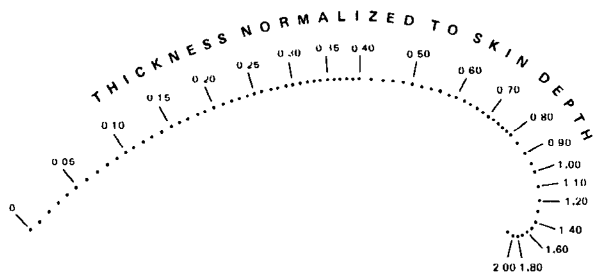

REFLECTION COEFFICIENT PLANE OVERLAY
FOR
CONDUCTING MEDIA

Fig. 2. Universal overlay.

To find the surface impedance Z_s the first step is the evaluation of the gold surface impedance normalized to the nickel, i.e., $\eta_e/\eta_b = \sqrt{(1/110)(1.42/4.54)} = 0.0534$. This normalized impedance must be transformed through the nickel layer which is characterized in terms of its skin depth of $1/\sqrt{\pi f \mu \sigma} = 1/\sqrt{(\pi)(2.46 \cdot 10^9)(110)(4\pi 10^{-7})(1.42 \cdot 10^7)} = 0.2567 \cdot 10^{-6}$ m. The layer of 200 Å is thus 0.0779 skin depths in thickness.

The spiral convergence point of the overlay is centered in the reflection coefficient plane and the spiral rotated until it passes through the original point Γ, which is the example is at $(0.0534-1)/(0.0534+1) = -0.899$. The latter calculation is, of course, generally dispensed with; it is redundant since the Smith Chart (or "$Z-\theta$" Chart) locates the point from the normalized impedance value directly. The size of overlay used for this example was observed to have a parameter value of t_0/δ of 0.202 when fitted to the initial $\zeta_0 = 0.0534$. The addition of $t/\delta = 0.0779$ to the starting value of the parameter gives $(t+t_0)/\delta = 0.280$ which overlaid a normalized impedance of $0.131 + j0.077$. Since $\eta_b = 0.274 + j0.274$ Ω the actual surface impedance is $Z_s = 0.015 + j0.057$ Ω. It may be noted that in this example the effect of the thin bonding layer is primarily on the reactive component of the impedance, since for gold $\eta_e = 0.014 + j0.014$ Ω.

IV. Appendix

An exponential spiral is described in polar coordinates r and θ and characterized in terms of the parameter t_1 as

$$r = K_1 e^{-2t_1/\delta} \qquad \theta = -2t_1/\delta + \theta_1.$$

A second spiral is characterized in terms of the parameter t_2 as

$$r = K_2 e^{-2t_2/\delta} \qquad \theta = -2t_2/\delta + \theta_2.$$

When the parameter changes by a small amount, in the first case

$$dr = -(2/\delta) r\, dt_1 \qquad d\theta = -(2/\delta)\, dt_1$$

and in the second

$$dr = -(2/\delta) r\, dt_2 \qquad d\theta = -(2/\delta)\, dt_2.$$

If the spirals pass through the same point r, θ the same increment in the parameters, $dt_1 = dt_2$ is required to produce the same increment in r and θ in either case. Hence the coincidence of every pair of points on the superimposed spirals requires that $t_1 = t_2 + t_0$, where t_0 is an arbitrary constant if K_1, K_2, θ_1, and θ_2 are arbitrary.

References

[1] H. Sobol and M. Caulton, "The technology of microwave integrated circuits," *Advances in Microwaves*, vol. 8. New York: Academic, 1974, pp. 36–40.

[2] S. Ramo, J. R. Whinnery and T. Van Duzer, *Fields and Waves in Communication Electronics*. New York: Wiley 1972, pp. 298–300.

[3] ——, *Fields and Waves in Communication Electronics*. New York: Wiley, 1972, p. 45.

A Time Domain Reflectometer Using a Semiautomatic Network Analyzer and the Fast Fourier Transform

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***Abstract*—A time domain reflectometer system is simulated by measuring the reflection coefficient in the frequency domain and then computing the time domain signal by the Fourier transform. The program has been written for the Hewlett-Packard 8409A Semiautomatic Network Analyzer. The computation time has been minimized by using the fast Fourier transform. The problems imposed by the difficulty of switching the HP 8409A between low- and high-frequency ranges are also discussed.**

I. Introduction

One advantage of the computer controlled automatic network analyzer is that the measured results can easily be used for further calculations. A very interesting application is to simulate a time domain reflectometer by means of the Fourier transform. An article [1] which described a system using the Hewlett-Packard 8542B Automatic Network Analyzer was published in 1974. The Fourier transform was performed by a truncated Fourier series.

A few years ago Hewlett-Packard introduced the HP 8409A Semiautomatic Network Analyzer which is a low cost version of the 8542B. The present article is a description of a Fourier transform program developed for the HP 8409A controller, which is a HP 9825 desktop computer. The program is different in several aspects from the program in [1]. The computation is performed by a fast Fourier transform implementation of the discrete Fourier transform, which is considerably faster than using a truncated Fourier series [2].

In the HP 8409A system the switching between the low frequency range (0.1–2 GHz) and the high-frequency range (2–18 GHz) is performed by changing some instruments, which is a rather time consuming operation. Therefore, only the high frequency range is used in the program.

II. Implementation

The Fourier transform of a signal consisting of a dc signal, a basic frequency and harmonics of the basic frequency, all with equal amplitude, is a pulse function. If the signal is band limited

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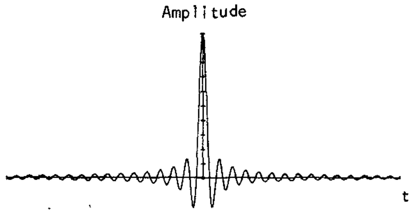

Fig. 1. The Fourier transform of a band-limited signal with equal amplitude harmonics.

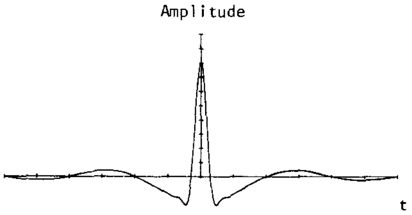

Fig. 2. The Fourier transform of a raised cosine window function with low-frequency truncation.

at a maximum frequency f_{max}, the time domain signal has time smear, which is similar to sidelobes in array antennas. If the signal is reflected from a discontinuity, the associated sidelobes can easily be confused with small discontinuities (Fig. 1).

The sidelobes can be minimized at the cost of an increased main lobe width by using a window function [3]. In this application additional sidelobes are introduced by the low-frequency truncation (Fig. 2). It has not been possible to decrease the low-frequency sidelobes by using a window function or by a linear extrapolation of the measured values to zero frequency. The only method known to the author for minimizing the low-frequency sidelobes is to insert measured or computed low-frequency values. Measured values are not used since it is time consuming to switch the network analyzer from high to low frequencies. Computed values can be very effective for simple networks but the approach is not suitable for a general purpose program. The low-frequency sidelobes must therefore be visually separated from the real curves.

The window function used in Fig. 2 is the "raised cosine" which is defined by

$$F(f)=1+\cos\left(\pi\cdot\frac{f}{f'_{max}}\right) \qquad (1)$$

where f'_{max} is the next higher harmonic above the maximum measurement frequency f_{max}.

The simulated input signal in the time domain is a pulsetrain with a periodicity of T seconds. The time domain response is calculated for N samples during the time T. In the frequency domain N frequency samples are measured from $-f_{max}$ to f_{max}. The resolution which is the time between two samples is therefore only dependent on the maximum measurement frequency

$$\frac{T}{N}=\frac{1}{2\cdot f_{max}}. \qquad (2)$$

T/N is the resolution in the total propagation time for the reflected signal. The resolution in the distance to a discontinuity is therefore $1/2$ of the above value times the propagation velocity or

$$D=\frac{1}{2}\cdot\frac{c}{\sqrt{\epsilon_r}}\cdot\frac{T}{N}=\frac{c}{4\sqrt{\epsilon_r}\cdot f_{max}}=\frac{4.2}{\sqrt{\epsilon_r}}\ \text{mm} \qquad (3)$$

where D is the distance resolution, $c/\sqrt{\epsilon_r}$ is the propagation velocity, and f_{max} is assumed to be 18 GHz. The resolution D as expressed by (3) will of course be increased if a window function is used.

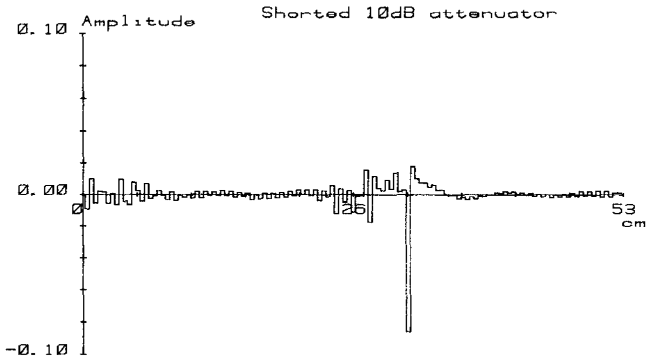

Fig. 3. Measured signal without a window function.

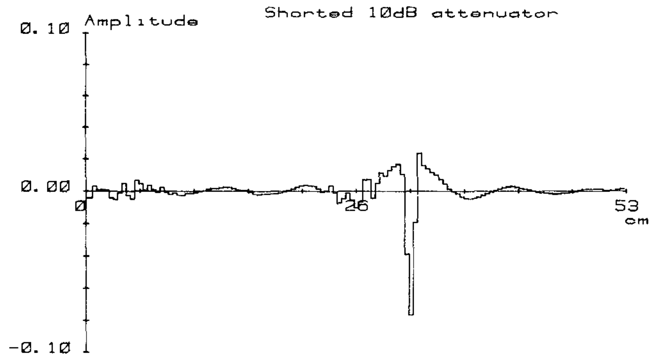

Fig. 4. Measured signal with a raised cosine window.

The total distance of analysis, the number of measurements, and the computation time are all dependent on the number of samples N. N should also be a power of two because of the fast Fourier transform. In the program N has been chosen as 128 which gives a total distance of 54 cm in air, 64 measured values in the frequency domain, and a total computation time of less than 15 s. Only 64 measured values are needed in the Fourier transform, since both positive and negative frequencies must be used. The negative frequency values can easily be found from the measured values, since a real time domain signal requires a symmetric real part and an antisymmetric imaginary part of the frequency domain signal.

III. Results

As an example of the program a 20-cm airline terminated by a shortcircuited 10-dB attenuator was measured. The Fourier transform was then computed with and without a window function. The results are shown in Figs. 3 and 4. The measured object can be split in four parts, which are clearly visible in Fig. 4. The first 5 cm are an adaptor and a connector of the airline, the next 16 cm are the homogeneous airline and the final 8.5 cm are another connector and the attenuator. The distance to the short circuit is 29.5 cm, where as the distance in the plot is 31.5 cm. The difference is caused by the dielectrics in the adaptor and the connectors which increase the measured distance.

IV. Availability

The program has been written in the HPL language which is used by the HP 9825 desktop computer. A copy can be obtained by writing to the author. If a tape cassette suitable for the HP 9825 is included, the program will be recorded on a file.

ACKNOWLEDGMENT

The help and encouragement of Prof. E. Folke Bolinder is gratefully acknowledged.

REFERENCES

[1] M. E. Hines and H. E. Stinehelfer, "Time-domain oscillographic microwave network analysis using frequency domain data," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 276–282, Mar. 1974.
[2] E. O. Brigham, *The Fast Fourier Transform*. Englewood Cliffs, NJ: Prentice-Hall, 1974.
[3] F. J. Harris, "On the use of windows for harmonic analysis with the discrete Fourier transform," *Proc. IEEE*, vol. 66, Jan. 1978.

Letters

Correction to "Extension of Existing Models to Ion-Implanted MESFET's"

PIETRO DE SANTIS

A list of the most important corrections to the above paper[1] is reported below. (The paper with all typographical errors corrected is available from the author upon request.)

In (9) Z_q is to be replaced by Zq and in (14) L should be erased in the denominator of the second fraction.

In (19), (B8), and (B12) $|_M$ and $|_D$ should be replaced by I_M and I_D.

All τ's in the argument of the hyperbolic functions must be replaced by π's.

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[1]P. de Santis, *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, pp. 638–647, June 1980.