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A NEW TYPE OF FIXED ECHO CANCELING DEVICE

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A NEW TYPE OF FIXED ECHO CANCELING DEVICE

by

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May 1947

Problem No. 39RO2-24

Approved by:

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ABSTRACT

A repetitive pulse has a frequency spectrum consisting of a Fourier series of spectral lines equal to the pulse repetition frequency and its harmonics.

A fixed echo canceling device is described which consists of a series of lumped circuit bridge-T rejection filters tuned progressively to the Fourier components of the pulse out to the 100th harmonic of the repetition frequency.

A fixed pulse cancellation ratio of 20 db was obtained with a resolution of 65 elements of range to a simulated moving target.

Since a resolution of 65 elements of range falls within the range of optimum writing speed for a cathode-ray tube indicator it is proposed that a device of this sort may have useful application for radar MTI.

Advantages over supersonic delay line and storage tube MTI systems are:

1. Saving of weight, space and complexity.
2. Increased ruggedness and dependability.
3. Simplified operation.

Disadvantages are:

1. Reduced resolution for expanded sweep operation.
2. Lack of flexibility in pulse rate (as with delay line systems.)

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A NEW TYPE OF FIXED ECHO CANCELING DEVICE

INTRODUCTION

1. The problem of removing fixed echoes from a radar indicator has been previously attacked by pulse to pulse comparison methods, utilizing the differences to indicate the presence of moving targets. This has been accomplished in practice by storage of signal (in a supersonic delay line or electron storage tube) and subsequent subtraction of the direct from the stored signal. Fixed echoes are canceled because they do not change with time, but moving targets appear in general as uncanceled signals and are shown on the radar indicator.

2. The frequency response of a repetitive pulse consists of a Fourier series of components starting at the repetition frequency and occurring at each harmonic. The significant energy is contained within the region below a frequency equal to the reciprocal of the pulse length. Analysis of the frequency response of a delay line or storage tube cancellation device shows a series of null frequencies at each of the Fourier component frequencies of the pulse, thereby, in effect eliminating fixed echo pulses.

3. Because of the complexity of dynamic balancing systems such as the delay line or storage tube fixed echo cancellation devices, the possibility of using linear circuit elements so arranged as to have a null response to each Fourier component of the pulse was considered. This could be accomplished by means of a series of rejection filters tuned to each Fourier component. The number of filters was determined by the bandwidth, or resolution desired in separating moving targets.

RESOLVING POWER REQUIRED ON A RADAR INDICATOR

4. Besides the radar itself, there are limiting factors on resolving power due to the human eye and to the finite spot size of the cathode-ray oscilloscope. The combined effects of the eye and spot size show an optimum writing speed for an indicator as a function of pulse width. These factors may be simplified in the general case to the extent that the actual pulse width on the indicator should be about one to two millimeters. Wide variations from this value will show a loss in sensitivity of as much as 4 db. Considering in a typical case a PPI indicator using a 9 inch tube giving a 4 inch range sweep, the optimum writing speed would be such as to just separate 50 to 100 targets in range. This can be called the range resolution (50 to 100 elements) of the indicator. With the presently available cathode-ray tubes, the maximum possible resolution is limited by spot size to approximately 250 elements, which is more than desired for best sensitivity.

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5. Most radar systems operate with a duty cycle of the order of 0.001 giving a maximum resolving power in range of about one part in 1000 (1000 elements). When expanded sweeps are used the resolving power (in terms of percent of sweep) is reduced proportionally. For example a 0.001 duty cycle radar with a pulse rate of 500 per second would have a resolution of 1000 elements on a 165 nautical mile sweep, but would have a resolution of 120 elements on a 20 mile expanded sweep, and a resolution of only 30 elements on a 5 mile sweep. Under many conditions a modification of the duty cycle of the radar would be desirable in order to maintain optimum writing speed. This is usually not possible because of average power limitations in the radar. It is possible, however, by pulse lengthening methods in the indicator to obtain optimum writing speeds and perhaps an increase in sensitivity of several db can be realized under limiting conditions of low duty cycle and long sweep. From the above considerations, a resolving power of 50 to 100 elements of the range sweep is believed sufficient and preferred over high resolution.

6. The resolving power of a fixed target canceling device needs to be no better than the resolving power of the indicator itself. For a radar indicator operating at close to maximum range (limited by the time between radar pulses) it can be concluded that a resolving power of 50 to 100 elements may be sufficient. A fixed echo canceling device driving into that indicator therefore needs a resolving power of only 50 to 100 elements. If expanded sweeps are necessary in the system, the resolving power of the fixed target canceling device is modified depending on how it operates. For example, a supersonic delay line system must have an increased resolution proportional to the range expansion; but in contrast, a storage tube can be swept with the same expanded sweep as the indicator and therefore needs no more resolution than 50 to 100 elements, regardless of the amount of expansion. Active competition between the two devices will remain, since it is as easy to get several thousand elements of resolution in the delay line as it is to get 100 elements in a storage tube.

7. The linear harmonic rejection filter cancellation device requires the same resolving power as a supersonic delay line cancellation system for expanded sweep operation. There is considerable physical difficulty in obtaining more than 100 elements of range resolution with the filter system. Its use should not be considered for applications where a large amount of sweep expansion is needed. For systems operating with 50 to 100% duty cycle on the indicator sweep, the system provides sufficient resolving power, cancellation of the same order of magnitude as delay line or storage tube systems, increased dependability, simplicity, ruggedness, saving in weight and space, and less critical operation.

HARMONIC REJECTION FILTER CANCELLATION SYSTEM

8. As previously mentioned an analysis of the frequency spectrum of a repetitive pulse shows that it is composed of discrete spectral lines at frequencies corresponding to the repetition frequency and its harmonics. The maximum order of harmonic of interest to radar is about nf_r , where n equals the reciprocal of the duty cycle, and f_r equals the repetition frequency. If the filter system passes frequencies not corresponding to the Fourier Series, pulses containing doppler fre-

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quency components would in general not be rejected.

9. As a result of the above considerations, work was started in June 1946 to test the practicability of such a system. A system of twenty bridge-T-rejection filters were connected in tandem, tuned progressively to f_r and its harmonics out to the twentieth harmonic, and terminated in a low pass filter which cut out all frequency components above the twentieth harmonic. A test pulse through this system was well canceled (30 db) and a resolving power of about 15 elements of range to a simulated moving target was obtained. These results were so promising that the design of a 100 filter system was undertaken. The 100 filter system was a good compromise between resolution and complexity, allowing sufficient resolution for a practical radar MTI system with sufficient simplicity to permit a real saving in space and weight over a delay line or storage tube system.

10. The 100 filter fixed echo canceling device was designed for a repetition frequency of 3000 pulses per second for convenience and to fit the XDK hemispheric radar in case it proved practical for that use. Figure 1 is a partial circuit diagram of the complete canceling device. Included in the diagram are: (1) the unusual frequency compensating driver which is necessary to obtain the best possible resolution in the system, and (2) the low pass filter on the output which removes frequency components above the 100th harmonic of the repetition frequency. See appendix for the filter constants. For convenience in construction and alignment, the filters were assembled in blocks of ten with an isolating amplifier included in each block (See Figure 2). Figure 3 is the assembled cancellation system. Two amplifiers were used in each of the last two blocks to make up for additional insertion loss in the higher frequency filter sections. Each filter consists of a conventional bridge-T-rejection filter with an adjustable powdered-iron core for frequency tuning and an adjustable-balancing resistor for amplitude balance. Although the coils were unshielded in the system, it has since been found desirable to shield each coil (particularly the higher frequency ones). This was done to eliminate magnetic coupling which causes tuning interaction between filters.

11. The special frequency compensating driver was necessary because the overall response of amplitude versus frequency dropped continuously from the low to the high frequency. This would be expected with circuits of finite Q. An attempt was first made to adjust the Q of each filter so that the relationship $Q_n = n^Q$ (where $Q_n = Q$ of the nth filter and $Q_1 =$ the Q of the filter at the repetition frequency) in order to obtain a flat response curve. This, however, introduced such severe attenuation in the system that it was discarded. By means of appropriate high pass R-C networks an approximation of a flat response could be obtained but again the insertion loss became prohibitive. A pulse distorting device was needed which would shape the receiver pulses in such a way that their effective amplitude versus frequency envelope would be the inverse of the envelope of the filter system response without causing excessive insertion loss. This was accomplished by means of the double-pulse driver which divided the single-pulse output of the receiver into two channels.

One channel delayed the pulse an appropriate amount and inverted its polarity. The delayed channel was then recombined with the undelayed channel to deliver a double-output pulse. By means of adjustment of amplitude and spacing of the delayed pulse the frequency response of the driving signal could be adjusted to compensate

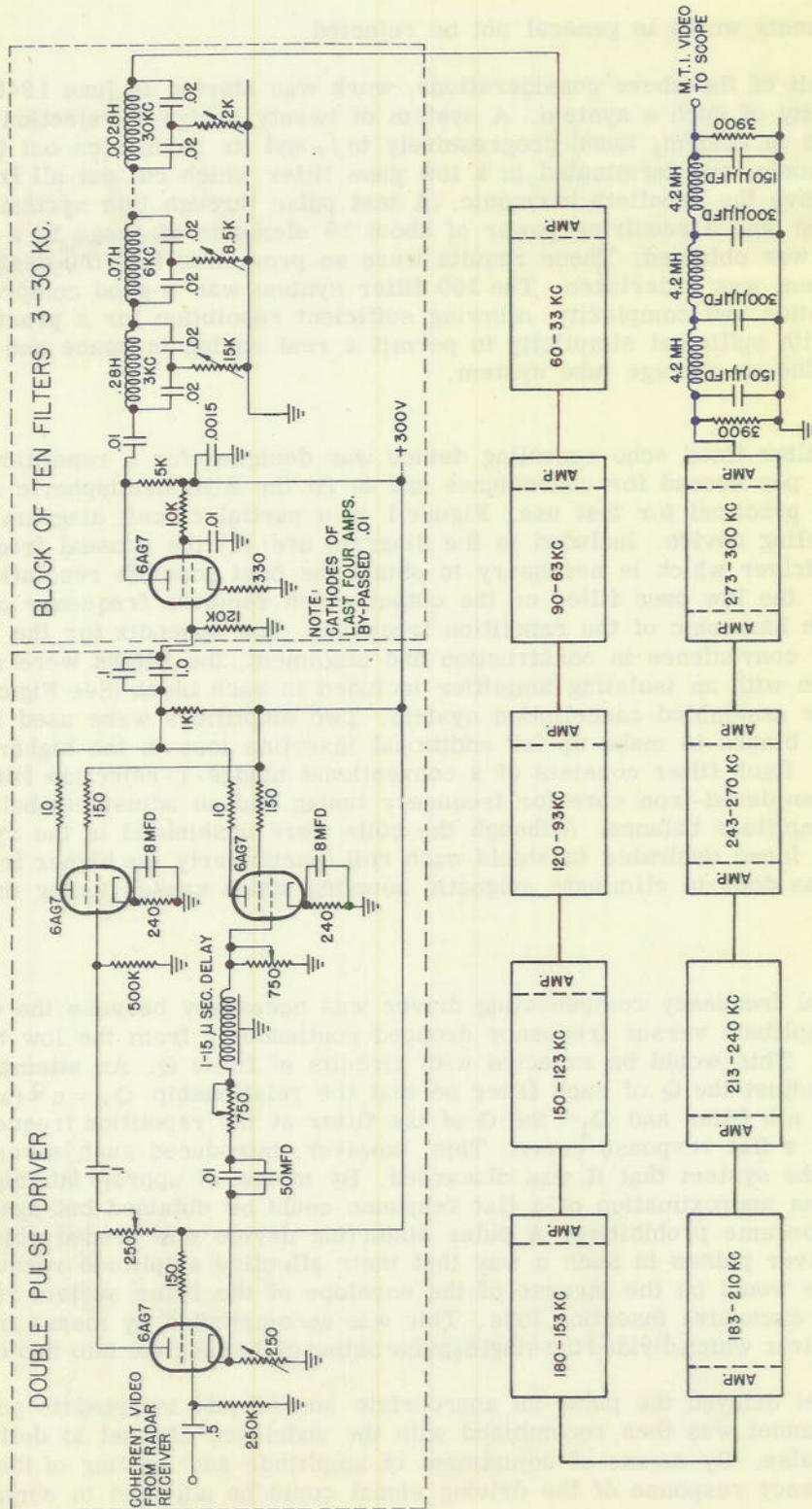


Fig. 1 Partial Schematic of the Complete Echo Canceling Device

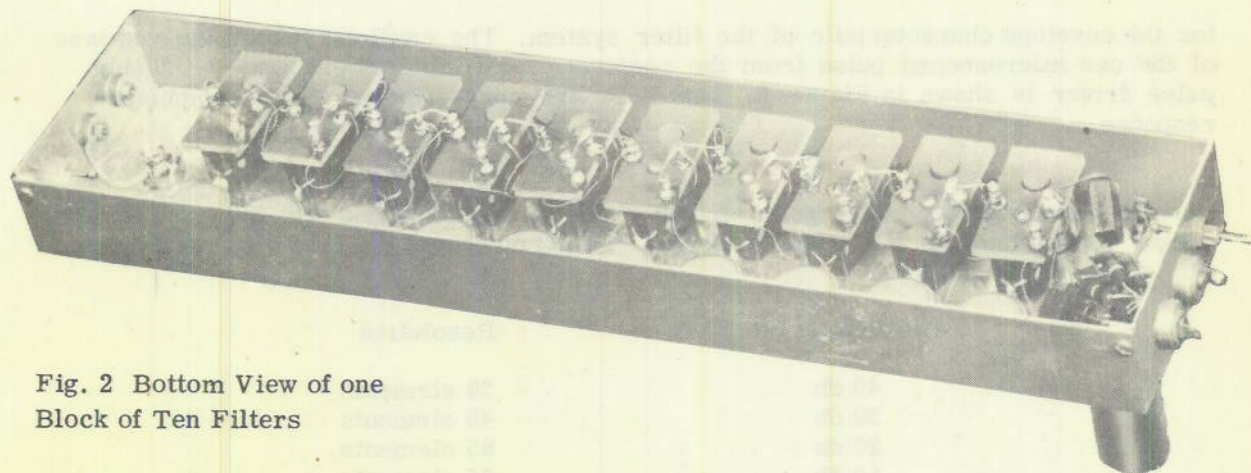


Fig. 2 Bottom View of one Block of Ten Filters

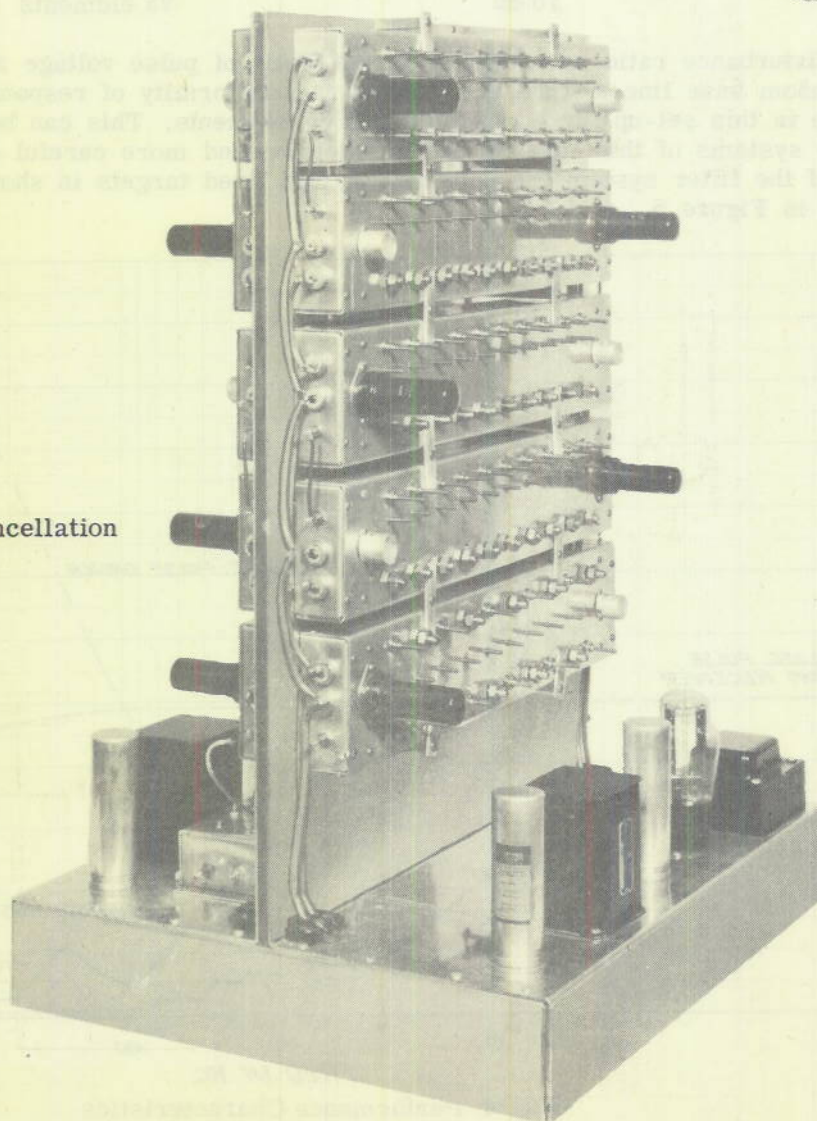


Fig. 3 Assembled Cancellation System

for the envelope characteristic of the filter system. The envelope frequency response of the one microsecond pulse from the receiver, the filter system, and the double pulse driver is shown in Figure 4. The solid line curve represents the combined response.

12. By means of the double pulse driver a flat video pass band was achieved which allows moving targets to be well resolved. Performance of this 100 filter cancellation device is as follows:

Cancellation Ratio	Resolution
40 db	20 elements
30 db	40 elements
20 db	65 elements
10 db	75 elements

The disturbance ratio on a moving target (ratio of pulse voltage at the proper range to random base line disturbances due to non-uniformity of response) is about four to one in this set-up for a resolution of 65 elements. This can be improved in future systems of this type by better shielding and more careful design. The operation of the filter system for both moving and fixed targets is shown by oscilloscope views in Figure 5.

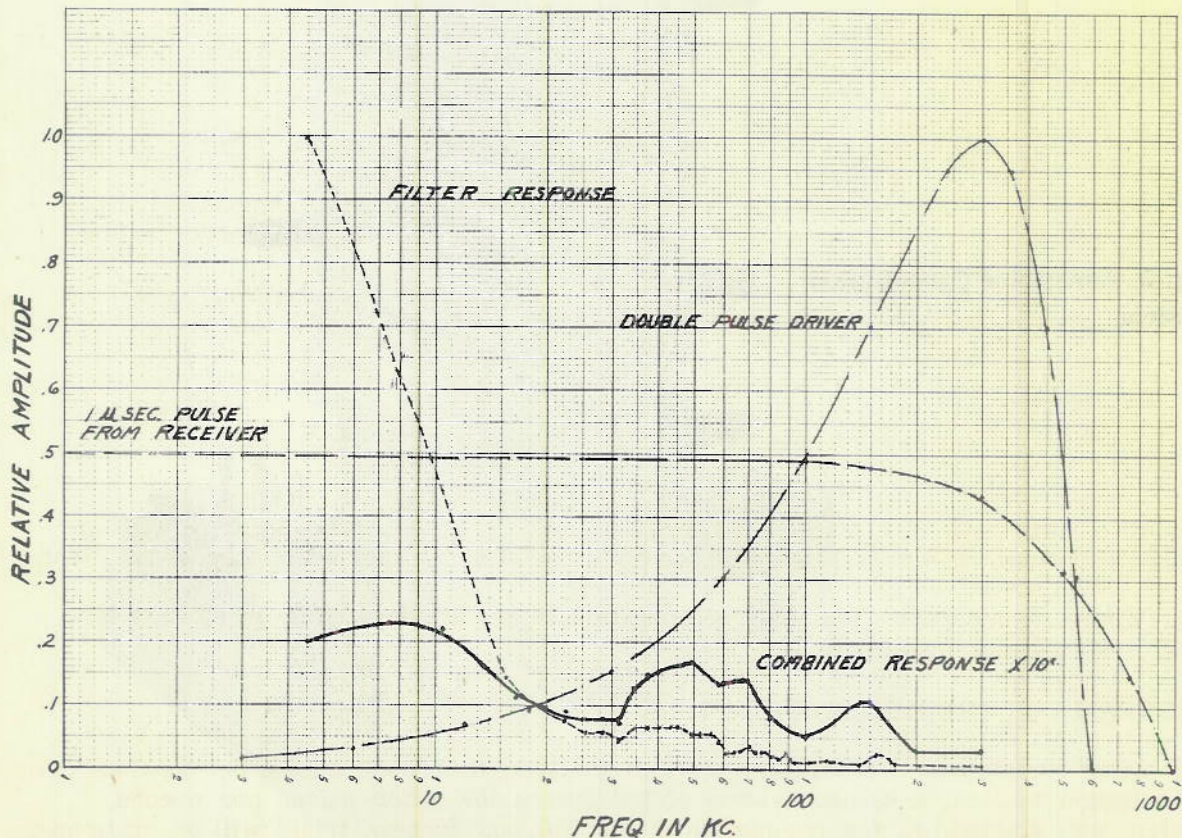
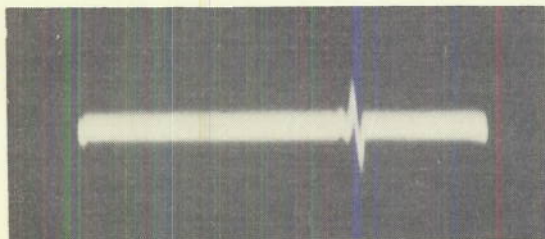
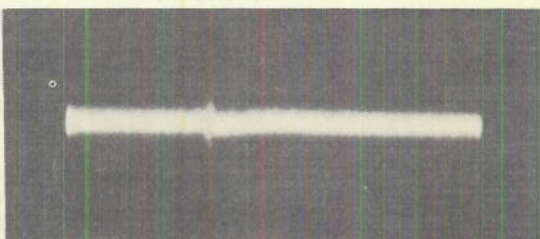


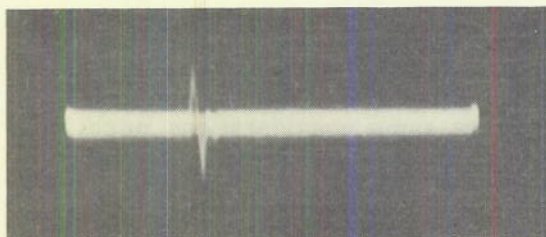
Fig. 4 Performance Characteristics



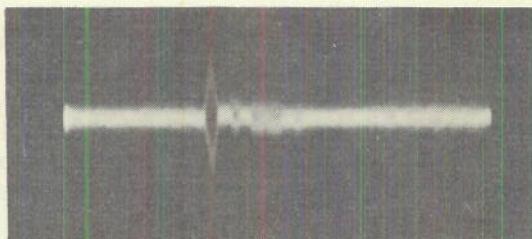
(a) Fixed Pulse at the Input to the Filter System.



(b) Filter Output with Fixed Pulse Input.



(c) Simulated Moving Target Pulse at the Input to the Filter System.



(d) Filter Output with Moving Target Input.

Fig. 5 Operation of Filter System Shown by Oscilloscope Wave Forms

CONCLUSIONS

13. The principle of fixed-pulse cancellation by means of a series of lumped-circuit-rejection filters has been proved practical with a relatively simple and compact system.
14. Cancellation ratios compare favorably with delay line and storage tube cancellation systems.
15. Resolution sufficient for high duty cycle range sweeps has been obtained.
16. Improved operating performance should be possible with improved design.
17. Because of its relative simplicity, ruggedness, and dependability, the harmonic rejection filter type of cancellation should be considered for radar systems without multiple ranges, or where MTI operation on the maximum range scale only is sufficient.
18. Where considerable flexibility of operation is needed delay line or storage tube MTI systems may be essential.

PROGRAM FOR THE IMMEDIATE FUTURE

20. After completion of laboratory tests of the 100 filter 3000 pulses per second cancellation system, a second system of 100 filters for a 500 pulses per second system was started. At the completion of the 500 pps system, trials will be made on a radar in comparison with a delay line system to evaluate the operational advantages

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and disadvantages of the filter system. Plans may go ahead for incorporation in the XDK and XDQ radars if the filter system is sufficiently successful operationally. (The XDK is an X-band hemispheric-search radar and the XDQ is a very high-power L-band long-range air-search radar.)

21. Future reports will be forth coming as the work progresses and results of operational tests will be given. If developments in delay line or storage tube systems nullify the present advantages of the rejection filter system, work will be discontinued. The filter system would increase in complexity inordinately in order to compete with delay line resolution.

22. The intentional narrowing of the video bandwidth by means of properly designed pulse distorting circuits to give optimum writing speed is believed to be a new idea. This idea might be applied to both storage tube and delay line systems to improve cancellation and to reduce size and complexity. These same considerations might make possible development of magnetic or electrostatic storage devices (of limited bandwidth) which would give sufficient resolution.

23. What has been described in this report is a fixed echo-canceling device. In addition to this device, as in any other system using doppler effects to detect movement of targets, a coherent pulse receiver (with coherent c-w injected) will be needed. Velocity compensation will be required for many applications where the radar will be mounted on a moving platform (ship, plane, etc.). Coherent pulse receivers have been described in MTI literature, but velocity compensation methods are usually in the untried "idea" stage. A later report will describe velocity compensation requirements and possible methods of accomplishment.

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APPENDIX

Filter Values

Filter No.	Frequency in Kc	R in Kilohms	C in μf	L in mh.	Filter No.	Frequency in Kc	R in Kilohms	C in μf	L in mh.
1	3	15	0.01	280	51	153	3		0.320
2	6	8.5		70	52	156	3		0.307
3	9	5.5		30	53	159	1		0.298
4	12	5.0		18	54	162	15		0.285
5	15	4.0		11	55	165	15		0.275
6	18	3.0		8	56	168	15		0.265
7	21	3.0		5.6	57	171	15		0.256
8	24	2.6		4.4	58	174	15		0.247
9	27	2.3		3.4	59	177	1.5		0.239
10	30	2.0	0.01	2.8	60	180	12	0.0034	0.231
11	33	50	0.001	23	61	183	2.5	0.005	0.152
12	36	48		19	62	186	3.5		0.147
13	39	50		17	63	189	2.5		0.142
14	42	48		14	64	192	2.5		0.138
15	45	40		12	65	195	2.0		0.134
16	48	50		11	66	198	4.0		0.130
17	51	48		9.7	67	201	2.5		0.126
18	54	30		8.6	68	204	10.0		0.122
19	57	35		7.5	69	207	3.0		0.118
20	60	40		7.0	70	210	1.5		0.115
21	63	40		6.4	71	213	3.0		0.112
22	66	20		5.7	72	216	2.0	0.005	0.109
23	69	40		5.2	73	219	1.5	0.005	0.106
24	72	35	0.001	4.9	74	222	1.0		0.103
25	75	30	0.001	4.5	75	225	6.0		0.100
26	78	50		4.1	76	228	4.0		0.098
27	81	35		3.9	77	231	4.0		0.095
28	84	19		3.6	78	234	1.5		0.093
29	87	40		3.3	79	237	3.5		0.090
30	90	22	0.001	3.1	80	240	7.0		0.088
31	93	7	0.002	1.45	81	243	3.0		0.086
32	96	10		1.35	82	246	7.0		0.084
33	99	11		1.3	83	249	5.0		0.082
34	102	20		1.21	84	252	6.0		0.080
35	105	10		1.14	85	255	7.0		0.078
36	108	10		1.08	86	258	6.0		0.076
37	111	6		1.02	87	261	4.0		0.075
38	114	16		0.97	88	264	3.0		0.073
39	117	27		0.92	89	267	3.5		0.071
40	120	10	0.002	0.88	90	270	10.0		0.070
41	123	8	0.0034	0.495	91	273	6.0		0.068
42	126	8		0.47	92	276	0.5		0.067
43	129	5		0.45	93	279	1.5		0.065
44	132	7		0.429	94	282	3.5		0.064
45	135	7		0.41	95	285	7.0		0.063
46	138	7		0.393	96	288	0.5	0.005	0.061
47	141	5		0.376	97	291	4.0	0.005	0.060
48	144	7	0.0034	0.361	98	294	1.0		0.059
49	147	7	0.0034	0.346	99	297	1.5		0.058
50	150	5		0.332	100	300	10.0	0.005	0.056



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