GLINT NO. 207
June 13, 1967

THE IF SYSTEM

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The IF System includes:

1. Delay units and housing
2. IF cables
3. IF amplifiers (Bandpass 10 to 70 MHz)
4. Automatic level control units
5. 5-way power splitters
6. Multipliers
7. Power supplies
8. Packaging using NIM system

1. Delay units and housing

Introduction: The pairs of waveforms from the antennas are essentially cross-correlated in the receiving system. In order that the correlation be maintained at its maximum for a particular pair of waveforms, the relative time delay between them must be small. The array introduces delays because a wavefront reaches some antennas earlier than others when the direction of arrival is not on the meridian. The delay system compensates for these delays.

The maximum delay introduced and consequently in need of correction is the time of travel of the incoming signal from antenna No. 1 to antenna No. 5. This distance of 675' corresponds to 686 nano seconds of delay. Because the hour angle motion is restricted to $\pm 5^h$ a delay of 675 ns will be sufficient.

Delay corrections are to be inserted in the individual IF cables from each antenna to the central receiver. The delay correction elements will be lengths of cable switched automatically as required by the radio source motion in the sky. All delay cables will be housed in a thermally stable environment. An insulated room along the cable run at the array center appears to be the best arrangement.

The question of how great the relative delay error can be before a correction is necessary can be answered by studying the form of the correlation function $C(\tau)$. This function forms the envelope of the interference fringes as recorded for a pair of antennas. For our system which will use both sidebands there are two terms in the expression. One is due to the IF bandshape and the other due to the separation of the two sidebands.

$$C(\tau_o) = \mathrm{sinc}(\Delta f\ \tau_o)\cos(2\pi f_{IF}\ \tau_o), \qquad (1)$$

for rectangular passbands of width Δf separated by two times f_{IF}. The variable τ_o is the total delay error. This expression is plotted in Fig. 1 for an IF amplifier of 10 to 70 MHz bandwidth.

A binary switching method is planned with the coded switching signals to be derived from a computer which operates from hour angle and declination data or possibly from timing information on punched cards. With the maximum delay of 675 ns, a 10 bit binary code yields a minimum delay increment and $C(\tau_o)$ reduction as follows:

$$\frac{675}{1024} = \underline{0.66}\ \text{ns} \quad \text{and a } \underline{2\%} \text{ drop in } C(\tau_o),$$

a 9 bit binary code yields

$$\frac{675}{512} = \underline{1.32}\ \text{ns} \quad \text{and a } \underline{6\%} \text{ drop in } C(\tau_o),$$

and an 8 bit binary code yields

$$\frac{675}{256} = \underline{2.64}\ \text{nx} \quad \text{and a } \underline{23.5\%} \text{ drop in } C(\tau_o).$$

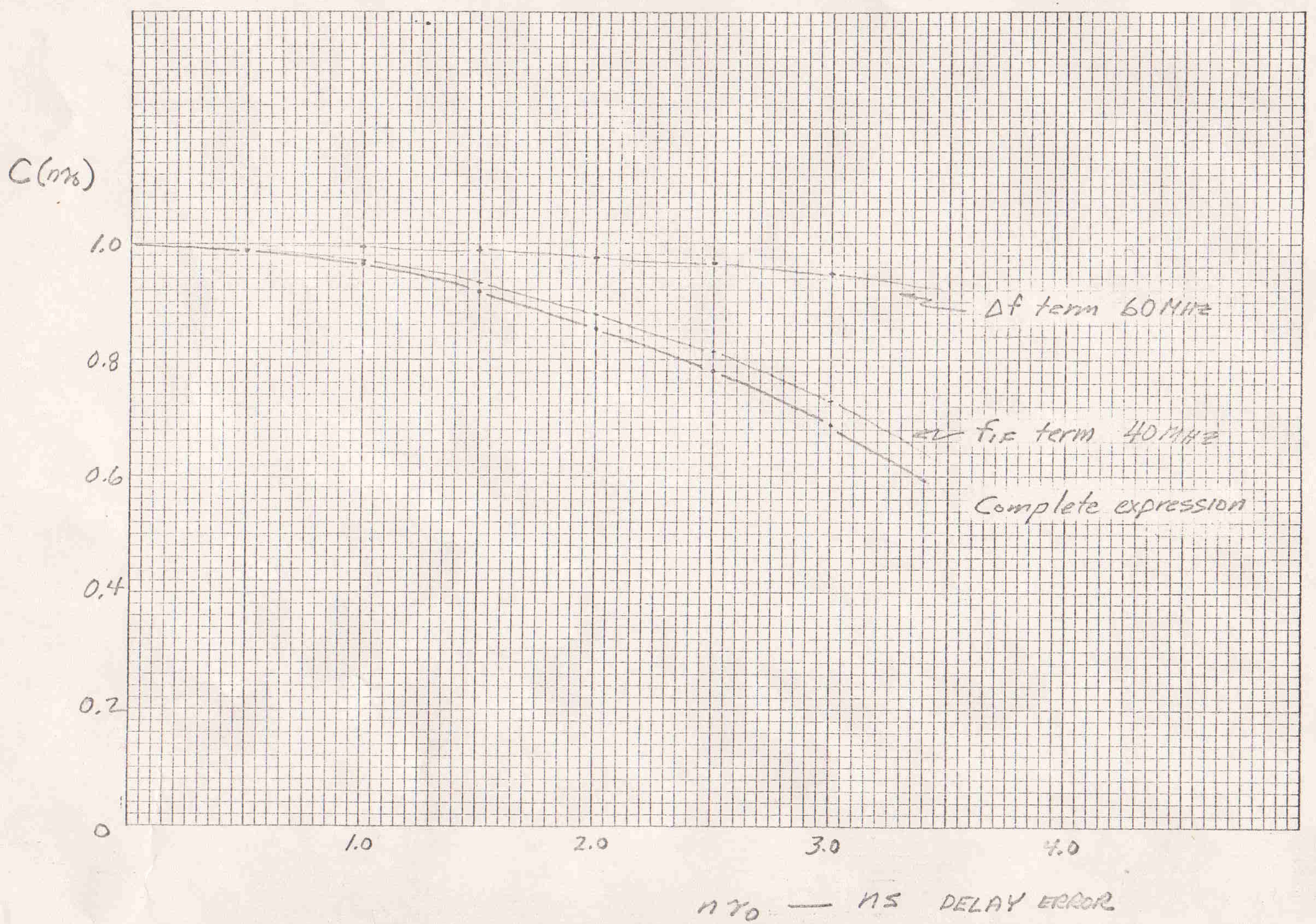


Fig. 1. Showing the correlation curve vs. delay error for our suggested receiver using a 10 MHz to 70 MHz IF AMPLIFIER.

This effect can be evaluated as follows: for a maximum percentage drop P, the average reduction in observed fringe amplitude will be approximately P/2. Since noise will be constant, observing time will have to be increased by the factor $(1 + \frac{P}{200})^2$ in order to compensate. This factor for the above case is:

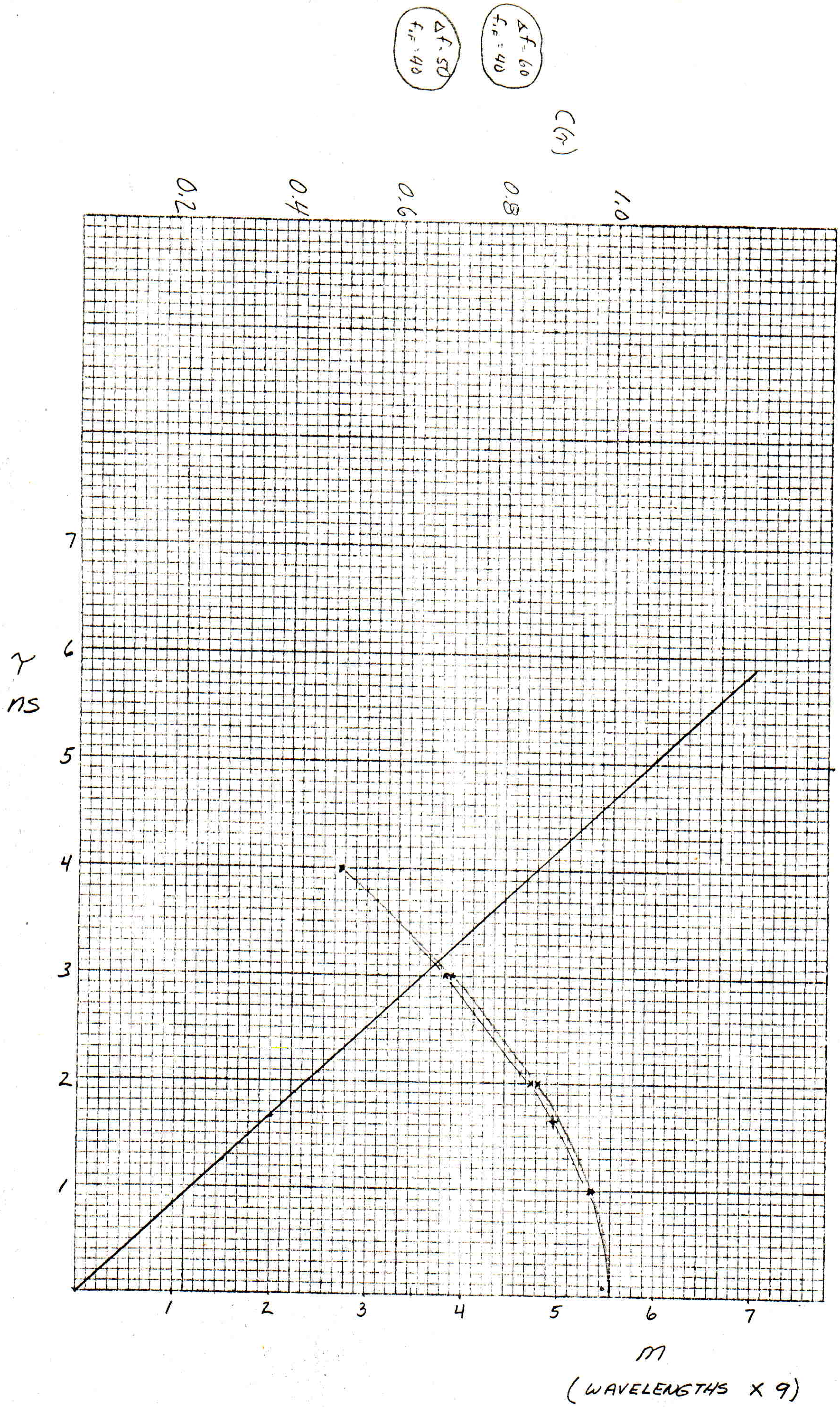
1.02 for 10 bit
1.06 for 9 bit
1.25 for 8 bit

Since the grating response order m is linearly related to delay, controlling the delay with an m number generator is a desirable scheme. From Fig. 2 a choice of setting delay when m has changed by 5 (max. error equivalent to $\Delta m = 2.5$ or 2.1 ns) yields an increase of observing time of 17%. For m = 4, the value is 11% and for m = 3, 7%. Using m = 3 with a delay change of 2.5 ns we can achieve 640 ns delay with an 8 bit system. This corresponds to $4^h\ 36^m$ on the equator. Five hour coverage occurs at a declination of $\pm 13^\circ$. By going to m = 2 with a delay change of 1.67 ns, we can achieve 852 ns delay with a 9 bit system which gives full hour angle coverage and an increase in required observing time of only 4%.

If all cables are cut and maintained to ±0.2 ns, the average system error will be ±0.6 ns, for 9 bits, corresponding to a 6% total average increase in observing time.

The possibility of achieving greater accuracy in cable lengths as well as going to a 10 bit system will be examined as experience with construction of delay elements progresses.

The IF transmission and delay cables can be made up using ½" Spiroline which costs $0.52 per foot. Its characteristics of stability, solid outer conductor for shielding purposes and low loss make it desirable. (RG 214/U



.841 @675'
.654 @525'
.467 @375'
.281 @225'

FIG. 2. Relationship between m, τ, and C(τ).

0.841 ns/m no. @ 675 ft. spacing

a double shielded polyethylene dielectric cable which we normally use costs $0.36 per ft.) Using Spiroline cable which has a velocity of propagation of 0.855, a delay of 0.66 ns requires 16.93 cm of line. This is a workable cable increment. At 25.65 cm/ns, 675 ns requires a minimum of 173.14 m (568 ft.) of cable in a delay package.

Total Cable Requirements

Switching When Needed		Fringe No. Switching
2 @ 675 ns	= 568 ft.	2 @ 728 ft.
	568	728
1 @ 525	= 442	1 @ 666
1 @ 375	= 316	1 @ 478
1 @ 225	= 189	1 @ 375
	2,083 ft.	2,975 ft.

We can compensate for the average frequency response of the delay cables with the IF amplitude response. (See section on Sloping Pass Bands below.) Depending upon where the white fringe is located when all delay cables are removed, various switching schemes can be used. In our case for a white fringe on the meridian, the IF cables would be of equal length from the centralized delay cable room to each antenna.

Attenuation Compensation of Delay Cables: When delay is added by switching a piece of cable into the IF line, some additional attenuation is also added. It is proposed to achieve the delay step required by switching between two cables, one of high attenuation per unit length used as an attenuation compensator and the second the low loss cable which provides the delay. The delay increment achieved is the difference between the delays of the two cables while the attenuation is held to the same value thru each path. These requirements can be expressed as:

$$c\tau_X = \frac{L_\ell}{v_{\ell/c}} - \frac{L_h}{v_{h/c}}$$

$$L_\ell \alpha_\ell = L_h \alpha_h$$

where X refers to the desired delay step, ℓ to the low loss cable and h to the high loss cable. c is the velocity of light, τ is delay in sec., L is length in feet, v/c is the relative velocity of propagation in the cable and α is the attenuation in db per unit of length. The two expressions can be solved for L_ℓ and L_h for a desired τ_X to yield

$$L_\ell = \frac{d(v_\ell/c)}{[1 - (v_\ell \alpha_\ell / v_h \alpha_h)]}$$

$$L_h = \frac{d(v_h/c)}{[(v_h \alpha_h / v_\ell \alpha_\ell) - 1]}$$

For use in these equations the cables of interest have v and α values as follows:

Cable	v/c	α_{40} db/100'	$\frac{v\alpha}{c}$	Cost
3/8" Spiro.	0.855	0.7	0.598	$0.45 /ft.
1/2" "	0.855	0.48	0.411	0.52 /ft.
7/8" "	0.855	0.27	0.231	0.74 /ft.
RG 21A/U	0.659	9.0	5.93	1.05 /ft.
RG 126A/U	0.695	17.0	11.83	1.89 /ft.
RG 196/U	0.695	7.2	5.0	0.19 /ft.

The following delay cable table was made up for an 8 bit system using ½" Spiroline and RG 196/U to give total delays as required for switching every third m value.

Loss / 100 ft.

0.48db 7.3 db.

1/2" Spiro RG-196/U

DELAY CABLE TABLE

TOTAL LOSS DB	DELAY NS	LENGTH L	LENGTH H	LOSS DB
2.87				
	320.00	299.51	19.97	1.44
	160.00	149.75	9.98	.72
	80.00	74.88	4.99	.36
	40.00	37.44	2.50	.18
	20.00	18.72	1.25	.09
	10.00	9.36	.62	.04
	5.00	4.68	.31	.02
	2.50	2.34	.16	.01
2.36				
	262.50	245.69	16.38	1.18
	131.25	122.84	8.19	.59
	65.62	61.42	4.09	.29
	32.81	30.71	2.05	.15
	16.41	15.36	1.02	.07
	8.20	7.68	.51	.04
	4.10	3.84	.26	.02
	2.05	1.92	.13	.01
1.68				
	187.50	175.49	11.70	.84
	93.75	87.75	5.85	.42
	46.87	43.87	2.92	.21
	23.44	21.94	1.46	.11
	11.72	10.97	.73	.05
	5.86	5.48	.37	.03
	2.93	2.74	.18	.01
	1.46	1.37	.09	.01
1.01				
	112.50	105.29	7.02	.51
	56.25	52.65	3.51	.25
	28.12	26.32	1.75	.13
	14.06	13.16	.88	.06
	7.03	6.58	.44	.03
	3.52	3.29	.22	.02
	1.76	1.65	.11	.01
	.88	.82	.05	.00

Delay Switching Elements: At the present time two possibilities for switching delay cables are being considered. One is diode switches and we will soon have experience on this approach based on R.B. Read's design at the Owens Valley Observatory.

The second approach is to use reed relays in as nearly a coaxial configuration as possible. Switching power requirements are similar for the two approaches and the main considerations are cost and performance.

The possibility of using transfer type switches to allow the use of one delay system in the two end antennas must be evaluated against the straight-forward approach of using two delay elements.

The IF system will have as an input an 8 to 10 bit binary code which can be directly used to control the relay or diode switch drivers.

Effect of Sloping Pass Bands on the Array Performance: We expect sloping pass bands because of cable attenuation characteristics. For example ½" Spiroline has 0.4 db more attenuation at 70 MHz than at 10 MHz for a 100' length. In the extreme case where one line has maximum delay the longest IF cable length will be say 1157 ft. with the shortest having only 537.5 with losses of 5.56 and 2.58 db respectively at mid band. (0.48 db/100')

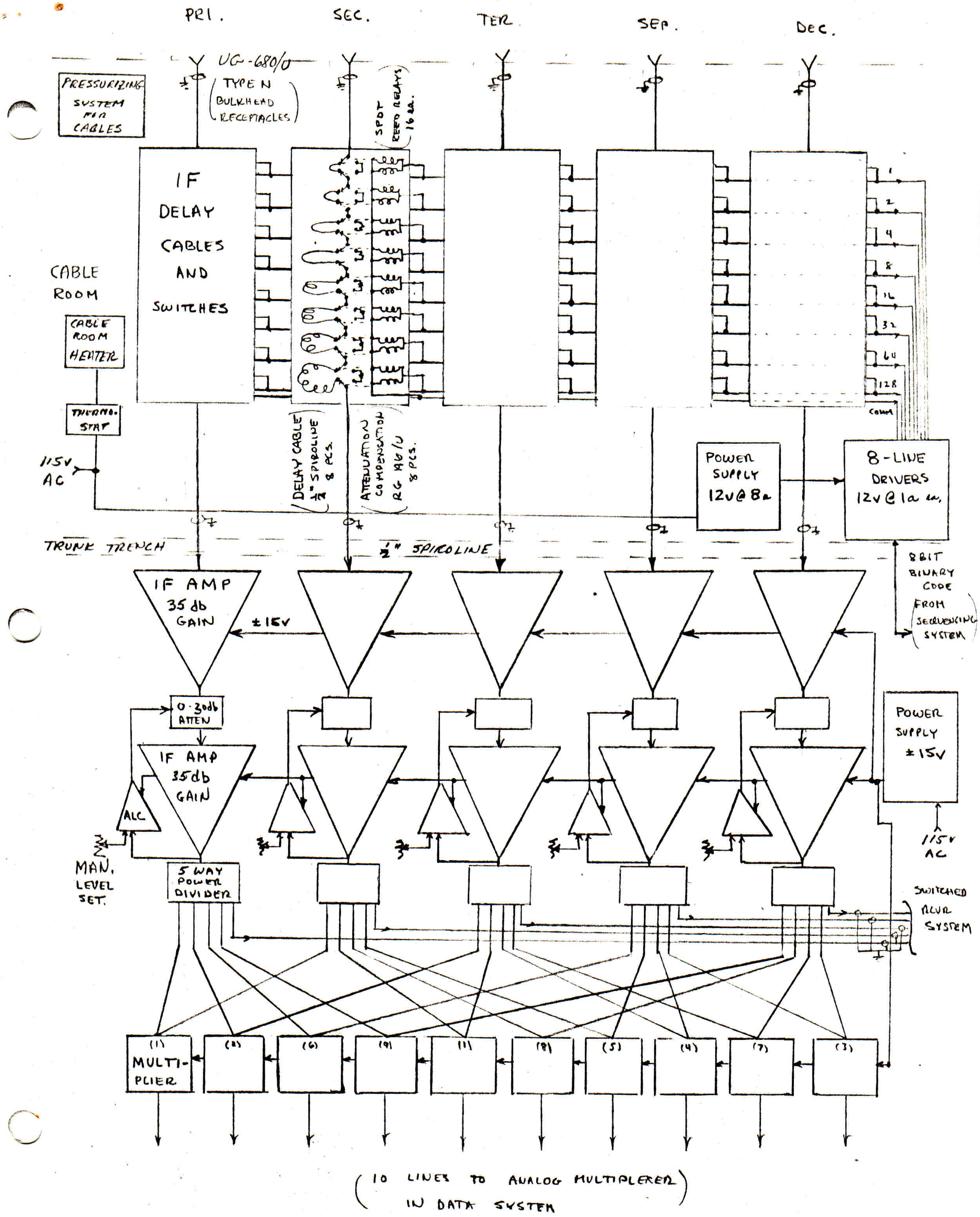
The output component for the highest spatial frequency will be down by 5.56 db or a factor of 0.278 if there is no ALC acting. This factor can be compensated for in the computer.

The slope to the pass band due to the different attenuations at 10 MHz and 20 MHz has an additional effect. For 1157 ft. of cable the high frequency end is 4.63 db below the low frequency end and for 537.5 ft. it is 2.15 db below the low frequency end. (0.344 and 0.61)

α_1 for the long lengths 0.328

α_2 for the short lengths 0.185

$$\Delta f = B \frac{1}{\left(1 + \frac{\alpha_1 \alpha_2}{3}\right)}$$



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This amounts to a 2% loss in the worst case. If the amplifiers were equalized to provide a flat response with zero delay, the loss would be minimized near the meridian.

These reductions in Δf appear to be nuisance factors which can be ignored in most instances.

2. IF Cables (covered above and below).

3. IF Amplifiers

IF Gain: We can determine the gain required in the IF system from the following gain-loss budget starting with these parameters

System Noise Temperature	650 °K Max.
	100 °K Min.
Noise Bandwidth (Double Side Band)	120 MHz Max.
	20 MHz Min.

Power levels corresponding to these extremes at the output of the RF System are:

$$P_{max} = 1.08 \times 10^{-12} \times \text{Net Gain w}$$
$$P_{min} = 2.76 \times 10^{-14} \times \text{Net Gain w}$$

Using a net gain of 33 db which allows 3.4 db of loss in the RF System we have

$$P_{max} = 2.16 \times 10^{-9}$$
$$P_{min} = 5.52 \times 10^{-11}$$

The multiplier input level for 20 mv rms is 8×10^{-6} w into 50Ω.

$$\text{Net IF Gain}_{max} = 51.6 \text{ db}$$
$$\text{Net IF Gain}_{min} = 35.7 \text{ db}$$

IF System Losses:

IF cables to cable house	2.6 db	(537.5')*
Average loss in delay cables	1.5	(310')
" " " switches and connectors	0.9	

*½" Spiroline midband loss of 0.48 db/100' @ 40 MHz.

IF cables to control room	0.5	(100')
5-way power splitter	10.	(7 db theo. + 3 db margin)
Total	15.5 db	

We therefore must provide a gain of from

51.6 + 15.5 = 67.1 db max

to 35.7 + 15.5 = 51.2 db min.

This will be provided with two IF amplifiers having gains of 35 db each and a variable attenuator controlled by the automatic level control unit (ALC) over a range of 0-30 db. The accompanying block diagram shows this arrangement.

4. Automatic Level Control (ALC): ALC operating to keep noise power constant will keep the multiplier input level for uncorrelated noise constant. It will also make it unnecessary to apply correction factors to the gain as a function of delay and consequently improves the gain calibration reliability between calibration observations.

The possibility of system noise temperature change producing gain changes as a result of the ALC is present and needs to be evaluated for the RF System chosen.

Strong sources will cause the ALC to reduce gain in the system and therefore care is required in interpreting results for strong sources. A first order correction factor based on an approximate system noise and the antenna temperature due to the source could be introduced in the computer reduction process.

5. 5-Way Power Splitters: The output from the second IF amplifier will be qually divided in either an active or passive dividing network. Isolation, loss and cost are factors entering into the specification.

6. Multiplier: The multiplier will be the subject of a separate glint. Its basic requirements are:

1. Provide an output proportional to the product of the two input voltages which

a. Has a constant factor of proportionality near unity over a range of correlated input levels from 0 to 20 mv rms.

b. Has an internal noise contribution which allows detection of correlated components at the input 40 db below the uncorrelated noise input level.

c. Has a sufficiently small dc offset with variations in uncorrelated noise input producing negligible output variations compared to detection level in item (b).

2. Maintain these characteristics over the IF pass band and over the range of temperature and voltage variation encountered in the laboratory.

7. Power Supplies

There will need to be separate dc supplies in the cable room and the control room. The cable room will need a 12v 8a supply with 1.0% regulation being satisfactory.

Temperature control of the cable room could require 208v, 1φ, 3 wire power depending on heating and cooling demands.

The control room IF System power will be a common ±15v dc supply which will be of high quality in all respects. Estimates of current requirements are @ +15v 0.5a
@ -15v 1.5a.

8. Packaging Using NIM System

The Nuclear Instrumentation Module System has been found to be a desirable packaging system for the IF System. This is documented in a report from the Radiation Laboratory at Berkeley. (UCRL-11702)

The local supplier is

Precision Metal Fabricators
552 Lewelling
San Leandro, California

At the present time we have one bin and six Size 2 modules which are suitable for the multipliers or IF amplifiers. The system is becoming more widely used and offers many advantages at a reasonable cost.

Job List for IF System

I. Delay Cables and Switches:

1. Evaluate and design switch elements
2. Mechanical design of delay system
3. Design cable room
4. Design delay switch driver
5. Specify logic level and type to be provided by sequencing system
6. Construct delay switches, measure and test delay cable assemblies

II. IF Amplifiers:

1. Write specifications for IF amplifiers, attenuator and ALC circuit, power dividers, and packaging
2. Decide on buy or build
3. Design NIM packaging for devices listed in item 1
4. Assemble and test modules

III. Multiplier

1. Evaluate present multiplier prototype
2. Redesign for production and order parts
3. Build 12 units in NIMs
4. Assemble multipliers in NIM bin
5. Test multiplier assembly.

Delay System Discussion

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The pairs of waveforms from the antennas are essentially cross-correlated in the receiving system. In order that the correlation be maintained at its maximum for a particular pair of waveforms, the time delay between them relative to an arbitrary time must be small. The array introduces delays because a wavefront reaches some antennas earlier than others when the direction of arrival is not on the meridian. The delay system compensates for these delays.

The maximum delay introduced and consequently in need of correction is the time of travel of the incoming signal from antenna No. 1 to antenna No. 5. This distance of 675' corresponds to 686 nanoseconds of delay. Because the hour angle motion is restricted to ±5 h a delay of 675 ns will be sufficient.

Delay corrections are to be inserted in the individual i-f cables from each antenna to the central receiver.

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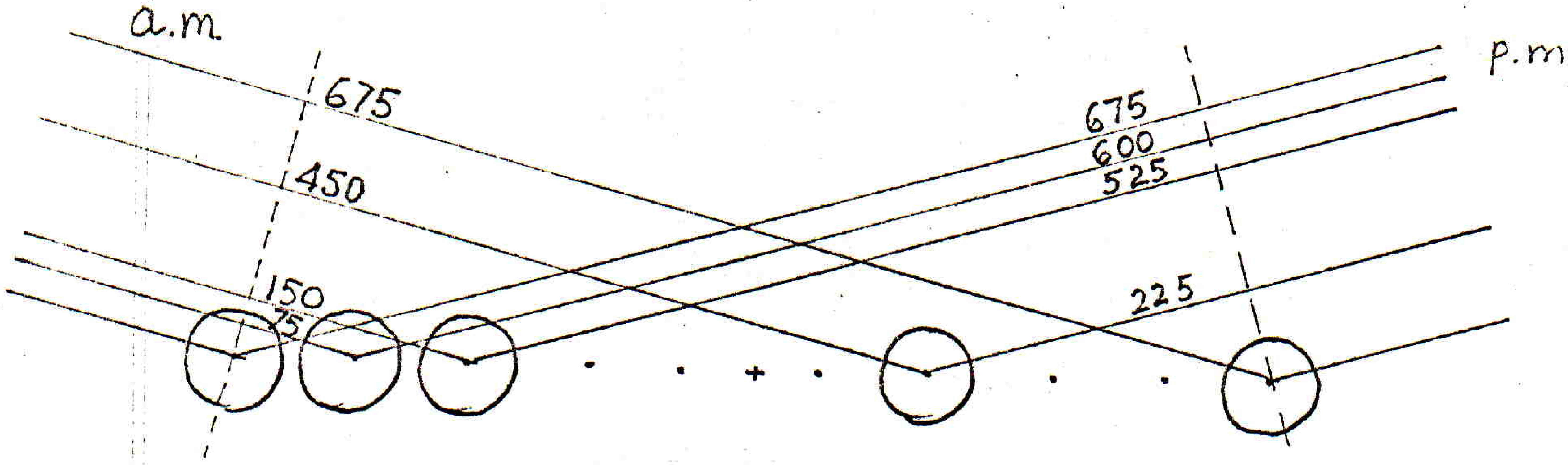
FURTHER DISCUSSION OF DELAY SYSTEM

Some numerical data



am.	0	75	150	450	675	nanoseconds
merid.	0	0	0	0	0	
p.m	675	600	525	225	0	

This diagram summarizes the range in delays in nanoseconds to the various antennas for hour angles ranging from -5^h to $+5^h$.

The velocity of e.m. waves is about 1 foot/ns, which helps in seeing the cable lengths involved, approximately.