

## Pure teflon improves circuit designs

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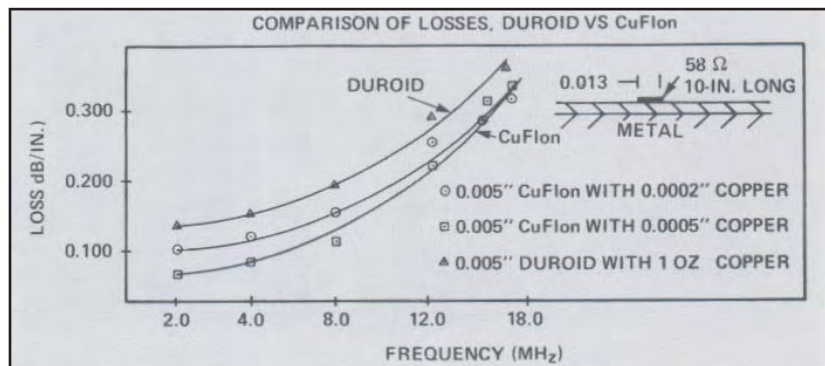
From VCOs to filters, for the circuit design engineer who is aware of the trade-offs, Teflon is a valuable substrate when used in the right applications.

With so many substrate materials available to the microwave circuit designer, material selection is often based on past experience, resulting in a design that is never fully optimized. Optimizing the design may involve trade-offs in electrical loss, tolerance, bandwidth, radiation and dispersion, size, environment, and cost. The selection of material also involves the choice of a transmission medium (stripline, coplanar, microstrip, etc.) for the particular circuit. Some materials are intrinsically more suitable to be used in one medium than in another. The choice, however, is usually based on the designer's background, practical experience, ingenuity, and many times, convenience.

Pure Teflon is used in special applications and components, such as cables, connectors, and coax adaptors. Because it is difficult to metalize and is temperature and mechanically unstable, its use as a substrate has been limited. But for the design engineer who is aware of the trade-offs, Teflon is a valuable substrate when used in the right applications. (Table).

The most obvious advantage of pure Teflon is its low loss (Fig. 1, 2). This property can often make the difference between meeting a critical loss specification through a simple printed geometry, or having to resort to more-expensive coaxial or waveguide structures. The low loss also means that higher CW power can be transmitted with fewer heating effects. The loss advantage becomes more pronounced where:

- Bandwidth limitations (bandpass filters) increase loss.



**1. The obvious advantage of Teflon is its low loss. The loss properties of Duroid and CuFlon are compared.**

- Every tenth dB is important, as in high-power circuits.
- Long line lengths are used in such devices as phase shifters, power dividers, and attenuators, as in phased array applications.
- Gain is hard to achieve, as in the high end of the microwave spectrum.

Nevertheless, dramatic improvements in loss cannot be expected in circuits where line losses were not significant in the first place.

Another important property of pure Teflon is an extremely tight tolerance on a dielectric constant, which results in filters repeatedly tuned on frequency, and in phase-sensitive networks having good unit-to-unit phase tolerances, thus eliminating the need for phase trimming. This property is enhanced by using a substrate with extremely thin copper plating that can maintain tight etching tolerances. The frequency uncertainty of a filter, or the

phase uncertainty of a phase shifter in stripline, can be expressed as:

$$\Delta f_o \text{ or } \Delta \theta_o = \sqrt{\Delta \epsilon_r + \Delta d} = \Delta T$$

Where  $\Delta \epsilon_r$  = dielectric constant uncertainty

$\Delta d$  = etching tolerance uncertainty

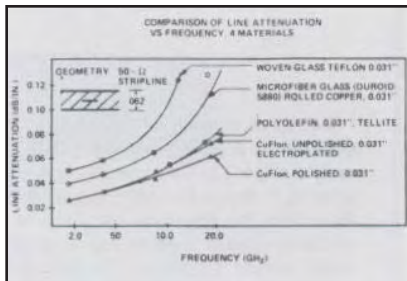
$\Delta T$  = temperature drift

The dielectric constant uncertainty is less of a problem in a microstrip circuit than in a stripline because wave propagation is partially in air. For thin copper platings the  $\Delta \epsilon_r$  and  $\Delta d$  are negligible and the only real contributor to frequency or phase uncertainty is temperature drift.

To achieve the wide bandwidth in filters, as well as tight coupling in couplers, narrow gaps between adjacent transmission lines are necessary. With very thin, closely controlled plating, gaps as narrow as 0.001 in. are practical. For this reason, close tolerances on coupling can be achieved.

Properties of Four Dielectric Board Materials				
	Teflon + (Woven) Glass	Teflon/Glass Microfiber	Pure Teflon (TFE)	Polyolefin
Trade name		Duroid®	CuFlon®	Tellite
Manufacturer	Keene (Newark, Del.) Atlantic Laminate (Franklin, N.H.)	Rogers (Chandler, Ariz.)	Polyflon (New Rochelle, N.Y.)	Tellite (Weston, Mass.)
Dielectric constant	2.55 ± 0.05	2.23 ± 0.02	2.10 ± 0.005	2.32 ± 0.01
Useful temperature range	-100 to +400°F - 74 to +205°C	-100 to +500°F - 74 to +260°C	-100 to +435°F - 74 to +225°C	-100 to +220°F - 74 to +105°C
Coefficient of expansion (× 10 <sup>6</sup> /°C)	1.9	10.0	12.9	10.8
Solderability	Excellent	Good	Excellent	Poor
Machining	Good (carbide)	Good (carbide)	Good (high speed)	Good
Price*	4	10	9	3
Plating thickness	½, 1, 2 ounce	½, 1, 2 ounce	¼, ½, 1, 2 ounce, or custom (can be dissimilar, each side)	½, 1, 2 ounce
Dissipation	0.0018	0.0009	0.00045	0.0003

\*Price at ½ ounce copper, each side on 0.031" substrate material; price given is relative to Duroid's price, assumed to be 10.



**2. Line attenuation vs frequency is compared for woven-glass Teflon, microfiber glass (Duroid), polyolefin, and CuFlon.**

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All low-dielectric-constant substrates are similar in radiation and dispersion for microstrip configurations. Radiation is a problem that becomes increasingly more serious with higher frequencies and thicker boards. To minimize the problem, designers resort to such techniques as meander lines, hairpin resonators, and channelized filters. If the design skills are not available, more mechanically complex stripline designs must be employed. If radiation is a common problem with a low-dielectric constant substrate, the opposite is true in the case of dispersion. This phenomenon is almost unnoticeable up to 60 GHz.

Circuit size is inversely proportional

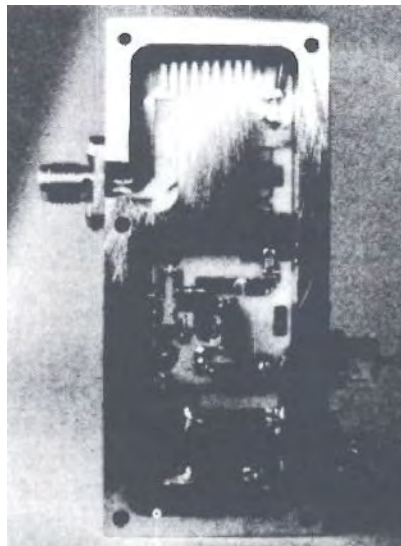
to the dielectric constant of the substrate. Teflon has the lowest dielectric constant and therefore will result in the largest circuit. While this may be a problem at the lower frequencies, it can be overcome through careful circuit design. At higher frequencies, tolerances are much more important than size reduction and the low-dielectric constant boards are larger, affording the designer some respite to tolerance specifications.

The first criterion in determining the suitability of a substrate material for a given application is the specified temperature limit of the board. This will usually exclude low-temperature Tellite (polyolefin) from the most stringent

**Designing Stable X-Band VCO**

Because of the fear of temperature problems, the least likely place one would expect to find pure Teflon being used is a stable oscillator applications. However, the low-loss property of the material makes it attractive in applications where power at X-band is the objective.

The voltage-controlled oscillator (VCO) is built in a NC-milled housing. The VCO is varactor-tuned over the frequency range 4675 to 4750 MHz, followed by a step recovery diode doubler. From 9350 to 9500 MHz, the minimum output power is 40 mW over a temperature range of -53 to +85° C. At room temperature over a narrow frequency range, 80 mW can be obtained. This performance is



**Voltage-controlled oscillator with the cover removed.**

possible using the high Q resonator on pure Teflon. The unloaded Q of the resonator is estimated to be 500 without the varactor. The low dielectric constant of the material helps provide the largest possible printed resonator with the tightest possible coupling.

The result is a 2-to-2.5 dB power output improvement over a similar circuit built on Teflon-glass. The doubler loss is only 3.9 dB over the frequency band, which is very close to the theoretical optimum of 3.0 dB. While the temperature compensation was partially realized by the varactor used to tune the VCO, a sensistor used in the bias circuit was empirically adjusted in value for zero temperature coefficient. Altogether a +/- 4 MHz maximum temperature drift over the range of -55 to +85° C was accomplished.

environments usually encountered in avionics. Teflon and glass-filled Teflon boards will survive the most severe environments, but glass filled Teflon will have less temperature dependence than pure Teflon. Again, good design will minimize the temperature problems with Teflon. A microstrip circuit is less temperature-dependent than its stripline equivalent simply because propagation, especially for low-dielectric-constant materials, is partially in air. Also, the dielectric-to-metal bond gives the dielectric rigidity. If a stripline design is used make sure the boards are embedded in a snug-fitting cavity so minimal movement with temperature and time is permitted.

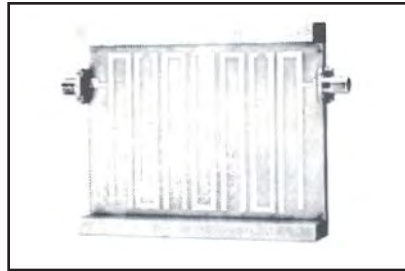
Two designs using Teflon-glass, Duroid, CuFlon, and Tellite are examined. All the materials measure 1/16 in. thick and are plated with 1 oz. (per square foot) of copper.

**Design 1**

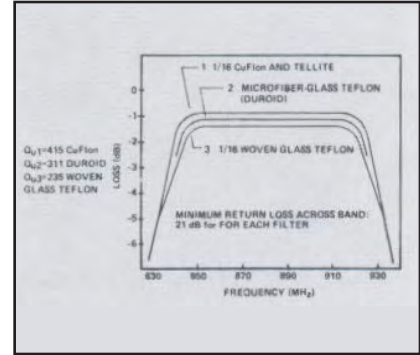
The key parameters for the design of an 880-MHz bandpass filter (used in a communication satellite earth station) are loss, flatness across the 860-900 MHz (0.1 dB max.), and rejection at 825 MHz (20 dB min.). To achieve this, a 7-section 0.01 dB Chebyshev design with an 85 MHz bandwidth was selected. A microstrip design (Fig. 3) was chosen because:

- It is easily integrated into other circuits, such as amplifiers and mixers.
- It has the fewest tolerance problems due to dielectric constant variables. Stripline suffers from variable compression problems.
- It is much simpler mechanically.
- It does not suffer from cold flow problems, which result in filter response changes with time.

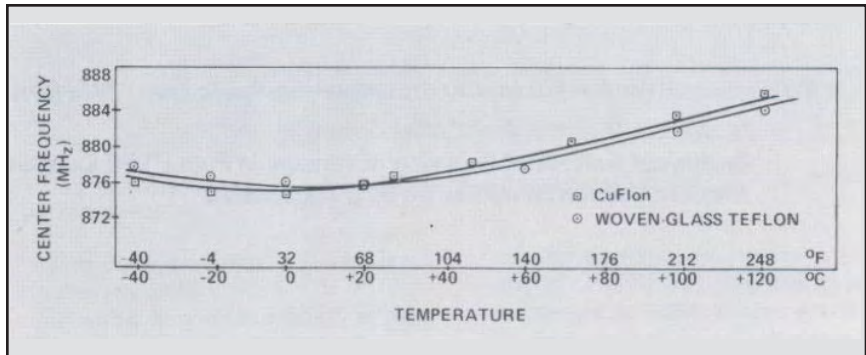
A compact, low-radiation hairpin resonator makes the best use of the available space and at the same time precludes the radiation problem that otherwise would result in higher losses. The end resonators were direct-connected to achieve the wide bandwidth requirements.



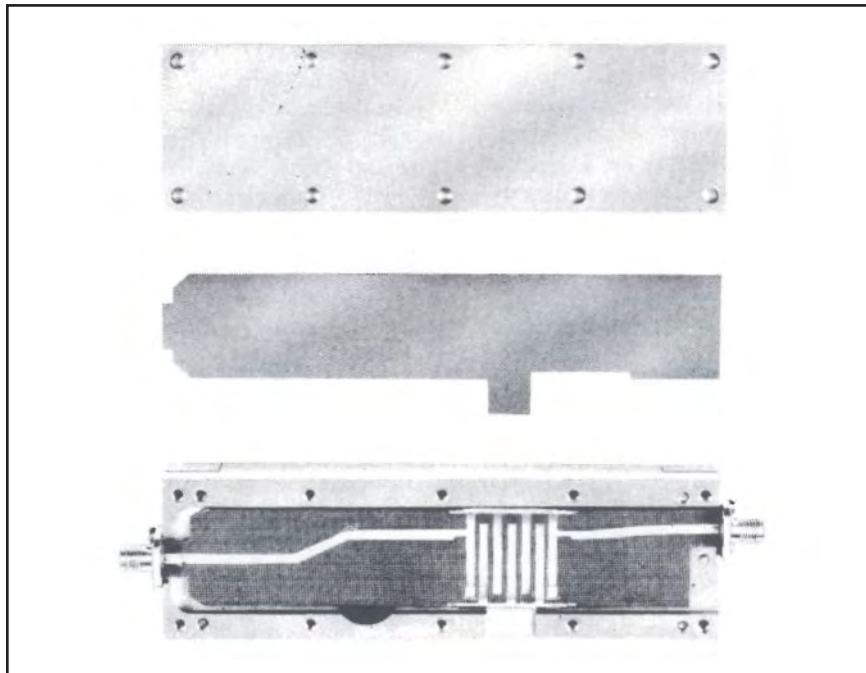
**3. For design 1, a 0.01dB Chebyshev design with an 85 MHz bandwidth was selected to meet the loss, 860-to-900-MHz flatness across the band, and rejection at 825-MHz specifications for an 880-MHz bandpass filter.**



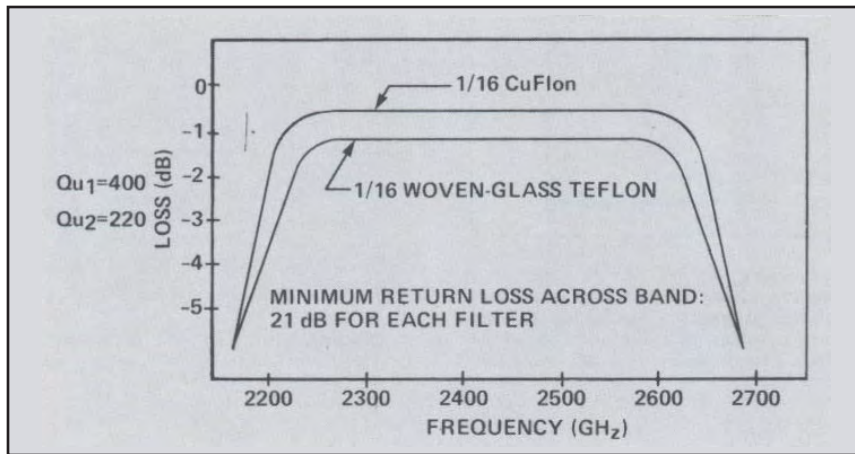
**4. Comparison of resonator *Q<sub>u</sub>* shows a big difference between the four materials tested.**



**5. There is a minimal temperature variation between CuFlon and woven-glass Teflon. This lack of variation is attributed to the design employed.**



**6. For design 2, a 7-section, 0.01dB Chebyshev design with a 420 MHz bandwidth was chosen to meet the loss characteristics, 2200-to-2600 MHz bandwidth, and 2-5 kW power handling ability of a stripline interdigital filter.**



**7. The stripline design** optimizes filter performance and provides a minimum return loss across the band of 21 dB for each filter.

The hairpin resonator technique is space-efficient, with virtually no waste of available board area. There is a big difference in resonator  $Q_u$  for each of the materials tested (Fig. 4), but only a small temperature variation among the materials (Fig. 5). This lack of variation is attributed to the design employed.

### Design 2

The important parameters for the design of a stripline interdigital filter (high-power transmitter application) include loss, a 2200 – to – 2600 MHz bandwidth, and a 2.5 kw (25 w average) power handling ability. A 7-section 0.01 dB Chebyshev design with

a 420 MHz bandwidth was selected. The wide bandwidth requires tight coupling between resonators, which implies the need for small gaps. The high peak power requirement makes it mandatory to keep the gaps as wide as possible. To meet these requirements, a stripline design was chosen (Fig. 6).

The filter is snugly fit into a milled cavity to reduce the chance of cold flow and minimize temperature drift. This design optimizes filter performance and provides a minimum return loss across the band of 21 dB for each filter (Fig. 7). The unloaded  $Q_u$  of the resonators seem to be limited by the soldered-on ground straps used to ground the resonators. It is possible that with plated-on ground straps, better performance may be achieved.

Pure Teflon is a viable substrate material that can solve many design problems when properly used. The temperature behavior compares well with that of its glass-filled counterparts, especially when used in microstrip circuits.