FAST SCAN SPECTRUM ANALYSER USING A DISPERSIVE DELAY LINE FOR PULSE COMPRESSION

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1. INTRODUCTION

For the observation of fast growing instability signals a real-time spectrum analyzer having a bandwidth of 100 MHz and a resolution of about 1 MHz is required. Since no commercial instrument fulfilling these specifications is available, the development of a "pulse compression receiver" has been started. Such a receiver while not truly operating in real-time can analyse the frequency range in times of the order of 1000 times faster than a conventional spectrum analyser.

The spectrum analyser described here makes use of a dispersive delay line in SAW (surface acoustic wave) technology. The set-up is still in an experimental stage as far as the operation (manipulation) is concerned, but its technical performance satisfies the specifications and has already proved its usefulness.
2. **SPECIFICATIONS**

Frequency span: 100 MHz
The start frequency can be set to any value by adjustment of the local oscillator to
f_{LO} = f_{START} + 1050 MHz

Frequency resolution:
for 3 dB amplitude difference: ≈ 0.35 MHz
for 20 dB amplitude difference: ≈ 0.7 MHz

Amplitude ripple within span: ±0.6 dB

Dynamic range:
- sidelobes: at least 24 dB below pulse amplitude
- noise: depending on input amplification 40..70 dB below maximum input level

Processing time: 10 µs

Trigger: external, V_{TR} = 2 V_{peak}
period ≥ 12 µs

3. **PRINCIPLE OF OPERATION**

The heart of the "pulse compression receiver" is the dispersive delay line (DDL) which has within its operating bandwidth a linear time delay versus operating frequency characteristic, Fig. 1.

![Characteristics of DDL](image)

**Fig. 1** - Characteristic of DDL

The input signal is mixed with a linearly swept local oscillator signal (refer to Fig. 2). A constant frequency input signal is thus converted to a linear FM signal at the mixer output. The DDL that follows the mixer has a delay versus frequency slope which is the exact inverse of the linear FM signal. The resulting output of the DDL is a compressed pulse.
The location in time of the pulse relative to the start time of the sweep is directly proportional to the input frequency and the magnitude of the compressed pulse is proportional to the magnitude of the input signal.

The following example with numbers illustrates the frequency to time conversion: (The values for the input- and sweep-frequency used in the example are not realistic (image frequency problem), but they simplify the demonstration).

With the particular DDL used, a linear sweep in 5 μs from 350 to 250 MHz, applied to the input of the DDL, creates a pulse 9 μs after the start of the sweep, because the delay of the DDL is 9 μs at 350 MHz and decreases linearly to 4 μs at 250 MHz. The same is true when sweeping in 10 μs from 350 to 150 MHz, since the slope \( s = -100 \text{ MHz}/5 \text{ μs} \) is maintained. (The fact that the sweep goes below 250 MHz does not modify the result, because the DDL has a bandpass characteristic [\( \text{BW} = 100 \text{ MHz} \), centred on 300 MHz active band of the DDL].)

The spectrum analyser is now easily realized by mixing the full sweep \( f_{SW} \) with an input signal \( f_{IN} \) in order to displace the original sweep (350 to 150 MHz) up to a maximum of 450 to 250 MHz. The result can be seen on the following page. (Fig. 3) which shows why the sweep should extend down to 150 MHz.
Fig. 3 — Time-frequency characteristics and symbolic input and output signals of DDL
With an input frequency of 50 MHz, the sweep starts at 400 MHz and it takes 2.5 µs (remember \( s = -100 \text{ MHz}/5 \text{ µs} \)) to get to 350 MHz, the beginning of the "active" band of the DDL. Therefore a pulse is generated 2.5 µs later than in the preceding case (referred to the start of the sweep). As we see, a frequency offset of 50 MHz gives a time offset of 2.5 µs for the output.

As a last example, the input frequency is chosen to be 100 MHz. The sweep applied to the DDL starts now at 450 MHz and it takes 5 µs to reach 350 MHz, the beginning of the passband of the DDL. The generated pulse appears 5 µs later than the one in the first example.

The result is a linear conversion of frequency into time over a span of 100 MHz with a total analysis time = 2 x 5 µs = 10 µs (2 x real-time processing time for a max. resolution).

4. BLOCK DIAGRAM DESCRIPTION

This section describes in more detail the elements making up the final receiver. Fig. 4 gives the block diagram while Figs. 5 and 6 show the spectra and frequency vs time relationships to be found at various points in the system.

4.1 Input mixer M1 and local oscillator

The input mixer plus local oscillator allows selection of the frequency band to be analysed. The local oscillator must be set to a frequency 1050 MHz above the lowest input frequency \( (f_{LO} = f_{INmin} + 1050 \text{ MHz}) \). Care must be taken to ensure that the input mixer is not over-driven (harmonic distortion) and that frequency specifications of the mixer correspond to the operating condition (with the mixer used in the set-up the minimum input frequency of the 100 MHz span can be chosen between 0 and 900 MHz).
Fig. 4 - Block diagram of the pulse compression receiver

\[ f_{LO} = f_{IM_{min}} + 1050 \text{ MHz} \]
Fig. 5 – Spectra at different points in the system for an example with an input frequency band from 0 to 100 MHz.
**Fig. 6** - Frequency/time relationship in the SAW spectrum analyser (f\textsubscript{IN} = 0 \ldots 100 MHz)
4.2 Band pass filter and amplifier Al

The band pass filter (comb type) passes only the lower side-band of the mixer output signal. Amplifier Al compensates the insertion losses of the input mixer and the bandpass filter. An attenuator was added between the mixer and bandpass filter to improve the impedance matching of the two elements.

4.3 Ramp generator

The Ramp Generator produces a saw-tooth signal which drives the VCO in order to obtain the linear sweep. Since the tuning characteristic of the VCO is not perfectly linear, the slope of the saw-tooth must be adjustable over its length to finally obtain a sweep which has the exact inverse time versus frequency characteristic to that of the DDL.

4.3.1 Principle of operation

![Diagram of ramp generator with fine corrected slope]

Fig. 7 - Ramp generator with fine corrected slope

The main ramp is generated simply by integrating the sum of a constant voltage (B) and a correction voltage which varies in time (C). As a result we get a non-linear slope.
4.3.2 Block diagram of the ramp generator

Fig. 8
The COUNTER & DECODER block generates the timing signals needed for the ANALOG MULTIPLEXER, the INTEGRATOR, and the RESET of the integrator. The timing sequence can be easily understood by studying the above diagram. Each trigger pulse allows the counter to start and generate a ramp. The time variable correction voltage (C) is generated by the ANALOG MULTIPLEXER which is switching through the voltages set by the potentiometers 1 to 16. The switches of the MULTIPLEXER are selected by the COUNTER.

At the output of the INTEGRATOR the amplitude of the saw-tooth can be adjusted (= FREQU. SPAN OF VCO). The OUTPUT AMPLIFIER (g ≈ 12) produces the tuning voltage for the VCO. With the OFFSET potentiometer the START FREQUENCY of the VCO can be adjusted.

![Output 2 V/div](image)

**Fig. 10** - Output signal of the ramp generator.

The slope correction is in the order of magnitude of 20%.

### 4.4 VCO

The function of the VCO has already been mentioned in Section 4.3.

To obtain the fast tuning rate of 200 MHz/10 μs, a VCO using a varactor with a frequency range of 1.0 to 2.0 GHz has been selected. The operation between 1.2 and 1.4 GHz has turned out to be convenient as far as linearity and voltage levels are concerned.
4.5 **Mixer M2**

This mixer converts the sweep signal from the VCO down into the frequency band of the DDL.

4.6 **Amplifiers A2 and A3**

The two amplifiers compensate the high insertion loss ($\approx 55$ dB) of the DDL.

4.7 **Dispersive Delay Line (DDL)**

The basic properties of the DDL are explained in Section 3 and of course in more detail in the literature.

One limitation should be mentioned here: side lobes appear in the output before and after the main response. The compressed pulse would normally have a $\frac{\sin x}{x}$ shape, the characteristic side lobe being at $-13.2$ dB. However, in the delay line used in this project an additional weighting function is implemented which reduces the side lobe levels to $-33$ dB for a perfectly matched input waveform. With the complete spectrum analyser set-up a side lobe level of $\leq -24$ dB was measured.

![Fig. 11 - Compressed pulse.](image)

(a) without corrected ramp
(b) with corrected ramp
Typical performance data for the DDL type WB 070A by RACAL MESL:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre frequency</td>
<td>300 MHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100 MHz</td>
</tr>
<tr>
<td>Time dispersion (linear)</td>
<td>5 µs</td>
</tr>
<tr>
<td>Insertion loss</td>
<td>&lt; 55 dB</td>
</tr>
<tr>
<td>Side lobe levels</td>
<td>≤ -30 dB</td>
</tr>
<tr>
<td>-3 dB pulse width</td>
<td>17 ns</td>
</tr>
<tr>
<td>-20 dB pulse width</td>
<td>≈ 35 ns</td>
</tr>
</tbody>
</table>

4.8 Oscilloscope

The oscilloscope used should have a bandwidth of at least 500 MHz. The trigger signal is produced by the RAMP GENERATOR, the sweep time being adjusted to 5 µsecs. If the scope has a precision trigger delay, it can be adjusted to get the complete 100 MHz span on the screen. By modifying the delay and sweep adjustment on the time base, the frequency span can be reduced to obtain the maximum resolution which is ultimately limited by the compressed pulse width to ≈ 700 kHz.

5. CONCLUSIONS

Comparing the performance of the SAW spectrum analyser with that of a normal spectrum analyser shows the following main differences.

advantage: the precessing speed is much higher, allowing observation of phenomena of short duration.

disadvantages: the dynamic range is only 24 dB, compared to about 70 dB of a normal spectrum analyser.
The resolution is limited to about 700 kHz because of the fixed width of the compressed pulse.
As mentioned in the introduction, the set-up is still an experimental model. Here is a short list of possible improvements:

- Stability measurements should show if the components are too sensitive to temperature changes.

- Careful layout and construction of a self-contained unit should give an improvement in dynamic range to about 30 dB.

- Addition of an envelope detector at the output would give a display looking like a normal spectrum analyser.

- Using a fast transient digitizer instead of the oscilloscope for display would allow storing phenomena of short duration and therefore allow accurate interpretation.

Fig. 12 - Spectrum display 0 ... 100 MHz

(a) with $f_{IN} = 50$ MHz
(b) with $f_{IN} = 10 - 20 - 30 ... 100$ MHz.
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Fig. 12 - Spectrum display 0 . . . 100 MHz

(a) with $f_{IN} = 50$ MHz
(b) with $f_{IN} = 10 - 20 - 30 . . . 100$ MHz.
1. \( f_{IN} = 0 \text{ MHz} \)
   - \( f_{DM} = 350 - 150 \text{ MHz} \)
   - \( f_m = 350 - 150 \text{ MHz} \)

2. \( f_{IN} = 50 \text{ MHz} \)
   - \( f_{DM} = 350 - 150 \text{ MHz} \)
   - \( f_m = 400 - 200 \text{ MHz} \)

3. \( f_{IN} = 100 \text{ MHz} \)
   - \( f_{DM} = 350 - 150 \text{ MHz} \)
   - \( f_m = 450 - 250 \text{ MHz} \)