3rd May, 1963. NI/GP/63/17.

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

GENERAL PURPOSES COMMITTEE.

Radio-frequency Power Amplifier Tubes for NINA.

The attached paper was considered by the NINA Project Committee on the 2nd May. It recommended that :

(i) The three firms named in paragraph 5 should be asked to tender to a suitable specification.

(ii) Providing that the quotations are not substantially different from those detailed in this paper, and providing that the R.C.A. quotation does not exceed £50 000, the General Purposes Committee should authorise the Contracts Branch of the A.E.A. Engineering Group to place a contract with R.C.A. for the following equipment :

1 S.P. Triode Type 2054
1 Cavity Circuit for the 2054
1 Tetrode Type 2041
1 Cavity Circuit for the 2041
1 Interstage coupling link for the above.

(iii) The three firms named in the appendix should be asked to tender on a suitable specification for a UHF Isolator.

(iv) The General Purposes Committee should authorise the Contracts Branch of the A.E.A. Engineering Group to place a contract for the lowest tender, providing it is not in excess of £16,000.

The money for this item is available in the appropriate part of the capital budget of the Electron Laboratory.

I ask the General Purposes Committee to approve these recommendations.

A. W. Merrison.

N.I.N.A. PROJECT COMMITTEE

RADIOFREQUENCY POWER AMPLIFIER TUBES FOR NINA.

1. Description of the R.F.System.

Plain cylindrical E_{010} cavities will be placed in a number, probably five, of long straight sections uniformly distributed around the magnet ring. They will be connected by short wave-guide stub lines to a closed ring of waveguide. This "ring system" will be fed with RF power at one point by a power amplifier, which will in turn be driven by a suitable driver controlled by a master oscillator.

The frequency of operation is nominally fixed. The voltage and power must rise during the accelerating cycle to allow for the radiated energy from the orbitting electrons. The structure is rather efficient, and considerably more power is supplied to the electron beam than is dissipated in the structure. This has two consequences: first, a rough knowledge of the structure losses will be adequate for specifying power levels, which will however depend critically on the magnitude of the circulating electron current. Secondly the variation of both resistive and reactive components of fundamental beam current during the acceleration process is of great importance and makes it impossible to preserve a continuous match between the power amplifier and the ring system. Two things are done to ease the load on the amplifier - frequency modulation is employed (of small deviation), and an isolator is placed at the output of the amplifier.

2. Time Scale.

To meet the NINA completion date of October 1966 the basic design of the RF System must be finished by the end of 1964. To complete this basic design experimental work on prototypes at full power must be carried out. The power involved here will be of the order 20 KW, preferably CW rather than pulsed. This requires a fairly large installation, and we believe the only sensible programme is to build at once the final amplifier chain and use it first for experimental purposes.

Thus we require RF power by mid 1964, and allowing 9 months for delivery and leaving only 3 months for assembly, we must place orders for the equipment by mid 1963.

3. Specificiation.

(a) Frequency.

The frequency has been chosen to be one-seventh of the injector frequency; i.e. 408 mc/s.

(b) Power.

The power requirements are shown in the accompanying graph. This is the total power curve and is the sum of the cavity power, beam power waveguide loss and isolator loss.

We require peak powers of 260 KW for 4 µA and 480 KW for 10 µA beam.

We require mean powers of 83 KW for 4 µA and 150 KW for 10 µA beam.

(c) Other factors in the specification are of relatively minor importance.

i) Gain: the maximum convenient nominal drive level is 1 KW so we would like a gain (for 500 KW out) of 27 db.

ii) Bandwidth: it is difficult to put a figure on this, but we shall require to apply rapid modulation under closed-loop conditions. Any component with a bandwidth less than 1 mc/s will tend to be a limiting factor in getting good closed-loop performance.

4. British Tubes.

Apart from some long-term development work initiated by R.R.E., there is as yet no British or European application for RF power of these values around this frequency. Even the new Band IV/V TV transmitter are breaking new ground and, for 25 KW, are using American klystrons. We can, therefore, state categorically that we can only get the tubes we require from the U.S.A., where they have been developed for the B.M.E.W. System in particular.

5. Tubes Available in the U.S.A.

From a general survey of the market it became apparent that three firms are in a position to offer tubes to the above specification. These are RCA who offer triodes (with tetrode driver), and Litton and Varian who offer klystrons. 408 mc/s is a normal frequency for all tubes quoted.

The authors have recently visited these firms and also CEA and DESY. The tubes offered are described in detail below. The authors also visited Eimac and were offered a klystron of approximately suitable specification. As this tube is still under development, and no price and delivery date can be quoted for it, it will not be considered further.

(a) VARIAN: offer the VA-842 klystron.

This is an unmodified BMEWS tube rated at 1 MW pk 75 KW mean output, 200 KW collector dissipation.

Power Under our duty cycle conditions, the mean efficiency would be 20-22%. Thus the DC input would be 400 KW for the 4 µA beam and the collector dissipation 320 KW. Varian state that this would be safe. However, an interlock with RF drive would be needed, and good control of the modulating anode is called for also, as this controls the DC input power to the tube.

Bandwidth 3 mc/s at full power. 1 mc/s at injection level.

Gain 30 db at full power.

items by sub-contract. We should also have to develop and manufacture the modulating anode circuit.

10 µA Beam This could be achieved by paralleling two such klystrons, but there would be no margin at all for out-of-balance effects.

(b) LITTON : offer the L 3403 S klystron.

The L 3403 is a BMEWS klystron with specification identical to the Varian tube. The L 3403S is a modified version with larger collector, longer drift tubes and greater bandwidth.

Power The requirements are as for Varian, and the efficiency is the same. Litton say the standard tube cannot be extended. The modified version will have a generous margin, and the collector will probably be safe at 450 KW. The modifications introduce no unknown quantities. The broad-band version already exists as the L 3694.

Bandwidth 5 mc/s at full power.

Gain 35 db at full power.

Life 4000 hours quoted for BMEWS. Have had collector failures, which is why they insist on making us a larger version.

Cost	First tube	: £35,000
	Spare tube	: £16,000
	Focussing magnet	: £ 3,000
	Ancillaries(wave-guide transition, socket, etc.)	: £ 2,000

Delivery 9 months.

Notes Litton are keen to make as much as possible for us. They have quoted for a floating deck modulating-anode control circuit at £13,000 but we feel the design is not the best for our requirements, and would probably develop this ourselves.

10 µA Beam As with Varian, two such tubes would be required, but there would be a reasonable safety margin on collector dissipation.

(c) RCA : offer a 2054 triode driven by a 2041 tetrode.

These are both commercial tubes, used in radar programmes. The family of super-power triodes, of which the 2054 is a member, is used in many accelerators. They are known for their long life at very high mean power levels.

Power For a 10 µA beam, the 2054 plate dissipation would be 480 KW. The tube has been run at a maximum of 550 KW, but this is claimed not to be its limit. The 2041 would be working at its normal rating.

Bandwidth about 3 mc/s.

Gain 27 db

Life Super-power tubes have run up to 40,000 hours. Statistics are very poor - some accident usually ends a tubes life. 10,000 hours should be possible. However, the life really depends on the excellence of the water cooling system. A Permutit system is certainly theoretically satisfactory, though costs may be marginally higher than for a system adequate for klystrons.

Cost	2054 tube	: £17,800
	2041 tube	: £ 3,040
	2054 cavity	: £16,500
	2041 cavity	: £ 6,500

Delivery   6 months

Notes Triode circuits are inherently prone to parasitics. This system only looks attractive because we can buy two proven tubes each in a proven cavity from RCA direct, no development work being involved.

6. Costs for 4 and 10 μA beams.

In this section we detail the capital cost for each system, for 4 and 10 μA beams in each case.

(a) Varian Klystrons.

Varian would quote for :

4 μA	£	10 μA	£
1 off VA 842	9,200	2 off VA 842	18,400
1 off Magnet	3,300	2 off Magnets	6,600
1 off W.G.Transition	1,000	2 off W.G.Transition	2,000
1 off socket	400	2 off Sockets	800
Additional equipment		Additional equipment	
Modulating Anode Source	6,000	Modulating Anode Source	7,000
		Diplexer	7,000
		Load balancing unit	2,000
Total	£19,900	Total	£43,800

(b) Litton Klystrons

Litton would quote for :

4 μA	£	10 μA	£
1 off L 3403S	37,000	2 off L 3403S	53,000
1 off Magnet	3,025	2 off Magnets	6,050
1 off socket	400	2 off sockets	800
Additional equipment		Additional equipment	
Modulating Anode Source	6,000	Modulating Anode Source	7,000
		Diplexer	7,000
Total	£46,425	Total	£73,850

(c) RCA Triodes

The 4 μA system with the R.C.A. Triode would adequately cover the 10 μA system also.

R.C.A. would quote for :

	£
1 off 2054 tube	17,800
1 off 2054 cavity	16,500
1 off 2041 tube	3,040
1 off 2041 cavity	6,500

Additional equipment

Extra cost of tube protection	2,000
Extra cost of filament supply	1,000
Extra cost of water cooling	1,000
Less on lower H.T. voltage	-1,500
Total	£46,340

In summary, the total costs for the various systems are :

	4 μA £	10 μA £
Varian Klystrons.	19,900	43,800
Litton Klystrons.	46,425	73,850
R.C.A. Triodes.	46,340	46,340

7. Recommendations.

(a) All the three firms considered should be asked to quote on suitable specifications so as to establish the accuracy of the figures obtained informally and quoted in this report.

(b) Although it is difficult to put a price on the advantages to be gained from a 10 μA beam, it is certainly greater than the £20,000 difference between the 4 and 10 μA beams. Again a system for 10 μA at 4 GeV will cope also with a beam of 1 μA (say) at 5 GeV.

We recommend therefore designing for 10 μA from the start.

(c) We recommend that, assuming that firm quotations are not very different from the figures given here, a contract be placed with R.C.A. for the following equipment :

1 S.P. Triode Type 2054
1 Cavity Circuit for the 2054
1 Tetrode Type 2041
1 Cavity Circuit for the 2041
1 Interstage coupling link for the above

Although the R.C.A. system fails, by a narrow margin, to be the cheapest, we prefer it for the reasons detailed in section 8.

(d) Wherever standard components exist such as sockets, wave-guide transitions, etc., they should be bought: we should not, however, invite any circuit development, such as for modulating anode supplies, in the U.S.A. We should not purchase control circuitry or power supplies in the U.S.A.

8. Reasons for the Recommendations.

(a) When the basic task is to build and use an accelerator one should use well proven components and avoid running them to the limit of their ratings.

(b) We wish to build NINA quickly and with a small labour force and therefore to minimise laboratory circuit developments.

(c) A third consideration is to have adequate R.F. power in hand. This applies particularly to NINA, owing to the complex nature of the load and the somewhat unknown requirements for beam trapping. Potential should be available for future development, and conservative ratings will, in any case, lead to long life and reliability.

We believe that in these three aspects the R.C.A. system is considerably superior for our purposes. In addition :

(d) With the R.C.A. system we would use the Type 2041 25 KW Driver for cavity tests and this could speed up the programme.

(e) The R.C.A. tubes would have a life warranty of 1000 hours. Klystron warranties would be for a nominal 100 hours life only unless we paid considerably more per tube.

(f) The modulator circuit is an awkward item to design and make for Klystrons and would involve a fair amount of development work for the R.F. Group.

(g) The H.T. voltage is 50 - 60 KV for Klystrons against 15 KV for Triodes and will be rather more expensive per kilowatt.

(h) The target figure of 10 μA involves the use of Klystrons in parallel with the attendant complexity of the diplexer unit and the paralleling of the modulating anode and drive terminals.

D. J. Thompson.
K. W. D. Tarry.
April, 1963.

APPENDIX

Requirement for UHF Isolator

All manufacturers of high power UHF power tubes (Klystrons and Triodes) rate their tubes as follows :

For guaranteed power output, load VSWR = 1.2 : 1 max.
For guaranteed operation without damage to tube,
load VSWR = 1.5 : 1 max.

In the 4 GeV electron synchrotron, with a mean output beam of 4 to 10 µA, something like three-quarters of the R.F. power is absorbed by the beam. After initial bunching, as its velocity is constant and losses are small, the effective R.F. current represented by the circulating beam is constant. The combination of magnetic field variation and increase in beam radiation require that the cavity voltage increase with time (or beam energy) in something like a sawtooth. Thus the load impedance presented to the power tube increases during the accelerating cycle, and it is impossible to maintain matched conditions.

A second point is that at injection the beam loads the ring system suddenly, and there will be complex transients during the bunching process. In the first place, the instantaneous reflection coefficient may be almost unity, and this might cause damage to the power tube; and secondly, as the tube output cavity will not be a good match to the waveguide, the trapping process will be affected by reflection of transients at the amplifier.

Thirdly, the load may at times flash over or short circuit.

Thus it is desirable, to minimise the risk of damage to the power amplifier tube, to use an isolator in the waveguide between tube and ring system. At 408 mc/s an isolator can be built with a forward loss of only 0.6 db (at full power rating) and a reverse attenuation of 10 db.

For power levels corresponding to a 4 µA output beam, the cost of such an isolator would be about £10,000. For double this power, as represented by a 10 µA output beam, the cost is likely to be £16,000.

The firms involved are :

1. Raytheon (U.S.A.): made the isolator for C.E.A., and there fore will have relatively little new development to do - likely to be lowest tender and are quite acceptable.

2. Sperry (U.S.A.): we have no direct contact with them but have been advised from two independent reliable sources that they, like Raytheon, have the necessary experience.

3. Marconi (U.K.): very keen to make it (and therefore likely to stop us getting duty-free import). Well beyond anything they have made to date, but they appear to have the necessary knowledge and techniques - the only problem is whether the inevitable "cut and try" procedures may take rather longer than for the American firms.

4. The following British firms have stated that they do not wish to tender; Mullard, Ferranti, E.M.I. Sanders (who also act for a number of European and other firms).

To summarise, we would be happiest with Raytheon, and feel that their experince might justify going to them even if Marconi underbid by a small margin; but if the lowest bid is clear-cut, we have confidence in accepting it from any of these three firms.

Thus we seek authorisation to go to tender to the above three firms for an isolator equivalent in power to the power amplifier tube chosen, and in due course to place a contract for supply of such an isolator, at a cost up to £16,000 or whatever is the lowest or approximate lowest tender.