HIGH POWER SOLID STATE RF AMPLIFIER PROPOSAL FOR IRAN LIGHT SOURCE FACILITY (ILSF)

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Abstract

Solid state RF amplifiers are being considered for an increasing number of accelerator applications. Their capabilities extend from a few kW of power to several hundred kilo watts and from frequencies less than 100 MHz to above 1 GHz. This paper describes the proposed general scheme for the high power solid state RF generator of the Iran light source facility (ILSF). The maximum expected power of the generator is 200 kW which is used for driving the storage ring cavities. Similar RF generator with lower output power can be used for driving the booster cavities.

HIGH POWER RF GENERATORS IN ACCELERATOR APPLICATIONS

High poser RF generators provide the necessary radio frequency power for linear accelerator, booster and storage ring in accelerators. The power in linear accelerator is in the form of pulses with very high peaks. Currently the only source for these pulses is microwave tubes such as Klystron. In the case of the booster and storage ring the RF sources are in CW format with much lower peaks compared to the linear accelerators. Historically microwave tube amplifiers were the only sources, but in recent years solid state amplifiers are also successfully used in some accelerator facilities.

THE SOLID STATE TECHNOLOGY

Solid state amplifiers are based on transistors instead of vacuum electron tubes as active device. First RF silicon devices were bipolar junction transistors (BJT) which were affected by thermal runaway and by secondary breakdown; respectively leading to temperature compensated bias circuits and reduced safe operating areas. With the development of the integrated circuit technology, the Metal Oxide Semiconductor Field Effect Transistor (MOSFET) could be manufactured. MOSFETs have higher gain, lower noise and stand higher VSWR compared to BJTs. The LD-MOS is a representative of the Enhancement-Metal-Oxide-Semiconductor FET group. There are several features, which improve RF and power properties of typical low power MOSFET transistors. The LDMOS has a higher breakdown voltage. GaAs based MESFET are used in high frequency operation e.g. telecommunication applications. GaAs has higher saturation velocity compared to Si. Nowadays an interest is growing towards Si-LDMOS in telecommunication area. Since Si is a developed material the structure of LDMOS gives both good high frequency and high power characteristics. Recently, solid state RF amplifiers are being considered for an increasing number of accelerator applications, both circular and linear. Their capabilities extend from a few kW to several hundred kW, and from less than 100 MHz to above 1 GHz. However, in case of high power ones, higher frequencies are more preferable considering the components sizes and required space. Solid state power amplifiers are very attractive for individually driven independently phased superconducting cavities in accelerators. This attraction is a consequence of features such as

- Modularity, (easier and quicker maintenance and possibility of reduced power operation in case of failure)
- Reliability,
- Safety, (Due to absence of high biasing voltages)
- Low maintenance cost,
- Long lifetime.

The first operational solid state high power RF amplifier to drive booster and storage ring cavities is the SOLEIL RF system [1]. The first operational results of the SOLEIL RF systems were reported in 2006. In the Booster the required RF accelerating voltage of 0.8 MV at 352 MHz is provided by a 5-cell copper cavity of the CERN-LEP type, powered with a 35 kW solid state amplifier. The amplifier consists in a combination of 147 modules of 330 W which is based on MOSFET transistors, integrated circulators and individual power supplies. The Booster RF power plant was installed and commissioned in summer 2005. In the storage ring the 650 kW required RF power will be transferred to the beam through 2 cryomodules, each containing a pair of 352 MHz superconducting cavities. The RF power is supplied by 4 solid state amplifiers (4x724 modules), capable of delivering up to 190 kW.

AMPLIFIER'S BUILDING BLOCK (UNIT AMPLIFIER)

Unit amplifier is a RF amplifier which consists of only one transistor block (in some cases this transistor block may have two or transistors inside but all of them are in one package). The design comprises several blocks for adjusting conditions for proper operation of the transistors in accordance to the requirements. The block diagram in Figure 1 represents a typical circuit considered in the design process. There are bias network, input matching network, output matching network, accessories networks and the input and output ports that are assumed to be 50 Ohm. Input
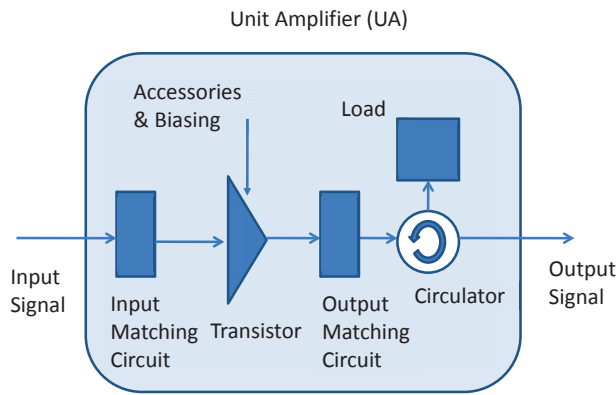
Figure 1: Block diagram of unit amplifier (UA).

Figure 2: Block diagram of a high power RF amplifier module.

signal from a 50 ohm line enters the input matching circuit which matches the impedance of the line to the input impedance of the transistor package. The amplified signal enters the output matching circuit which matches the transistor output impedance to the 50 ohm line. The circulator is placed after the transistor to protect it against any reflection from the next stage after the unit amplifier. Any reflection from the next stage enters the load which is attached to the circulator. The unit amplifiers (UAs) are the heart of the high power solid state amplifier. High power amplification can be achieved by the parallel combination of the output power of several individual UAs.

Our proposed unit amplifier is based on the transistor BLF578 which is LDMOS transistor from NXP Company. Our simulations show that more than 700W could be achieved at 500MHz [2]. The UA at its output port has a circulator with a high power termination that provides stability and isolation required in combining system. Each UA has its own DC power supply. The BLF578 requires 50V power supply with no more than 20A at its maximum output power. The current consumed by BLF578 must be continuously monitored for the safe operation of amplifier which one of the accessory circuits. In order to operate a transistor for a certain class, the gate and drain DC voltages have to be biased carefully to the certain operation point (quiescent point or q point). The reason is that the choice of q-point greatly influences linearity, power handling and efficiency. In addition, the choice of optimal q-point is important for a certain operation frequency. The class-AB amplifier shows a flexible solution for a trade-off between linearity and efficiency of the previous classes. Therefore, the conduction angle is π-2π and typically chosen closer to the threshold voltage. Thus, the transistor response of class-AB is wider than for class-B due to the operation point. Also, the power efficiency is higher than for class-A. Many telecommunication applications utilize this mode.
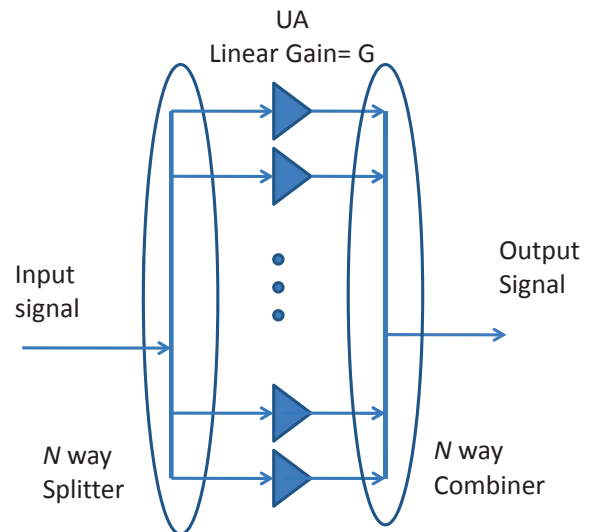
RF POWER COMBINERS/SPLITTERS

A unit amplifier can provide RF power in the range of 300-1000 W in 100 to 500 MHz band. To achieve higher RF power, these low power modules have to be combined using RF power combiners/splitters. Radio frequency power combiners enable the use of the solid state power amplifier modules for high power applications such as accelerators. In general combiners are passive, multiport, and reciprocal [3], [4]. Since combiners are reciprocal the same device can be used to divide or combine signals. But in real high power amplifier systems splitters and combiners have different structures. It is mainly due to the power level of the signals in these two structures. Figure 2 shows a general schematic view of a combining system. The input signal is divided into N signals using a splitter and each signal goes through an amplifier. The amplified outputs are combined using a combiner.

COMBINING SCHEME FOR THE ILS 200 kW SOLID AMPLIFIER SYSTEM

In the following the proposed combining system for the 200 kW RF generator which provides the necessary RF power for the operation of the storage ring cavity of the ILSF is explained. The unit amplifier is based on the BLF578 transistor with minimum 700 W output.

5 kW Amplifier Combining System

Figure 3 shows the combining scheme of the 5 kW amplifier system. The output of the first unit amplifier is divided into eight branches using a splitter and each branch contains a unit amplifier. The outputs of the unit amplifiers are added using a combiner which generates 5 kW in
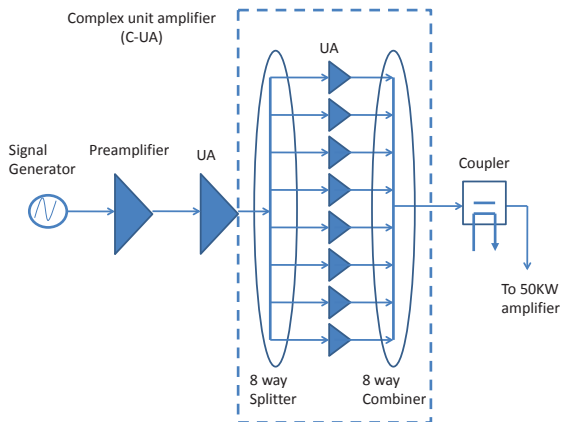
Figure 3: Block diagram of 4 kW solid state amplifier.

the output. A coupler is placed in the output of 5 kW combiner to sample the power for controlling purposes. For a lossless combining system based on a 700 W unit amplifier the output power of the combination is more than 5 kW, but losses are unavoidable hence, the actual output is between 5 to 5.6 kW.

50 kW Amplifier Combining System

Figure 4 shows the combining scheme of the 50 kW amplifier system. The 5 kW amplifiers are added in two groups. Each group consists of five, 5 kW amplifiers which generates 25 kW of power. Two 25 kW outputs are added together and 50 kW is generated. Some of the power generated is lost because of insertion loss of combiners and cables. So in the progress of the project and after prototyping some minor changes may be required in the system.

200 kW Amplifier Combining System

Figure 5 shows the combining scheme of the 200 kW amplifier system. Adding four of the 50 kW amplifier the 200 kW power necessary for the storage ring cavity is generated. A high power circulator at the end of the amplifier system before entering the cavities protects the whole system from reflections.

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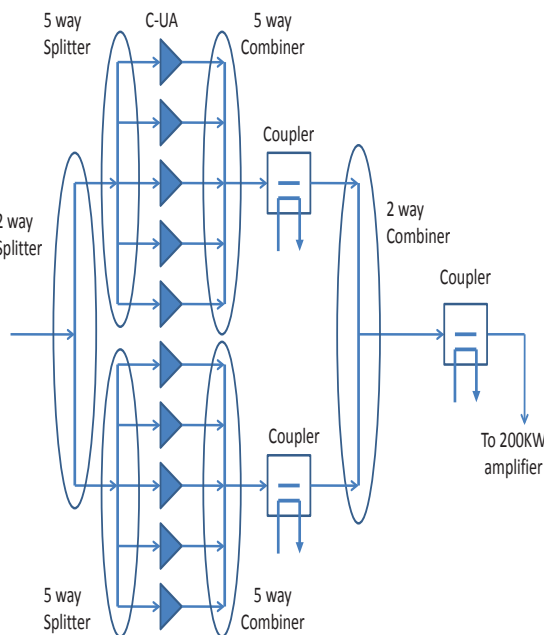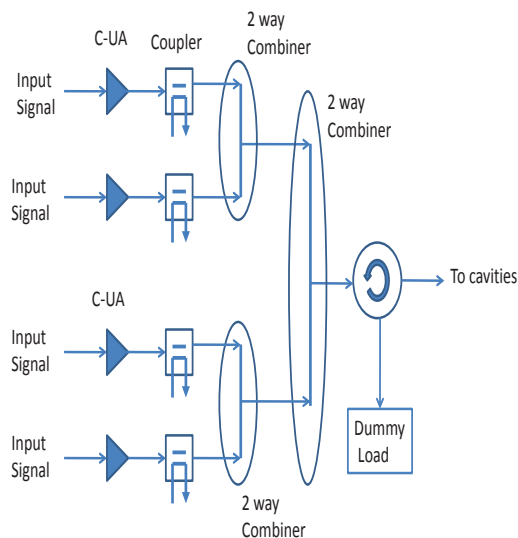

Figure 4: Block diagram of 4 kW solid state amplifier.

Figure 5: Block diagram of 4 kW solid state amplifier.