Design and Development of Low Cost and Light Weight Microwave filters by using Metalized ABS Plastic as a Substitute of High Cost Substrate and Metals

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ABSTRACT
The main objective to introduce the ABS (Acryonitrile Butadyne Styrene) plastic substrate in place of RT- Duroid substrate for microstrip filters is to reduce the cost. The cost of plated ABS plastic substrate is substantially less (Rs. 4/- sq.inch) compared to the cost of RT-Duroid (US$ 02/-/- sq.inch). Two microstrip (hairpin line) band pass filters at 1537.5 MHZ and 1575.42 MHz have been developed and tested. The performance of filters have been verified over temperature range, -10 deg. C to 60 deg. C.The ABS plastic blocks have been used in place of metal blocks of brass, copper and Commercial Aluminium to fabricate three dimensional microwave cavity filters for communication systems.The specific gravity of ABS plastic is 1.03 gms/cubic cm compare to 2.7, 6.3 and 9.6 gms/cubic cm of Com. Al, Copper and Brass respectively. Hence the weight of metallized ABS cavity filters will be 1/3rd , 1/6th and 1/9th of the com. Al, copper and brass cavity filters.

General Terms
Acryonitrile butadiene styrene plastic, poly tetra flouroehtelene, RT-duroid, thermal conductivity, surface resistivity, heat distortion temperature, coating, plating.

Keywords
Microstrip, substrate, hairpin line filter, dielectric constant, insertion loss, dissipation factor, quality factor, bandwidth.

1. INTRODUCTION
With the development of the electronic industry in India, there is continuous need for new materials having better performance properties with stringent size and weight limitation. Such needs can be tailor made by plastic materials, which have very high rate of environmentally safe processablility and production process, maintaining the accuracy and level of functional properties. As new plating processes groom, metalized plastics play a bigger role as replacement of conventional materials on cost, weight and performance basis. Currently plated thermoplastic ABS is widely used in automotive and decorative uses but is untouched for passive microwave component applications in communication.

2. CHOICE OF MATERIAL
At microwave frequencies the current density is maximum near the surface and it falls off exponentially with depth. Thus as long as there is a thin layer of silver, copper or any other highly conductive material on surface, the body can be of wood, plastic or anything else; without affecting the microwave propagation. In addition to size and weight the other factors determining the type of body material are machining tolerances, water absorption, ability to handle power, efficiency, problems in matching, shielding, and reliability[1]

Acrylonitrile Buadiene Styrene (ABS) plastic has excellent toughness, rigidity and gloss[2][3]. They are cheaper than engineering plastics like nylons, polyacetals and polycarbonates. The important physical and electrical properiates like tensile modulus, tensile strength, surface hardness, porosity, coefficient of thermal expension, thermal conductivity, heat distortion temperature, dielectric strength, dissipation factor, surface resistivity, etc. were found to be favorable for such applications. Moulding from ABS exhibit better and uniform impact strength in all the directions. Another important feature of ABS is that it is the only plastic which can be commercially electroplated. It is found that electroplated ABS parts show improvement in properties like surface hardness, tensile and flexural strength, heat resistance, chemical resistance, weather resistance etc. The electrical properties of ABS plastics are unaffected by temperature and humidity. Dielectric strength, power factor, and dielectric constant are reasonably good to allow it to be used in electronic or electrical applications like coil formers, connectors, wave guides etc[3].Thus for our study, ABS (platable) plastic material was selected for the design, development and fabrication of substrate type (instead of RT-Duroid) and cavity type (instead of metal) band pass filters in microwave frequency range for communication systems[4].

3. COATING/PLATING PROCEDURE
The copper thickness was built by electroplating. Silver plating is done after deposition of copper on plastic. The deposits were subjected to environmental tests such as humidity and corrosion resistance, thermal cycling, thermo vacuum, baking, hot and cold storage etc. tape test was used to check the adhesion of the coating after each test. Mechanical properties of the coatings were evaluated by micro hardness test, surface roughness and peel strength. To verify the assumption of replacement of very costly substrates and metals with plated ABS plastic, some planar structured(hairpin line) and cavity type band pass filters (coaxial, helical and comb line) having different centre frequencies and bandwidths were designed and fabricated. The standard design tools and techniques were used for all types of cavity band pass filters but for hairpin line filters necessary design corrections were applied [5][14][15].

ABS with 10% butadiene is more suitable for electroplating than ABS with 16 to 27% butadiene. Several trials were conducted for electroplating on ABS plastic. The articles were immersed in the mixture of chromic acid and sulphuric acid to improve mechanical adhesion. Poor etching leads to skip plating or poor adhesion of the plating and possible blistering. Thus etched articles are not to be treated with sensitizer and activators stannous chloride and palladium chloride solution are used for this purpose. The deposited palladium nuclei on the plastic surface, initiates electroless plating of copper or nickel or gold or other metals. We have carried out electroless copper deposition for our work. Finally deposited with electroplated copper or silver to get highly conductive surface.

Table 1. Properties comparison (as per data sheet and catalogues)

Sr. No.	Property	RT – Duroid # 5880	ABS – Plastic # AP78EP
01.	Dielectric Constant Er (relative)	(2.22 $-^{+}$ 0.02) upto 10 GHz (Eeff =1.89 for 50 line)	Er = (2.8 – 3.8) at 1 MHz Eeff = (1.89 to 2.12) upto 10 GHz measured on HP 8510 Table-1
02.	Dissipations factor (ten)	(0.0009 to 0.0010) UP TO 10 GHz	0.0024 at 9.2 GHz (measured)
03.	Specific gravity	2.20 gms/gm^3	1.05 gms / cm^3
04.	Heat distortion temperature	> 260^0 C	84^0 C
05.	Power handling capability	120 W	72 W
06.	Thermal Expansion (Linear)	48×10^{-6} $mm/mm/^0C$	70×10^{-6} $mm/mm/^0$ C
07.	Tensile strength	450 Kg /gm^2	430 Kg /gm^2
08.	Volume resistivity	2×10^{13} to 2×10^{14} ohm-cm	10^{13} to 10^{16} ohm/cm
09.	Elongation at Break	17.6 %	25 %
10.	Hardness R- scale	R - 88	R - 110
11.	Deformation under Load	(0.6 -1.0) %	(0.4 0.6) %
12.	Tensile modules	30×10^3 Kg/gm^2	23×10^3 Kg/gm^2

4. PERFORMANCE EVALUATION

The transmission characteristics of metalized ABS plastic filters in the form of substarte and cavity were tested to compare with RT-Duroid and commercial Aluminum filters by using the network analyzer. The electrical parameters of metalized ABS filters; like centre frequency, insertion loss at the centre frequency, 3dB bandwidth, stop band attenuation were measured and compared with that made from RT-Duroid and Aluminum alloy in the temperature range from -20 deg C to -60deg C, as shown in the comparison tables. Thus this new plastic material is getting use in making different types of band pass filters for ground and space application [6][7]

Though, the dielectric constant and dissipation factor above 1 MHz are not given in the literature, we have measured effective dielectric constant (Єeff) up to 10 GHz and verified practically by the performance of two hairpin line band pass filters at 1537.5 and 1575.42 MHz. The insertion loss is more due to higher dissipation factor. So if the insertion loss is not very critical, the very low cost microstrip hairpin line filters can be developed by using plated plastic substrate in place of RT-Duroid (#5880,Єr=2.22).The measurement method of Єeff also has been verified by cross checking the value of Єeff for RT-Duroid (#5880), for 50 ohms line up to 10 GHZ (Table 1) on network analyzer HP-8510[8][10][12]

5. DESIGN PROCEDURE

The design procedure available for RT-Duroid #5880 has been applied to calculate the dimensions of resonators for hairpin line filters. The existing design tables and graphs are sufficient to carry out the design calculations[9][11][16][18]

6. EXPERIMENTAL RESULTS

Two hairpin line microstrip band pass filters have been optimized on Network Analyzers HP8754 A and HP8510. The resonator lengths, practically found at 1537.5MHz and1575.42MHz have been verified the correctness of measured Єeff of ABS plastic substrate[5]. The correctness of measurement method is also verified with the help of value of Єeff, measured and available in the data sheet of # 5880, RT-Duroid, supplied by Rogers Corp. USA. We have measured Єeff for ABS plastic and RT-Duroid, having electrical lengths of 150 and 50 mm of 50 ohms microstrip line of each substrate material (table-1).In our experiments we used the microstrip filters fabricated on ABS plastic substrate by using positive/negative of RT-Duroid based filters. The centers of response were achieved at lower frequencies than that of RT-Duroid. The filters were optimized by trimming-out the resonator lengths. The band widths with respect to center frequencies were not similar to RT-Duroid based filters in both cases.[13][15]

So, if the insertion loss and bandwidth are not critical, low cost microstrip filters can be developed by using ABS-plastic substrate as an alternative to RT-Duroid substrate [9][10].

Table 2. Measurement of Effective Dilectric Constant(Єeff) of ABS on Network Analyzer

Frequency of measurement in MHz	RT.DUROID #5880				ABS-PLASTIC # AP78 EP			
	Measured Electrical length in (mm) for		є eff	є eff	Measured Electrical length in (mm) for		є eff	є eff
	150mm physical length of 50 Ohm line	50mm physical length of 50 Ohm line			150mm physical length of 50 Ohm line	50mm physical length of 50 Ohm line		
45.0	230.76	96.26	1.345	1.81	231.22	93.82	1.374	1.89
650.0	232.18	96.18	1.360	1.85	233.15	95.35	1.378	1.90
1500.0	234.49	97.79	1.367	1.87	234.61	95.71	1.389	1.93
2500.0	235.82	97.62	1.382	1.91	235.70	95.40	1.403	1.97
4500.0	236.75	97.15	1.396	1.95	237.14	96.14	1.410	1.99
7000.0	242.11	97.91	1.442	2.08	250.32	108.22	1.421	2.0
10000.0	251.43	106.53	1.449	2.10	263.07	117.47	1.456	2.1
From DATA sheet of REGOERS CORP. Er=2.22 $\pm$ 0.02, up to 10GHz. є eff=1.89 for 50 ohm line. Dissipation factor: 0.0009. Measured є eff is approximately equal to actual є eff (1.89). Which verifies correctness or our test method of measurement. (Table-2)					From DATA sheet by ABSTRON Er=(2.8 – 3.3) at 1MHz. є eff (measure) =1.89-2.12 for 50 ohm line from 45MHz to 10GHz. Dissipation factor: 0.0024 at 9.0GHz. Measured by wave guide method. 19x19x3 mm^3 sheet of ABS plastic.			

Table 3. Verification of correctness of our test method

S.No.	For RT-DUROID # 5880 T ROGERS CORP. USA	For ABS-PLASTIC # AP78EP ABSTRON INDIA
01.	Thickness of substrate: 1-6mm	Chosen thickness for filters: 1-6mm
02.	As per DATA sheet: є eff=1.89 for 50 ohm line upto 10GHz	Measured є eff=1.89 to 2.12 from 45MHz – 10GHz
03.	Length of resonator ($\frac{\lambda}{4}$) at 1537.5 MHz & 1575.42MHz $\frac{\lambda}{4} = \frac{3\times10^{11}}{4\times1537.5\times10^{6}\sqrt{1.89}}$ =35.628 at 1537.5MHz $\frac{\lambda}{4}$ =34.483 at 1575.42MHz	Practically (found) lengths of hairpin line resonators are 31.0mm and 32.0mm at center frequencies 1537.5 & 1575.42 respectively. Therefore, $\sqrt{eeff} = \frac{3\times10^{11}}{4\times1537.5\times10^{6}\times(\frac{\lambda}{4})}$ = 1.96 at 1537.5 MHz and 1.94 at 1575.42MHz.
04.	By our test method, є eff =1.87 at 1500MHz and varies form 1.89 to 2.12 for 45MHz to 10GHz. Thus the measured values of є eff are very close to the actual є eff (1.89 for 50 ohm line), which verifies the correctness of our test method.	By the same test method, є eff =1.93 (Table-1) for which is very close to the values found practically, є eff=1.94 & 1.96 at 1537.5MHz & 1575.42MHz. This also provides the proof of the correctness of our method adopted for measurements of є eff.

Table 4. Achieved Results at various temperatures

Parameter	Unit	Test temperatures: Room temperature		-10^0C		-20^0C		$+50^0C$		$+65^0C$	
		Com A1	ABS plastic	ComA 1	ABS plastic	ComA1	ABS plastic	ComA1	ABS plastic	Com. A1	ABS plastic
Center Freq.	MHz	1636	1636	1636. 5	1636.3	1639	1638	1635.6	1635.7	1632	1634
0.1dB BW	MHz	± 10	± 10	± 9.5	± 9.9	± 9.2	± 9.7	± 9.6	± 9.9	± 9.2	± 9.6
3.0dB BW	MHz	± 20	± 20	± 19.5	± 19.6	± 19.1	± 19.5	± 20.0	± 20.0	± 19.3	± 19.6

Table 5. Design and development of various types of metal cavity bandpass filters

Type of filter	Freq. Band MHz	Center Freq. MHz	Band width MHz	Insertion loss dB	I/O return loss dB	Stop band attenuation dBc	Size (LxBxH) MMxMMxM M	Weight grams
VHF/UHF								
Helical	52-55	53.5	± 1.5	1.0	16	30dBc @60MHz	200x50x72	80
Helical	85-88	86.5	± 1.5	1.0	16	30dBc @80MHz	200x50x72	80
Helical	320-328	324.0	± 4.0	6.0	15	>30dBc @ ± 8MHz	105x38x25	41
Helical	591-609	600.0	± 9.0	2.2	20	>30dBc @ ± 18MHz	100x23x33	28
Combline	1050-1350	1200.0	± 150	1.5	15	>30dBc @ ± 300MHz	155x45x30	55
L-BAND								
Co-axial	1530-1545	1537.5	± 7.5	0.4	20	>30dBc @ ± 90MHz	130x44x37	90
Co-axial	1626-1646	1636.0	± 10	0.4	20	>30dBc @ ± 90MHz	152x52x41	130
S-BAND								
Combline	2500-2690	2595.0	± 85	1.5	16	>30dBc @ ± 2000MHz	120x25x20	110
C-BAND								
Combline	4170-4200	4190.0	± 20	1.5	15	>30dBc @ ± 40MHz	107x21x18	30
Combline	4570-4610	4590.0	± 20	1.5	15	>30dBc @ ± 40MHz	126x23x17	40
Combline	5850-5930	5890.0	± 40	2.0	16	>30dBc @ ± 80MHz	95x18x12	50
Ext. C-BAND								
Combline	6725-7025	6835.0	± 150	2.0	15	>30dBc @ ± 500MHz	100x11x13	100

Achieved Results

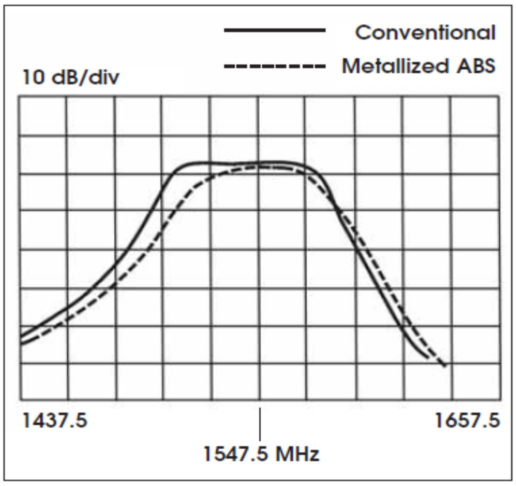

Fig 1: Measurement of the 1537.5 MHz hairpin line filter.

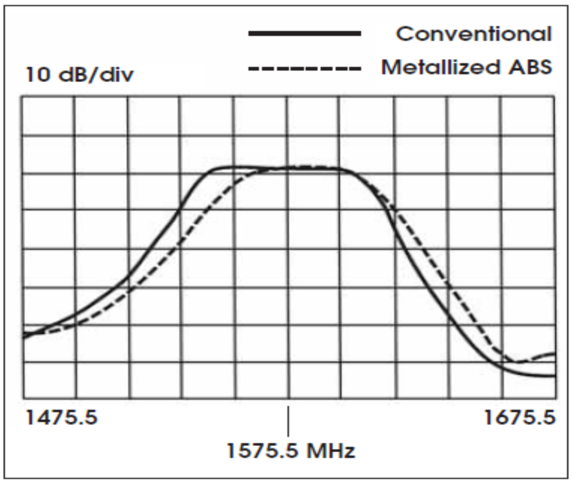

Fig 2: Measurement of the 1575.42 MHz hairpin line filter

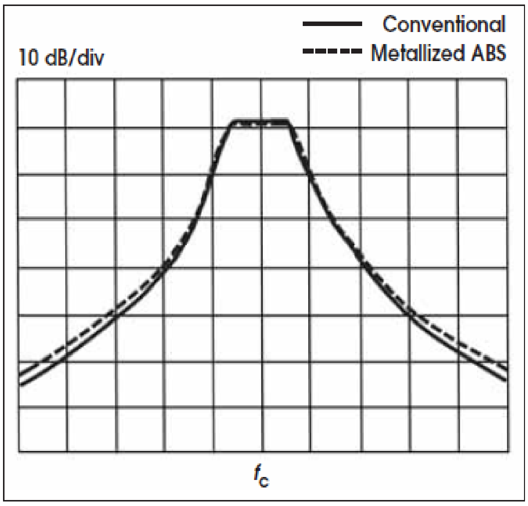

Fig 3: Bandpass plots for the 1537.5 MHz coaxial cavity filter

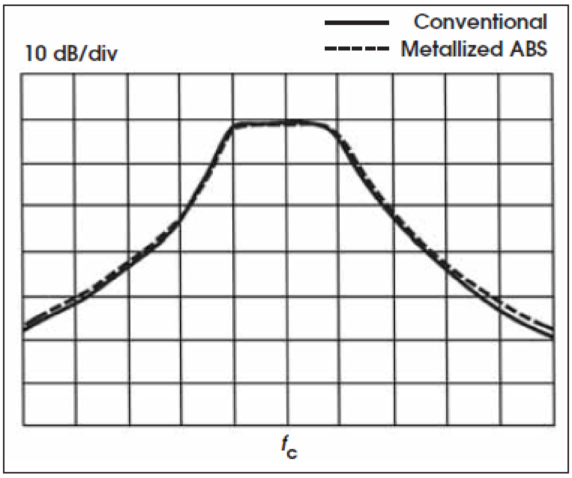

Fig.4: Bandpass plots for the 1636.o MHz coaxial cavity filter

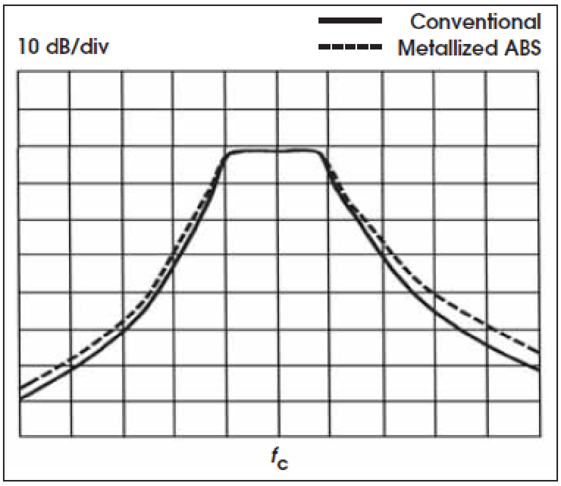

Fig 5: Bandpass plots for the 600 MHz helical filter

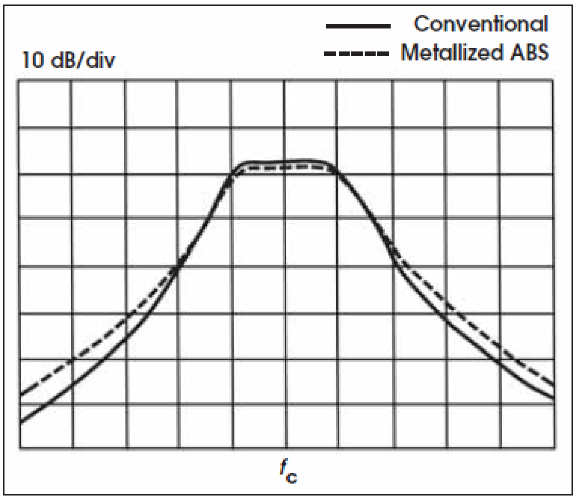

Fig 6: Bandpass plots for the 4190 MHz combline filter

7. CONCLUSION

It can be concluded that metallised ABS plastic at UHF and SHF exhibits electrical behavior similar to that of metals. Although additional work is required before large scale use of ABS can be implemented by industry, the superior performance will undoubtedly make it the material of choice for future high performance microwave equipments in satellite earth stations.

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