RF SYSTEM SPECIFICATIONS FOR A LINEAR ACCELERATOR*

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Abstract

A linear accelerator contains many systems; however, the most complex and costly is the RF system. The goal of an RF system is usually simply stated as maintaining the phase and amplitude of the RF signal within a given tolerance to accelerate the charged particle beam. An RF system that drives a linear accelerator needs a complete system specification, which should contain specifications for all the subsystems (i.e., high-power RF, low-level RF, RF generation/ distribution, and computer interface control). This paper defines a format for the specifications of these subsystems and discusses each RF subsystem independently to provide a comprehensive understanding of the function of each subsystem. This paper concludes with an example of a specification spreadsheet allowing one to input the specifications of a subsystem. Thus, some fundamental parameters (i.e., the cost and size) of the RF system can be determined.

INTRODUCTION

An linear accelerator (LINAC) consists of five subsystems; ion or electron sources, accelerating structures, RF, beam diagnostics and interface and controls. Using this terminology, a system configuration block diagram is illustrated in figure 1. A review of the linear accelerators and the systems that compose a LINAC is presented in numerous papers [1]. This paper will focus on defining the essential parameters that derive an RF subsystem by including fundamental parameters of the other subsystems. Using this approach to define an RF subsystem, allows one to design a general RF subsystem that can be used in a variety of LINACs.

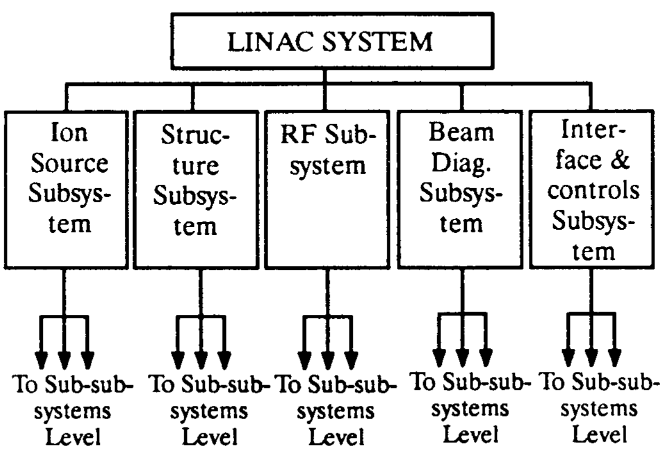

Figure 1. Simplified block diagram of the system configuration of a LINAC

RF System Description

From the title heading of this section, the terminology has changed such that, the RF subsystem is now referred to a system thus, the LINAC system should be referred to as a super-system. It is important to note that each level (i.e., system, subsystem and sub-subsystem) will have a set of specifications. The primary goal of any RF system is to provide RF power to a high Q structure and maintain the amplitude and phase of the RF fields in the accelerating cavity within a specified tolerance. This is why most RF specifications simply state these tolerances. While this type of specification provides a foundation to design an RF system, the specification does not provide any insight into the complexity of the system. A LINAC RF system is illustrated in fig. 2.

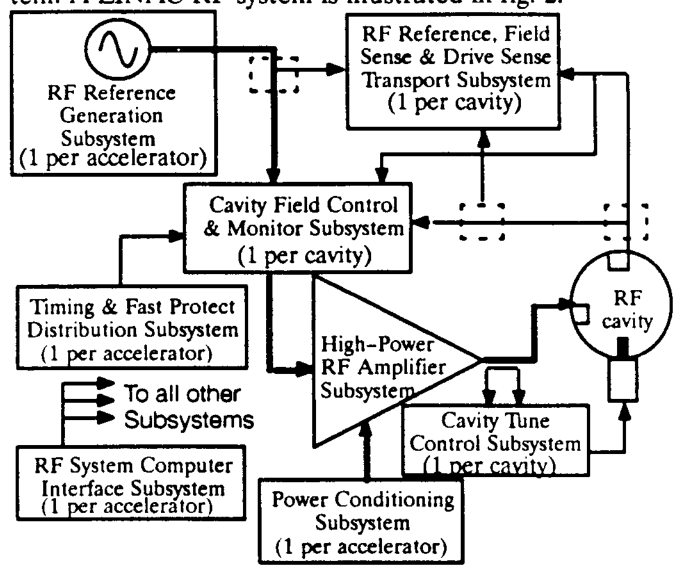

Figure 2. Simplified block diagram of a LINAC RF system

Figure 2 contains the four components that the specification stated above requires such as; a RF reference subsystem, a cavity control subsystem, an RF amplifier and an RF cavity. Each of these subsystems will be discussed in the following section. In addition, figure 2 illustrates peripheral subsystems which are also needed to meet the specification. It is important to note that characteristics from other systems, for example the characteristics of the ion source, are needed to predict the effects of beam loading on the RF fields. Also, the resonant frequency and the unloaded Q of the RF accelerating structure are needed in determining the type of high power amplifier and the accuracy of the low-level RF subsystem.

Subsystem Description

If the RF subsystem is considered a system and the LINAC is now a super-system of the RF system, this paper defines the key terminology that is needed to accurately assess the size, cost and complexity of an RF system. Each subsystem has a set of key parameters which when defined allows one to determine the types of components that should be used at the sub-subsystem level. These key parameters of the RF subsystems are defined in the following sections.

RF Generation Subsystem

There are two types of RF generation/ distribution subsystems being used in LINACs "star" [2] and a "serial" [3].

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Both RF generation/ distribution systems provide a phase-stable RF signal that surpasses the phase-stability requirements of the LINAC. For this subsystem to exhibit any drift in phase would directly translate into phase error thus, the beam would not "see" the specified accelerating field. Figure 3 presents the block diagram for a star RF generation/ distribution subsystem configuration. In the star configuration, an independent RF reference signal is sent to each accelerating cavity and each cavity is controlled independently while, in a serial configuration the RF reference signal is allocated through a main distribution subsystem and then the RF reference system is monitored with a control system.

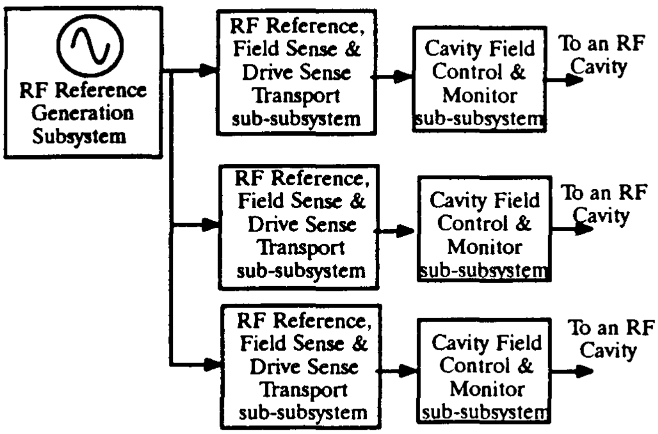

Figure 3. Star configuration of an RF generation/ distribution subsystem

Using figure 3, the critical parameters of this subsystem are defined as:

1. Operating Frequency
2. Output power level of the subsystem
3. Frequency stability of the RF source (long-term and short-term)
4. Distance from the RF reference to the accelerating structure
5. Phase stability of the monitoring loop
6. Operating temperature

Low-Level RF Subsystem

The primary goal of the low-level RF subsystem is to regulate and monitor the fields in the RF accelerating structures. There are two standard approaches in designing a low-level RF subsystem a frequency and power dependant system or a frequency and power invariant system. However both design implementations have similarly specified performance parameters which characterize the fields such as the rise, fall and settling time of the RF field. To further define these parameters, a control theory perspective will be implemented. Figure 4 illustrates the dynamic response of a low-level RF subsystem to an RF signal.

Figure 4 graphically defines key parameters that are needed in designing a LLRF subsystem such as, the rise time (t_r) which is dependant on the fill time of the RF accelerating cavity, settling time (t_{sp}) which is dependant on the Q of the cavity and the resonant frequency. The figure also describes the dynamic position error which is the tolerance in magnitude after the settling time period in response to a function. The dynamic velocity errors defined as the tolerance in magnitude during the rise time period.

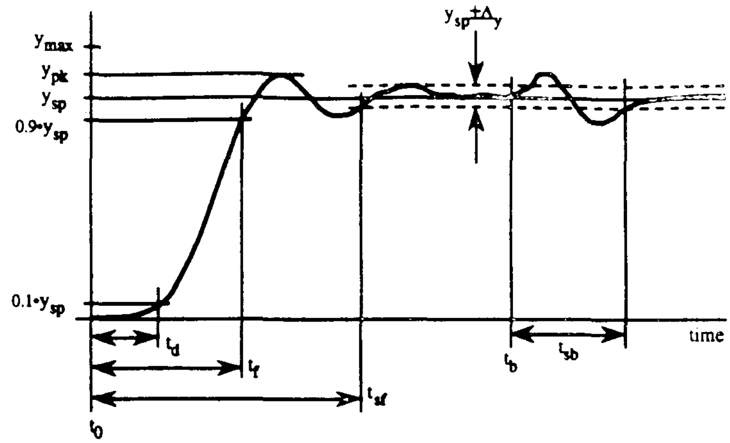

Figure 4. Response of the LLRF control to an RF signal.

While figure 4 defines general parameters for a LLRF subsystem, the frequency and power dependant realization such as, an amplitude and phase low-level subsystem is implemented using precision digital phase shifters and attenuators. Thus, in addition to the general parameters the following key parameters are unique to this implementation such as, the operating frequency and operating power levels of the phase shifters and attenuators.

The frequency and power independent system such as, an in-phase and quadrature (I & Q), orthogonalizes the amplitude and phase of the RF signal into two vectors, I and Q [4]. If one down-converts to baseband, simple integrated circuits can be used to monitor and control the magnitude of the I and Q vectors thus, the component tolerances are the key parameters.

High-Power RF Subsystem

In this section the definitions of the characteristics parameters of the High Power RF (HPRF) subsystem are discussed. A general block diagram is illustrated below (see figure 5). The primary function of the high power RF system is to amplify the low-level RF signal to the required power levels such that, the RF cavity has the proper field magnitude to accelerate and bunch the beam.

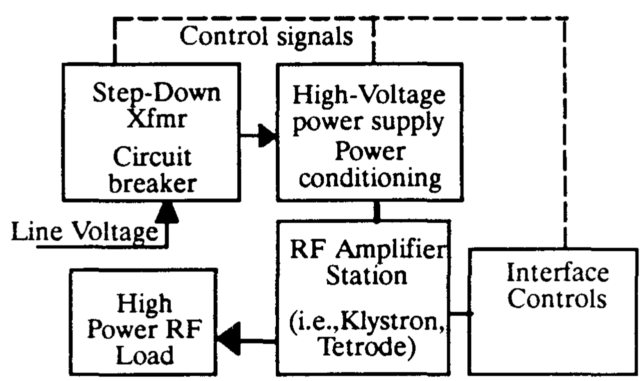

Figure 5. Block diagram of a HPRF subsystem

In figure 5, the HPRF subsystem is separated into five sub-subsystems; a transformer/ circuit breaker, a high-voltage power supply, an amplifier, interface controls and a RF load. Each sub-subsystem has a distinct set of specification which defines the component explicitly; however, the subsystem has a specification which integrates the component specification and defines the interfaces between each component.

For example, the power supply has the following key parameters:

1. Output voltage
2. Peak output current
3. Input voltage
4. Flat-top Ripple

And the amplifier has these selected key parameter:

1. Output Peak Power
2. Output Average Power
3. Frequency
4. Duty
5. Efficiency

These examples are not complete but, do provide fundamental information which allows one to begin designing the HPRF subsystem. For example, knowing the power supply voltage and current parameters allows one to determine if an energy storage network is needed. And knowing the amplifier output power (peak and average) allow one to determine the type of amplifier (solid-state, tube (grid or cavity configuration).

Computer Interface Controls

This subsystem provides the LINAC user with important information on the status of the RF system that is "user-friendly"and easily accessible. There are three formats that are currently being used in LINACs CAMAC, Allen Bradley Panel View and VME/VXI. The last two standards are discussed in this section. Because the software interface is dependant on the type of accelerator and of the users, this section will focus on the hardware interface between the subsystems. All three systems have manufacture qualified basic modules such as, I/O binary or analog devices.

The VXIbus standard evolved from VMEbus standards to incorporate more instrumentation modules into an open system architecture. A consortium of instrument manufacturers (i.e., Hewlett Packard, Tektronix, Colorado Data Systems, Racal Dana and Wavetek) was formed to develop an integrated set of system standards (i.e., rules, recommendations) (VMEbus Extensions for Instrumentation 1989) that must be strictly adhered, as to, provide a customer with a fully integrated standardized system. The specific benefits of conforming to this type of a system include a concise module format with data bus, local bus, address bus, clock and integrated power supplies (i.e., 5V, $\pm$12V, $\pm$24V) with a cooling system as a basic features of the system architecture. This standard allows one to access the appropriate data of a subsystem and determine the status.

The Allen-Bradley (AB) panel view standard is similar to the VXI/VME standard but, the AB has a software strawman program which allows one to begin developing a graphical interface. The AB standard can interface with the VME/VXI system using a DATA HIGHWAY configuration. Thus allowing one the flexibility of implementing both systems.

Thus, the key parameters are the speed of processing the data (i.e., does the data need to be processed in real-time) and the compatibilities with a software interface.

RESULTS

Using the terminology discussed in the previous section, a specification spreadsheet is derived and is illustrated in figure 6. This particular spread sheet is for the LLRF subsystem.

Particular Condition	Units	Limits		Design Goals
		Min.	Max.	
Gen. parameters				
Resonant Freq.	MHz			
Drive Freq.	MHz			
RF sys. Duty	%			
RF Pulse width	µs			
Unloaded Q				
Shunt Resistance	Ω			
Trans. line Z_0	Ω			
Sys. Bandwidth	Hz			
RF drive Level	dBm			
I parameters				
Magnitude	A			
Dyn. Vel. Error	%			
Dyn. pos. Error	%			
Rise Time	µs			
Settling Time	µs			
Beam on Time	µs			
Beam I	mA			
Quantization Res.	Bytes			
Q parameters				
Magnitude	A			
Dyn. Vel. Error	%			
Dyn. pos. Error	%			
Rise Time	µs			
Settling Time	µs			
Beam on Time	µs			
Beam I	mA			
Quantization Res.	Bytes			

Figure 6. An example of a specification spread sheet for the LLRF subsystem

CONCLUSION

While the spreadsheet illustrated in the previous section is not the final specifications of the LLRF subsystem, the spread sheet allows the RF development team to begin defining sub-subsystems at the beginning of the project.

ACKNOWLEDGMENTS

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REFERENCES

[1] B. R. Cheo and S. P. Jachim, "Dynamic Interactions Between RF Sources and LINAC Cavities with Beam Loading," IEEE Trans. Elec. Dev., vol. 38, no. 10, pp. 2264-2274.

[2] A. H. Regan and P. M. Denney, "RF Reference for the Ground Test Accelerator," IEEE Particle Accelerator Conf., May 1991, vol. 5, pp. 2946-2948.

[3] RF Distribution System at the SLC," IEEE Particle Accelerator Conf., March 1989, pp. 1987-1989.

[4] S. Haykin, Communication System. New York: John Wiley & Sons, 1987, pp. 80-89.