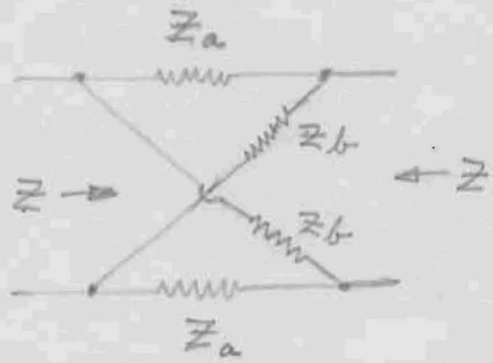
4 February 1961

Lattice Phase Shifters



Pass band when Z_a & Z_b have opposite signs. Then the attenuation constant is zero; image impedance Z is a resistance and phase shift β is:

$$\tan\frac{\beta}{2} = -j\sqrt{Z_a/Z_b} \quad \text{and} \quad Z = \sqrt{Z_a Z_b}$$

Let $Z = 636\Omega$, $Z^2 = .4046\cdot10^6$, $f = 2.13\cdot10^6$, $\omega = 13.38\cdot10^6$

Now $Z_a = Z\tan\frac{\beta}{2}$ and $Z_b = Z^2/Z_a$

Let $\beta = 15^\circ$, $\tan\frac{\beta}{2} = .132$

so $Z_a = 84.0$ ohms, $Z_b = 4820\Omega$

If β leads:

$X_a = \frac{1}{\omega C}$ and $C = 890$ pf

$X_b = \omega L$ and $L = 360\mu h$. about 2pf distributed across Z_b will be 37400Ω which is large compared to 4820Ω in coil.

If β lags:

$X_a = \omega L$ and $L = 6.3\mu h$

$X_b = \frac{1}{\omega C}$ and $C = 15.5$ pf

These are all realizable.

$\beta = 15^\circ = 5.86$m which is larger than variations of ground.

Let $\beta = 5^\circ$, $\tan\frac{\beta}{2} = .044$

so $Z_a = 28.0$ ohm, $Z_b = 14460$ ohms

If β leads:

$X_a = \frac{1}{\omega C}$ and $C = 2670$ pf

$X_b = \omega L$ and $L = 1080\mu h$

about 2pf distributed capacity across Z_b will be 37400Ω which is comparable to Z_b. The effect is to increase apparent inductance of Z_b which must be reduced accordingly.

If β lags:

$X_a = \omega L$ and $L = 2.1\mu h$

$X_b = \frac{1}{\omega C}$ and $C = 5.2$ pf

$\beta = 5^\circ = 1.95$m which is about size of irregularities in ground.

18 Feb 61

Continuing calculations of 4 Feb 61

Assume a new frequency 10% less ~~than~~ $2.13 \cdot 10^6$

$f = 1.916 \cdot 10^6$, $\omega = 12.04 \cdot 10^6$

Thus β = 10% less ~~than~~ $15^\circ = 13.5^\circ$, $\tan\frac{\beta}{2} = .1188$

Keep $Z = 636\,\Omega$, $Z^2 = .4046 \cdot 10^6$

so

$Z_a = 636 \cdot .1188 = 75.6\,\Omega$

$Z_b = \frac{.4046 \cdot 10^6}{75.6} = 5350\,\Omega$

If β leads:

$X_a = \frac{1}{\omega C}$ and $C = 1100\,pf$

$X_b = \omega L$ and $L = 444\,\mu h$

If β lags:

$X_a = \omega L$ and $L = 6.28\,\mu h$

$X_b = \frac{1}{\omega C}$ and $C = 15.54\,pf$.

Lagging phase shifters will be achromatic as long as $\tan\frac{\beta}{2} \propto \frac{\beta}{2}$ or $\beta < 45^\circ$

Leading phase shifters will shift phase ~~most rapidly as~~ in reverse direction to frequency changes but still will be useful up to about $\beta = 30^\circ$ or so where ~~[illegible]~~ Δf = 20% or less, $\Delta f \Delta\beta < 15^\circ$

Apparently the reference point should be lowest spot in the terrain. Then all phase shifters will be lagging type. Thus the array will be achromatic up to about $\Delta f \Delta\beta = 45^\circ$

$\frac{1100}{890} = 1.235$, $\frac{440}{360} = 1.235$ OK

Assume $\beta = 16.7^\circ$, $\tan\frac{\beta}{2} = .147$

Keep $f = 1.916 \cdot 10^6$

$Z_a = 636 \cdot .147 = 93.4\,\Omega$

$Z_b = \frac{.4046 \cdot 10^6}{93.4} = 4330\,\Omega$

If β leads,

$X_a = \frac{1}{\omega C}$ and $C = 890\,pf$.

$X_b = \omega L$ and $L = 360\,\mu h$.

~~Since X_a is determining parameter,~~

When $\beta = 15^\circ$ at $f = 2.13 \cdot 10^6$

The lead at $\Delta f = -10\%$ will be 16.7° when 13.5° is desired.

18 Feb 61

Phase Shifters

at $f = 2130$ kc, $\lambda = 140.9$ m, $1^\circ = 0.391$ m $= 1.284$ ft.

$5^\circ = 6.42$ ft., $10^\circ = 12.84$ ft, $15^\circ = 19.26$ ft.

Use no correction 0 to 3.21 ft terrain change

Use 5° correction 3.21 to 9.63 ft terrain change

Use 10° correction 9.63 to 16.05 ft terrain change

Use 15° correction 16.05 to 22.47 ft terrain change.

Thus all elements will be within $\pm 2\frac{1}{2}^\circ$ of correct.

$7^\circ = 9.0$ ft., $14^\circ = 18.0$ ft., $21^\circ = 27.0$ ft.

Use no correction 0 to 4.50 ft. terrain change

Use 7° correction 4.5 to 13.5 ft. terrain change

Use 14° correction 14.5 to 22.5 ft terrain change.

Thus all elements will be within $\pm 3\frac{1}{2}^\circ$ of correct.

Only two types of shifters will be needed.

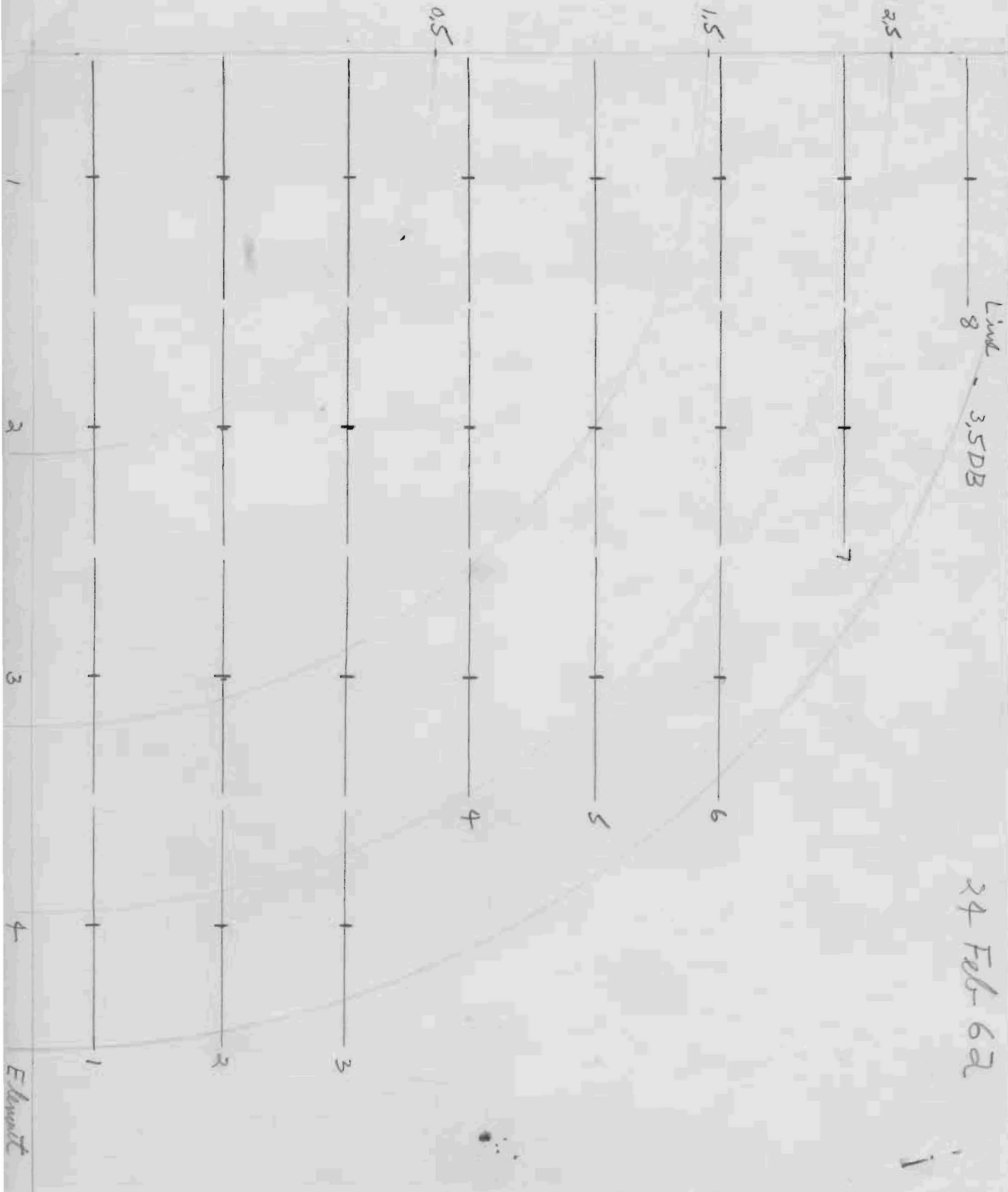
Use 0 correction 0 to ~~[illegible]~~ $6\frac{1}{2}$ ft $\qquad 10^\circ = 12.84$ ft.

Use 10° correction $6\frac{1}{2}$ to $19\frac{1}{2}$ ft

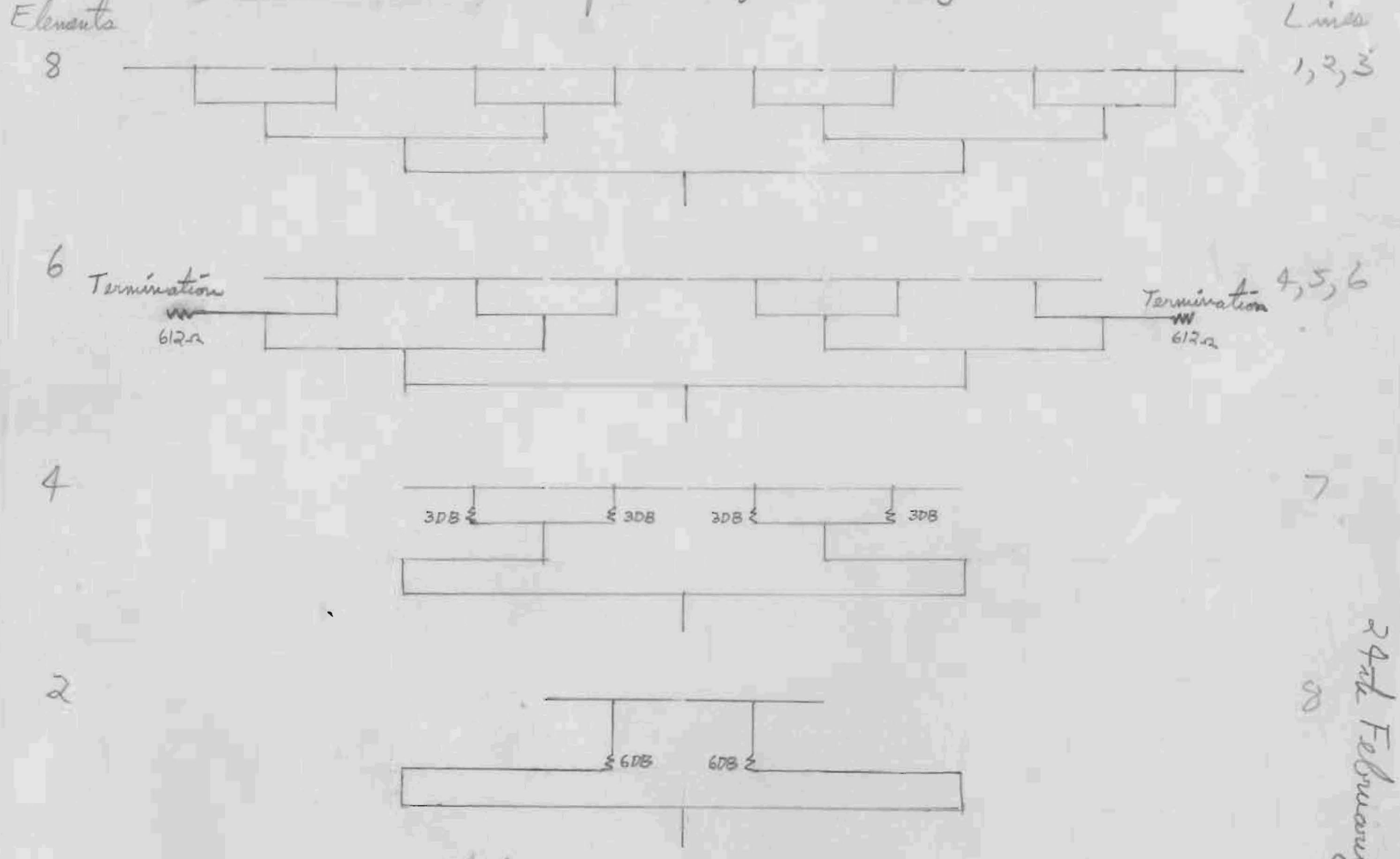
all elements $\pm 5^\circ$ of correct

only one type of shifter

DB Attenuation



Attenuation to Compensate for Missing Elements



Scale 1 inch = 440 feet.

24th February 62

This design used.   24 Feb 1962

Distribution of Current Over Array

The edge current to be 0,707 times center current (3DB) tapered according to cosine law; $45^\circ / 7.5'' = 6^\circ$ per inch

DB attenuation	0,5	1.5	2.5	3,5
Current ratio	.944	.842	.750	.668
$\theta = \cos^{-1}$ (ratio)	19,28°	32.65°	41.40°	48.10°
radius, inches	3,21	5,44	6.90	8,02

all elements will have correct currents ± 0,5 DB = ± 6%
Decoupling mask of 3DB over entire array
Taper plus missing element plus mask in DB at each position.

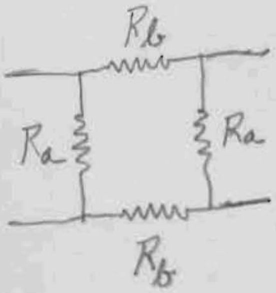
Line \ Element	1	2	3	4
8	3 + 6 + 3 = 12			
7	2 + 3 + 3 = 8	3 + 3 + 3 = 9		
6	2 + 0 + 3 = 5	2 + 0 + 3 = 5	3 + 0 + 3 = 6	
5	1 + 0 + 3 = 4	2 + 0 + 3 = 5	2 + 0 + 3 = 5	
4	1 + 0 + 3 = 4	1 + 0 + 3 = 4	2 + 0 + 3 = 5	
3	0 + 0 + 3 = 3	1 + 0 + 3 = 4	2 + 0 + 3 = 5	3 + 0 + 3 = 6
2	0 + 0 + 3 = 3	1 + 0 + 3 = 4	1 + 0 + 3 = 4	3 + 0 + 3 = 6
1	0 + 0 + 3 = 3	0 + 0 + 3 = 3	1 + 0 + 3 = 4	3 + 0 + 3 = 6

25 Feb 1962

Attenuator Pads for Antenna Couplers

π type

$R = Z = 612\ \Omega$



DB	α	α^2	$\alpha+1$	$\alpha-1$	α^2-1	Ra ohms	Rb ohms
3	1.414	2.00	2.414	.414	1.00	3570	108
4	1.585	2.52	2.585	.585	1.52	2704	147
5	1.778	3.16	2.778	.778	2.16	2185	186
6	2.00	3.98	3.000	1.00	2.98	1835	228
8	2.51	6.31	3.51	1.51	5.31	1422	324
9	2.82	7.95	3.82	1.82	6.95	1285	377
12	3.98	15.84	4.98	2.98	14.84	1024	570

These resistors have about 0.5 pf shunt capacity. at 2.13 mc the $X_c = 1/6.28\cdot 2.13\cdot 10^6 \cdot 0.5\cdot 10^{-12} = 10^6/6.68 = 150{,}000$ ohms shunt reactance which is large compared to the largest resistor of 3570 ohms.

Pad		Ra		Rb		Terminations
DB	Number	Ohms	Commercial	Ohms	Commercial	
3	16	3570	3300	108	100	12 resistors of
4	28	2704	2700	147	150	612 ohms.
5	24	2185	2200	186	180	or
6	16	1835	1800	228	220	560 Ω commercial
8	4	1422	1500	324	330	
9	4	1285	1200	377	390	
12	4	1024	1000	570	560	

25 Feb 62

Carbon Resistors about $\frac{5}{8}$" long

Required		Purchase			
Ohms	Number	Ohms	Number	Accuracy	
108	34	100	70	10%	
147	58	150	60	5%	
186	50	180	50	5%	
228	34	220	40	5%	✓
324	10	330	10	5%	✓
377	10	390	20	10%	✓
570	10	560	10	5%	✓
1024	10	1000	10	5%	✓
1285	10	1200	20	10%	
1422	10	1500	20	10%	
1835	34	1800	40	5%	
2185	50	2200	50	5%	
2704	58	2700	60	5%	
3570	34	3300	70	10%	
This allows one extra of each size pad.					
612	15	680	30	10%	✓

Grote Reber

23 March 61

Parallel round wires from Terman

Center spacing D
diameter d

Capacity $= 12.07 \cdot 10^{-12} / \log_{10} \frac{2D}{d}$ farads per meter

Inductance $= 0.921 \cdot 10^{-6} \log_{10} \frac{2D}{d}$ henries per meter

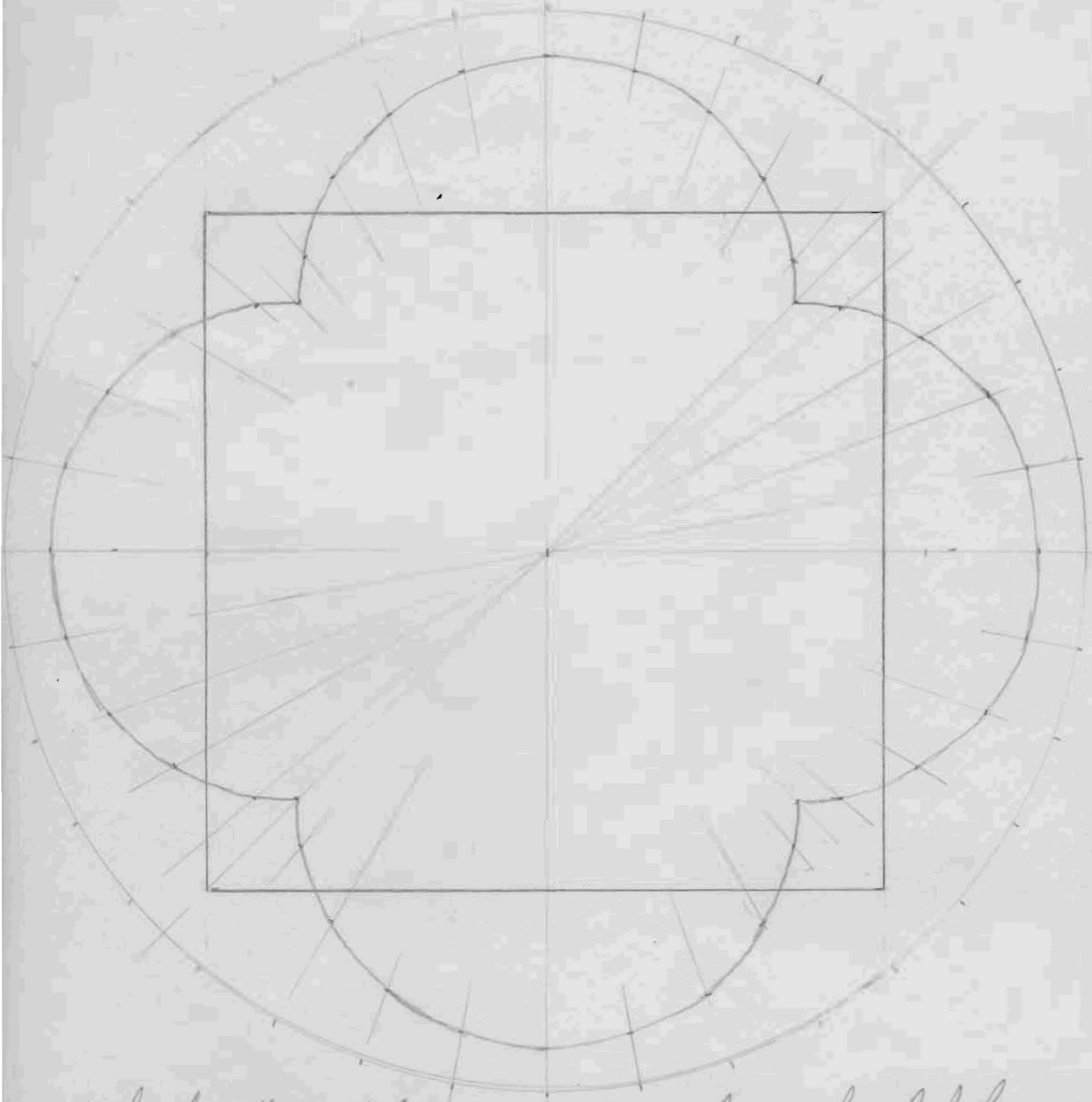
Impedance $= (L/C)^{1/2} = 276 \log_{10} \frac{2D}{d}$ ohms

Coupling $= K = M / (L_1 L_2)^{1/2}$

Line attenuation is:

$$\gamma = \frac{0.03143 \sqrt{f_{mc}}}{d_{in} \log_{10} \frac{2D}{d}} = \frac{8.686 \sqrt{f_{mc}}}{d_{in} Z_{ohms}}$$ DB per 1000 ft.

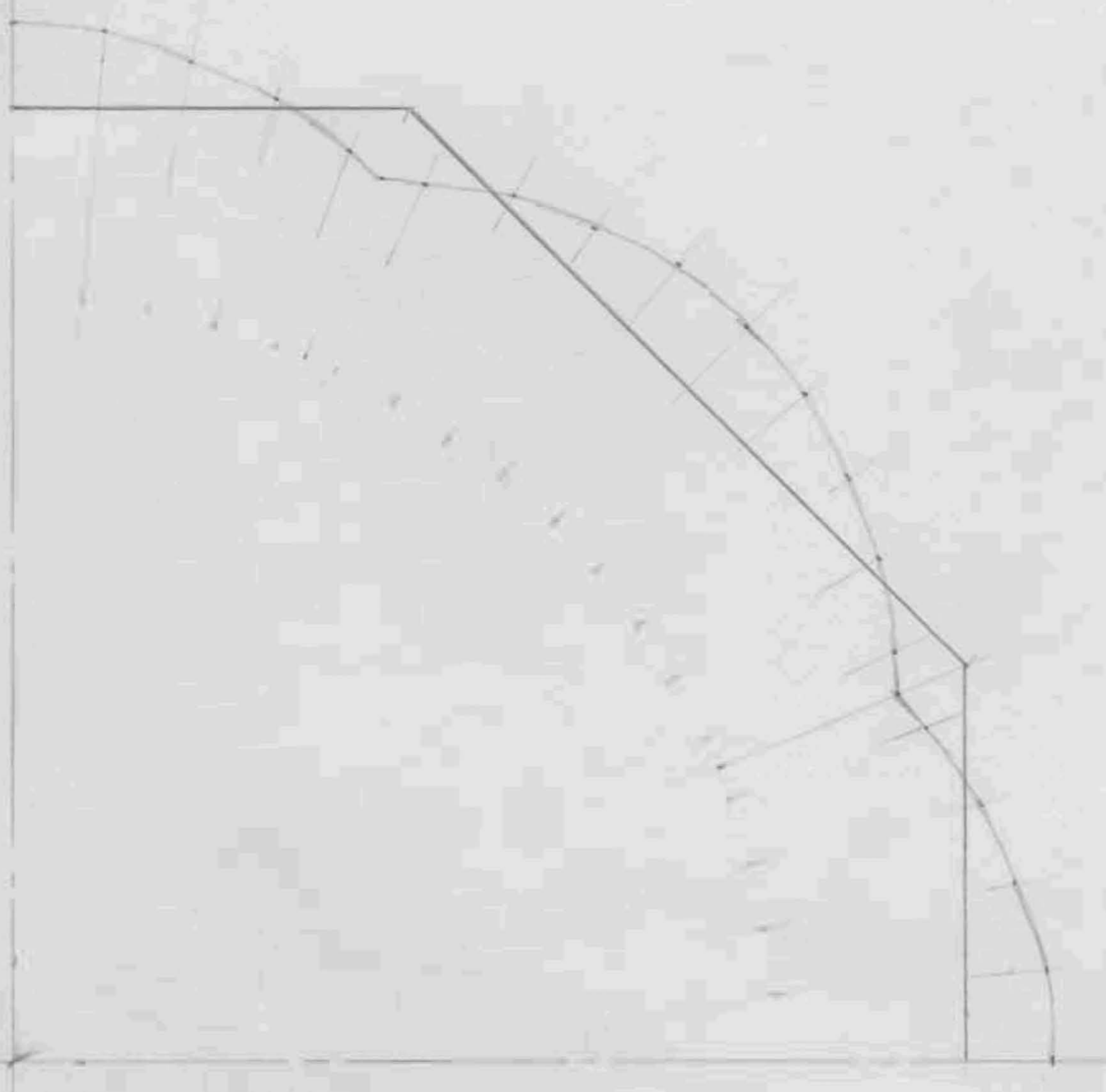
24 March 61



Uniformly illuminated square aperture produces cloverleaf beam.

24 March 61

Uniformly illuminated octagonal aperture produces a scolloped beam, nearly circular



25 March 61

Line Attenuation

Wide spacing reduces the variation of impedance due to water on wire, and swinging and vibration of wires.

Let $d = 0.080''$, $D = 6\frac{5}{8}''$, then $Z = 612$ ohms

at 2.13 mc, $\lambda = 140.9$ m, so $D = 6.625/39.37 \cdot 140.9 = .0012\lambda$

Use a line support every 110 ft = 33.5 m = 0.238λ which is close to $\lambda/4$. This will reduce standing waves.

$$\gamma = \frac{8.686\,(2.13)^{1/2}}{.080 \cdot 612} = 0.259 \text{ db}/1000 \text{ ft}.$$

East and West Feed lines

1st Branch 880 feet = 0.228 DB

2nd Branch 440 feet = 0.114 DB

3rd Branch 220 feet = 0.057 DB

Loss impedance between adjacent antennas 0.114 DB

Loss impedance between adjacent pairs 0.228 DB

Loss impedance between opposite halves 0.456 DB

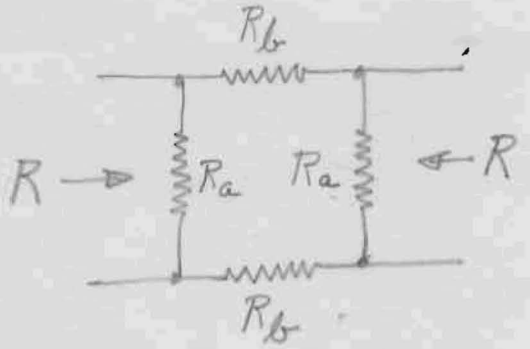
On N/S line the maximum asymmetry when $\theta = 45°$ gives an excess line length of $30a = 30 \cdot 77.8$ ft = 2334 feet. The right end E/W line will have $2.334 \cdot 0.259 = 0.605$ DB more attenuation than left end E/W line. 0.605 DB is small compared to 3 DB taper of illumination, so system is OK.

26 March 61

Attenuator Pads

$$\alpha = \frac{\text{load current without attenuator}}{\text{load current with attenuator}}$$

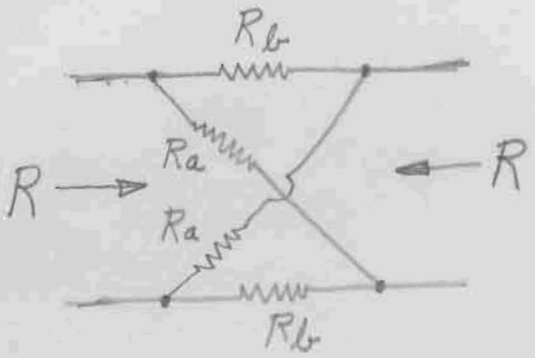
TYPE



$$R_a = R\left(\frac{\alpha+1}{\alpha-1}\right)$$

$$R_b = \frac{R(\alpha^2-1)}{4\alpha}$$

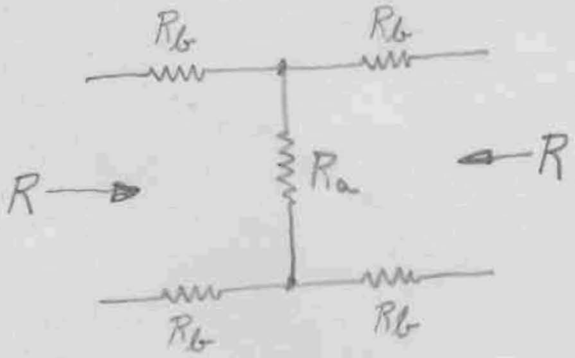
π



$$R_a = R\left(\frac{\alpha+1}{\alpha-1}\right)$$

$$R_b = R\left(\frac{\alpha-1}{\alpha+1}\right)$$

Lattice



$$R_a = \frac{2\alpha R}{\alpha^2-1}$$

$$R_b = \frac{R}{2}\left(\frac{\alpha-1}{\alpha+1}\right)$$

T