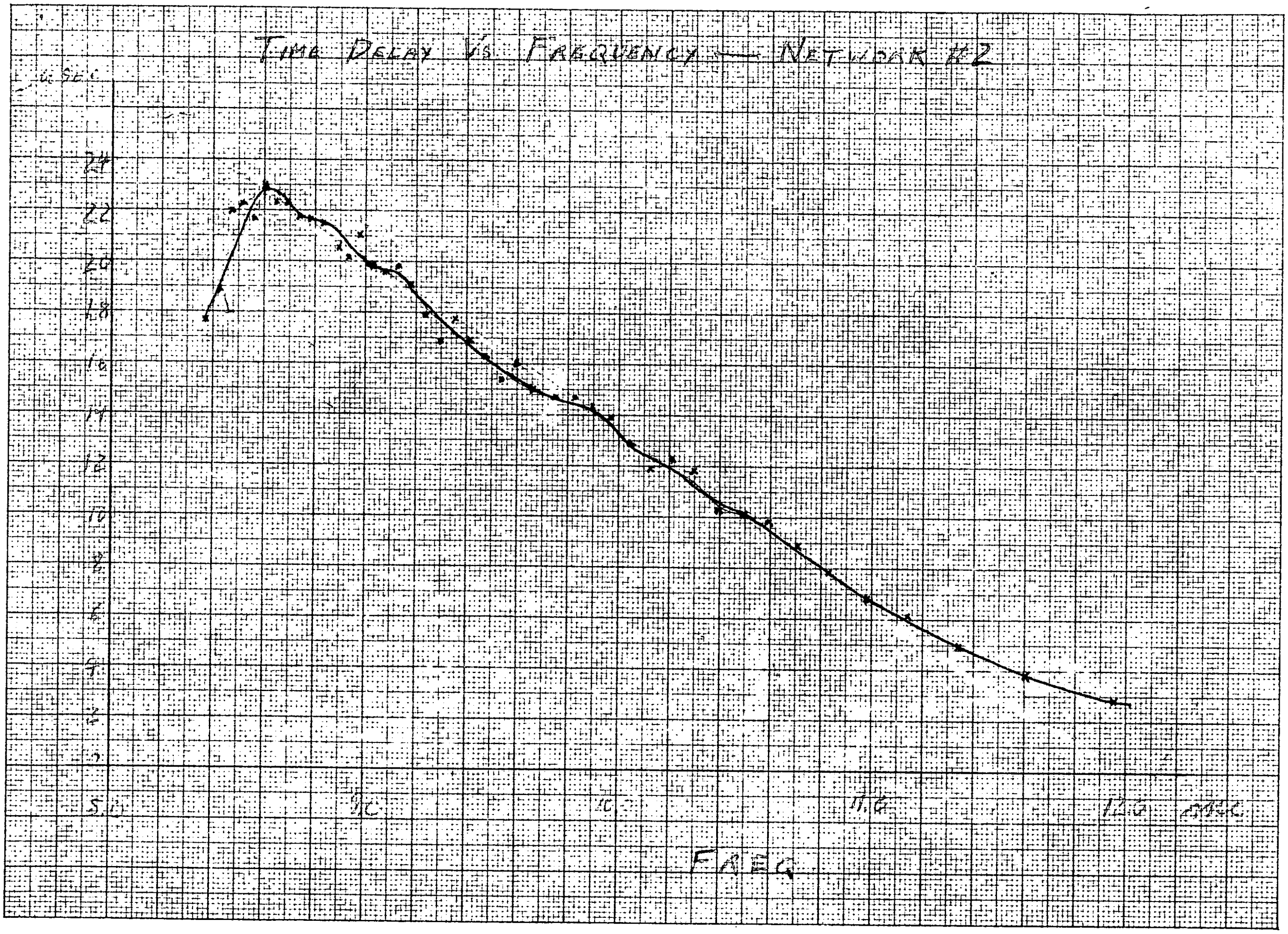
$$\Delta \varphi = 90^\circ \frac{Y}{(1+Y^2)^2}$$

Y is a dummy variable proportional to frequency. The computer was then programmed to find the output with this phase distortion. A comparison of the computed output to a sin x/x is shown in graph 3. The width of the main lobe is essentially the same, but the output is skewed and the largest slidelobe is 10 db below the maximum output instead of 13 db in the sin x/x. A photograph of the experimentally observed output is included to compare with the computer results.

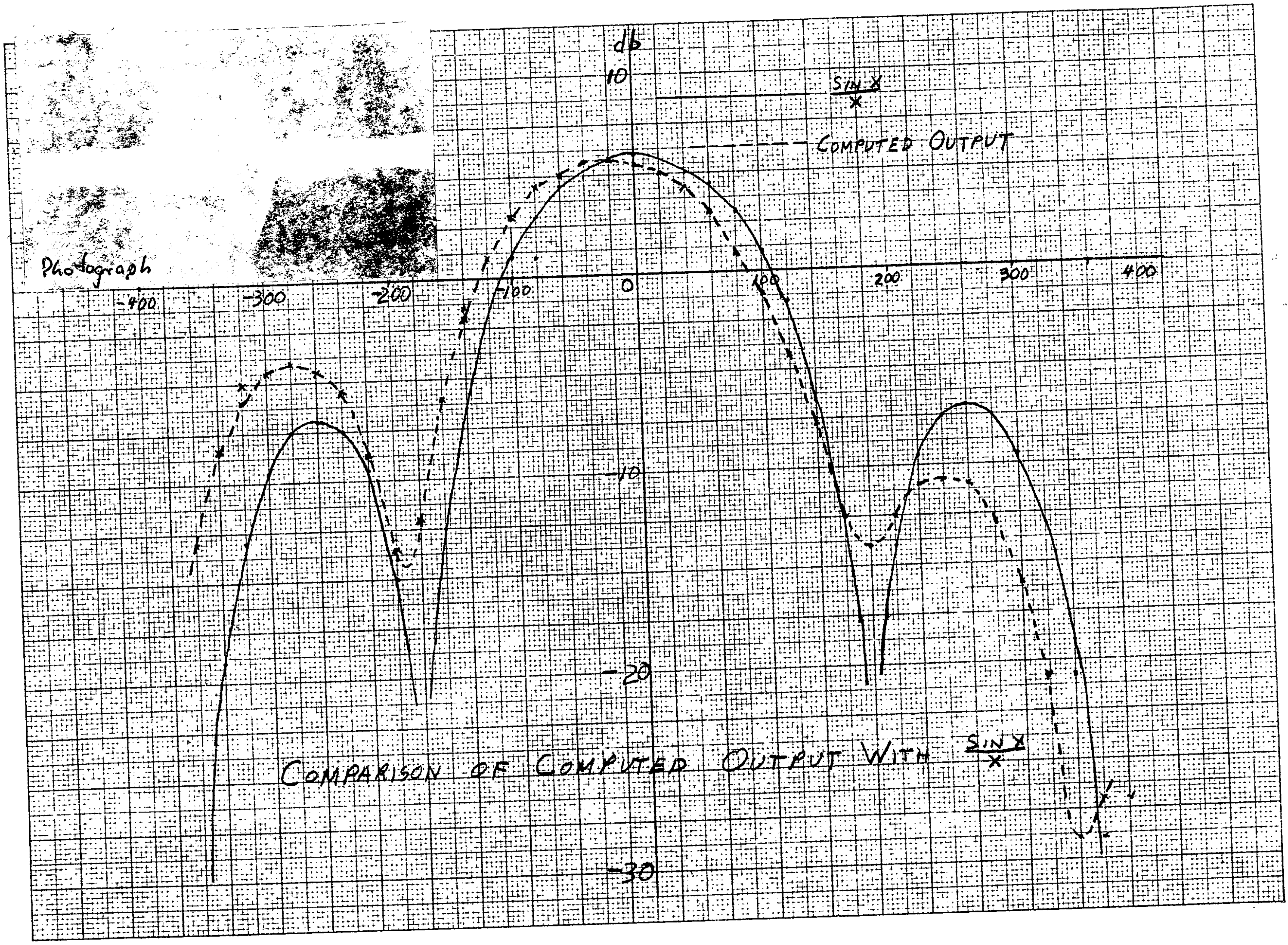
During the next month the system should be completed and tests on it begun. In addition some more effort in amplitude shaping to reduce sidelobes is expected.



TIME DELAY VS. FREQUENCY — NETWORK #1



TIME DELAY VS FREQUENCY — NETWORK #2


Photograph
db
10
SIN X
X
COMPUTED OUTPUT
-400
-300
-200
-100
0
100
200
300
400
-10
-20
-30
COMPARISON OF COMPUTED OUTPUT WITH SIN X
X

NEW RECEIVING TECHNIQUES

PROGRESS DURING DECEMBER 1960

This is the sixth in a series of letter reports on a feasibility study to examine the principles and limitations of the frequency-time transformation as applied to a self adjusting spectrum filter, together with breadboarding of some critical circuits.

Construction of a second compressive network which when added to the present system, will complete the cycle of frequency to time to frequency transformation is underway.

This second filter is similar to and interchangeable with the first network although it will be used to produce dispersion because of the inverse sweep applied to it. The difference is the care and precision used in making the toroidal coils and in alignment of the filter sections. For the first filter, the Q meters used for measuring the inductors were found to have errors of 3 to 4% and inductance values were found to vary as much as 2% after Q doping. For the second filter toriods were adjusted on an accurate Wayne-Kerr bridge at the frequency at which they are to resonate in the completed filter. These inductors were Q doped, allowed to set, and then readjusted to the proper value. With this technique inductance values are in error by less than ± 1% of their theoretical value.

It is thought that the linearity of delay will be improved compared to the first filter. This fact will be checked experimentally.

To investigate the use of linear time delay networks over wide bandwidths a quadruplet section was built at 200 Mc with a linear time delay range of 50 Mc and a time-delay-bandwidth product of 20. This section was built in a volume approximately 1/7 of the value used in the compressive network at 10 Mc in line with the idea of miniaturization. At this frequency it was found that the small volume had a marked effect on the insertion loss. This was due to the lowering of the Q of the reactors by the proximity of the case and to the detuning effect introduced by small changes in physical layout. With the available components it was found that the maximum insertion loss of the section was 10 db. Such a large loss per section would adversely affect the delay linearity and would require the use of complex amplitude compensation networks. Lump circuit techniques are not recommended for compression at 200 Mc.

Analysis of the effect of non-linearities present in the compression system, by using computer techniques, has been found to be more involved than previously thought. A power series approximation to the time delay curve does not give a good fit to the measured data. A new approach is needed if any useful results are to be obtained.

PROGRAM FOR NEXT INTERVAL

Future efforts involve further investigation of the feasibility of building a miniaturized linear time delay network, the testing of the second filter, a breadboard system, and further use of pulse shaping for effective sidelobe reduction.

NEW RECEIVING TECHNIQUES

PROGRESS DURING NOVEMBER 1960

This is the fifth in a series of letter reports on a feasibility study to examine the principles and limitations of the frequency-time transformation as applied to a self adjusting spectrum filter, together with breadboarding of some critical circuits.

Effort has been concentrated this month on improvements to the present compressive system and to looking at possible use of this technique in noise analysis. In addition there has been further analysis of the time delay linearity and its effects upon compression and side-lobe level.

Main improvement in the present system has occurred with the addition of pulse shaping. Two general types have been approximated; first, Gaussian and second, sin x/x. These were chosen because the Gaussian is a close approximation to the minimum side-lobe Dolph-Tchebycheff characteristic, and the sin x/x in the limit produces an ideal square pulse. Both were found to effectively reduce side-lobes.

The sin x/x shaping was approximated by a three section filter having a single tuned passband with a frequency reject on each side of the passband. Side-lobe suppression was found to be greatly dependent upon the distance between the reject bands with maximum suppression occurring when this distance was approximately equal to the oscillator sweep. The Gaussian response was approximated with a four pole Bessel filter. In general all side-lobes were reduced with this filter while the sin x/x had its greatest effect upon the side-lobes near the main pulse.

The compression characteristics of the network were measured using the test set up shown in Figure 1. The sweep width of the L.O. was adjusted for different values of compression. It was found that the ratio of actual to theoretical compression was approximately 1.0 at low values of compression. This ratio slowly decreased, until at maximum theoretical compression of 48 it was 0.67. (See Graph #1). The ratio of main lobe to first side-lobe was measured in the same set up. This quantity varied between 8 db and 10.4 db compared to a theoretical value of 13.4 db (see Graph #2).

In the noise analysis problem preliminary design has begun on a system with a 20 Kc bandwidth and 100 cps resolution using a center frequency of 100 Kc. The filter would have 28 Kc linear bandwidth and a maximum theoretical compression of 392. With quadruplets as the basic section, the network would consist of 500 all pass sections. Element values have been tabulated (Table 1) and seem to be easily realizable. The basic all pass section is shown in Figure 2.

The main concern with the above system is whether the desired linearity can be maintained to achieve the high compression required. In order to give assurance of the desired compression, a technique of splitting the compression between two filters has been given consideration. This method uses networks of equal bandwidth and compression, but with the center frequencies staggered to cover twice the bandwidth. The output of one of the compression networks is sent through a delay line and then is summed with the output of the second network. (See Figure 3). Effectively, both differential time delay and bandwidth are doubled giving a compression four times that of a single filter.

Additional analysis of the phase response measurements of the compressive network has resulted in more accurate determination of the differential time delay. It was found that greatest error in linearity occurs between 8.6 and 9.2 Mc where the maximum deviation amounts to 5%. Over the remainder of the band, 9.2 to 11.4 Mc, the linearity is within 1%.

An attempt is being made to determine the effect of non-linearities on the system. A preliminary analysis assuming uniform step changes in time delay over the frequency band has determined that the compression is not greatly effected, but that the side-lobe level increases appreciably with decreased linearity. At present we are investigating computer techniques to determine the actual effect of the measured time delay upon the output.

The noise analysis capability of the system has been retested. Using the same test set up as shown in last months report, pictures were taken for equal power densities of the wide band and narrow band inputs. As seen in the two photographs (Figures 4 and 5) the narrow band noise is discernible only after passing through the compressive filter.

PROGRAM FOR NEXT INTERVAL

Detail study of the principles and limitations of the network will continue. An investigation will be made as to the extent to which the size of the compressive network can be reduced without sacrificing any performance characteristics.

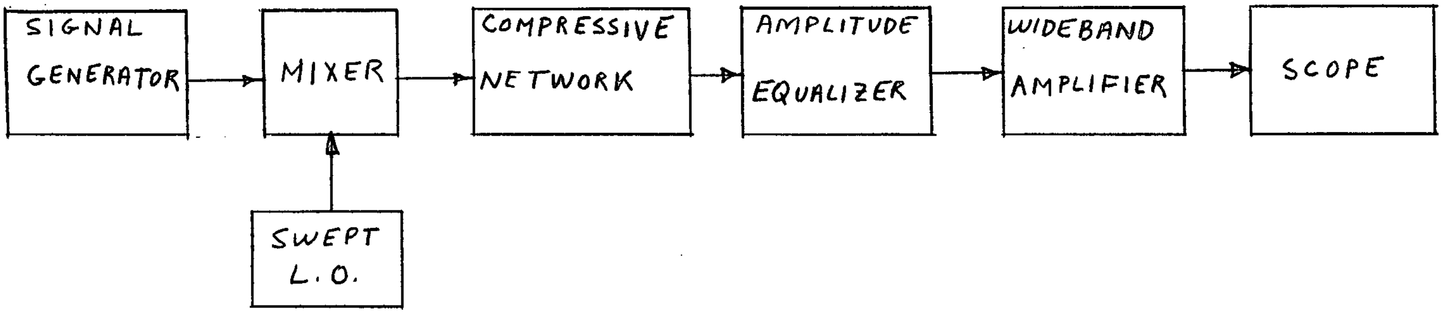


FIGURE 1.- TEST SET-UP FOR COMPRESSION MEASUREMENTS.

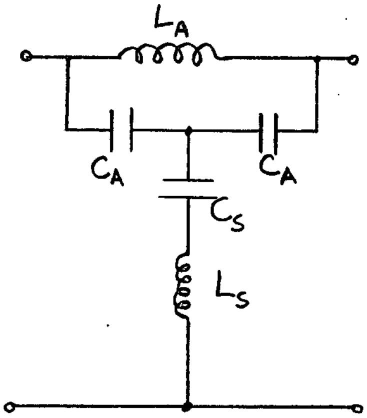


FIGURE 2.- BASIC ALL-PASS SECTION

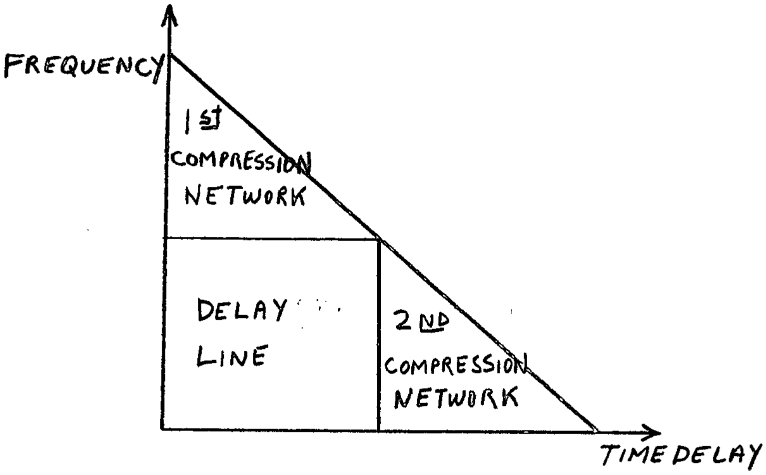


FIGURE 3.- METHOD OF COMBINING TWO COMPRESSIVE NETWORKS

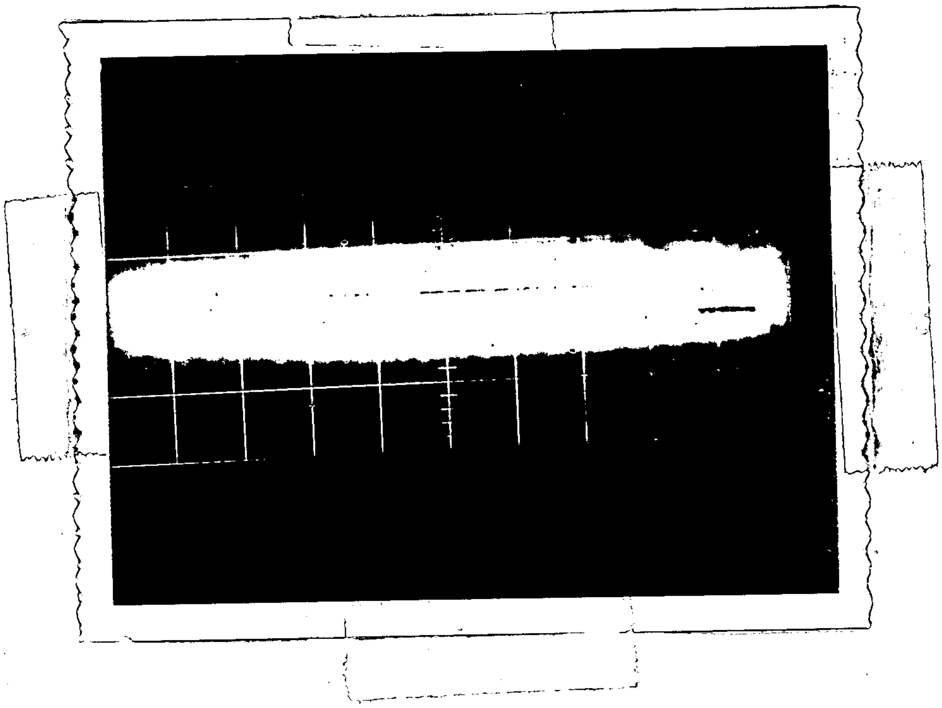


FIGURE 4 - Equal power density wide band and narrow band noise input.

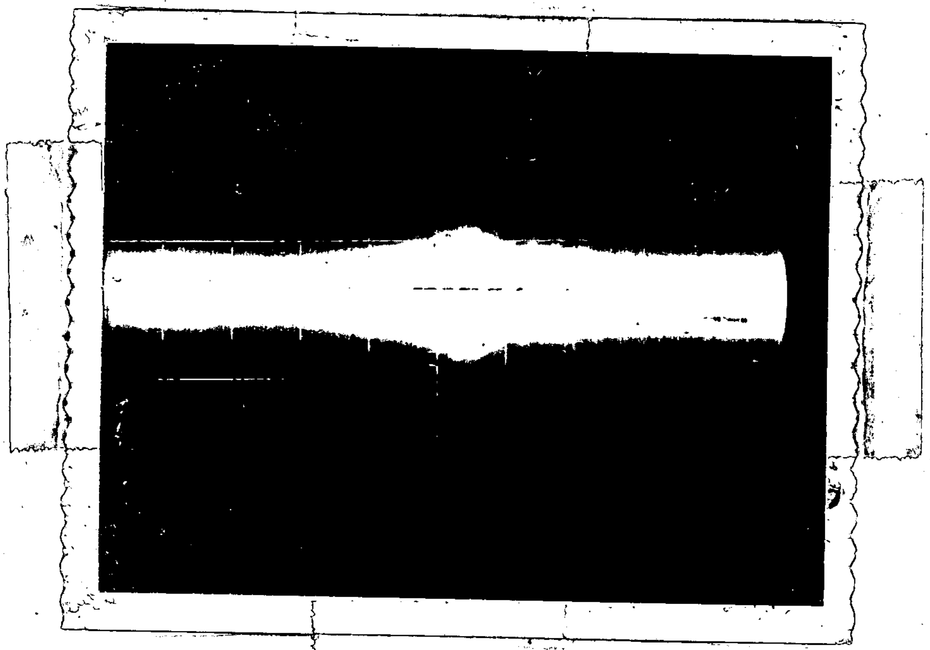
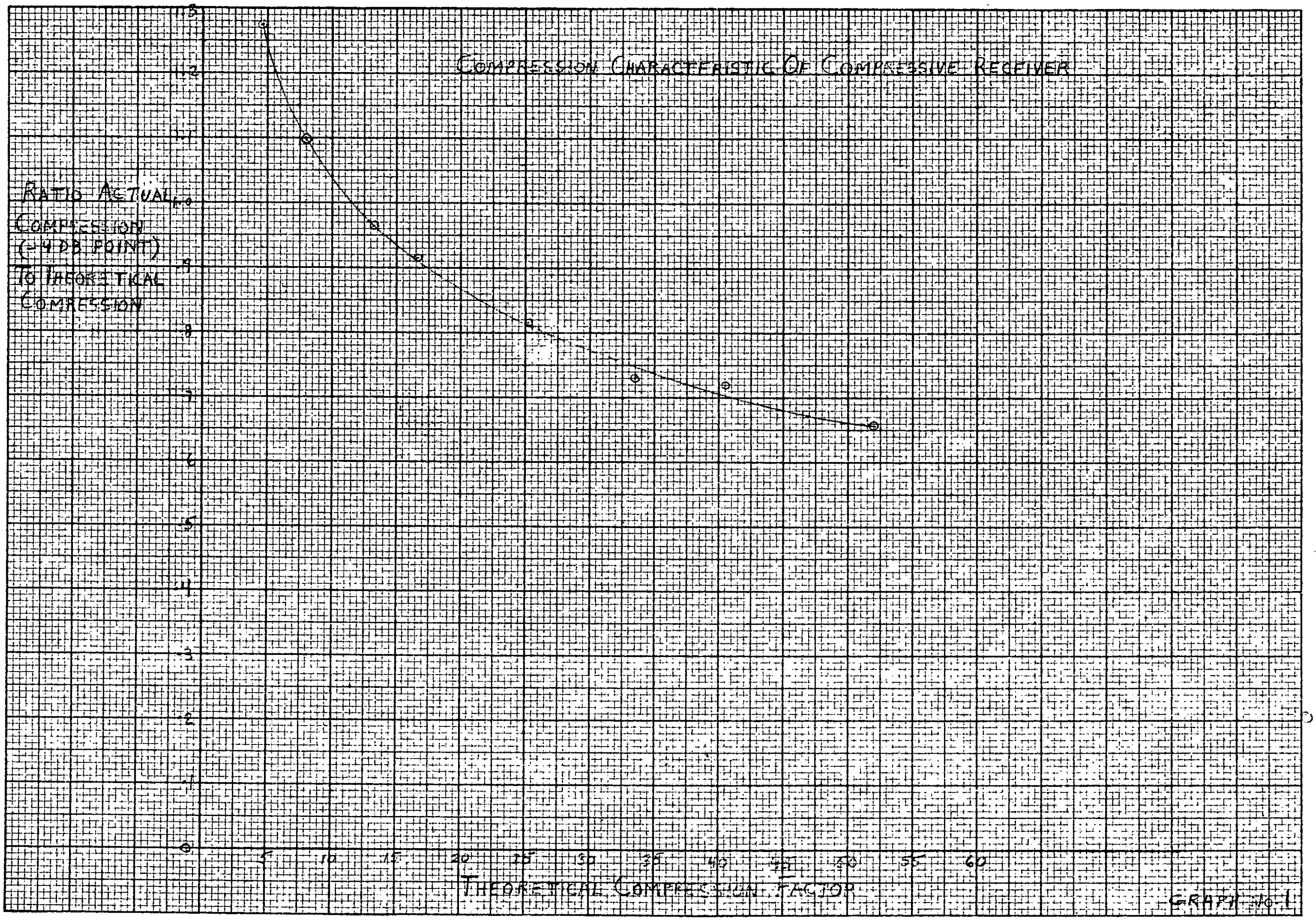
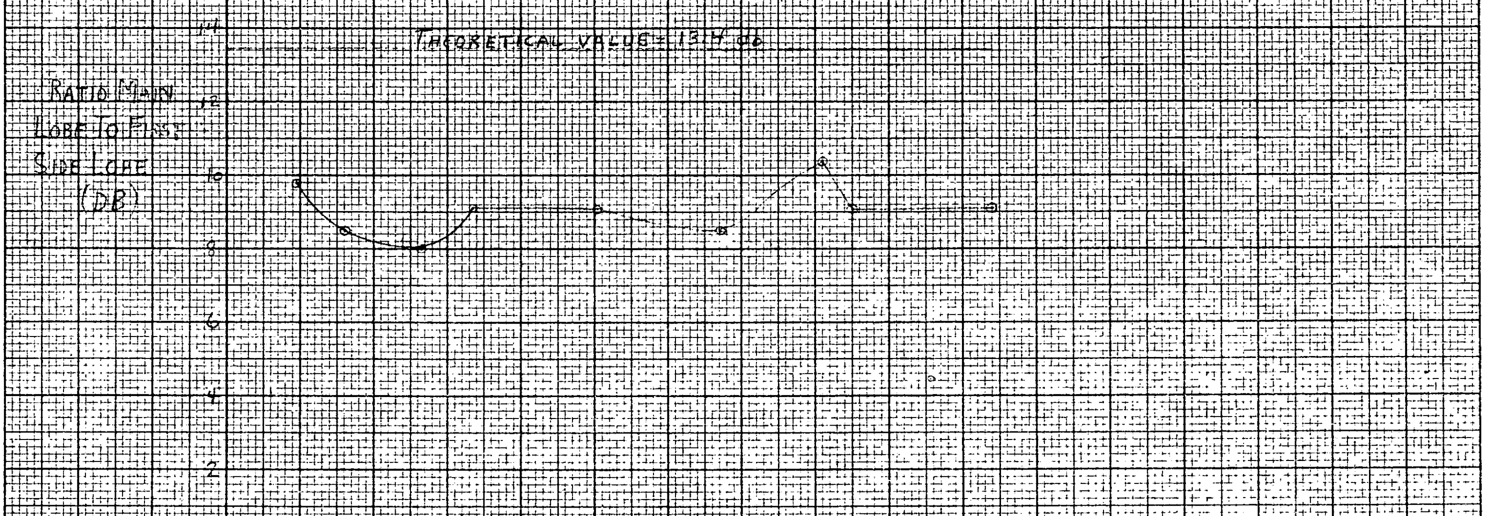


FIGURE 5 - Equal power density wide band and narrow band noise output.


COMPRESSION CHARACTERISTIC OF COMPRESSIVE RECEIVER
RATIO ACTUAL
COMPRESSION
(-4 DB POINT)
TO THEORETICAL
COMRESSION
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
5
10
15
20
25
30
35
40
45
50
55
60
THEORETICAL COMPRESSION FACTOR

GRAPH NO. 1

RELATIVE SIDELOBE LEVEL OF COMPRESSIVE RECEIVER



GRAPH No. 5

	L_a uh	L_b mh	C_a uf	C_s uf
Pole 1	29	1.0	.24	.0033
Pole 2	38	.70	.16	.0045
Pole 3	44	.53	.12	.0052
Pole 4	50	.40	.092	.0059

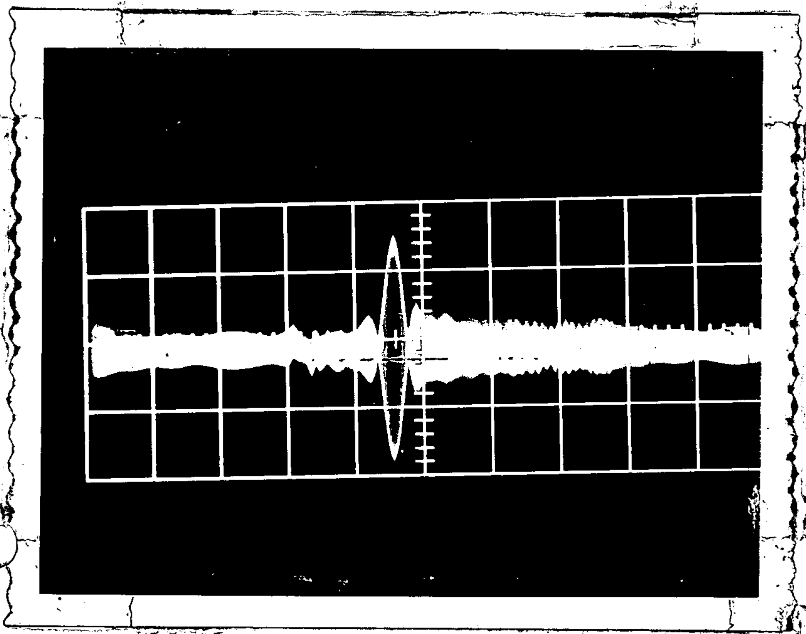
TABLE 1 - Element values of Quadruplet

File RD-161
T.O.3

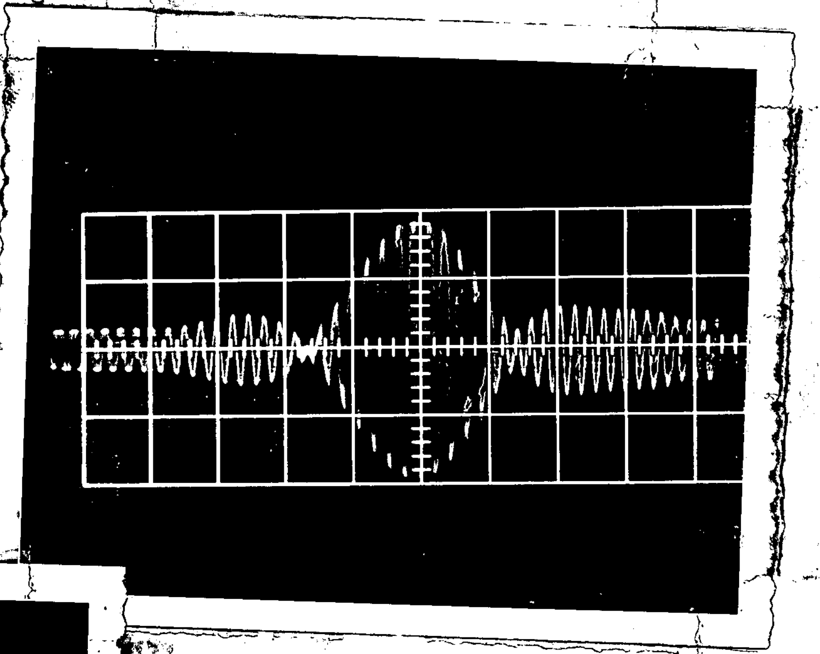
NEW RECEIVING TECHNIQUES
PROGRESS DURING OCTOBER 1960

In the past month general tests of the compressive system have shown it to work as expected as is discussed in our previous monthly reports. In earlier reports we have indicated that the compressed pulse would have a $\frac{\sin x}{x}$ amplitude modulation because of the band limited character of the system. As observed in the Breadboard receiver the compressed pulse is a distorted or asymmetric $\frac{\sin x}{x}$ pulse giving larger side lobes after main lobe than prior to it. It is expected that the asymmetry of the side lobes can be attributed to the fact that the delay network is band limited and also the frequency sweep is slightly non-linear.

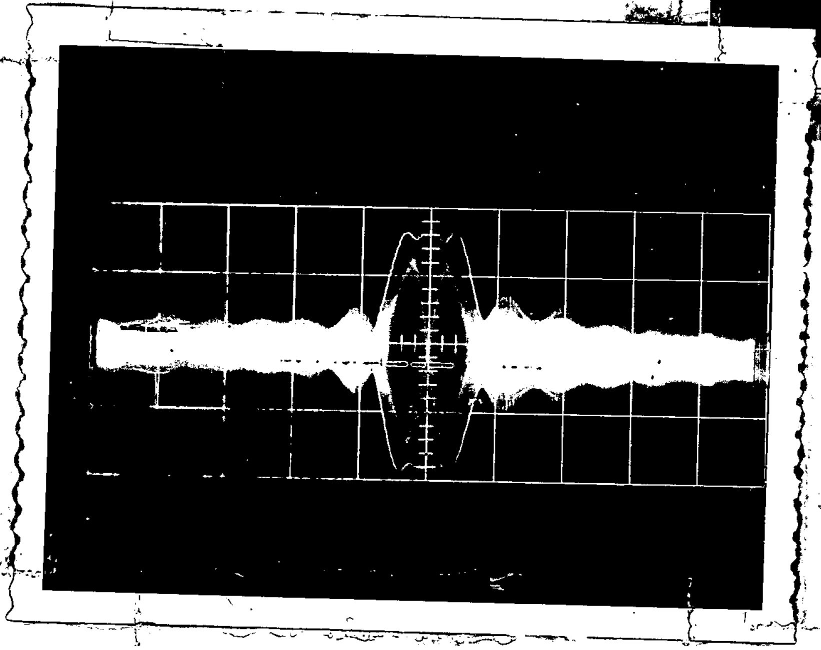
Preliminary tests have been made with both one and two signals in the receiver passband. With a 2 Mc sweep, signals of equal amplitude can be distinguished at a separation of 100 Kc. The frequency resolution of the receiver was further demonstrated by observing the carrier and sidebands of an input signal amplitude modulated with 100 Kc. This produces 3 separately discernible pulses as viewed on the display scope. Photographs of compressed pulses are shown below.



Compressed Output with
one signal in passband.
Sweep width 2 Mc
Time scale 2 usec/cm
Figure 1



Enlarged view of compressed
pulse showing swept R.F.
under envelope
Time scale 0.4 usec/cm
Figure II



Compressed output with
two signals in passband.
Frequency separation
is 88 Kc.
Time scale 1 usec/cm
Figure III

The system block diagram used in these tests is given below.

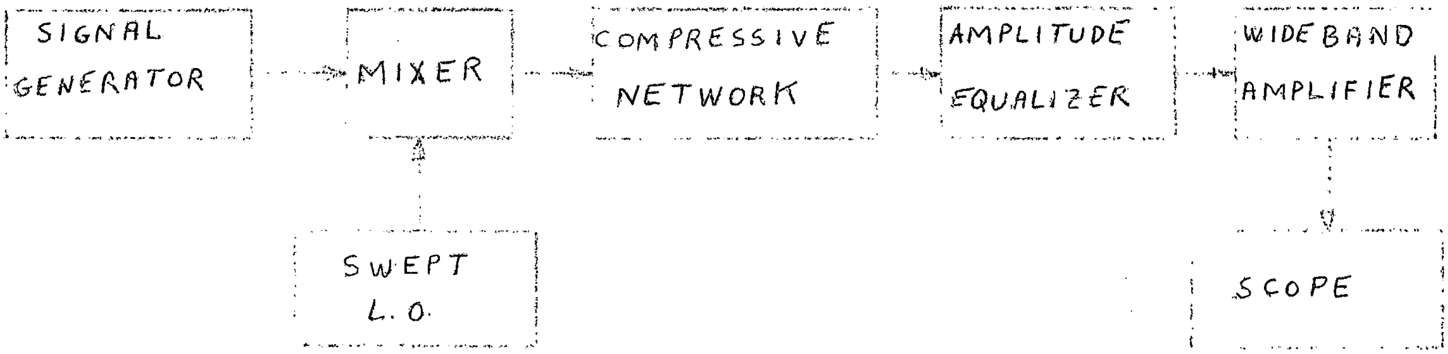


Figure IV

Noise inputs were further investigated to ascertain the response of the system to complex noise inputs. Below is given a block diagram which describes the method used to get the above input.

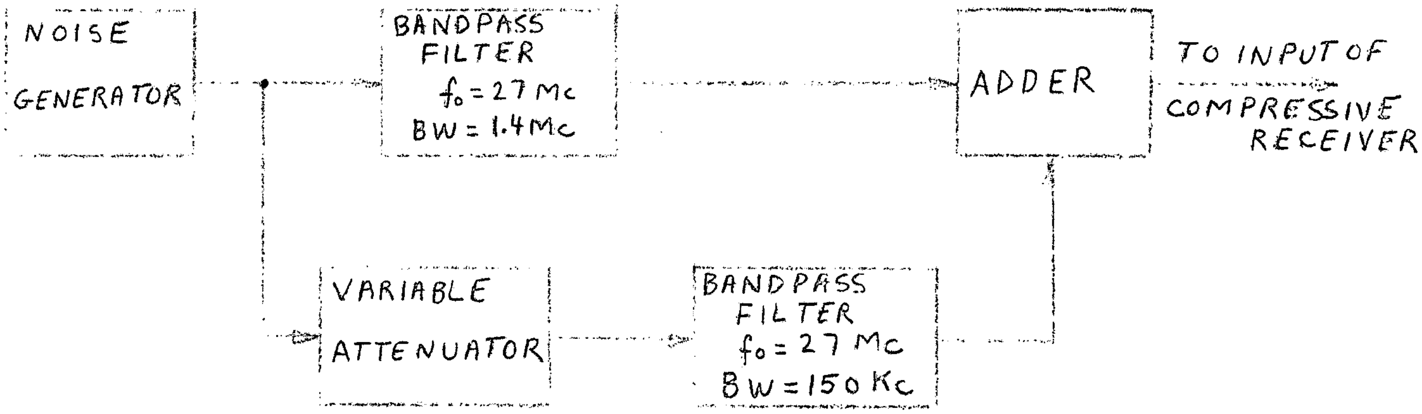


Figure V

The noise generator provides wide band noise which is passed through a bandpass filter equal to system bandwidth. To this relatively wide band noise is added an extra amount of relatively narrow band noise in the center of the band. When this complex input signal is viewed directly on a A-scope it is impossible to tell the presence, let alone the frequency location, of the narrow band noise within the wide band noise. However, when it is viewed with a compressive receiver, the narrow band noise groups in a clearly definable manner as is indicated in the photograph below. It should be noted that this can be done with a 100% intercept probability. Frequency can be read by calibrating the sweep voltage in terms of frequency.

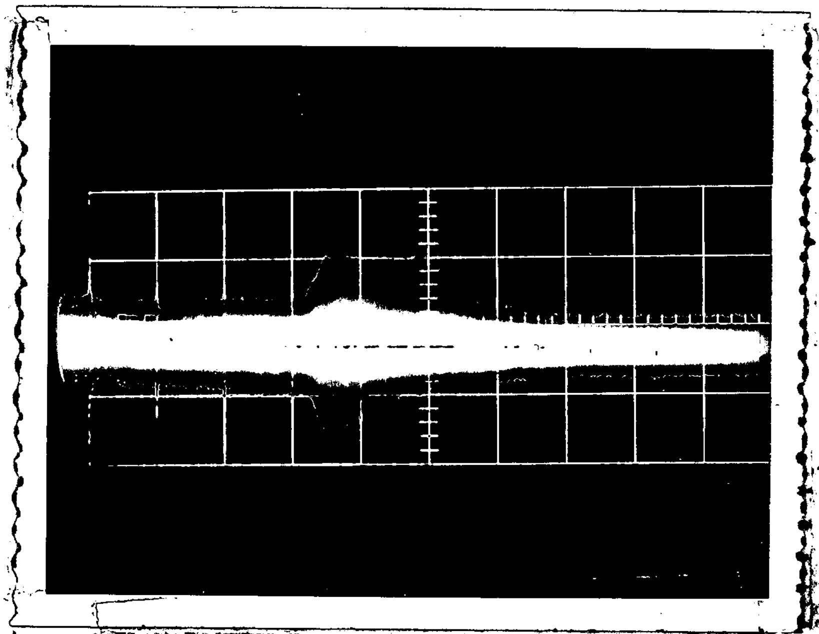


Figure VI - photograph of the output display with wide and narrow band noise both present.

The results to date are not the best that can be obtained with our compressive filter. The equipment has been run at a compression factor about 15 when it has a theoretical capability of 50.

Future effort is being concentrated on an accurate measurement of the time delay characteristic of the compressive network and on obtaining a more linear swept L.O. A truly linear swept L.O. is necessary to achieve compression ratios that approach the theoretical.

Effort will also be spent on consideration of a compressive network of bandwidth of 50 Kc to be used as a spectrum analyser with a 100% intercept probability and RF bandwidth of 25 Kc. It is felt that resolution of 5 Kc within the bandpass of 25 Kc is easily possible with the technique used in this system.

File RD-161
T.O.3

NEW RECEIVING TECHNIQUES

PROGRESS DURING SEPTEMBER 1960

This is the third in a series of letter reports on a feasibility study to examine the principles and limitations of the frequency-time transformation as applied to a self-adjusting spectrum filter, together with breadboarding of some critical circuits. In accordance with discussions with the contractor's representative the filter is no longer restricted to exclusion of all signals above a present threshold.

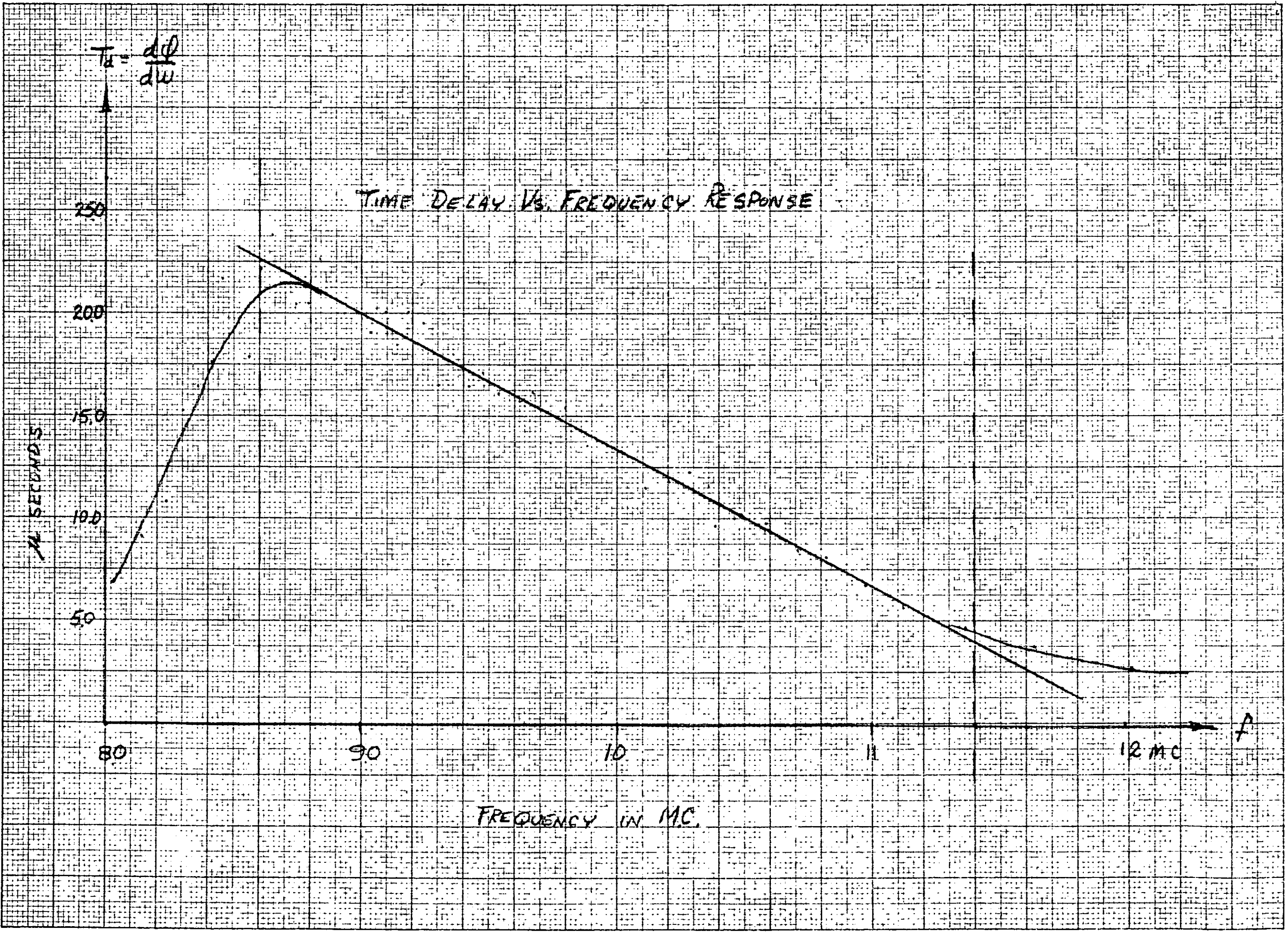
A compressive network consisting of 60 cascaded all-pass sections has been built. The inductors and capacitors in the individual sections were adjusted to ± 1% of the theoretical values. The maximum attenuation of the network is about 30 db and occurs at the lower edge of the band (6.6 Mc). A band pass filter will be required to remove spurious responses occurring outside of the band of interest.

Initial measurement of the phase response of the network has been made. From the data, a differential time delay vs frequency response was calculated and plotted. The plot shows an average linearity of 5 percent in the pass band.

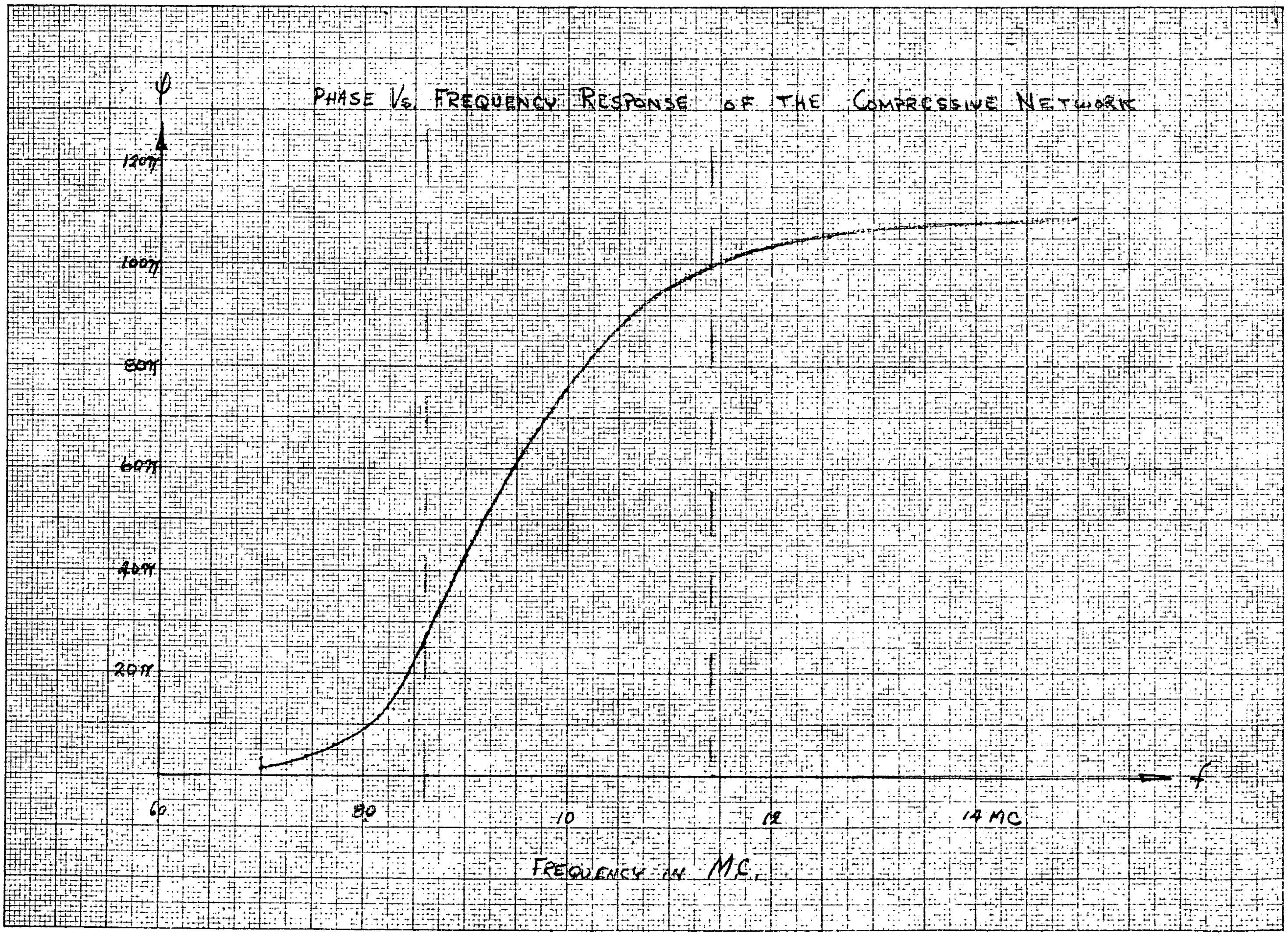
It is believed that the linearity is better than 2 percent and that the phase measuring technique rather than the network contributes to the deviations from linearity. The phase measurement was made by measuring frequencies for which the network provides 2 radians of phase shift (always relative to the previous measurement). The output from a signal generator is divided into two parts, one part being fed to a filter and a second to an attenuator. The output from the attenuator is adjusted to have its amplitude equal to the output available from the filter. The difference between the attenuator and filter outputs is obtained by means of a CRT with a differential amplifier. The signal generator frequency is then adjusted for a minimum output as viewed on the CRT. This frequency is recorded. The signal generator frequency is varied and each successive "zero" (minima) encountered is recorded. The spacing between the zeros is at intervals of 2 radians. Other phase and time delay measuring techniques are being explored that would provide more accurate data.

PROGRAM FOR NEXT INTERVAL

The compressive network, oscillators, mixers, amplifiers and filters will be integrated to form a compressive receiver. Evaluation tests will be started.



$T_d = \frac{d\phi}{d\omega}$
TIME DELAY VS. FREQUENCY RESPONSE
μ SECONDS
250
200
15.0
10.0
5.0
80
90
10
11
12 MC
f
FREQUENCY IN MC.


PHASE Vs. FREQUENCY RESPONSE OF THE COMPRESSIVE NETWORK
ψ
120π
100π
80π
60π
40π
20π
60
80
10
12
14 MC
f
FREQUENCY IN MC.

25 July 1960

NEW RECEIVING TECHNIQUES
PROGRESS DURING JULY 1960

This is the first in a series of letter reports on a feasibility study to examine the principle and limitations of the frequency time transformation as applied to a self-adjusting spectrum filter together with breadboarding of some critical circuits. The specific type of self-adjusting filter is expected, with use of amplitude signals as a criteria, to reject all signals above a specified signal level.

Present effort on this project is familiarization of project personnel with the suggested techniques, and as a preliminary measure, by heuristic reasoning to supplement presently available knowledge of compression techniques to communication problems.

Compression techniques have been utilized in radar applications where the problem is to illuminate a target with a maximum amount of energy. Radar transmitters have become peak power limited and as proposed by

R. A. Dicke* (reference 1) a pulse of long r-f duration is transmitted which is linearly swept in frequency (low to high). The echo return from this transmitted pulse is applied to a network (a compressive filter) which linearly delays lower frequencies longer than high frequencies. The output of the network is a narrow pulse which is utilized for range resolution accuracy of the radar target. As is shown in reference 1 the shape of the compressed pulse follows a Sin X/X amplitude pattern. A student of transforms (LaPlace, Fourier, etc) would possibly anticipate this result.

In the communications application proposed, the transformation is accomplished by means of a swept L.O. In viewing a CW signal in a band restricted receiver following a mixer which also receives a swept L.O. input, the i-f output will "plot out" the bandpass of the network. This i-f output can be considered as a pulse containing a carrier which is linearly swept. As in the radar transmission previously described, this fm pulse is applied to a compressive network. It is expected here, that the CW signal transformed into the time domain will exhibit a Sin X/X modulation as obtained from compression of the swept radar pulse. If there were no bandwidth

*Ref. 1 - Charles E. Cook, "Pulse Compression - Key to More Efficient Radar Transmissions", Proc. IRE, March 1960, pp 310-320.

restrictions the Sin X/X function would shrink into an impulse and could be simply gated out of the receiver. On the other extreme if the bandwidth is made narrow the i-f output becomes continuous in time and cannot be gated. Bandwidth considerations, rate of decay of Sin X/X type functions, degree of signal exclusion required, feasibility of constructing time delay networks, other receiver parameters, etc. are among the considerations which are to be studied.

PROGRAM FOR NEXT INTERVAL

During the next interval the effort will be divided into several areas. One area will be of more detailed study of the principles and limitations of the self-adjusting spectrum filter applied to amplitude criteria. Other parallel effort will be directed towards bread-boarding of essential parts of such a receiver (a swept receiver, compressive network, and time gates). During this interval a conference is expected to be held with the contractors representative to further discuss proposed objectives.