Case Study

Avionics Research Facility[1]

A group of foreign investors is interested in producing and marketing a line of high-technology products with applications to avionics. The group is considering two alternative means of securing the necessary technology. The first possibility is to license the technology from an existing manufacturer who does not offer the products in the geographic markets that the group intends to serve. The second is that the group could invest in a new research facility and develop the products on its own.

Clearly, licensing is the easier and faster alternative. However, the investors are concerned that the existing manufacturer may seek an unjustifiably high royalty for granting the license. The investors also see some advantages to developing their own research capabilities. By doing so, they could gain expertise and capabilities to develop other related products in the future. As a means of evaluating the alternatives, the investors retained an engineering consulting firm to prepare an estimate of the cost of developing the products using a yet-to-be-constructed "green field" research facility.

If the investors decide to construct the facility themselves, product design and development activities would begin immediately in a temporary facility the investors would lease. Hiring and other initial steps in the start-up would begin next month, in January 1996. If the licensing option is not chosen, the investors wish to complete development of all products over a five-year period.

Products

The investors plan to develop two types of products that are used in conjunction with each other. The primary product type is a transmitter/receiver unit. The investors intend to produce eight different models of transmitter/receiver units (A through H), with varying features and capabilities. The units also vary in terms of the research and development efforts that are expected to be required. Rather than directly estimating the research and development cost of each, the consultants used a customary approach based on estimating the R and D cost for one type of unit. The R and D costs of the others are estimated by applying "relative difficulty factors" to the base estimate. Exhibit 1 shows the relative difficulty factors for the various transmitter/receiver units the investors plan to develop.

The secondary product type is a power regulator unit. The investors intend to develop nine models of power regulators (R through Z). The power regulators also vary

[1] The identities of the parties, nature of the products, and time frame of the case are disguised to preserve confidentiality.

in terms of development difficulty, as shown in Exhibit 2. In general, power regulators require less development effort than transmitter/receiver units. Consequently, design teams can be somewhat smaller.

Sizing the Project

The consultants based their estimate of development cost on construction of a hypothetical facility that would carry out the development efforts. Product-development timing considerations and technical requirements associated with designing, constructing, and testing prototype products jointly determined the size and configuration of the facility. The consultants assumed that each transmitter/receiver unit and each power regulator would be assigned to a "design team" of engineers and technicians. Each design team would consist of four to eight people and would require a similar number of direct support personnel, such as draftsmen and machinists.

The consultants determined that during the five-year period, each transmitter/receiver team could complete the design work for two units and that four additional teams could handle development of all nine power regulators. Using six as the average team size for the total of eight teams, the consultants estimated that the headcount of design teams would be 48. An additional 48 people were estimated to be required for direct support. Beyond this, the consultants estimated that overhead support would require an additional 48 people and that management, general, and administrative (MG&A) support would require 10 people. The consultants used the resulting total, 154 people, as a basis for sizing the hypothetical facility. Exhibit 3 contains a summary breakdown of the estimated staffing requirements.

Based on industry norms, the consultants assumed that 400 square feet of floor space would be required per employee. The resulting estimate of facility size is about 60,000 square feet. Exhibit 4 contains a breakdown of the consultant's estimate of facilities requirements. The exhibit also contains the consultant's estimate of the capital cost of the facility. The facility would require from 6 to 12 months to construct and the early stages of development would be carried out in temporary facilities.

To complete the estimate of facilities cost, the consultants developed a detailed list of equipment requirements and associated costs. Exhibit 5 contains a summary of the equipment cost estimate by function.

Program Schedule

The consultants assumed that the development facility would come on line over a period of months, and that hiring and training would take place during the first year. Exhibit 6 contains the consultants' overall program schedule of activities by month for the five years of the venture. Exhibit 7 is a graphical depiction of the schedule. Shading in the chart reflects program initiation activities, first-round design and development activities, and second-round design and development activities.

Based on the program schedule, the consultants developed a hiring plan. The plan reflects the mix of capabilities that the project would require at various times, ranging from senior level management, and experienced engineers to clerical and custodial staff. A condensed version of the hiring plan is contained in Exhibit 8. Exhibit 9 shows the cumulative staffing plan and provides information on hourly salary and benefits costs.

As a means of estimating cost, the consultants developed a detailed schedule of the steps involved in completing the two benchmark products and estimated the person-months of time required by calendar month for direct engineering and other direct employees. Their estimates of labor hour requirements are summarized in a three-dimensional matrix of design and development steps, calendar month, and type of labor input required. An entry in the matrix represents the number of person months of a particular type of employee required for that process step in that month. The estimates are summarized in a condensed format in Exhibit 10 for the two benchmark products.

Development Cost Estimate

The consultants used a "build-up" approach to estimate the total cost of the facility. Exhibit 11 shows the estimated cost of fully developing prototypes for the two benchmark products. In both cases, they used their estimates of total person months, together with the most recent wage rate data from the Bureau of Labor Statistics to estimate direct labor costs. They assumed that a typical month includes 167 work hours. To estimate factory overhead, they applied a factor of 1.75 to the direct labor estimate. The factor was based on industry norms for the relation of factory overhead to direct labor. To estimate materials costs, they assumed that a certain number of prototypes would need to be produced and tested before a successful prototype was achieved. More specifically, they assumed that 30 iterations would be required to achieve an acceptable product of either type and that final testing would require three completed prototypes. Finally, they applied a factor of 0.1 to the estimate of total direct factory cost for management, general, and administrative overhead. The resulting estimate of total labor and material cost for product A is $5.624 million. For product R, the estimate is $3.046 million.

In Exhibit 12, the consultants used the estimates from Exhibit 11 and the difficulty factors from Exhibits 1 and 2 to estimate the total labor and materials costs of manufacturing all of the planned products. They recognized that the teams will be cutting their teeth on the first round of products, and that the learning from the first round will result in some cost savings in the second round. Accordingly, they applied a learning factor adjustment of .9 to the second round of products. Their resulting estimate is that the labor and materials costs of developing the products will be $65.8 million. Of this total, $33.3 million is for transmitter/receivers and $32.5 million is for power regulators.

The cost estimates in Exhibit 12 do not tell the full story. First, they do not include the first-year costs associated with developing the facility, staffing it, and training the development teams. Second, they do not include the cost of leasing the temporary facility.

Third, they do not include the costs of acquiring and equipping the design and development facility. The consultants estimated first-year costs at the annual "running rate" of labor based on the four years of operation reflected in Exhibits 11 and 12. That is, they subtracted materials expense for both products in Exhibit 11, and used the results as estimates of labor costs for the benchmark products in Exhibit 12. To derive the one-year running rate, they divided the total in the adjusted Exhibit 12 by four years. The resulting estimate of first-year labor costs is $13.774 million. The temporary facility lease cost was estimated based on the 60,000 square-foot facility the venture would eventually need, and an annual lease rate of $8.50 per square foot. Other elements of cost are as developed in the exhibits and figures. The estimated total cost, as shown in Exhibit 13, is $90.8 million.

Investor Reaction

The consultants presented their estimates to the investor group at a meeting in late 1995. While the investors were satisfied with the technical/engineering expertise the consultants brought to the analysis, they were less satisfied with the financial aspects of the report. Various members of the team raised a series of issues:

1.) Assuming that the total cost estimate is correct, the report is not very helpful for telling them *when* the cash will be needed. Clearly, it is not all needed at the start, nor is it needed at a uniform rate per year.

2.) The estimate of first-year cost may be too high. Why, if the venture is starting from a base of zero, is first year labor cost assumed to be as high as in subsequent years? Also, even if the figure of 400 square feet per worker is used, it seems unlikely that a 60,000 square-foot facility would be required in the first year. Could the scheduling information the consultants generated be used to develop a better estimate of first-year cost?

3.) The consultants seem to be ignoring the effects of inflation on cost. One investor pointed to the data the consultants used to generate their wage and cost assumptions (Exhibits 14 and 15). Could the consultants have used the data from those exhibits to forecast wages and other costs more accurately?

4.) Because of the structure of the report, it is difficult for the investors to evaluate the sensitivity of cash needs to specific assumptions. The investors would like to have an integrated model they can use to test the effects of changing assumptions. For example, an integrated model would enable them to assess sensitivity to the estimates of total cost and timing of cash needs to factors such as degree of difficulty, overhead cost, and materials cost.

5.) Beyond these technical matters, the investors had some other concerns. Most fundamentally, they questioned how the results of the analysis could be used to determine a reasonable royalty for licensing the technology instead of developing it from the ground up. As aspects of this, they were concerned about how to

consider the foregone opportunity of selling the products during the five years that would be required if they decided not to license. On the other hand, they wondered how to assess the benefits of having their own research and development team and facility. After all, if things went according to plan, in five years they would have a state-of-the-arts facility and a well-trained group of technical teams.

Exhibit 1[2]

Transmitter/Receiver Development Difficulty Factors	
Product	**Relative Difficulty Factor**
A (benchmark)	100%
B	50%
C	50%
D	60%
E	60%
F	70%
G	120%
H	120%

Exhibit 2

Power Regulator Development Difficulty Factor	
Product	**Relative Difficulty Factor**
R (benchmark)	100%
S	100%
T	100%
U	100%
V	120%
W	120%
X	140%
Y	160%
Z	200%

[2] Downloadable Excel files are available for all exhibits.

Exhibit 3

Staffing Requirements		
General Management		3
Sender/Receiver Units		40
Four teams of six	24	
Materials and testing	14	
Clerical staff	2	
Power Regulators		30
Four teams of five	20	
Fabrication	7	
Clerical staff	3	
Facilities and Maintenance		19
Services		50
Finance and Administration		10
Human Resources		2
Total		**154**

Exhibit 4

Facilities Space Allocation (sq. ft.) and Cost Estimate ($000)		
Function	**Space**	**Cost**
Basic facility		$3,600
Office space	15,000	225
Cleanroom	4,000	400
Processing	2,000	100
Manufacturing test lab	6,000	300
Machine shop	5,000	100
Environmental lab	4,000	80
Inspection	3,000	45
Testing and packaging	10,000	200
Stockroom	3,000	24
Cafeteria, halls, restrooms	8,000	38
Total	**60,000**	**$5,112**

Exhibit 5

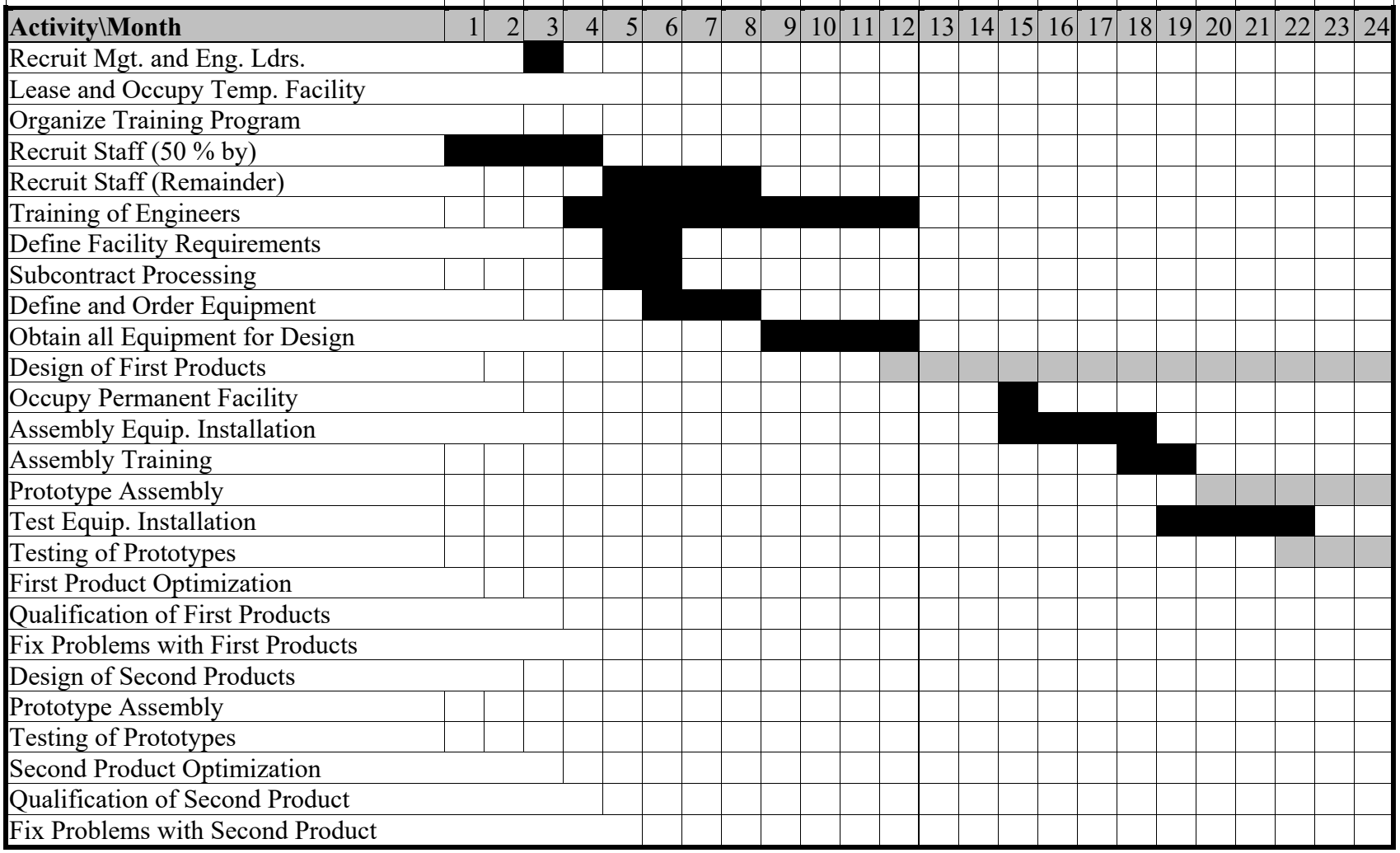
Equipment and Improvements Cost Estimate ($000)	
Administration	$510
Assembly	851
Exhaust	185
Processing	800
Machine shop	525
Inspection	200
Laboratory	285
Stockroom	25
Sender/Receiver testing	1,700
Power Regulator testing	500
Total	**$5,581**

Exhibit 6

Program Schedule	
Activity	**Month**
Year 1	
Recruit management and engineering leadership	3
Lease and occupy temporary facility	2
Organize training program	2
Complete recruiting of first 50% of staff	4
Begin training	4
Define facility requirements	6
Complete subcontracting arrangements	6
Complete recruiting of remaining staff	8
Obtain all equipment needed for development work	12
Training sufficient to begin design work	12
Year 2	
Begin design of 8 products (8 teams)	12
Occupy facility	15
Begin equipment installation	15
Assembly processing equipment operative	18
Begin assembly training and equipment debugging	18
Begin prototype assembly	20
Testing facilities complete	21
Begin prototype testing	22
Year 3	
Complete design work on first-round products	26
Begin design of second-round products	26
Begin iterative optimization of first-round products	28
Complete optimization of first-round products	36
Begin assembly of second-round products	36
Year 4	
Begin qualification of first-round products	36
Complete design work on second-round products	40
Begin iterative optimization of second-round products	40
Complete qualification of first-round products	40
Fix any problems with first-round products	48
Year 5	
Complete optimization of second-round products	48
Complete qualification of second-round products	52
Fix any problems with second-round products	56

Exhibit 7

Project Schedule



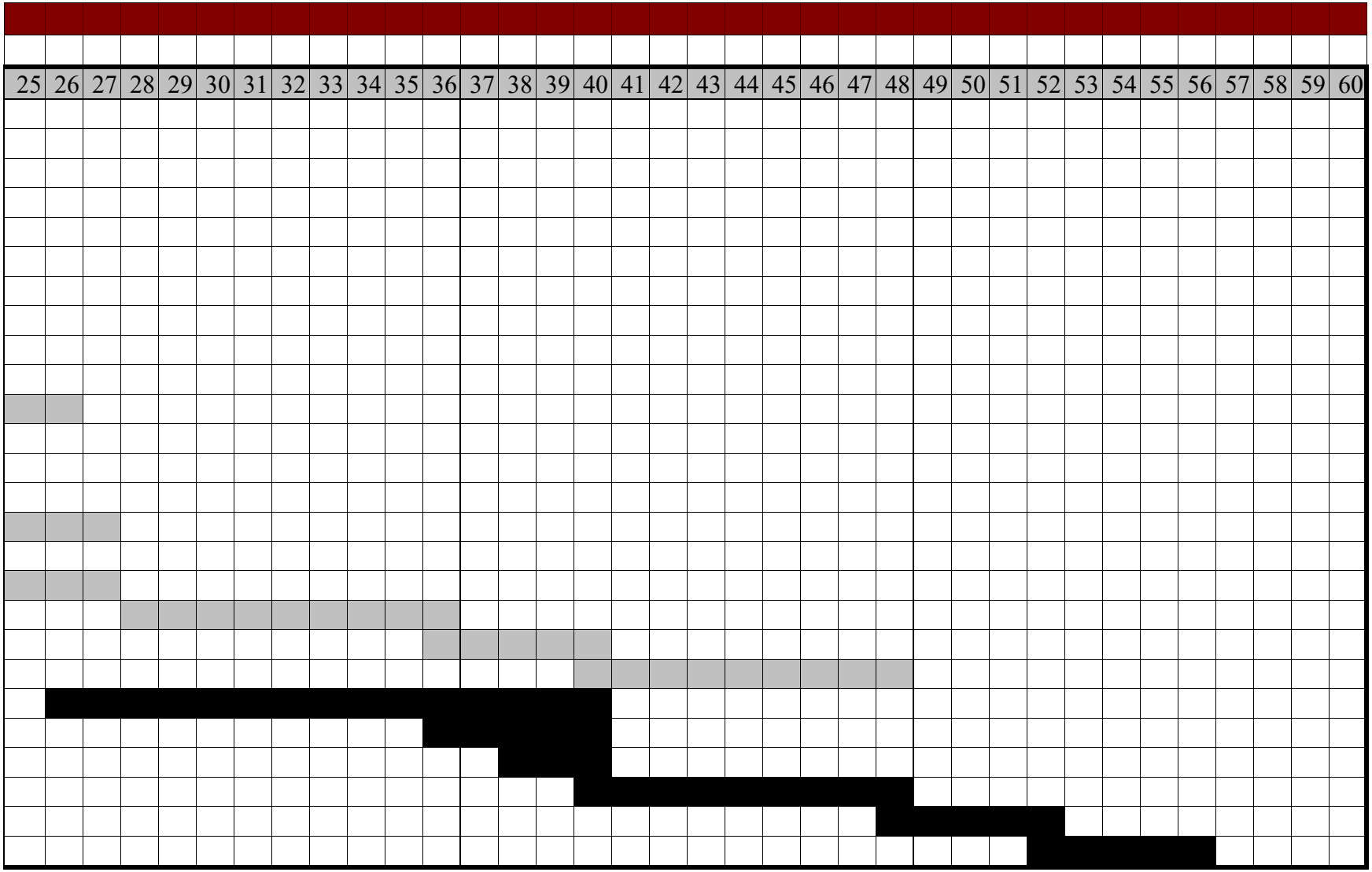

25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

Exhibit 8

Hiring Plan	Total	1	2	3	4	5	6	7	8
Management	3	1	1	1					
Human Resources	2	1	1						
Finance and Administration	10	4	3	2	1				
Services	50	1	1	1	3	10	10	13	11
Facilities and Equipment	19	5	1	3	1	3	2	2	2
S/R Engineering	30	6	4	7	8	5	6	4	
Clerical	2	1		1					
Project Engineer	24	5	4	4	5	3	3		
Testing and Materials	14			2	3	2	3	4	
Power Mgt. Engineering	30	6	5	8	6	2	1	1	1
Clerical	3	1		1		1			
Project Engineer	20	5	4	6	5				
Testing and Fabricating	7		1	1	1	1	1	1	1
Total	**154**	**24**	**16**	**22**	**19**	**20**	**19**	**20**	**14**
Cumulative		**24**	**40**	**62**	**81**	**101**	**120**	**140**	**154**

Exhibit 9

Staffing Plan	Rate	Total	1	2	3	4	5	6	7	8	9 to end
Management	$56.41	3	1	2	3	3	3	3	3	3	3
Human Resources	$14.86	2	1	2	2	2	2	2	2	2	2
Finance and Administration	$13.03	10	4	7	9	10	10	10	10	10	10
Services	$28.83	50	1	2	3	6	16	26	39	50	50
Facilities and Equipment	$31.84	19	5	6	9	10	13	15	17	19	19
S/R Engineering											
Clerical	$8.94	2	1	1	2	2	2	2	2	2	2
Project Engineer	$48.07	24	5	9	13	18	21	24	24	24	24
Testing and Materials	$31.67	14	0	0	2	5	7	10	14	14	14
Power Mgt. Engineering											
Clerical	$8.94	3	1	1	2	2	3	3	3	3	3
Project Engineer	$48.07	20	5	9	15	20	20	20	20	20	20
Testing and Fabricating	$16.41	7	0	1	2	3	4	5	6	7	7
Total		154	24	40	62	81	101	120	140	154	154

Exhibit 10

Program Schedules for Benchmark Products
(Person Months)

Month	Product A: Sending/Receiving Unit			Product B: Power Regulator	
	Project Engineer	Testing and Materials		Project Engineer	Testing and Fabricating
13	6.00	1.00		4.00	0.00
14	8.00	1.00		5.75	0.25
15	9.00	1.00		6.50	1.00
16	10.00	2.00		6.25	1.50
17	8.00	3.00		5.75	2.00
18	8.00	2.00		4.75	1.75
19	6.00	2.00		3.00	1.50
20	6.00	2.00		2.50	1.50
21	7.00	2.00		3.25	1.50
22	8.00	2.00		2.75	1.50
23	8.00	3.00		2.50	1.00
24	6.00	4.00		2.50	1.00
25	7.00	2.00		3.00	2.00
26	7.00	2.00		7.50	3.00
27	5.00	2.00		3.25	3.00
28	5.00	2.00		1.75	2.00
29	5.00	2.00		3.50	1.50
30	5.00	2.00		4.25	1.00
31	5.00	2.00		4.25	2.00
32	5.00	2.00		2.50	2.00
33	5.00	2.00		2.50	2.00
34	5.00	2.00		3.25	2.00
35	5.00	2.00		3.25	2.00
36	5.00	2.00		3.25	2.00
37	0.00	0.00		0.00	0.00
38	0.00	0.00		0.00	0.00
39	0.00	0.00		0.00	0.00
40	0.00	0.00		0.00	0.00
41	0.00	0.00		0.00	0.00
42	0.00	0.00		0.00	0.00
43	0.00	0.00		0.00	0.00

44	0.00	0.00		0.00	0.00
45	0.00	0.00		0.00	0.00
46	0.00	0.00		0.00	0.00
47	0.00	0.00		0.00	0.00
48	0.00	0.00		0.00	0.00
49	0.00	0.00		0.00	0.00
50	0.00	0.00		0.00	0.00
51	0.00	0.00		0.00	0.00
52	0.00	0.00		0.00	0.00
53	0.00	0.00		0.00	0.00
54	0.00	0.00		0.00	0.00
55	0.00	0.00		0.00	0.00
56	0.00	0.00		0.00	0.00
57	0.00	0.00		0.00	0.00
58	0.00	0.00		0.00	0.00
59	0.00	0.00		0.00	0.00
60	0.00	0.00		0.00	0.00
Total	154.00	49.00		91.75	39.00

Exhibit 11

Total Cost for Product A (Transmitter/Receiver)			
	Total Months	**Hourly Earnings**	**Total**
Project Engineer	154	$48.07	$1,236,264
Testing and Materials Staff	49	$31.67	$259,156
Total Direct Labor			$1,495,420
Factory Overhead			$2,616,985
Tooling		$100,000	
Fixtures		$50,000	
Parts		$850,000	
Total Materials			$1,000,000
Total Factory Costs			$5,112,405
MG&A Costs			$511,240
Total			$5,623,645

Total Cost for Product R (Power Regulator)			
	Total Months	**Hourly Earnings**	**Total**
Project Engineer	91.75	$48.07	$736,541
Testing and Materials Staff	39	$16.41	$106,878
Total Direct Labor			$843,419
Factory Overhead			$1,475,983
Tooling		$90,000	
Fixtures		$80,000	
Parts		$280,000	
Total Materials			$450,000
Total Factory Costs			$2,769,402
MG&A Costs			$276,940
Total			$3,046,342

Exhibit 12

Product Development Labor and Materials Cost Estimate

Transmitter/Receivers	Initiation Month	Difficulty Factor	Learning Factor	Estimated Cost
A (benchmark)	13	1.0	1.0	$5,623,645
B	13	0.5	1.0	$2,811,823
C	13	0.5	1.0	$2,811,823
D	13	0.6	1.0	$3,374,187
E	26	0.6	0.9	$3,036,768
F	26	0.7	0.9	$3,542,896
G	26	1.2	0.9	$6,073,537
H	26	1.2	0.9	$6,073,537
Total				$33,348,215

Power Regulators	Initiation Month	Difficulty Factor	Learning Factor	Estimated Cost
R (benchmark)	13	1.0	1.0	$3,046,342
S	13	1.0	1.0	$3,046,342
T	13	1.0	1.0	$3,046,342
U	13	1.0	1.0	$3,046,342
V	13	1.2	0.9	$3,290,049
W	26	1.2	0.9	$3,290,049
X	26	1.4	0.9	$3,838,391
Y	26	1.6	0.9	$4,386,732
Z	26	2.0	0.9	$5,483,416
				$32,474,006
Total Labor and Material				$65,822,221

Exhibit 13

Summary of Total Cost Estimate for Design and Development	
First-year costs	
Cost of recruiting, training, and setting up facility	$13,773,805
First-year facilities lease	$510,000
Total	$14,283,805
Permanent Facilities and Equipment	
Facilities (Exhibit 4)	$5,112,000
Equipment and Improvements (Exhibit 5)	$5,581,000
Total	$10,693,000
Development Labor and Materials	
Transmitter/Receiver Units (Figure 6)	$33,348,215
Power Regulators (Figure 6)	$32,474,006
Total	$65,822,221
Total Cost Estimate	$90,799,026

Exhibit 14

Capital Equipment Producer Price Index

Seasonally
Adjusted
Group : Stage of processing
Item : Capital equipment
Base Date : 1982:00

Data:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	121.0	121.4	121.8	122.1	122.1	122.5	122.9	123.3	123.8	124.1	124.5	124.8
1991	125.6	125.8	126.0	126.1	126.5	126.6	126.7	126.8	127.2	127.6	127.8	128.0
1992	128.2	128.3	128.6	129.0	129.0	129.0	129.1	129.4	129.4	129.7	129.9	130.1
1993	130.4	130.7	130.9	131.1	131.2	131.1	131.5	131.6	131.7	131.8	132.2	132.4
1994	132.9	133.1	133.3	133.7	134.1	134.3	134.4	134.6	134.9	134.4	134.4	134.9
1995	135.5	135.8	135.9	136.3	136.5	136.6	136.8	136.9	136.9	137.6	138.0	137.9

Bureau of Labor Statistics
catron_b@bls.gov

Exhibit 15

Materials Producer Price Index													
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Ann**
1990	115.5	115.9	117.3	117.5	117.9	118.2	121.9	122.2	121.1	121.3	121.8	121.0	119.3
1991	121.7	121.7	122.8	123.3	123.1	123.2	127.7	127.1	126.3	126.3	126.0	126.6	124.6
1992	126.5	126.7	126.8	127.2	127.2	127.2	129.1	129.7	129.7	129.6	129.9	129.9	128.3
1993	134.3	135.0	135.7	135.7	135.6	135.7	137.3	137.6	137.6	137.8	137.8	137.9	136.5
1994	137.9	137.9	137.9	138.0	138.2	138.6	140.1	140.3	139.4	139.5	139.5	139.4	138.9
1995	140.2	140.5	140.5	140.8	141.3	143.7	144.0	142.3	142.4	142.4	142.4	142.2	141.9

Series ID : pcu3812#1
Not Seasonally Adjusted
Industry : Search, detection, navigation, and guidance systems and aeronautical and nautical navigation systems
Product : Aeronautical, nautical, and navigational instruments
Base Date : 1985:12

Wage Indices

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	589.18	597.7	597.64	601.68	594.61	597.17	602.03	602.57	615.75	610.67	609.94	618.98
1991	602.88	615.4	619.71	616.59	617.37	624.48	612.23	625.24	641.83	636.16	637.65	648.37
1992	642.72	657.49	652.97	647.01	648.28	645.7	642.41	658.94	655.32	661.92	668.05	654.64
1993	651.06	664.17	659.88	659.23	669.24	656.1	655.52	666.47	659.88	667.58	663.53	663.25
1994	674.87	670.96	672.52	674.87	688.14	672.95	671.74	672.13	676.65	694.41	685.42	688.16
1995	694.03	691.42	693.74	703.56	697.24	695.8	706.26	699.33	709.91	722.46	711.23	714.36

BLS Series ID:
EEU80871104
Industry: Engineering
Services
SIC Code: 8711
Data Type: AVERAGE WEEKLY EARNINGS OF PRODUCTION
WORKERS

SIC Code: 871

Data Type: NONSUPERVISORY-WORKER AVERAGE WEEKLY EARNINGS -- IN CURRENT DOLLARS

Quarter/Year	4Q92	1Q93	2Q93	3Q93	4Q93	1Q94	2Q94	3Q94	4Q94	1Q95	2Q95	3Q95
Engineer A	32.72	33.21	33.21	33.21	35.21	35.73	35.73	35.73	37.87	38.42	38.42	38.42
Sr. Engineer A	48.04	48.76	48.76	48.76	51.69	52.45	52.45	52.45	55.6	56.41	56.41	56.41
Sr. Engineer B	40.93	41.55	41.55	41.55	44.04	44.69	44.69	44.69	47.37	48.07	48.07	48.07
Technician Electronic Sr.	26.97	27.37	27.37	27.37	29.02	29.44	29.44	29.44	31.21	31.67	31.67	31.67