Fermi National Accelerator Laboratory

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Improved Bunch Spreader Modules

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1. Introduction

In order to raise the threshold beam current of instabilities in the fixed target run, it is required to increase the longitudinal emittance, and hence the bunch length. The bunch spreader developed by G. Jackson [1] used a noise generator through a sharp-cut band pass filter (BPF) instead of a coherent signal. In that filter, the pass band frequency was near twice the synchrotron frequency $2f_s$. The bandwidth of the filter was fixed between 350Hz and 600Hz, though twice the synchrotron frequency changed from 500Hz to 300Hz after transition in Main Ring. The noise through the filter is applied to an RF amplitude modulator. In the Tevatron, where the synchrotron frequency f_s varies from 120Hz to 40Hz during acceleration, the noise is applied to a phase shifter at the frequency of f_s. So, we need a tunable filter which tracks $2f_s$ in the Main Ring and f_s in the Tevatron.

This note describes details of improved bunch spreader modules using a tunable filter used in both the Main Ring and the Tevatron. A brief description about this module along with a beam test done in the Main Ring is shown in ref.[2].

2. Tunable Filter

Voltage tunable filters are commercially available, however, they are unsuitable for this project because their bandwidth is not flexible. Therefore, a modulation method which needs a mixer or a multiplier is employed to control the frequency band of the filter. Two signals with different frequencies are prepared, one is a noise signal coming from a noise generator through a fixed BPF and the other is a sine wave from a voltage-controlled oscillator. They are applied to a multiplier and the output signal of the multiplier produces two frequency components at the sum and the difference frequencies of the input signals. Only the difference signal is used, the sum signal is filtered away.

3. Circuit Description

3.1 General

The block diagram of the module is shown in Figure 1. This module has a noise source tunable in frequency, amplitude and timing. The function and performance of each part will be described below. The prototype of the module has been built and is installed in a single width NIM module. Though the noise frequencies are different between the Main Ring and the Tevatron, the circuit boards are common for easy maintenance.

3.2 Noise generator

The noise source is the thermal noise of a resistor. Since the noise source voltage is very small, it is amplified with gain of about 80dB by two operational amplifiers (TL084). The noise band is limited by the gain-bandwidth of the amplifiers. The output of the noise generator is seen in Figure 2. The rms voltage of the noise is larger than an expected value from the thermal noise.

3.3 High Q BPF

In order to remove higher frequencies produced by the mixing, the pass band frequencies of the BPFs are around 2kHz in the Main Ring and around 560Hz in the Tevatron. Since the pass band of the BPF is shifted to higher frequencies without changing a bandwidth, the BPF should have a higher Q value. In order to realize such a filter using operational amplifiers (TL084), a 2nd order positive-feedback filter [3] is adopted. The advantage of this type of filter is the ability to change the center frequency and the Q value independently. The details of this filter are explained in the Appendix.

Three stages of 2nd order filters makes 6 poles. The 1st stage determines a lower cut-off frequency, the 2nd the center frequency and the 3rd an upper cut-off one. Since the resonant frequency and the Q value of each stage are controllable, the total bandwidth can be changed from 50 to 200 Hz in the Main Ring and from 10 to 30 Hz in the Tevatron within the ripple of ±3dB. Typical spectra of the output of the high Q BPF are seen in Figure 3. If a sharper filter is required, it is possible to change to four stages with 8 poles. The stability of the resonant frequency is acceptable.

3.4 Voltage-Frequency Converter (VFC)

The conversion coefficient of the VFC (Burr-Brown, VFC42) is changed to be 100Hz/V in the Main Ring and 20Hz/V in the Tevatron. The input voltage is expected to be 0 to +10V. The output signal of the VFC is a square-wave of constant 25μs width, which contains many higher harmonics components. Stretching the pulse and a low pass filter reduce such components.

3.5 1st Multiplier

The two signals come into the 1st multiplier (AD534) as shown in Figure 1. This multiplier is used for frequency control. Several spectra are produced by the multiplier, however, the spectrum we need is a lowest one. A subsequent BPF reduces higher modes more than 20dB below as seen in Figure 4.

3.6 2nd and 3rd Multipliers

The 2nd multiplier is used for amplitude control of the noise. It is necessary to give an external signal from 0 to 10V to it. The 3rd one is for gate control. The gate pulse is made from external two pulses, start and stop. The maximum gate time is set at the Timer to be 1.8sec in the Main Ring and 20sec in the Tevatron.

3.7 APG Combiner

The noise signal is summed with the RF voltage control (APG) and sent to the RF amplifier. In the Tevatron bunch spreader, however, the noise signal is sent to a phase shifter without the APG input. The noise signals without the APG input are shown in Figure 5. When the frequency control voltage V_f changes, the noise band changes as shown in Figure 6-(a) and (b).

4. Conclusion

The bunch spreader works as a tunable noise source. The performance of the bunch spreader modules is summed up below.

Table 1. Performance of Modules

	Main Ring	Tevatron
Frequency Range	0 - 900 Hz	10 - 210 Hz
Frequency Stability	0.8 Hz/C°	0.2 Hz/C°
F/V Conversion Rate	100 Hz/V	20 Hz/V
Bandwidth	50 - 200 Hz	10 - 30 Hz
Number of Poles	6 or 8 (optional)	6 or 8 (optional)

Acknowledgements

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References

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[1] G. Jackson, "Main Ring Bunch Spreaders: Past, 1987/1988 Fixed Target Run, and Proposed Future", TM-1572, February, 1989.

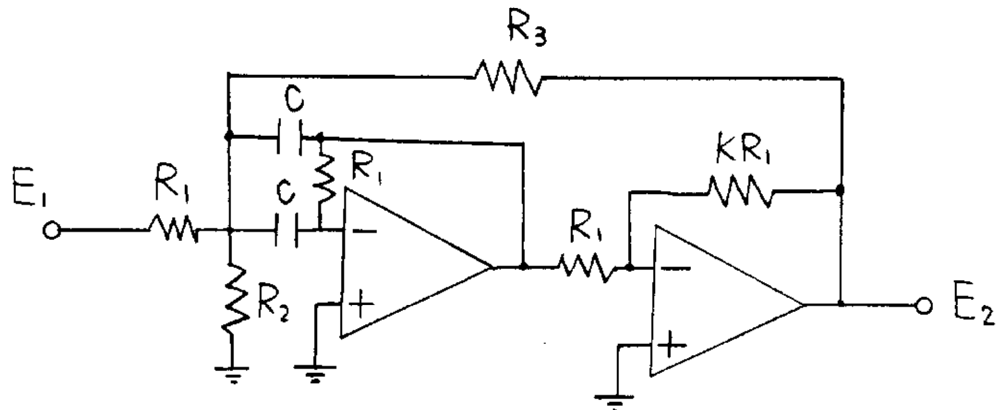
[2] G. Jackson and T. Ieiri, "Stimulated Longitudinal Emittance Growth in the Main Ring", to be published in Proceedings of the 1989 IEEE Particle Accelerator Conference and Fermilab-Conf-89/83.

[3] J.L. Hilburn and D.E. Johnson, "Manual of Active Filter Design", McGraw-Hill Co., (1973).

Appendix

Positive Feedback Band Pass Filter [3]

A 2nd-order positive feedback type of BPF is made up by two operational amplifiers as shown below. The first amplifier plays the multiple feedback type of BPF[3] and the second one does positive feedback through the resistor R_3.



The voltage transfer function is given as

$$\frac{E_2}{E_1}(S) = \frac{S \cdot \frac{K}{R_1 C}}{S^2 + S \cdot \frac{1}{R_1 C} \cdot \left[2 - \frac{KR_1}{R_3}\right] + \frac{1}{C^2 R_1} \cdot \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]}, \quad (1)$$

where $s=j\omega$ and $\omega=2\pi f$. The resonant frequency f_0, the bandwidth Δf and the gain G_0 at f_0 are obtained from eq.(1).

$$f_0 = \frac{1}{2\pi C} \cdot \sqrt{\frac{1}{R_1}\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]} \quad (2)$$

$$\Delta f = \frac{1}{2\pi R_1 C} \cdot \left[2 - \frac{KR_1}{R_3}\right] \quad (3)$$

$$G_0 = \frac{K}{\left[2 - \frac{KR_1}{R_3}\right]} \quad (4)$$

Since R_2 is usually much smaller than R_1 and R_3, the f_0 can be changed by varying R_2 without changing Δf and G_0. The quality factor or Δf is adjusted by K within the limit of $KR_1 < 2R_3$. If $KR_1 \geq 2R_3$, the BPF will oscillate.

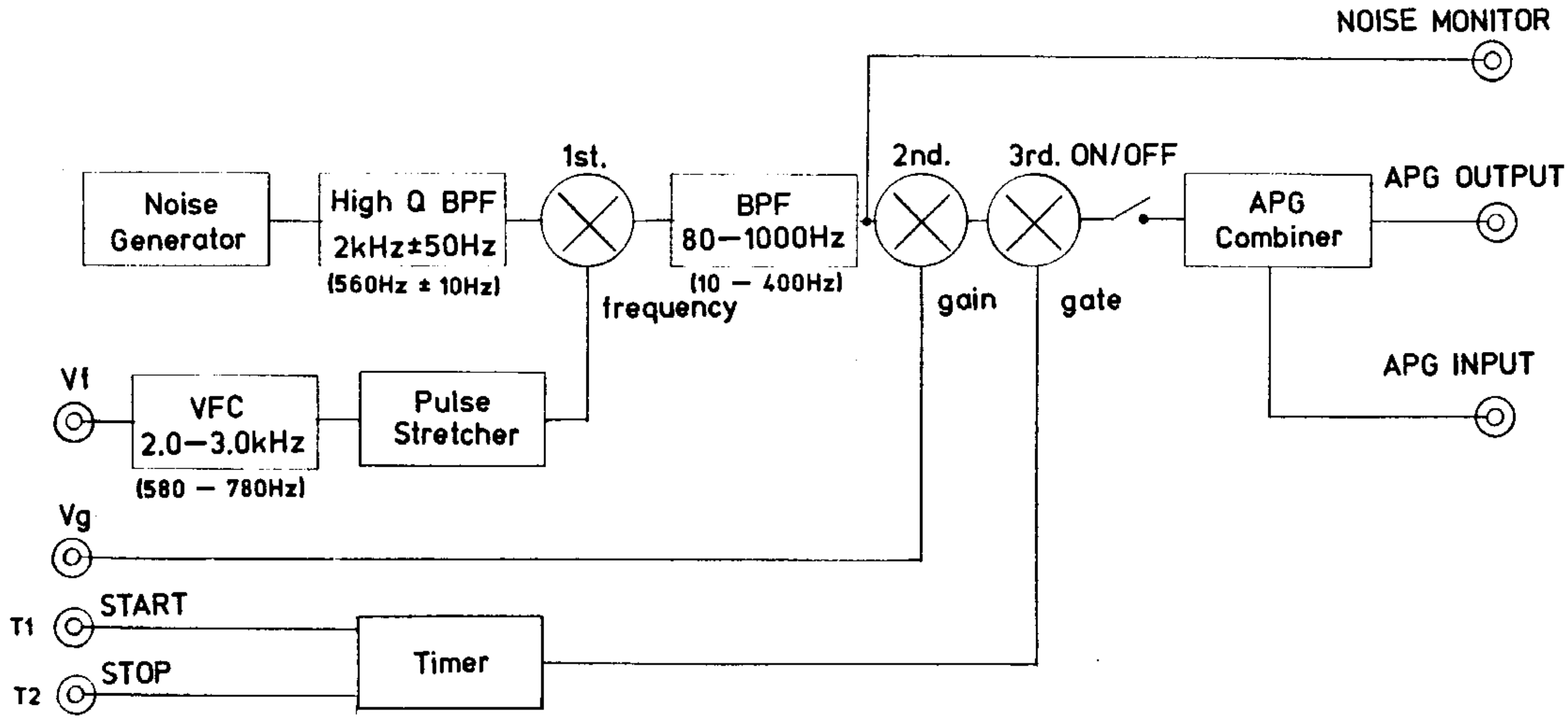
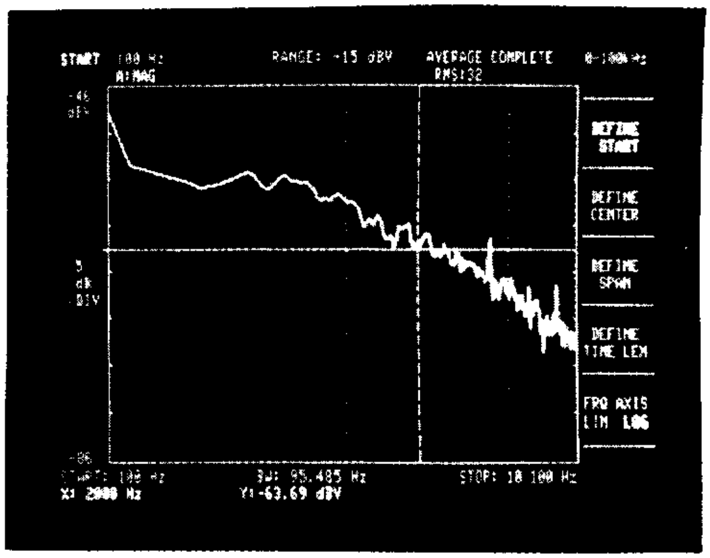
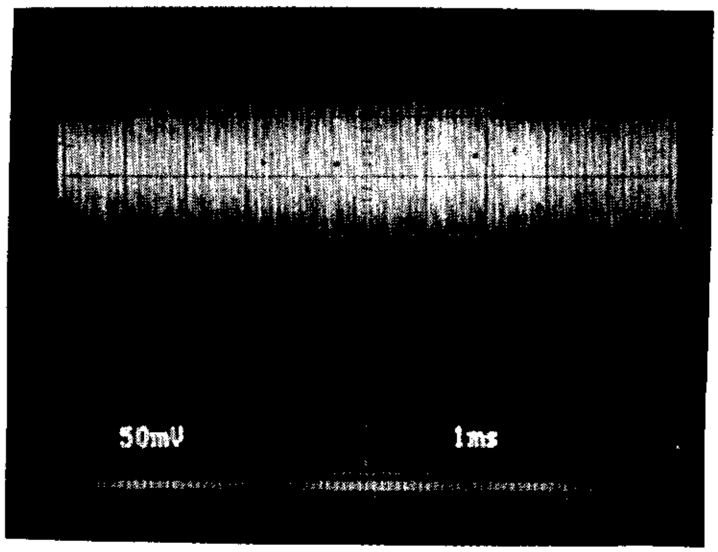


Figure 1. Block Diagram of Bunch Spreader, Values in parentheses are for Tevatron.

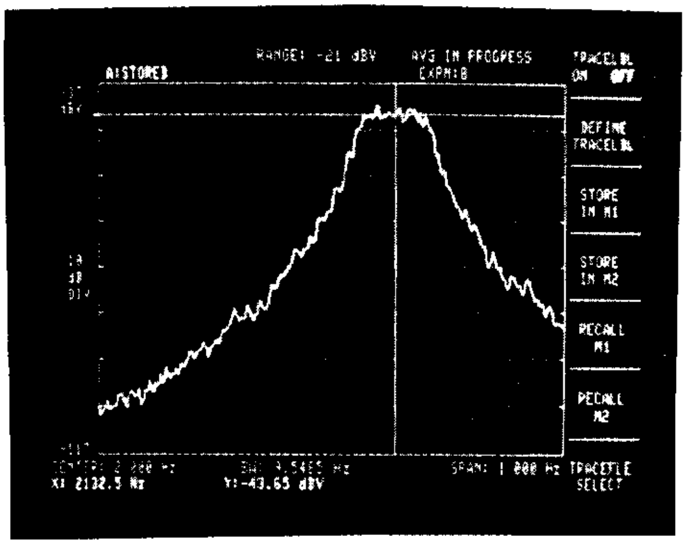


(a)

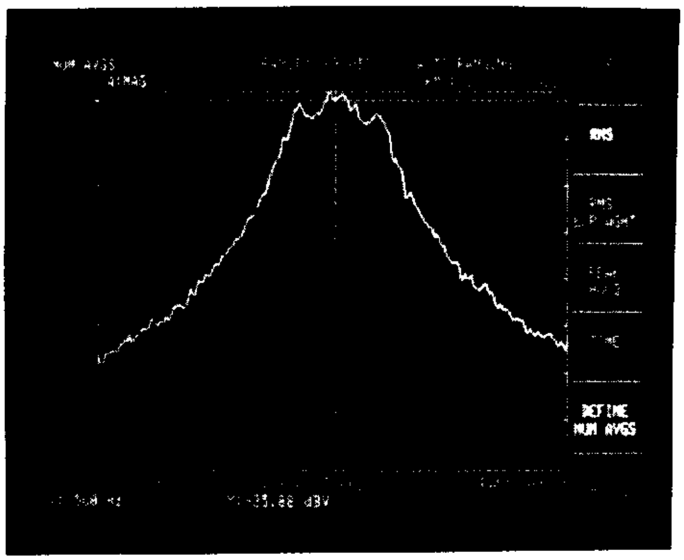


(b)

Figure 2. Output of Noise Generator, (a) in frequency domain, H: Log frequency from 100Hz to 10kHz, Bandwidth=95Hz, V: 5dB/div, (b) in time domain, H: 1msec/div, V: 50mV/div.

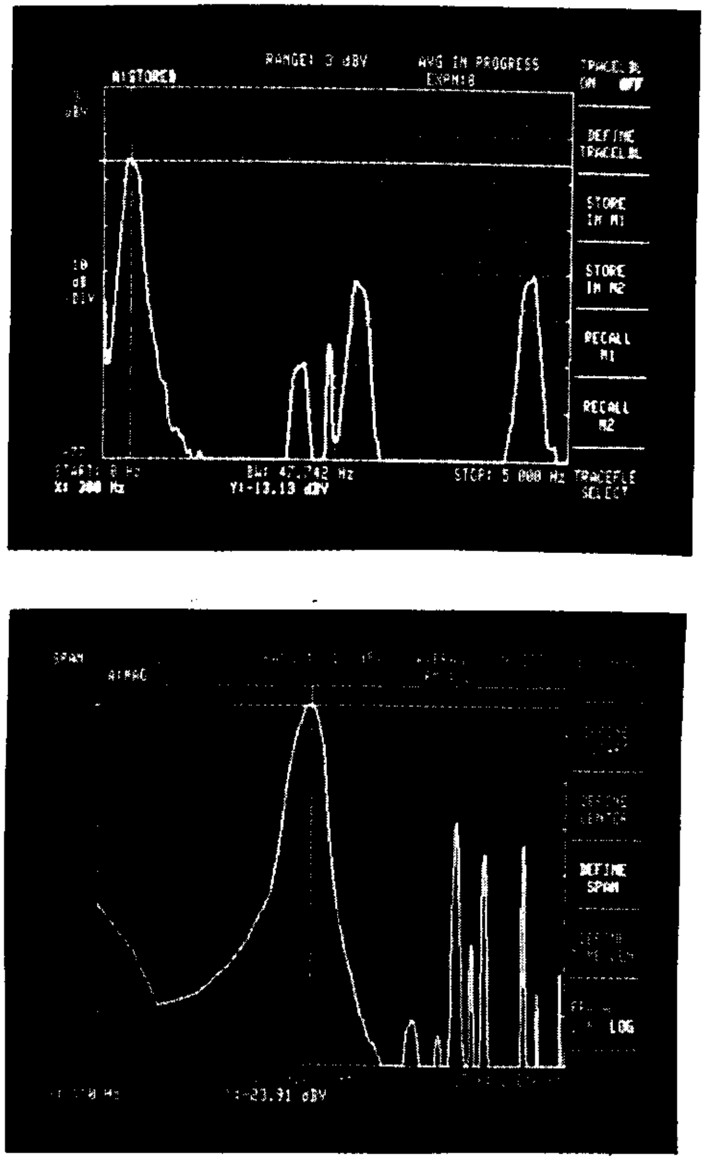


(a)



(b)

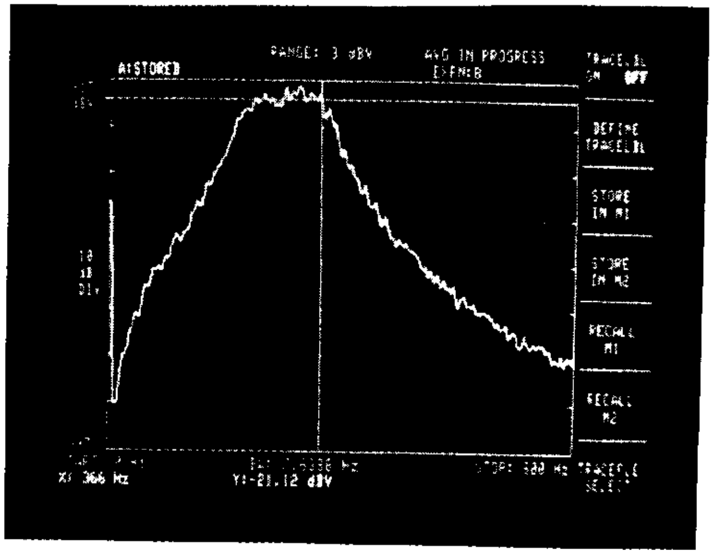
Figure 3. Output Spectra of High Q BPFs, (a) Main Ring, H: 100Hz/div, V 10dB/div, the center frequency is 2122.5 Hz, (b) Tevatron, H: 10Hz/div, V: 10dB/div, the center frequency is 560 Hz,.



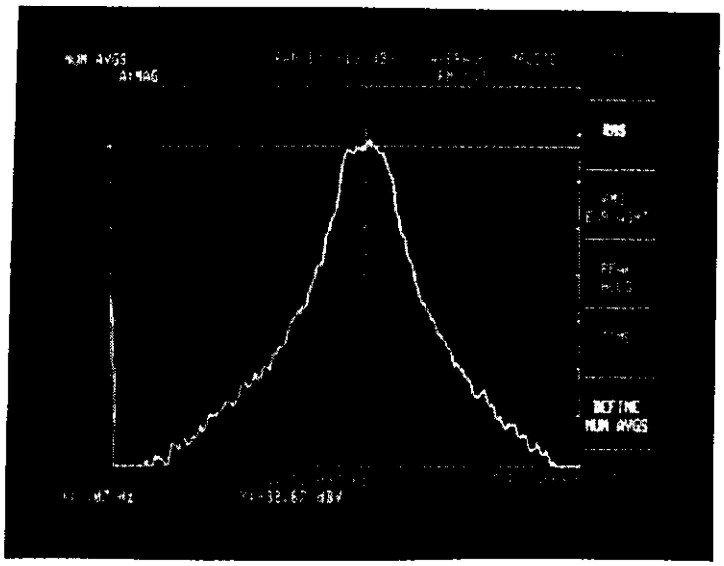
(a)

(b)

Figure 4. Outputs of BPF after the 1st Multiplier, (a) Main Ring at V_f=7.0V, H: 500Hz/div, V: 10dB/div, (b) Tevatron at V_f=5.0V, H: Log frequency from 10 - 2000Hz, V: 10dB/div.



(a)



(b)

Figure 5. Typical Output Spectra, (a) Main Ring with band of 240 - 370Hz when V_f=7.0V, H: 100Hz/div, V: 10dB/div, (b) Tevatron with band of 98 - 115Hz when V_f=5.0V, H:20Hz/div, V: 10dB/div.

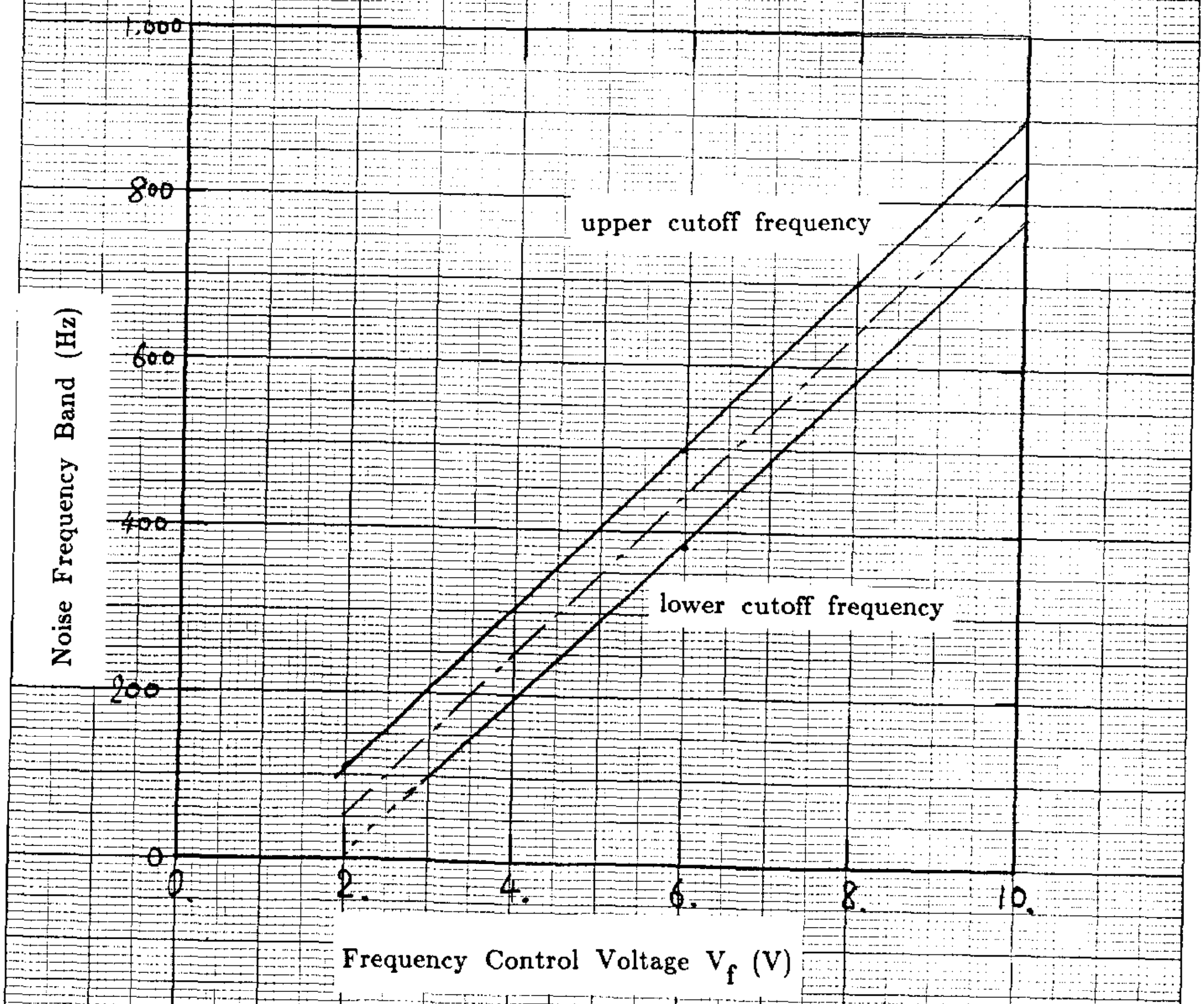


Figure 6-(a). Relation between Noise Band and Frequency Control Voltage V_f of Main Ring Bunch Spreader.

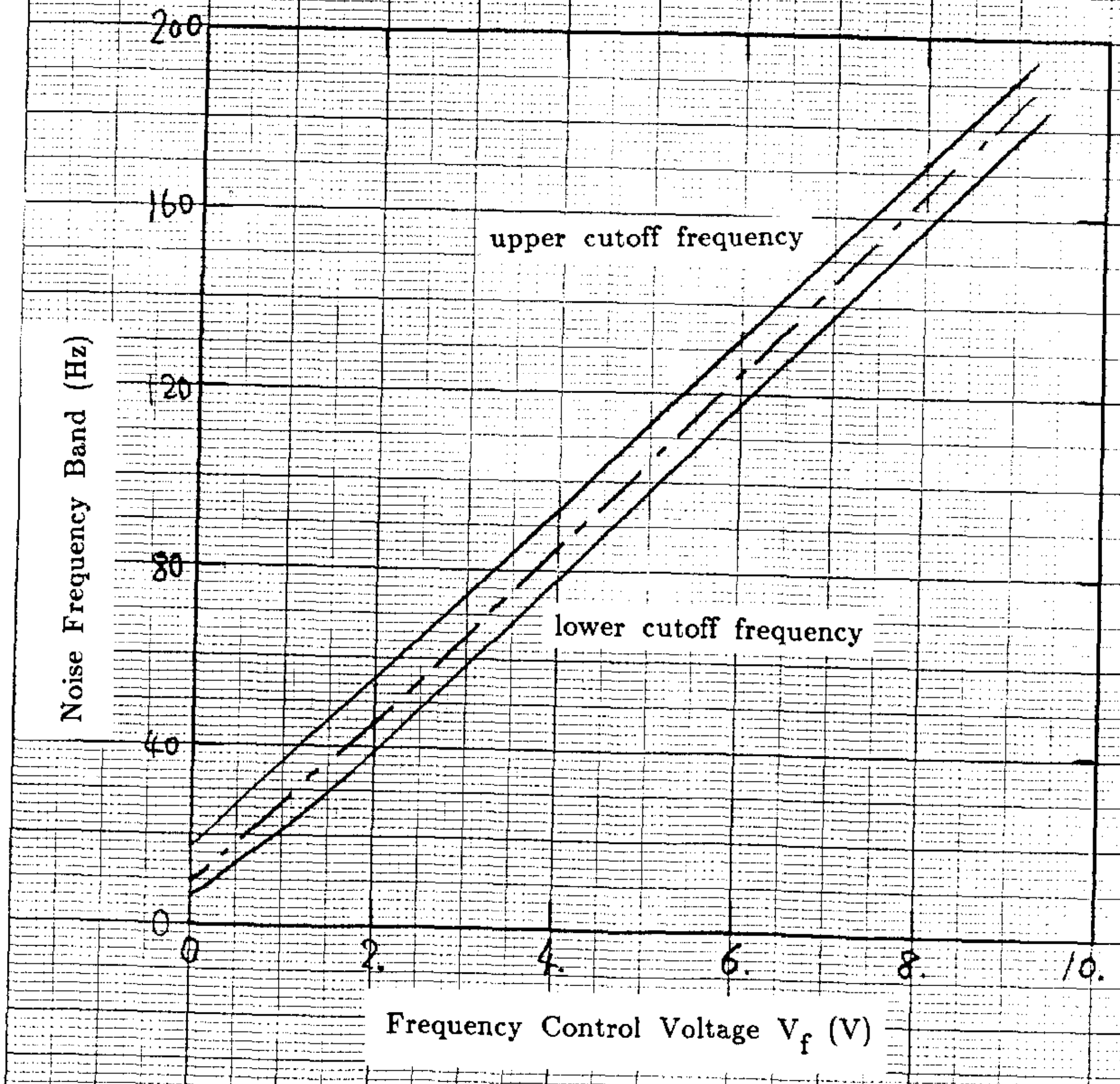


Figure 6-(b). Relation between Noise Band and Frequency Control Voltage V_f of Tevatron Bunch Spreader.